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

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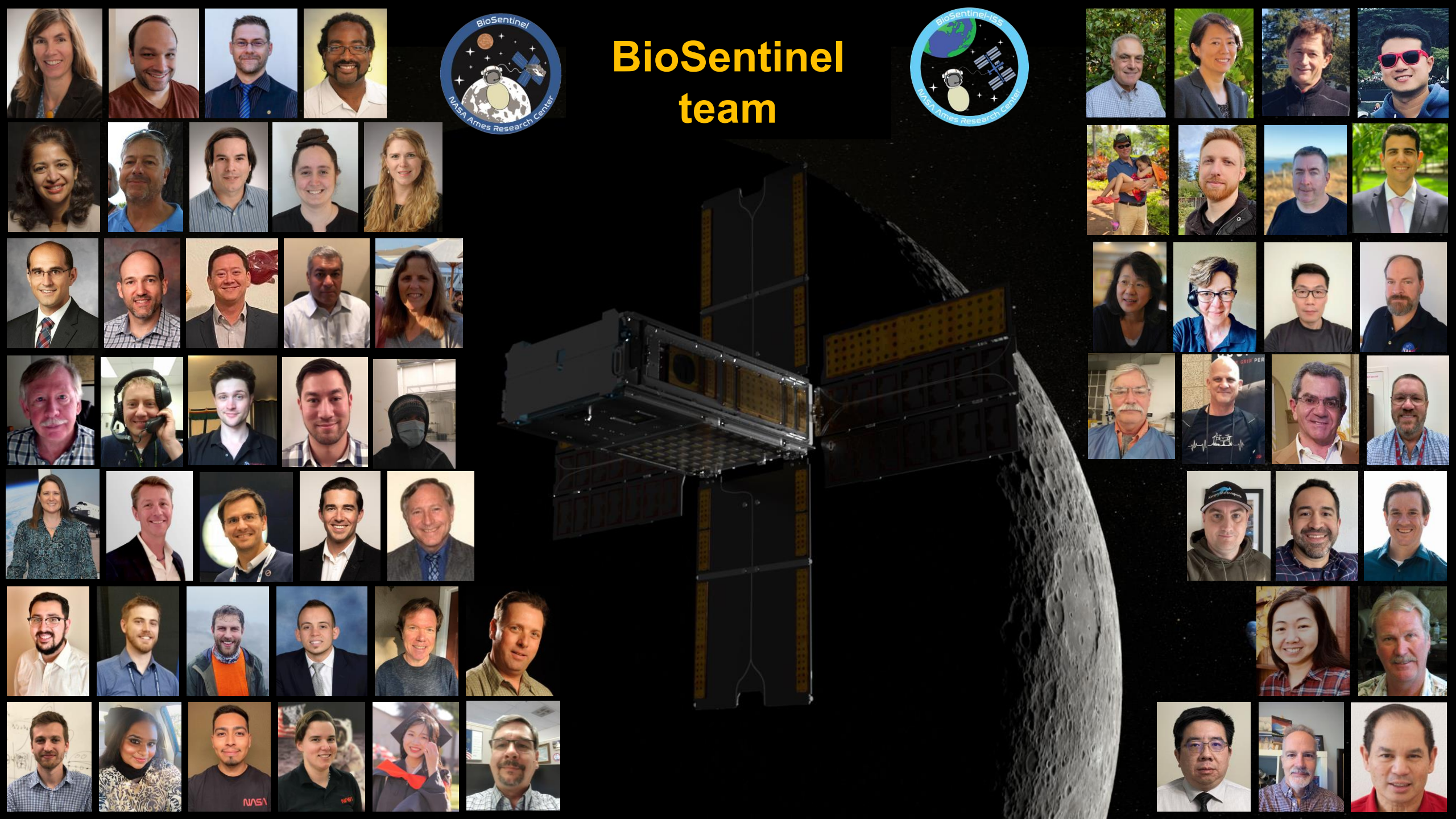
BioSentinel team



Recent publications

ASTROBIOLOGY
Volume 20, Number 8, 2020
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DOI: 10.1089/ast.2019.2068

Introduction to BioSentinel

BioSentinel: A Biological CubeSat for Deep Space Exploration

Sofia Massaro Tieze,[1,2] Lauren C. Liddell,[2,3] Sergio R. Santa Maria,[2,4] and Sharmila Bhattacharya[2]

ASTROBIOLOGY
Volume 20, Number 8, 2020
Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2019.2073

Research Article

BioSentinel: Long-Term *Saccharomyces cerevisiae* Preservation for a Deep Space Biosensor Mission

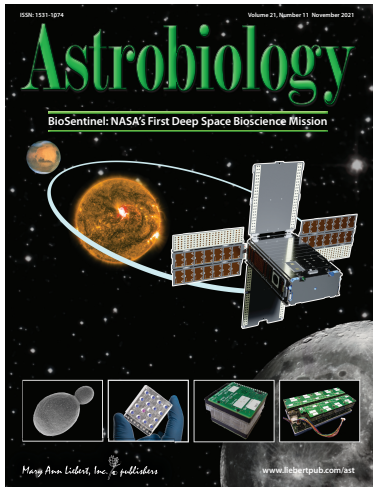
Sergio R. Santa Maria,[1,2] Diana B. Marina,[2,3] Sofia Massaro Tieze,[2,4] Lauren C. Liddell,[2,5] and Sharmila Bhattacharya[2]

ASTROBIOLOGY
Volume 21, Number 5, 2021
Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2020.2305

Research Article

BioSentinel: A Biofluidic Nanosatellite Monitoring Microbial Growth and Activity in Deep Space

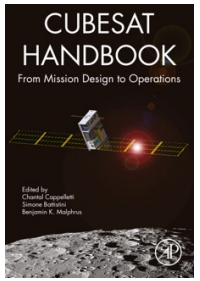
Michael R. Padgen,[1] Lauren C. Liddell,[1,2] Shilpa R. Bhardwaj,[1,3] Diana Gentry,[1] Diana Marina,[1,4] Macarena Parra,[1] Travis Boone,[1,5] Ming Tan,[1,6] Lance Ellingson,[1,5] Abraham Rademacher,[1,5] Joshua Benton,[1,7] Aaron Schooley,[1,5] Aliyeh Mousavi,[8] Charles Friedericks,[1] Robert P. Hanel,[1] Antonio J. Ricco,[1] Sharmila Bhattacharya,[1] and Sergio R. Santa Maria[1,9]

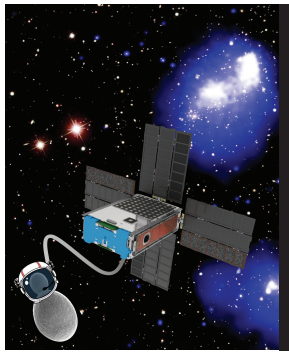


CubeSats for microbiology and astrobiology research

7

Luis Zea[a], *Sergio R. Santa Maria*[b], *and Antonio J. Ricco*[b]
[a]BioServe Space Technologies, University of Colorado, Boulder, CO, United States,
[b]NASA Ames Research Center, Moffett Field, CA, United States





Feature Article:

DOI. No. 10.1109/MAES.2019.2953760

BioSentinel: A 6U Nanosatellite for Deep-Space Biological Science

***Antonio J. Ricco, Sergio R. Santa Maria, Robert P. Hanel, Sharmila Bhattacharya, BioSentinel Team,* NASA Ames Research Center**
***Radworks Group,* Johnson Space Center**

proceedings
MDPI

Proceedings

Developing Technologies for Biological Experiments in Deep Space †

Elizabeth M. Hawkins [1,2,3], Ada Kanapskyte [1,4] and Sergio R. Santa Maria [5,6,*]

biosensors
MDPI

Perspective

Space Biology Research and Biosensor Technologies: Past, Present, and Future †

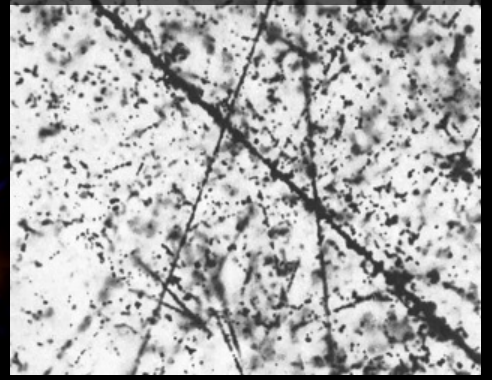
Ada Kanapskyte [1,2], Elizabeth M. Hawkins [1,3,4], Lauren C. Liddell [5,6], Shilpa R. Bhardwaj [5,7], Diana Gentry [5] and Sergio R. Santa Maria [5,8,*]

What are we going to encounter beyond LEO?

Reduced gravity

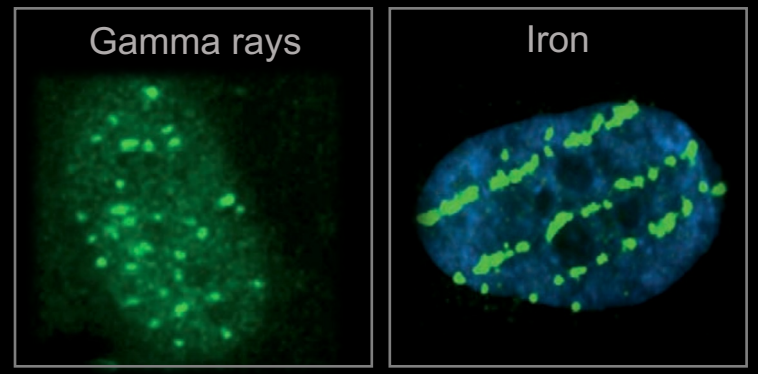
Space radiation (CGRs & SPEs)

Apollo XI particle tracks



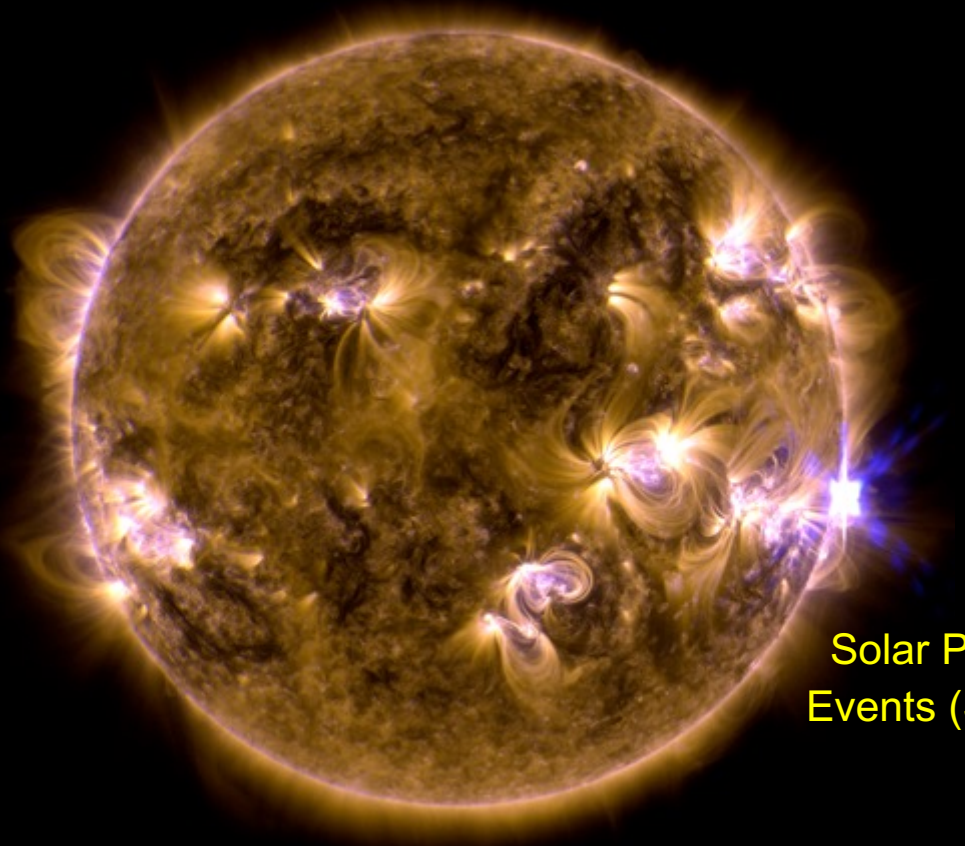
Schaefer *et al*. 1972

Cell nuclei showing DNA damage



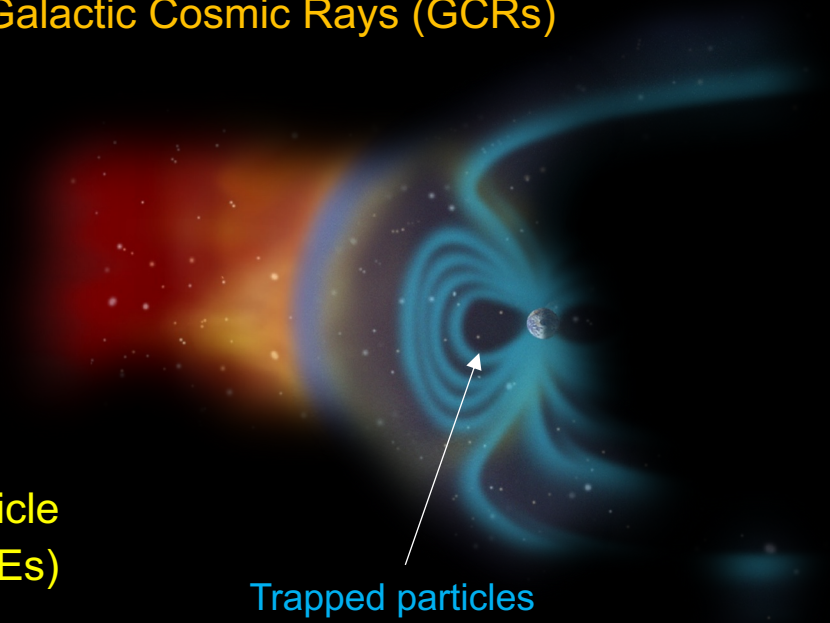
Cucinotta & Durante, 2006

What are we going to encounter beyond LEO?



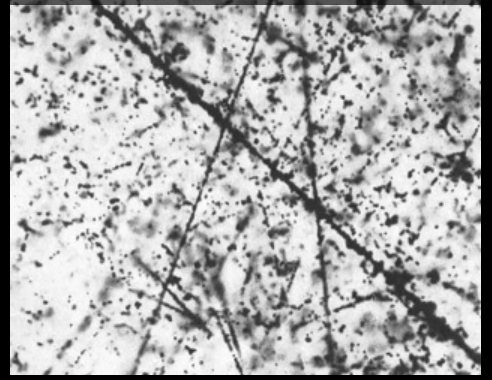
Solar Particle Events (SPEs)

Galactic Cosmic Rays (GCRs)



Trapped particles

Apollo XI particle tracks



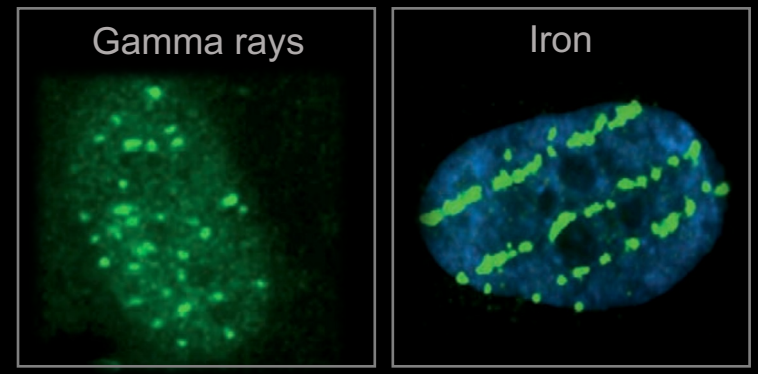
Schaefer *et al*. 1972

- 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

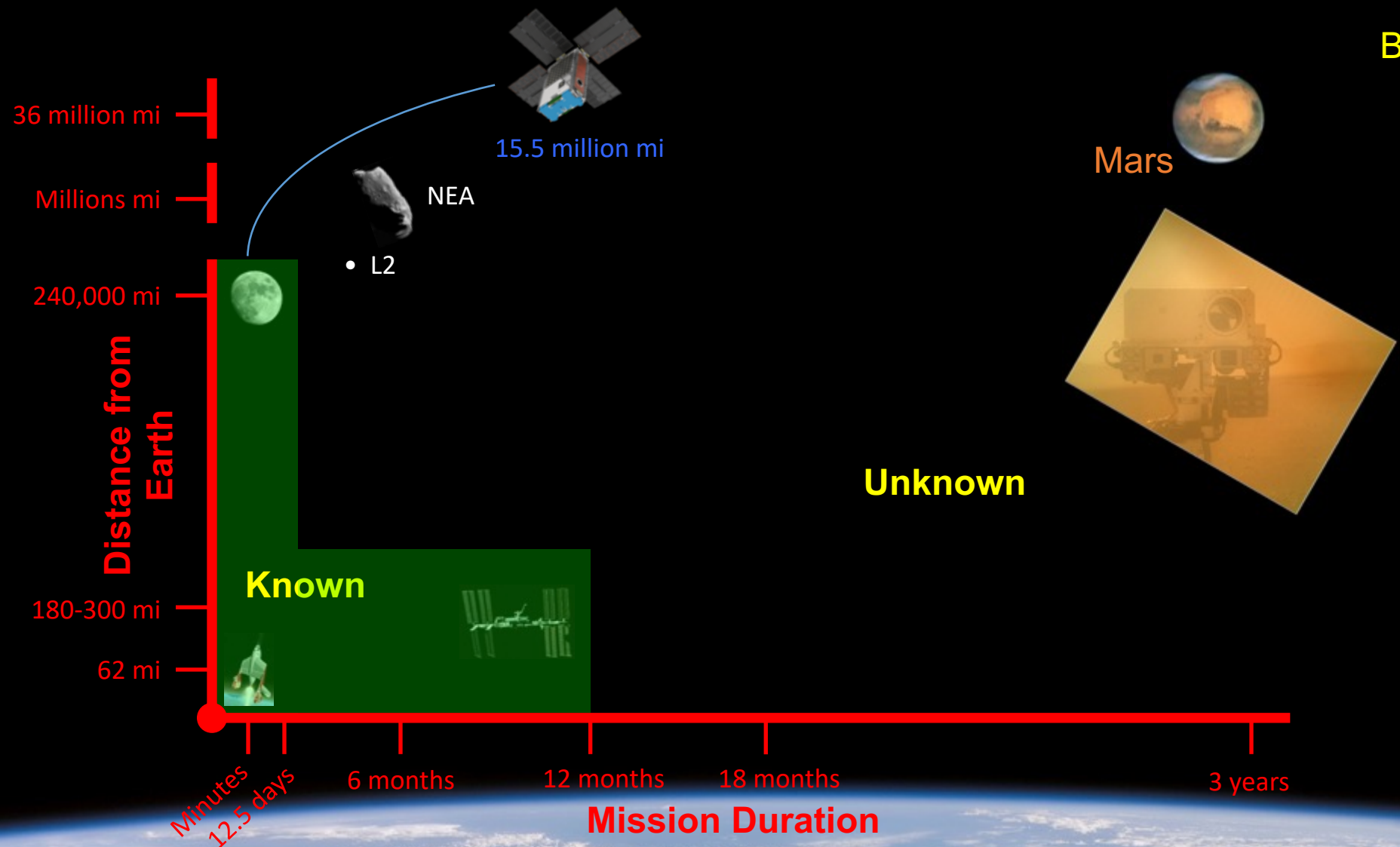
GCRs – biology effects poorly understood (but most hazardous)

Cell nuclei showing DNA damage



Cucinotta & Durante, 2006

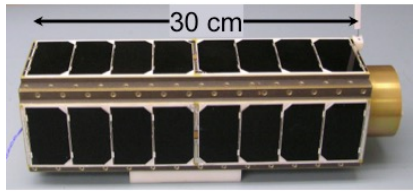
The limits of life in space – as we know it – is 12.5 days on a lunar round trip or 1.2 years in LEO. As we send people further into space, we need to understand the biological risks and how they can be addressed

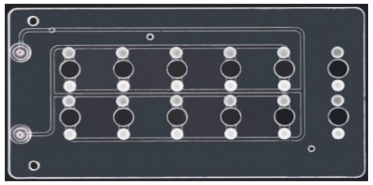


NASA Ames biological CubeSat missions

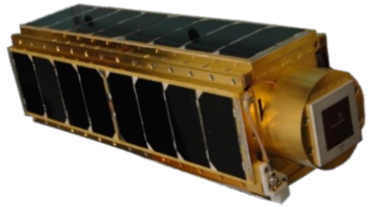
Ames Research Center

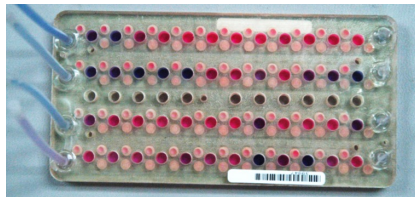
GeneSat-1
3U 2006



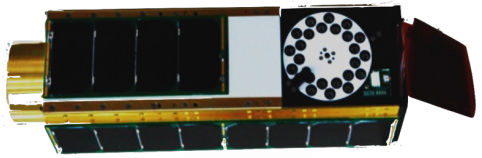


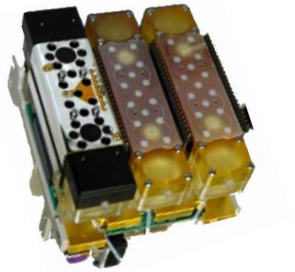
PharmaSat
3U 2009



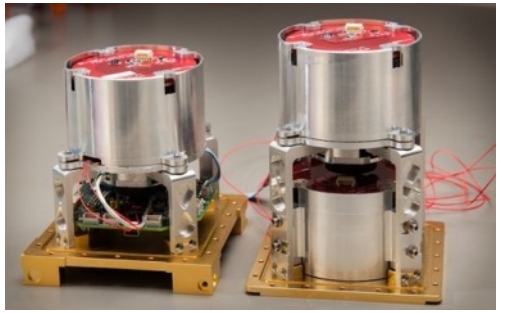


O/OREOS SESLO
3U 2010



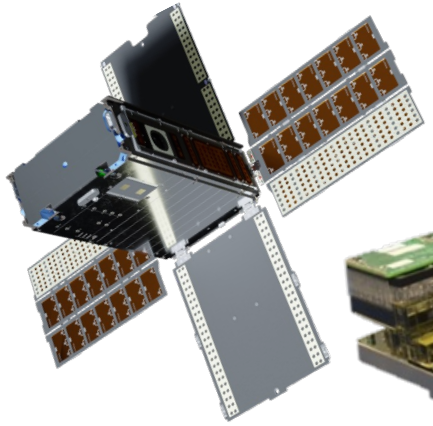


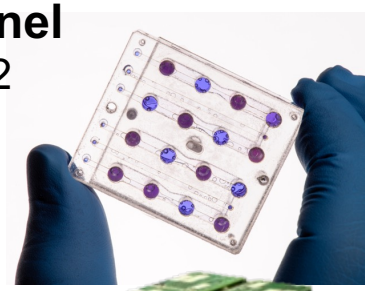
SporeSat
3U 2014

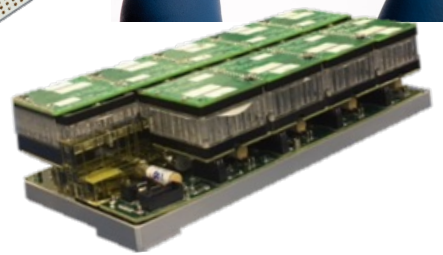


EcAMSat
6U 2017

BioSentinel
6U 2022





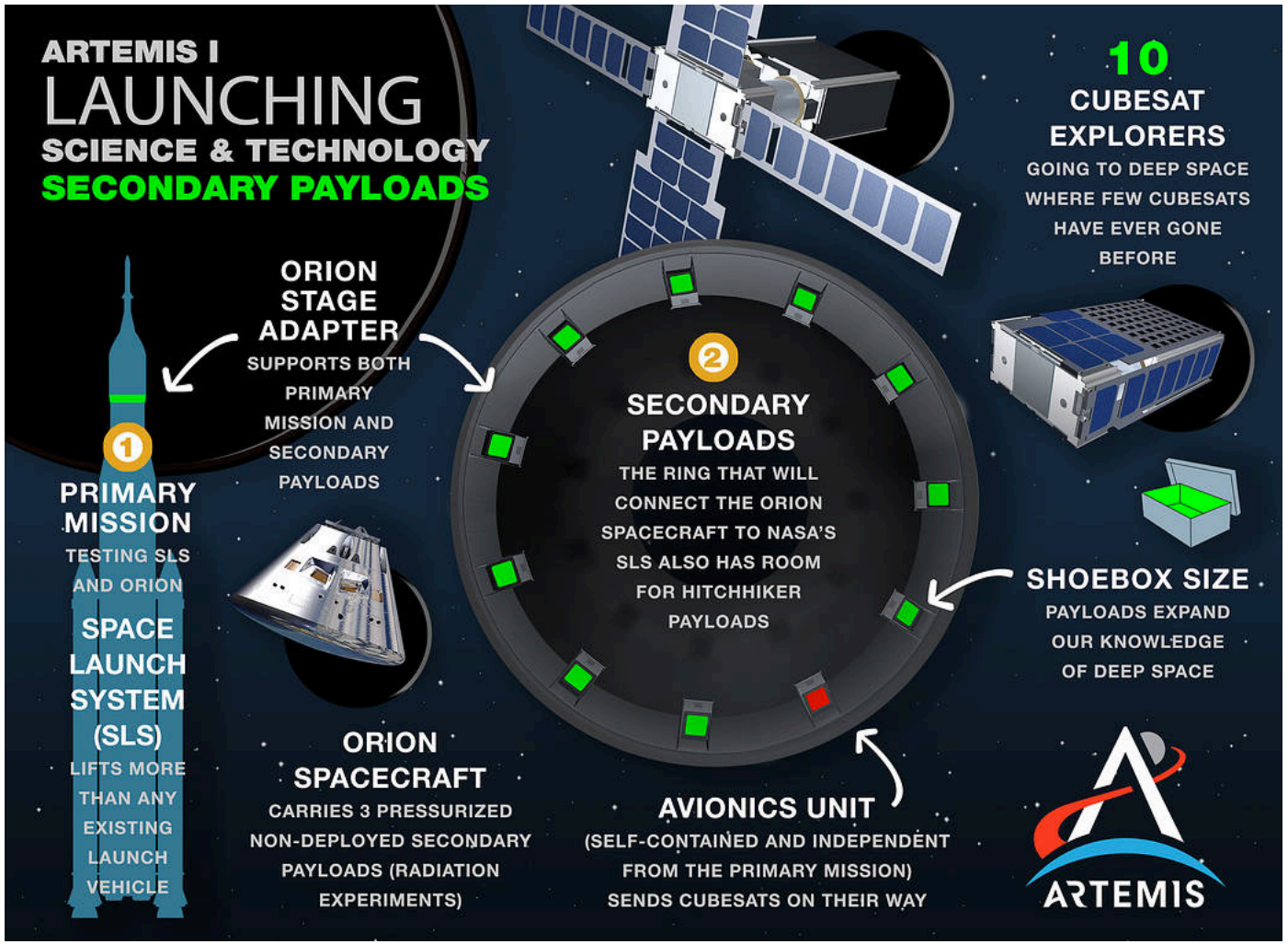


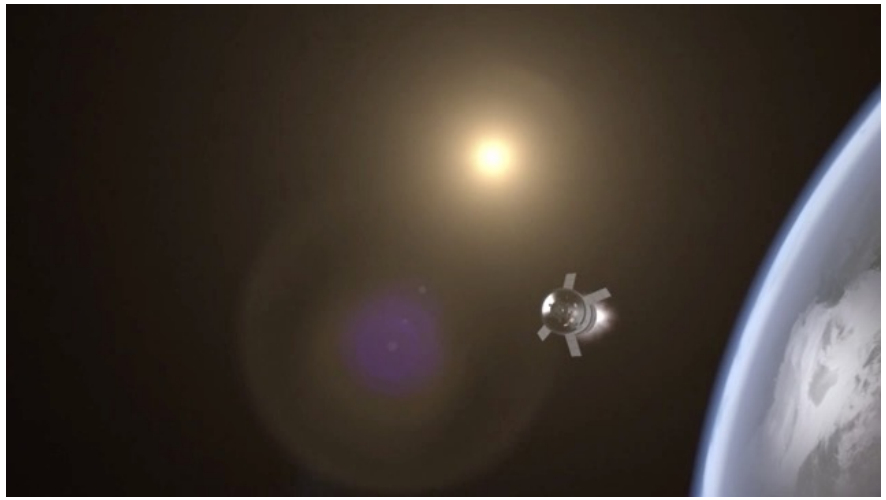
NASA Artemis I mission

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 TC) burns as necessary to n for Earth's atmosphere.

15 CREW MODULE SEPARATION FROM SERVICE MODULE

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

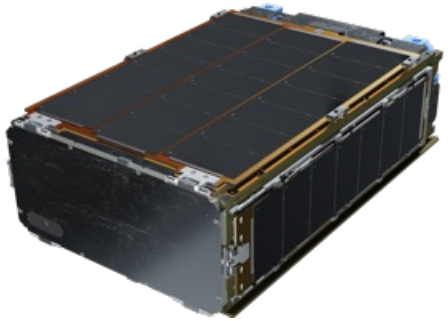
17 SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ship.

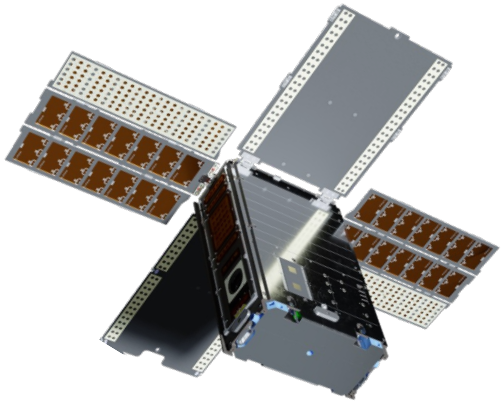
BioSentinel mission

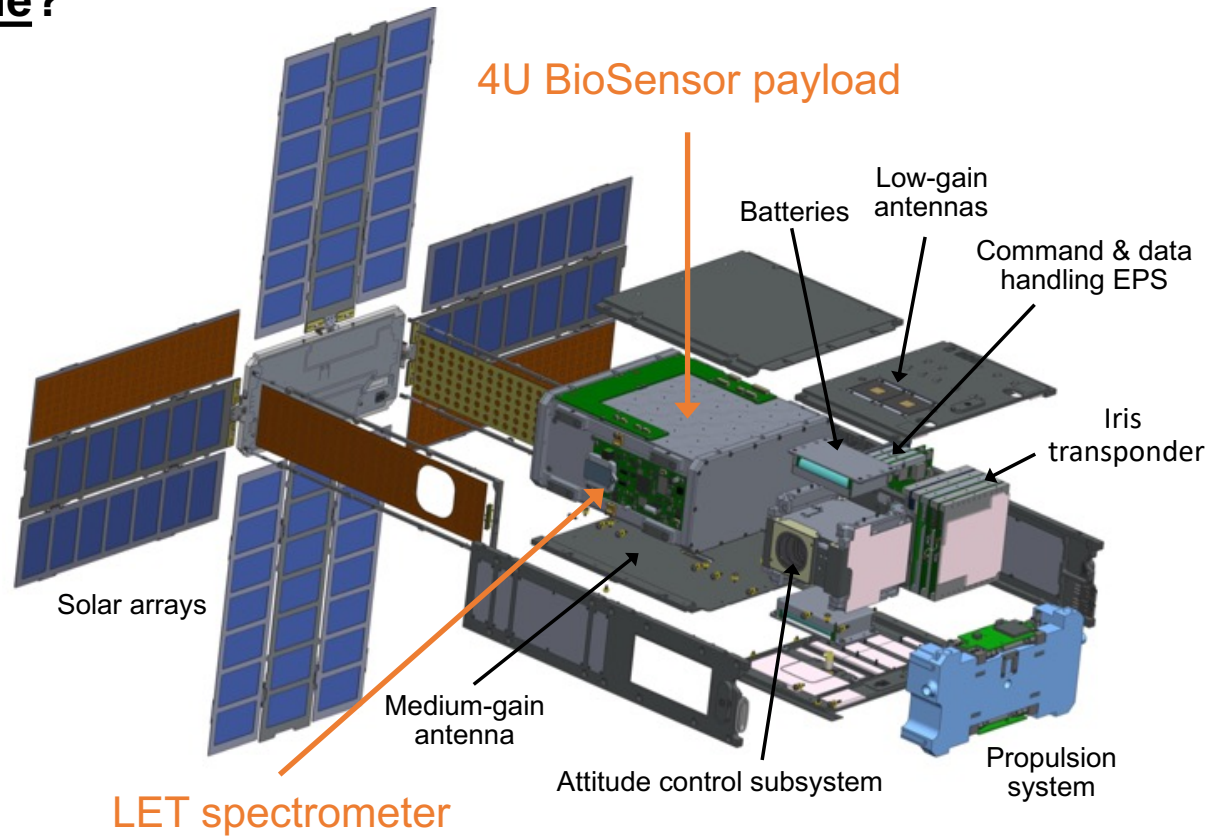
Objectives:

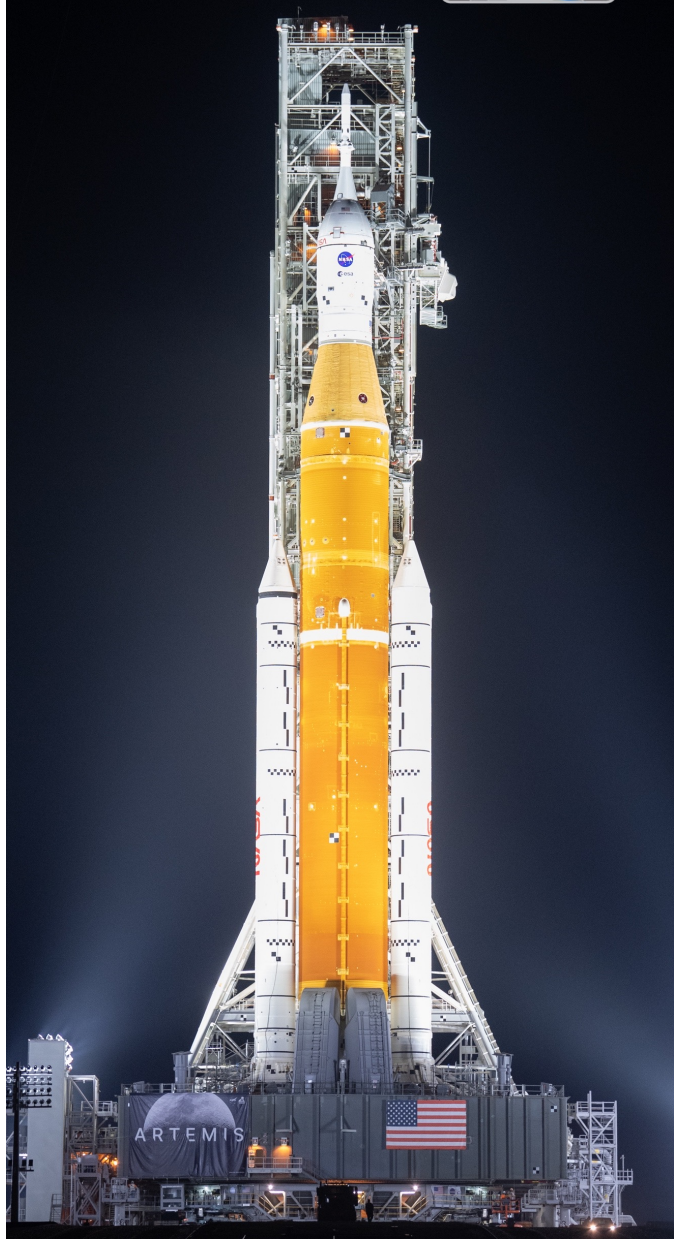
- Develop a deep space tool with autonomous life support technologies
- Study the space radiation environment beyond LEO and its effect on biology

What is it & what's inside?







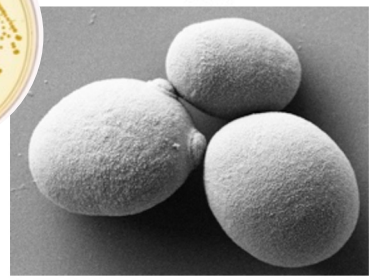


BioSentinel: key components

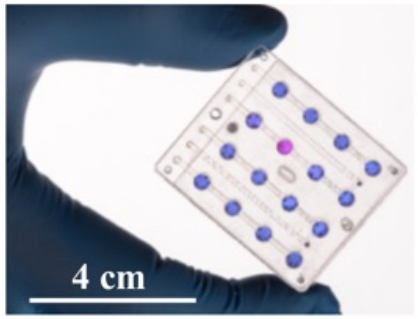
Subsystem	Description	Vendor	Subsystem	Description	Vendor
4U BioSensor			**LET spectrometer**		
Fluidics	18 PC cards & manifolds with integrated valves, pumps, bubble traps & desiccant chambers	NASA ARC	Radiation sensor	Timepix-based sensor (TID and LET particle characterization)	NASA JSC
Optics	3 LED 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 instrumentation

Budding yeast

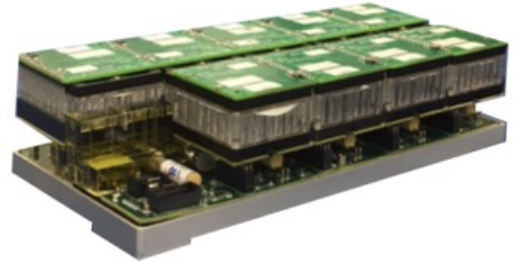


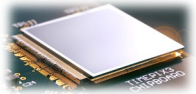
16-well fluidic card (x18)



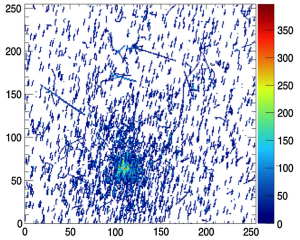
Card stack

9-card fluidic manifold (x2)

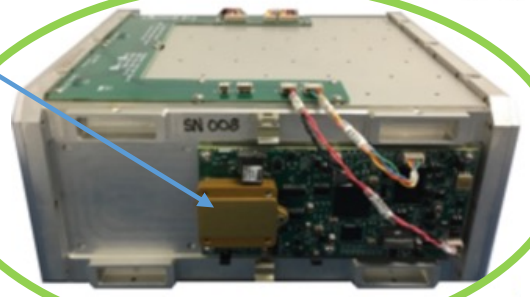




LET spectrometer

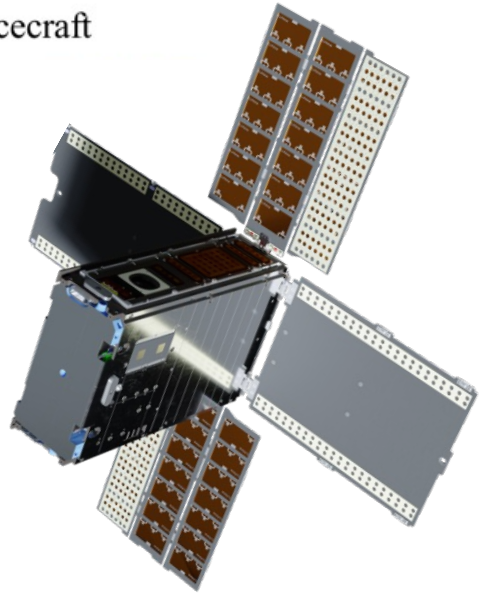


4U BioSensor payload

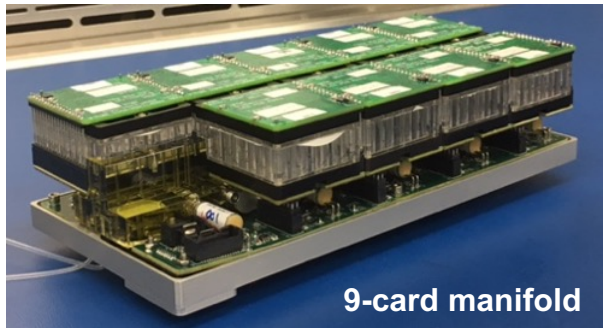


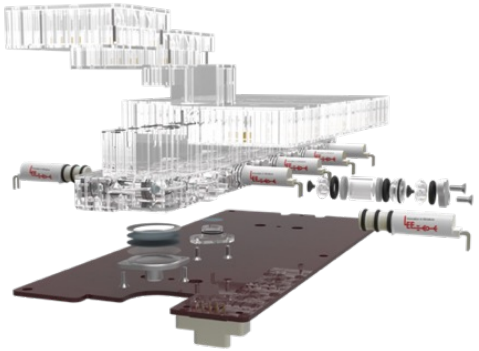
ISS
(& Ground)

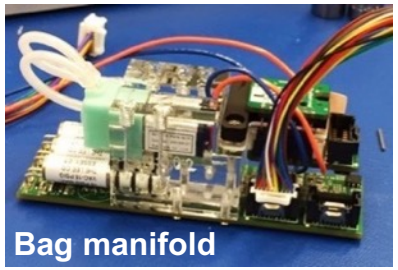
6U BioSentinel spacecraft

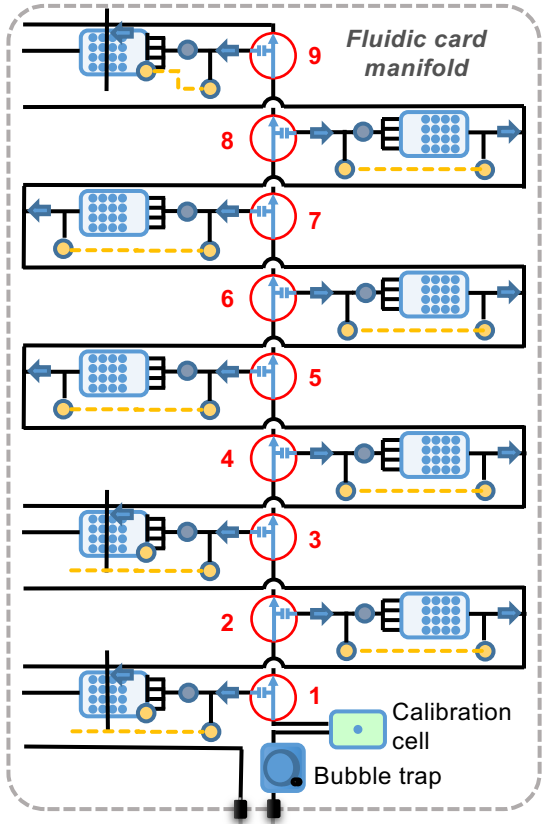


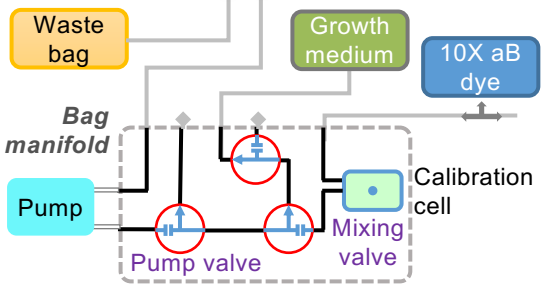
BioSentinel: microfluidics

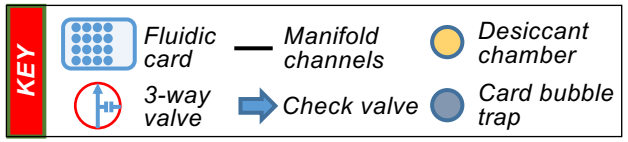


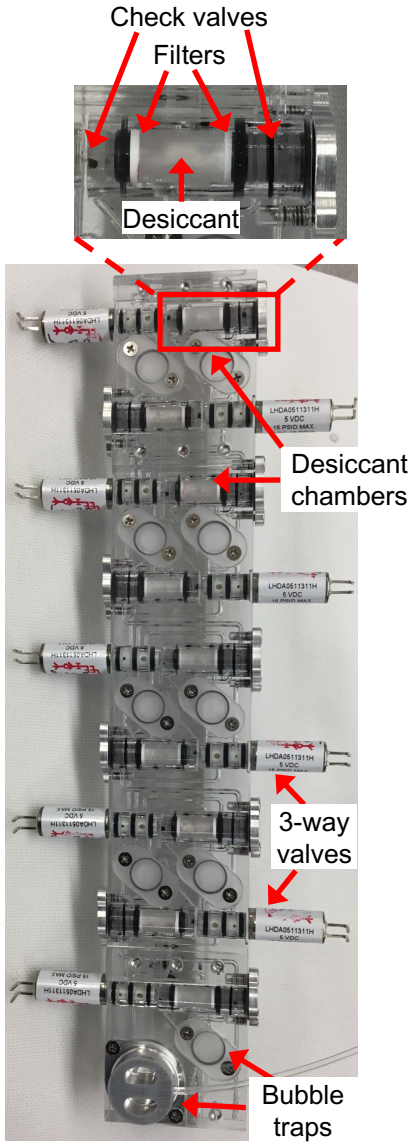


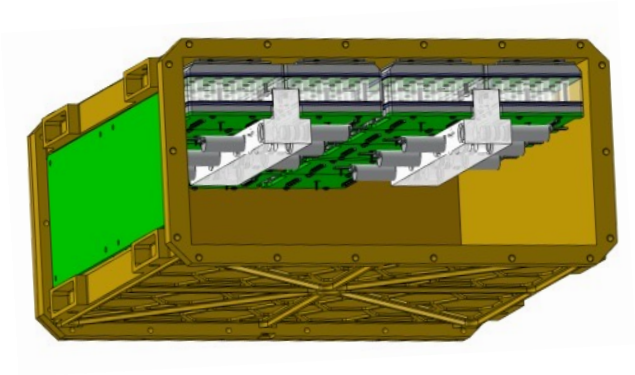


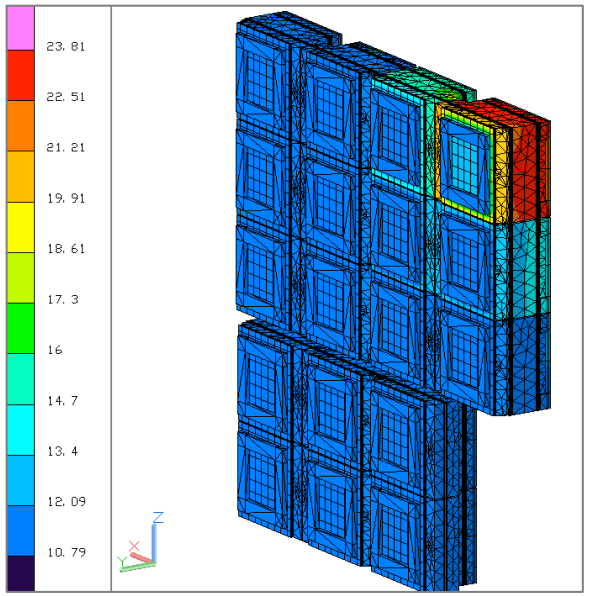






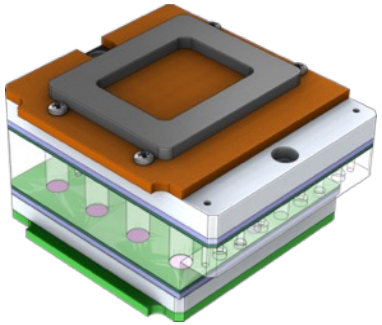


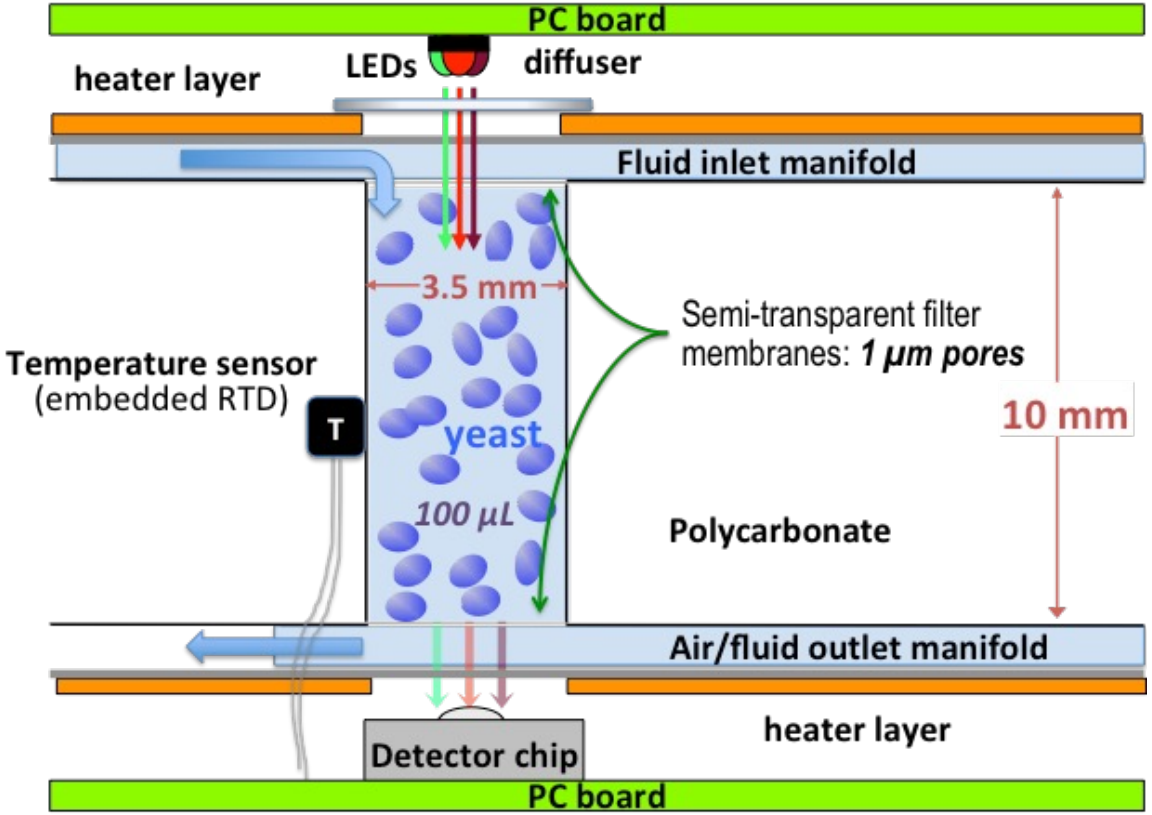




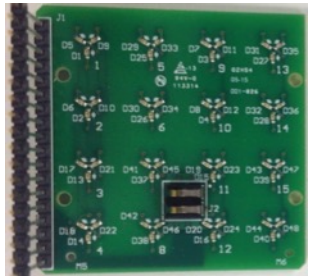
BioSentinel: microfluidics

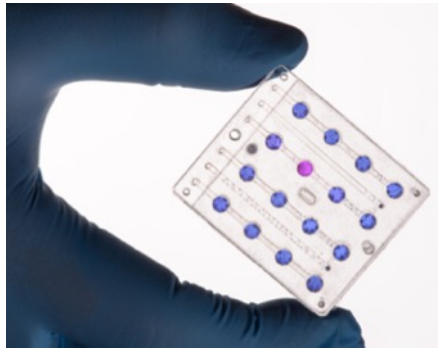
Microfluidic card (x18)



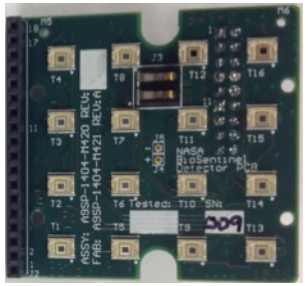


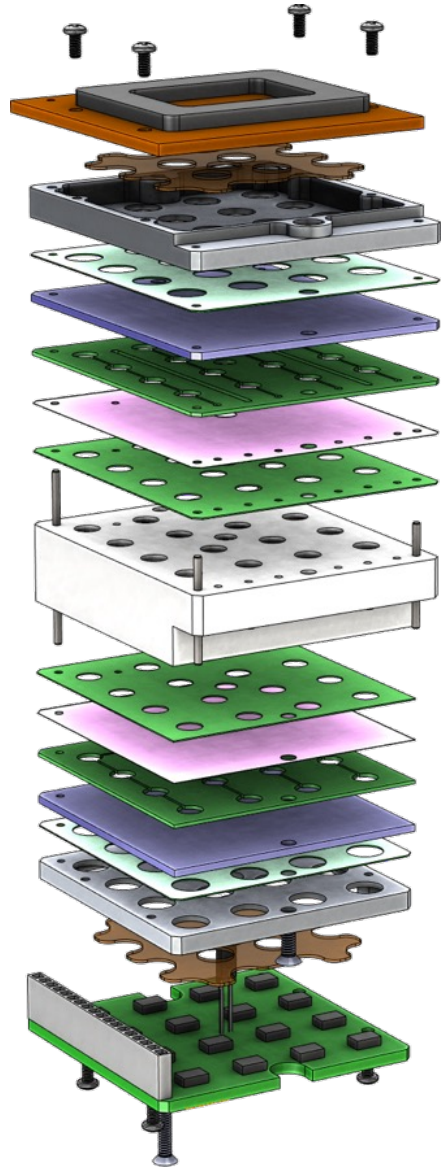
3-LED emitter





Photodiode detector array





Optical Source

Heater layer

Fluidic card

Heater layer

Optical detector

BioSentinel: optical detection system

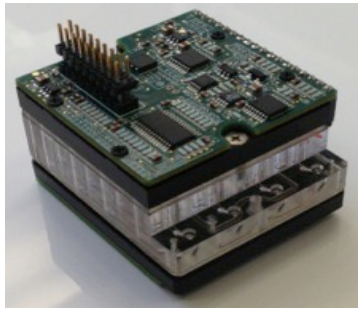
Dedicated 3-color optical system at each well to track growth *via* optical density and cell metabolic activity *via* dye color changes

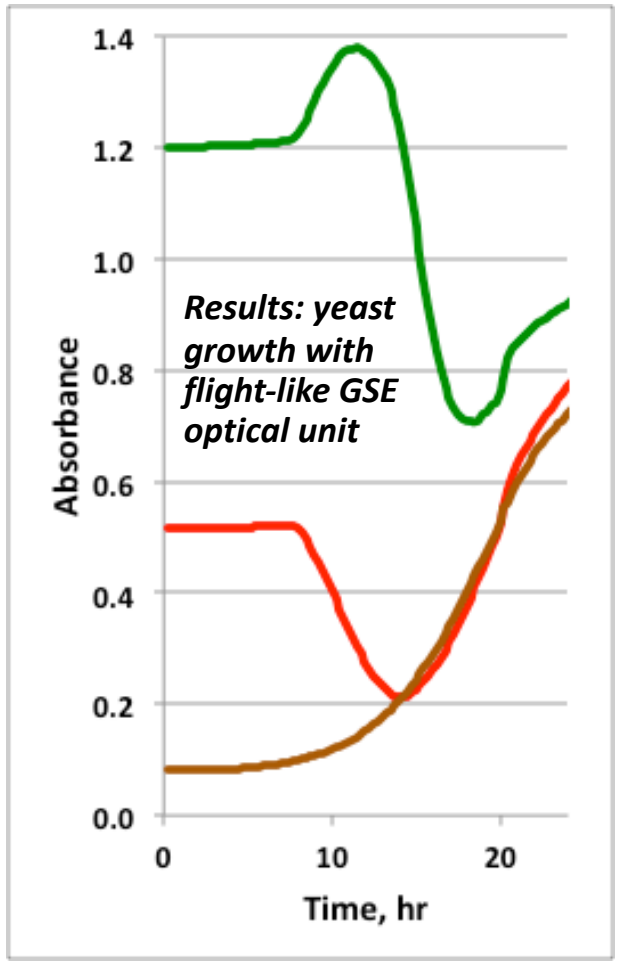
LEDs:

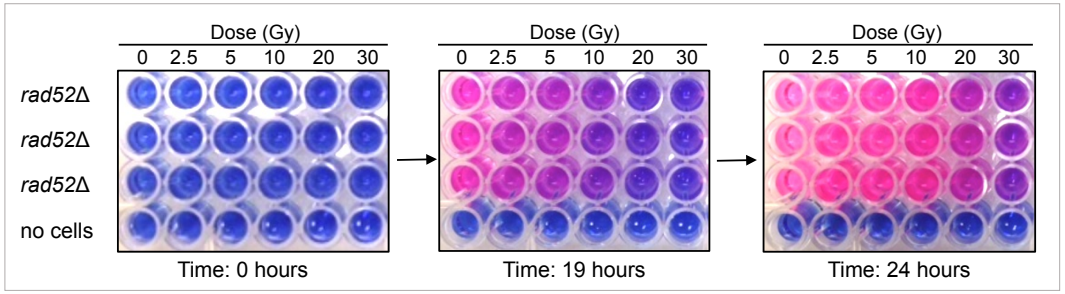
570 nm (green, measures pink)

630 nm (red, measures blue)

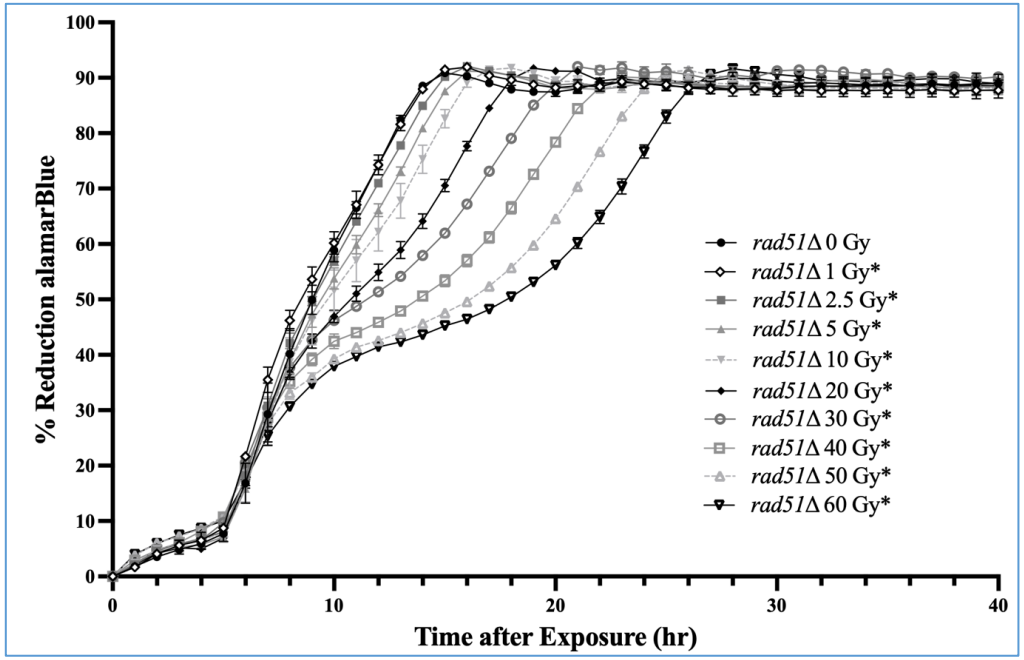
850 nm (infrared, measures growth)







alamarBlue turns pink when cells are metabolically active



HR repair defective cells show sensitivity to ionizing radiation

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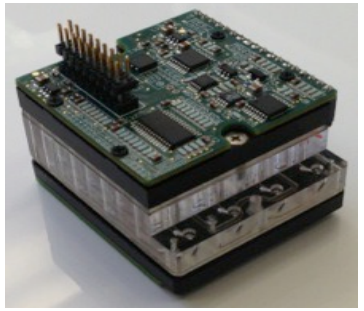

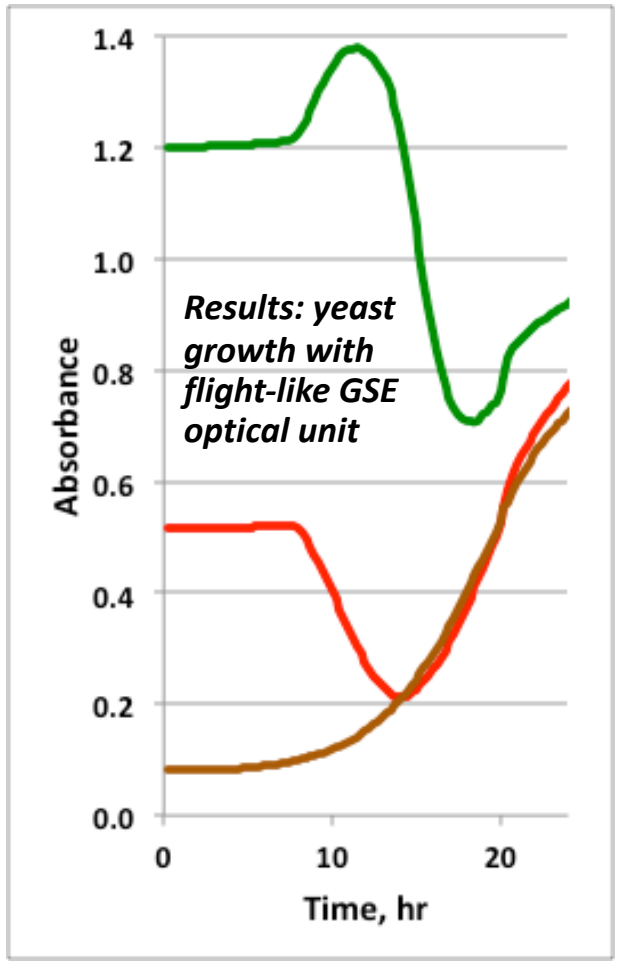

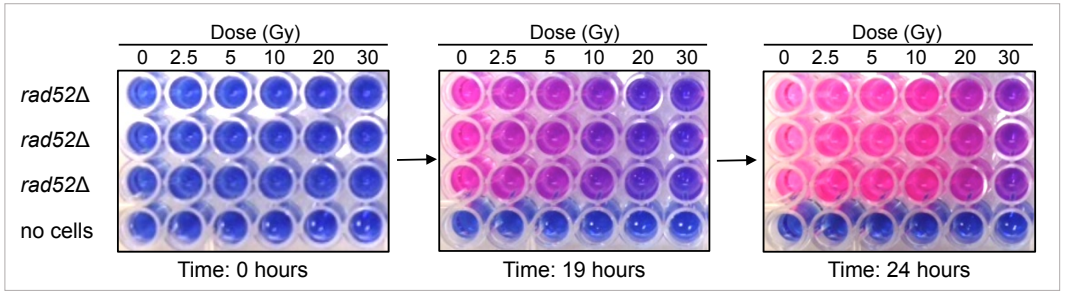

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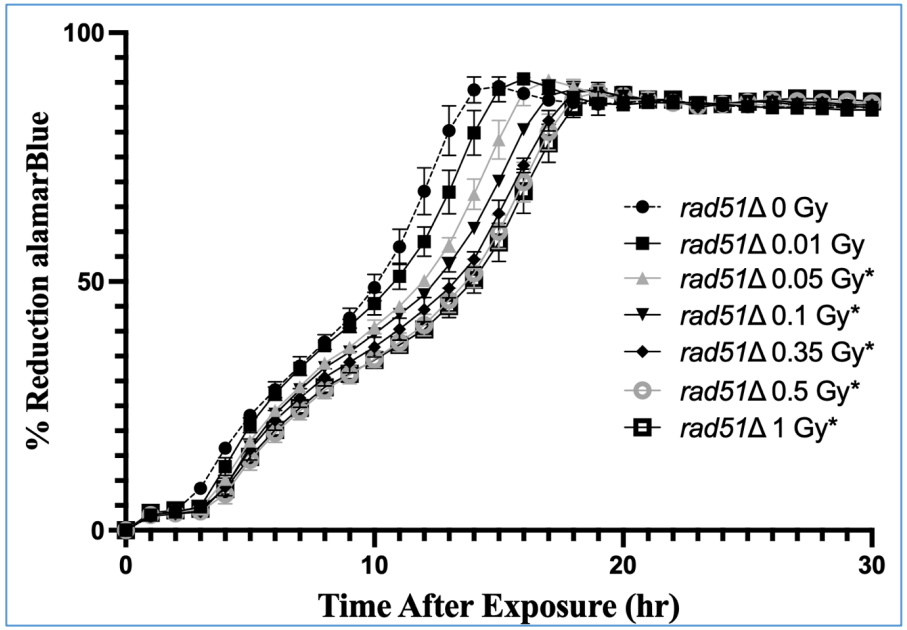
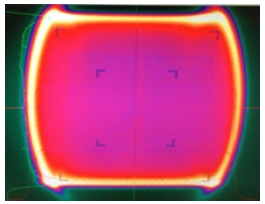


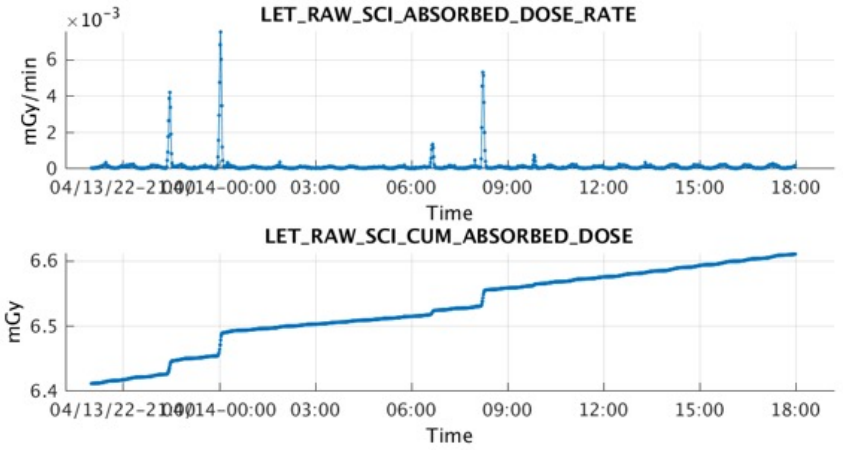


HR repair defective cells show sensitivity to GCRsim ionizing radiation

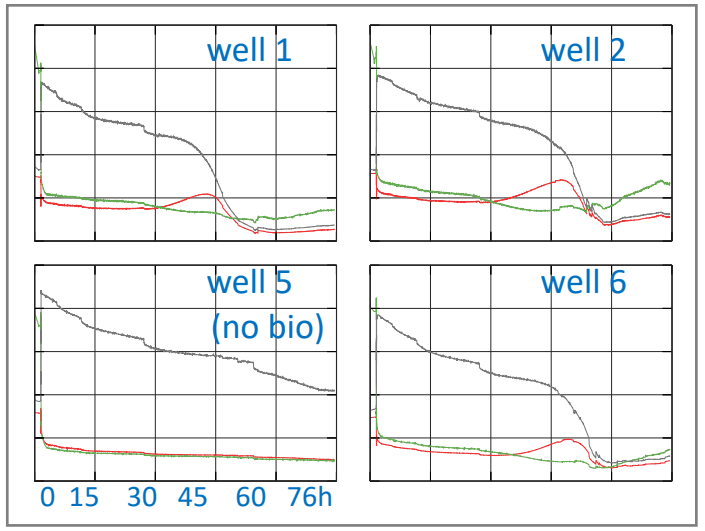
BioSentinel: ISS experiment

- ISS instrument launched on SpaceX CRS-24 on Dec 21, 2021, and installed into SABL incubator
- First set of cards activated in late-Jan 2022; last one completed in mid-June
- ISS payload returned on SpX-25 in late-August
- Data used as LEO control and to validate instrumentation

ISS LET spectrometer data from April 14

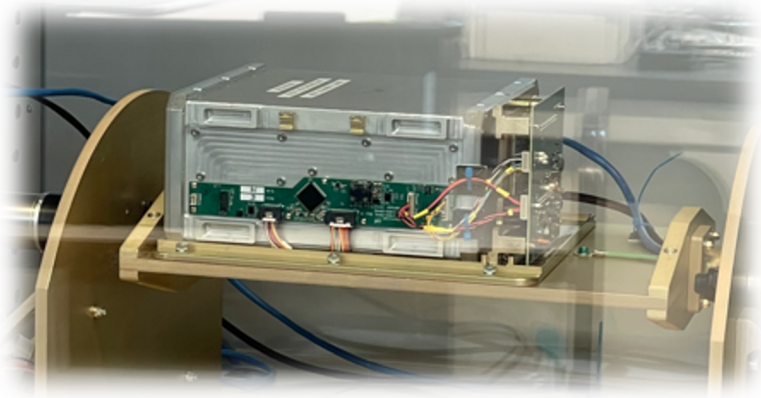


Card 8 optical readings after ~72 hours



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

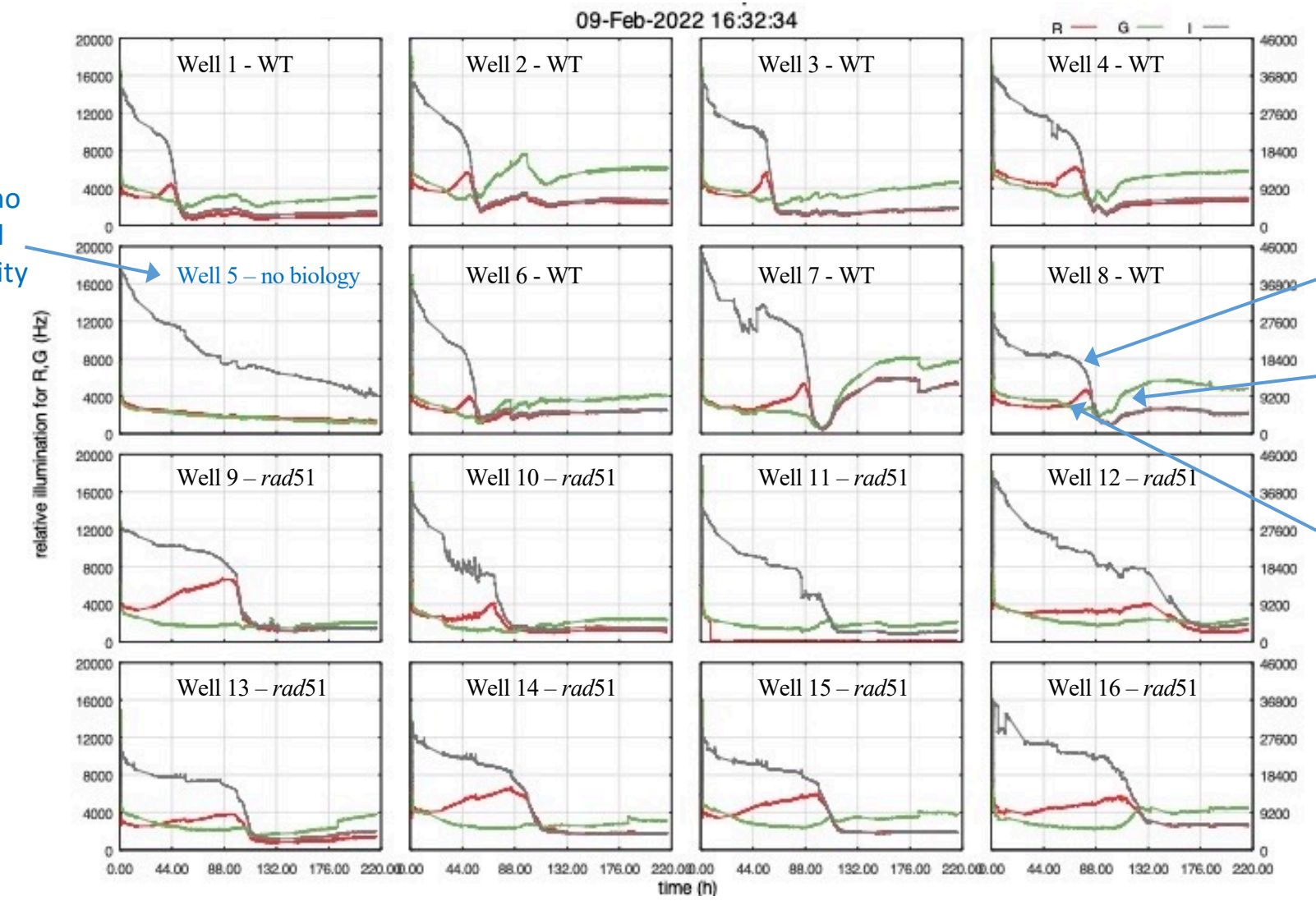
Reagents (growth medium and alamarBlue dye) working properly



Ground control unit at NASA ARC

BioSentinel: ISS experiment

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

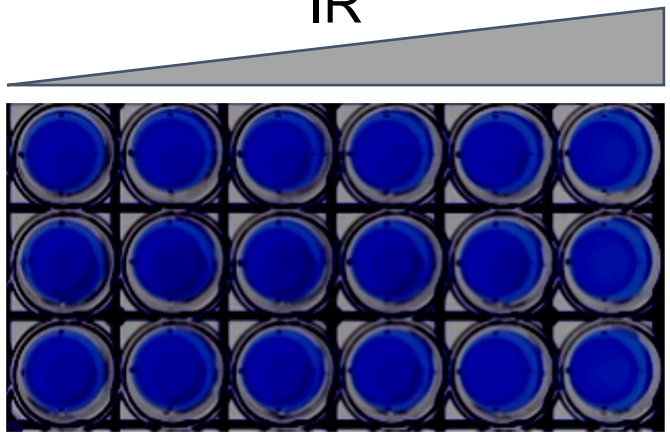


850nm readings show cell growth

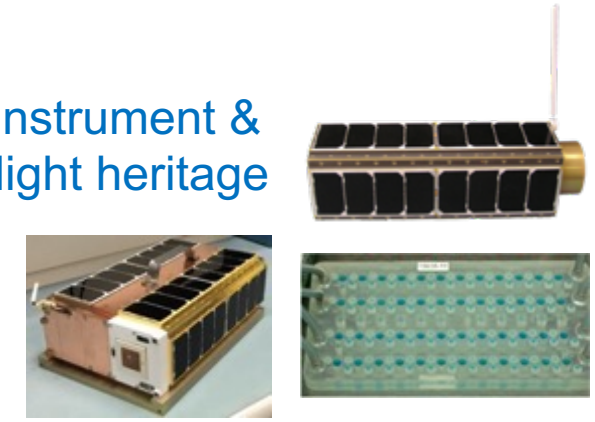
570nm readings (green, going down then up) show transition to pink color, then clear

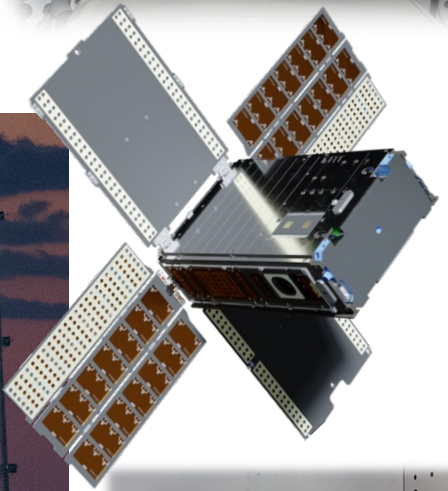
630nm readings (red, going up) show disappearance of the blue color

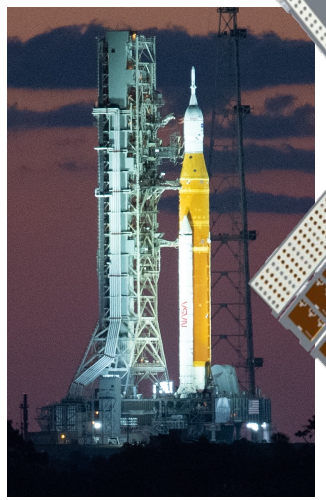
BioSentinel: how did we get here?



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

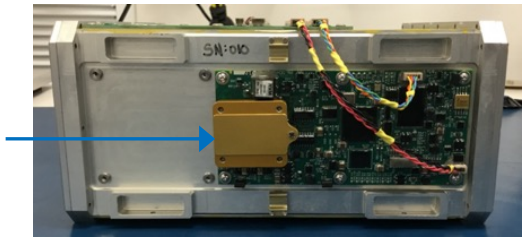
BioSentinel: radiation environment characterization

- LET spectrometer mounted outside the BioSensor enclosure
- Reports cumulative dose, dose rate & particle distribution based on LET
- Performing nominally; unaffected by BioSensor issues

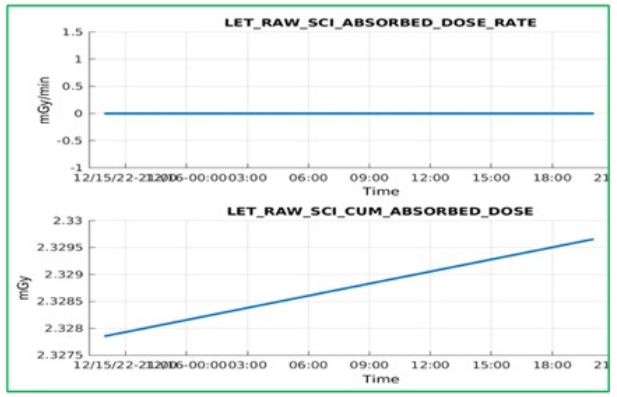
Science objectives:

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

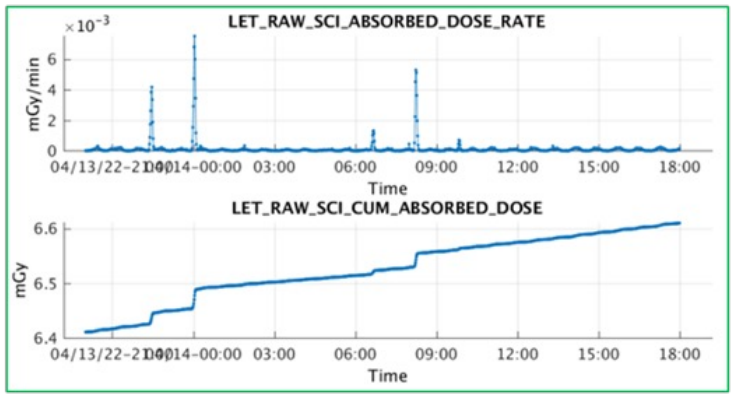
	Absorbed dose rate (mGy/day)	**Total absorbed dose** (6-mo mission)
Ground	~ 0.0003	0.055 mGy
ISS (Jan 31 – Jun 17, 2022)	0.217	-
Free-flyer	0.306	55.78 mGy
Free-flyer (transport modeling)	0.25 ± 0.04	-



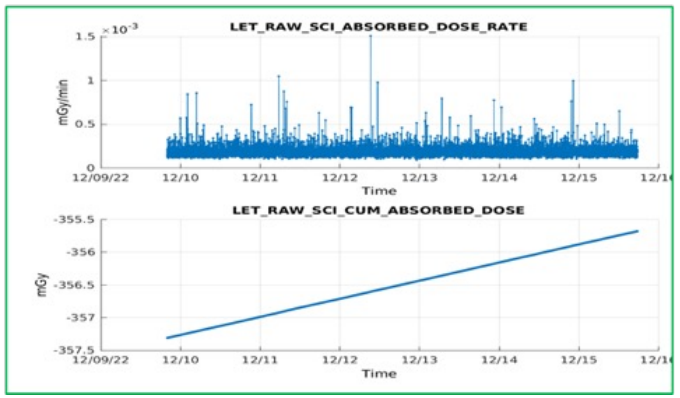
Ground LET spectrometer – Dec 16



ISS LET spectrometer – April 14



Free-flyer LET spectrometer – Dec 16



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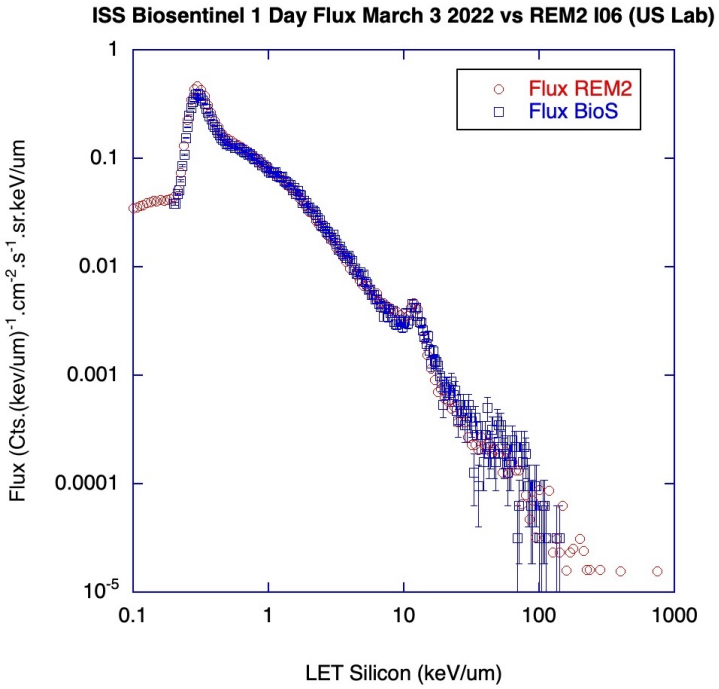
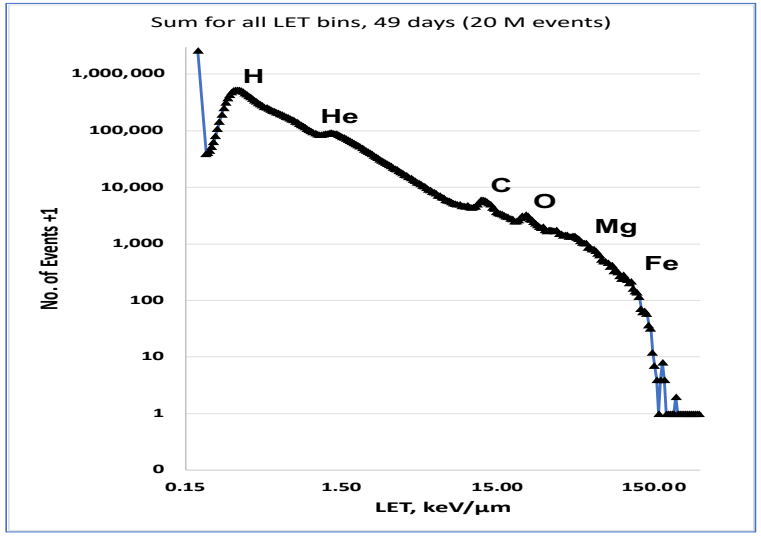
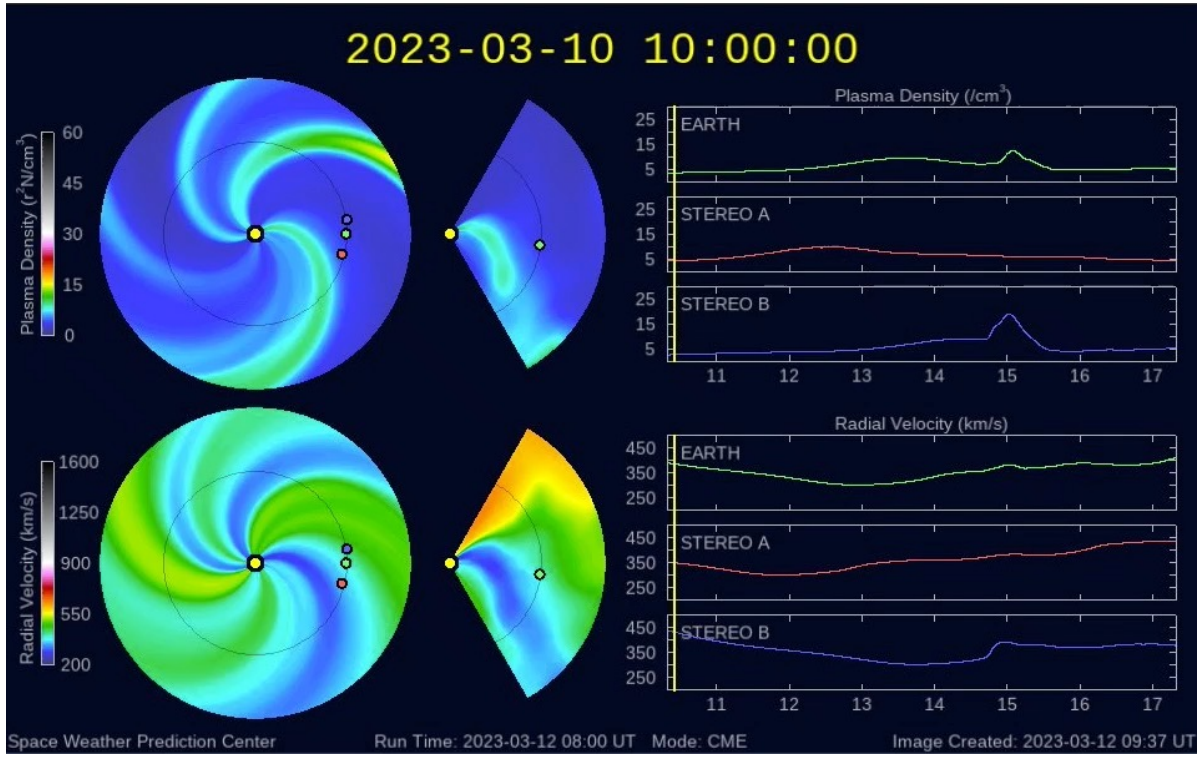


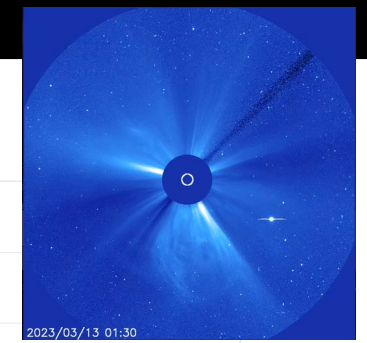
LET spectrum (in Si; 20M events); first 49 days

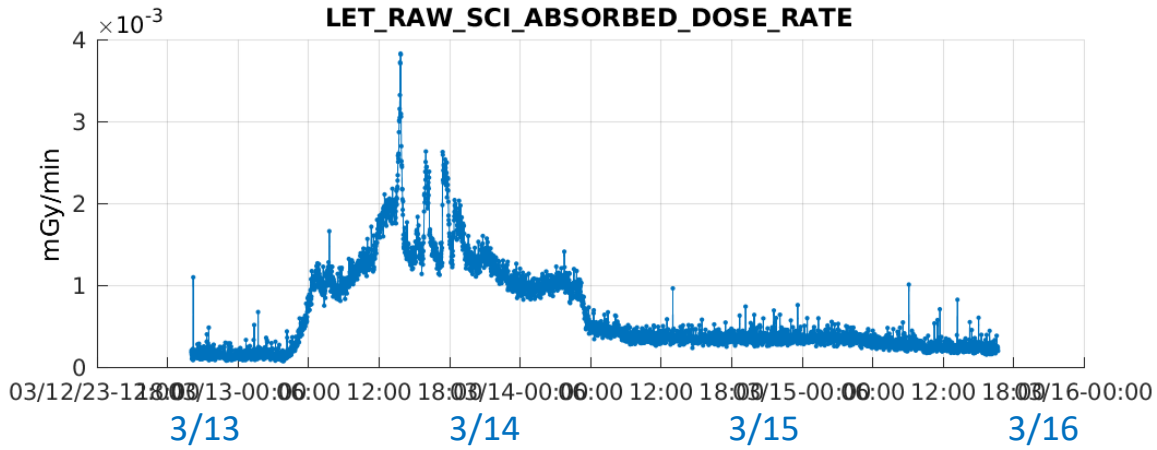


BioSentinel: radiation environment characterization

- 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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Top Issue: multiple launch delays

How the project managed the issue?

Long-term testing (reagents, biology, etc.)
Environmental monitoring requests at KSC
Constant communication with partners

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: top risks & lessons learned

	Risk Description	Mitigation Approach
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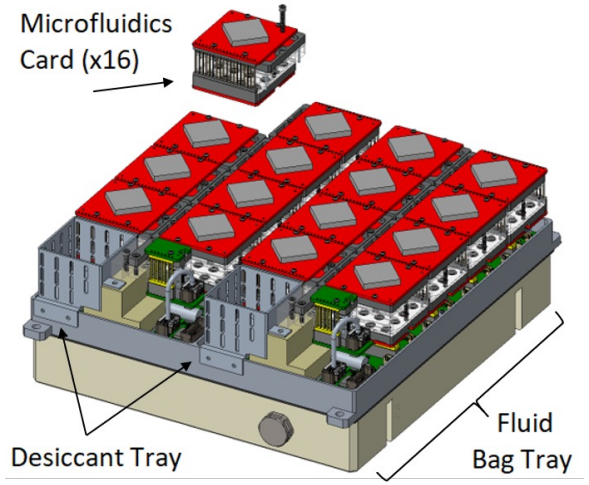
Issues, lessons learned & mitigations

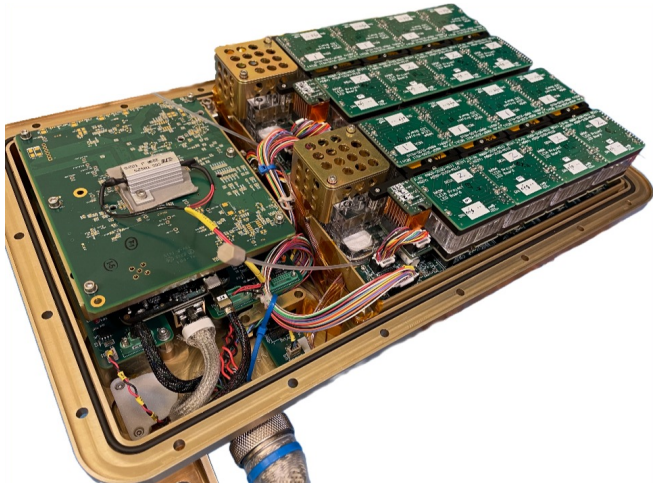
	What Happened?	What did we learn from it?	Proposed Mitigation Strategies	Recommended Actions
1	Lower yeast viability	Long duration effects inside sealed enclosure (↑ RH)	Late integration and/or payload swap	Modify design for future missions to include late load & integration; ↑ desiccant inside enclosure
2	Unknown launch date	Loss of personnel & constant changes in trajectory	Analyze risks associated with unique mission conditions	Document for future personnel on why 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/scaled-down EVT to feed potential design changes

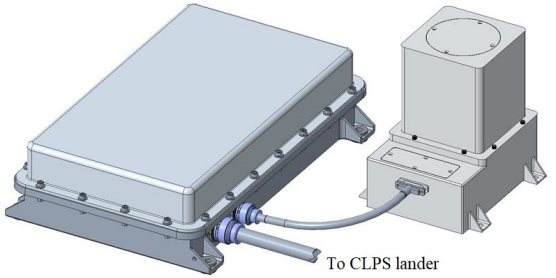
How are we improving LEIA based on lessons learned from BioSentinel?

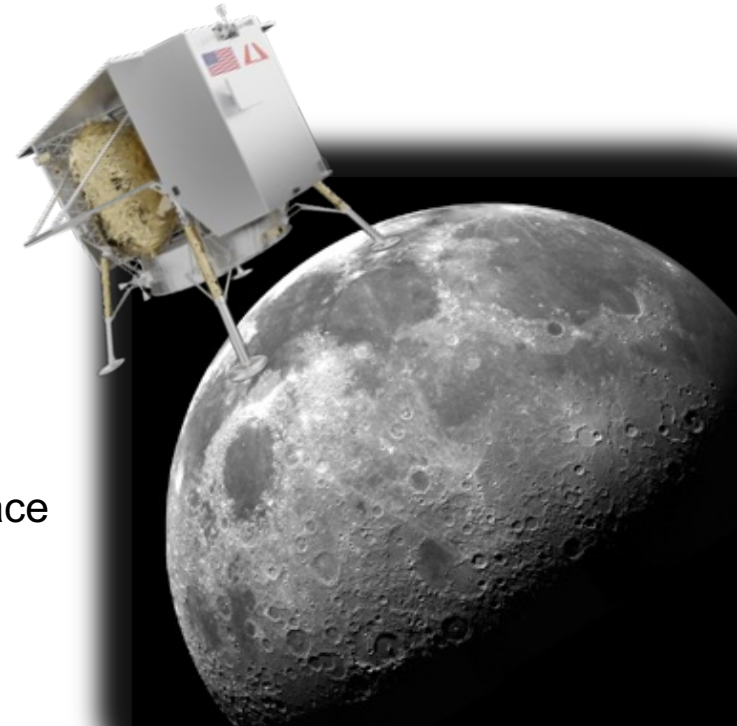
LEIA lunar surface mission

LEIA: Lunar Explorer Instrument for space biology Applications







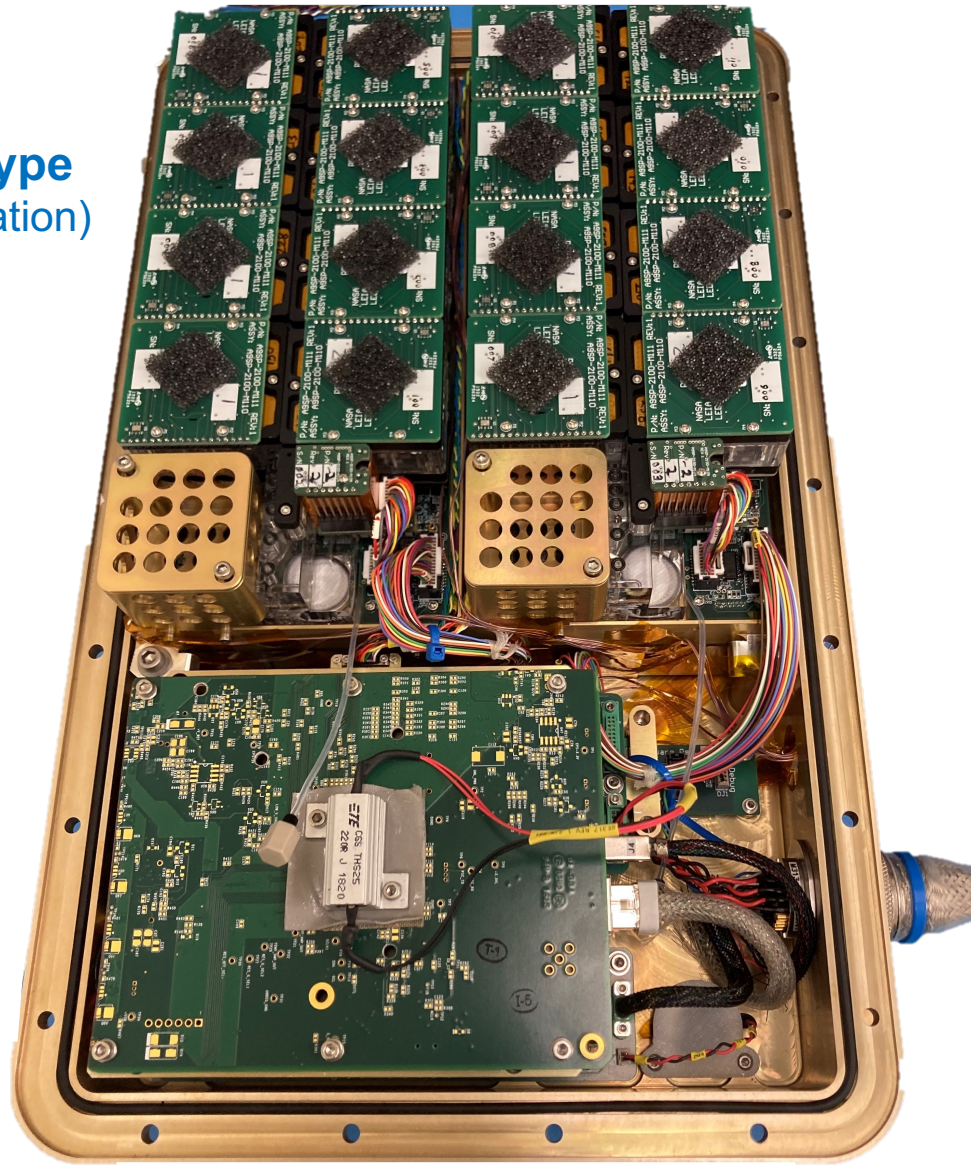


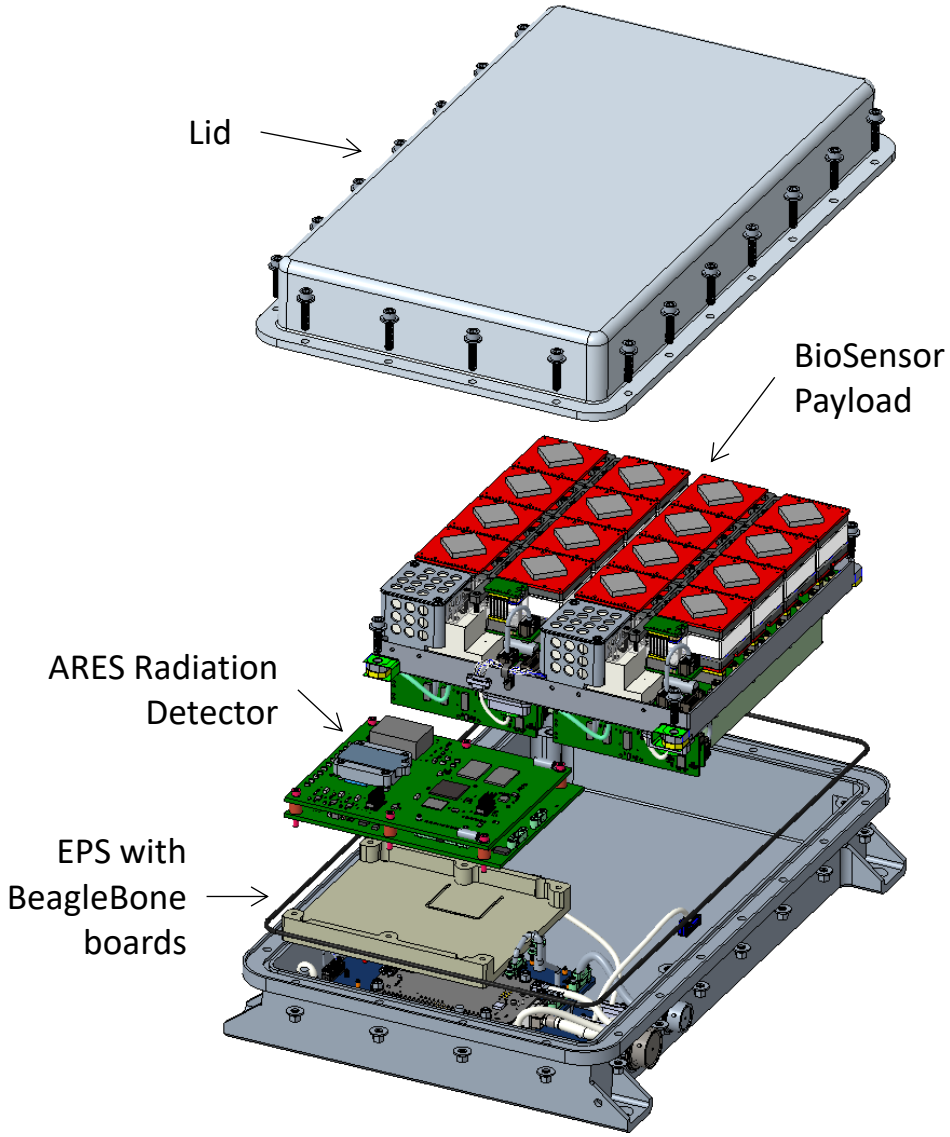
Science Aims:

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

LEIA improvements

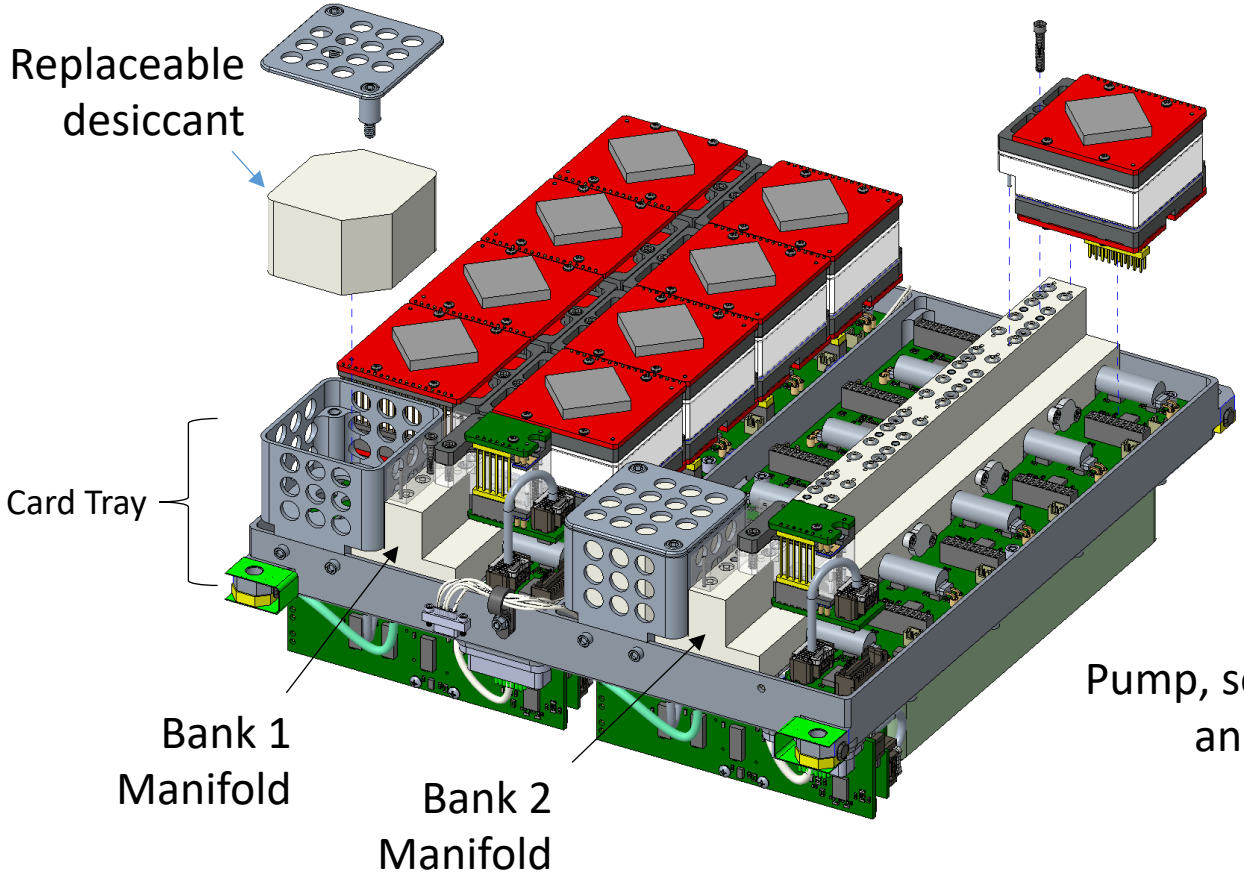
LEIA prototype
(open configuration)



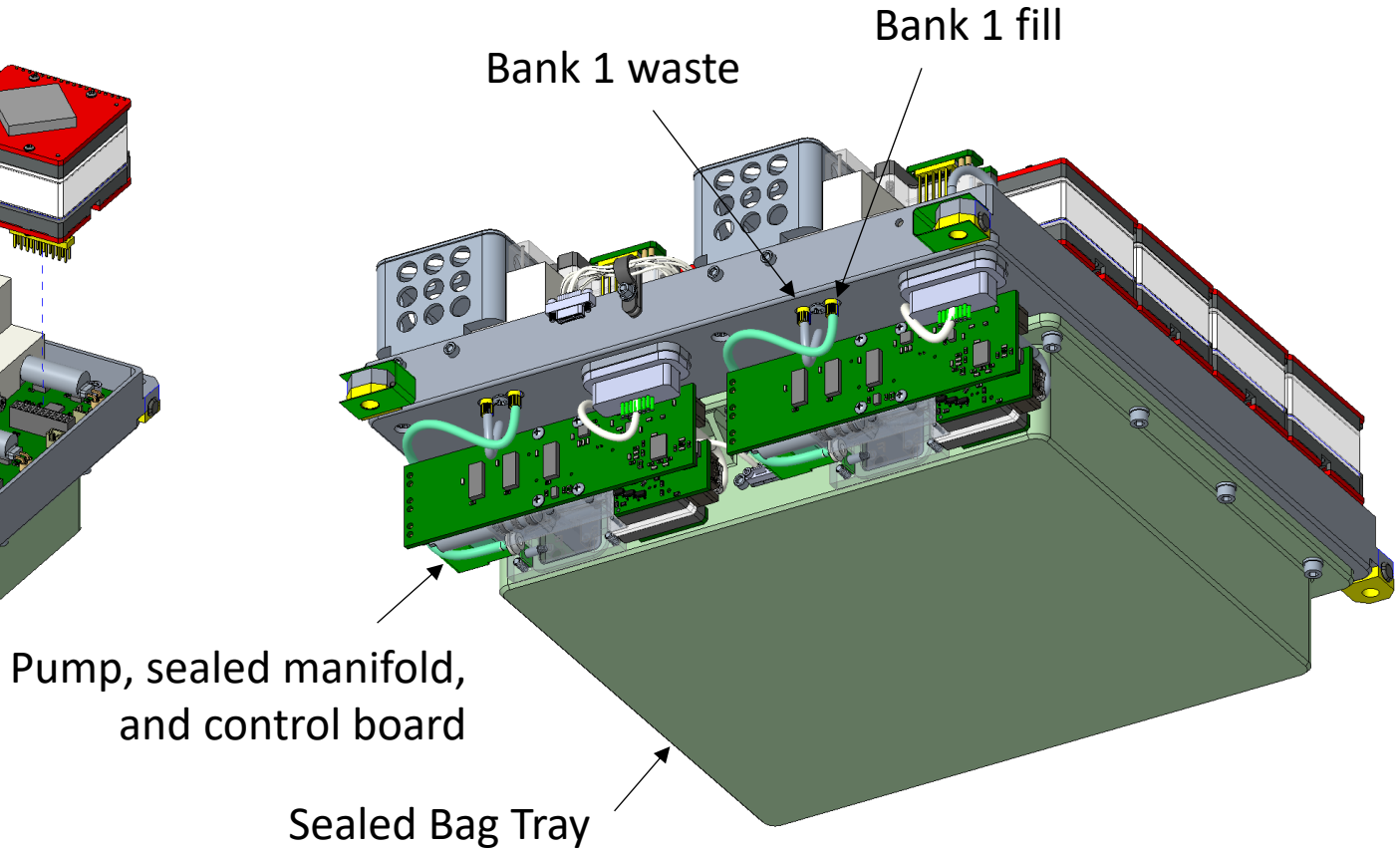


LEIA improvements

How are we preventing high humidity inside the BioSensor enclosure?

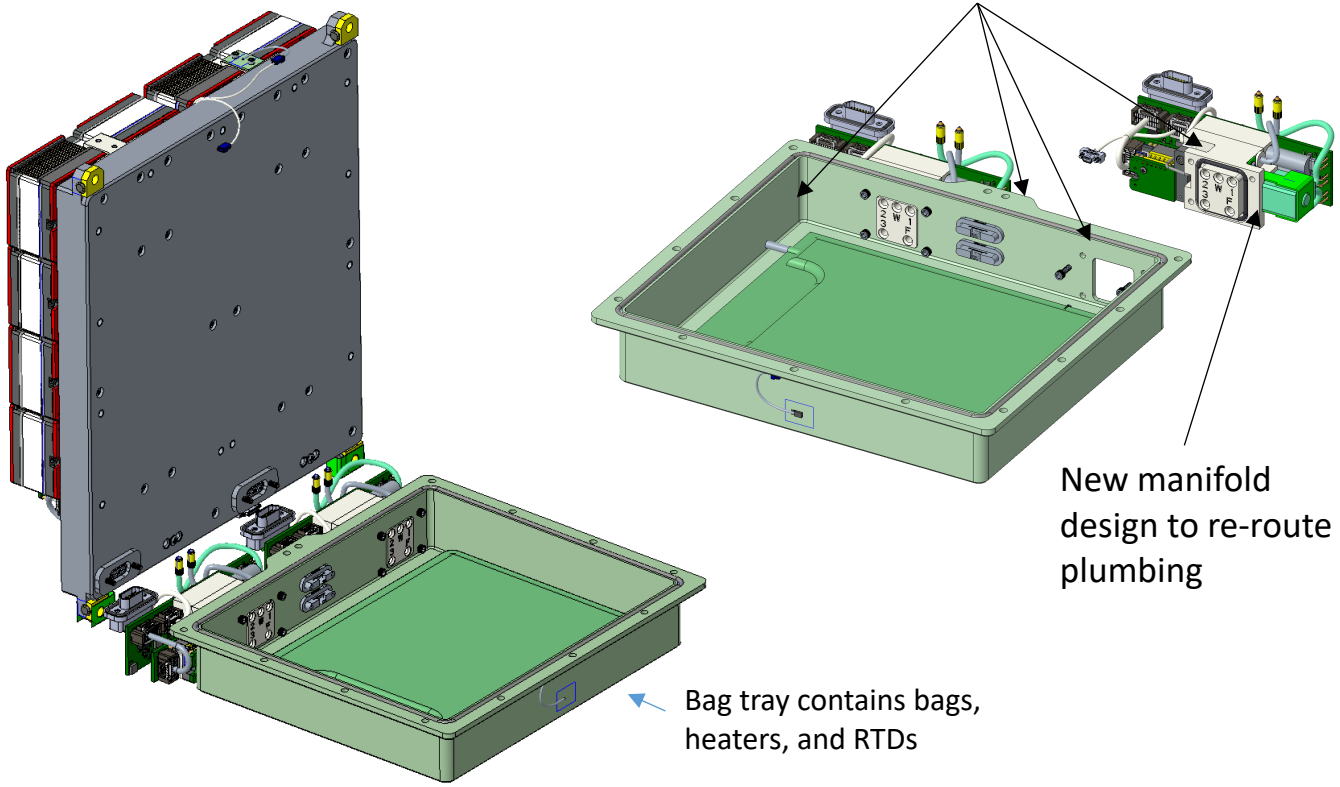


Increased desiccant

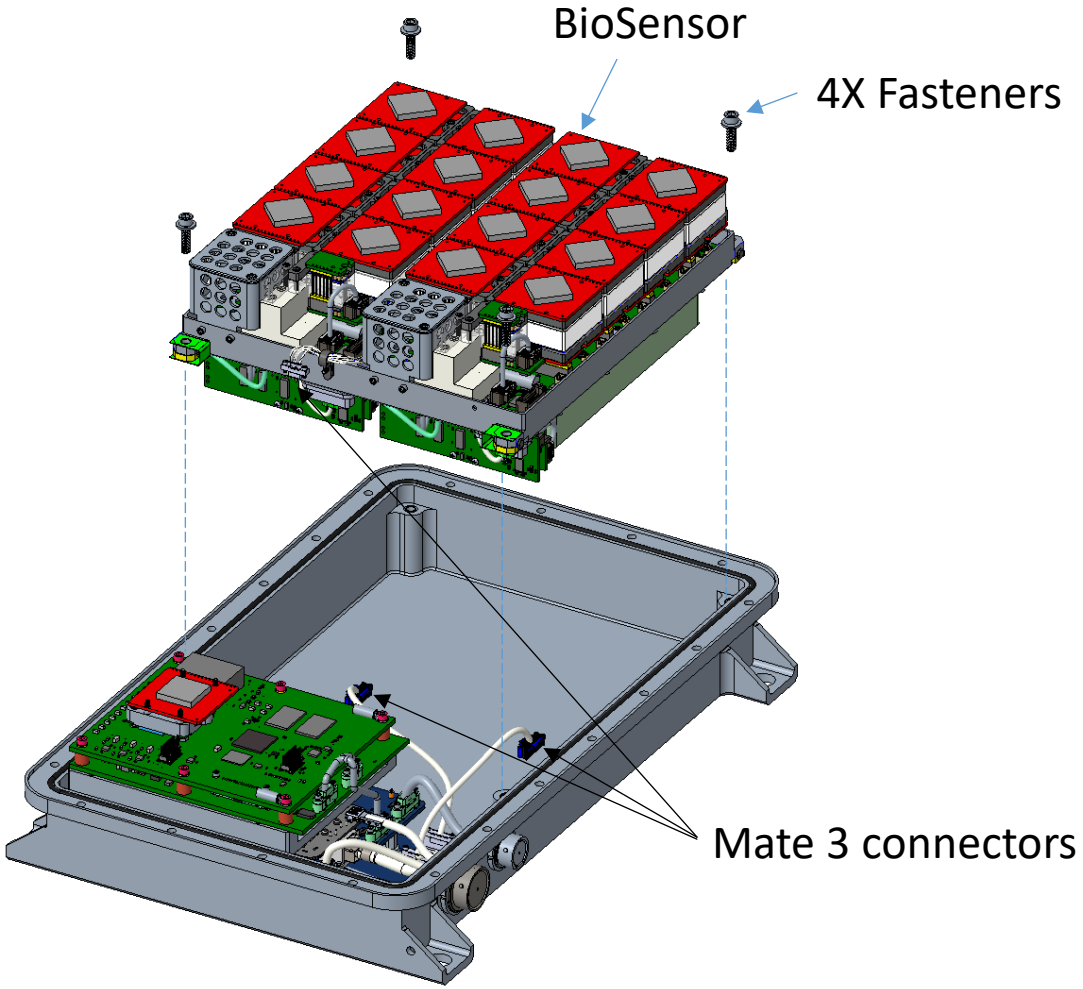


Improved seals & protected connectors

LEIA improvements



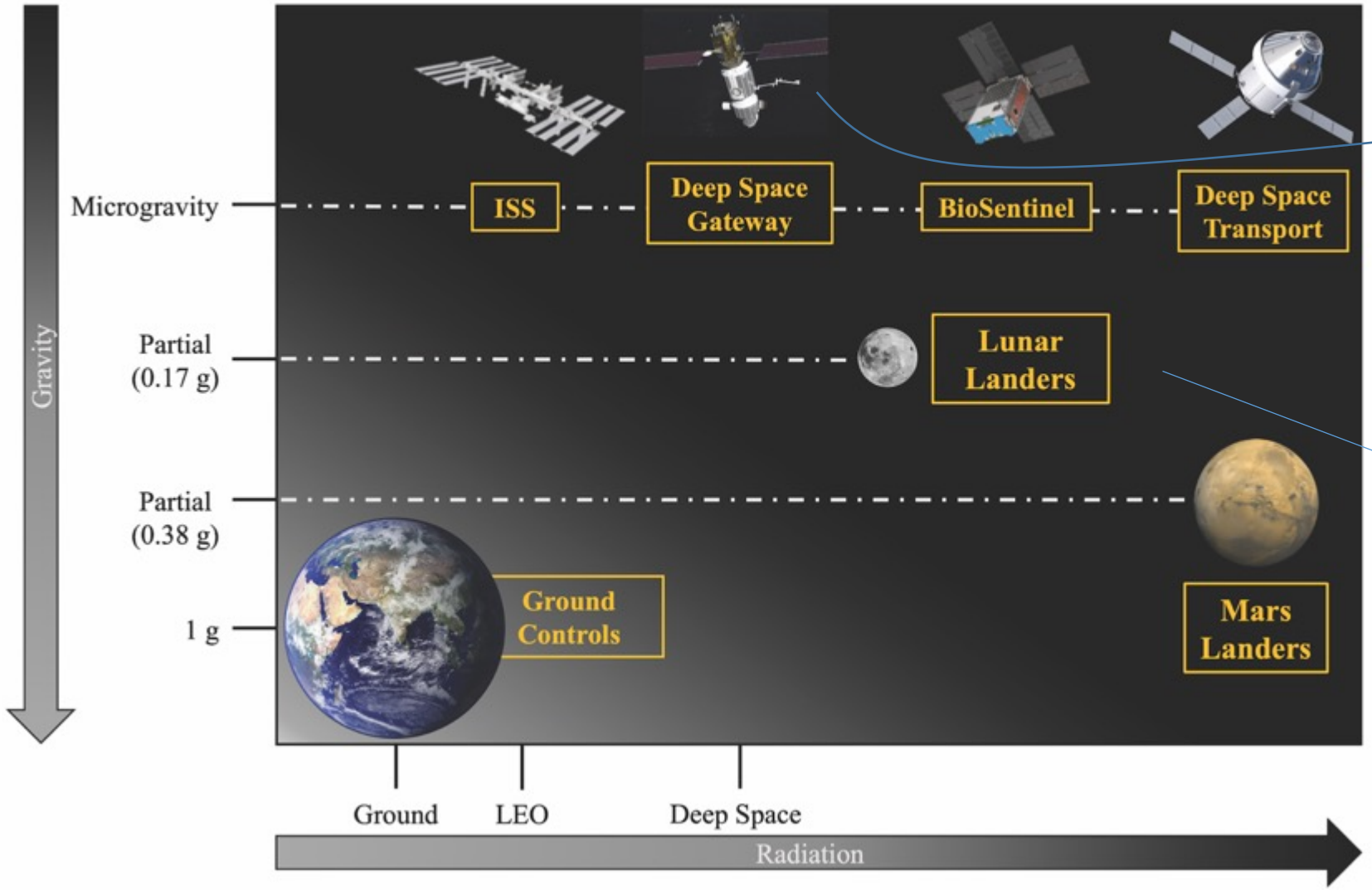
Redesigned bag tray & re-routed plumbing

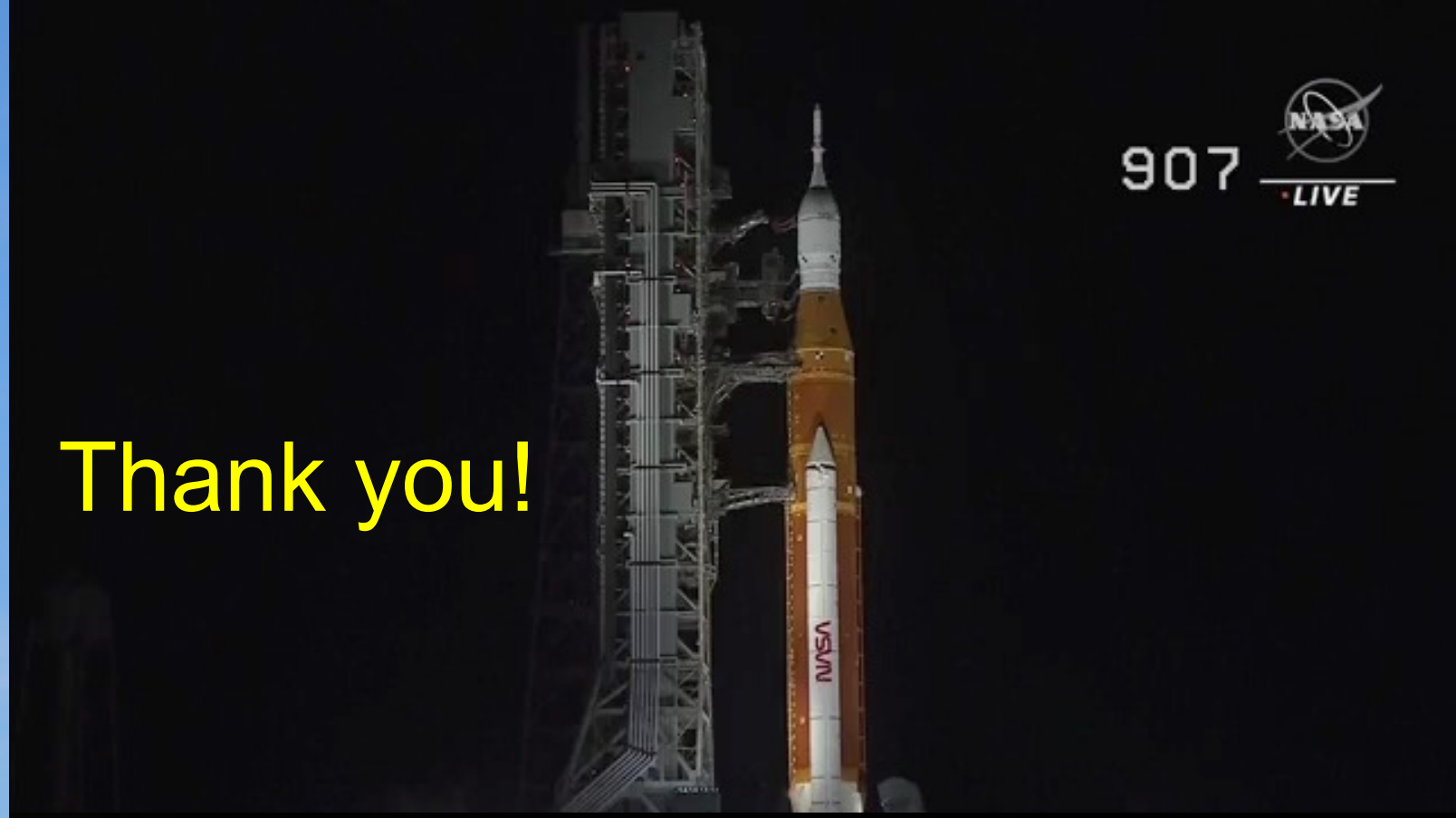


Late load installation

BLEO instrumentation: future & ongoing

A flexible design that will be used in different space environments





Thank you!