Without Gravity:
Designing Science Equipment for the International Space Station and Beyond

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Topics

1. What is microgravity?
2. Overview of the effects of space flight microgravity on biology
3. Differences between ground lab and space flight lab
4. Factors for designing equipment for space-based research
5. Examples of microgravity-modeling hardware on Earth
6. Examples of flight hardware that enable microgravity research in space
7. New Technology Challenges for Future Exploration

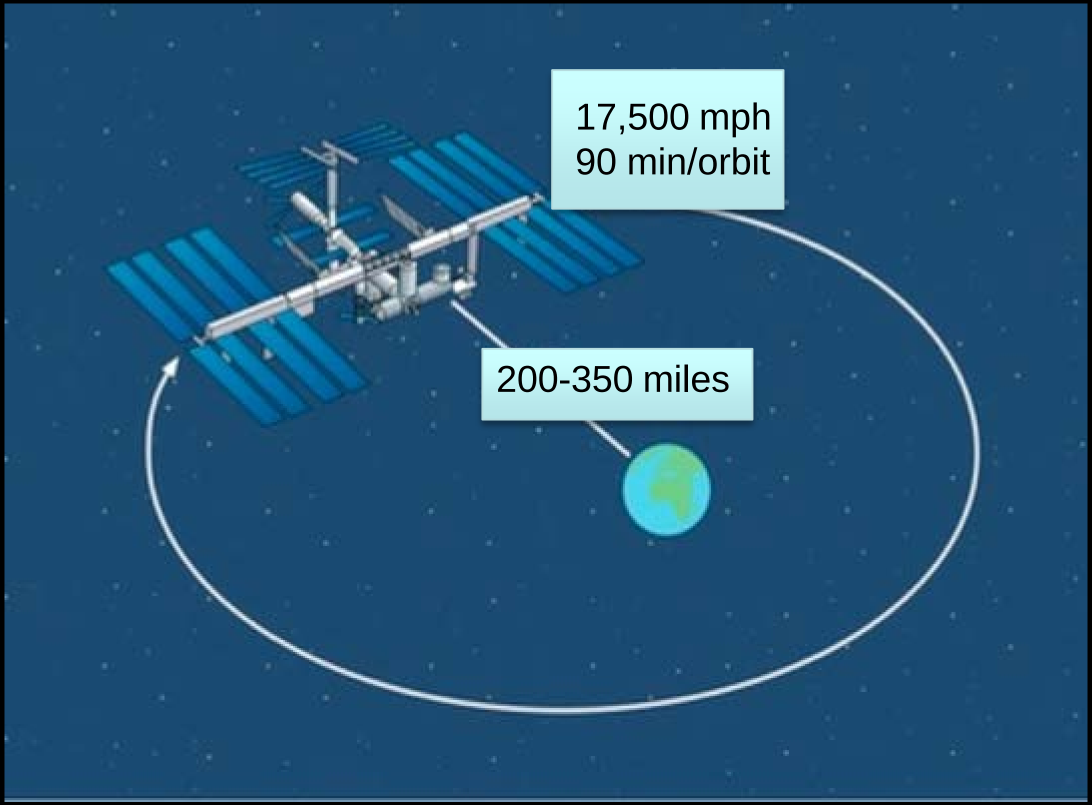
Gravity

Newton's Law of Gravitation states: Any object that has mass attracts other objects to it. The mass of the Earth creates a force that we have designated as 1g.

1 x gravity

Leaving Earth

Microgravity created by Orbiting Earth



At 250 miles above Earth:

- Low Earth Orbit
- ~ 9% reduction in the gravity level: 9.8 m/s^2 to 8.9 m/s^2

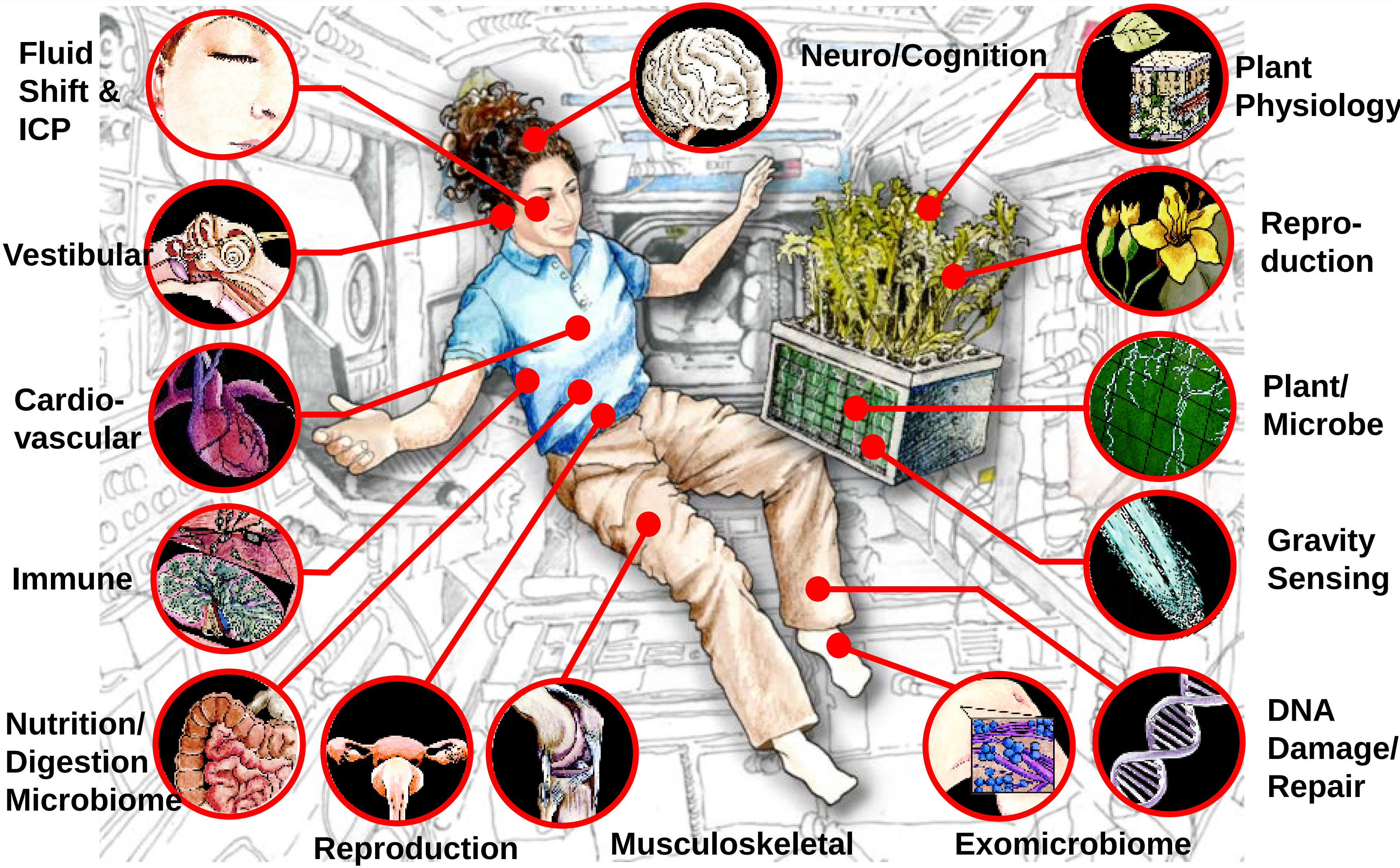
Microgravity is achieved by Orbiting the Earth

- ~17,500 mph – Continuous “free fall” around the earth
- Common acceleration while in free fall due to gravity with the sum of all other forces being zero.

What Happens in Space Flight and Microgravity on the Body?

- Loss of hydrostatic pressure
  - Fluid pressure differential between your feet and head equalizes
- Loss of mechanical loading
- Space Flight environment stress

Physiological Changes



Space Flight and Aging Analogs

Function	Aging	Space
Muscle	↓	↓
Bone	↓	↓
Immune System	↓	↓
Reproduction	↓	↓
Memory	↓	?
Behavior and Performance	↓	↓
Radiation Damage Repair	↓	?

NASA Space Biology

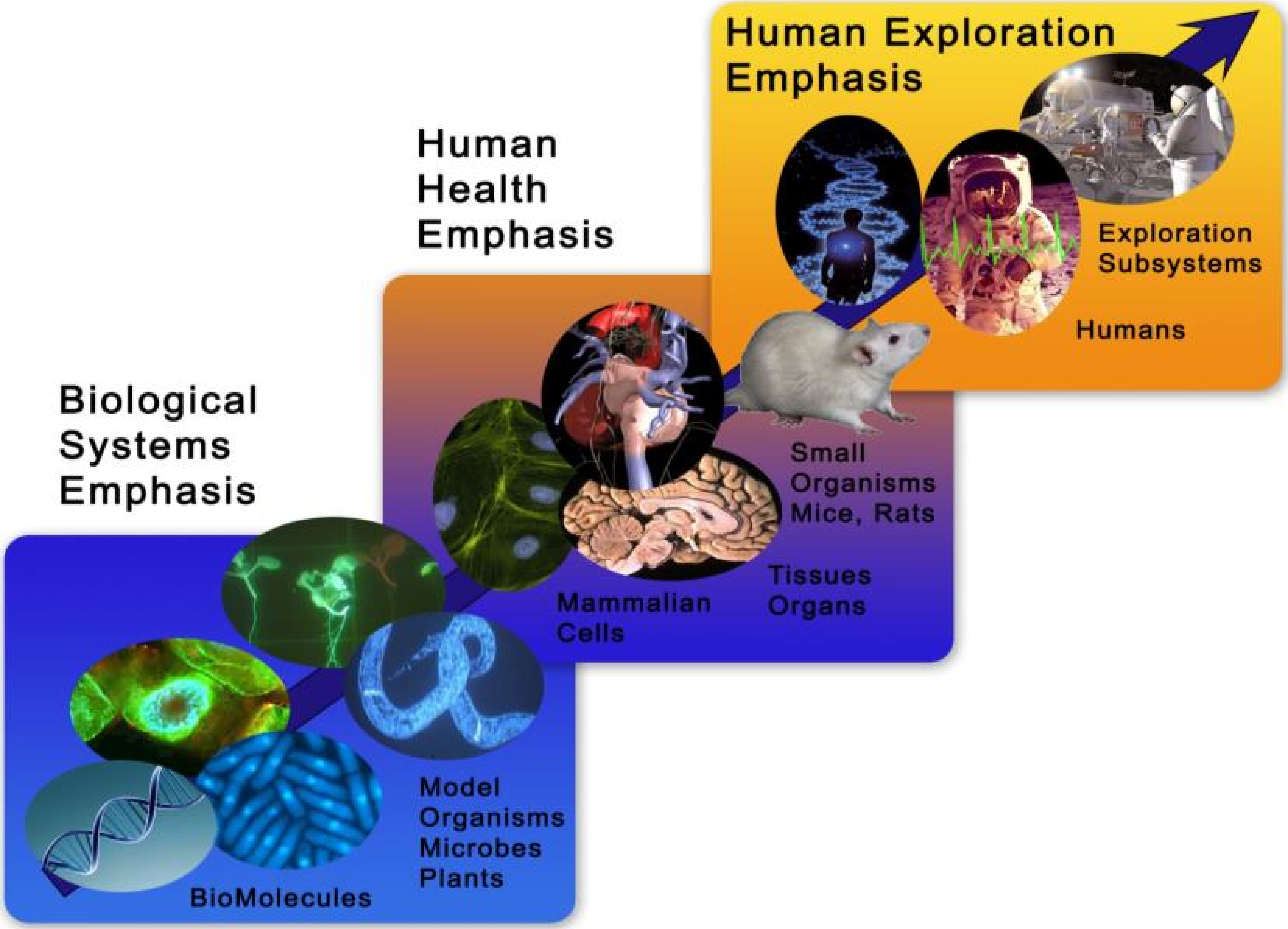
NASA Space Biology studies biology in space flight to:

- Understand how life responds to and adapts to the space flight environment
- Define biological mechanisms affected by and sense this environment
- Define the nature of biological responses to gravity changes
  - Manipulating gravity as an independent variable
- Build knowledge benefits to furthering human space exploration
- Build knowledge that will benefit Earth (academic science and medicine)
- Inspire and educate the next generation of scientists and engineers

Why Conduct Biological Research In Space?:

- Unique environment for new biological discoveries
- Address questions for the role of gravity in biological function
- Accelerated changes to the human body that are analogous clinical disease on Earth – can study in days, weeks, and months rather than years – contribute fundamental biological knowledge to Earth benefits
- We humans will explore space beyond the bounds of low Earth orbit

Space Biology Research Themes



Designing Considerations for Science Equipment for Space Flight Research

Translating Ground Experiments to Flight Experiments

Ground Laboratory

Space Laboratory Facilities


ISS


ISS

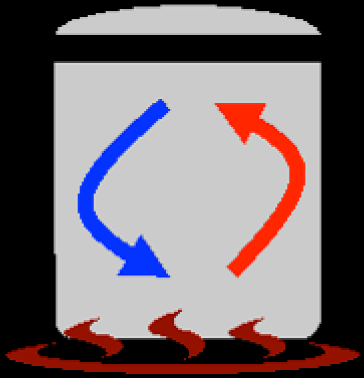

GeneSat-1


Biosatellite

What factors must be considered when designing space flight research hardware?

- Gravity dependent processes do not work in microgravity
- Things float in microgravity

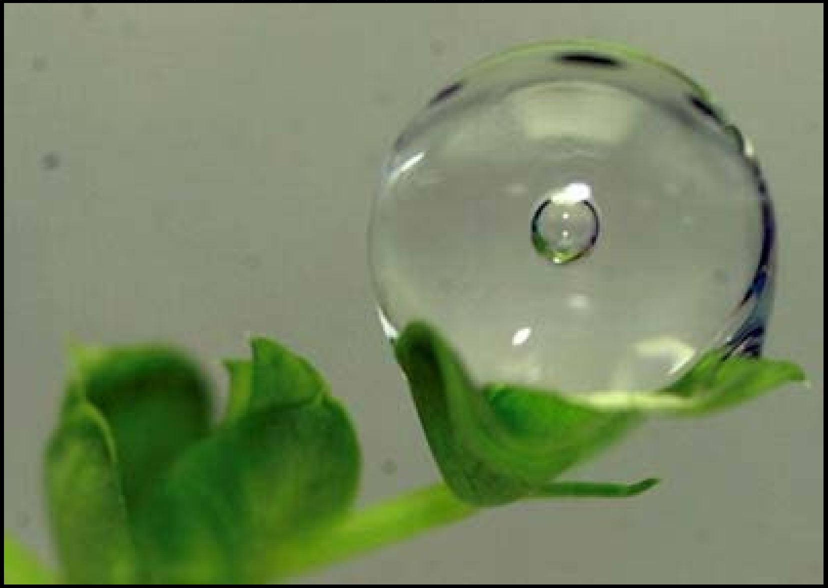
On Earth In Microgravity



Gravity dependent thermal convection and mixing do not work in microgravity

- Diffusion and Brownian motion are dominant in microgravity
- Rely on thermal transfer by conduction in microgravity

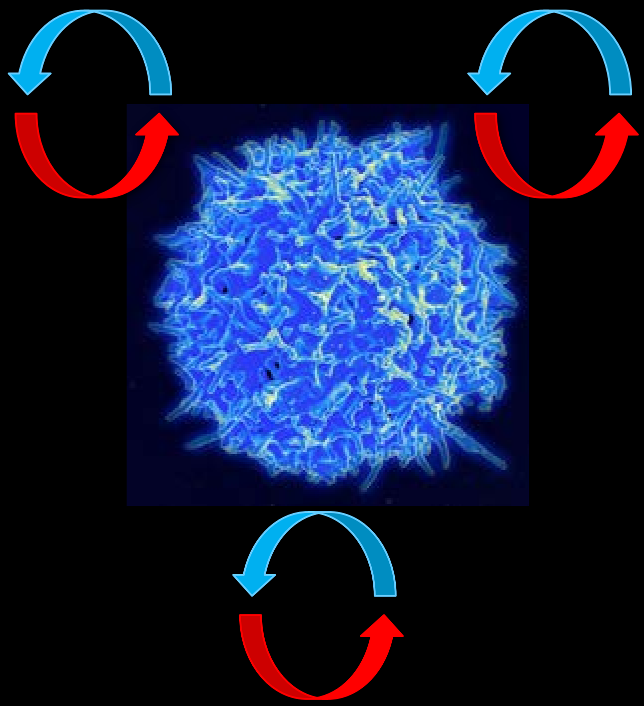
What factors must be considered when designing space flight research hardware?



- Air bubbles do not rise
- Solutions of different densities do not readily mix

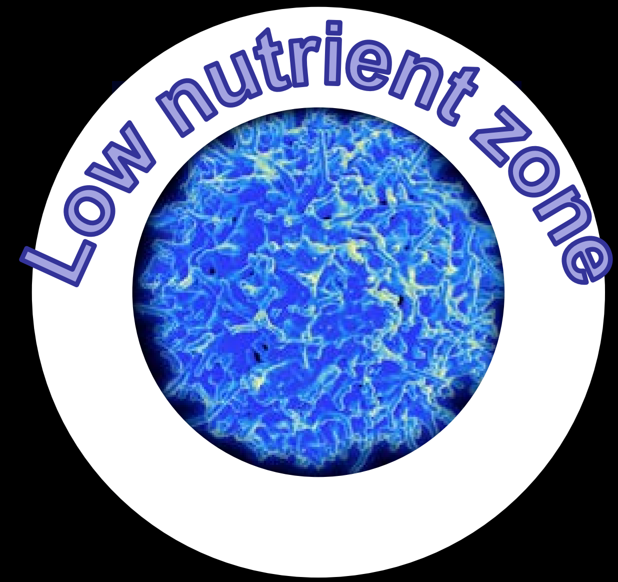
What factors must be considered when designing space flight research hardware?

On Earth



Gravity dependent mixing allows for fresh food medium to get to the cell

In Microgravity



Diffusion and Brownian motion dependent mixing in microgravity – limited to no refresh of food source around cell due to inefficient mixing with fresh medium

- An injected solution doesn’t mix efficiently
- Introduced gas mixture does not mix into solution efficiently

What factors must be considered when designing space flight research hardware?

1) Investigating microgravity effects:
- Limit mechanical forces created by the hardware to a level below that detectable by biology
  - Impact: Hardware or procedure induced mechanical loading or stimulation could mask microgravity effects
    - o Example mechanical forces that mask microgravity effects:
      - ❖ Fluid shear force from injecting medium or solutions
      - ❖ Hardware vibrations
      - ❖ Mechanical mixing
      - ❖ Air flow shear force
    - o 1g control and partial gravity (artificial gravity) on-orbit

2) Containment of biohazards or toxicological hazards
- 1 to 3 levels of containment

3) Automation to reduce the amount of time Crew works with the experiment

4) Biocompatibility of materials used for the hardware, including adhesives
- Off-gassing, leaching

5) Compatibility with chemicals and solutions

5) Limited power availability

6) Constrained size of the hardware and hardware electrical interfaces

7) Data downlink and commanding

7) Ergonomics acceptable to the Astronauts and Human Factors group

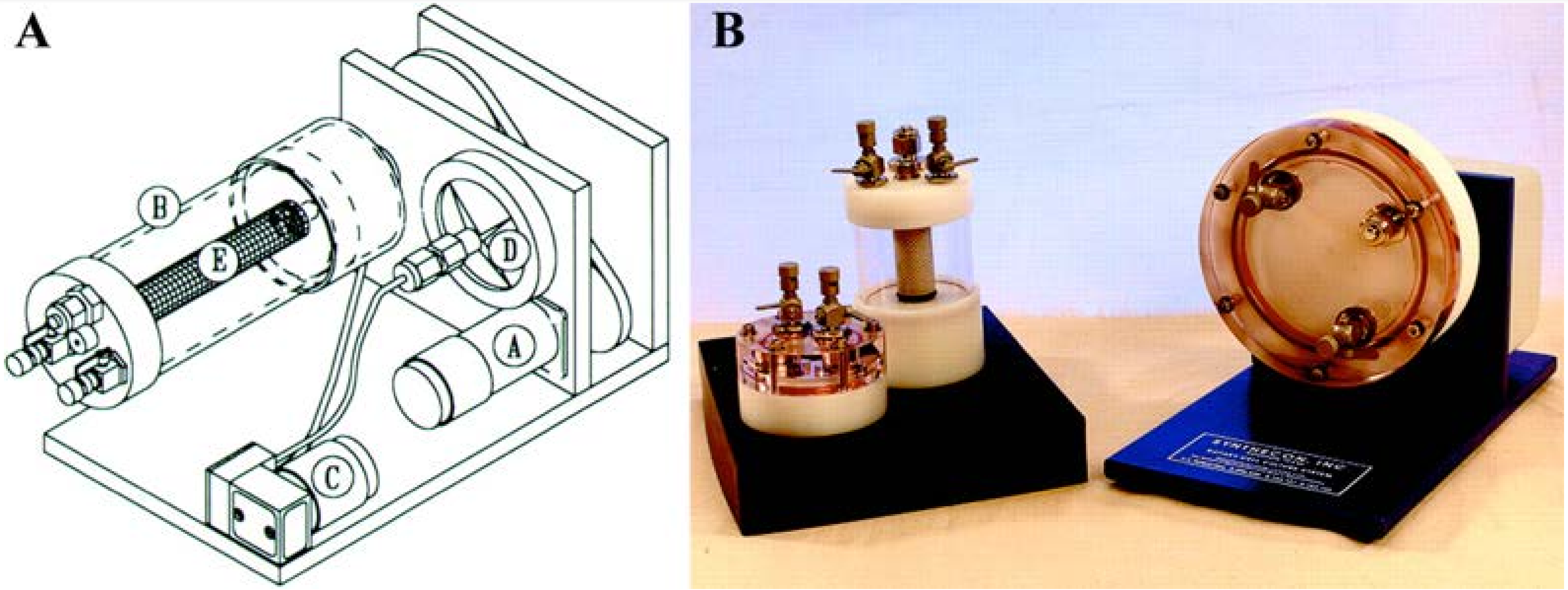
8) Safety considerations for handling and use

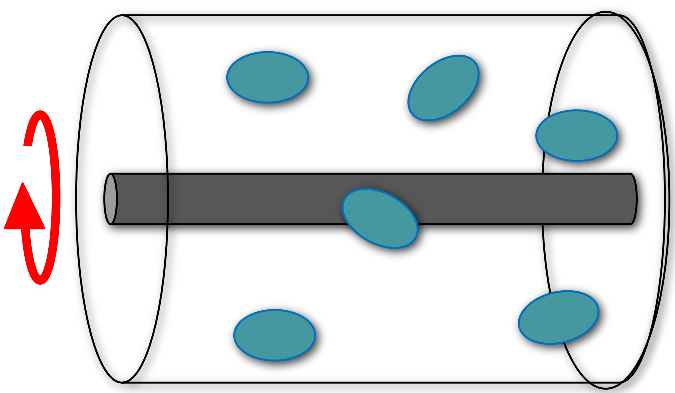
9) Radiation shielding considerations

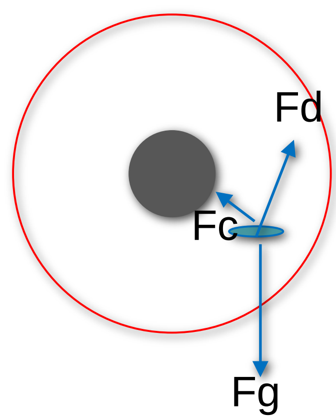
10) Maintaining cleanliness and sterility of experiment containers

Ground-Based Equipment to Study Microgravity

"Microgravity Simulators"

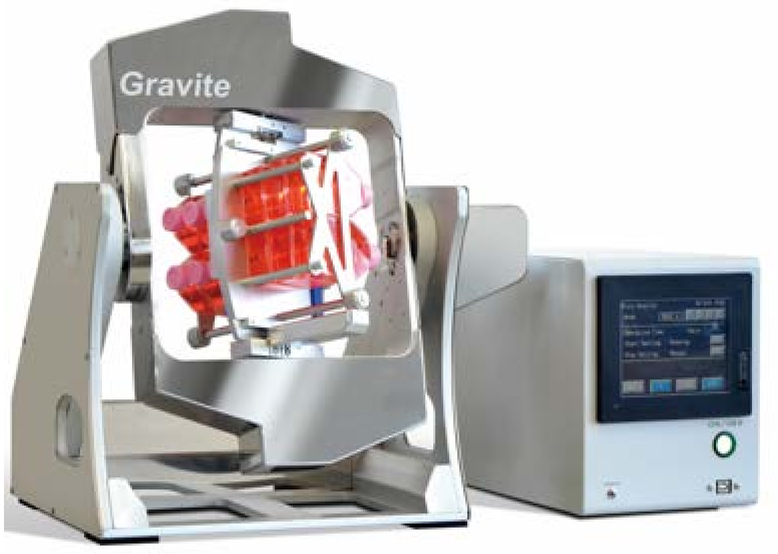






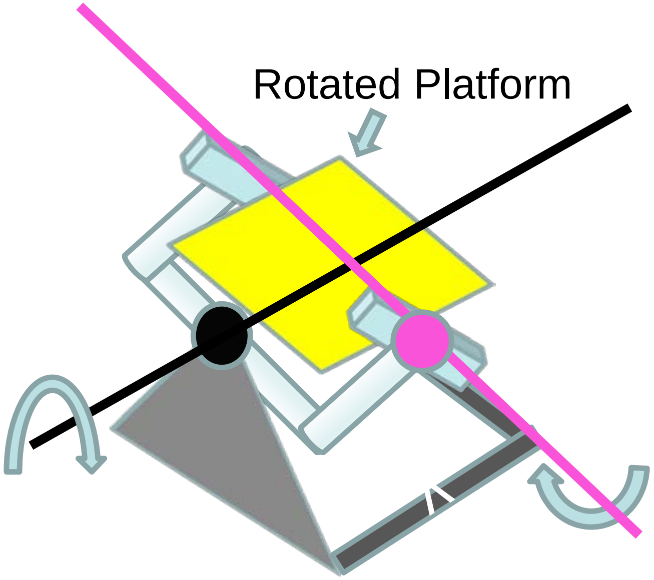
Balance of gravitational force, centrifugation force, and fluid drag force keeps the specimen suspended in a modeled microgravity-like environment

3-D Clinostat/Random Positioning Machine



Gravite
Space Bio-Laboratories Co., Ltd
Hiroshima, Japan

- Independent and simultaneous rotation around 2 axes
- Randomize g-forces resulting in modeled microgravity
- Rate of rotation varies g-force from modeled microgravity to fractional gravity (ex. lunar and Mars), and hypergravity (2g - 3g)

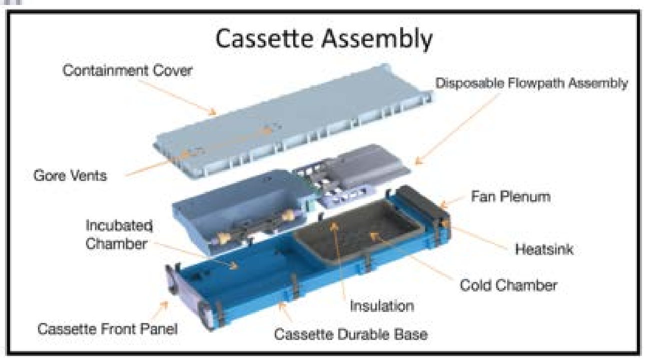


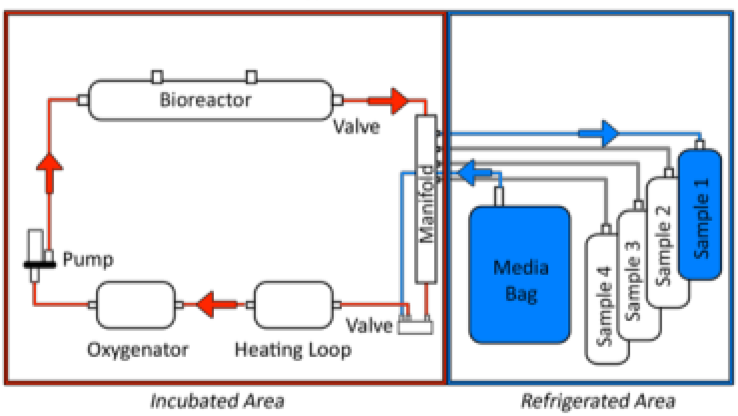
Space Flight Equipment to Study Microgravity Effects on Biology

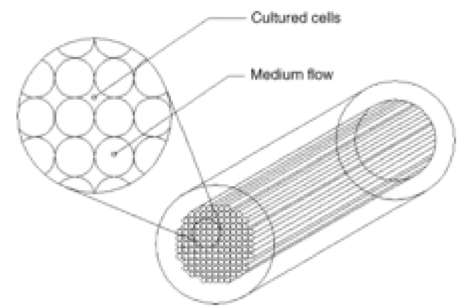
Examples that meet the challenges of Microgravity research

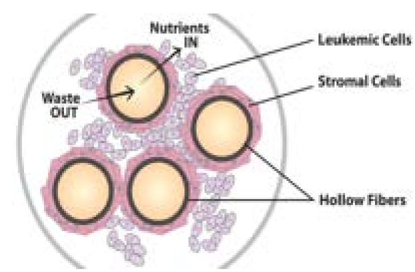
NASA Bioculture System

- Closed loop fluidics system
- Automated medium feed and sampling
- Hollow fiber bioreactor protects cells from flow shear during feeded
    - Medium diffuses through pores in the capillary wall to feed the cells
- Gas supply system, thermal control – incubation, refrigeration





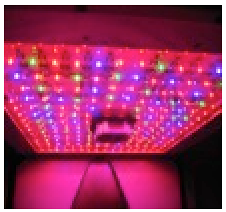




NASA Veggie Unit #2

Veggie is an easily stowed, high growth volume, low resource facility capable of producing fresh vegetables and supporting science experiments on ISS. It also provides real-time psychological benefits for the crew, and facilitates outreach activities.

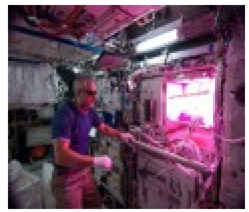
Veggie Configured for Growth of Vegetables



Veggie Light Bank

Veggie Plant Pillow

Veggie + 6 Plant Pillows

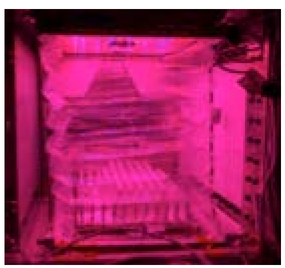


Veggie on ISS

Astronaut Steve Swanson harvesting Lettuce.

Veggie Configured for Petri Plate Science Experiments

Petri plate holder with *Arabidopsis* petri plates inserted.



Petri plate holder containing up to 30 *Arabidopsis* plates in Veggie with bellows closed.

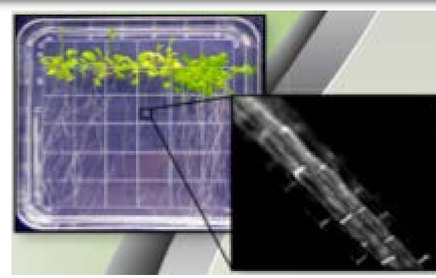


Image of *Arabidopsis* root taken in the Light Microscopy Module (LMM).

Astronaut Butch Wilmore fixing plants on the ISS using a Kennedy Space Center Fixation Tube (KFT).

Specifications:

Light:

- 100-500 µmol m^{-2} s^{-1} PPF of Red (630 nm), Blue (455nm) and Green (530 nm)

Cabin Air Fan Settings:

- Low / High / Off

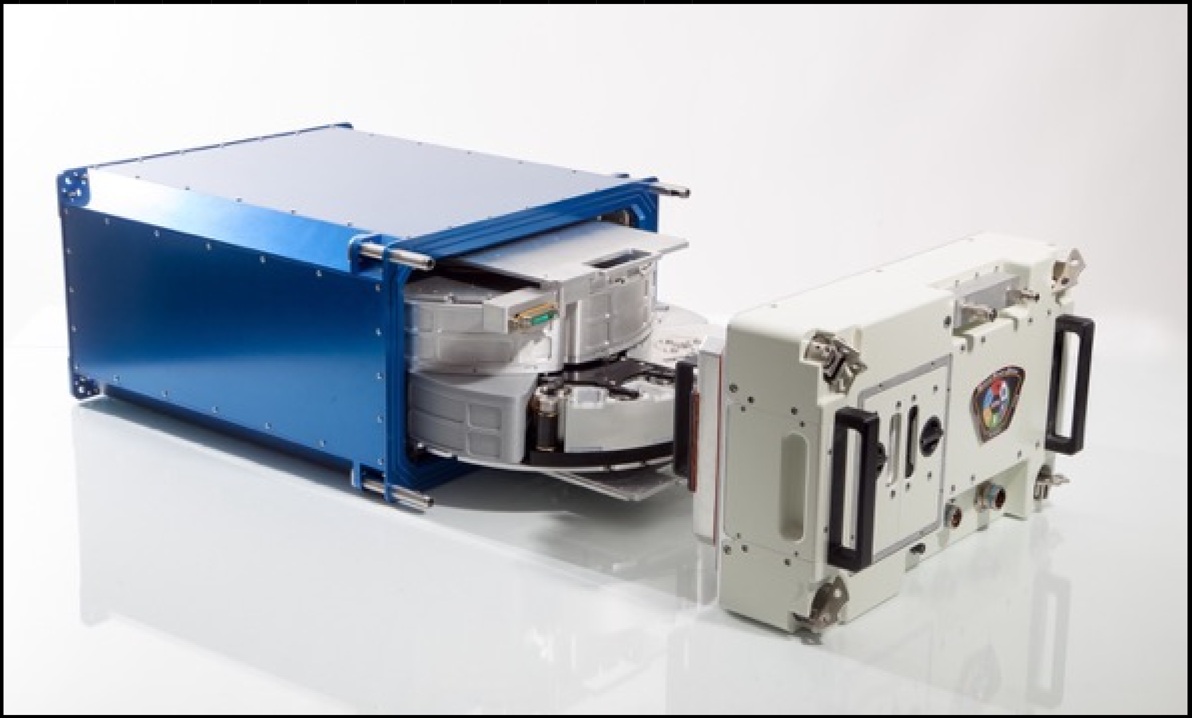
Baseplate Footprint:

- 29.2 cm x 36.8 cm

Max. Height:

- 47.0 cm empty
- 41.9 cm with root mat

Multi-Purpose Variable-g Platform
Techshot



- Two independent centrifuges capable of microgravity (not spinning), fractional gravity, and 1g to 2g
  - On-orbit 1g control and partial gravity studies (Artificial Gravity)
  - Allows manipulation of gravity as an independent variable in space
- Automated sample culturing capabilities
- Crew access possible
- Different culture modules for different types of organisms
- Thermal and gas environment control

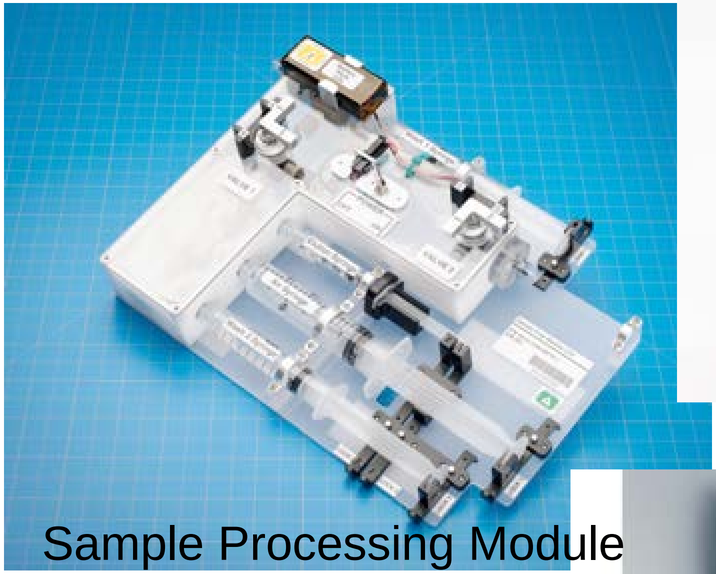
Sample Transfer Tool

ACT^2

- Safe doubly-contained sample transfers to orbit, from orbit, and between equipment in space
- Freezable down to -80 C
- Standard Luer connector

Wetlab-2
On-Orbit Quantitative Gene Expression Analysis

- Commercial Polymerase Chain Reaction (PCR) hardware – Cepheid Smart Cycler
- Sample Processing Module – extraction and purification of RNA or DNA in microgravity
- Glovebag to reduce risk for cross contamination with non-sample RNA or DNA
- ISS hand-held drill to spin the sample tube rotor – surrogate centrifuge
- Data analyzed by smart cycler and downlinked to Science team


Sample Processing Module


Cepheid Smart Cycler

Kate Rubin using the Disposable Glovebag



Pipette Loader with Debubbler

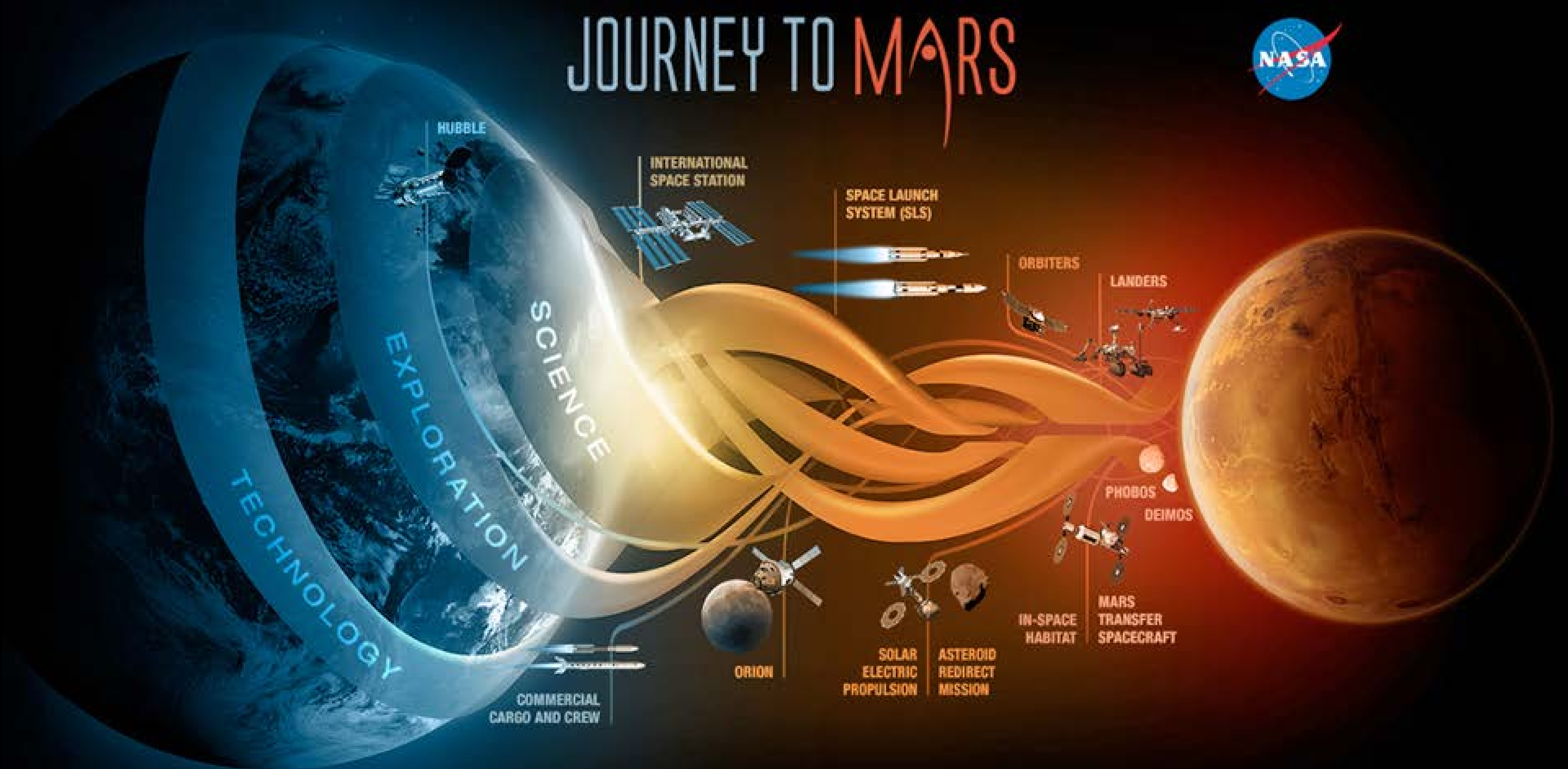

Repeater Pipette with Positive Displacement Tip

Jeff Williams using the drill to spin the rotor


Technology Considerations for the Next Generation of Space Exploration:

To Mars and Beyond

An Integrative Approach to Human Exploration of Our Solar Syste



Space Missions: 6 to 12 months
Return: hours

Earth Reliant
- Learn fundamentals

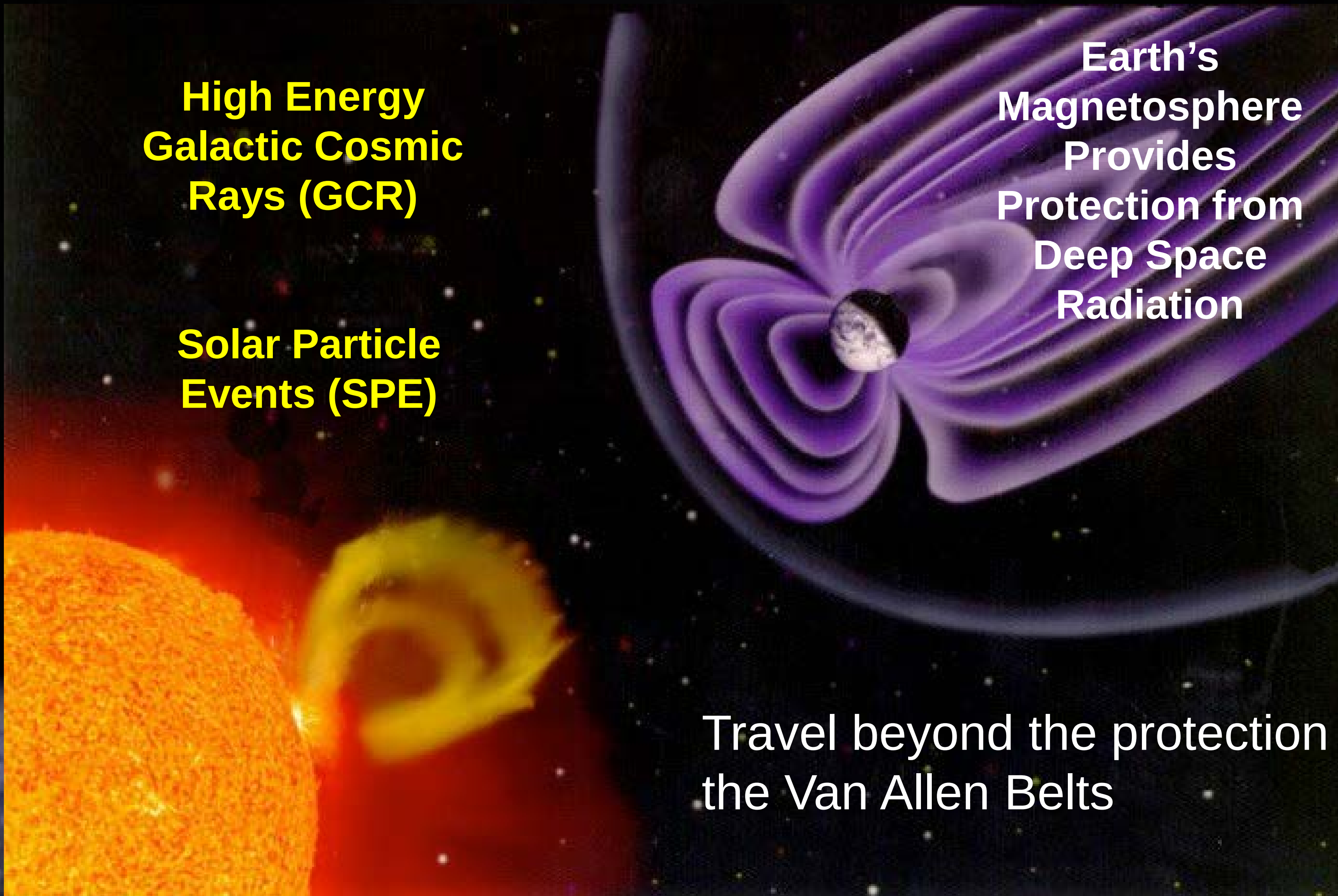
Space Missions: 1 month to 12 months
Return: days

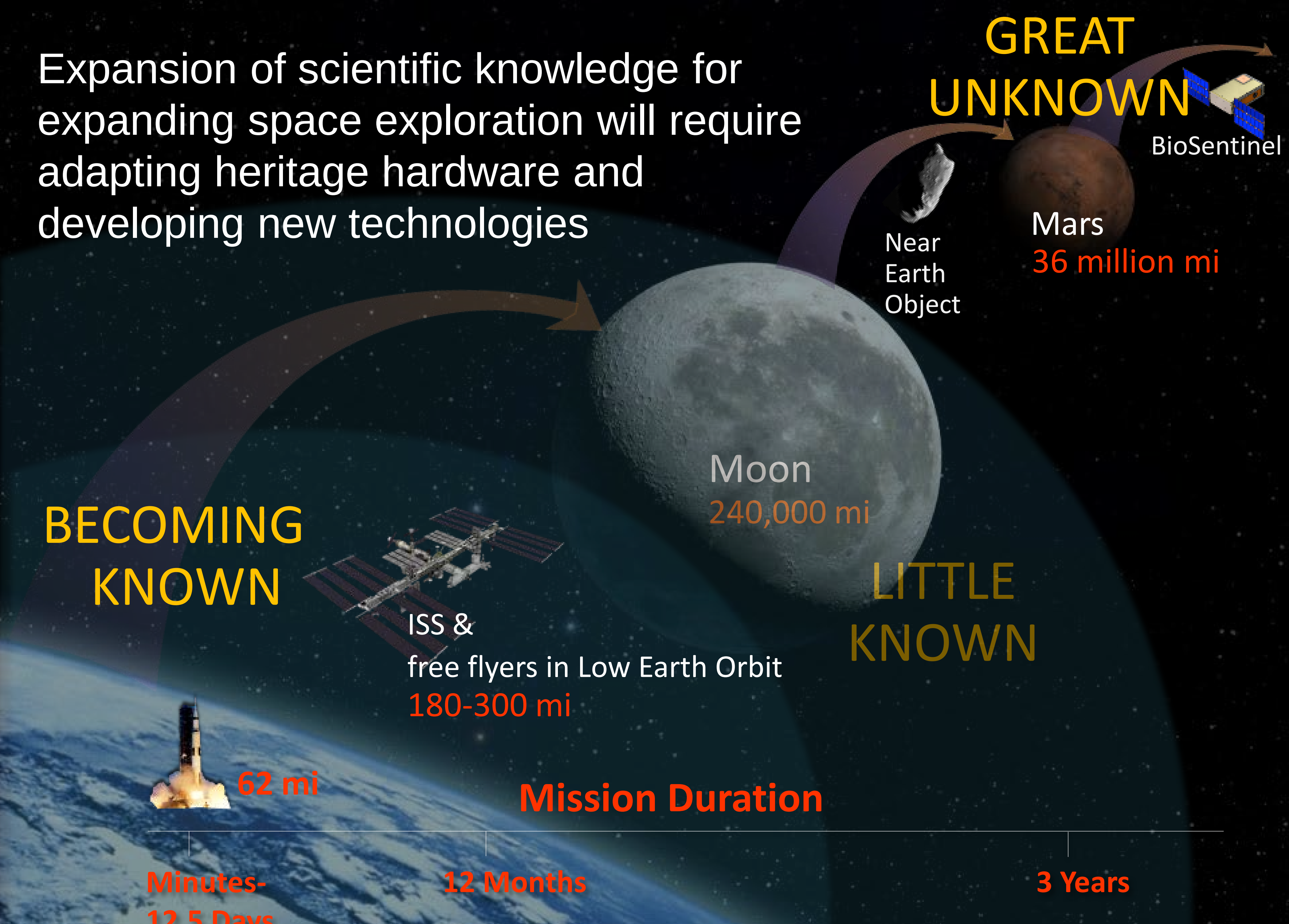
Proving Ground
- Go beyond low Earth Orbit

Space Missions: 2 to 3 years
Return: months

Earth Independent
- Expand Capabilites
- Explore Mars

The Unique Deep Space Environment: Microgravity + Deep Space Radiation



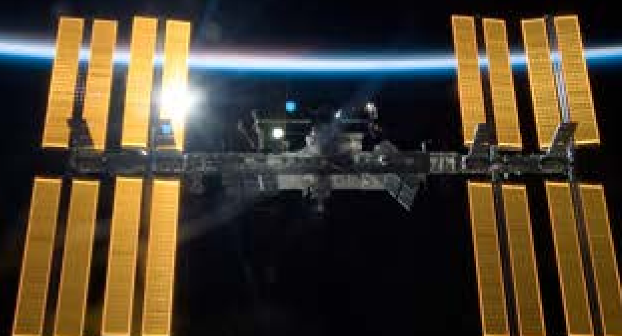

Expansion of scientific knowledge for expanding space exploration will require adapting heritage hardware and developing new technologies
GREAT UNKNOWN
BioSentinel
Near Earth Object
Mars
36 million mi
Moon
240,000 mi
BECOMING KNOWN
LITTLE KNOWN
ISS &
free flyers in Low Earth Orbit
180-300 mi
62 mi
Mission Duration
Minutes-
12.5 Days
12 Months
3 Years

Dr. Louis Yuge (University of Hiroshima; Space Bio-Laboratories, Co., Ltd.)

Dr. Yumi Kawahara (Space Bio-Laboratories, Co., Ltd.)

AS ONE

NASA ARC and KSC
- WetLab-2
- Bioculture System
- Veggie



Techshot

Thank You