Lunar BioSensor: an autonomous instrument to study the effects of the lunar environment on biological organisms

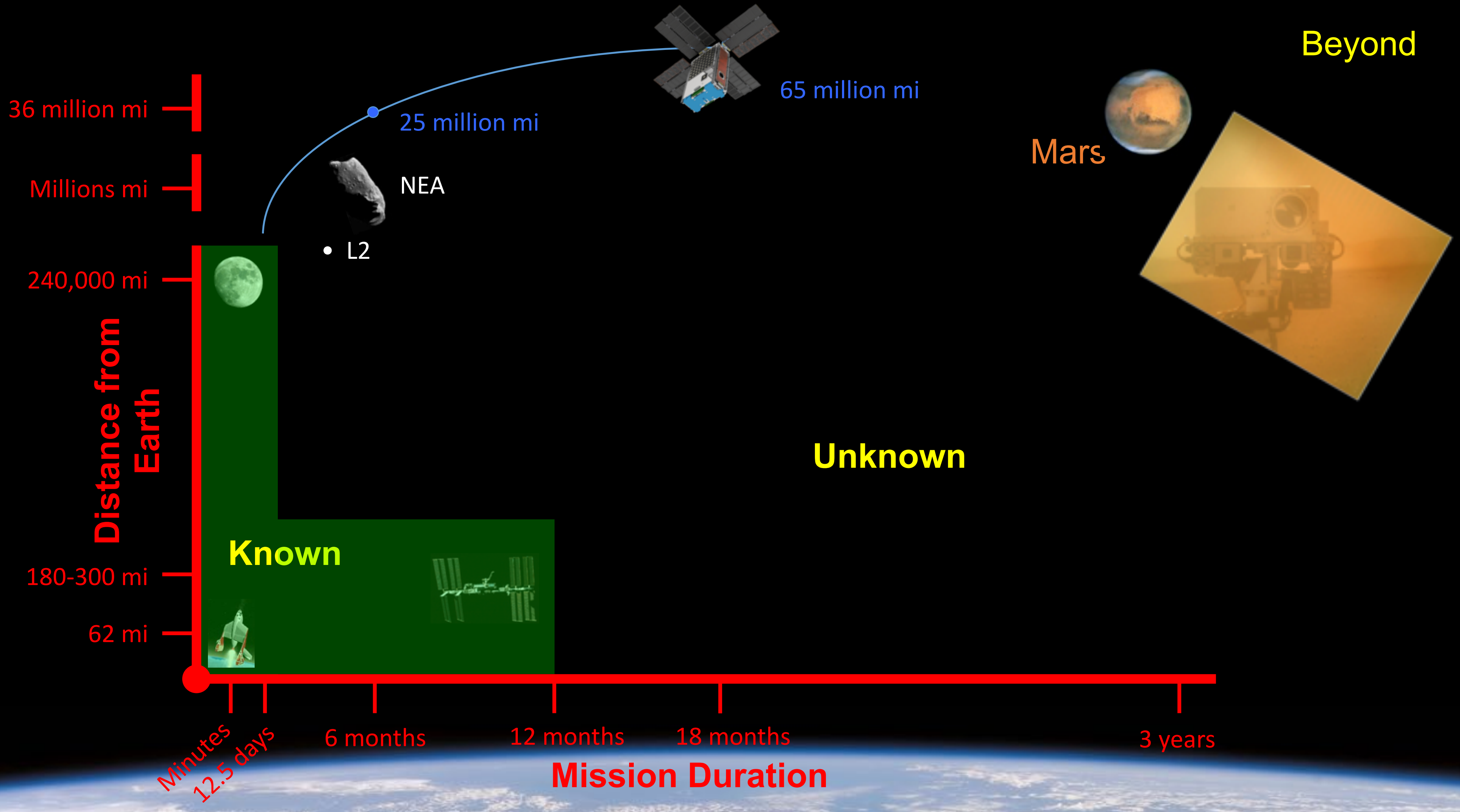
Sergio R. Santa Maria

Research Professor, COSMIAC Research Center
University of New Mexico

Lead Project Scientist, BioSentinel mission
NASA Ames Research Center

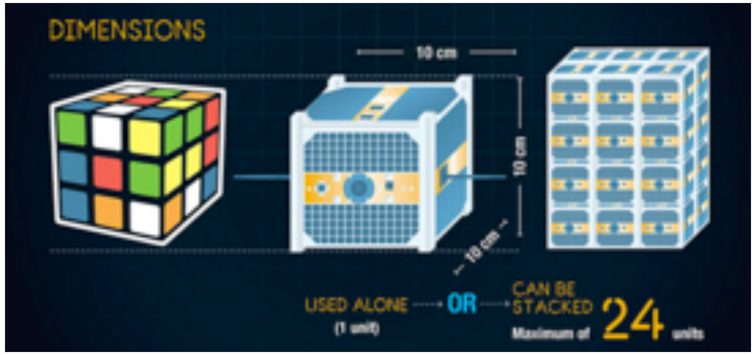
sergio.santamaria@nasa.gov

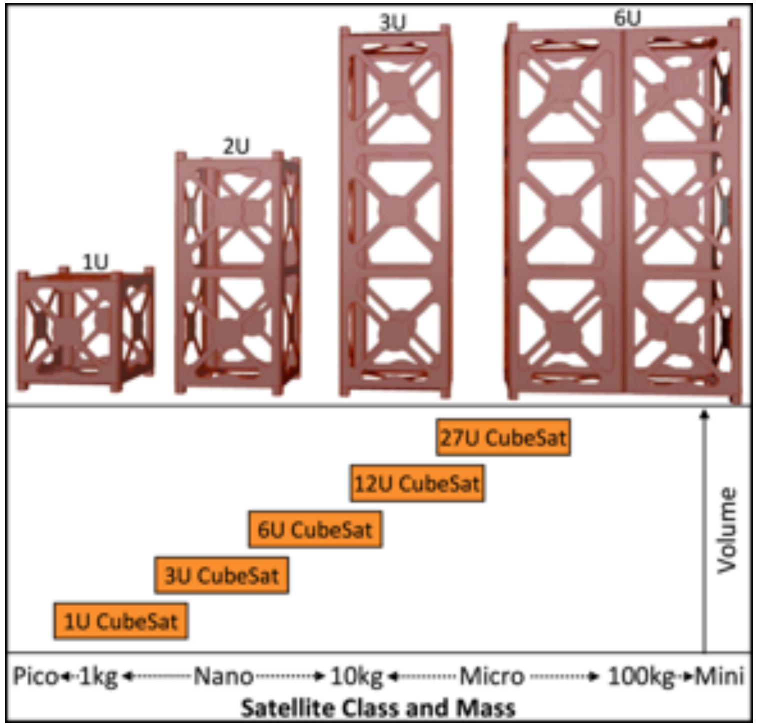
The limits of life in space – as we know it – is 12.5 days on a lunar round trip or ~1.5 years in LEO. As we send people further into space, we can use model organisms and/or biosensors to understand the biological risks and how they can be addressed



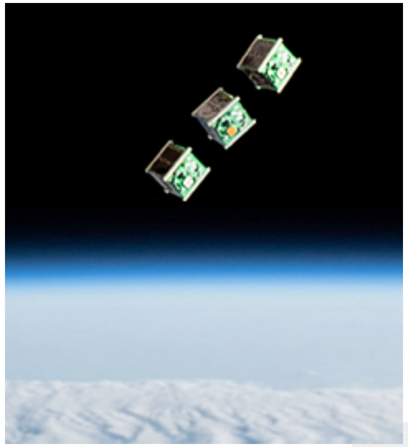
CubeSats

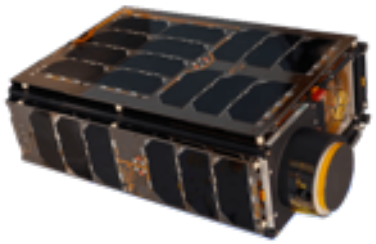
CubeSat configurations

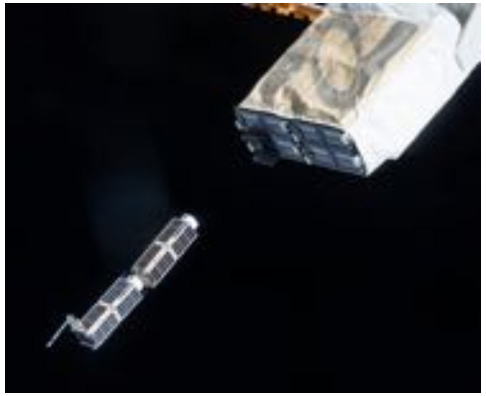




Poghosyan & Golkar, 2017

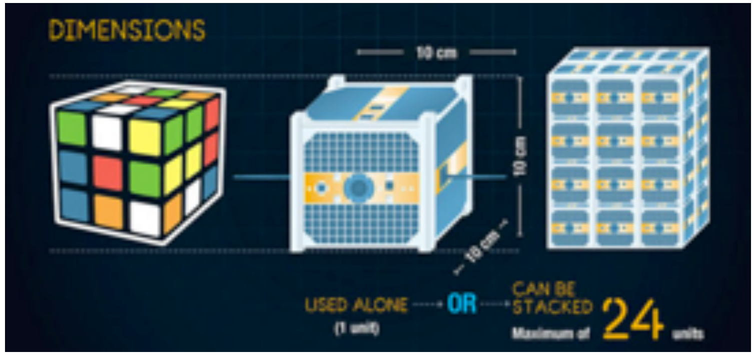


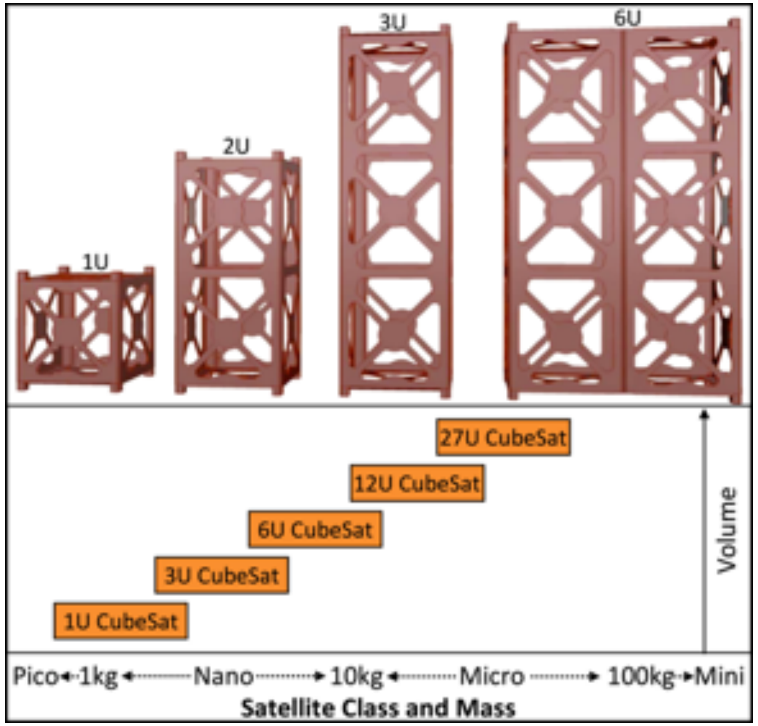




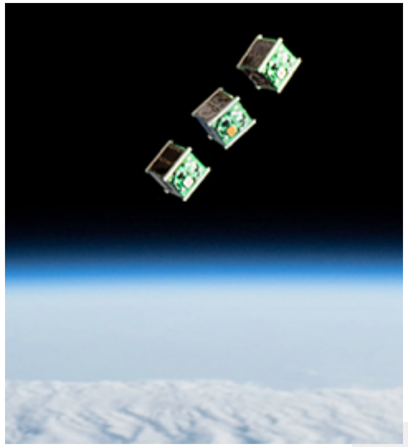
CubeSats

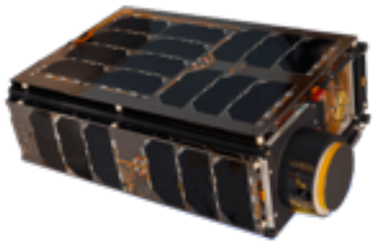
CubeSat configurations

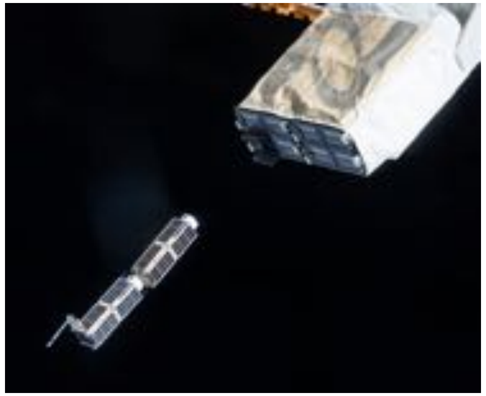




Poghosyan & Golkar, 2017



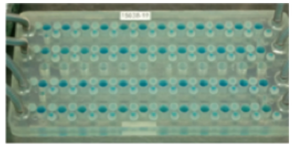




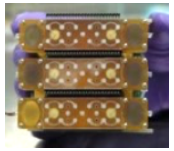
GeneSat-1 (3U, 2006)

Ames Research Center

PharmaSat (3U, 2009)

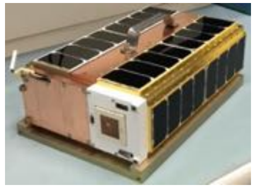


O/OREOS (3U, 2010)



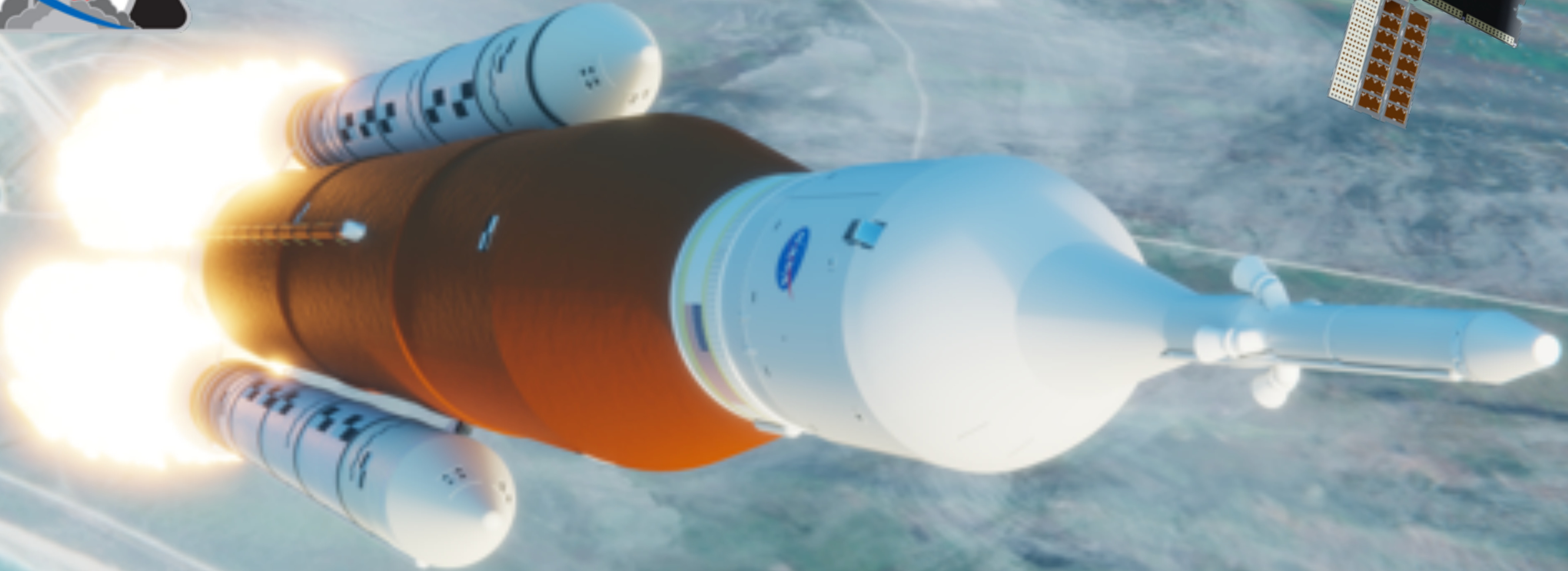
SporeSat (3U, 2014)

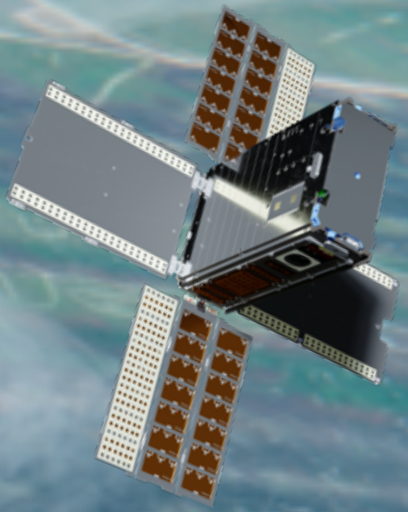
EcAMSat (6U, 2017)



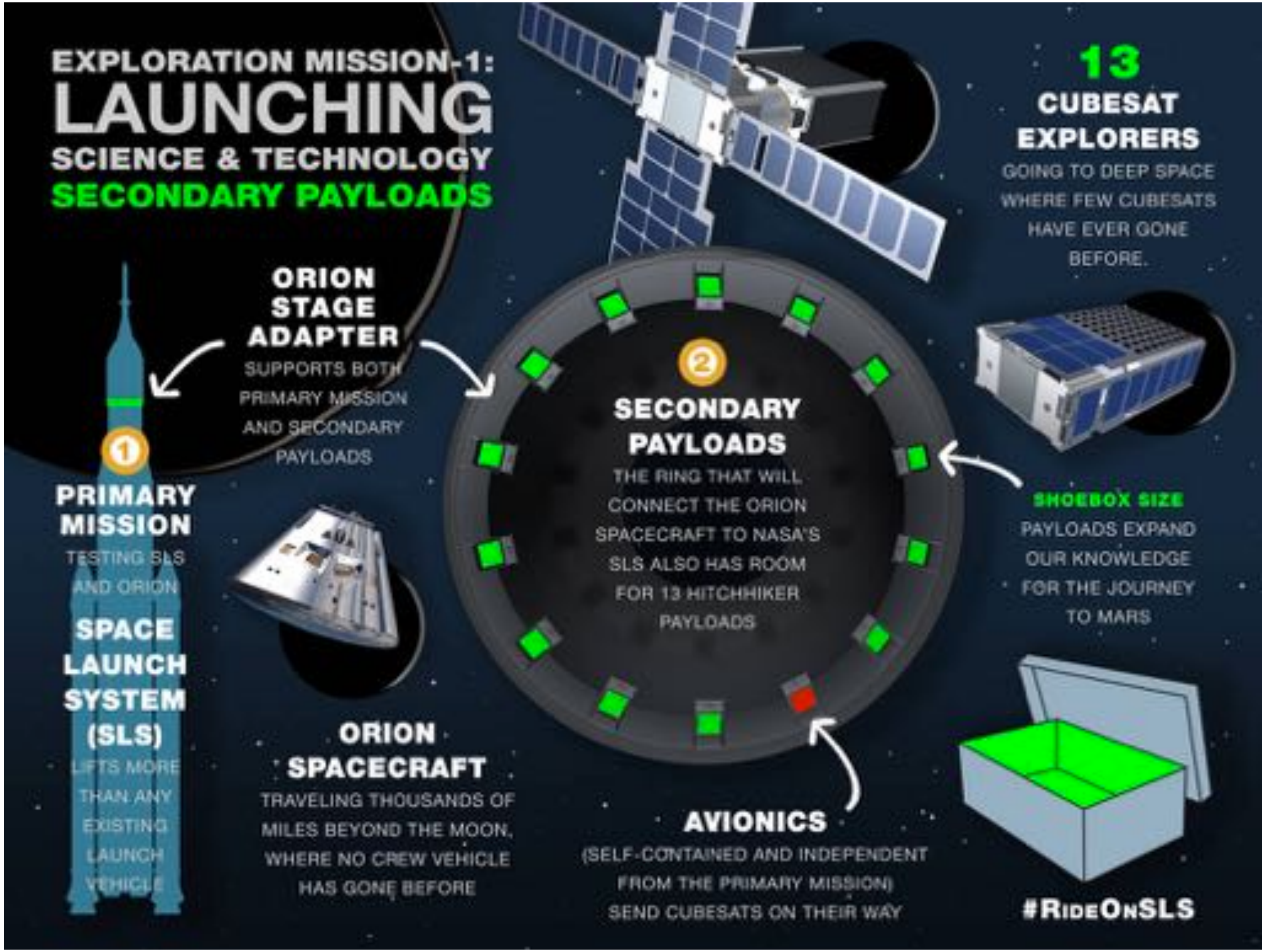
Artemis-1 mission & BioSentinel

(launch 2022)





Artemis-1: secondary payloads (6U CubeSats)



EXPLORATION MISSION-1: LAUNCHING SCIENCE & TECHNOLOGY SECONDARY PAYLOADS

ORION STAGE ADAPTER
SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS

① **PRIMARY MISSION**
TESTING SLS AND ORION

SPACE LAUNCH SYSTEM (SLS)
LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE

ORION SPACECRAFT
TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE

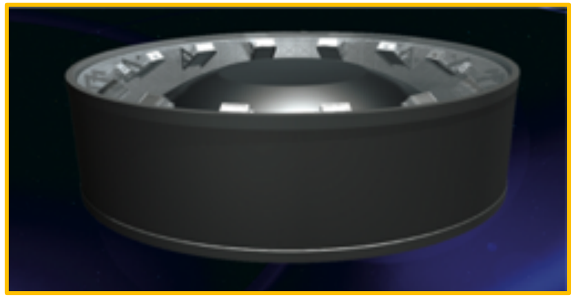
② **SECONDARY PAYLOADS**
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS

AVIONICS
(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION) SEND CUBESATS ON THEIR WAY

13 CUBESAT EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.

SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS

#RideOnSLS



BioSentinel mission: NASA's 1st interplanetary bio satellite

Main objective: develop an instrument with autonomous life support technologies to study the biological effects of the space radiation environment at different orbits

- First biological CubeSat beyond low Earth orbit (LEO)
  - First CubeSat to combine biological studies with autonomous capability & physical dosimetry beyond LEO
  - Secondary payload in SLS ARTEMIS-1 (launch in FY22)
  - Far beyond the protection of Earth's magnetosphere (~0.3 AU from Earth at 6 months; ~40 million km)
  - BioSentinel will allow to compare different radiation & gravitational environments (deep space, LEO, lunar surface…)

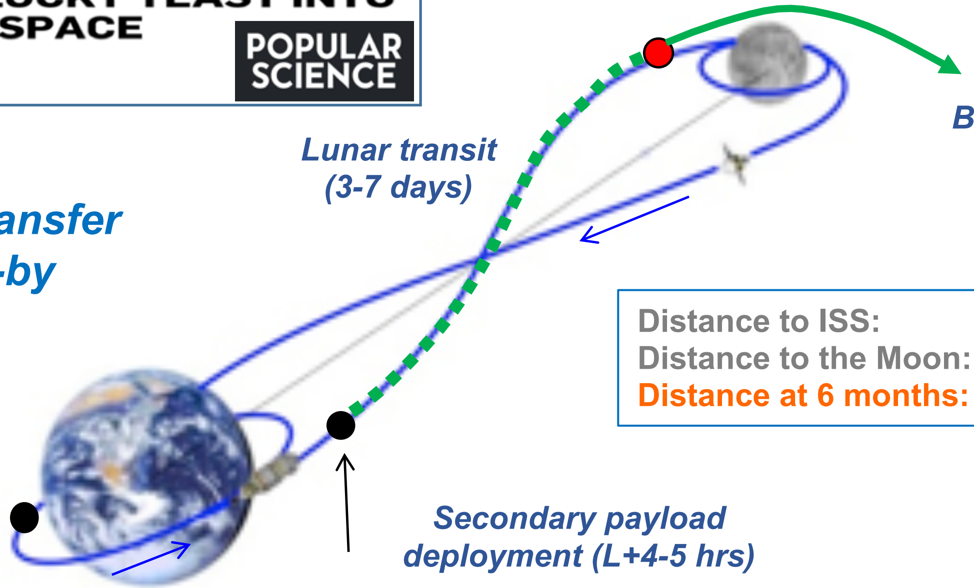
SPACE

NASA IS SENDING SOME LUCKY YEAST INTO RADIATION-FILLED DEEP SPACE

WHERE NO YEAST HAS GONE BEFORE

By Shannon Stirone May 15, 2015

POPULAR SCIENCE



Lunar Transfer & Fly-by

Launch

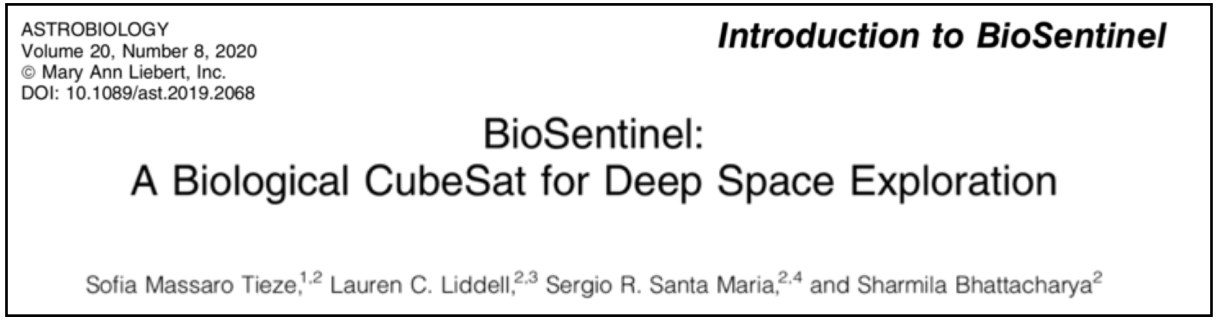
Secondary payload deployment (L+4-5 hrs)

Lunar transit (3-7 days)

BioSentinel escapes into a heliocentric orbit

Distance to ISS:	~ 350 km
Distance to the Moon:	~385,000 km
Distance at 6 months:	~40'000,000 km

Team publications (2020)

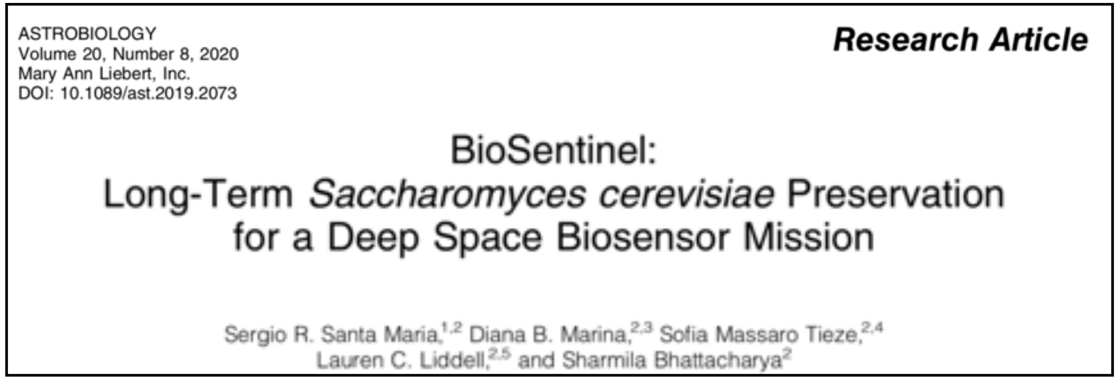


ASTROBIOLOGY
Volume 20, Number 8, 2020
© Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2019.2068

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]

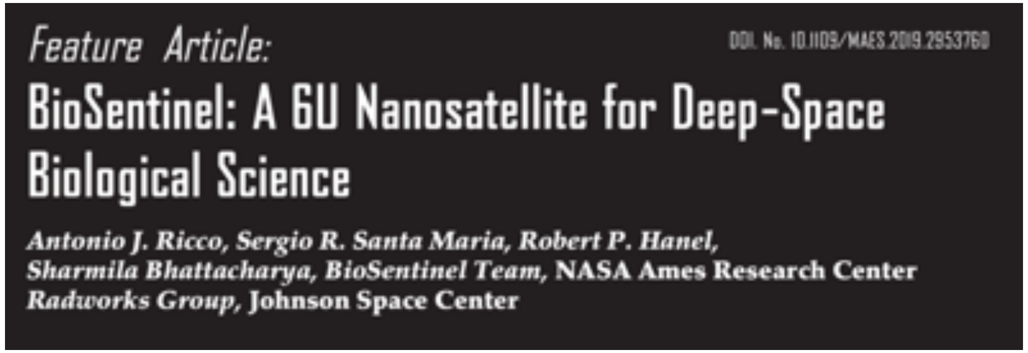


ASTROBIOLOGY
Volume 20, Number 8, 2020
Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2019.2073

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]



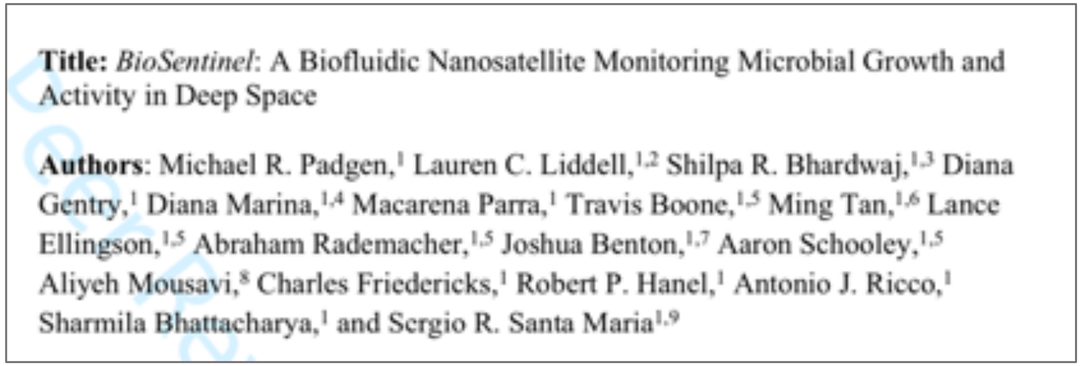
Feature Article: DOI. No. 10.1109/MAES.2019.2953760

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**

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



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

Authors: 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]

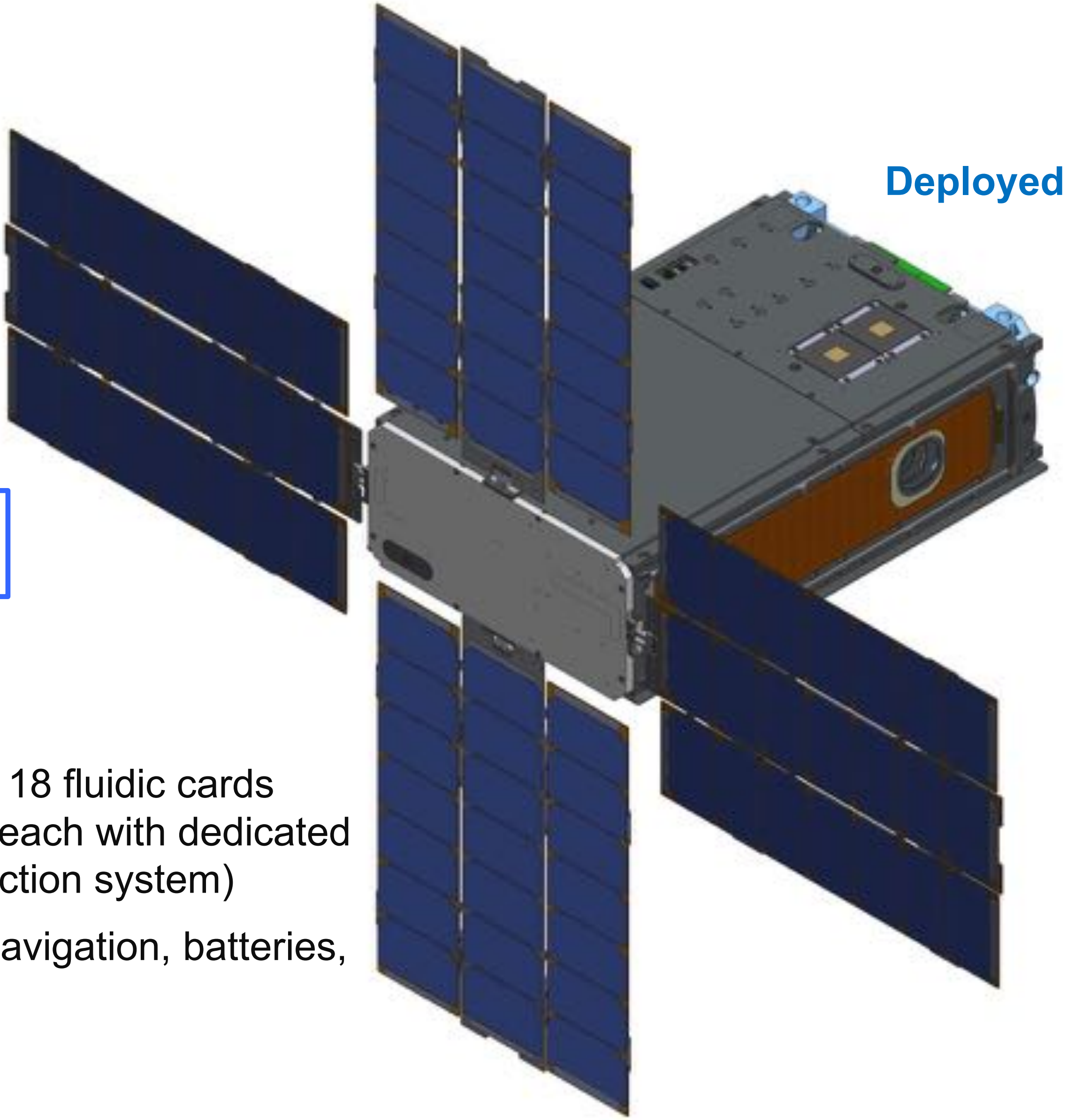
proceedings MDPI

Proceedings

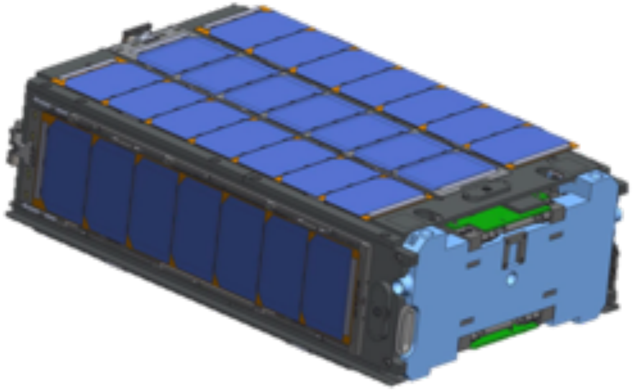
Developing Technologies for Biological Experiments in Deep Space †

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

BioSentinel: a 6U nanosatellite for deep space



Deployed



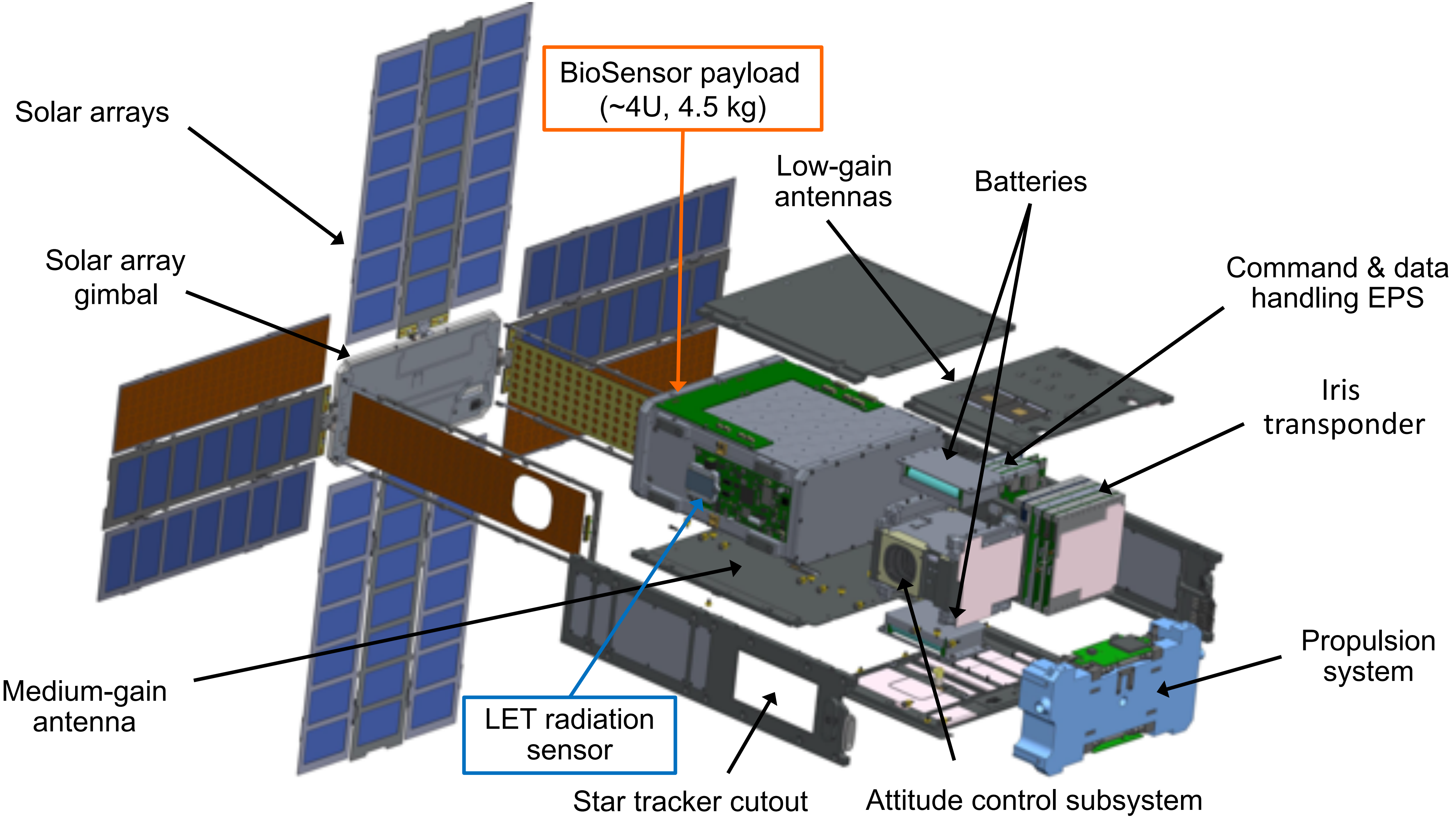
Stowed

6U CubeSat
37 x 24 x 12 cm ~ 10 L

Spacecraft sections:

- BioSensor payload (~4U with 18 fluidic cards loaded with desiccated cells, each with dedicated thermal control & optical detection system)
- Spacecraft bus (propulsion, navigation, batteries, transponder, star tracker…)

BioSentinel: a 6U nanosatellite for deep space



BioSensor payload (~4U, 4.5 kg)

Solar arrays

Solar array gimbal

Low-gain antennas

Batteries

Command & data handling EPS

Iris transponder

Propulsion system

Medium-gain antenna

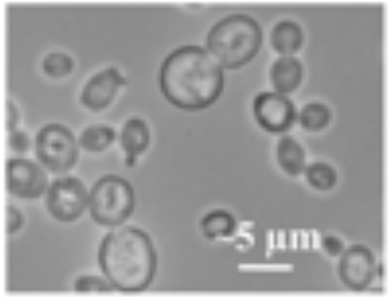
LET radiation sensor

Star tracker cutout

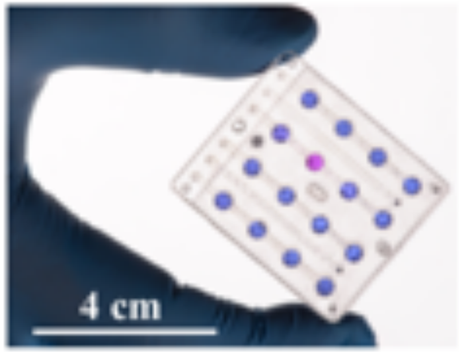
Attitude control subsystem

BioSentinel: a 6U nanosatellite for deep space

Budding yeast

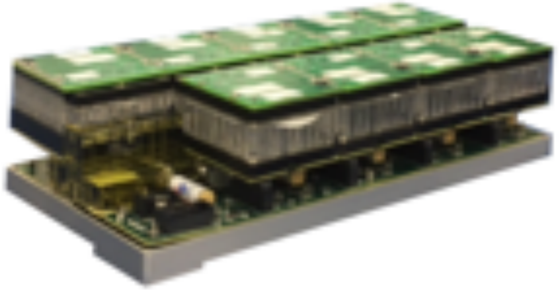


16-well fluidic card (x18)

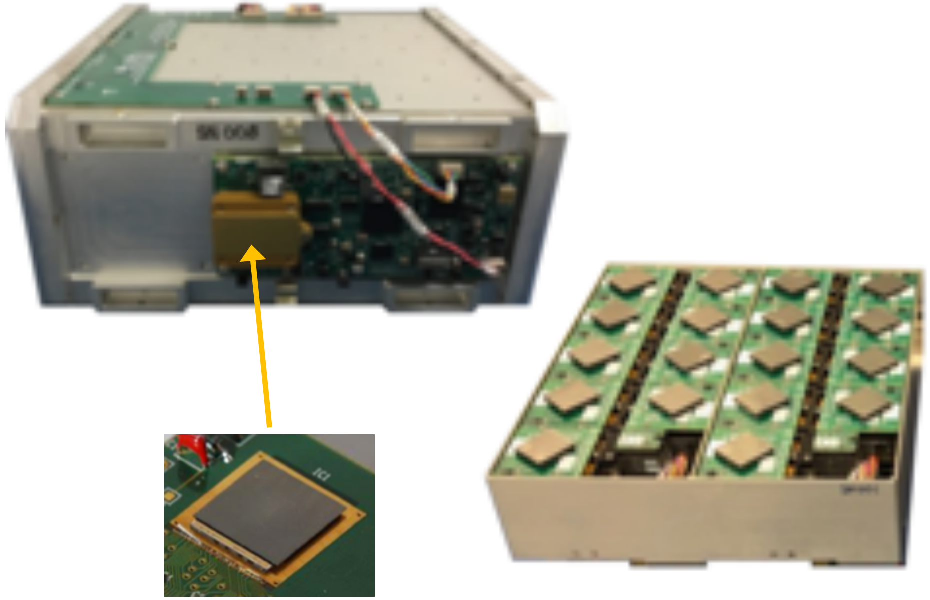


Card stack

9-card fluidic manifold (x2)

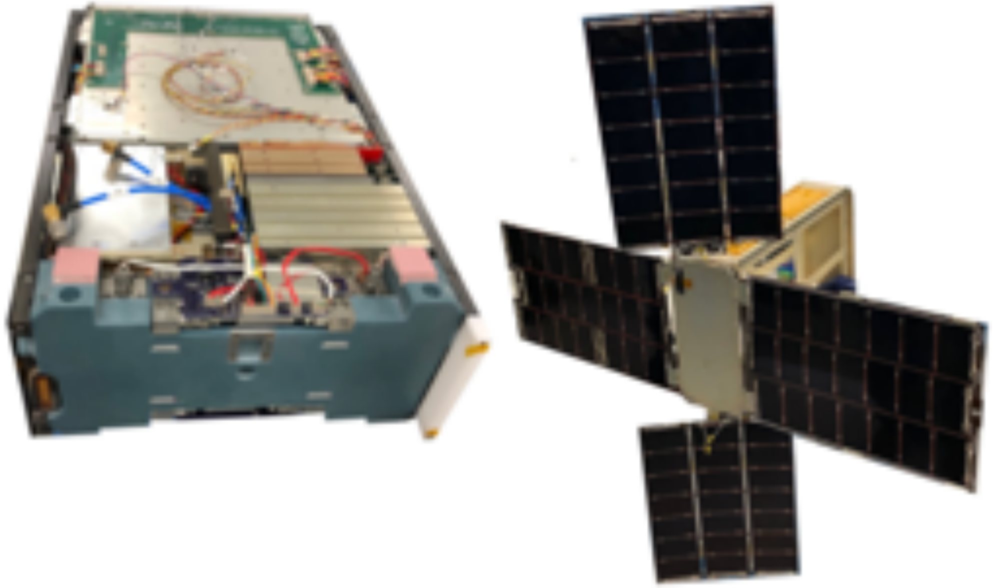


4U BioSensor payload



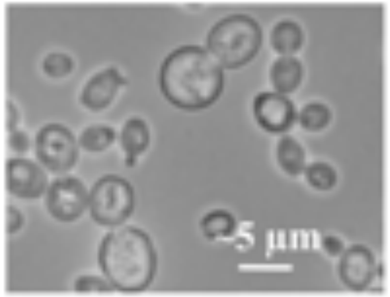
LET spectrometer

6U BioSentinel spacecraft

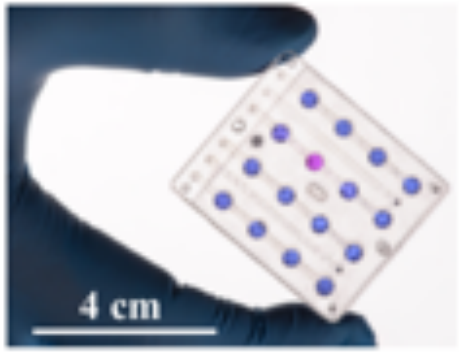


BioSentinel: a 6U nanosatellite for deep space

Budding yeast

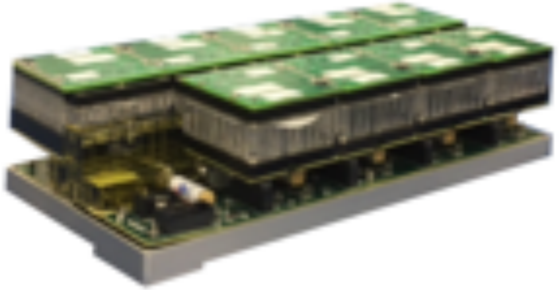


16-well fluidic card (x18)

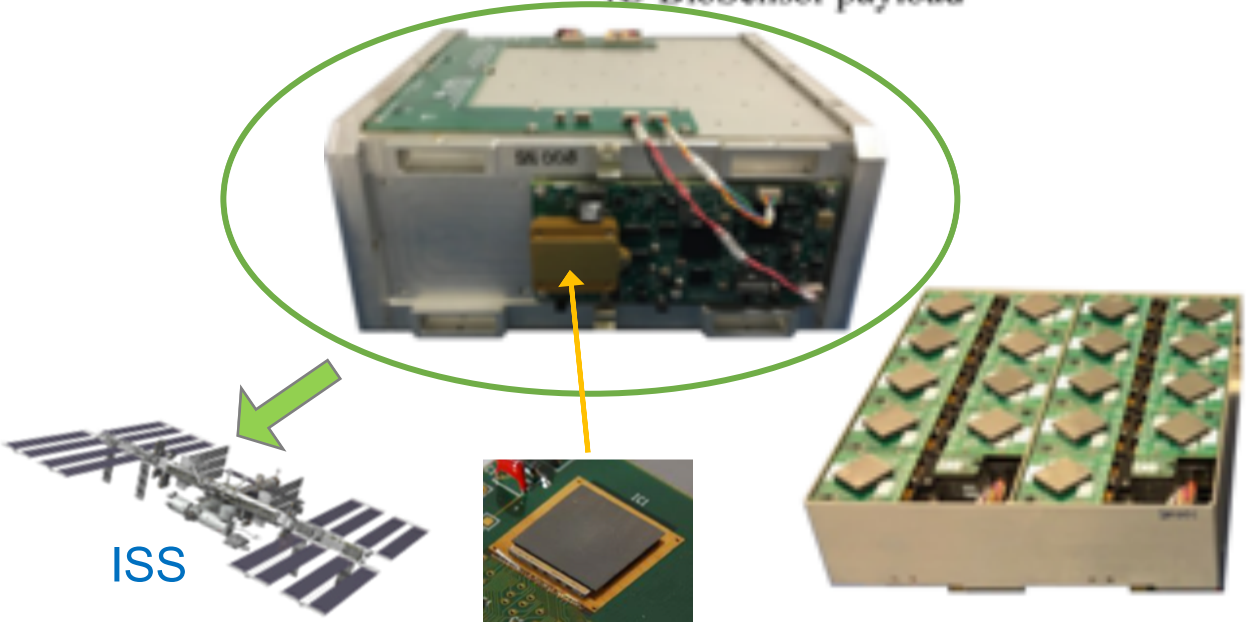


Card stack

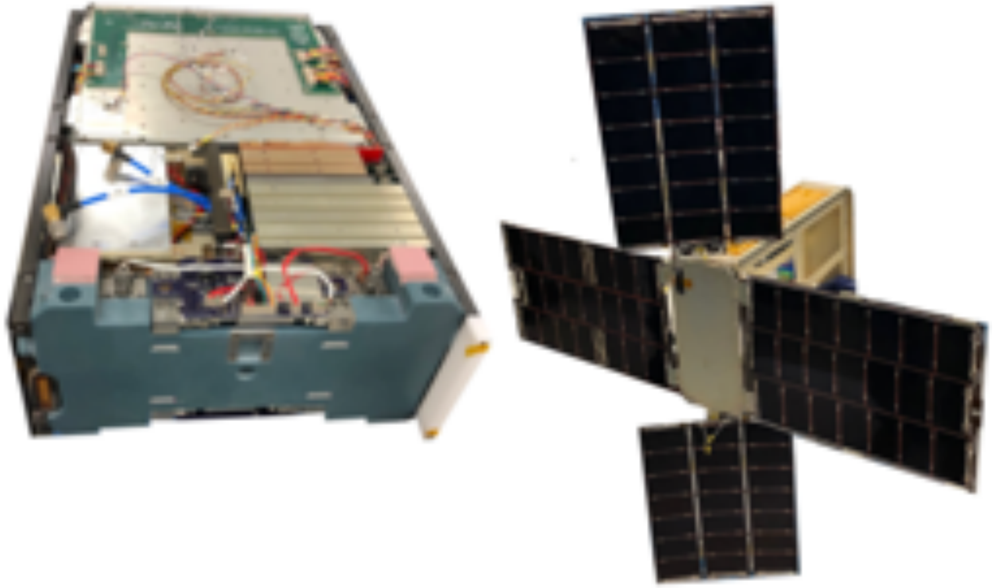
9-card fluidic manifold (x2)



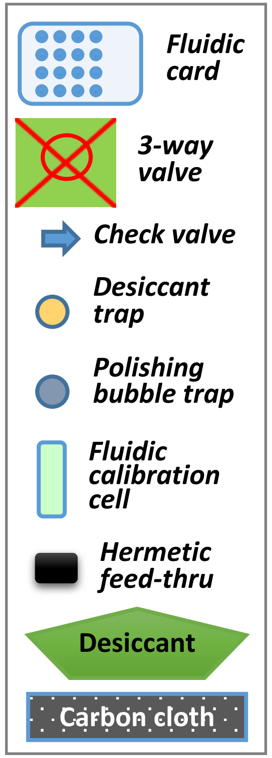
4U BioSensor payload

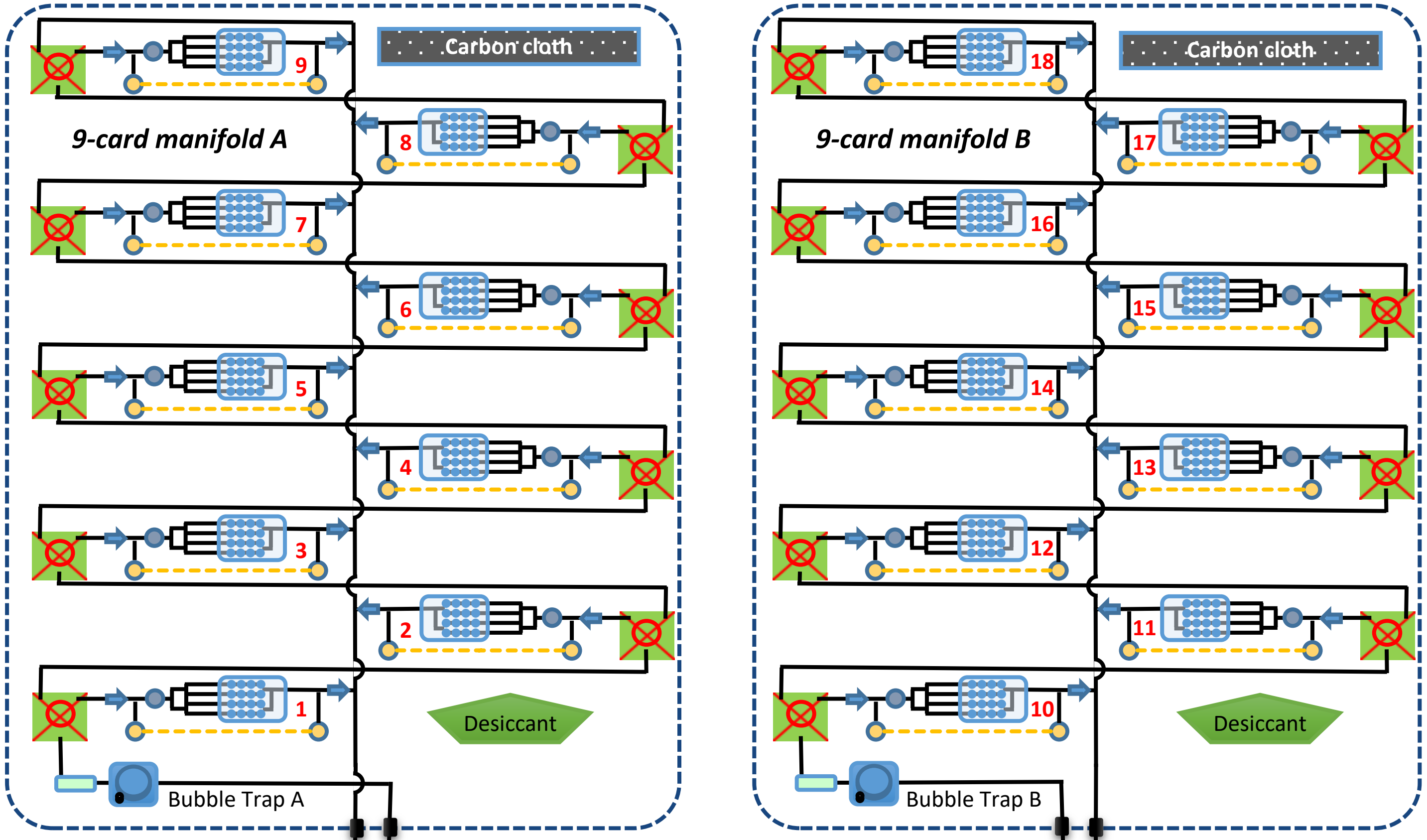


6U BioSentinel spacecraft



Lunar BioSensor: microfluidics system

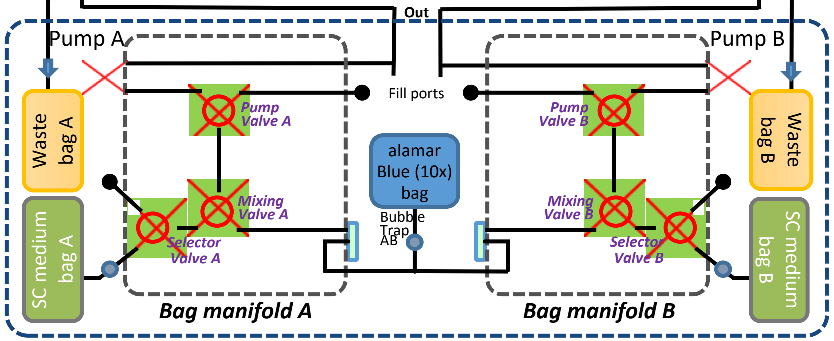


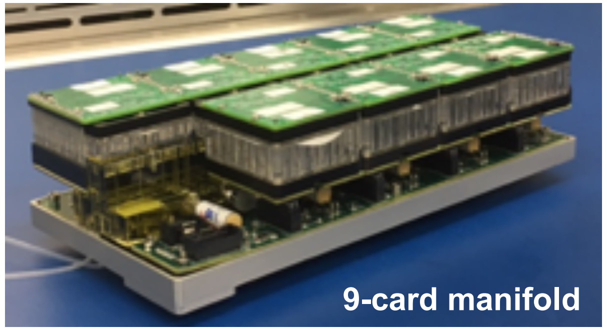


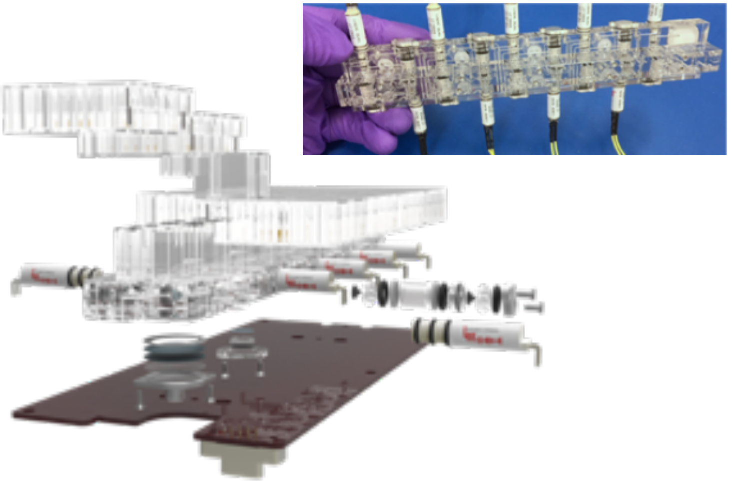
Card box A

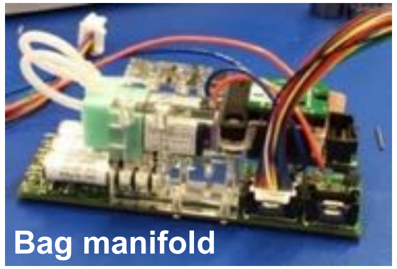
Card box B

Bag box



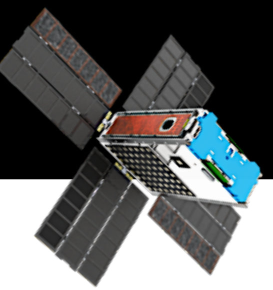




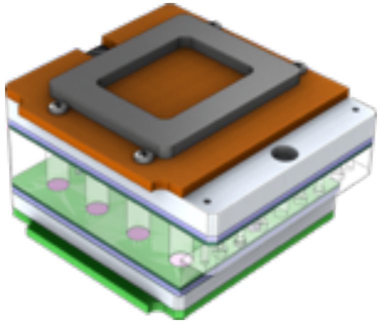


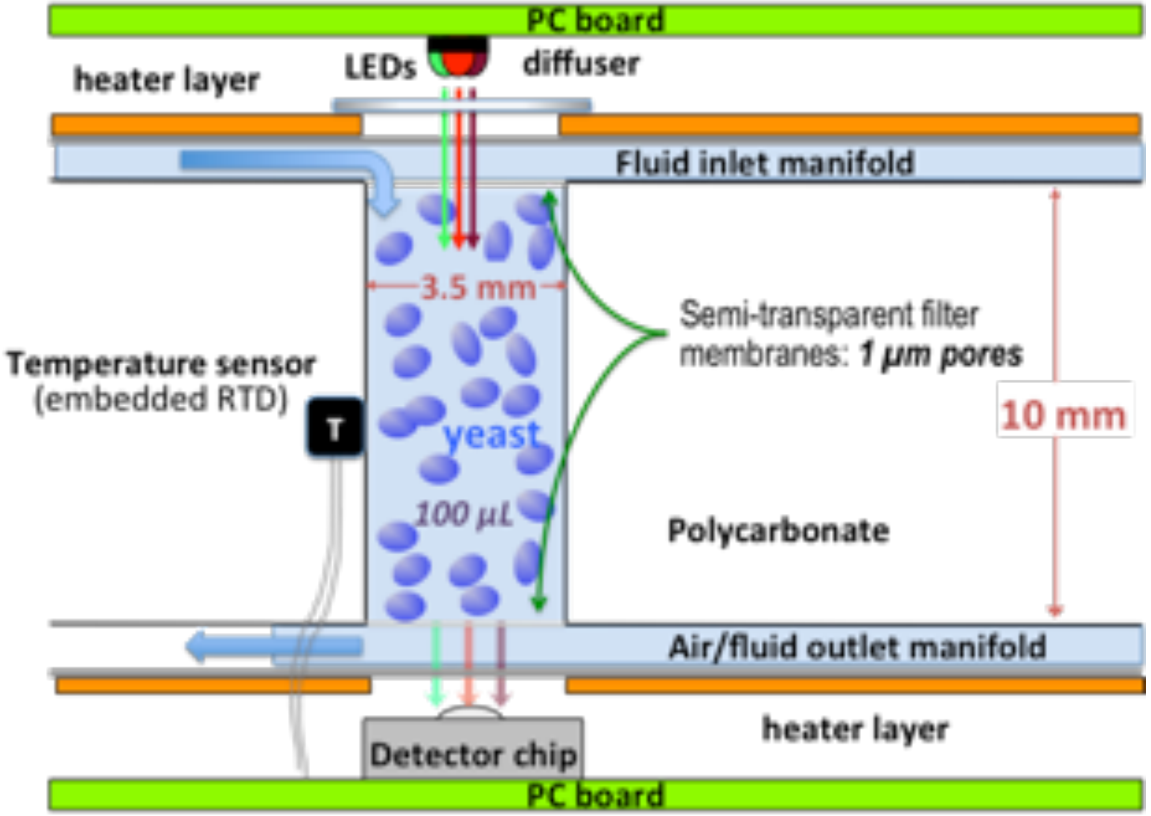
Manifold-integrated components:
- *2 pumps*
- *24 active & 38 check valves*
- *2 main bubble traps*
- *4 optical calibration cells*
- *18 fluidic cards with small bubble traps & desiccant traps*
- *288 microwells total*

Lunar BioSensor: microfluidics card

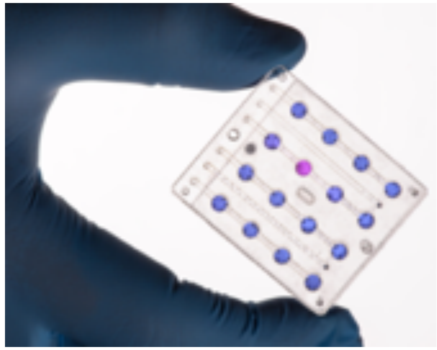


Microfluidic card (x18)

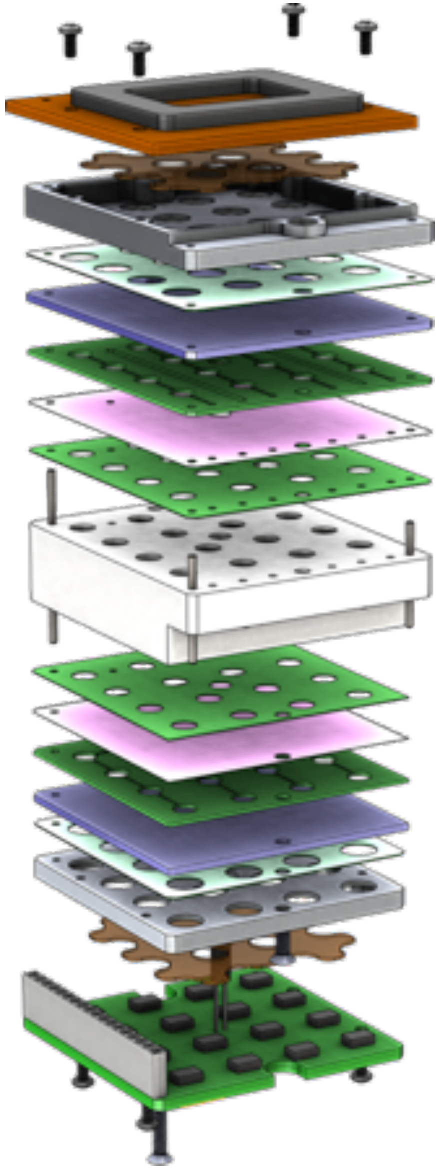




3-LED emitter



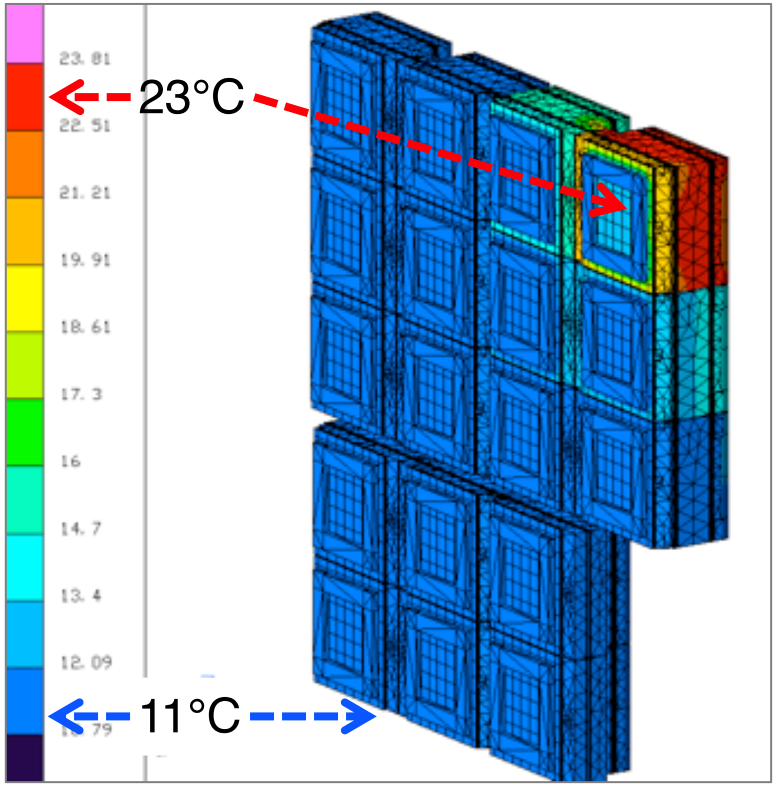
Photodiode detector array

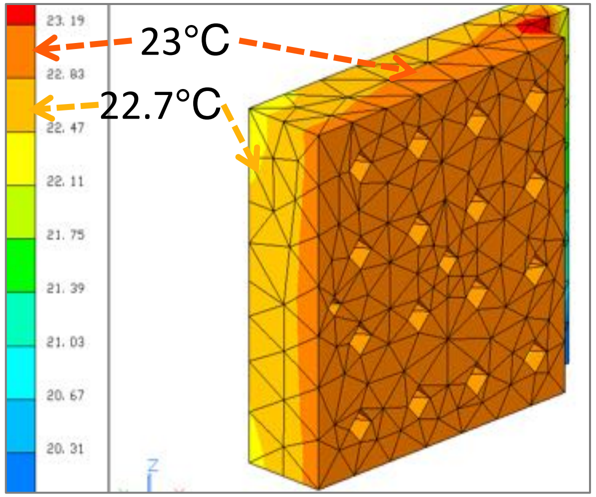


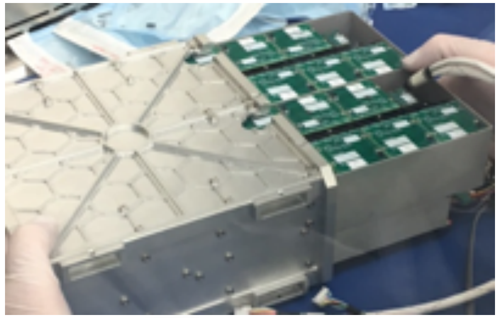
Lunar BioSensor: temperature control

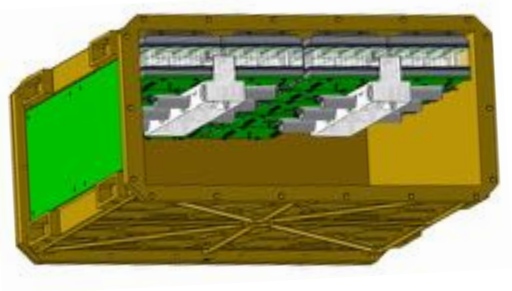
- 23°C: biology temperature for “active growth” fluidic card
- ~ 9°C for non-active cards: maintain biological viability
  - “Keep-alive” 4°C minimum at all times, cards & reagents
- Challenge: no active control from L-6+ months to deployment

As-modeled, < 0.5 W to heat one card

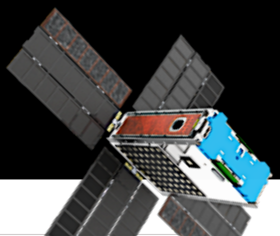








Lunar BioSensor: optical detection system

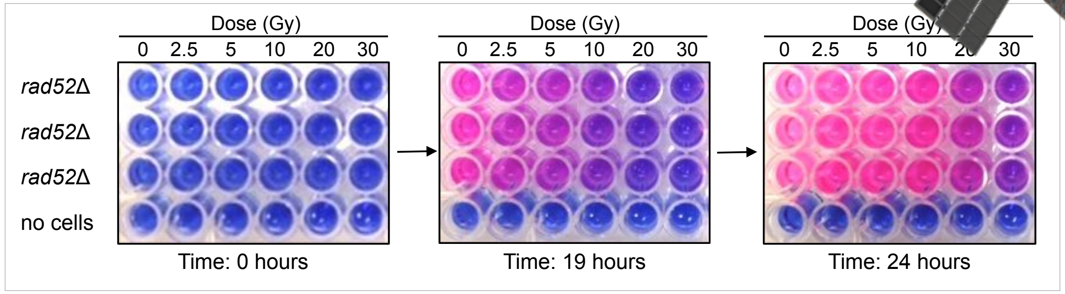


Dedicated 3-color optical system at each well to track growth *via* optical density and cell metabolic activity *via* dye color changes

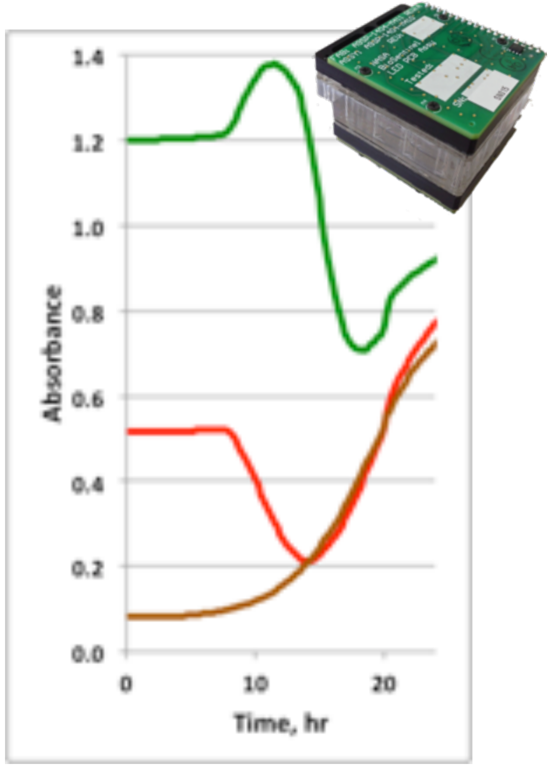
LEDs: 570 nm (green, measures pink)

630 nm (red, measures blue)

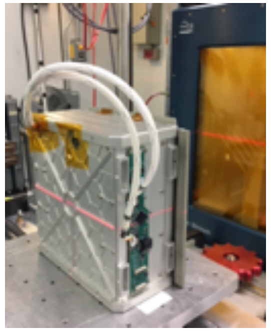
850 nm (infrared, measures growth)

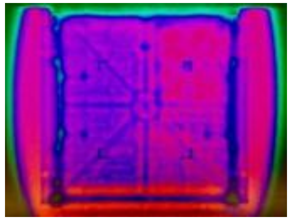


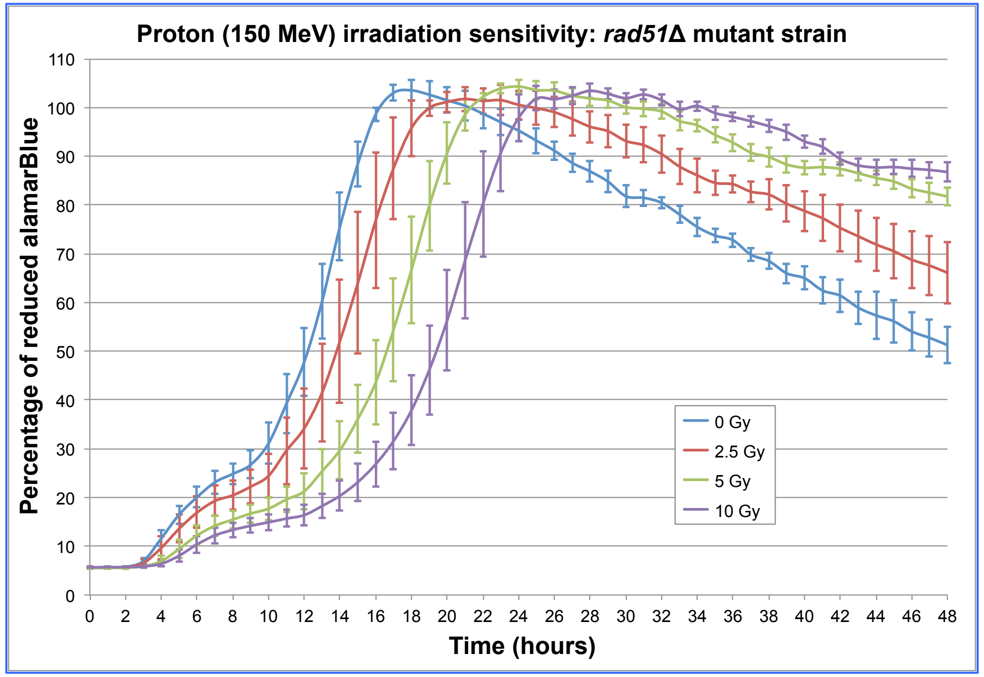
alamarBlue turns pink when cells are metabolically active



Yeast growth with flight-like optical unit







HR repair defective cells show sensitivity to ionizing radiation

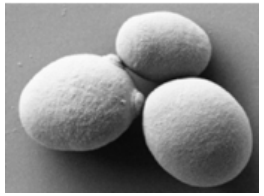
Lunar BioSensor

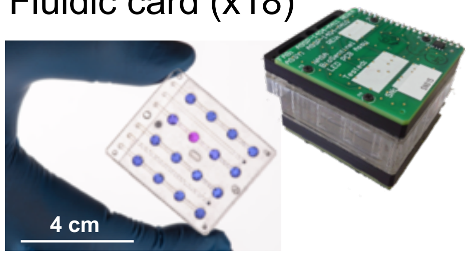
Research Goals:
- Measure the biological response to ambient lunar radiation and gravity in a model organism (budding yeast)
- Compare biological response to onboard dosimetry & BioSentinel experiments (deep space free flyer, ISS & ground controls)

Instrument Capabilities:
- Fully automated microfluidics & optical detection systems
- 18 fluidic cards with 16 microwells per card (288 replicates)
- Dedicated active thermal control per card
- Optical detection system for cell growth & metabolic activity
- Onboard LET spectrometer for radiation dose and energy characterization
- Utilize lunar lander for power and data relay

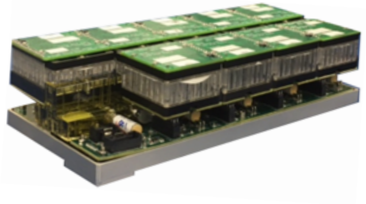
Development Approach:
- Replicates payload design from BioSentinel free flyer & ISS missions
- Existing payload resource requirements and structure easily adaptable to lander mechanical interface and location
- Strategize thermal management approach to suit lunar environment

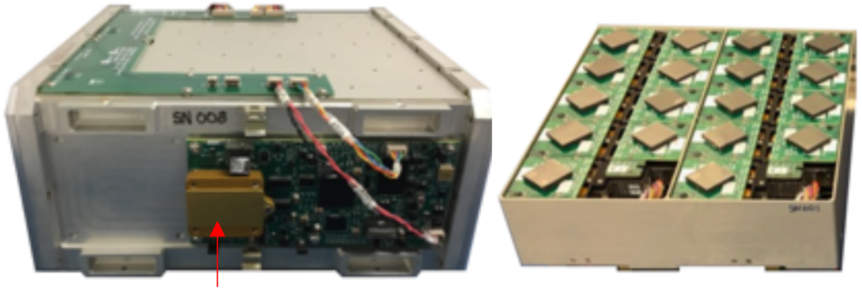
Requirements	Instrument specifics
Mass	~ 7.5 kg (5 kg instrument + 2.5 kg interface)
Volume	~ 8 – 9 liters
Power	Dependent on thermal environment Typical: < 8 – 10 W average, < 13 W peak
Communication	Wired RS-422 / < 2 Mbit per day
Current TRL	TRL 6/7 (higher by launch date)
Lander site location	Anywhere on the Moon


Budding yeast



Fluidic card (x18)

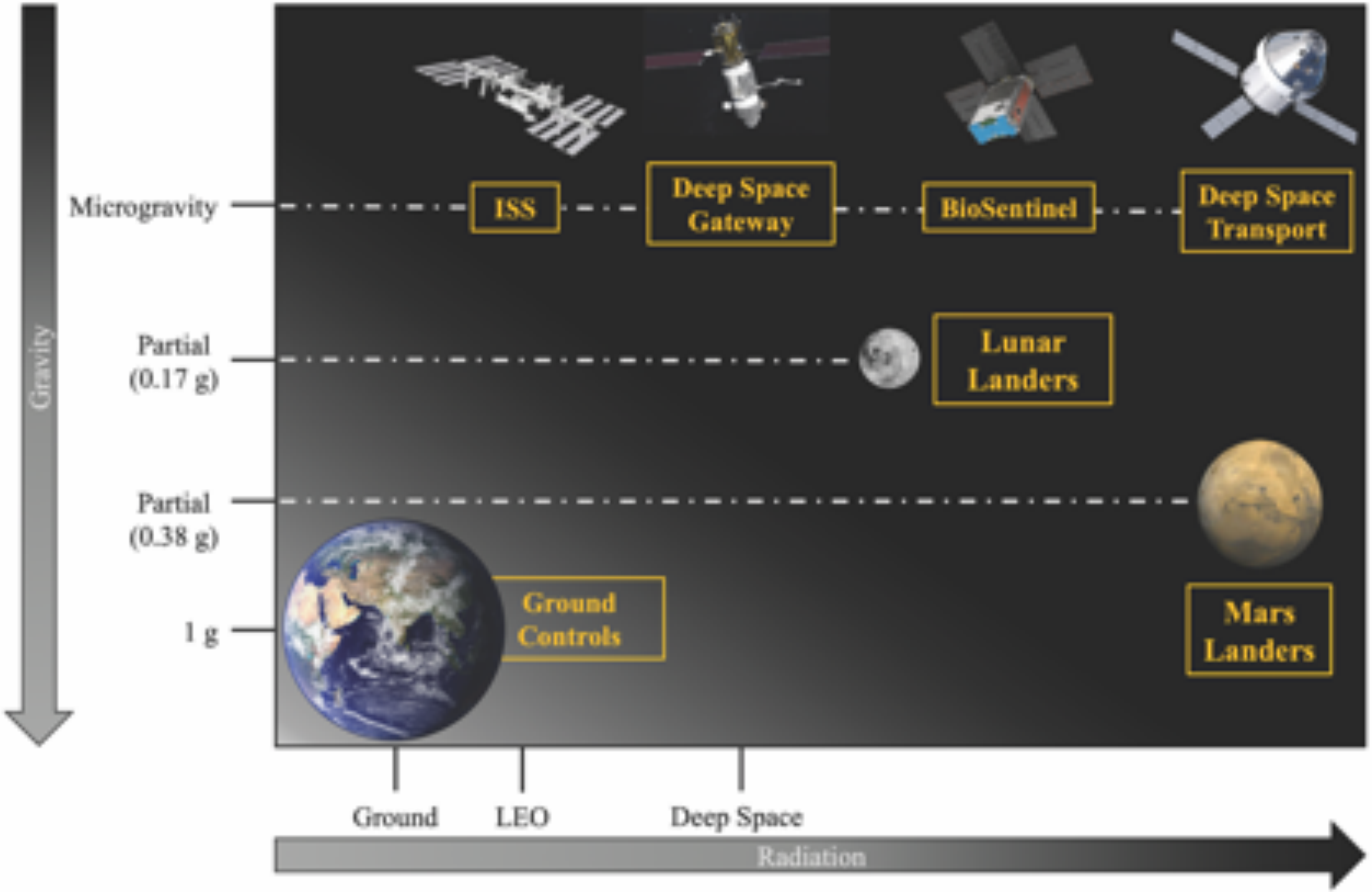

Fluidic manifold (x2)


4U BioSensor payload

LET spectrometer

Future & ongoing objectives

Mapping the radiation / gravity continuum of biological effects using a common instrument



BioSentinel
NASA Ames Research Center

BioSentinel-ISS
NASA Ames Research Center

Conclusions & wish list

- **Small satellite-based instruments can do real science in LEO and in deep space**
  - Enabled by instrument miniaturization, new micro technologies & automation
  - Adaptable technologies for different platforms (ISS, free-flyers, landers, gateway)
  - Real-time, *in-situ* experiments provide insights on dynamics not available from sample return approach

Conclusions & wish list

- **Small satellite-based instruments can do real science in LEO and in deep space**
    - Enabled by instrument miniaturization, new micro technologies & automation
    - Adaptable technologies for different platforms (ISS, free-flyers, landers, gateway)
    - Real-time, *in-situ* experiments provide insights on dynamics not available from sample return approach

- **So, what can we do with a BioSensor-like instrument?**
    - Flying biology in desiccated form (long-term pre-launch preparation)
    - Filling microfluidic cards in reduced gravity + radiation to study DNA damage response & mutagenesis
    - Radiation shielding studies (*e.g.*, new materials, lunar regolith)
    - Acquisition of beneficial mutations using genetic markers (fluid exchanges)
    - Antibiotic/antifungal resistance studies
    - Gene expression using chromogenic/fluorescent proteins
    - Gene inactivation to study your favorite cellular pathway (*i.e.*, thermal inactivation)
    - Different investigations within same 4U payload (*i.e.*, 2 manifolds, 18 cards, 288 wells)

Thank you!

sergio.santamaria@nasa.gov