Enabling the Study of Polar Radiation of Model Organisms

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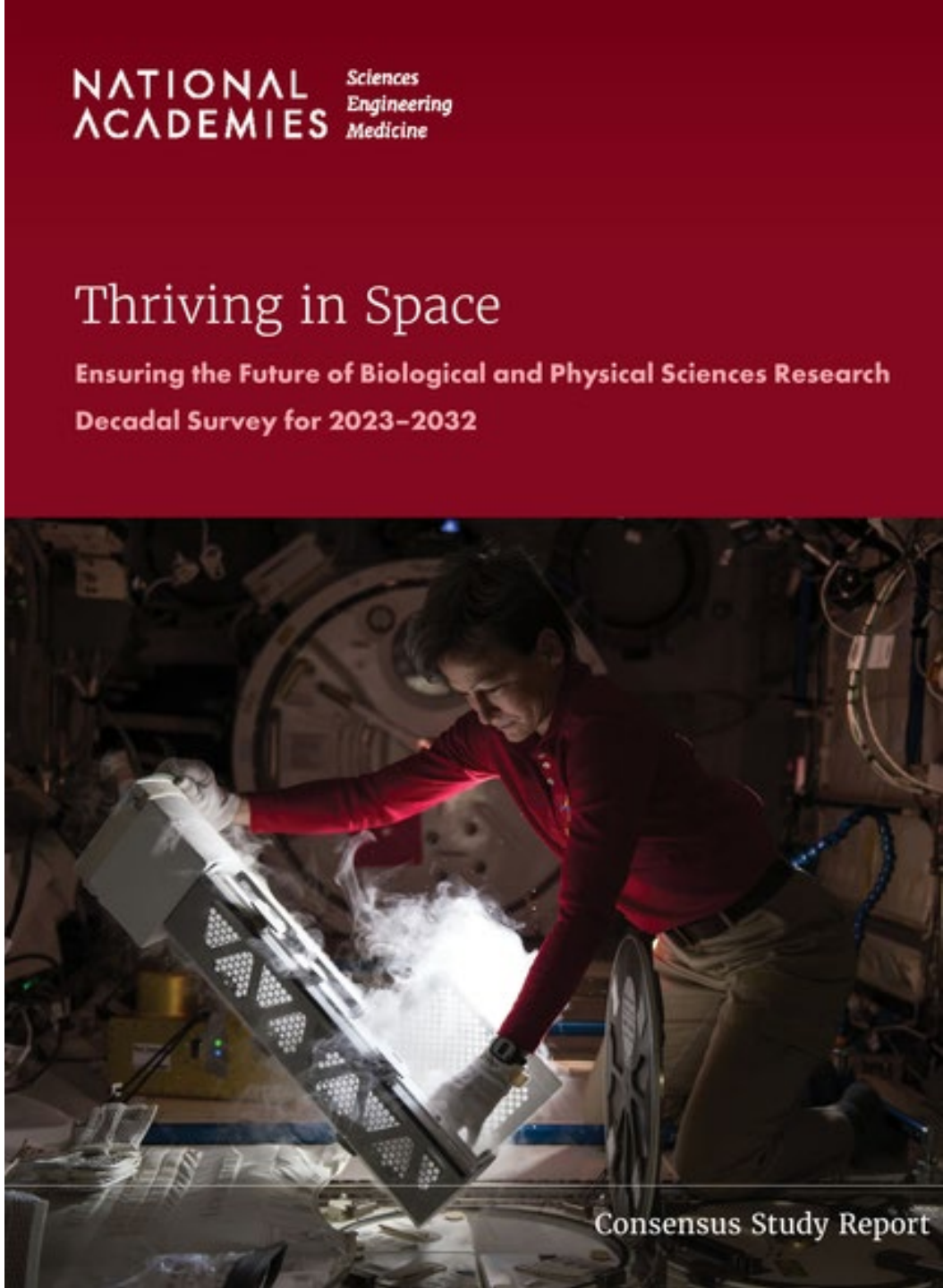
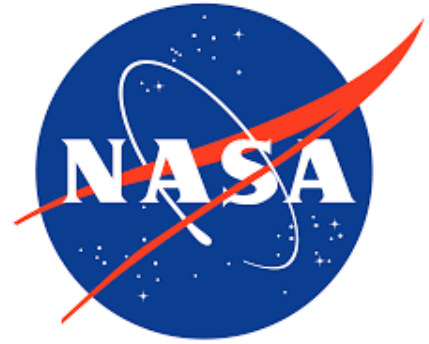
One of several campaigns discussed…

- BLiSS – Bioregenerative Life Support Systems
- MATRICES – Manufacturing Materials and Processes for Sustainability in Space
- PFaST – Probing the Fabric of Space-Time
- **PRoMO – Polar Radiation of Model Organisms**
  - Modeled “deep space radiation” environment
  - Not selected as one of the highlighted campaigns
    - Mostly due to Time and Cost
  - Still important enough to be included as a “notional concept”



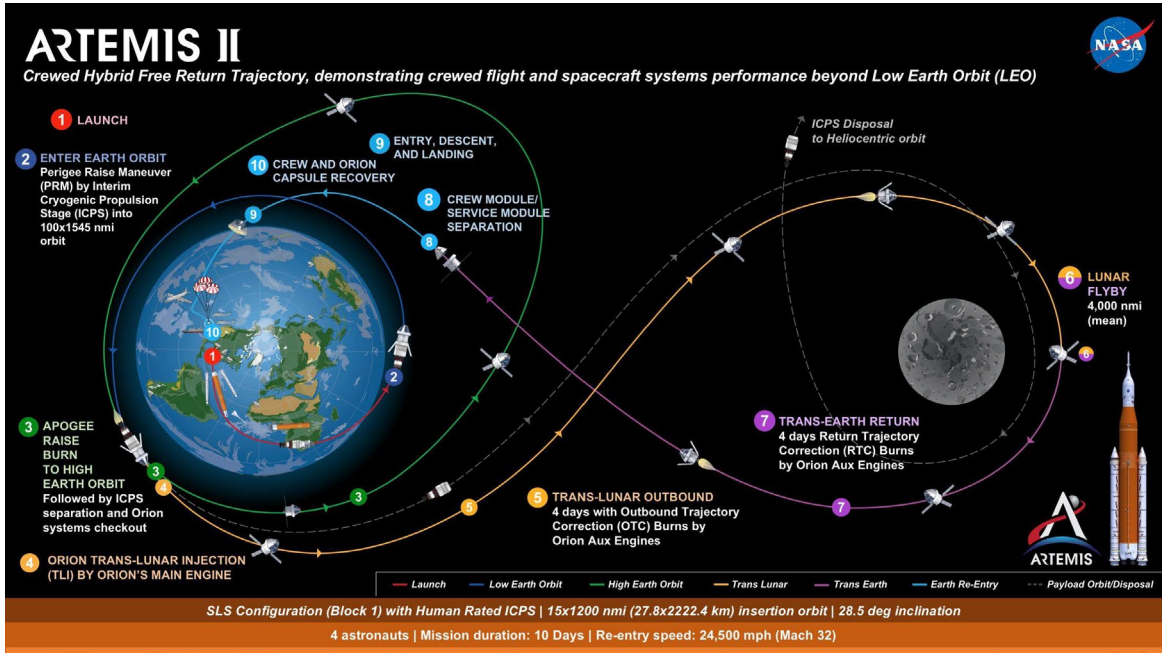
Why is this important? Who cares?

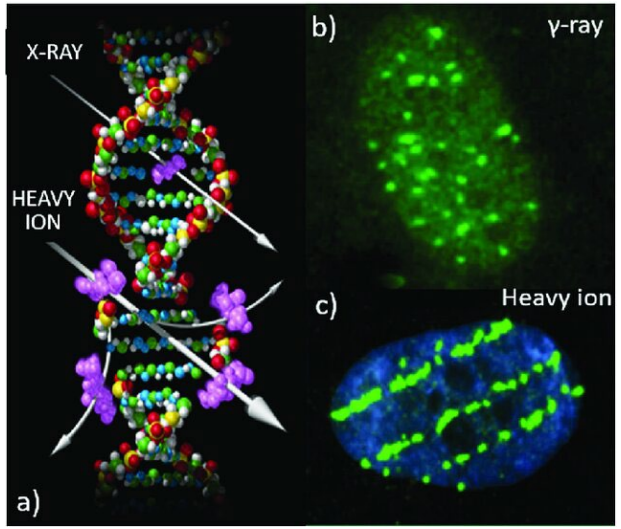
- Astronaut Health (International spacefaring community)
- Spaceflight is a model for Accelerated Aging (NIH/NIA/NIAID/DoD)
  - Age-dependent degenerative disease
  - Cancer
- Multi-model experiments improves translational science (NCATS)
- Life in extreme environments (NSF)
- Other agencies within NASA
  - Space Weather (Heliophysics)

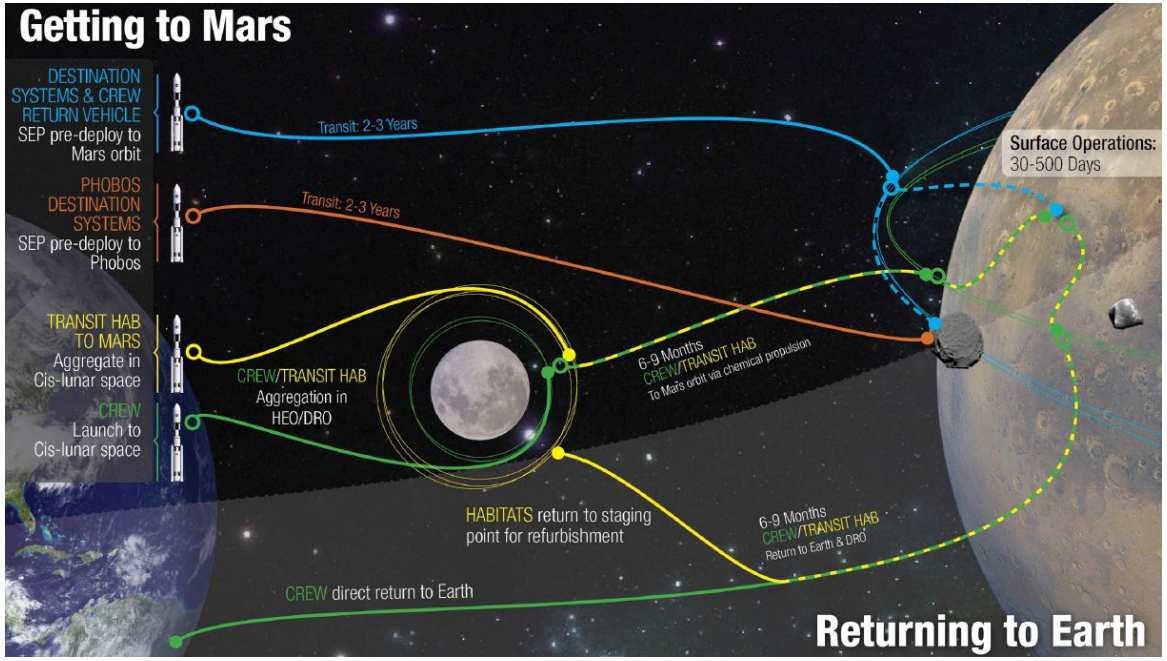


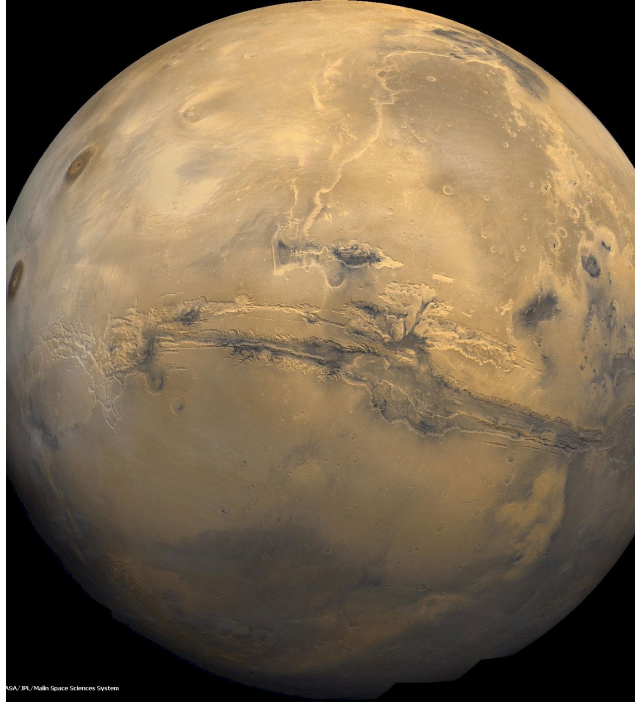
Rationale

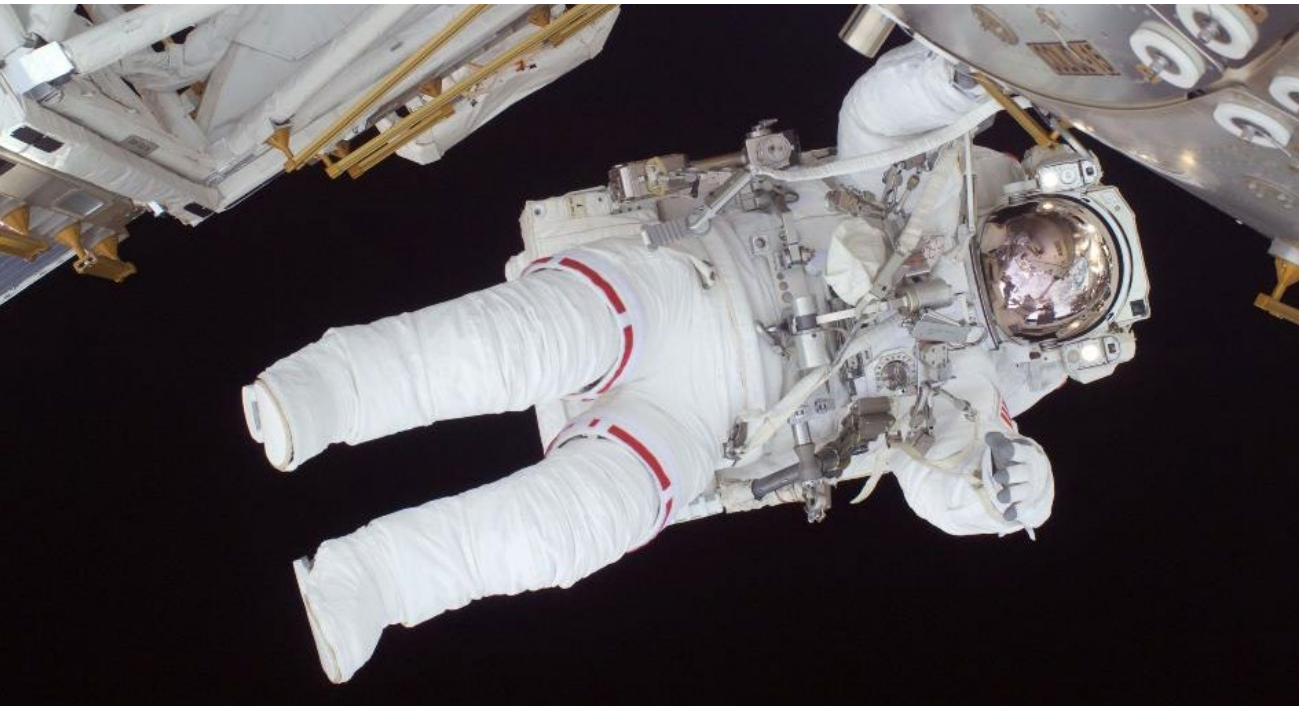
- Biological effects of the deep space radiation environment beyond LEO are relatively unknown
  - Although there are fewer HZE particles in terms of fluence, their biological effects are much greater
- Combined effects of GCRs with microgravity are virtually unknown
- Long-term GCR exposures are currently unfeasible on Earth





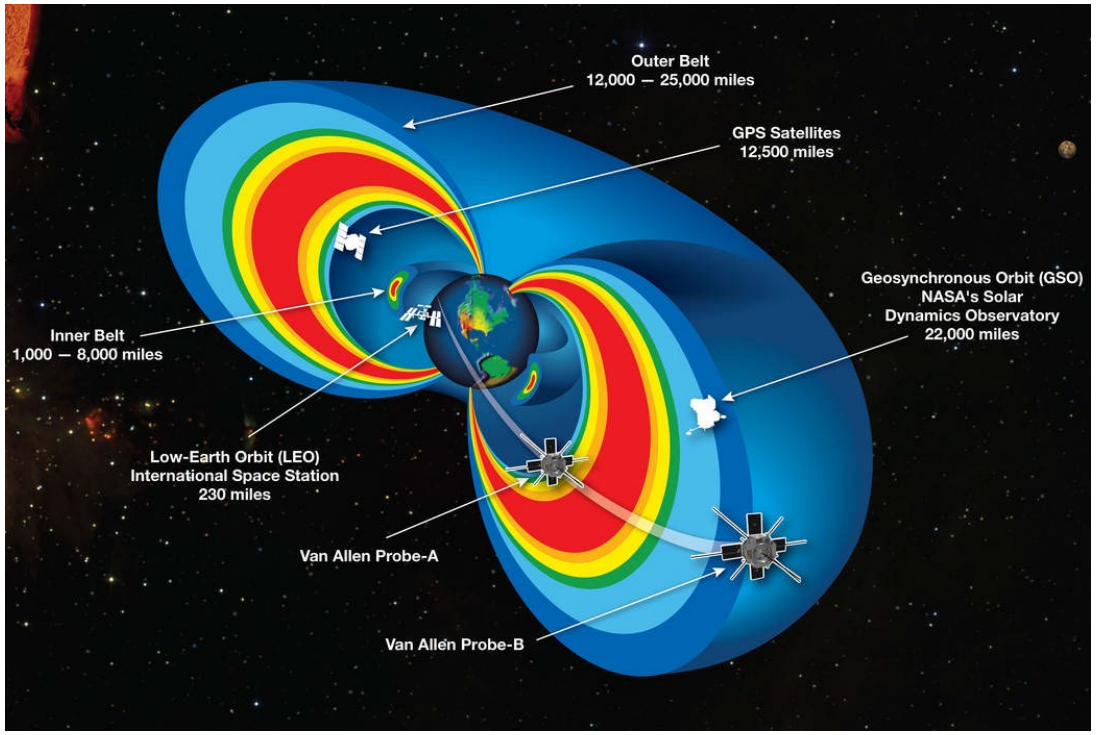


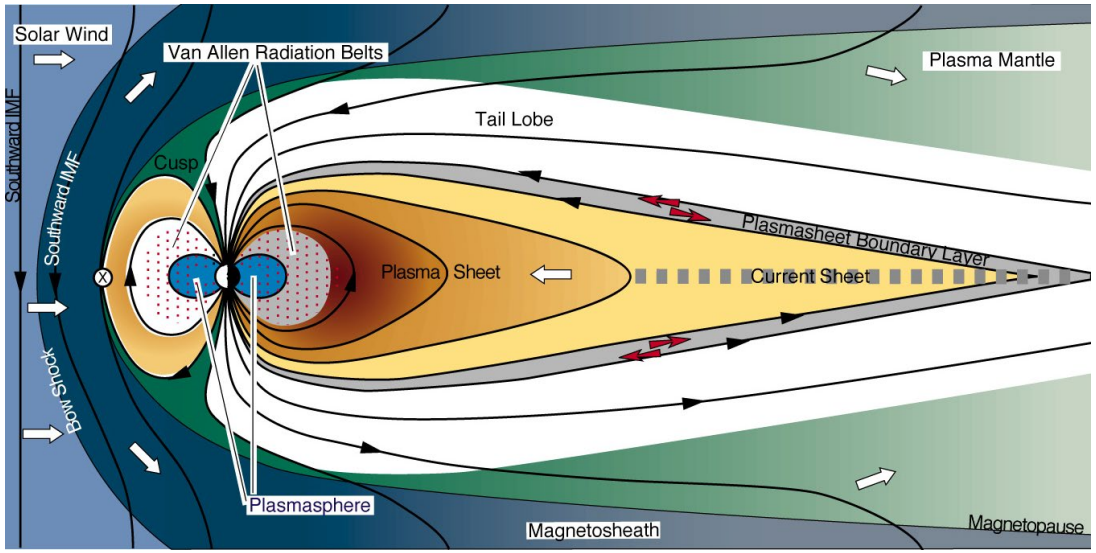




Spaceflight Environment

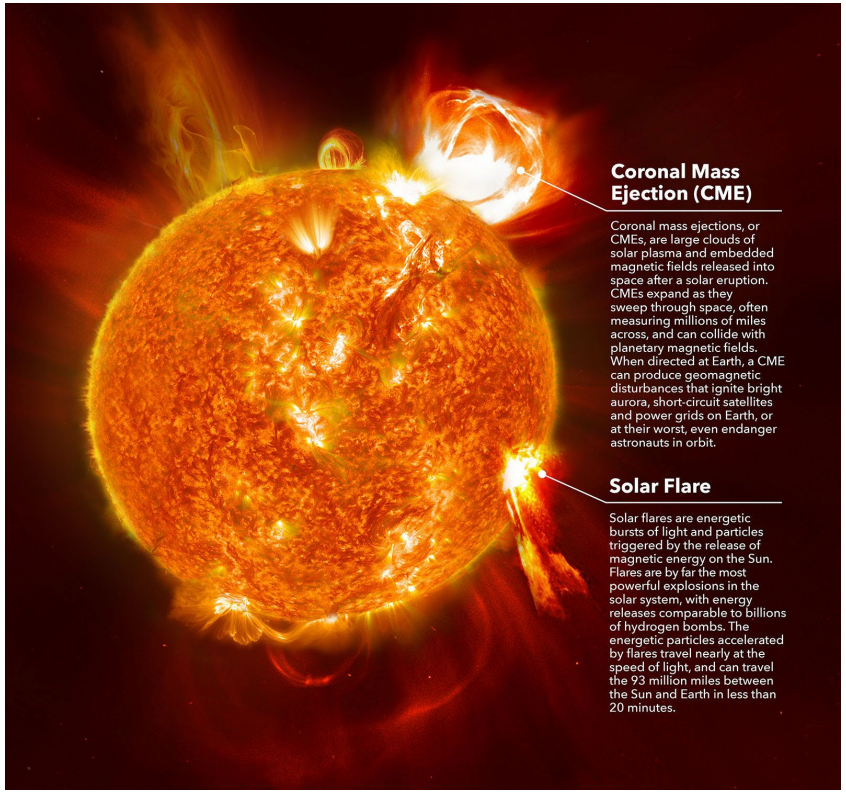
- Microgravity
  - Unloading
  - Fluid Shifts
  - “Dead Spaces”
- Stress
  - Psychological
  - Circadian Rhythms
- Radiation
  - Solar Particle Events
  - Galactic Cosmic Rays
  - Van Allen Belts

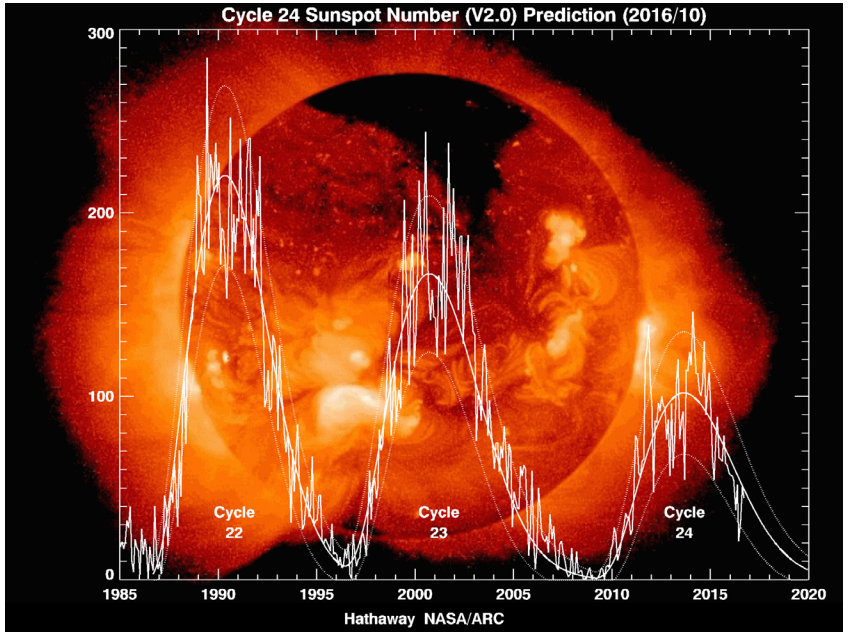




Van Allen Belt Particles

- Composition & Energies
  - Protons: E ~ 0.04 to 500 MeV
  - Electrons: E ~ 0.04 to 7 MeV
  - Heavier Ions: E Low
- Location of populations shifts with time
- Average counts vary slowly with solar cycle
- Counts may increase by orders of magnitude with magnetic storms
- Omnidirectional motion
- Offers some protection for earth from the space radiation environment beyond
  - Less protection at the poles



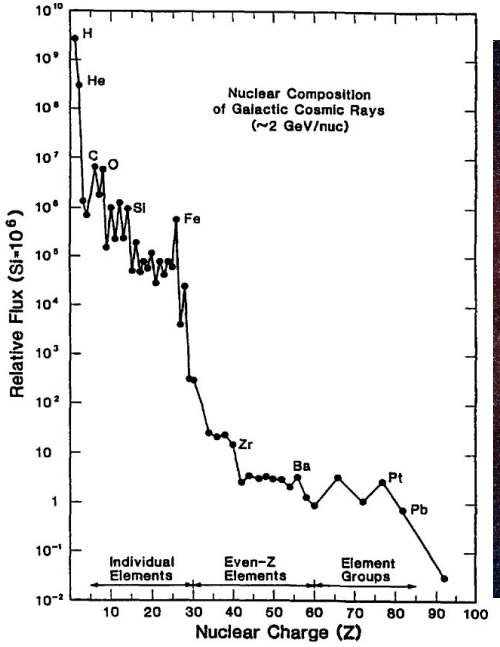


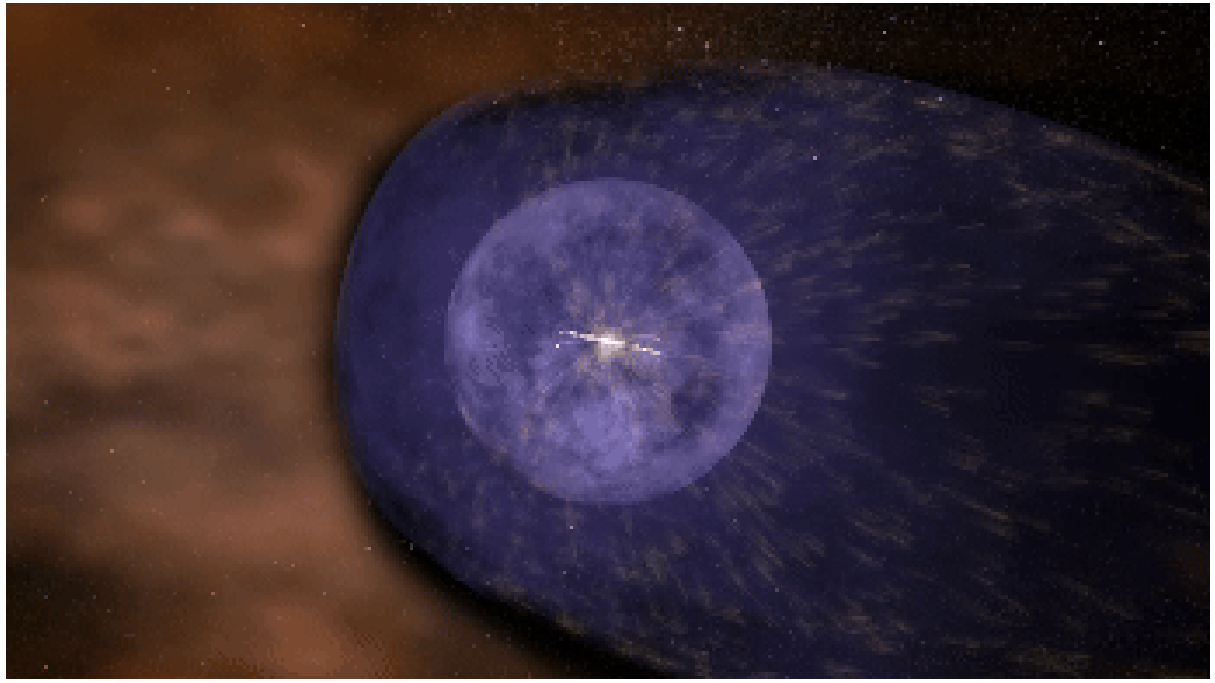
Solar Particle Events

- Composition
  - Protons = 80-95%
  - Alpha particles = 5-10%
  - High Z High Energy particles (HZE) < 1%
    - Iron, Carbon, Oxygen, Silicon
- Energies
  - Mostly 10-100 MeV/n
  - Some extremely high energies
- Typically last hours to days
  - Changing dose rate and energy spectrum
- Relatively random and unpredictable
  - Frequency follows 11-year solar cycle
  - More frequent during solar maximum
- Directionality follows Sun’s magnetic field lines

Galactic Cosmic Rays

- Composition
  - Protons = 85-90%
  - Alpha particles = 10-12%
  - High Z High Energy particles (HZE) = ~1%
    - Iron, Carbon, Oxygen, Silicon
- Energies
  - Mostly 0.1-10 GeV/n
  - Some extremely high energies
- Relatively constant dose rate
  - ~ 1-2 mSv/day
- Generally Omni-directional

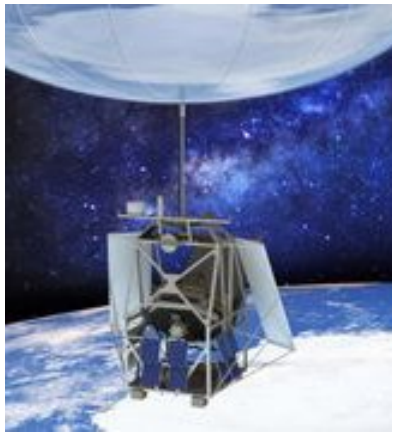


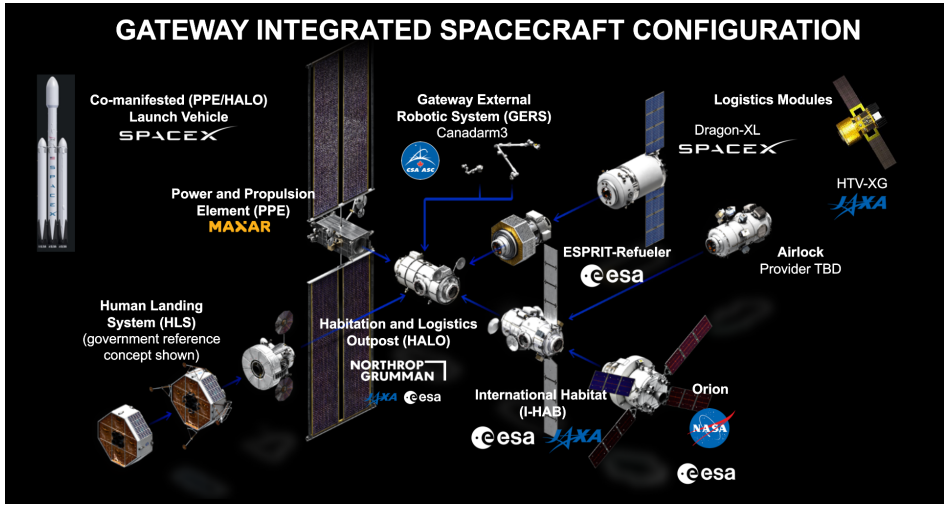


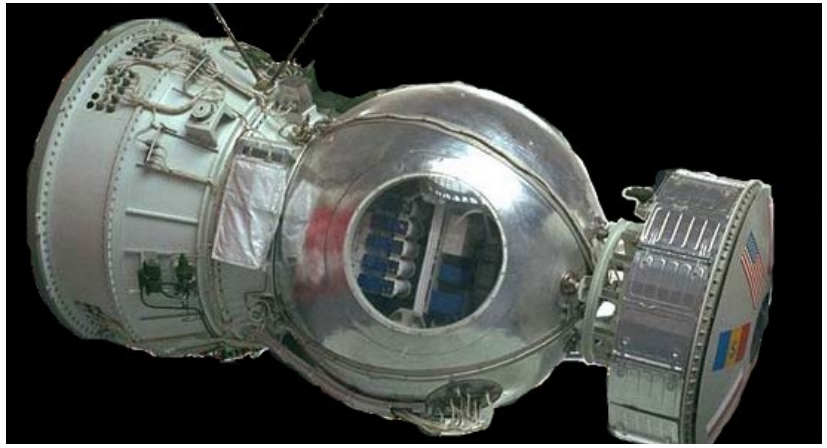
NASA/Goddard Space Flight Center, Conceptual Image Lab

Limitations of current radiation models

- Photons (gamma or x-rays)
  - Correct doses and (possibly) dose rates
  - Wrong radiation type
- Proton Treatment Centers
  - Can be used to simulate SPEs
  - Generally correct dose-time & energy profiles
  - Single radiation type
  - Not GCRs
- NASA Space Radiation Laboratory
  - Can be used to model GCRs & SPEs
    - Multiple HZE species with correct proportions
    - Generally correct doses & energies
  - Limited to relatively acute exposures





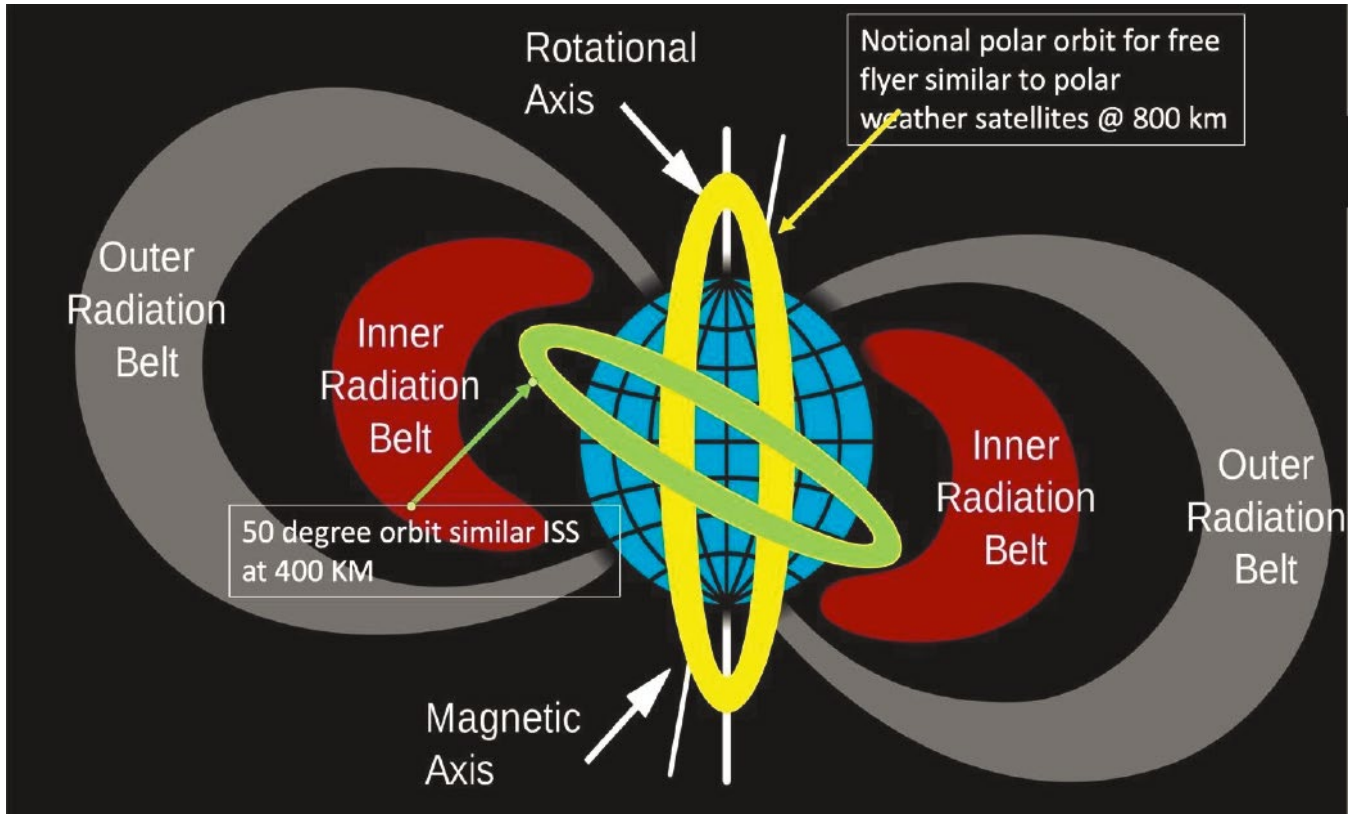


Several mission types discussed as part of this potential campaign

- New radiation facilities with greater flexibility than BLN/NSRL dedicated to BPS priorities
- Polar balloon
  - Focused on radiation environment
- Free-flyer to the Moon or “Something” at cis-lunar
  - Has both the ‘real’ radiation environment & microgravity
  - Lunar Gateway will not have sufficient resources
- “Rodent Mission of Unusual Size”
  - Free-flyer in a polar orbit
  - Similar to ‘real’ radiation environment & microgravity
  - Included multiple strains of mice and rats

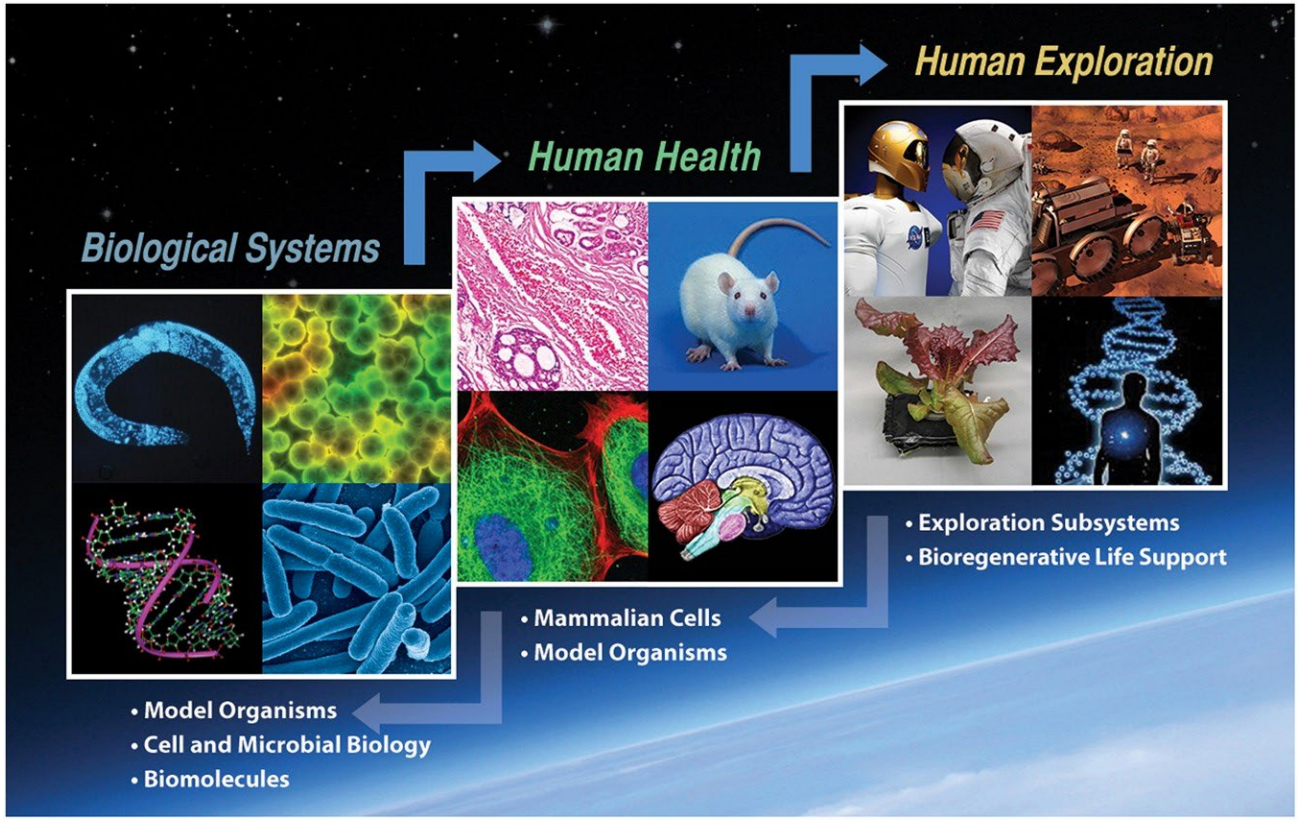
Suggested Mission Profile for PRoMO

- Orbit
  - 800 km
  - ~90 degree inclination
  - Allows exposure to HZE environment
- Duration
  - 90 days
- Estimated dose
  - ~0.25 Gy
  - Depends on solar activity
- Multiple research models



Some Example Experiments
(in increasing complexity)

- Bacteria/Nematodes/Drosophila
  - Multi-generational
  - Multiple genetic variants
- Organoids or “Chips in Space”
  - Human tissues
  - Genetic Diversity in Humans
  - Interactions between organ systems
    - Mini-me astronauts?
  - Repeated sampling/measurements
- Rodent Models
  - Genetic Diversity
    - Inbred vs outbred strains
    - Genetic modifications
  - Allows systems biology
  - Combined with other relevant stressors
    - Lunar or Martian Dust?



npj Microgravity **3**, 5 (2017). https://doi.org/10.1038/s41526-016-0002-8

Some necessary infrastructure…

- Launch site
  - Transport of samples & supplies to launch site
  - Domestic facilities for sample prep or animal housing
  - Sterile conditions for tissue culture work, etc.
- Adequate “ground controls”
- Transport of samples from landing site
- Support personnel (Investigators, Engineers, Technicians, Students)

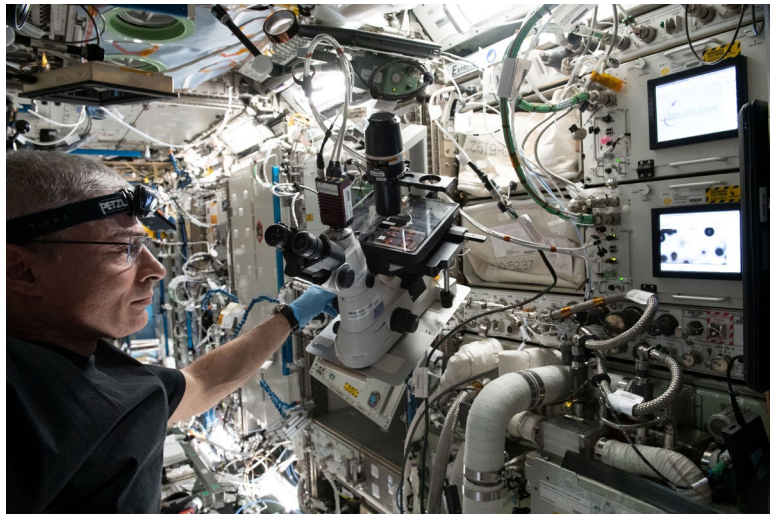
Vehicle Requirements (and some hopes)

- Radiation
  - Measurements throughout vehicle
  - Modeling of environment inside the configured vehicle
    - HZE + Shielding = Fragments/Secondaries
- Telemetry
  - Physiological Data
  - Environmental Parameters
- Life support systems
  - Automated fluidic & gas systems
  - Media/Food replacement
  - Waste management
  - Lighting
  - Thermal control
  - Air filtration
  - Emergency euthanasia for animal studies

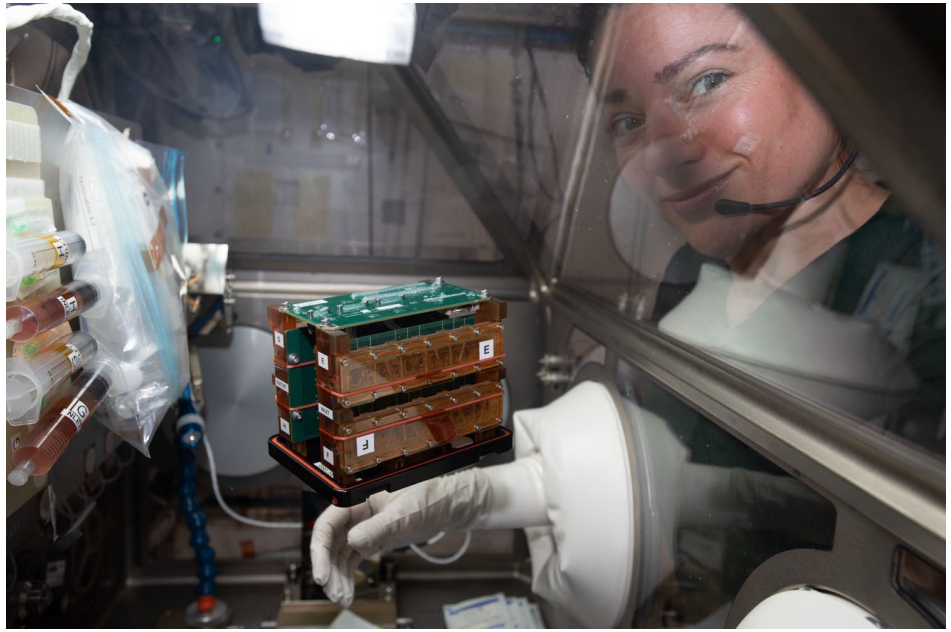
https://en.wikipedia.org/wiki/Bion_%28satellite%29

More Requirements…

- More automation
  - Limited experiment control
  - Sample collection, preservation & return
  - In situ analysis
  - Incubators, microscopes, etc
  - Centrifuge controls
  - Cold stowage for samples, media, etc
- Video monitoring for animals
  - Health monitoring
  - Behavior



Examples of existing hardware that might be modified



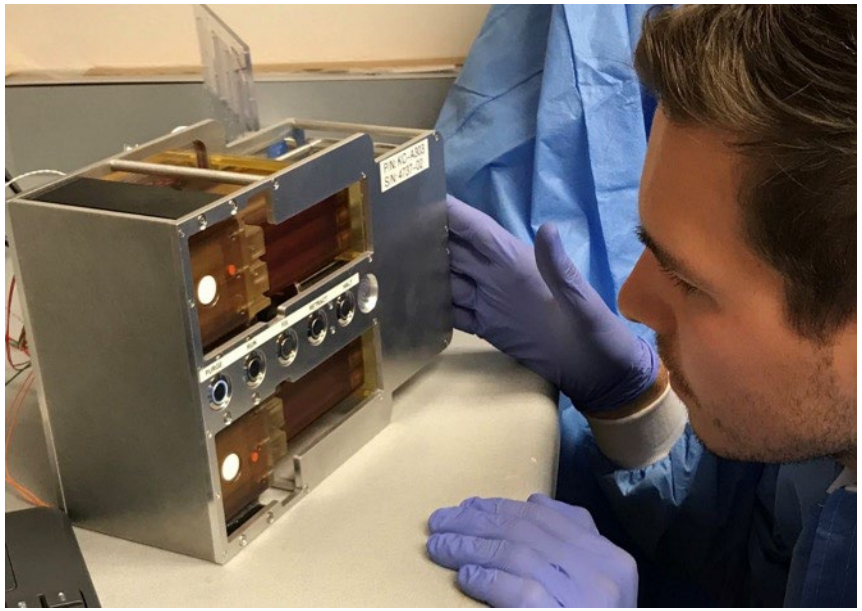
Engineered Heart Tissue

Kidney Cells Automated Lab-on-a-Chip

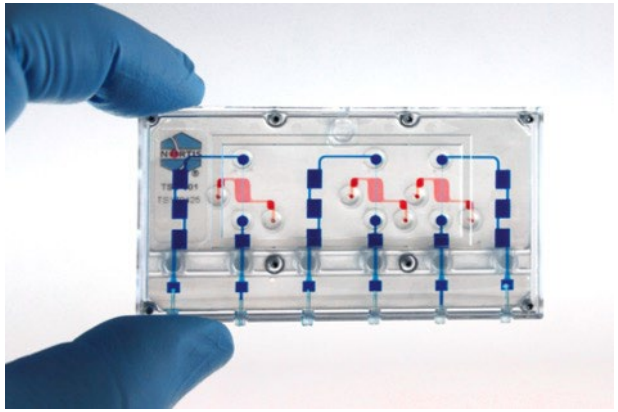
Chips in Space

UNIVERSITY of WASHINGTON

72 Samples ~48 ft^3 in lab



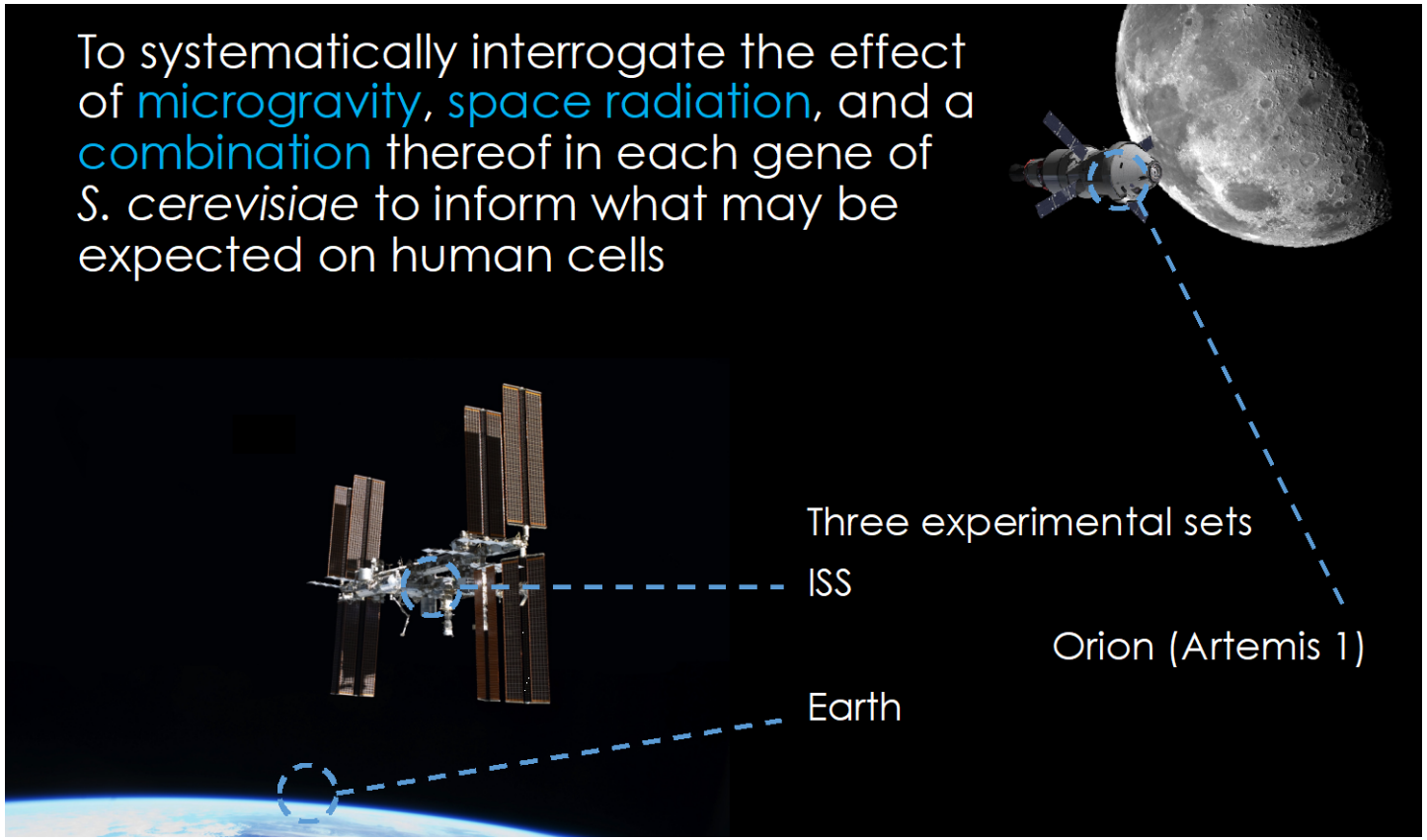
72 Samples ~2 ft^3 for launch

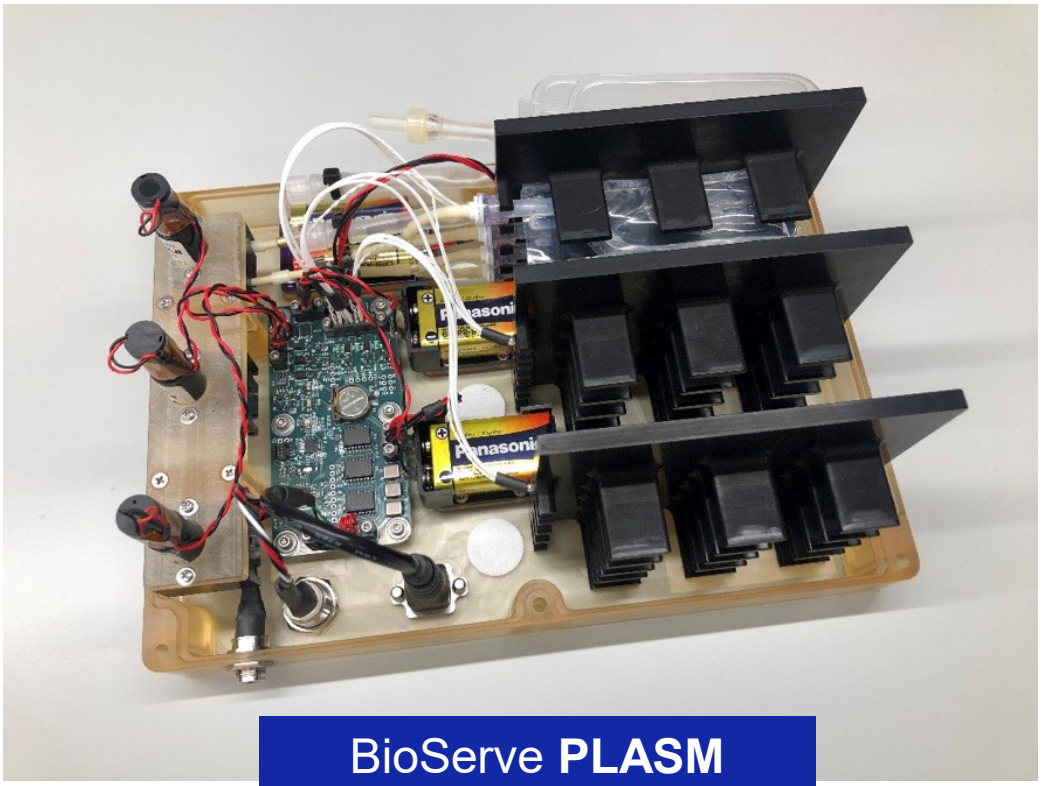


BioServe **Kidney Cells** Payload launched on SpX-17, May 4th, 2019

PLASM (Deletion Series Yeast Study)

- Completely Autonomous Payload (Data, Power, Activation).





BioServe **PLASM** Payload launched on Artemis-1

BioCell

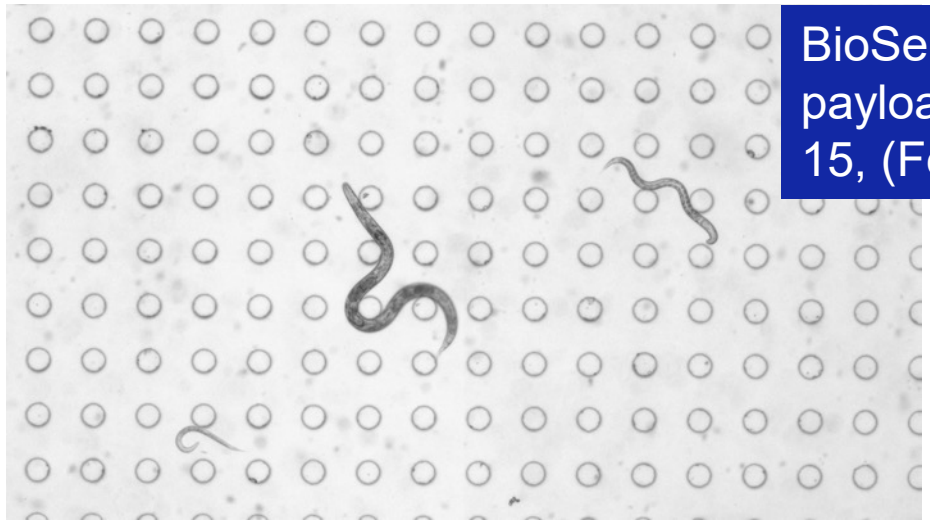
Compatible with:

- Attached or suspended cell cultures
- Plate Reader
- Microscope
- Gas exchange
- Media Exchange
- Cryogenics
- Fixation
- Integration into Automated Systems

Past investigations (Selection):

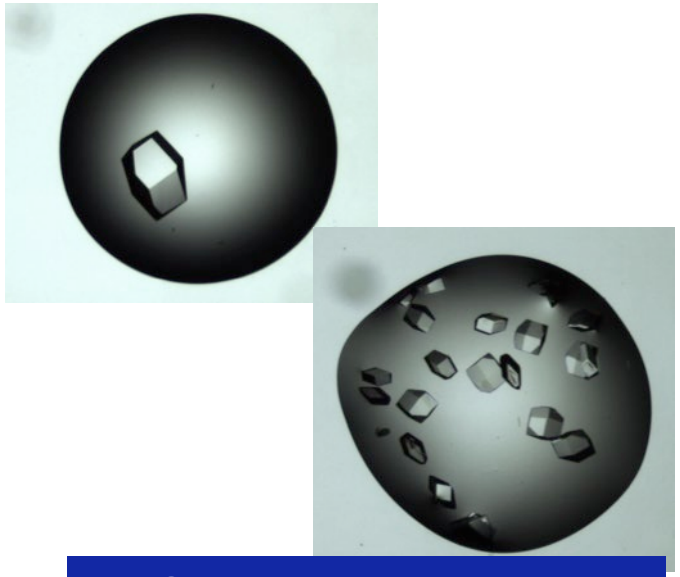
- Stem Cells
- Heart Cells
- Bone Cells
- Cancer Cells
- Bacteria
- Biofilm
- Yeast
- …

Microscope Samples



BioServe **Micro-16** payload launched on NG-15, (February 20th, 2021)

BioServe **Heart Cells** payload launched on SpX-9, (July 18, 2016)



BioServe **Protein Crystallography-1** payload launched on SpX-14, (April 2, 2018)

Two AEMs and Life Support System on NG

Thank you!