Biological CubeSats: what have we learned so far and what is next?

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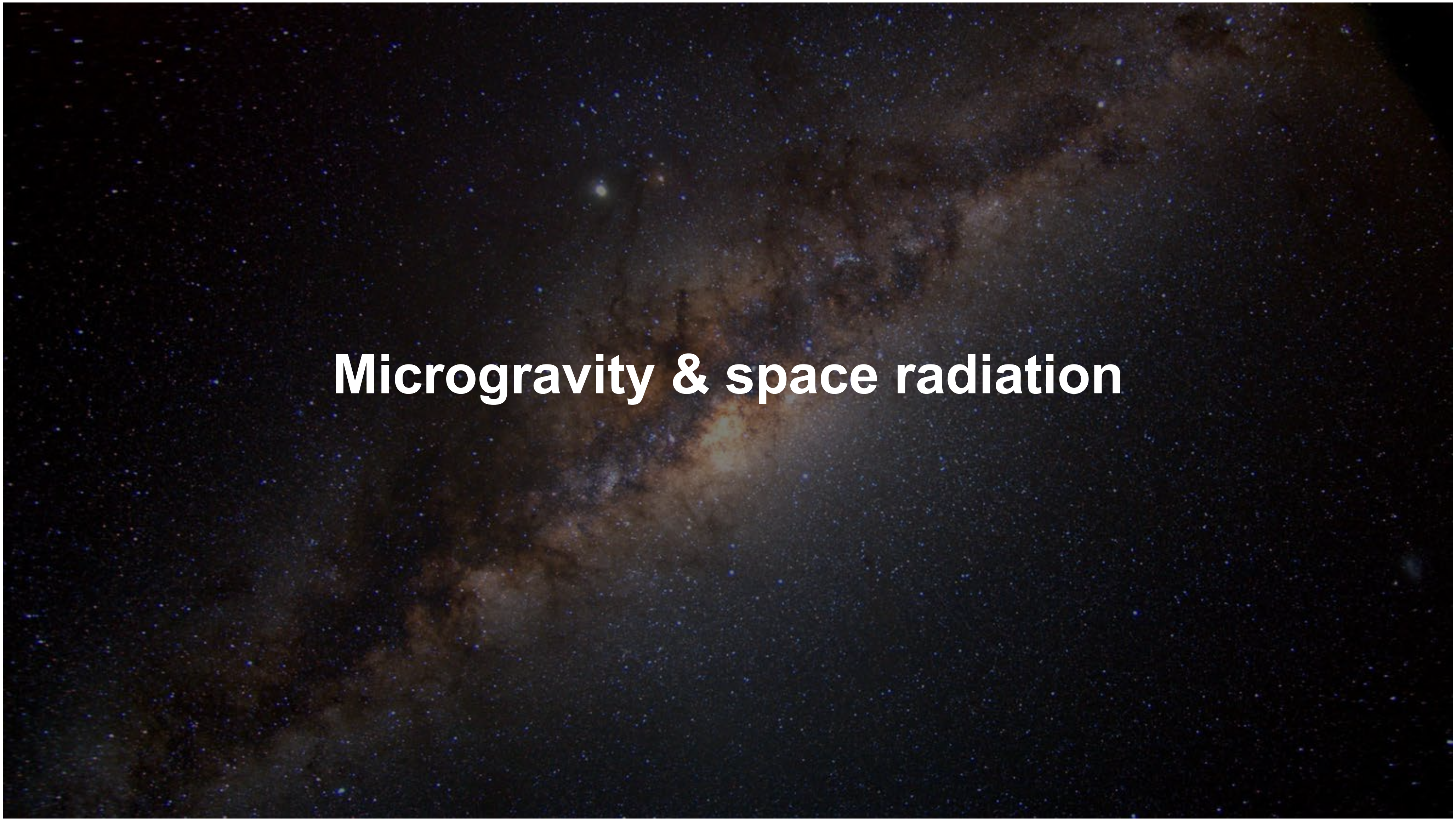
Space Biosciences
NASA AMES RESEARCH CENTER

THE UNIVERSITY of NEW MEXICO


Microgravity & space radiation


Microgravity effects
NEW NATIONAL GEOGRAPHIC CHANNEL – COMING JANUARY 7
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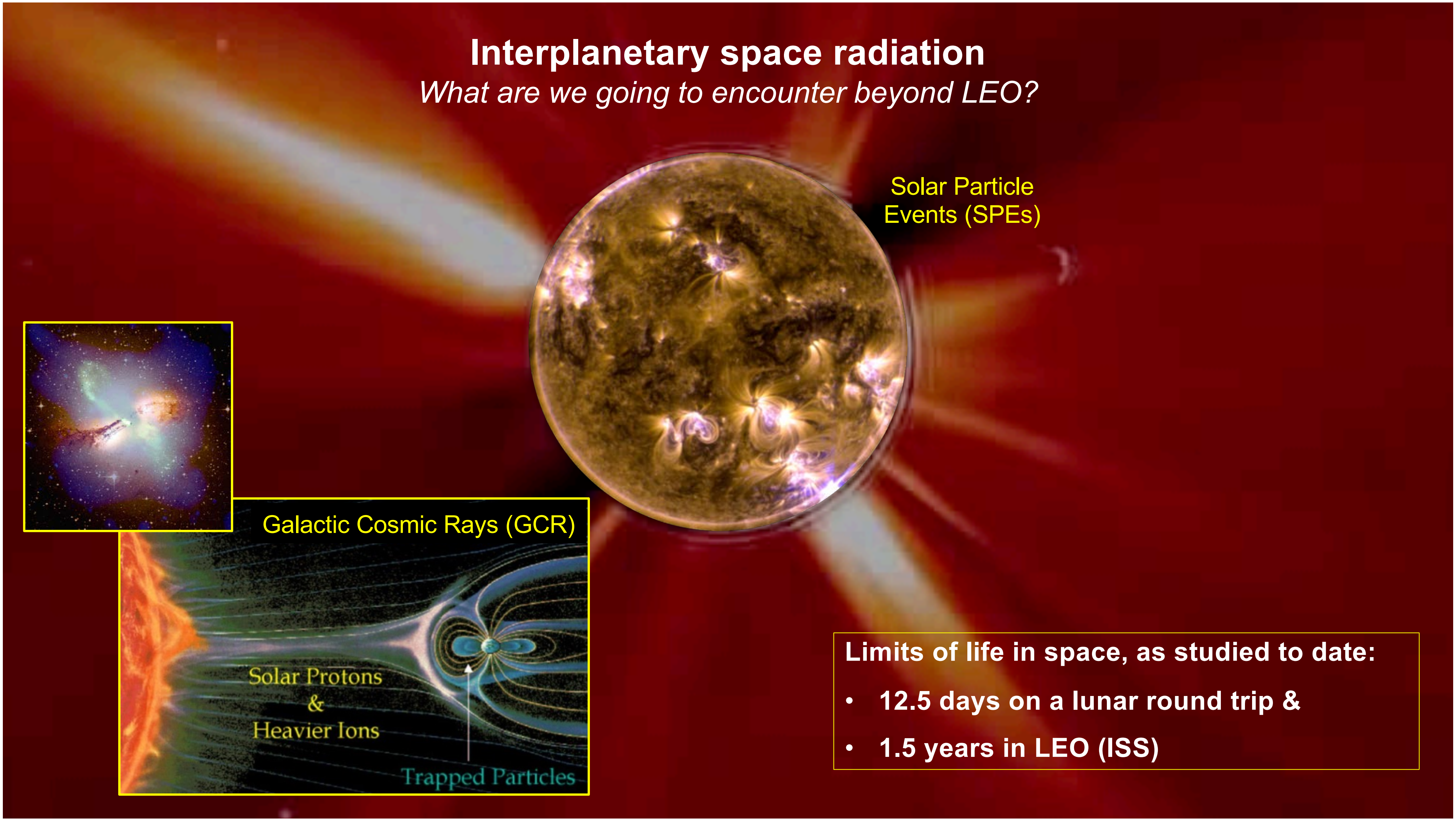
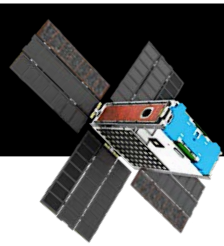
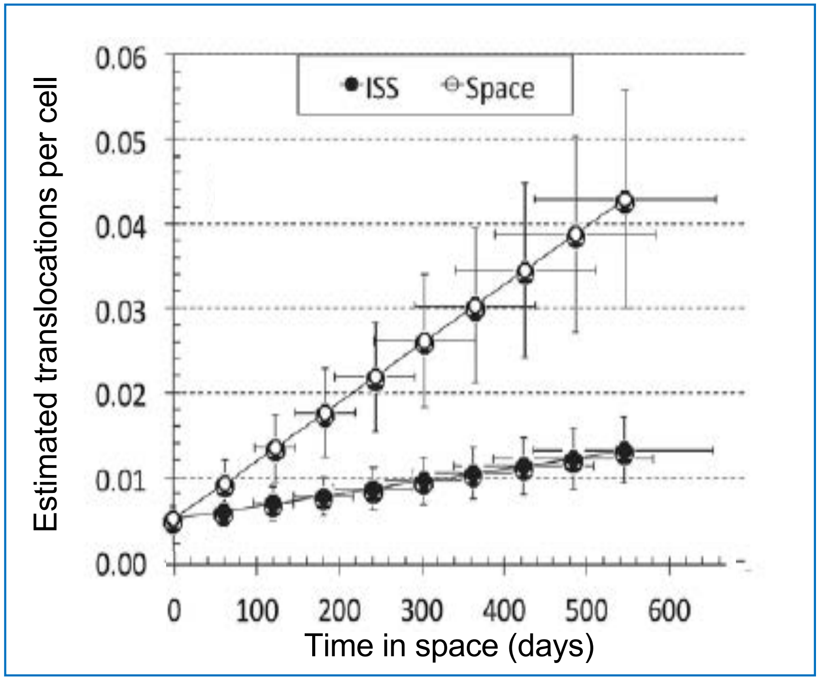
2001
THE BODY IN SPACE
SURVIVING THE ODYSSEY
Great Barrier Reef
Australia's Coral Kingdom 30
Ancient Ashkelon
Dead Men Do Tell Tales 66
Japan's Imperial Palace
First Look Inside 94


Interplanetary space radiation
What are we going to encounter beyond LEO?
Solar Particle Events (SPEs)
Galactic Cosmic Rays (GCR)
Solar Protons & Heavier Ions
Trapped Particles
Limits of life in space, as studied to date:
• 12.5 days on a lunar round trip &
• 1.5 years in LEO (ISS)

Space radiation effects

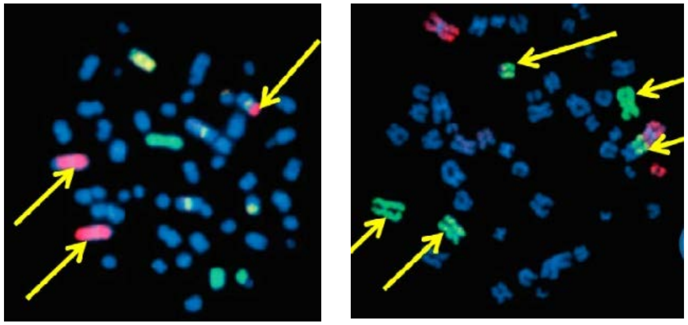


Radiation & spaceflight damages chromosomes as measured in astronauts' white blood cells (lymphocytes) – <u>expect effect to be greater in deep space than on ISS</u>



Straume et al. 2017

- Astronauts have ⬆ in # chromosomal abnormalities, even at low Earth orbits, during ISS, Mir & STS (Hubble shuttle) missions
- The relative increase in frequency of these chromosomal abnormalities ranges from 1.5 to 1.8 times more than pre-flight levels (95% CL)
  - ➢ GCR will be much more abundant as astronauts go to higher orbits beyond Earth's protective magnetosphere

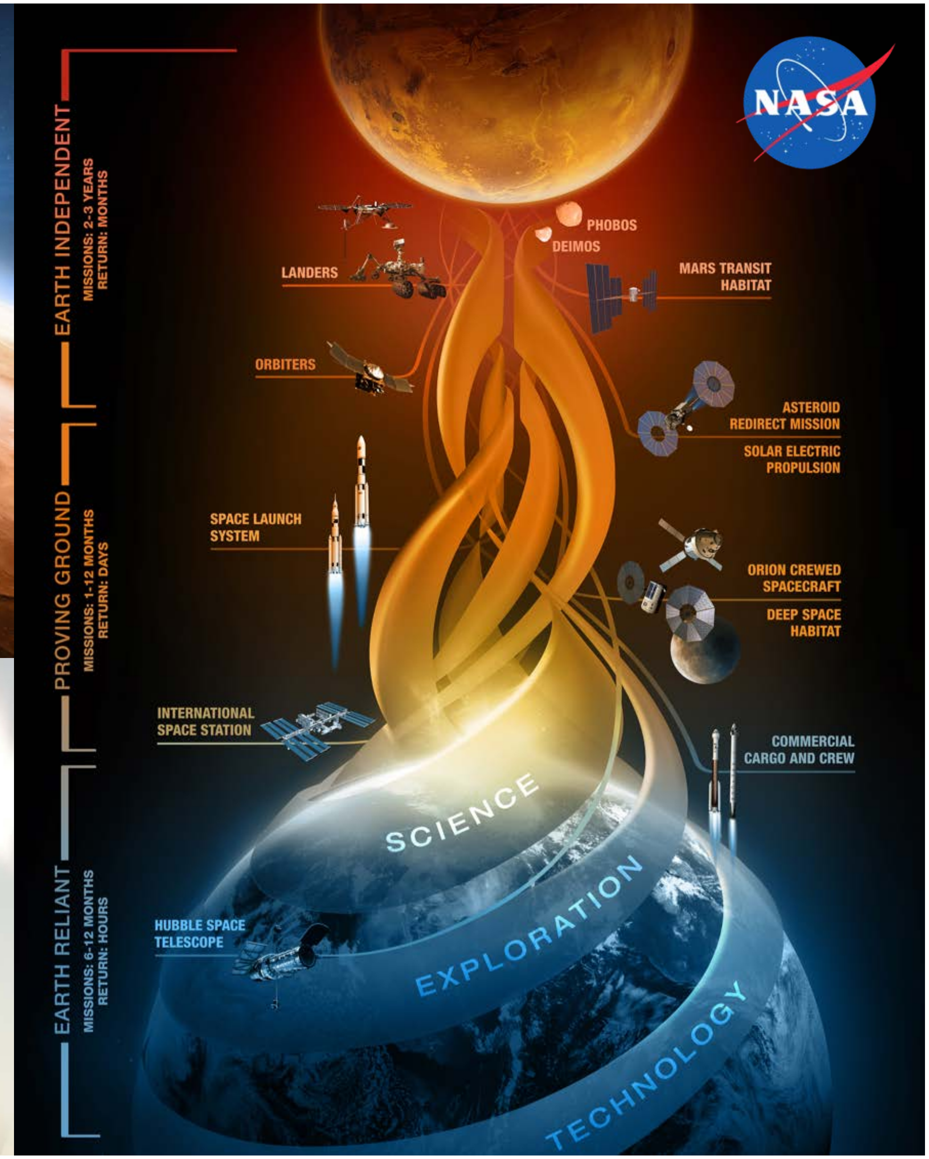


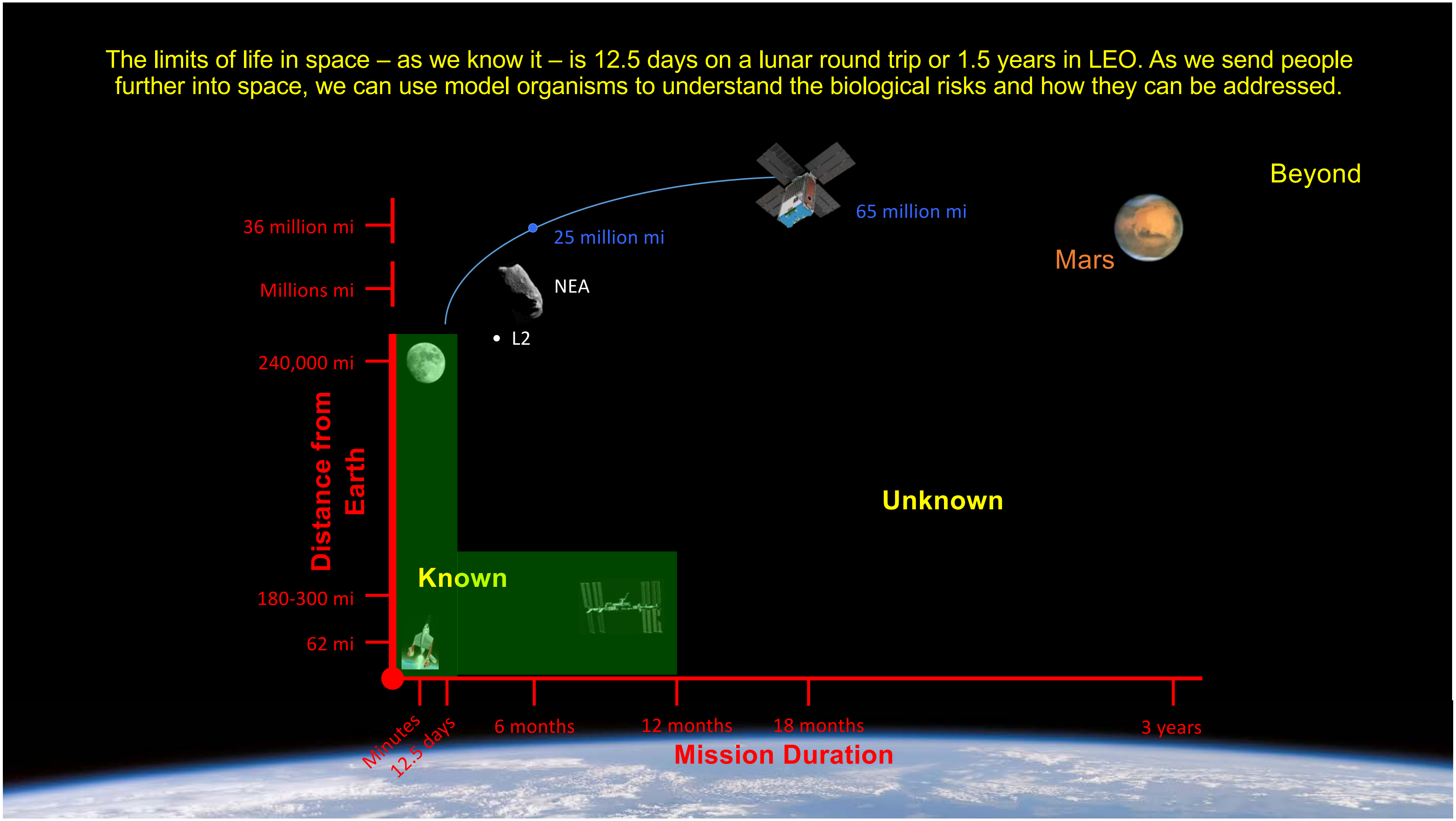
Chromosomes 1, 2, 4 in red, green, and yellow (ISS)

Cucinotta et al. 2008

What’s next for NASA?

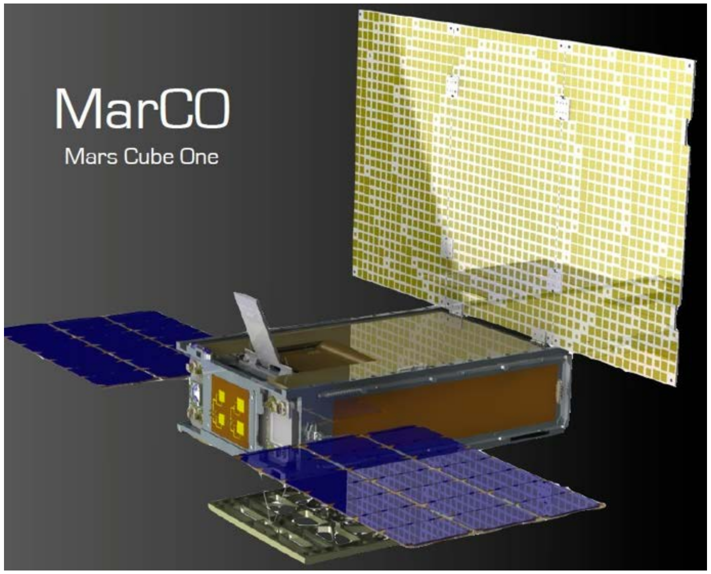

NASA'S JOURNEY TO
MARS

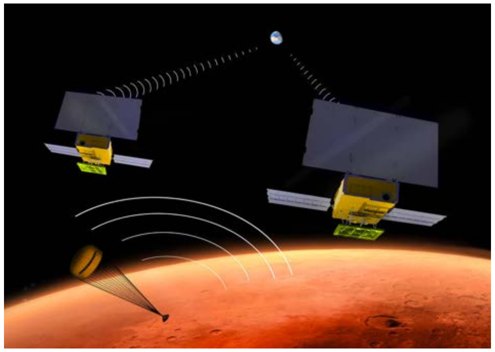

EARTH INDEPENDENT
MISSIONS: 2-3 YEARS
RETURN: MONTHS
PROVING GROUND
MISSIONS: 1-12 MONTHS
RETURN: DAYS
EARTH RELIANT
MISSIONS: 6-12 MONTHS
RETURN: HOURS
PHOBOS
DEIMOS
LANDERS
MARS TRANSIT HABITAT
ORBITERS
ASTEROID REDIRECT MISSION
SOLAR ELECTRIC PROPULSION
SPACE LAUNCH SYSTEM
ORION CREWED SPACECRAFT
DEEP SPACE HABITAT
INTERNATIONAL SPACE STATION
COMMERCIAL CARGO AND CREW
HUBBLE SPACE TELESCOPE
SCIENCE
EXPLORATION
TECHNOLOGY

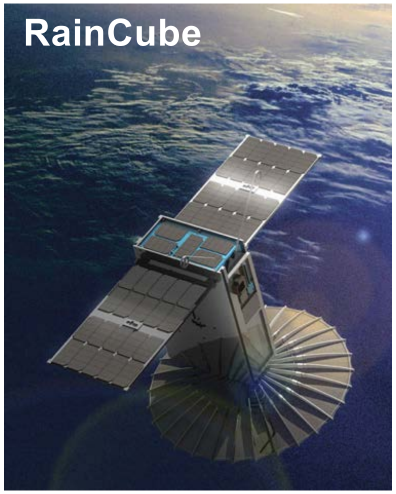

The limits of life in space – as we know it – is 12.5 days on a lunar round trip or 1.5 years in LEO. As we send people further into space, we can use model organisms to understand the biological risks and how they can be addressed.
Beyond
65 million mi
25 million mi
Mars
NEA
L2
36 million mi
Millions mi
240,000 mi
Distance from Earth
Unknown
Known
180-300 mi
62 mi
Minutes
12.5 days
6 months
12 months
18 months
3 years
Mission Duration

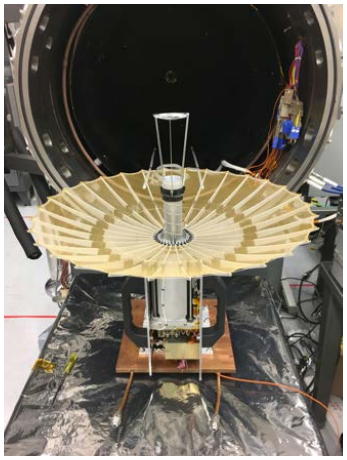
CubeSats

CubeSat technologies

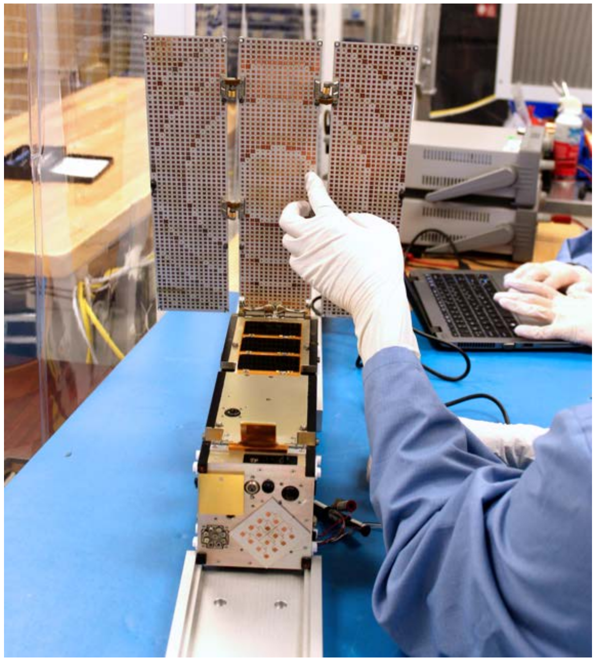




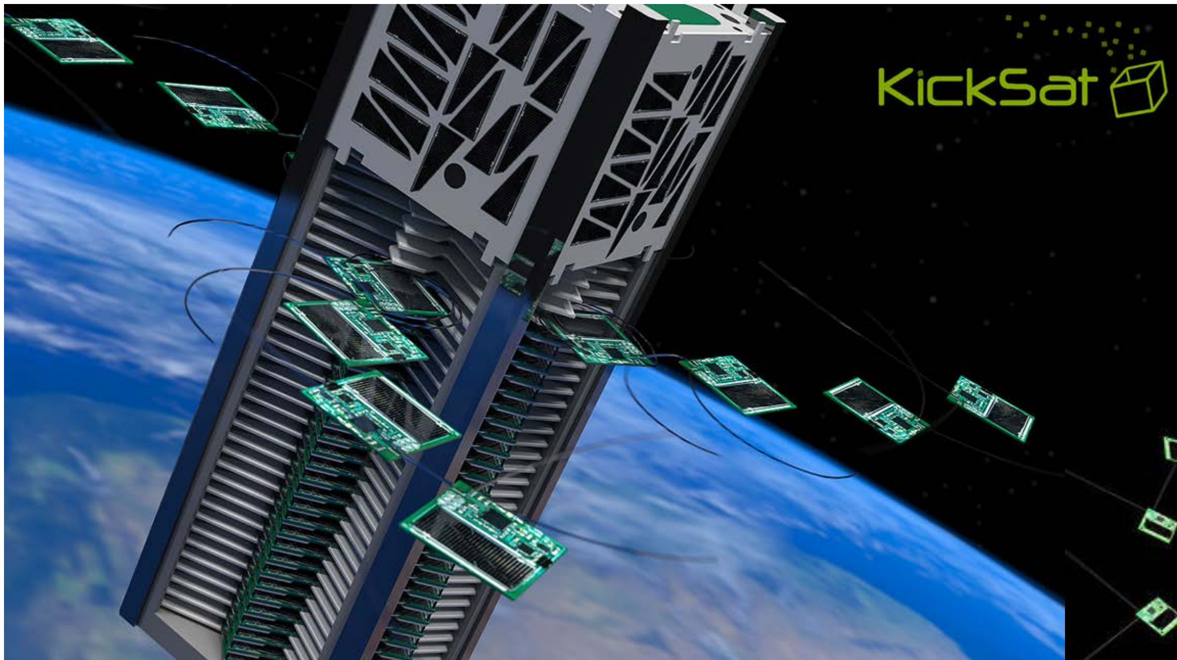


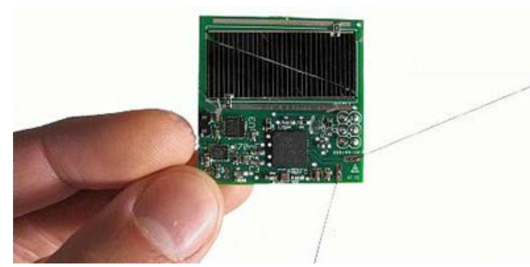


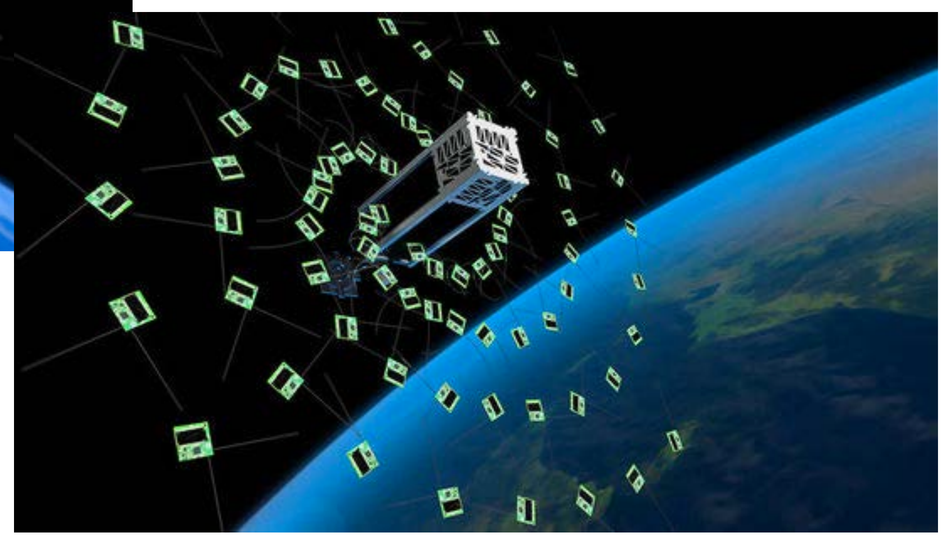
ISARA (Integrated Solar Array and Reflectarray Antenna)



CubeSat technologies

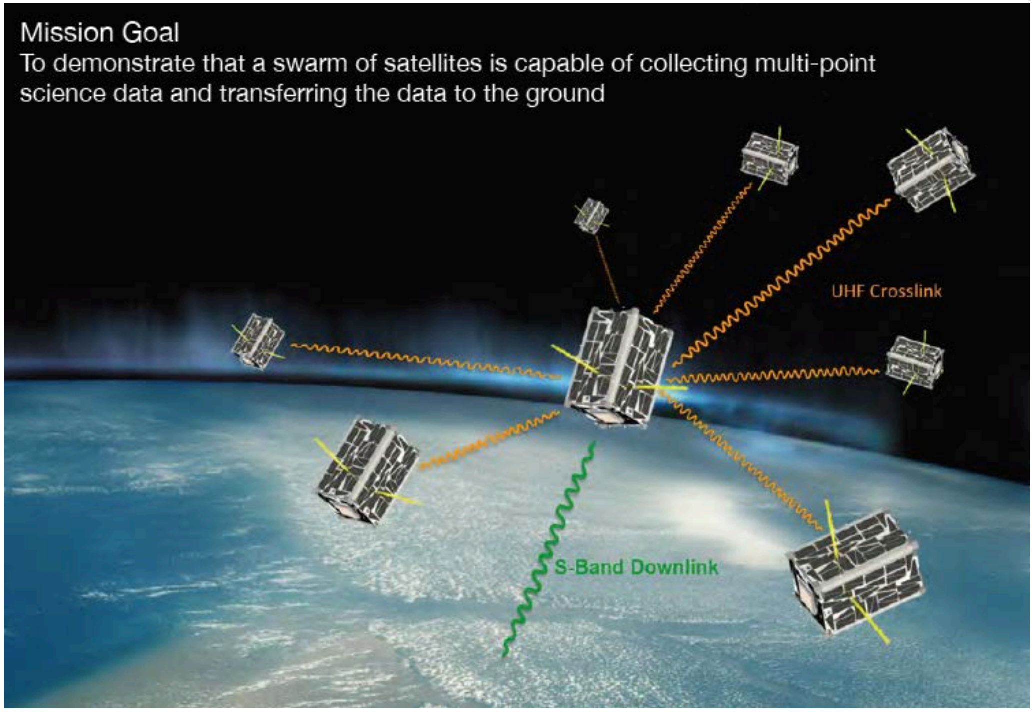


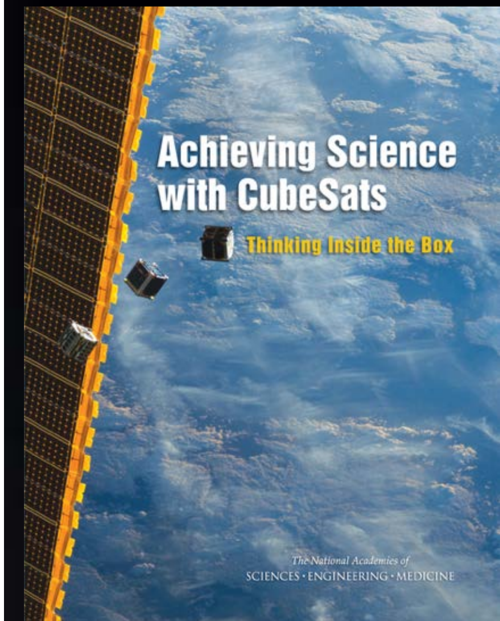




CubeSat technologies

EDSN (Edison Demonstration of Smallsat Networks)



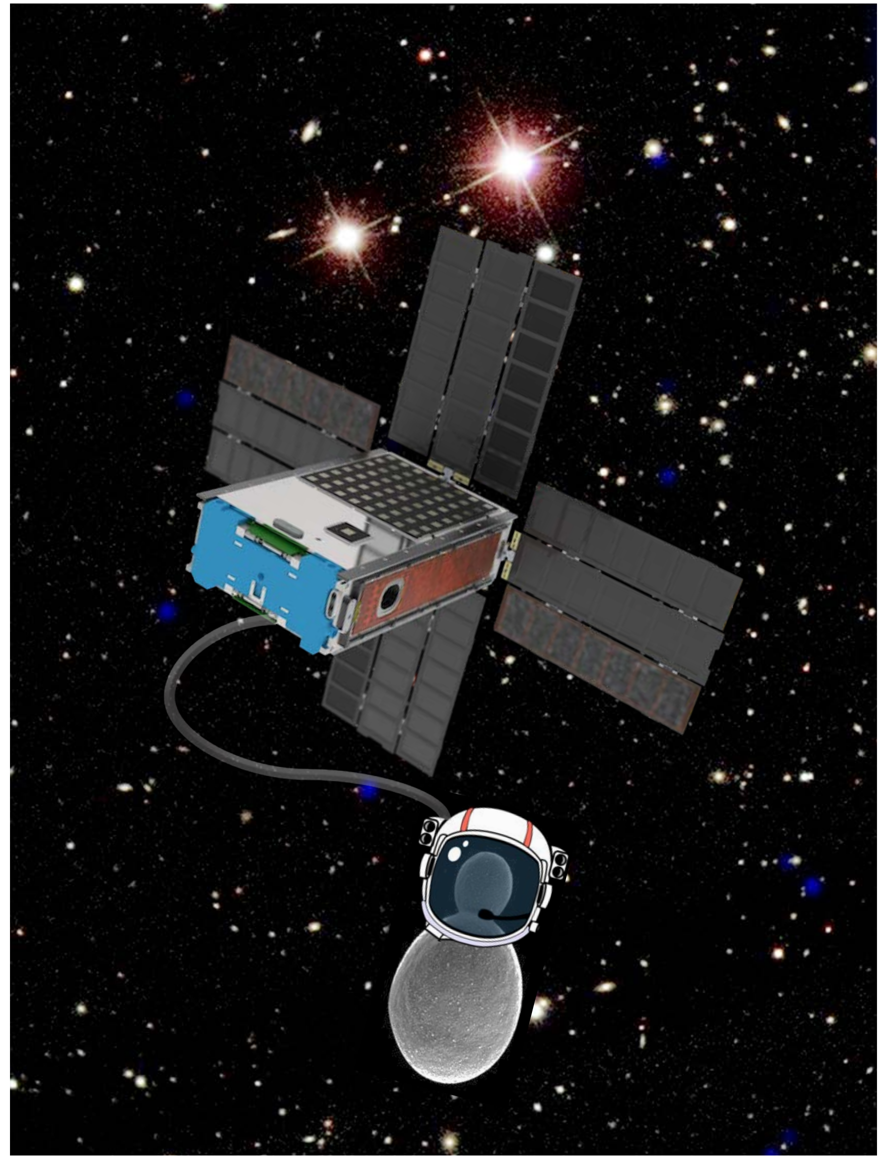


Why Cubesats?

- Small Sats are ever more capable: technology miniaturization
- Access to space: multiple low-cost launches possible (test, learn, iterate)
- Excellent education vehicle (worldwide)
- Autonomous operations
- Technology migration: ISS; landers/orbiters for moon, Mars, other planets

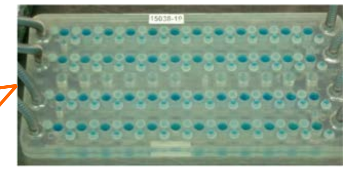
Biological missions using CubeSats

(NASA Ames Research Center, 2006 – 2018)

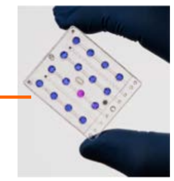


NASA Ames pioneering biological space missions

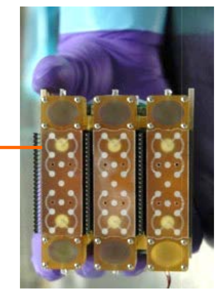
E. coli GeneSat-1 (2006 / 3U): ***gene expression***
EcAMSat (2017 / 6U): ***antibiotic resistance***



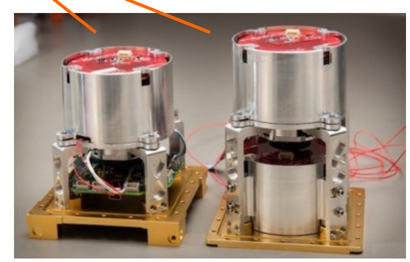
S. cerevisiae PharmaSat (2009 / 3U): ***drug dose response***
BioSentinel (2019 / 6U): ***DNA damage repair***



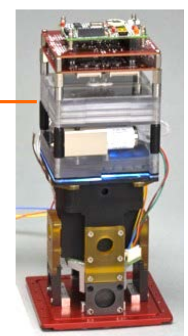
B. subtilis O/OREOS* (2010 / 3U): ***survival, metabolism***
ADRoIT-M** (20xx / 6U): ***mutations / lithopanspermia***



C. richardii SporeSat-1 (2014 / 3U): **ion channel sensors, μ-centrifuges**
SporeSat-2 (2018 / 3U): ***plant gravity sensing threshold***



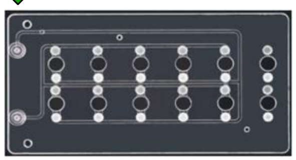
C. elegans FLAIR (20xx / 3U): ***dual-wavelength fluorescence imager***

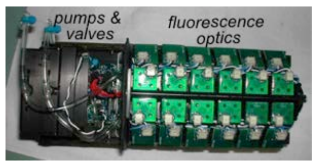


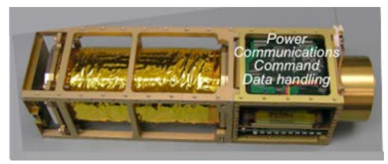
**Organism/Organic Response to Orbital Stress*
***Active DNA Repair on Interplanetary Transport of Microbes*

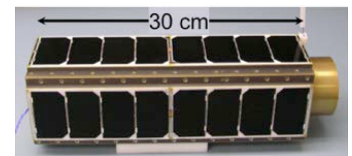
GeneSat mission

1st biological nanosatellite in Earth's orbit, 1st real-time, *in-situ* gene expression measurement in space

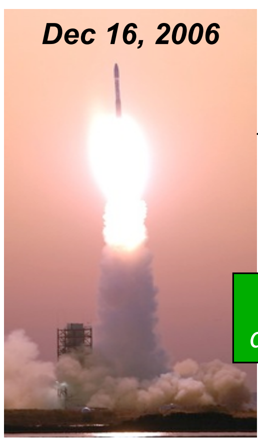




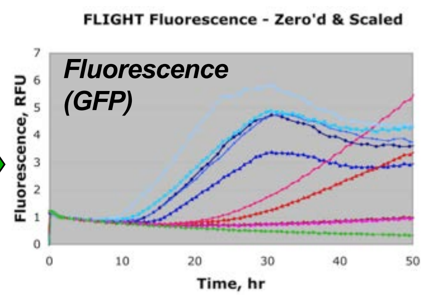




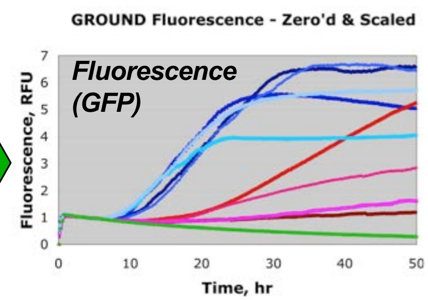
- Model organism: *E. coli* (~ 0.5 x 2 µm bacteria)
- Nutrient deprivation in dormant state (6 weeks)
- Launch: Dec 2006 to low Earth orbit (440 km)
- Nutrient solution feed upon orbit stabilization, grow *E. coli* in microgravity
- Monitor green fluorescent protein (GFP): gene expression
- Monitor optical density: cell population



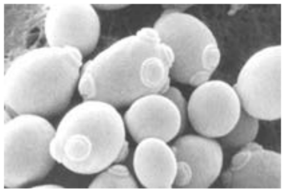
Telemeter data to Earth



Compare to ground data



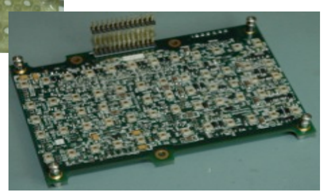
PharmaSat mission

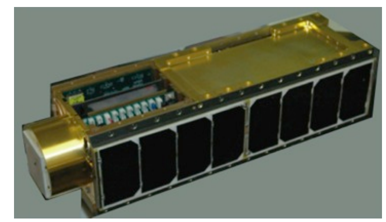


S. cerevisiae

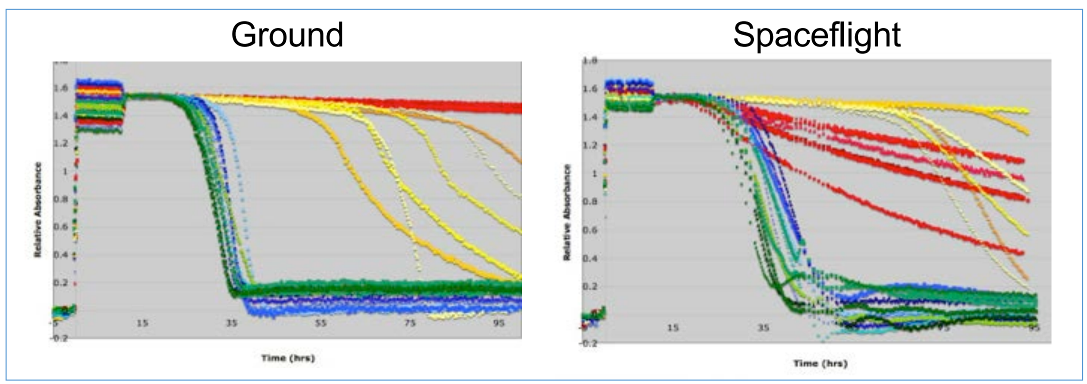
Effect of Microgravity on Yeast Susceptibility to Antifungal Drugs

- Grow yeast in multiwell fluidics card in microgravity
- Measure inhibition of growth by antifungal
- Optical absorbance (turbidity: cell density)
- Metabolism indicator dye: alamarBlue
- Control + 3 concentrations of antifungal





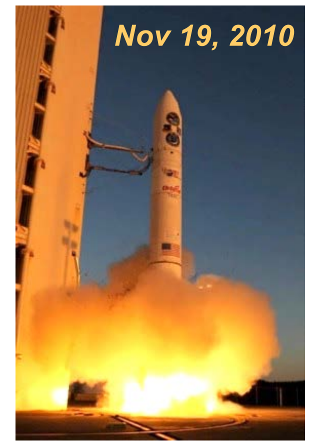
May 19, 2009

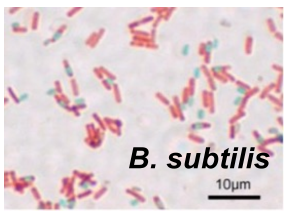


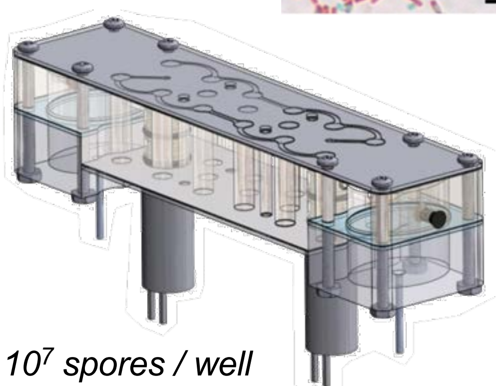
O/OREOS mission

Organism / Organic Response to Orbital Stress

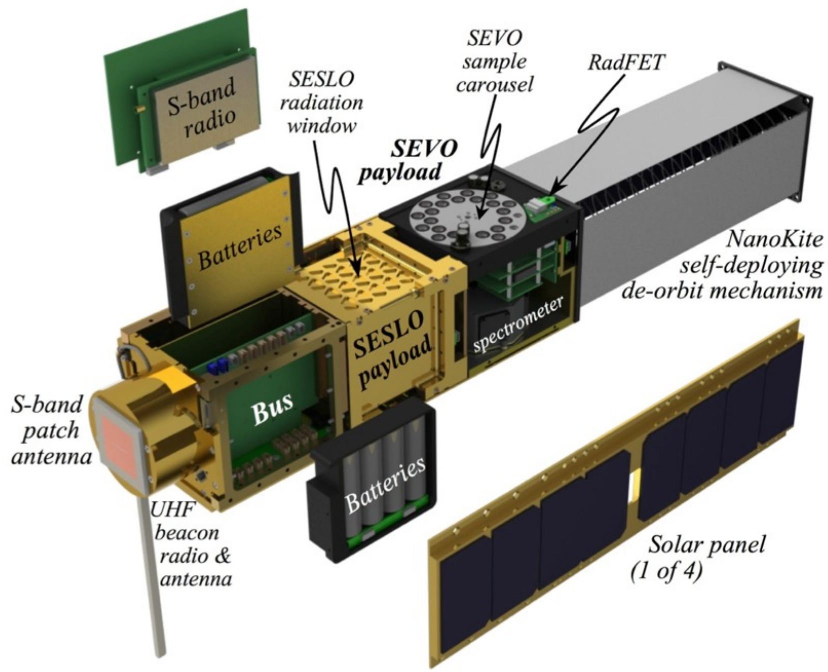
- Effects of space exposure on biological organisms (6 mo) & organic molecules (18 mo)
- Monitor survival, growth, and metabolism of *B. subtilis* using *in-situ* optical density /colorimetry (SESLO: Space Environment Survival of Living Organisms)
- Track changes in organic molecules and biomarkers: UV / visible / NIR spectroscopy (SEVO: Space Environment Viability of Organics)

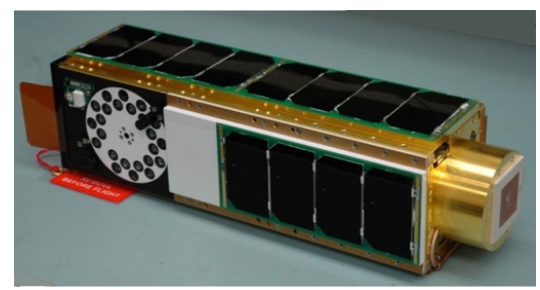






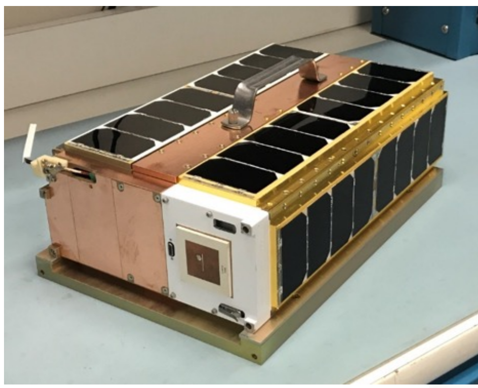
10^7 spores / well (75 μL per well)

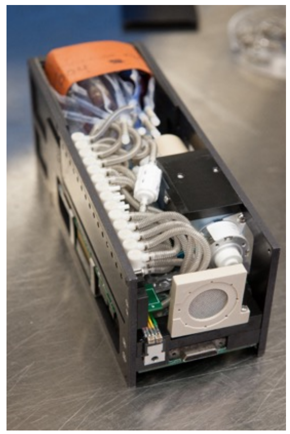


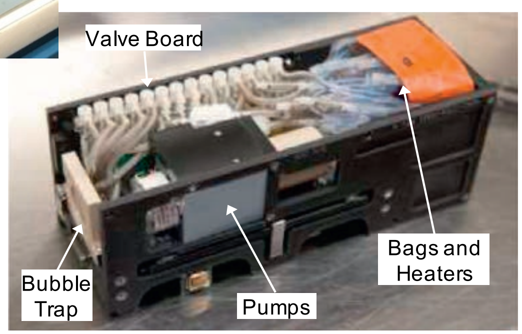


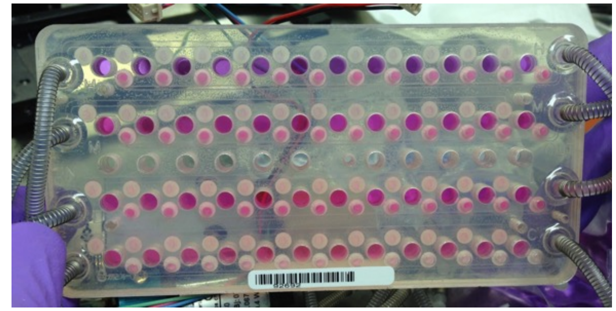
EcAMSat mission

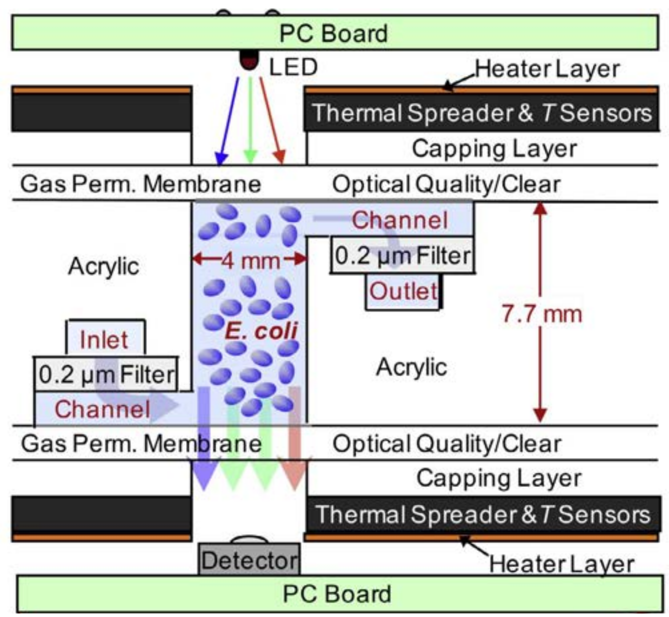
E. coli AntiMicrobial Satellite mission





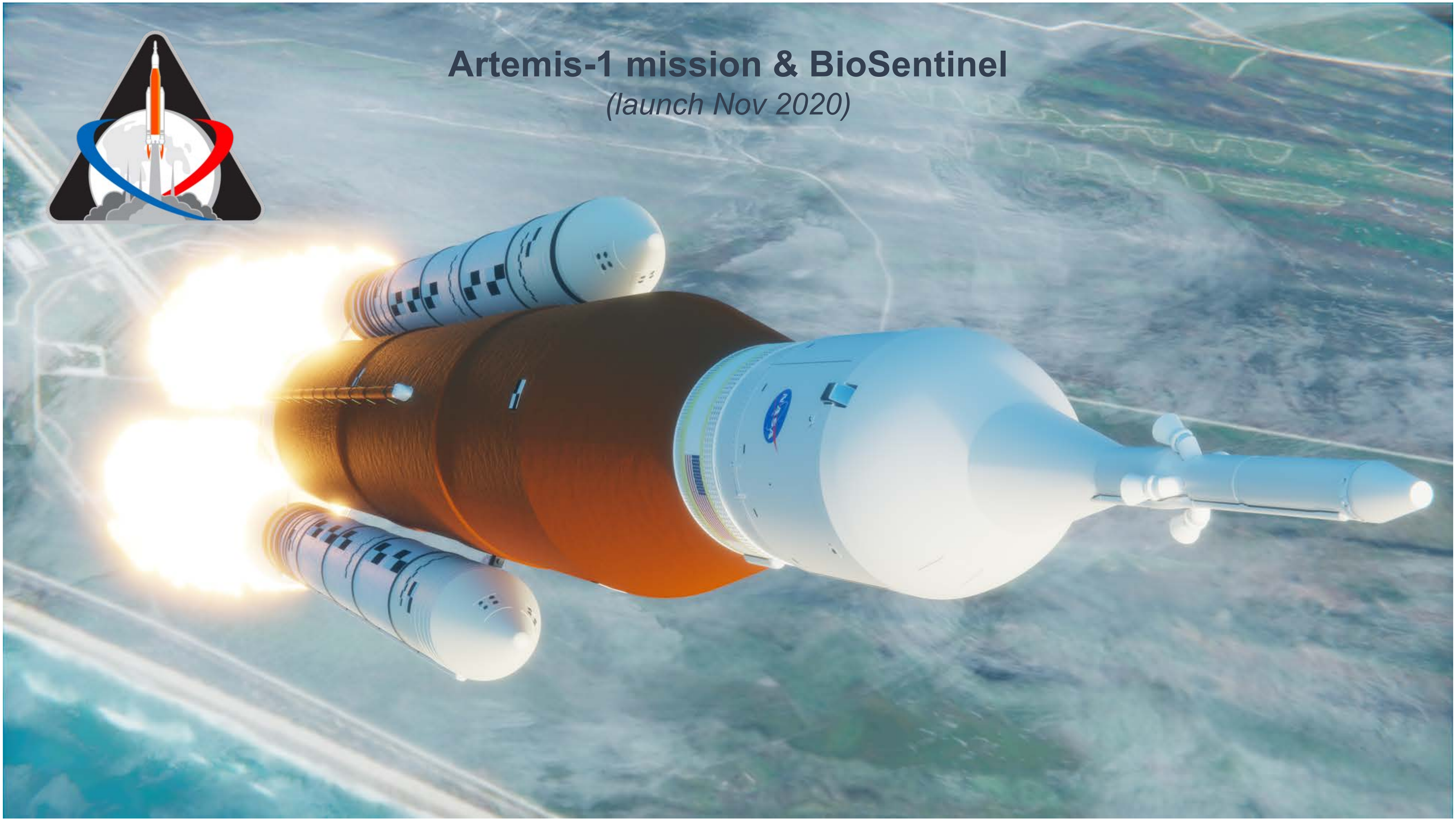






Artemis-1 mission & BioSentinel

(launch Nov 2020)

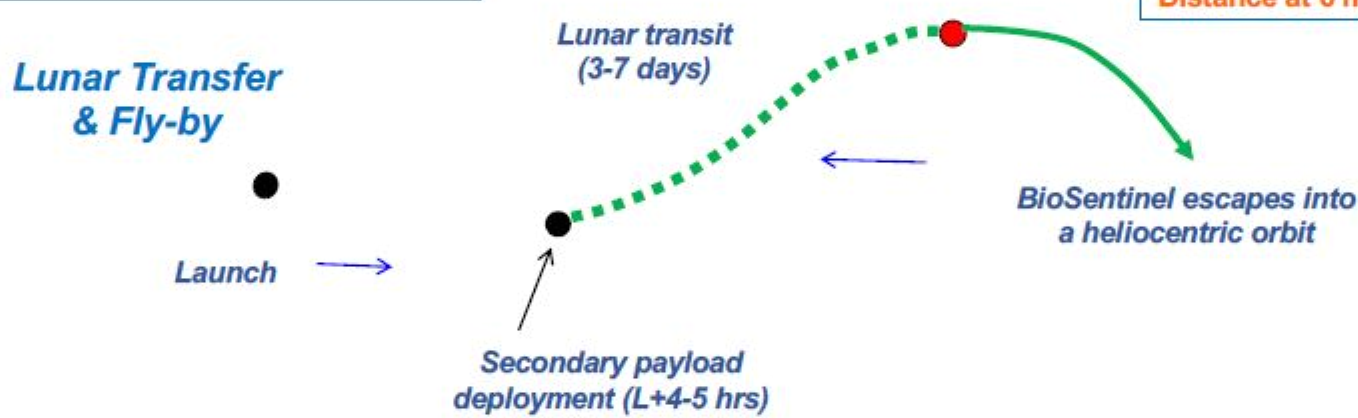


BioSentinel mission

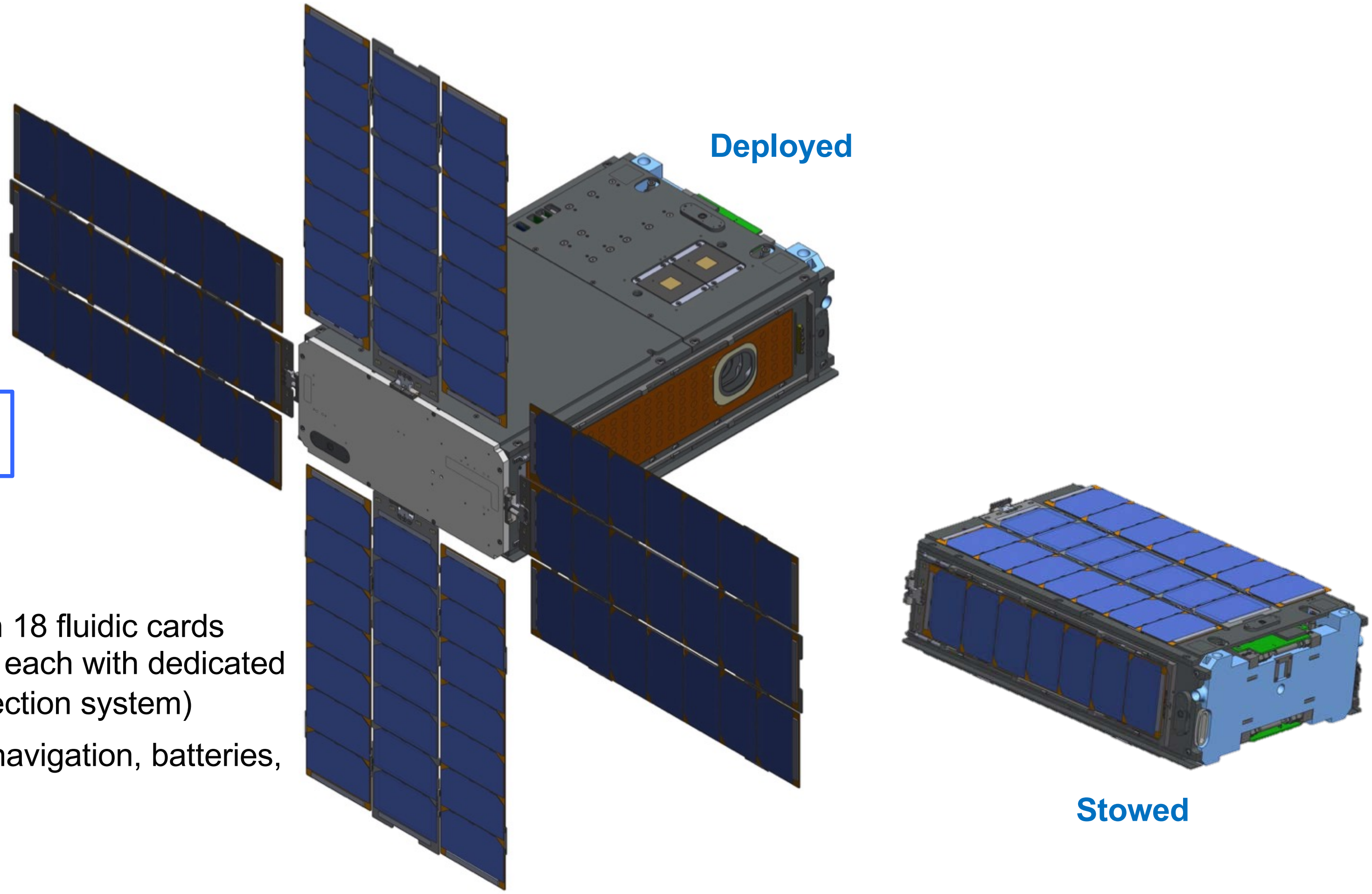
Main objective: develop a tool with autonomous life support technologies to study the biological effects of the space radiation environment at different orbits

- First biological study beyond low Earth orbit (LEO) in almost 50 years
  - First biological 6U CubeSat to fly beyond LEO
  - First CubeSat to combine biological studies with autonomous capability & physical dosimetry beyond LEO
  - Secondary payload in SLS ARTEMIS-1 (launch in Nov 2020) – currently 13 payloads
  - 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 and gravitational environments (free space, ISS…)

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



BioSentinel: a 6U nanosatellite for deep space

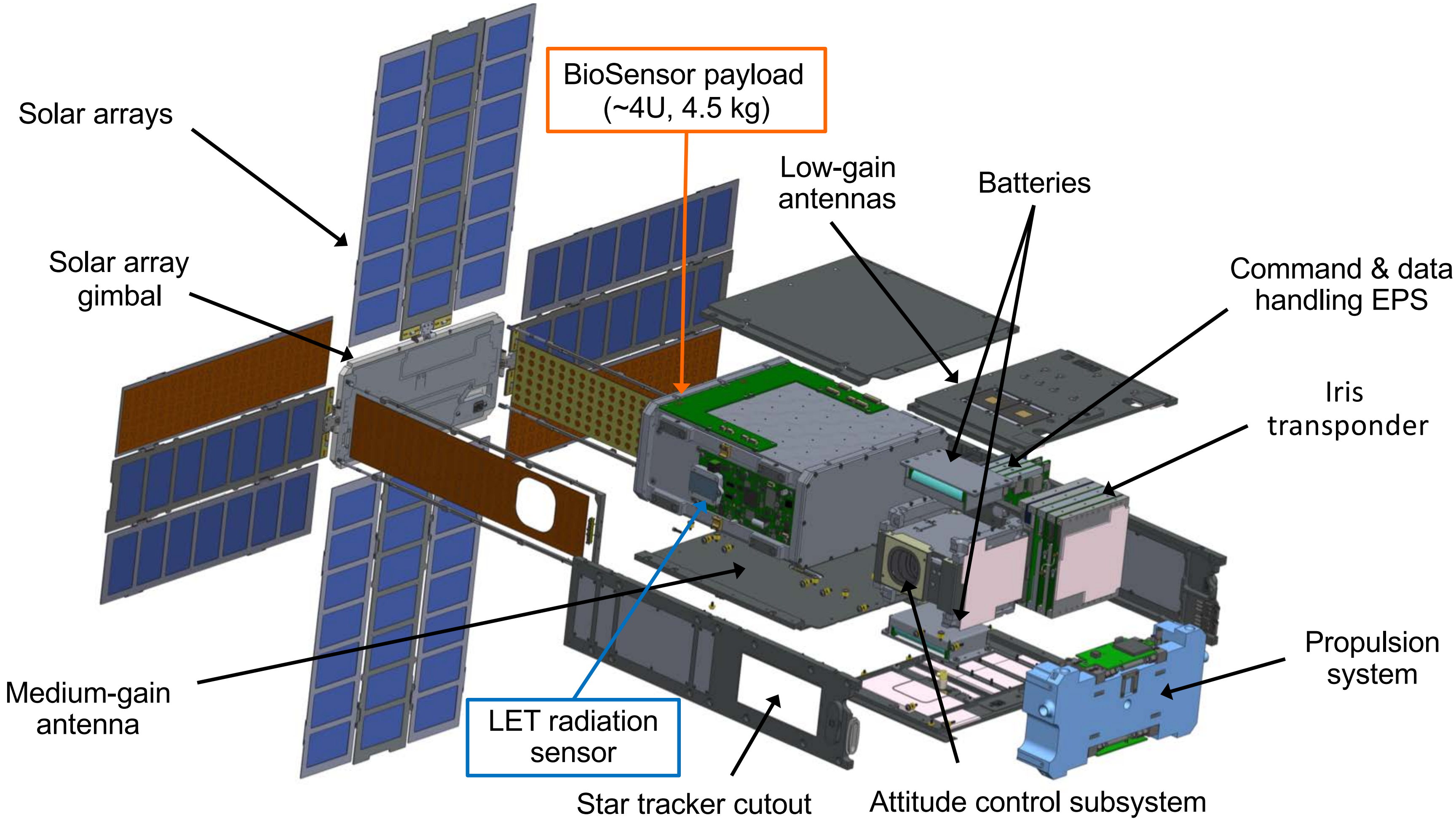


6U CubeSat
37 x 24 x 12 cm ~ 10 L

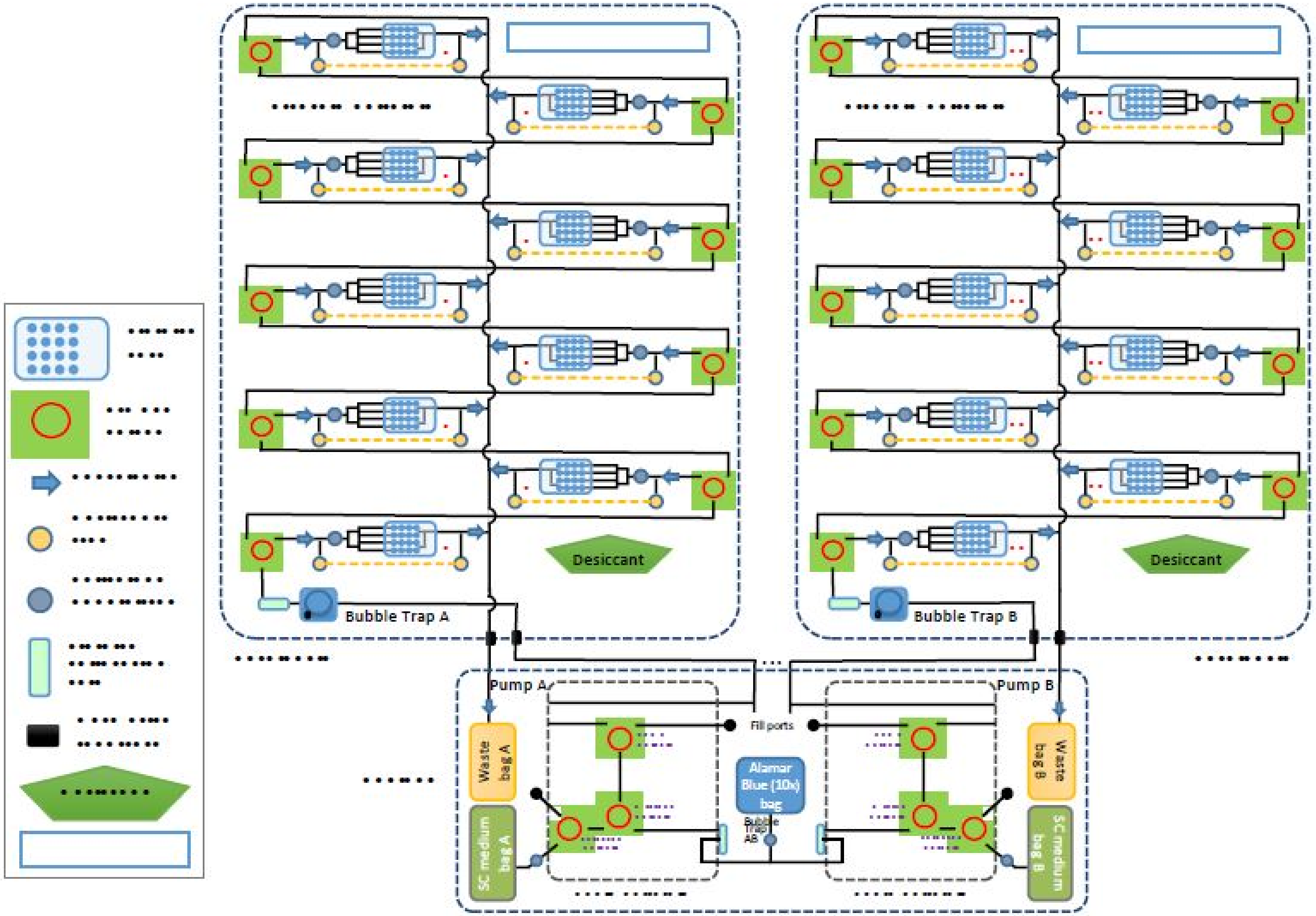
Spacecraft sections:

- 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



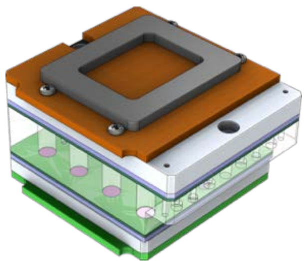
BioSentinel: microfluidic system

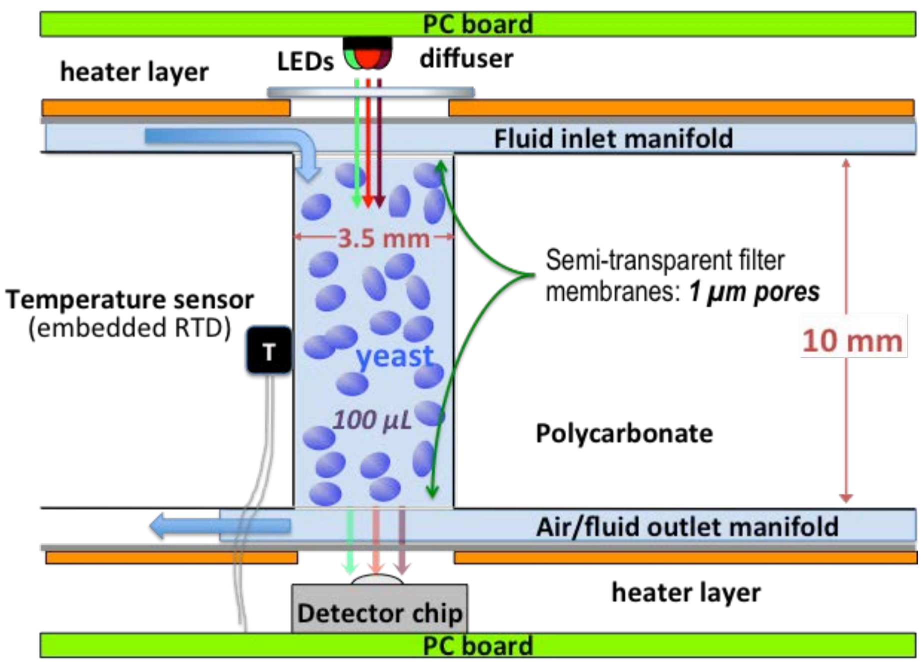


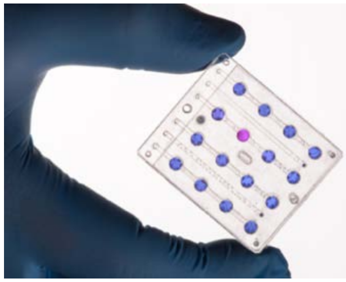
Manifold-integrated components:

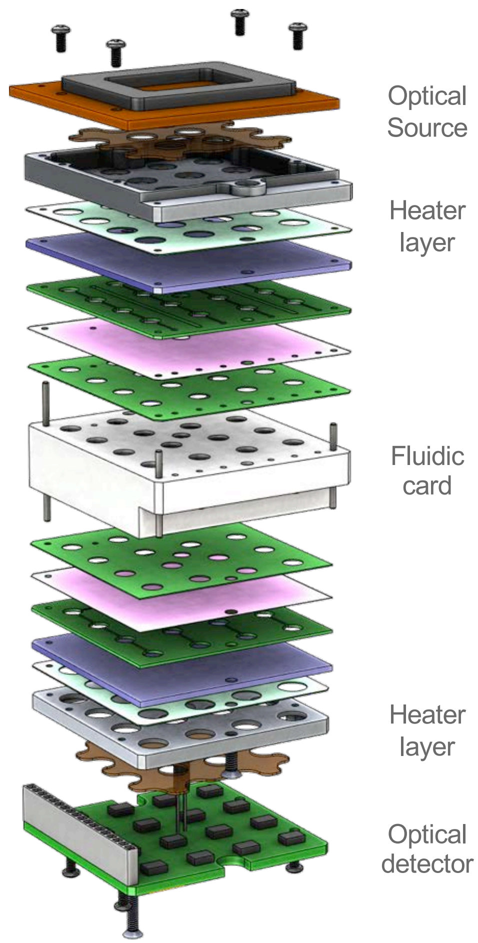
- *2 pumps*
- *24 active & 38 check valves*
- *2 main bubble traps*
- *18 desiccant traps*
- *4 optical calibration cells*
- *18 fluidic cards with 18 small bubble traps*
- *288 microwells total*

BioSentinel: microfluidic card









Conclusions

- **Nanosatellites / CubeSats can do real science in LEO and in interplanetary space**
  - Tools / devices / methods of bio / micro / nano technologies are enablers
  - Real-time, *in-situ* experiments provide insights on dynamics not available from expose-and-return strategies
- **Heritage of astrobiology and fundamental space biology experiments in LEO is a major enabler for interplanetary biological missions**
  - Flying biology dry, filling fluidic microwells in microgravity
  - Long-term materials biocompatibility, stasis > 1 year, yeast in microgravity
  - Radiation-tolerant design (*e.g.*, O/OREOS functional after > 4 years)
  - High-heritage sensors, fluidic components & approach, optical measurement approach to growth & metabolism

Future (and ongoing) objectives

A flexible design that can (and will be) used on different space platforms