

Microbes in Deep Space

Fundamental research into
microbial responses to spaceflight stressors
to facilitate human exploration

Jessica Audrey Lee
NASA Ames Research Center



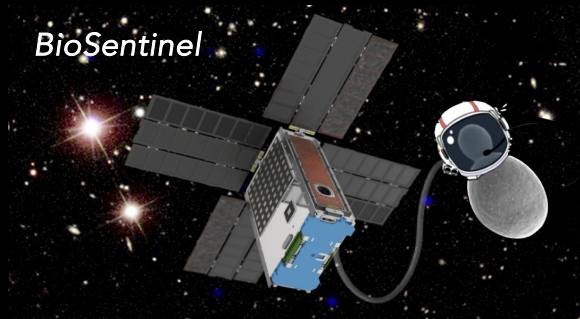
5 μm



image credit: NASA



Microbes are essential to space exploration



Ricco et al. 2020 doi: 10.1109/MAES.2019.2953760

Model organisms to investigate space effects on biology



credit: Miki Hyunh, NASA

Potential to keep astronauts healthy through regenerative life support and microbial biotech



credit: NASA

They're coming with us anyway: microbiomes of astronauts and spacecraft

What microbes experience in space depends on how they get there

HAZARD ONE Space Radiation



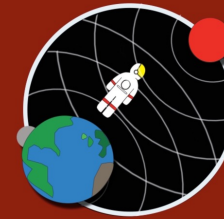
HAZARD TWO Isolation



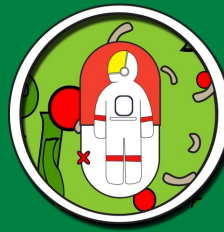
HAZARD THREE Distance from Earth



HAZARD FOUR Gravity Fields



HAZARD FIVE Hostile/ Closed Environments





Fluid Processing Apparatus.
image credit: NASA



Fluidic card with yeast, BioSentinel mission.
image credit: NASA



Space Algae. image credit: NASA Johnson





Advanced Plant Habitat. image credit: NASA



DATE: 52
LOCATION: ALC 10A2
RESULTS: T+5 days: 3



Curiosity rover. image credit: NASA

Space microbiology in the GERMS lab

Gravitational Effects and Radiobiology of Microbes in Space

Research topic

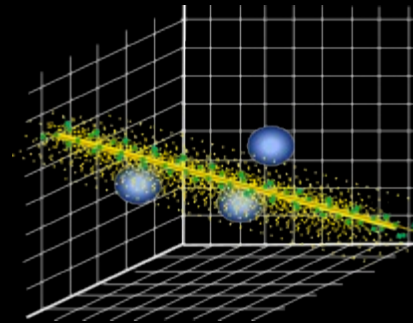
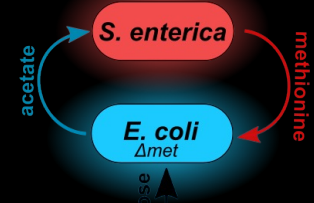
Fundamental effects of space environment on microbes

Methods

- wet-lab research
- computational modeling

Specific focus areas

- Multispecies communities
- Evolutionary timescales
- Single-cell effects

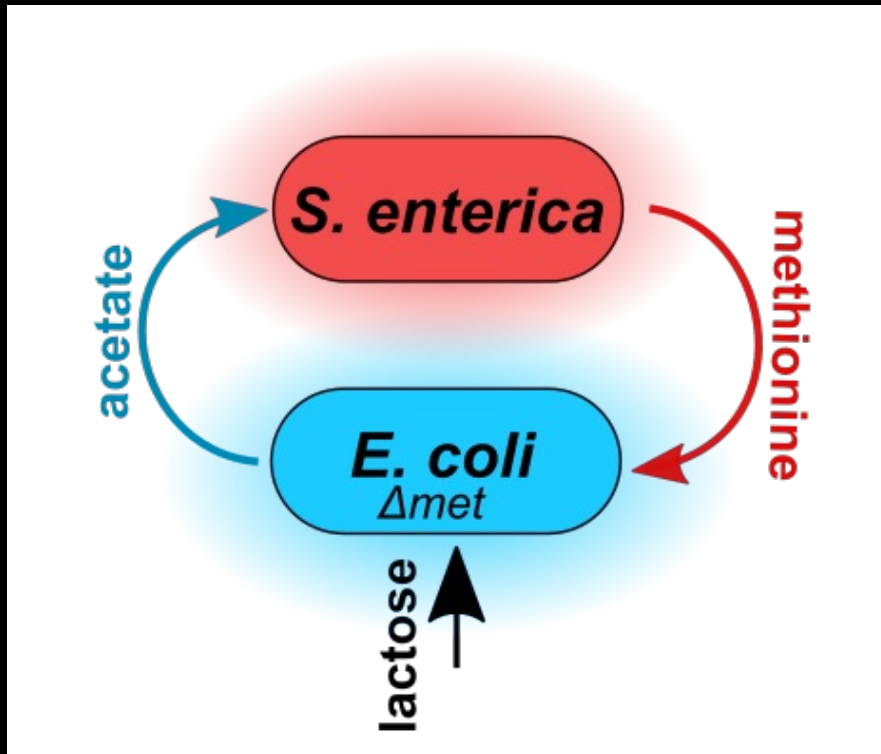


Plus, a special program at NASA Ames:

Beyond LEO Instrumentation and Science Series (BLISS)

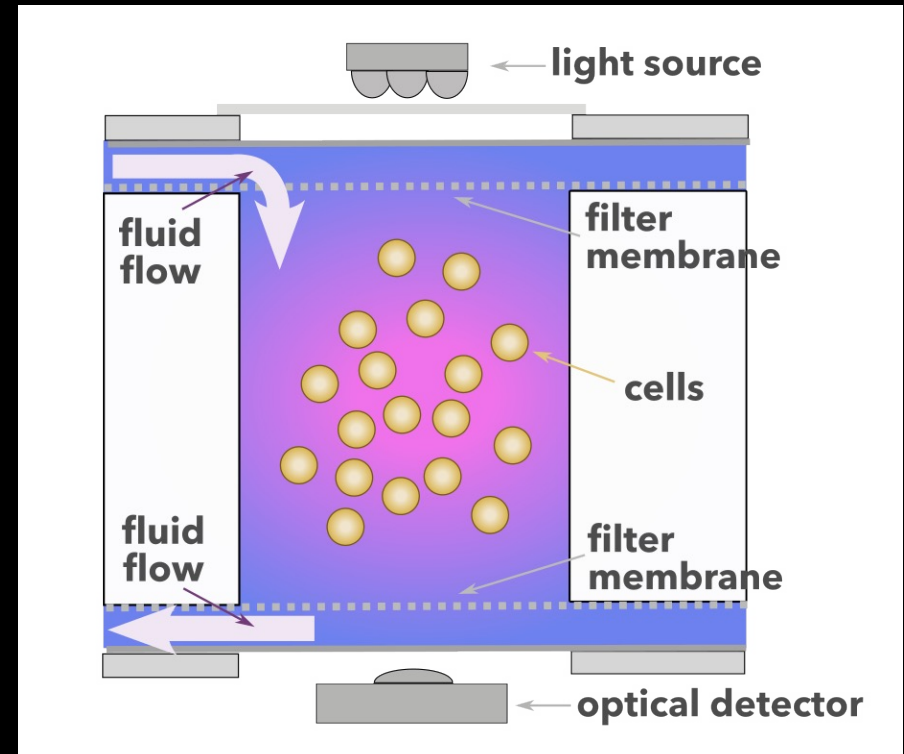
Two model systems we use

Microgravity



Model cross-feeding
bacterial community

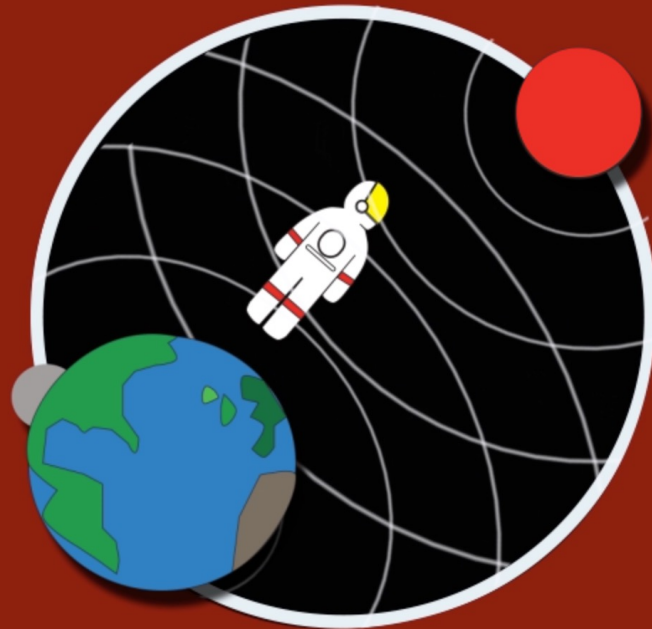
Deep-space radiation



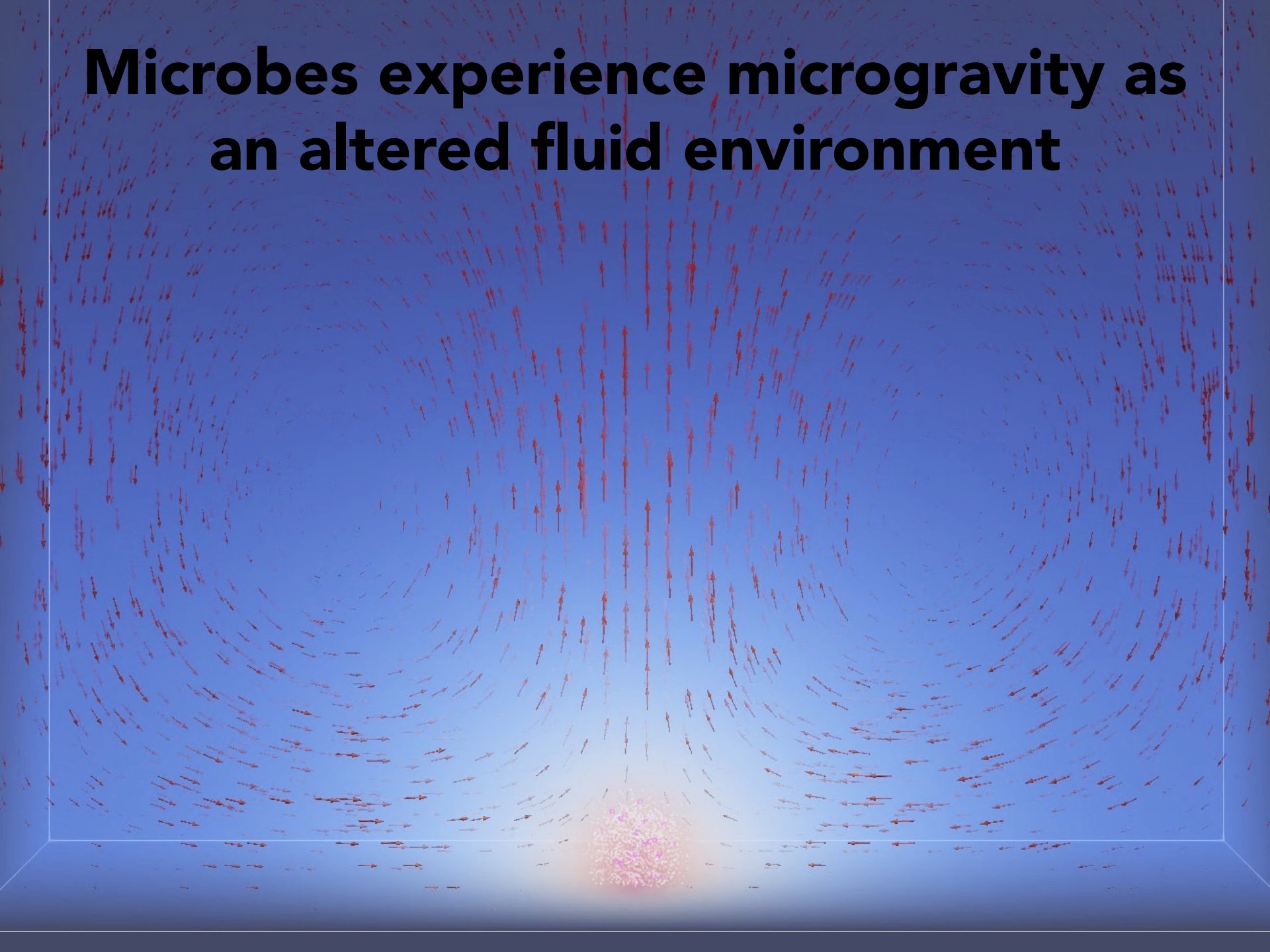
Yeast monoculture
with alamarBlue

HAZARD FOUR

Gravity Fields



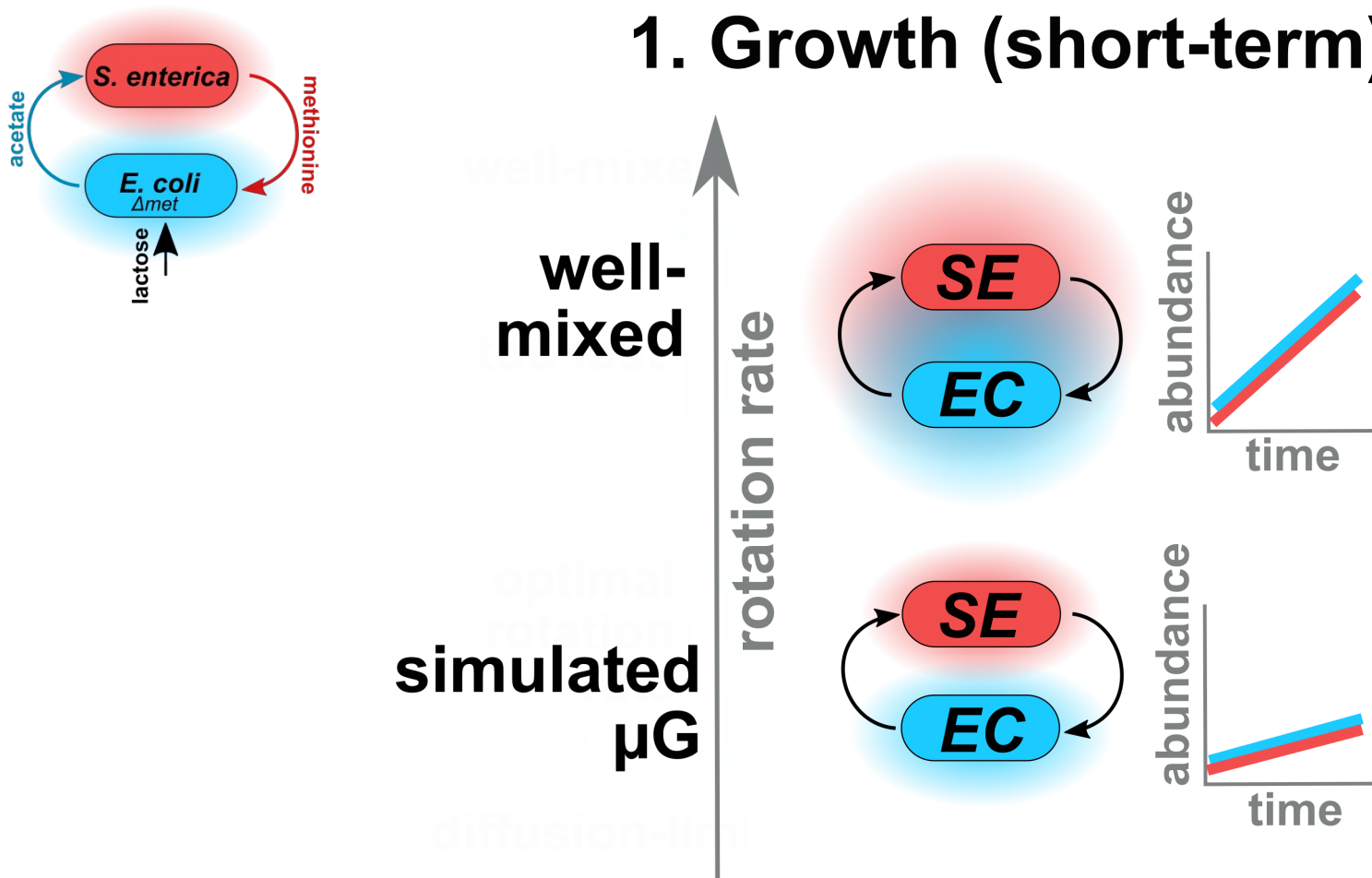
Microbes experience microgravity as an altered fluid environment



Microgravity should slow interspecies metabolite exchange

One hypothesis for the effects of spaceflight on microbial communities

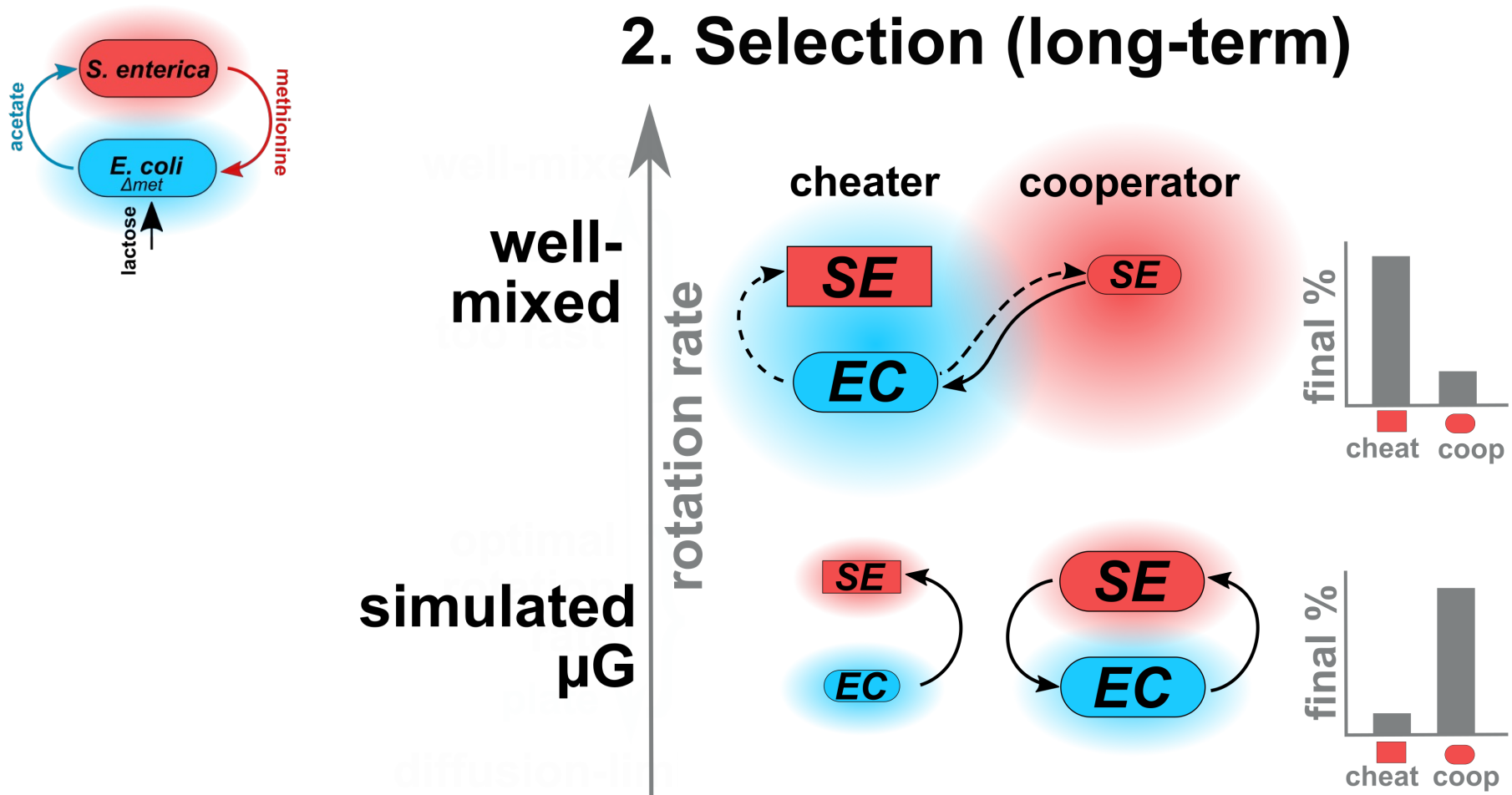
1. Growth (short-term)



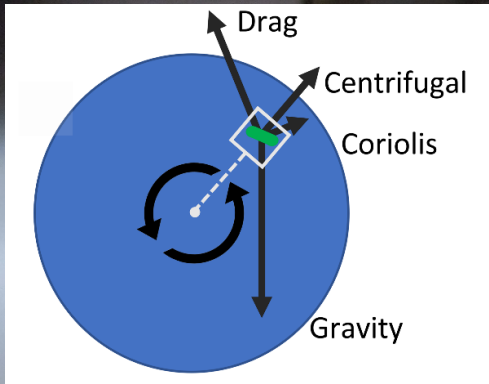
Microgravity should favor cheaters over cooperators

Another hypothesis for the effects of spaceflight on microbial communities

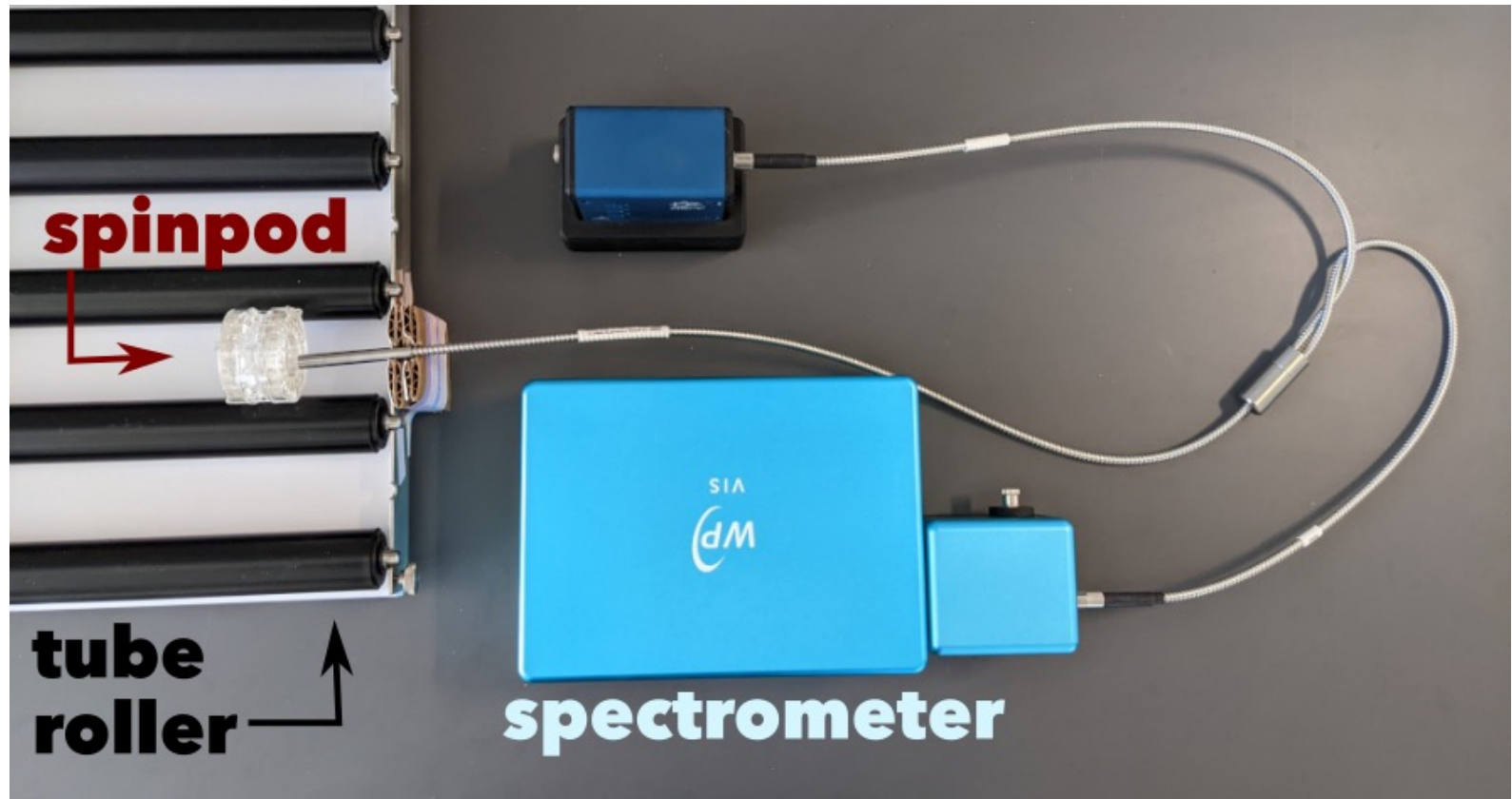
2. Selection (long-term)



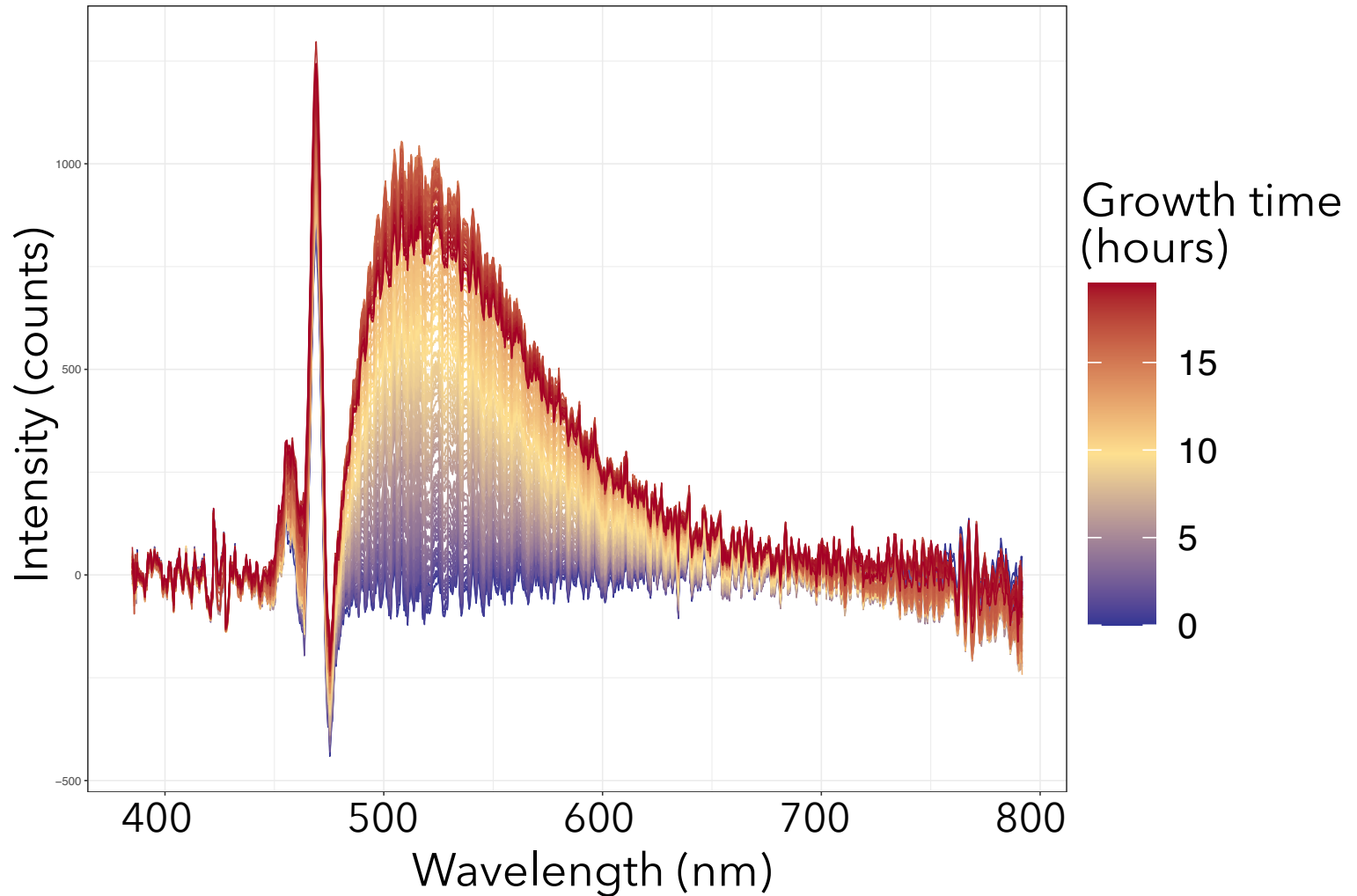
Rotational wall vessels attempt to simulate the microgravity fluid environment



**With fluorescence, we can measure
growth and species ratios
while in simulated μ G**

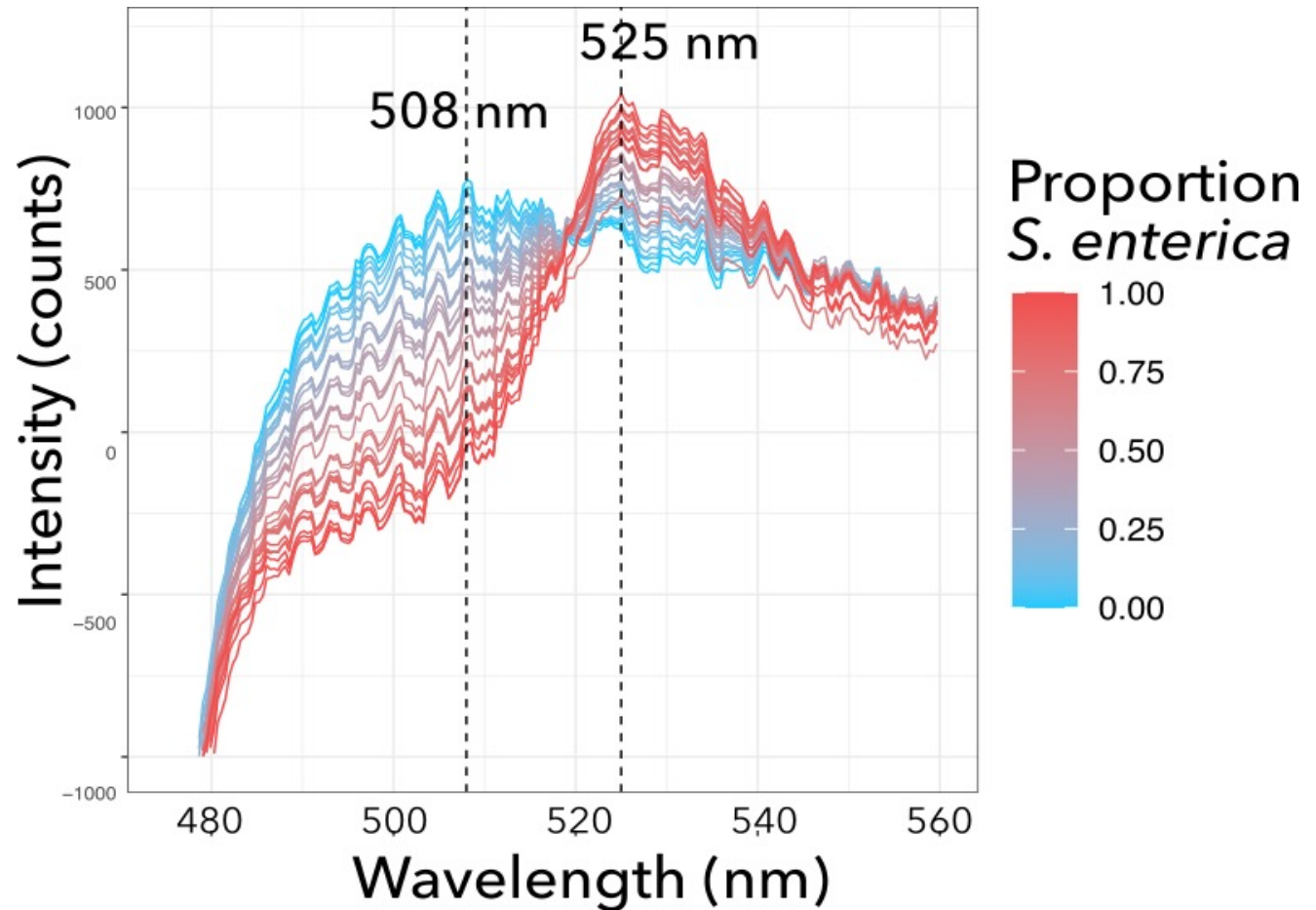
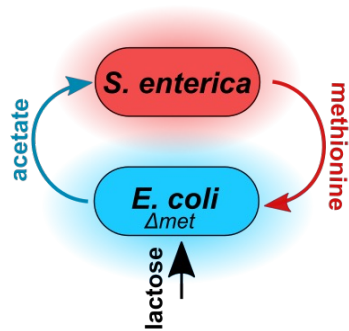


With fluorescence, we measure growth and species ratios while in simulated μ G



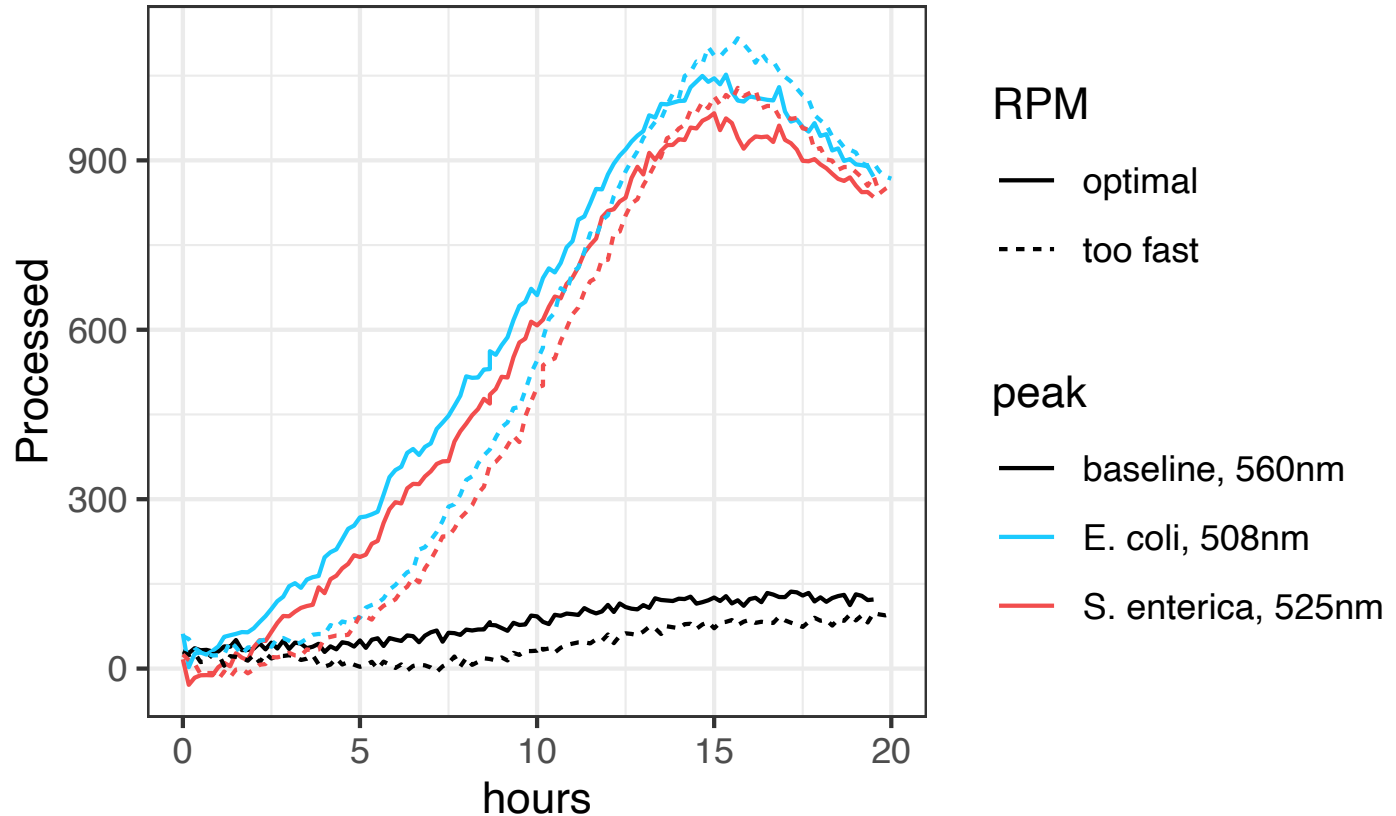
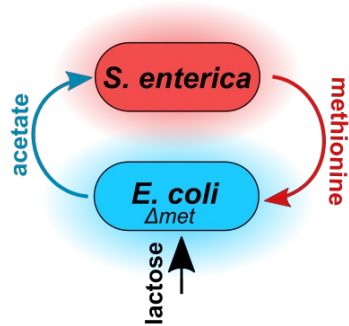
The fluorescence peak from cells increases as biomass increases

With fluorescence, we measure growth and species ratios while in simulated μG



Ratio of peak heights at 508 nm and 525 nm is correlated to species ratio

Rotation rate affects the fidelity of the microgravity simulation

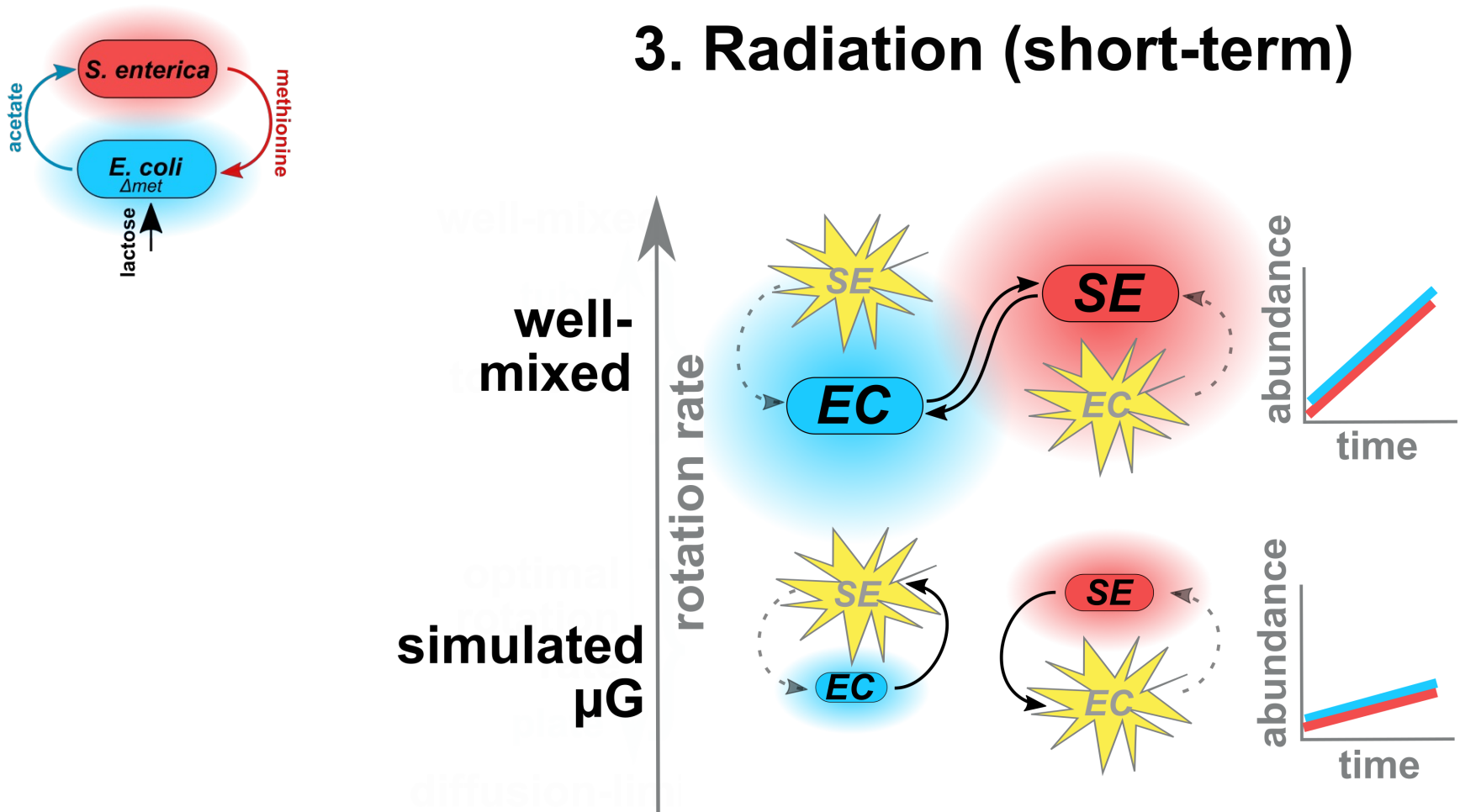


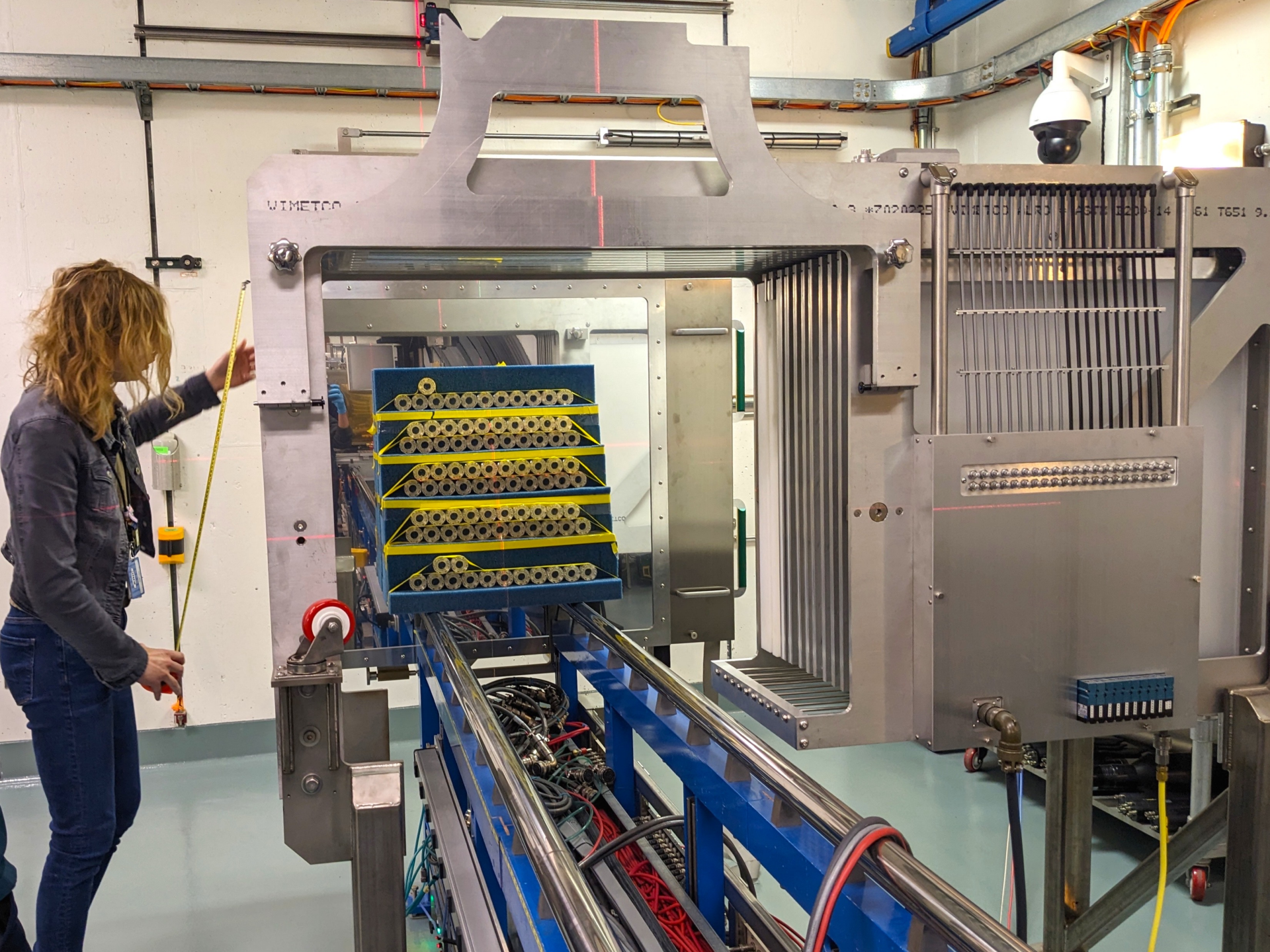
Rotation rate affects growth rate. For *E. coli* (508 nm):
simulated μG : $\mu_{\max} = 6.07 \times 10^{-3}$
well-mixed: $\mu_{\max} = 8.93 \times 10^{-3}$

Radiation might make communities as weak as the weakest link

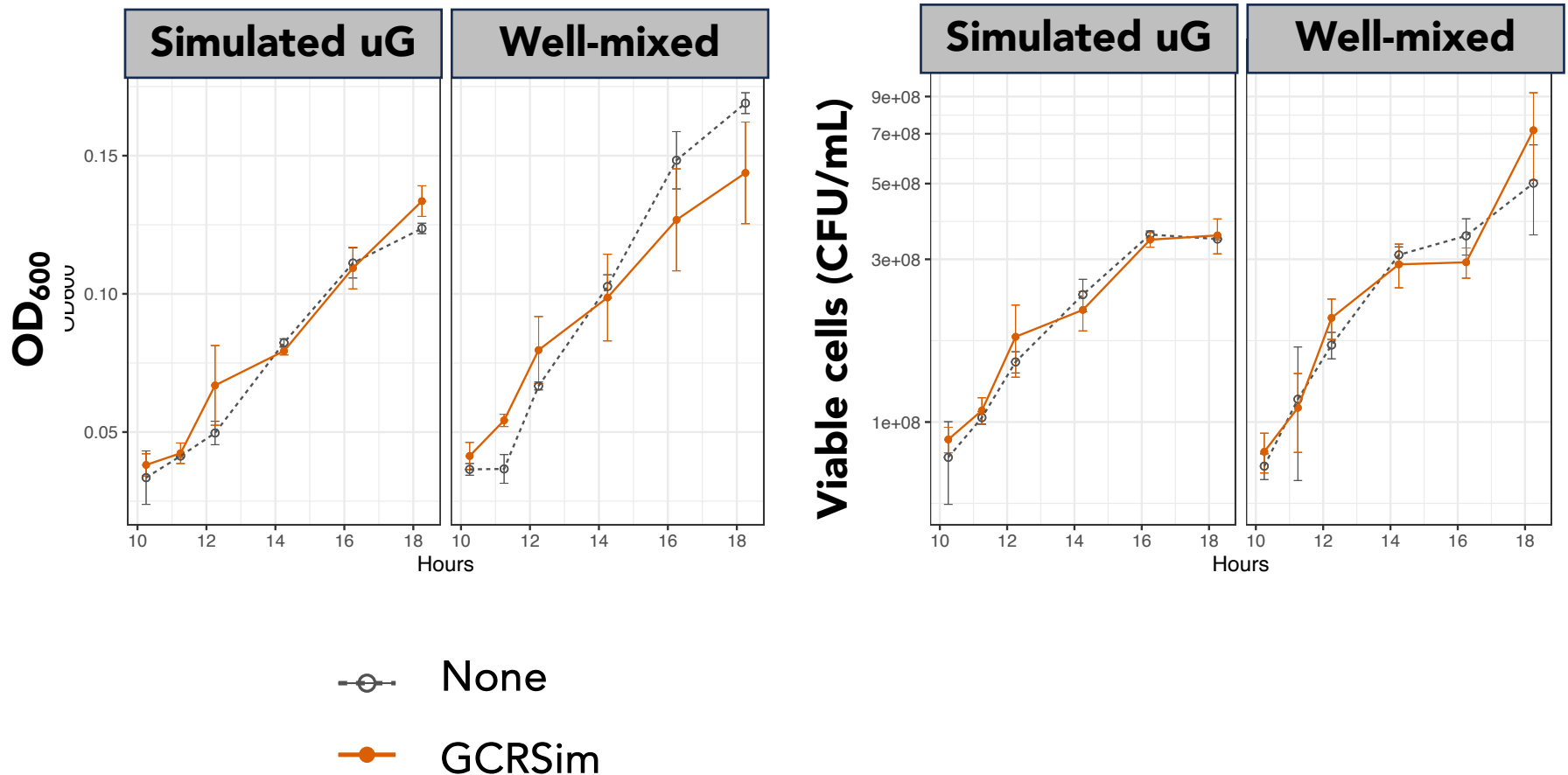
A third hypothesis for the effects of spaceflight on microbial communities

3. Radiation (short-term)



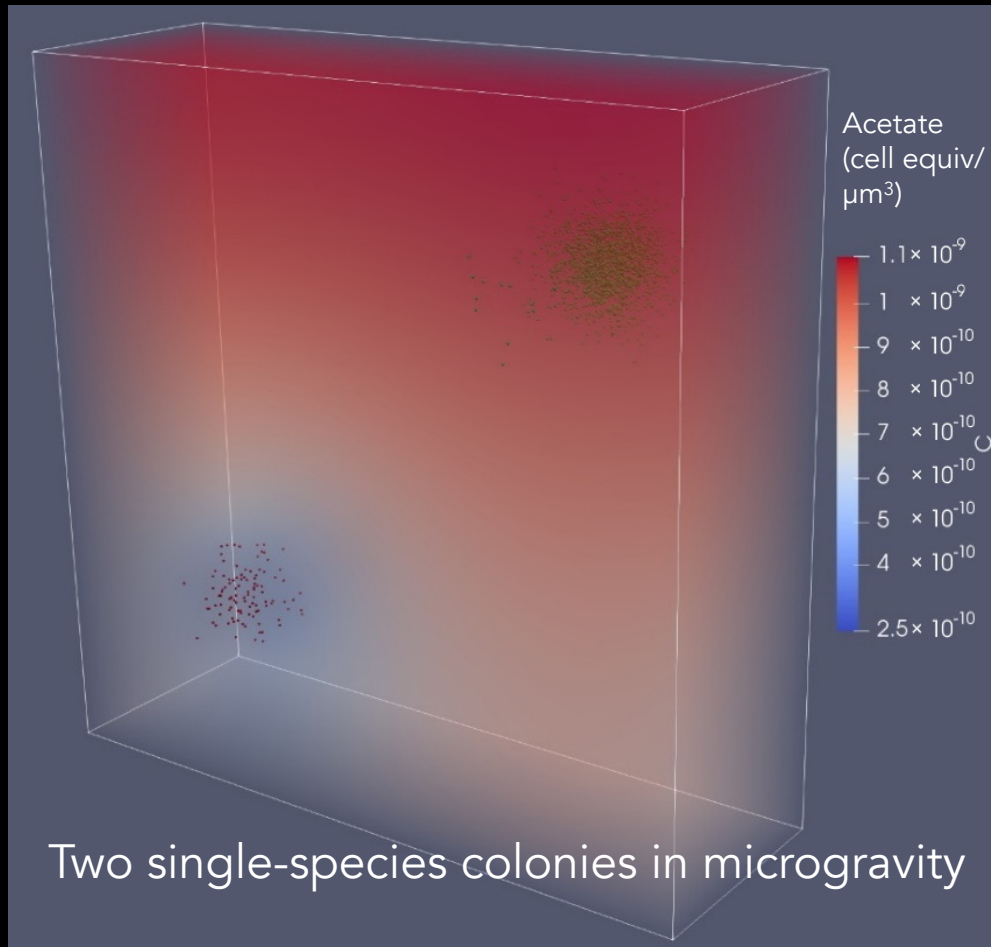


Radiation effects are not as strong as microgravity effects



CAMDLES

*CFD-DEM Artificial Microgravity Developments for Living Ecosystem Simulation:
a computational model of multispecies bacterial communities
in real and simulated microgravity*



CAMDLES simulates:

- fluid flows
- bacterial growth and metabolism
- chemical fluxes
- gravity

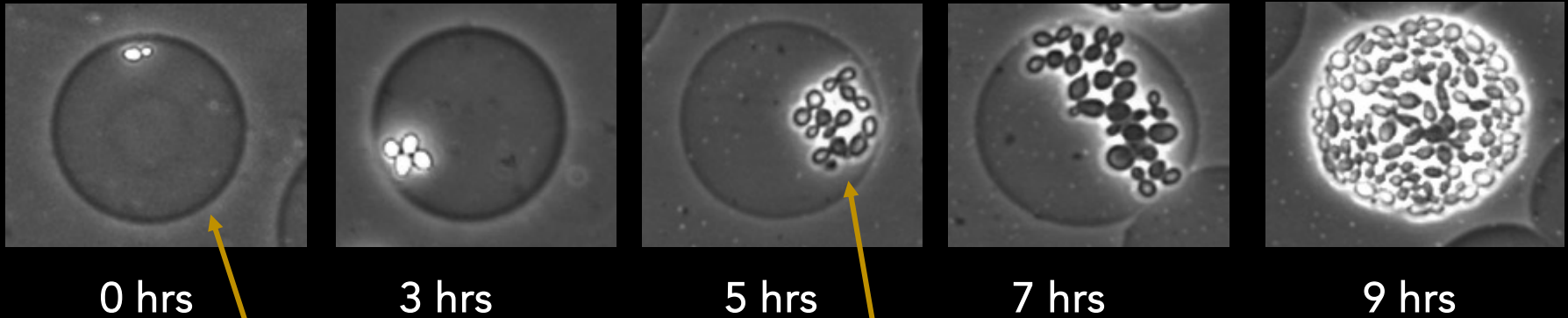
HAZARD ONE

Space Radiation



Single-cell yeast radiobiology

Lab study on the effects of spatially heterogeneous deep-space radiation



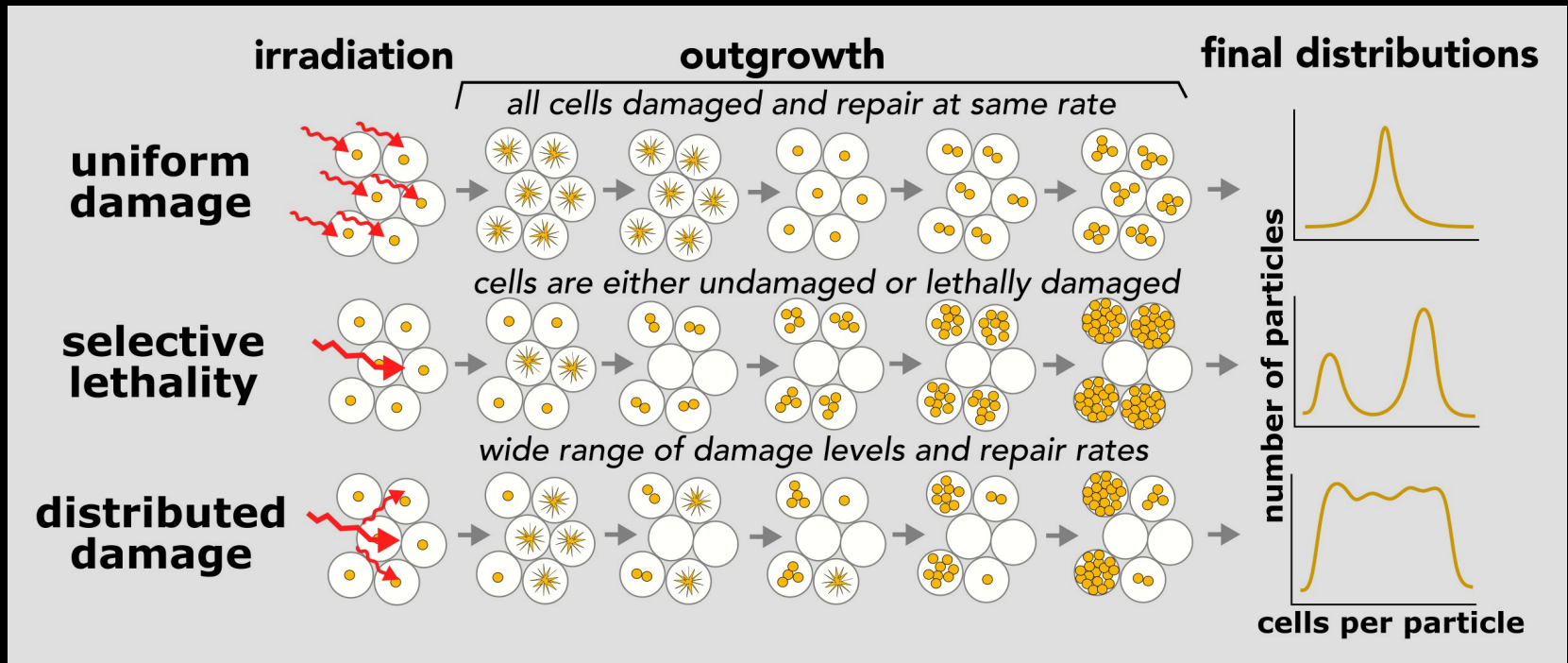
PicoShells made of Polyethylene glycol (PEG) contain cells but allow nutrient exchange

Individual cells are isolated in PicoShells. Progeny stay together as a colony inside shell

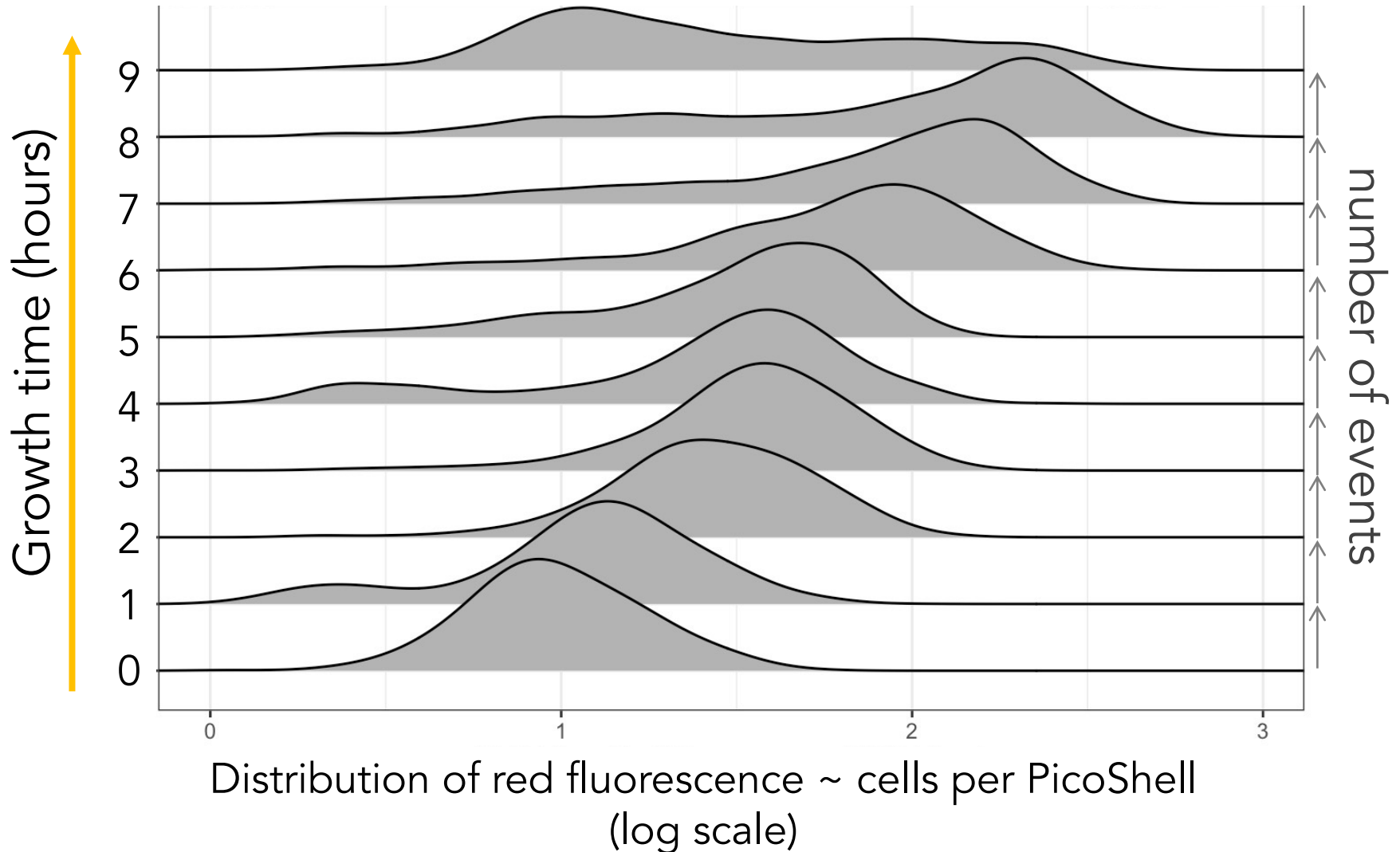
Collaboration with the Di Carlo lab, UCLA

Encapsulation allows us to survey the distribution of single-cell responses

Hypotheses



Flow cytometry enables tracking growth of clonal colonies over time

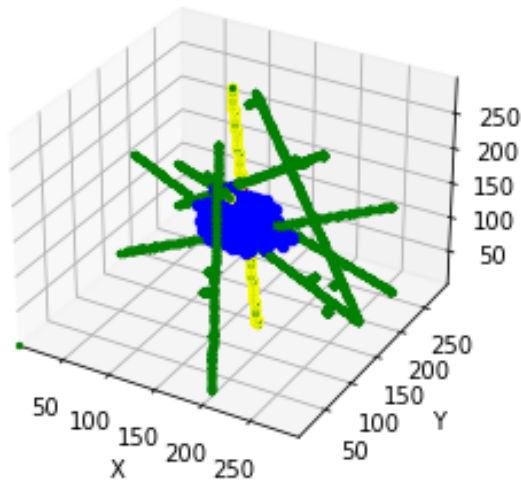


AMMPER

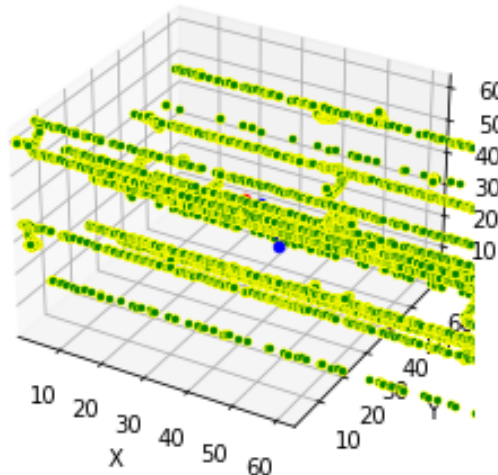
*a computational model of yeast populations
exposed to Galactic Cosmic Ray (GCR) radiation*

- yeast population growth
- radiation energy deposition (from RITRACKS)
- ROS generation
- cell damage and recovery

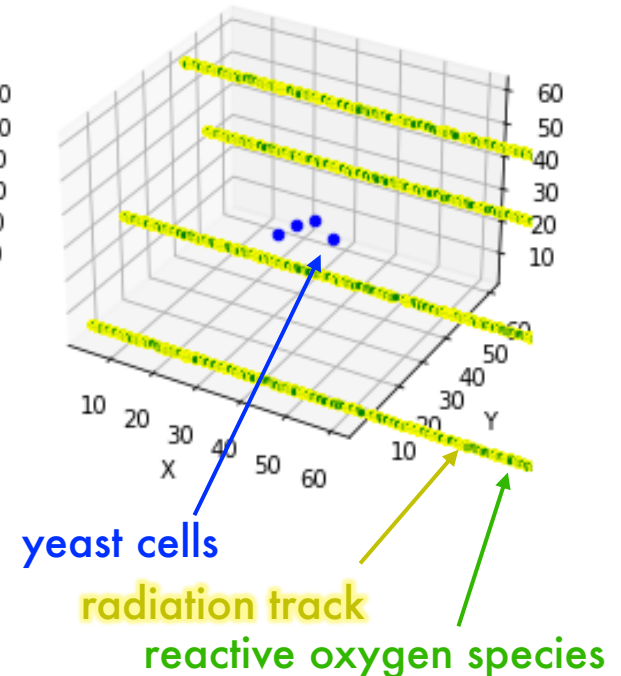
Deep Space



Accelerator
(simulated GCR)

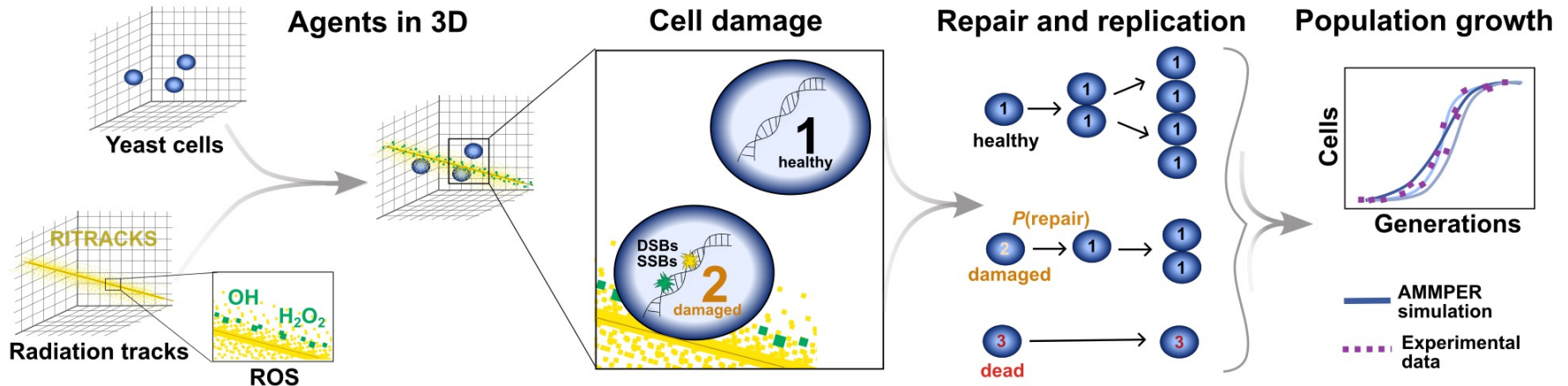


Accelerator
(150 MeV protons)



AMMPER

*a computational model of yeast populations
exposed to Galactic Cosmic Ray (GCR) radiation*

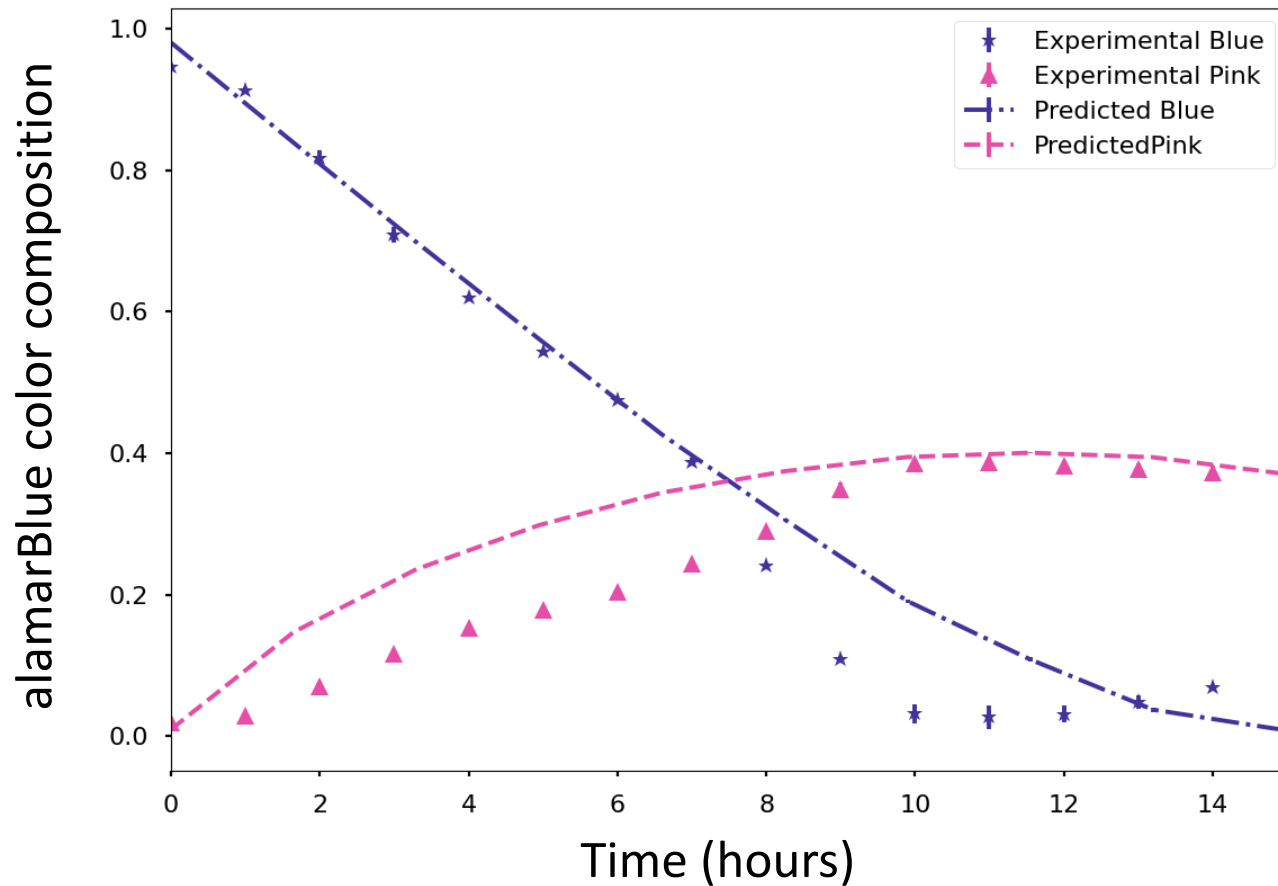


Preprint now on BioRxiv!

Singh et al. (2023) <https://www.biorxiv.org/content/10.1101/2023.10.29.564630v1>

Open-source software available at <https://github.com/nasa/AMMPER>

AMMPER v2.0 simulates yeast growth and metabolism



microbial metabolism catalyzes
alamarBlue reaction: **blue** → **pink** → **colorless**



BLISS

Beyond LEO Instrumentation & Science Series

NASA Ames Research Center

Part of the Ames Space Biology Portfolio
as part of the Thriving in Deep Space (TIDES) pivot

We are sending humans to the Moon... and beyond

But what do we know about
how to help organisms thrive
in deep space?

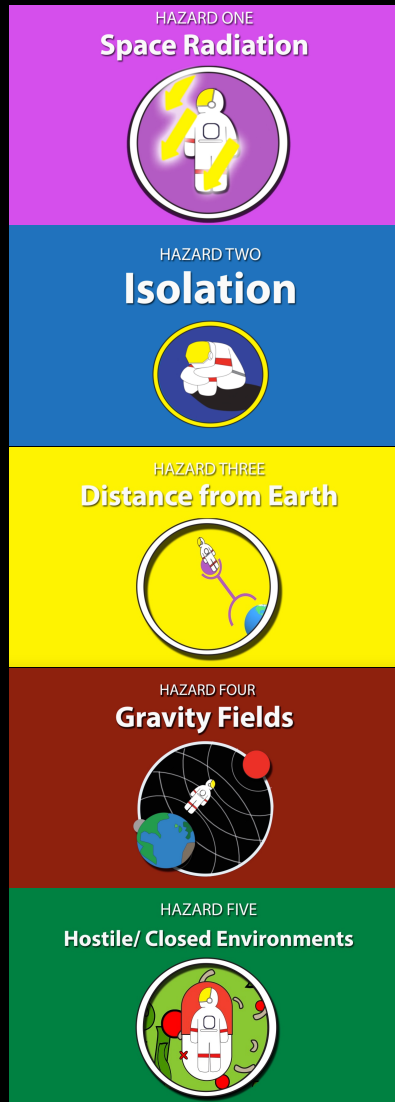
Most space biology research
to date has been in Low Earth
Orbit (Shuttle, ISS) or
suborbital flight.

image credit: NASA



The deep space environment is different

5 hazards of human spaceflight



Space radiation: different type and higher doses

Isolation and **distance from Earth** require developing greater self-sufficiency in food, life support, medicine

Gravity: not just microgravity, but also partial G on planetary surfaces

Planetary environments include challenges like dust / regolith

Research Beyond LEO presents new challenges

Current BLEO platforms involve...

- **Longer payload integration / transit periods**
→ longer stasis periods for organisms
- **Lower mass/volume/data limits**
→ compact, efficient hardware
→ onboard data processing
- **Little / no crew time**
→ autonomous / passive hardware
- **Little / no sample return**
→ in situ measurement;
assays that return only data



Lunar Explorer Instrument for space biology Applications

a South Pole Lunar surface investigation

Motivation.

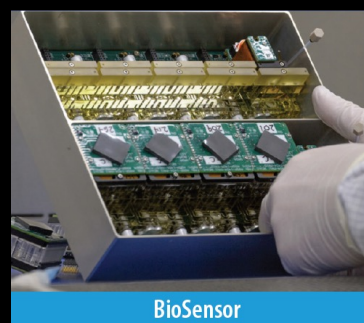
- What are the radiation health risks for crewed exploration of the lunar surface?
- Will proposed mitigations for crew health using in-space biomanufacturing be effective beyond low Earth orbit?

Approach.

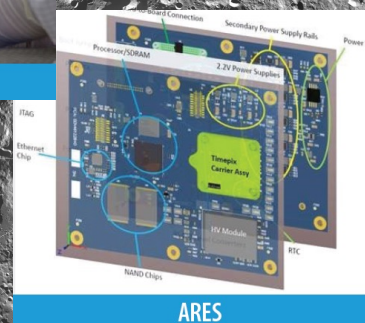
- Engineer yeast strains to test growth and metabolism for sensitivity to radiation.
- Measure biologically relevant radiation in transit and on the lunar surface.

Expected Outcomes and Impact.

- Determine cellular sensitivity to the lunar environment.
- Evaluate feasibility of bioproduction on the Moon.
- Test genetic strategies to enhance cellular tolerance to the lunar environment.
- Determine ground truth radiation risks for crew.



BioSensor



ARES



Mini-FND

Image credits: NASA

Team: Dr. A. Mark Settles (PI), Dr. Sergio Santa Maria (Deputy PI), Dr. Donald M. Hassler (Co-I, SwRI), David Pletcher (PM), Leandro James (SE)

For more information: <https://www.nasa.gov/ames/leia>

BLISS Science Working Group

SWG membership

- Diverse members of research community
- Some NASA, mostly external
- Expertise in variety of model organisms, experimentation and instrumentation, research approaches, institution types, career stages
- Meet monthly: guest speakers, discussion, report writing

2021 & 2022 Annual Reports *available online!*

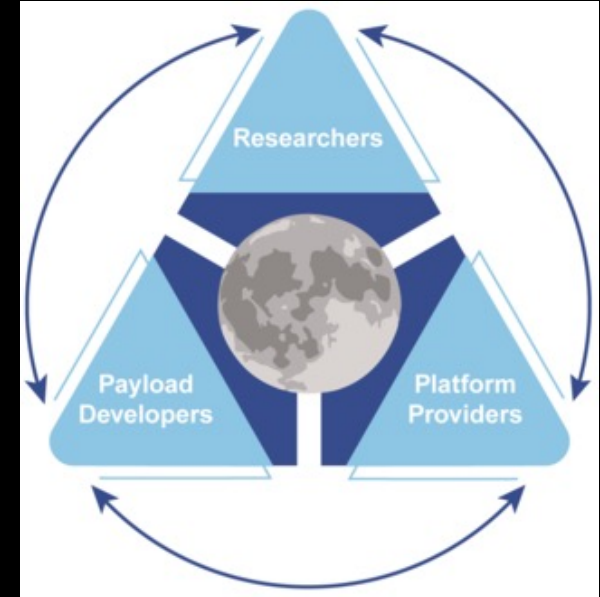
- 2021: research & tech development areas for next 5 years
- 2022: 5-15 year timeframe; applications of AI/ML
- 2023 (in development): Enhancing the Payload Development Process for Lunar Gateway and Lunar Surface



Other BLISS activities

Building research community

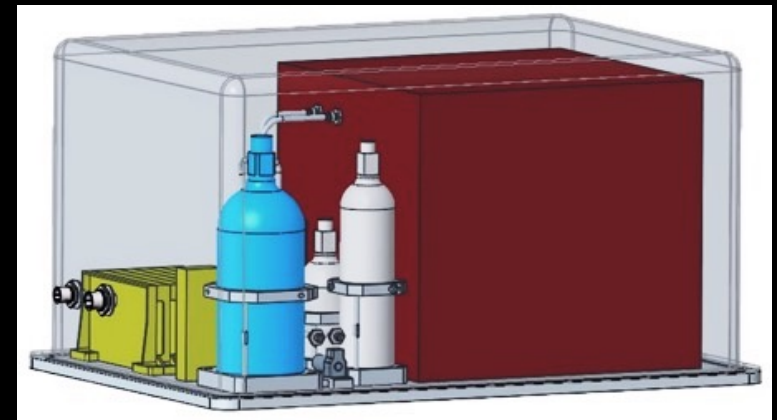
- 2022 Lunar Biology Technology (LBTech) virtual conference
- 2023 session on BLISS at the annual meeting of the American Society for Gravitational & Space Research



<https://www.nasa.gov/ames/research/space-biosciences/BLISS/LBTech/>

Generating resources for future missions

- Mini-ECLSS habitat study
- BLEO open hardware database



Thank you!

CAMDLES and cross-feeding communities

Rocky An

Jess Gonzalez

Nathan Moreno

Juliana Gesztes

Umme Nur Habiba

Timothy Lannin (Northeastern)

Will Harcombe (U. Minnesota)

Jeremy Chacón (U. Minnesota)

BLISS and LEIA

Matthew Lera

Lynn Harrison

Christopher Carr

Candice Tahimic

Mark Settles

Sergio Santa Maria

AMMPER and yeast radiobiology

Amrita Singh

Daniel Palacios

Madeline Marous

Pramesh Sharma

Diego Salgues

Sarah Pierce

Dino Di Carlo (UCLA)

Mark van Zee (UCLA)

Sergio Santa Maria

Diana Gentry

Lauren Liddell



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