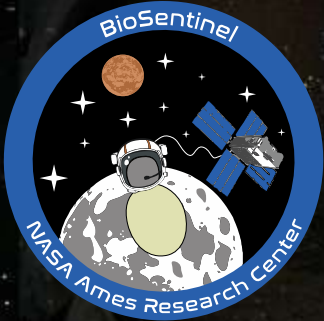




BioSentinel: NASA's First Deep Space Biological Mission

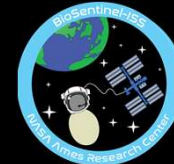


Andres Mora Vargas*, Rachel Gilbert, Sergio R. Santa Maria, Diana Gentry, Jeffrey Homan, Matthew Napoli

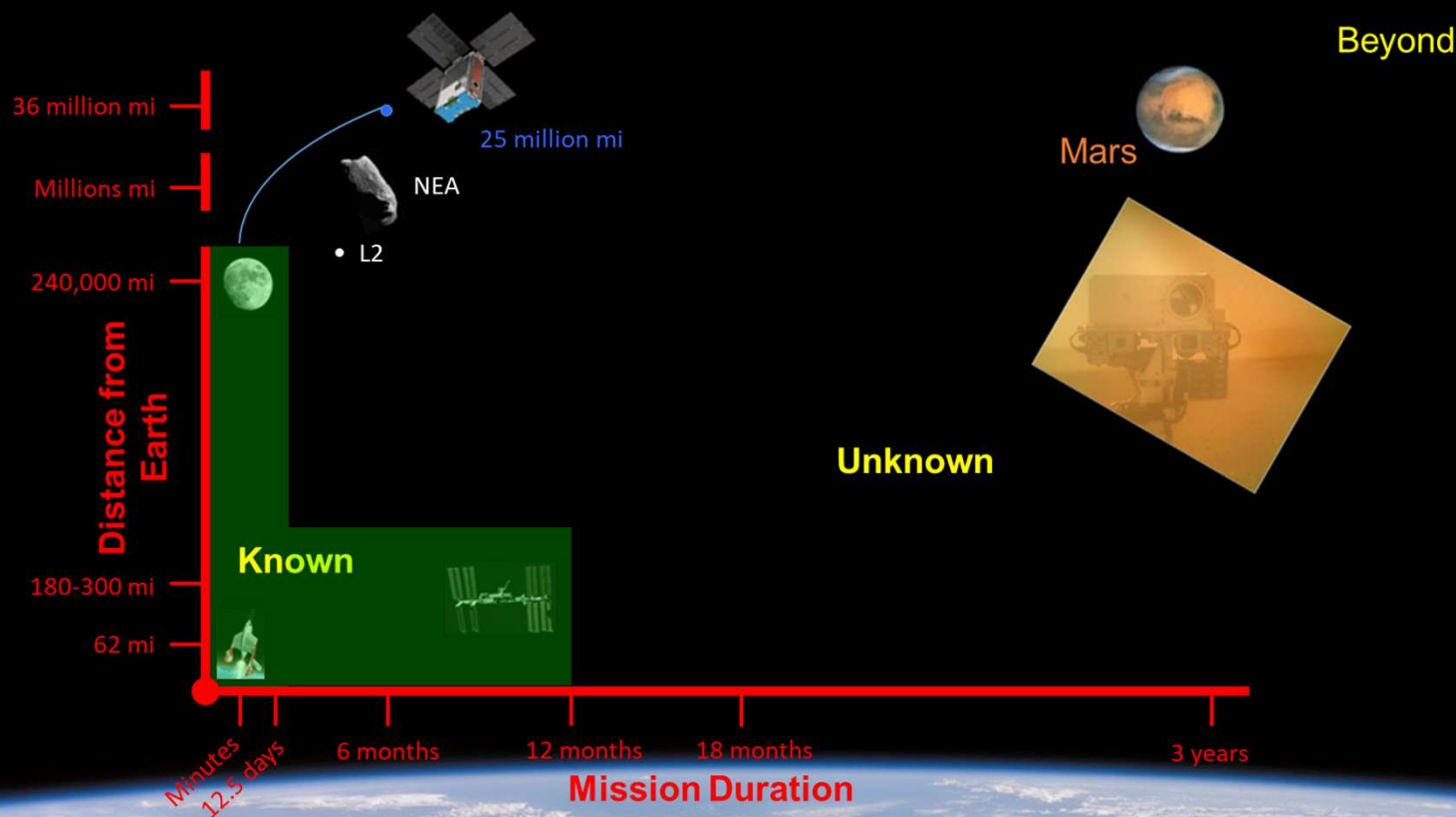
2022-09-22
Room W05, 01:45pm
IAC-22,A1,8,x70761

73rd International Astronautical Congress, Paris, France





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

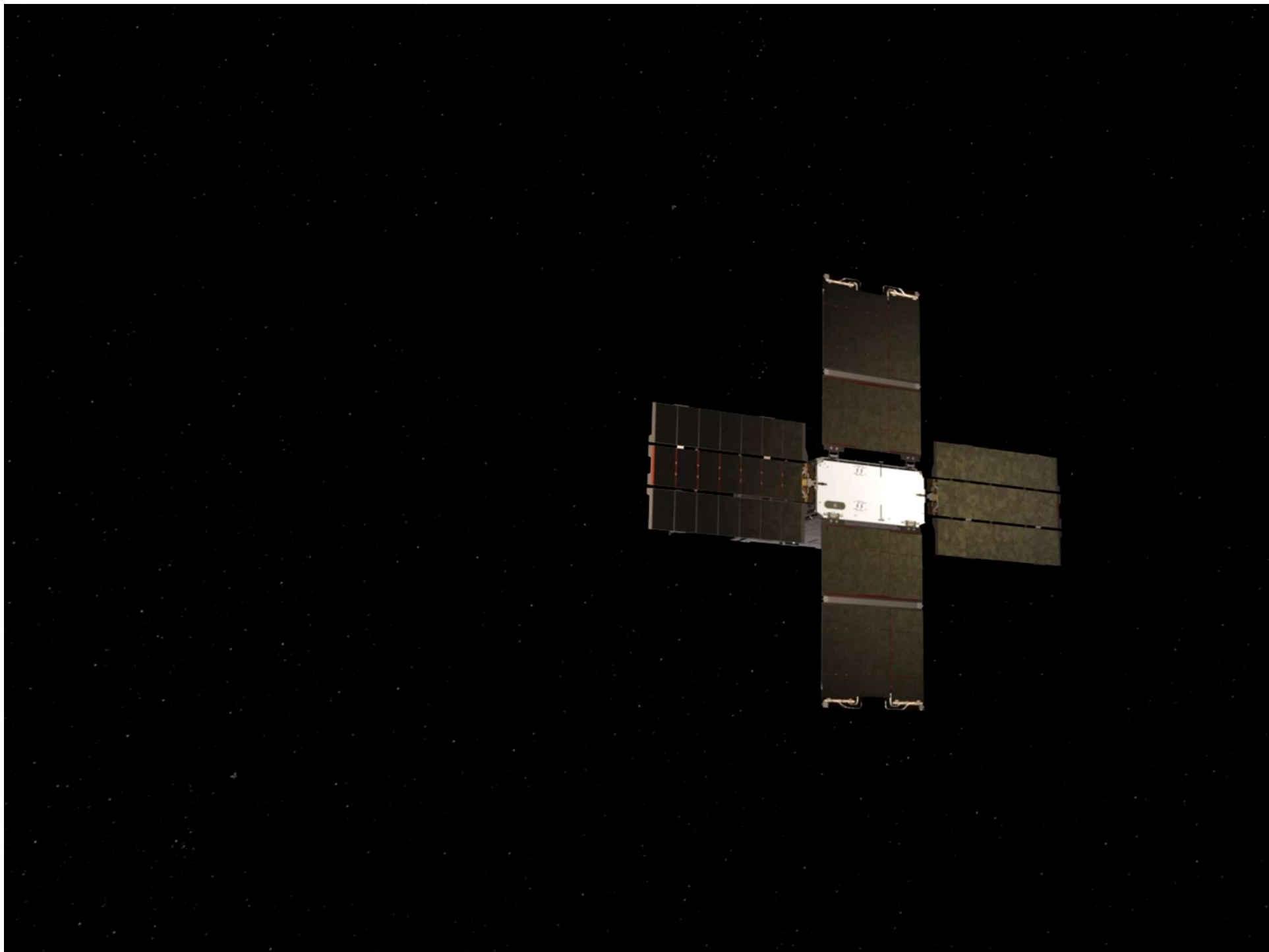




Outline



- What's BioSentinel?
- Science Objectives
- Payloads
- BioSentinel's Mission Segments
- Data Management
- Preliminary Results
- Conclusions





What's BioSentinel?



BioSentinel is a yeast radiation biosensor that will investigate the response to cell damage caused by space radiation, and will provide a tool to study the true biological effects of the space environment.

Why?

Space radiation environment's unique spectrum cannot be duplicated on Earth. It includes high-energy particles, is omnidirectional, continuous, and of low flux.

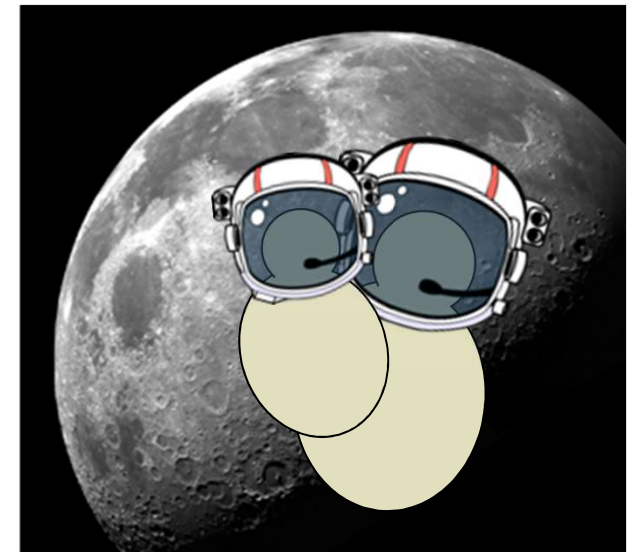
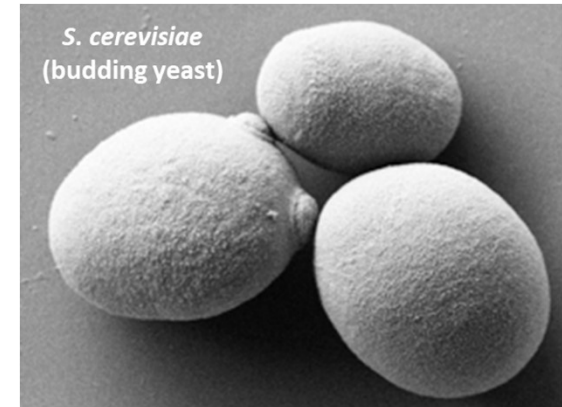
How?

Lab-engineered *S. cerevisiae* cells will sense & repair direct (and indirect) damage. Yeast cells will remain dormant until rehydrated and grown using a microfluidic and optical detection system.

Why budding yeast?

It is a eukaryote; easy genetic & physical manipulation; assay availability; flight heritage; ability to be stored in dormant state

While it is a simple model organism, yeast cells are the best for the job given the limitations & constraints of spaceflight





Outline



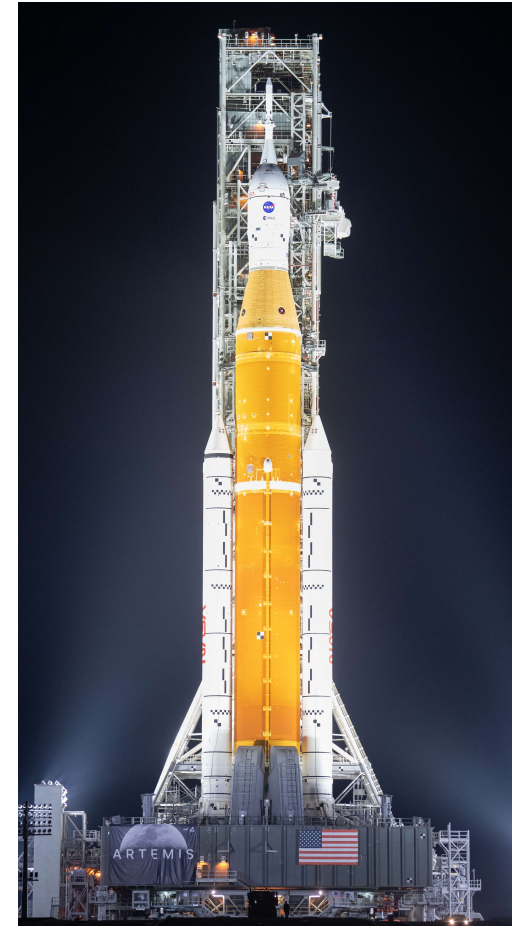
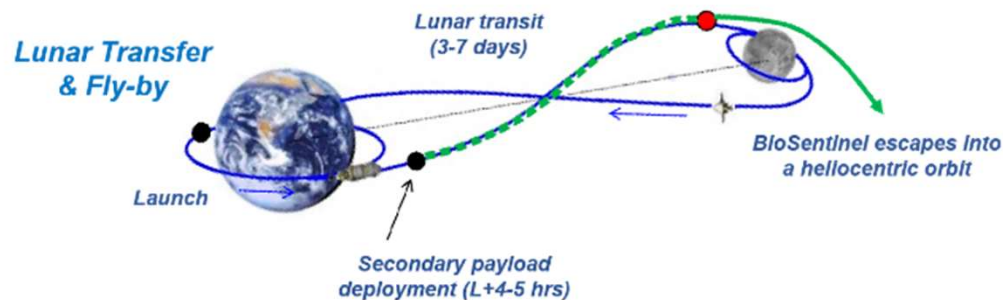
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Science Objectives



- Develop a deep space tool with autonomous life support technologies to study the biological effects of the space radiation environment
- NASA's first biological study in interplanetary deep space
- First CubeSat to combine bio studies with autonomous capability & dosimetry beyond LEO
- Far beyond the protection of Earth's magnetosphere
- BioSentinel will allow us to compare different radiation & gravitational environments (deep space, ISS, ground)





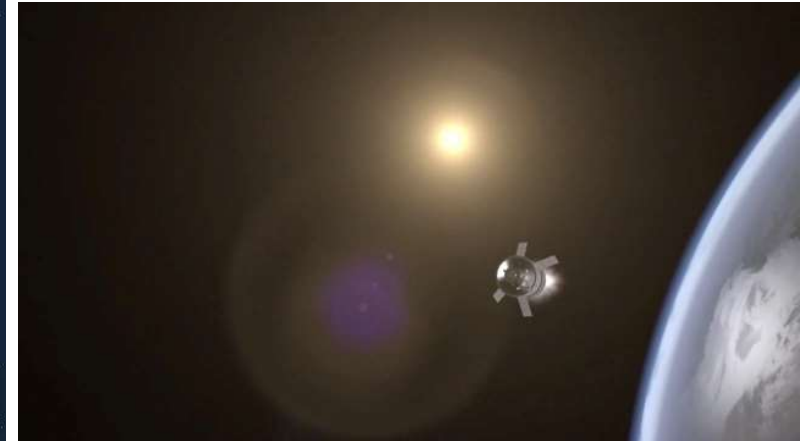
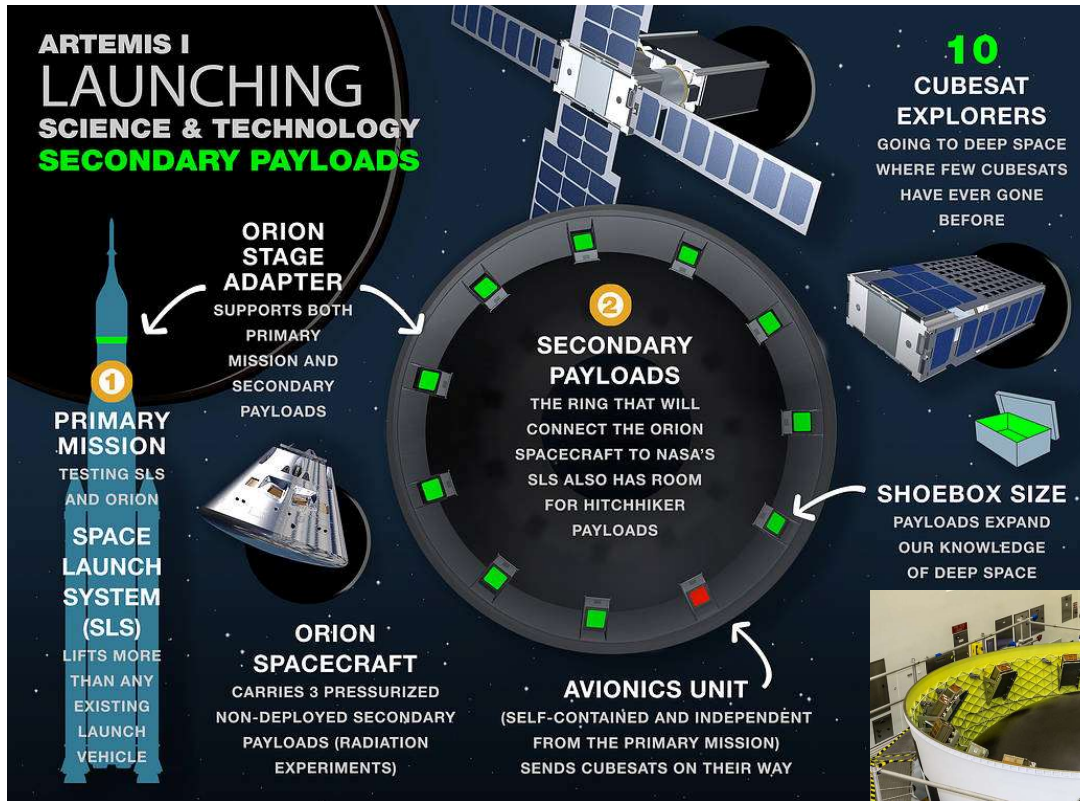
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Payloads



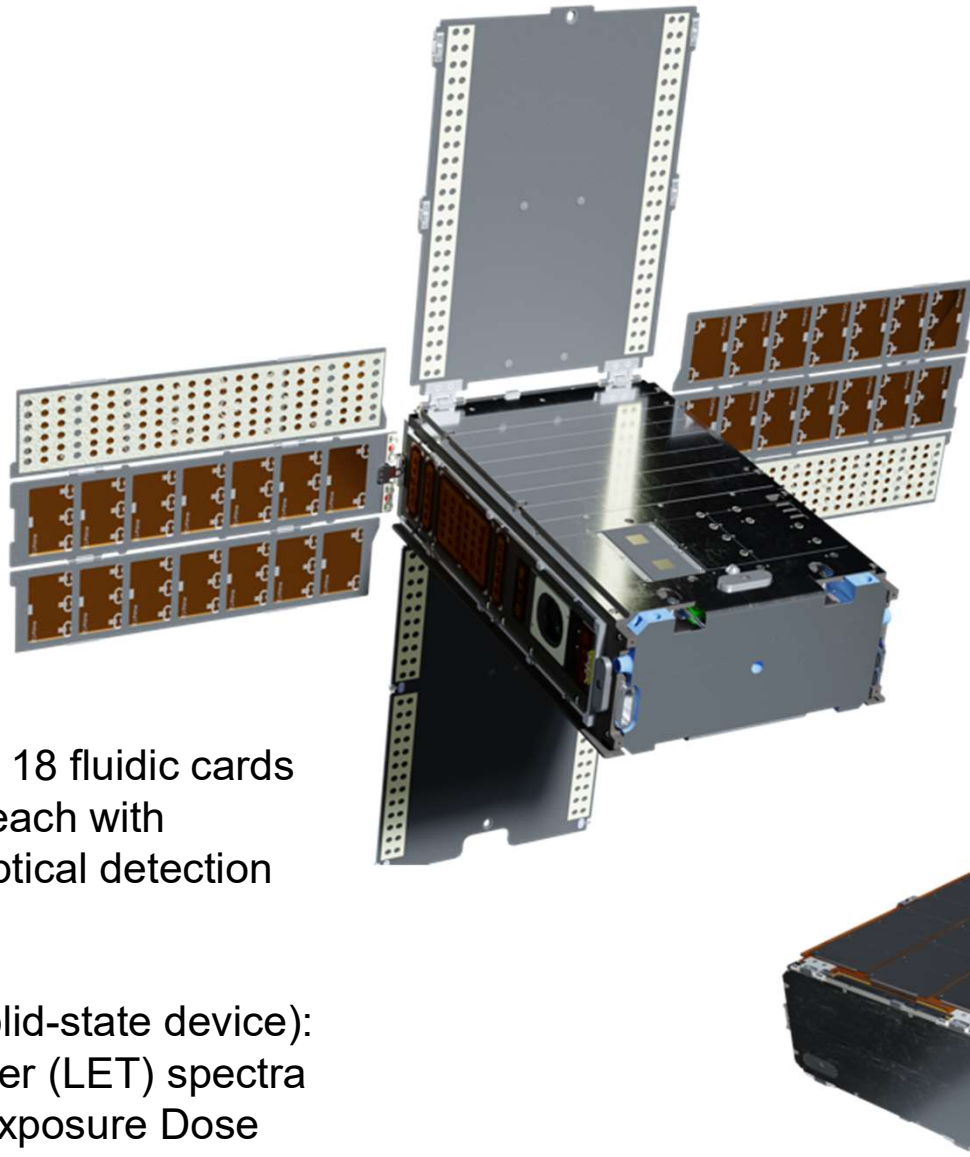


Payloads



6U Cubesat

37 x 24 x 12 cm ~ 10 L

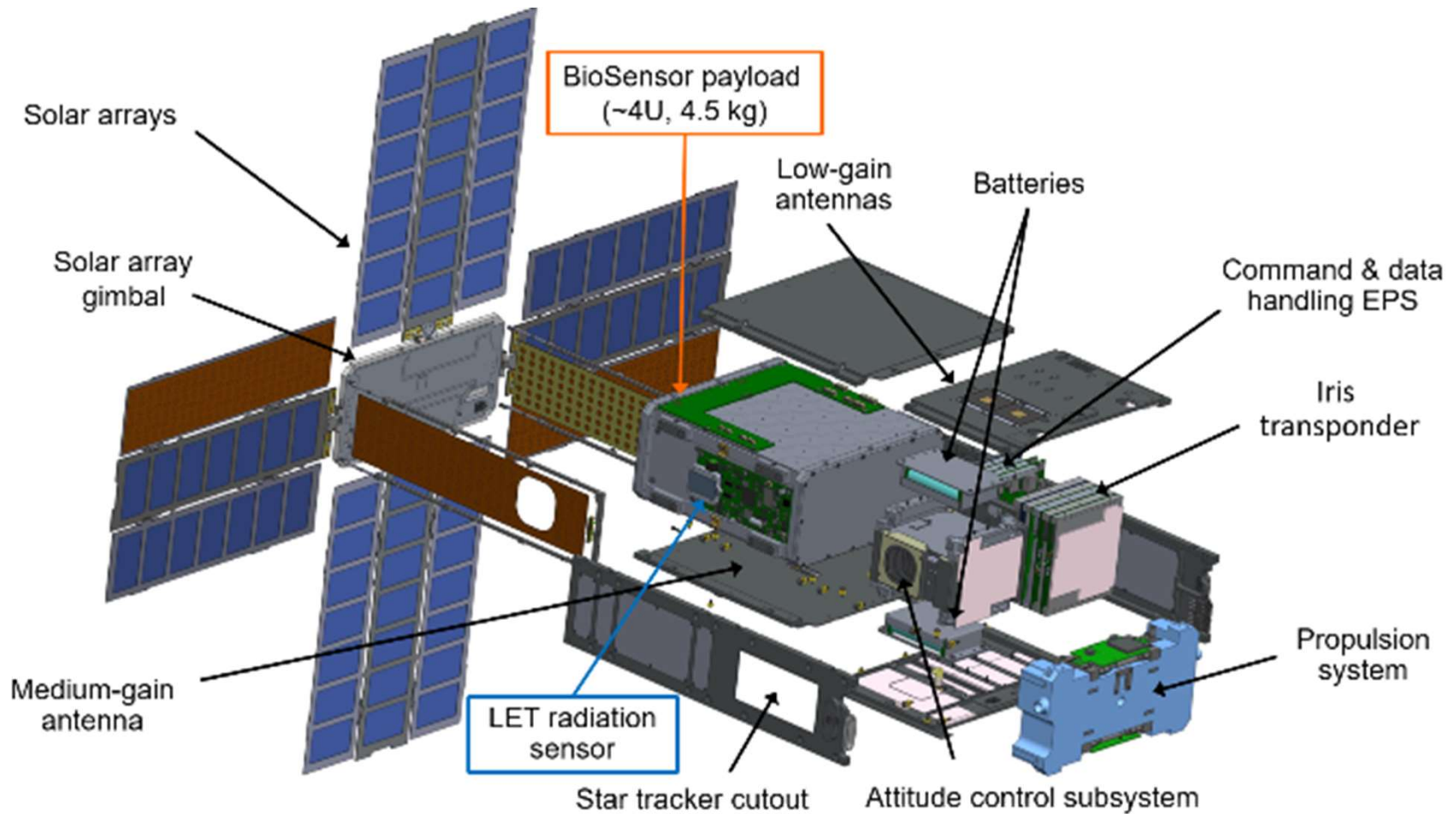


Spacecraft sections:

- BioSensor payload (~4U) with 18 fluidic cards loaded with desiccated cells, each with dedicated thermal control & optical detection system
- LET spectrometer (Timepix solid-state device): measures linear energy transfer (LET) spectra and Total Ionizing Radiation Exposure Dose



Payloads

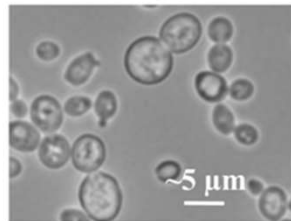




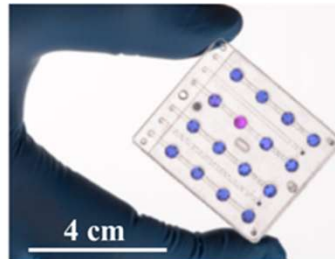
Payloads



Budding yeast



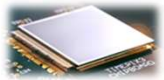
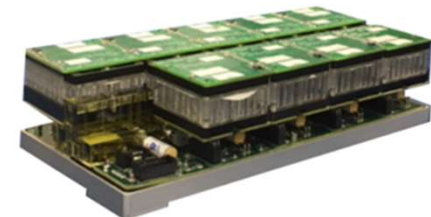
16-well fluidic card (x18)



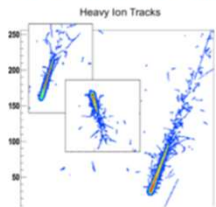
Card stack



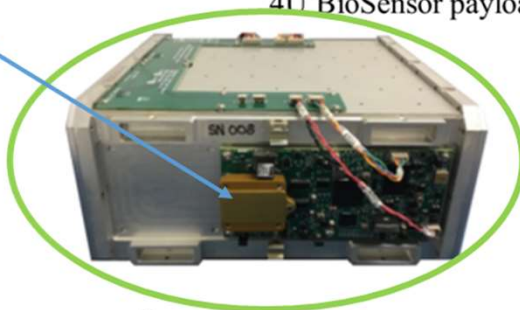
9-card fluidic manifold (x2)



LET spectrometer



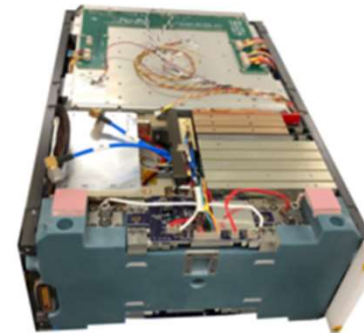
4U BioSensor payload



ISS
(& Ground)



6U BioSentinel spacecraft





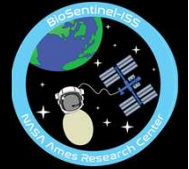
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SOC Design

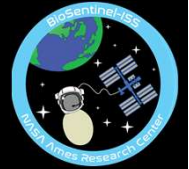


- Mission Segments
 - Free-flyer

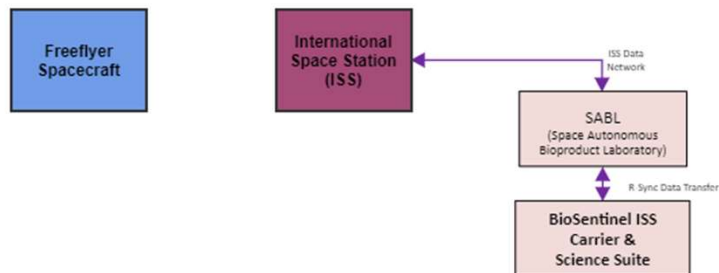




SOC Design

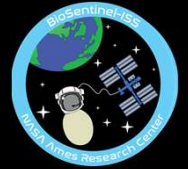


- Mission Segments
 - Free-flyer
 - ISS

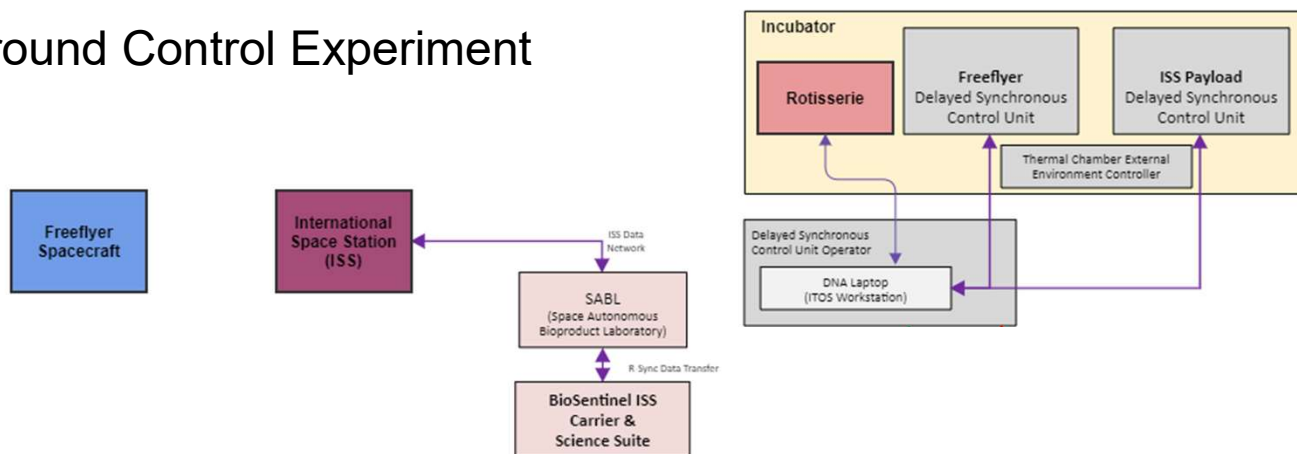




SOC Design

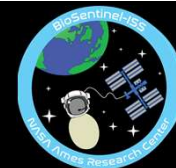


- Mission Segments
 - Free-flyer
 - ISS
 - Ground Control Experiment

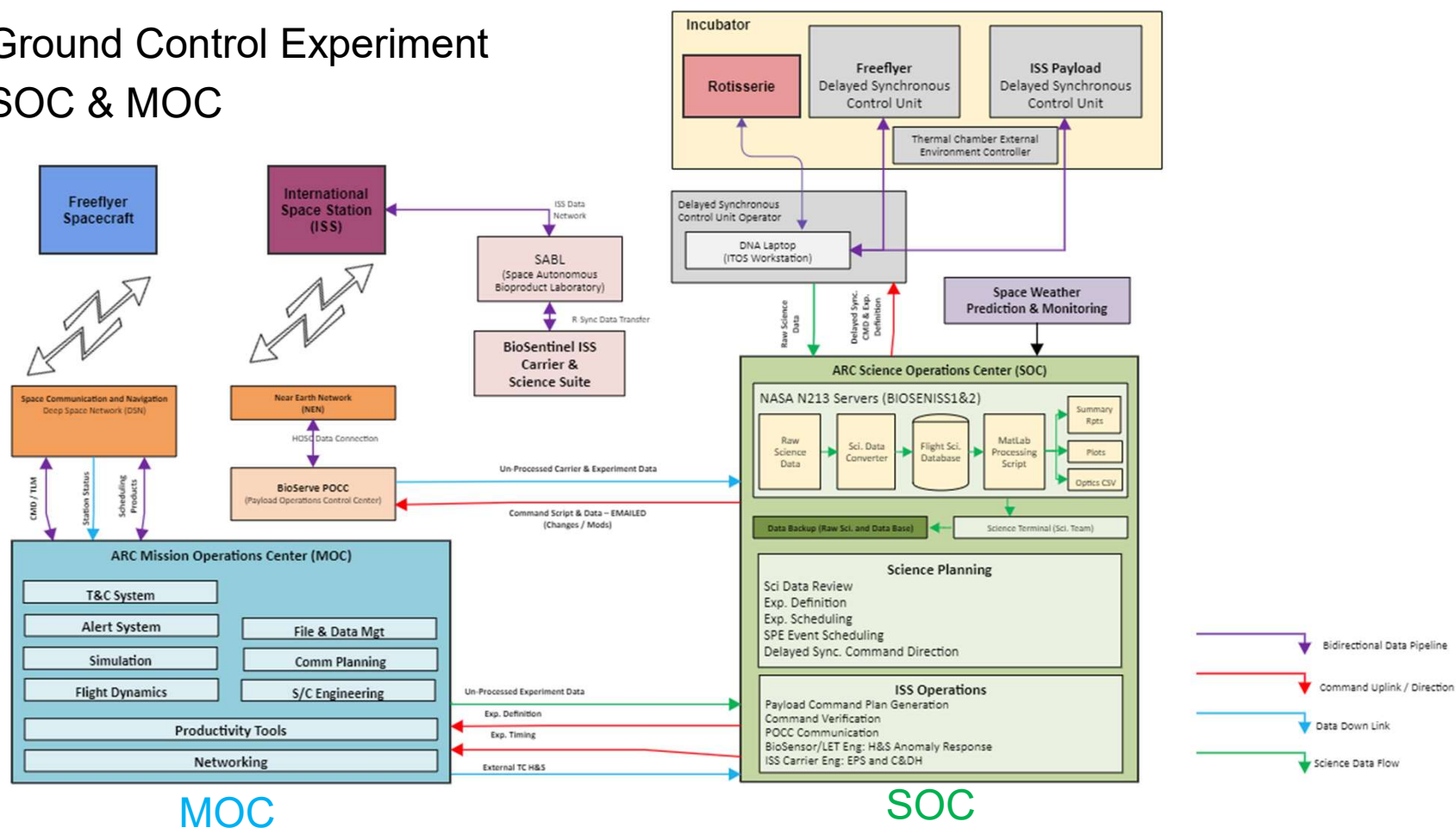




SOC Design



- Mission Segments
 - Free-flyer
 - ISS
 - Ground Control Experiment
 - SOC & MOC

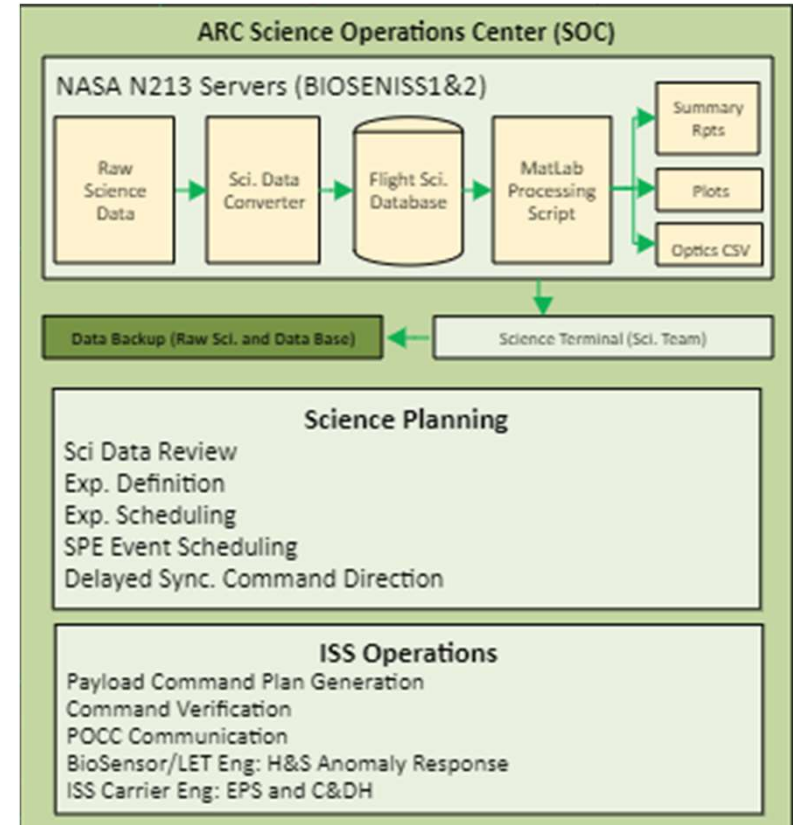




SOC Functions



- Two identical, mutually redundant servers (BIOSENISS3, BIOSENISS4) host the data archive and processing tools
- In charge of:
 - Science planning
 - Instrument activity plans for uplink to Free-flyer
 - Science data retrieval from MOC
 - Forwarding of processed science data to distribute to the scientific community
- Serves as the back-up archive for all science data for the life of the mission





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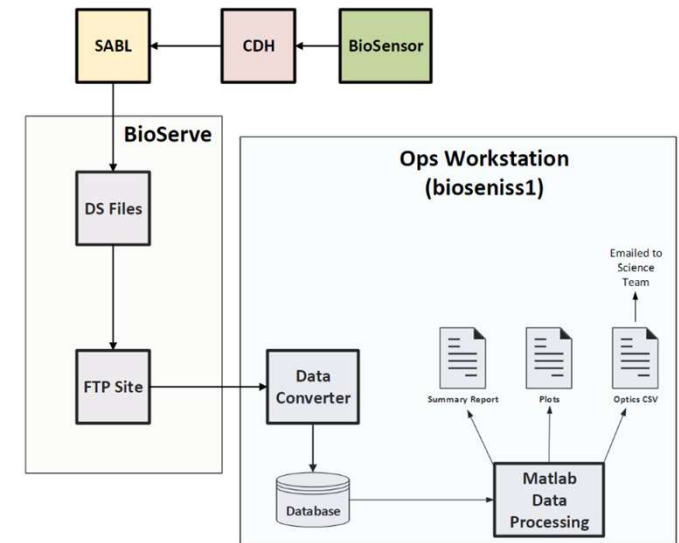


Data Management

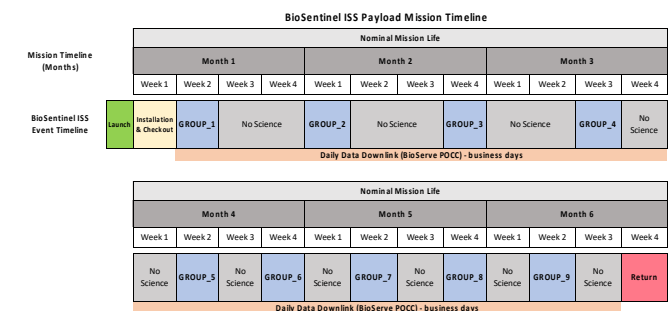


ISS Segment

- ISS FSW stores all telemetry data in Data Store (DS) files
- One file is generated per day in location /SDCARD/sdram1/hk with name "YYYYMMDDHHMMSS.hk"
- BioServe will rsync the DS files onto the SABL laptop on the ISS and then transmit the files to the ground
- The files will reside on the BioServe server 'bst-biosentinel-data' at CU Boulder
- A SOC server periodically checks and pulls over updated files from the BioServe server and captures the flight data in a file-based database residing on it
- The data is processed by a MATLAB program to generate a text-based report, plots, and CSV files used by the Science Team



ISS Segment Data Processing



ISS Segment Mission Timeline



Outline



- What's BioSentinel?
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Preliminary Results



- ISS Experiments started January 2022
- Comparison between 2 strains (wild & *rad51Δ* types) and 1 control (no biology)
- BioSentinel's Optical Detection System

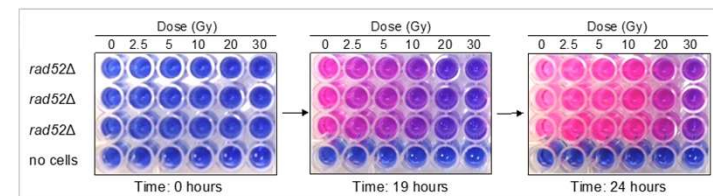
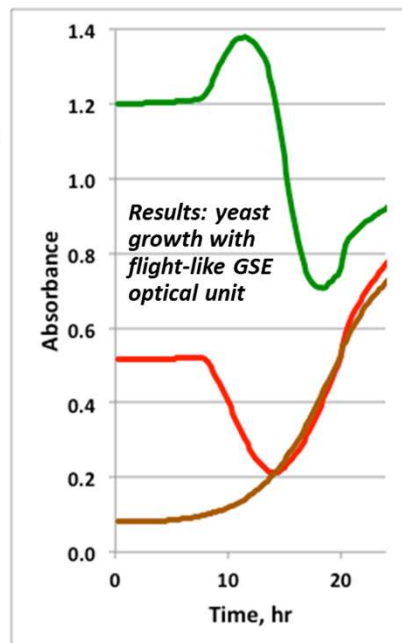
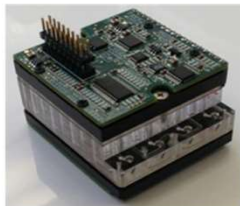
Dedicated 3-color optical system at each well to track growth *via* optical density and cell metabolic activity *via* dye color changes

LEDs:

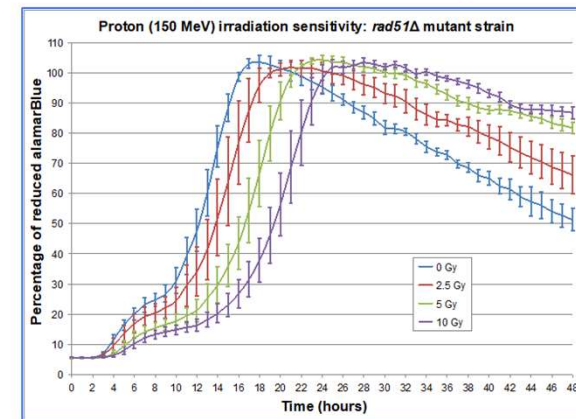
570 nm (green, measures pink)

630 nm (red, measures blue)

850 nm (infrared, measures growth)



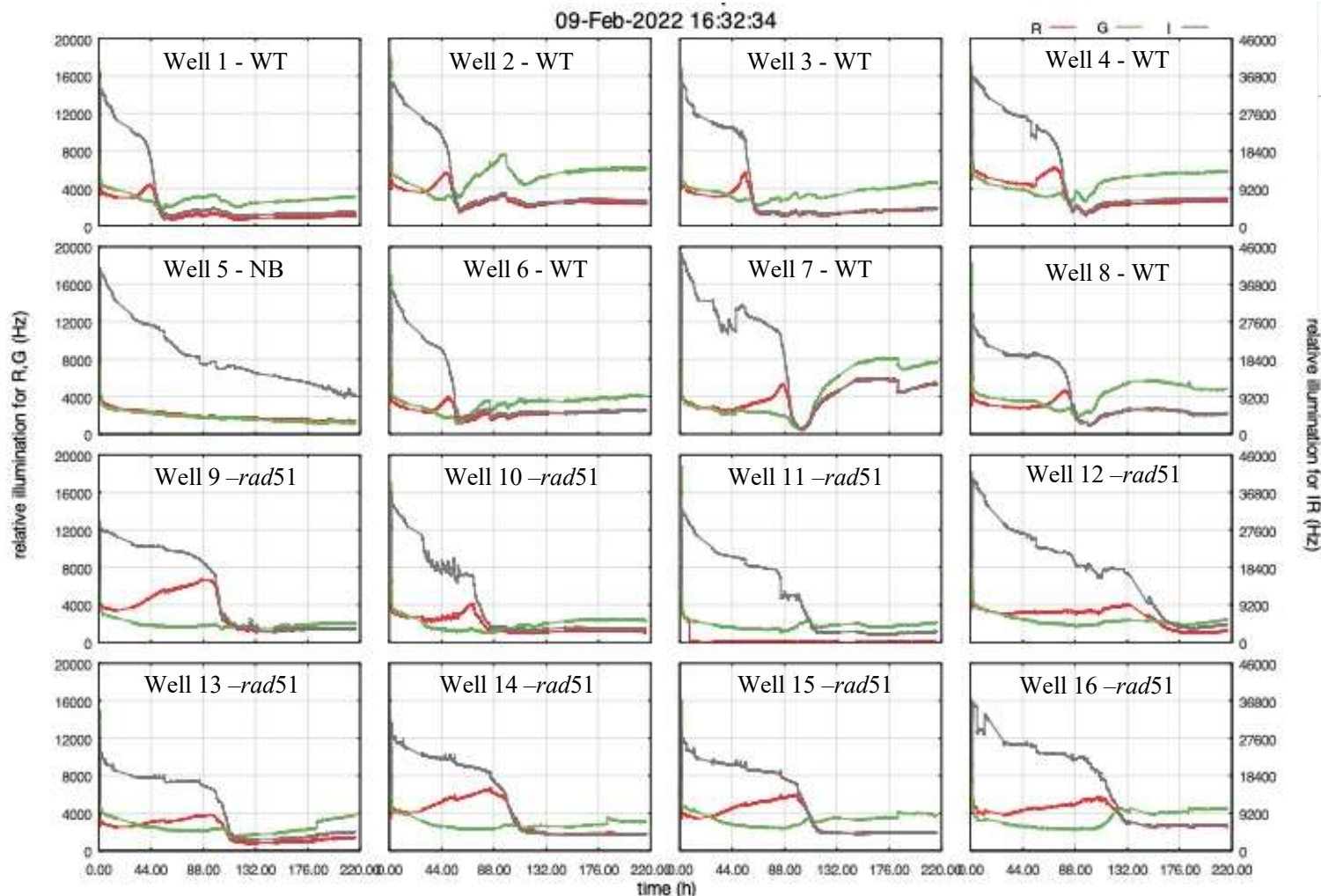
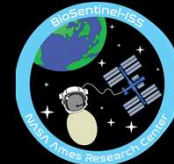
alamarBlue turns pink when cells are metabolically active



HR repair defective cells show sensitivity to ionizing radiation



Preliminary Results



850nm readings show cell growth

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

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

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

ISS Card 8:

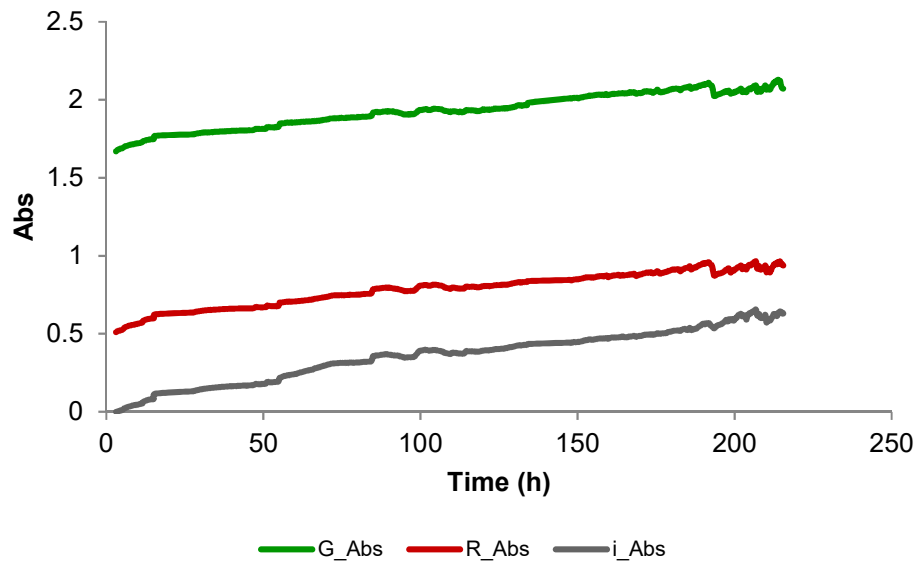
- Frequency output
- Over 220 hrs experiment



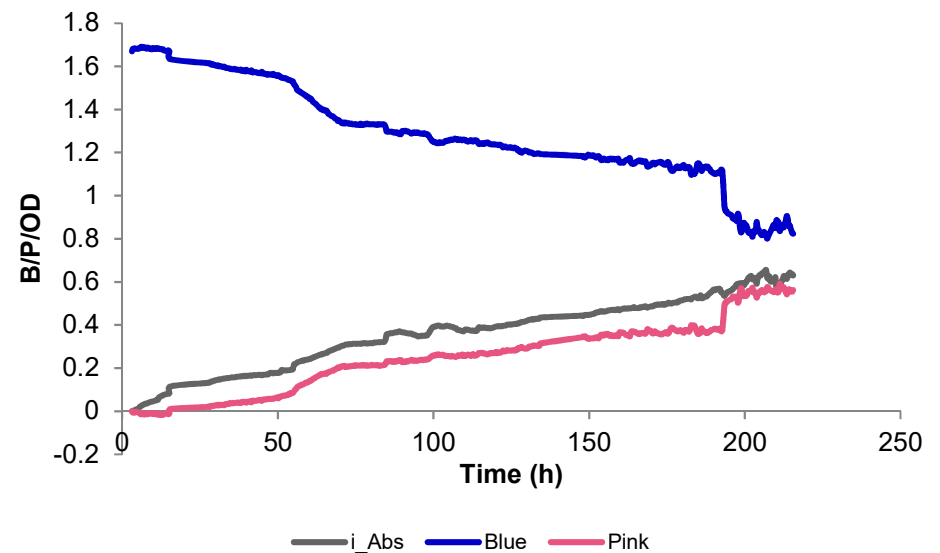
Preliminary Results



BioS-ISS card 8 - Jan 31, 2022
Well 5 Abs



BioS-ISS card 8 - Jan 31, 2022
Well 5 B/P/OD



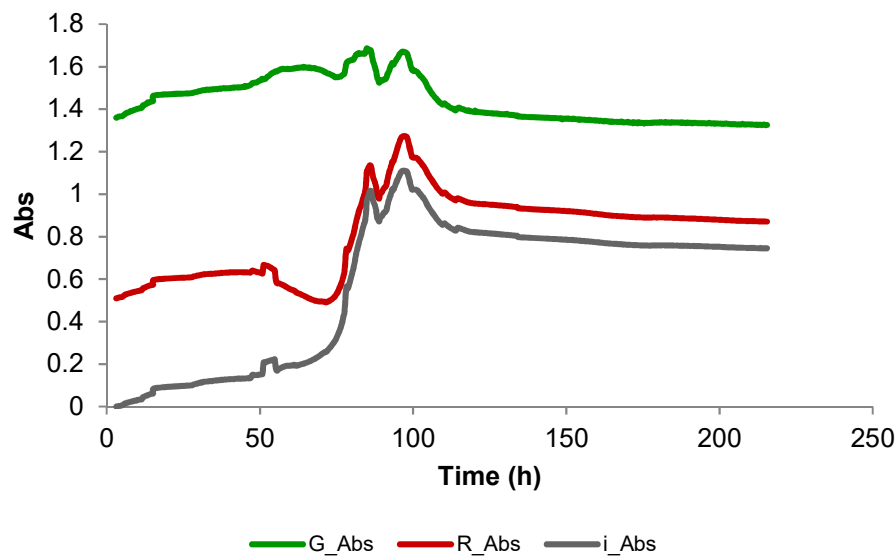
- Card 8, Well 5 – No Biology
- Left → Absorbance measurement for each of the LEDs
- Right → Conversion from absorbance to the measurement of the alamarBlue dye
- No reduction of the blue dye
- No increase of the grey (growth) or pink dye



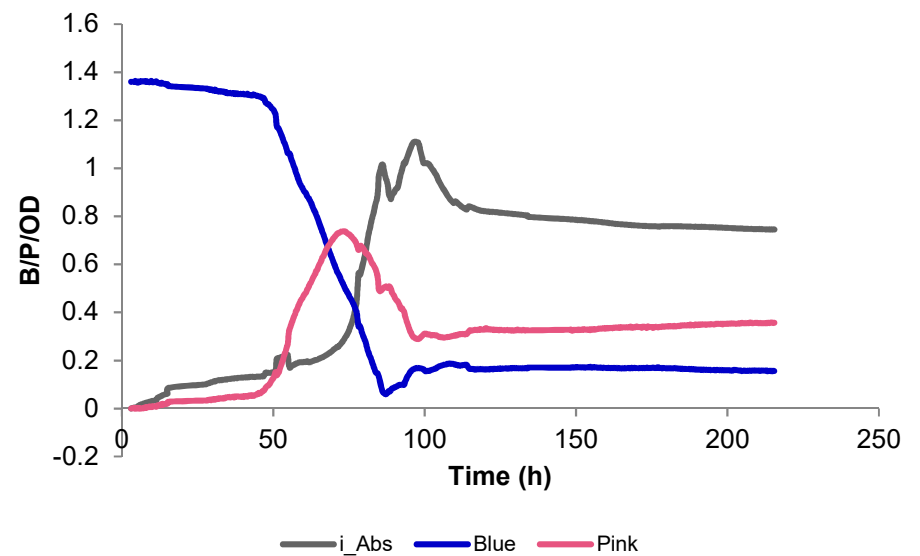
Preliminary Results



BioS-ISS card 8 - Jan 31, 2022
Well 4 Abs



BioS-ISS card 8 - Jan 31, 2022
Well 4 B/P/OD



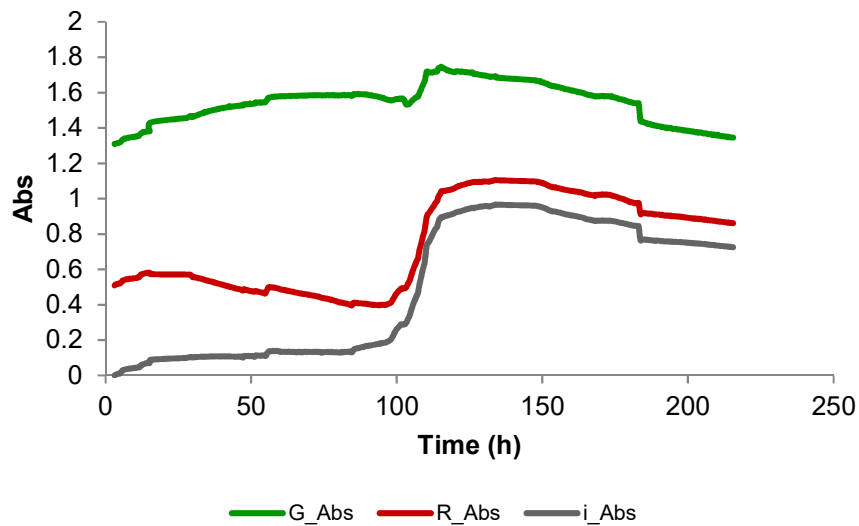
- Card 8, Well 4 – Wild type strain
- There is a reduction of the blue dye as the cells grow
- There is an increase in pink line as the blue dye is converted to pink
- Grey shows cell growth measurement



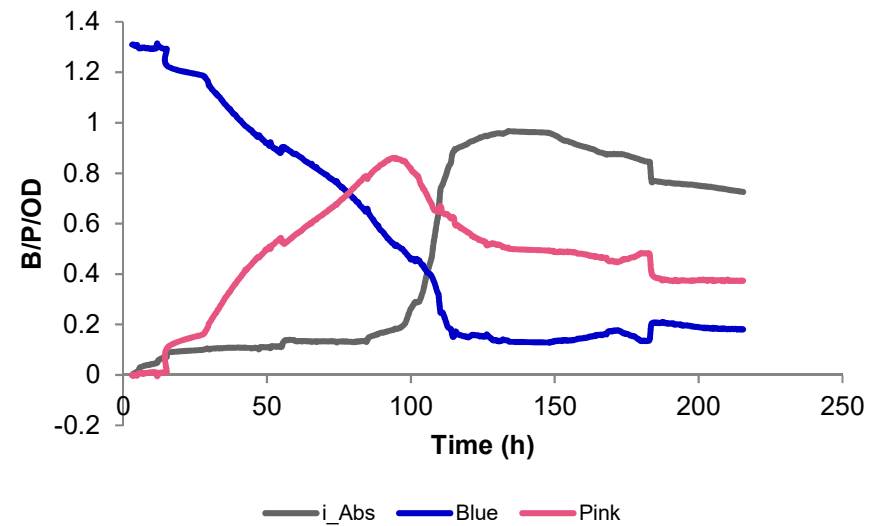
Preliminary Results



BioS-ISS card 8 - Jan 31, 2022
Well 13 Abs



BioS-ISS card 8 - Jan 31, 2022
Well 13 B/P/OD



- Card 8, Well 13 – *rad51* Δ strain
- There is a reduction of the blue dye as the cells grow
- An increment in the pink line as the blue dye is converted to pink
- Grey shows cell growth measurement

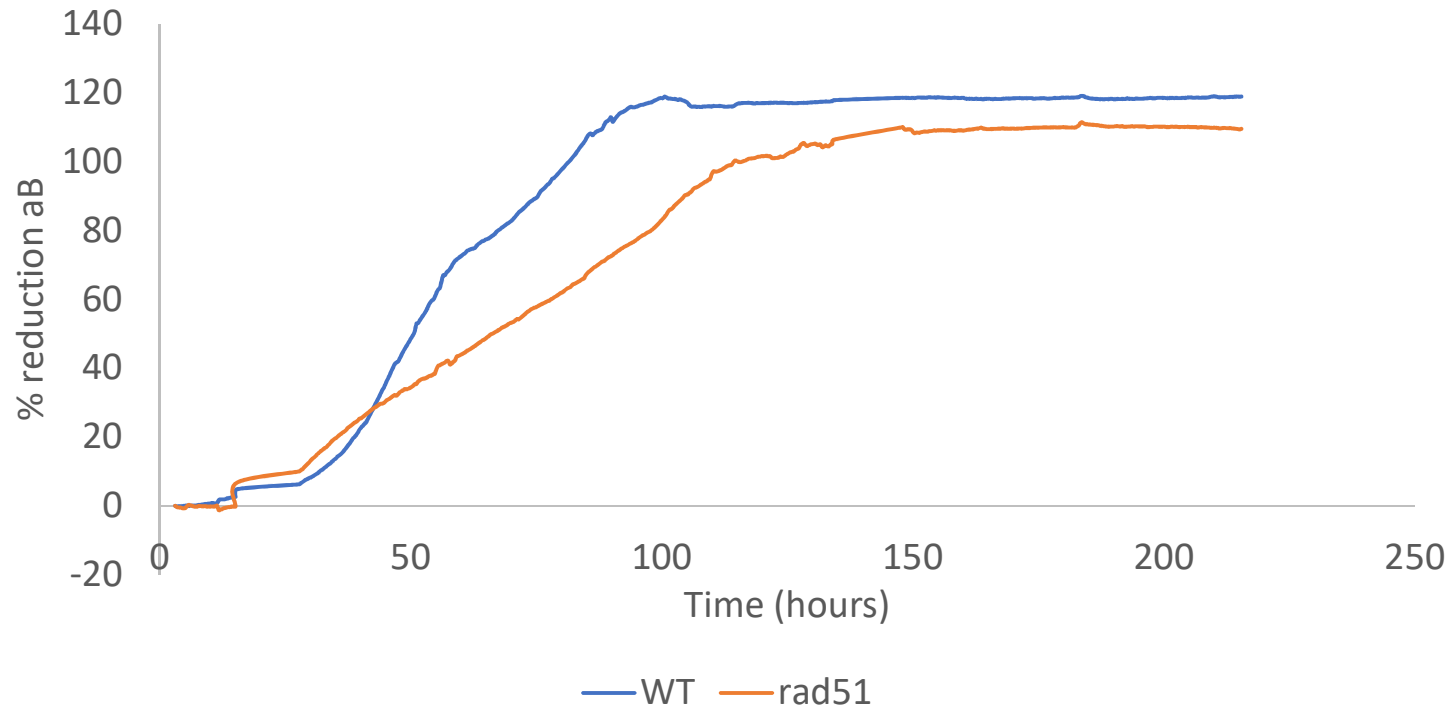


Preliminary Results



BioS-ISS card 8 - Jan 31, 2022

Average % reduction aB



- Average Reduction Percentage – Wild type and *rad51*Δ strains
- *WT* reduction of blue is faster than the reduction of the *rad51*Δ mutant
- This is expected, as the *rad51*Δ mutant is slower-growing and is more sensitive to radiation



Outline



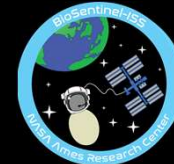
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Conclusions



- BioSentinel's mission objectives, science, its different mission segments
- Payloads:
 - Biosensor and LET spectrometer
 - Deep space radiation's effect on the studied strains
- Data acquisition and science report generation by all four segments
- ISS preliminary results show, as expected, the *rad51Δ* mutant strain metabolizes slower than the wild type strain
- Further analyses necessary and will include a full statistical comparison of the curves presented as well as a comparison with ground controls units

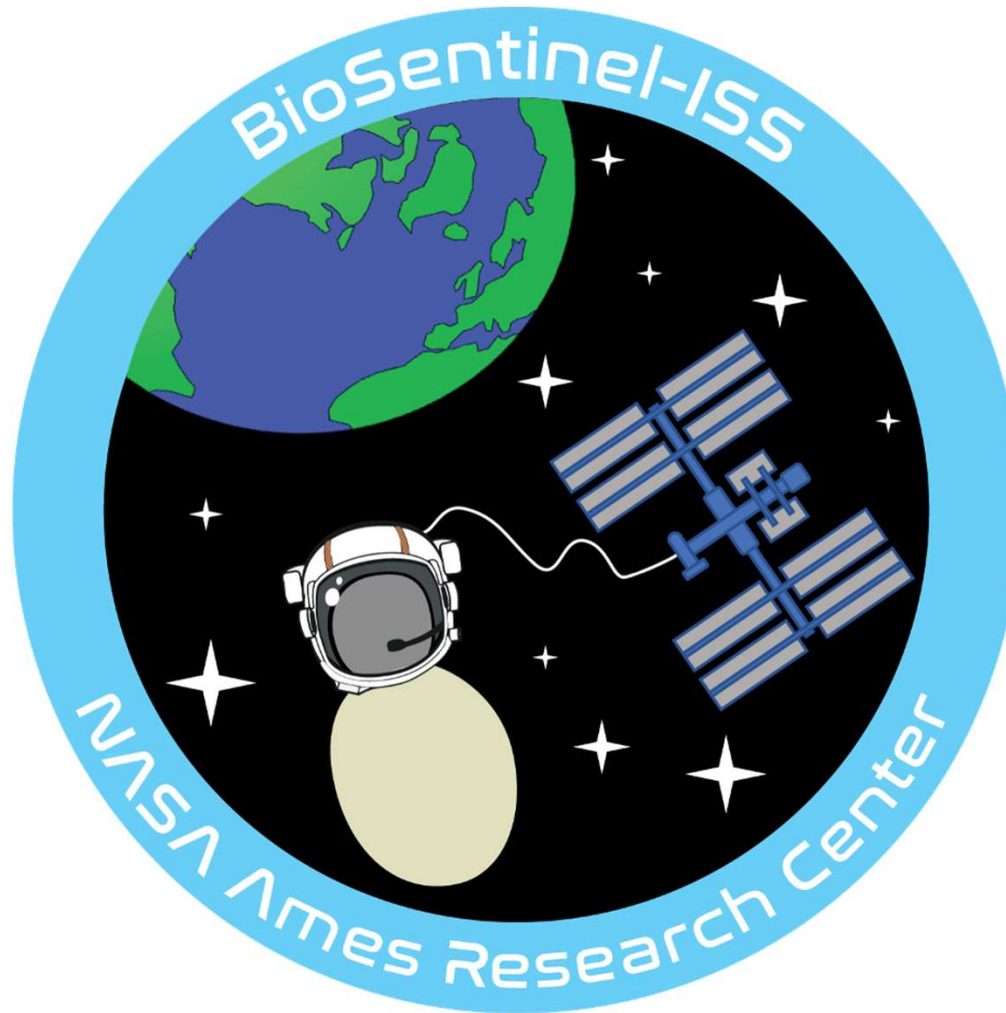


BioSentinel Team





Questions?





- Backup

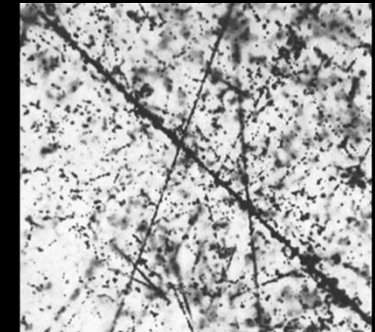


What are we going to encounter in deep space?



Galactic Cosmic Rays
(GCRs)

Apollo XI particle tracks

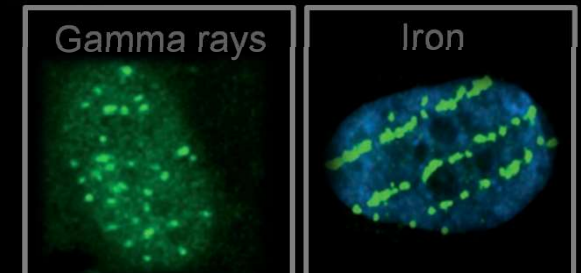


Schaefer *et al.* 1972

Solar Particle
Events (SPEs)

Trapped particles

Cell nuclei showing DNA damage



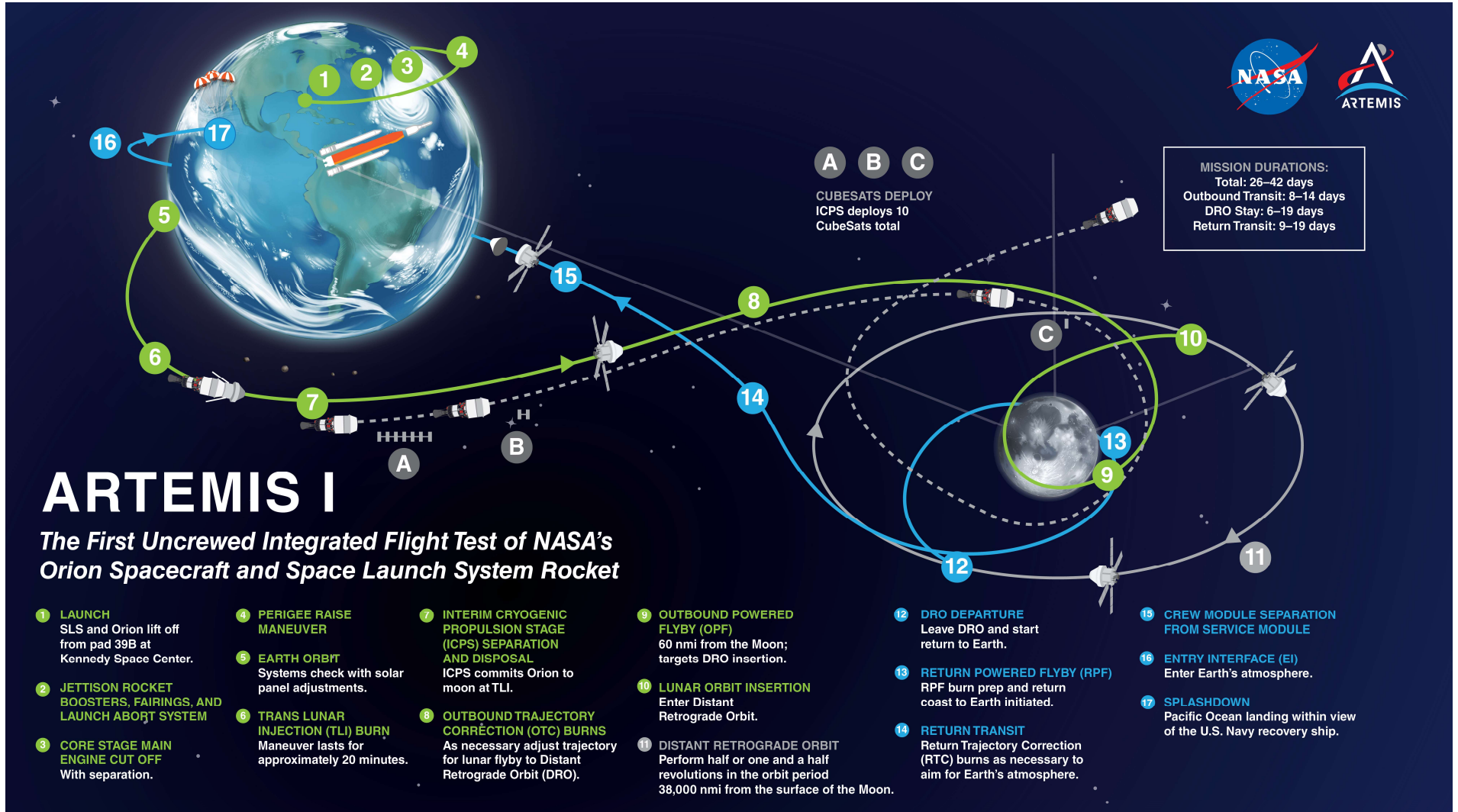
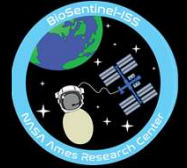
Cucinotta & Durante, 2006

- Both SPEs & GCRs are interplanetary, modulated by the 11-year solar cycle
- SPEs: sporadic, transient (mins to days); high proton flux (low-medium energy)
- GCRs: high-energy protons and highly charged, energetic heavy particles
- GCRs not effectively shielded; can break up into lighter, more penetrating pieces

Challenges: SPEs – unpredictable; large doses in short time
GCRs – biology effects poorly understood (but most hazardous)

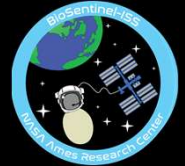


Payloads

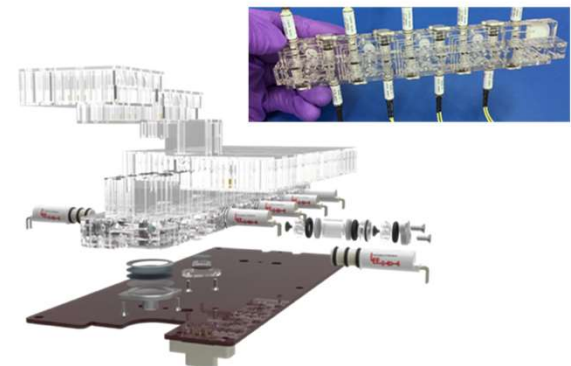
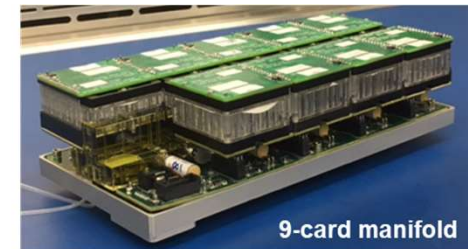
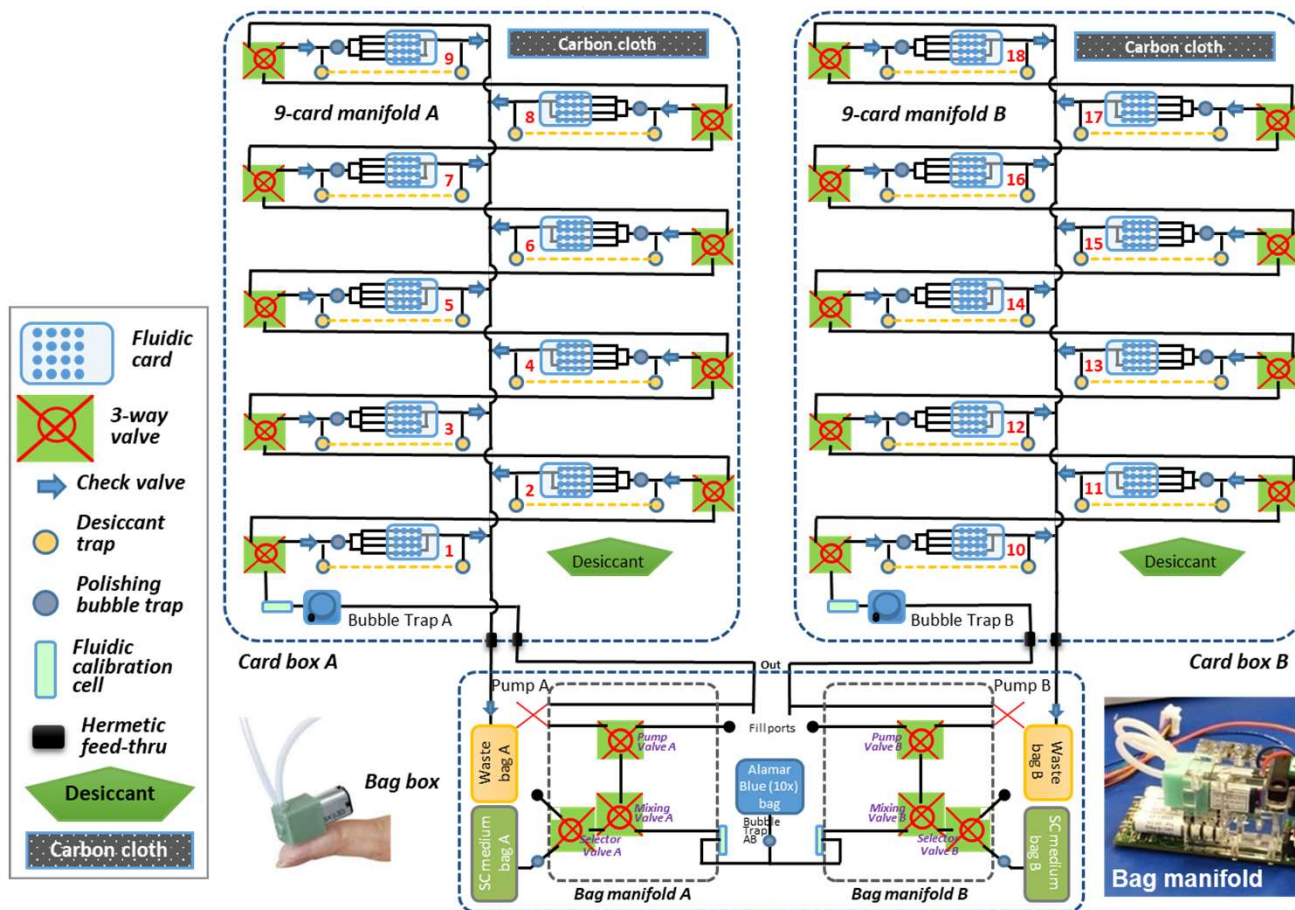




Payloads



- BioSensor



Manifold-integrated components:

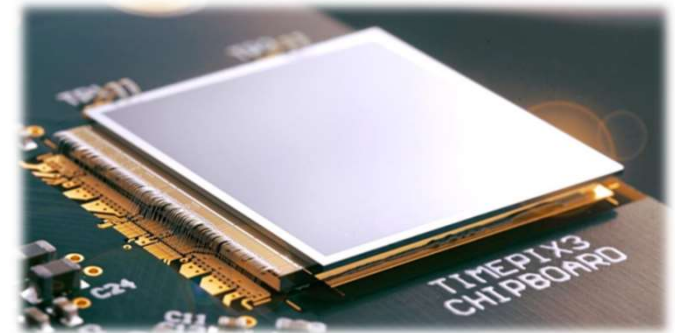
- 2 pumps
- 24 active & 38 check valves
- 2 main bubble traps
- 4 optical calibration cells
- 18 fluidic cards with small bubble traps & desiccant traps
- 288 microwells total



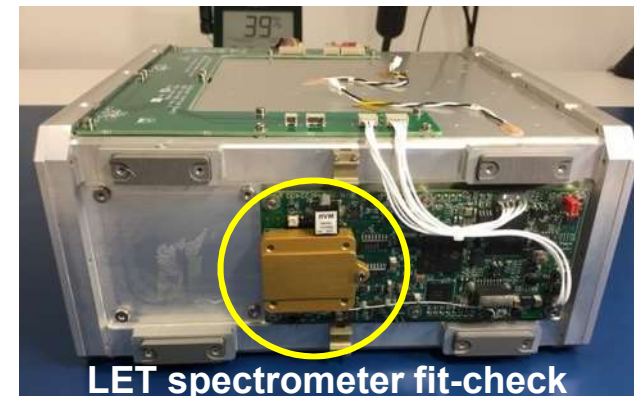
Payloads



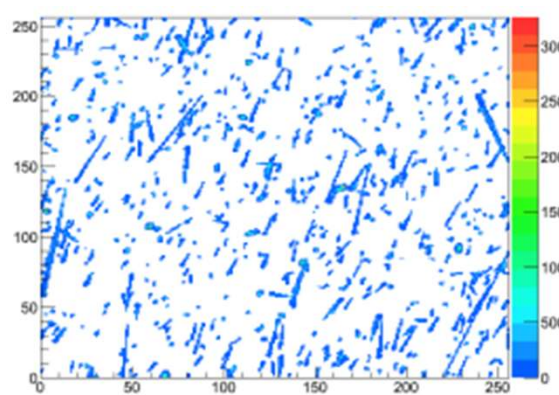
- LET spectrometer device: Timepix solid-state device
 - Measures linear energy transfer (LET) spectra and Total Ionizing Radiation Exposure Dose
 - Time-over-threshold (TOT) mode. Wilkinson-type ADC (*direct energy measurement per pixel*)
 - LET 0.2 – 300 keV/ μm into 256 bins, 3% width; store hourly bin totals
 - Download “local space weather” periodic snapshots



LET spectrometer



LET spectrometer fit-check



Typical TimePix frame
(256 x 256 x 14 bits)