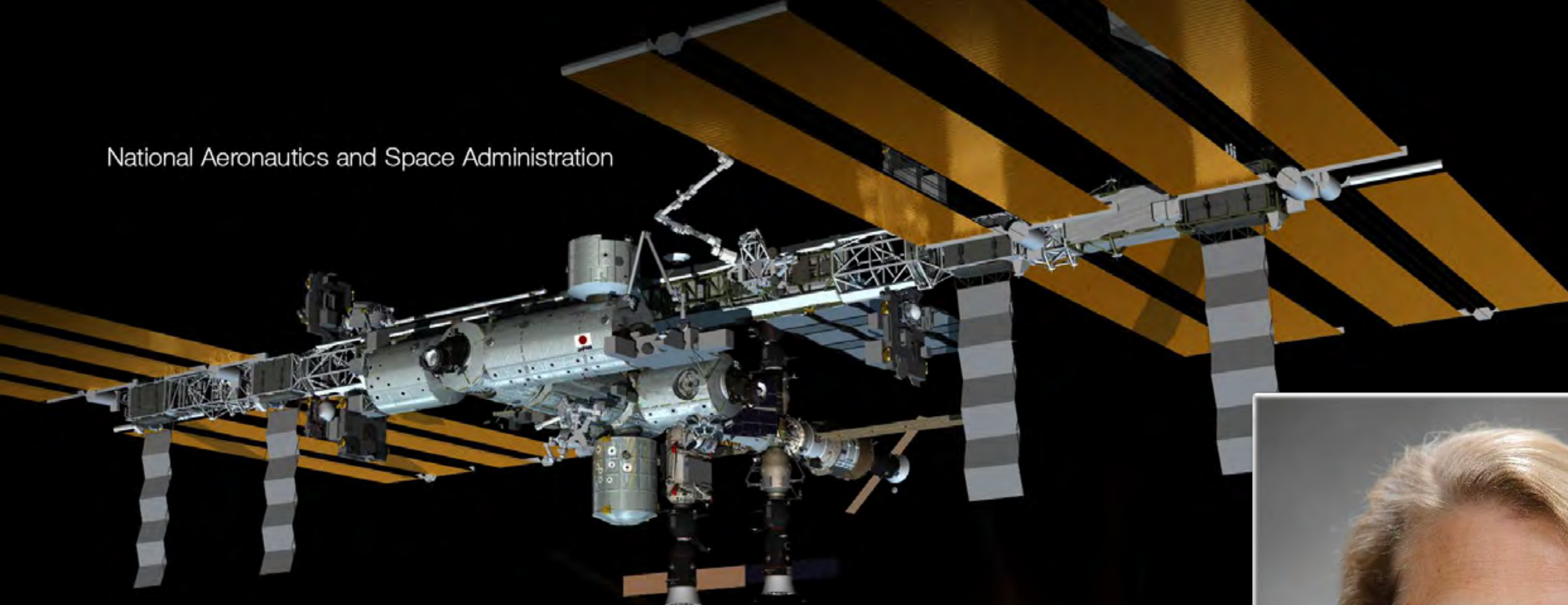


Space Biophysics:
Accomplishments, Trends, Challenges

Bensen Memorial Lecture
Miami University
7 April 2015

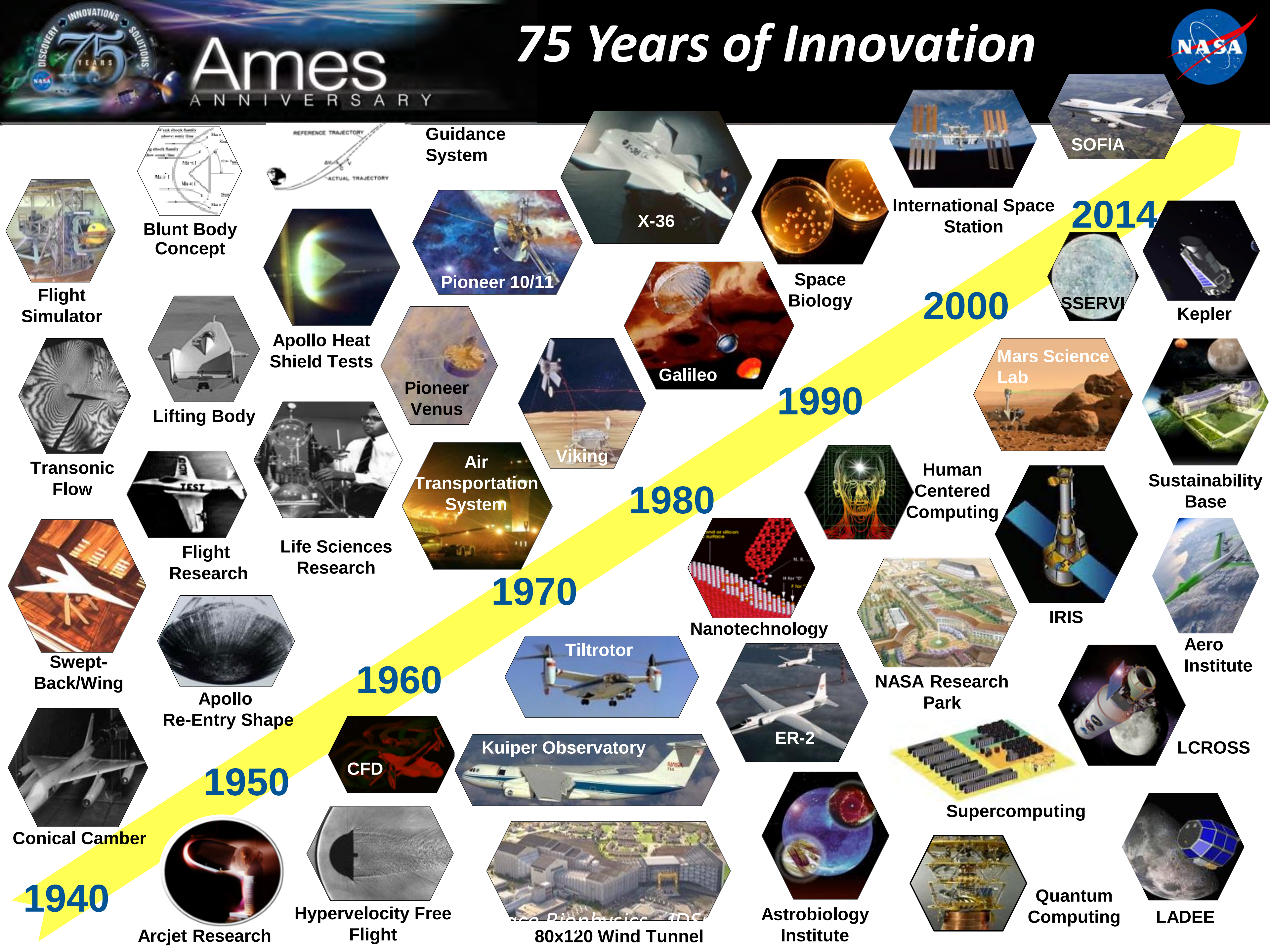
Space Biophysics - JDSmith

Dr. Jeffrey D. Smith
Space Biology Manager
NASA Ames Research Center
Moffett Field, CA

Jeffrey D. Smith, NASA Ames Research Center

Abstract

Physics and biology are inextricably linked. All the chemical and biological processes of life are dutifully bound to follow the rules and laws of physics. In space, these physical laws seem to turn on their head and biological systems, from microbes to humans, adapt and evolve in myriad ways to cope with the changed physical influences of the space environment. Gravity is the most prominent change in space that influences biology. In microgravity, the physical processes of sedimentation, density-driven convective flow, influence of surface tension and fluid pressure profoundly influence biology at the molecular and cellular level as well as at the whole-body level. Gravity sensing mechanisms are altered, structural and functional components of biology (such as bone and muscle) are reduced and changes in the way fluids and gasses behave also drive the way microbial systems and biofilms grow as well as the way plants and animals adapt. The radiation environment also effects life in space. Solar particle events and high energy cosmic radiation can cause serious damage to DNA and other biomolecules. The results can cause mutation, cellular damage or death, leading to health consequences of acute radiation damage or long-term health consequences such as increased cancer risk. Space Biophysics is the study and utilization of physical changes in space that cause changes in biological systems. The unique physical environment in space has been used successfully to grow high-quality protein crystals and 3D tissue cultures that could not be grown in the presence of unidirectional gravitational acceleration here on Earth. All biological processes that change in space have their root in a biophysical alteration due to microgravity and/or the radiation environment of space. In order to fully-understand the risks to human health in space and to fully-understand how humans, plants, animals and microbes can safely and effectively travel and eventually live for long periods beyond the protective environment of Earth, the biophysical properties underlying these changes must be studied, characterized and understood. This lecture reviews the current state of NASA biophysics research accomplishments and identifies future trends and challenges for biophysics research on the International Space Station and beyond.


Ames
ANNIVERSARY
INNOVATIONS
DISCOVERY
SOLUTIONS
75 YEARS
75 Years of Innovation
NASA
1940
1950
1960
1970
1980
1990
2000
2014
Flight Simulator
Blunt Body Concept
Guidance System
X-36
Space Biology
International Space Station
SOFIA
Kepler
SSERVI
Pioneer 10/11
Apollo Heat Shield Tests
Lifting Body
Transonic Flow
Pioneer Venus
Viking
Galileo
Mars Science Lab
Sustainability Base
Human Centered Computing
IRIS
Air Transportation System
Life Sciences Research
Flight Research
Swept-Back/Wing
Nanotechnology
NASA Research Park
Aero Institute
Apollo Re-Entry Shape
Tiltrotor
ER-2
LCROSS
Conical Camber
CFD
Kuiper Observatory
Supercomputing
Arcjet Research
Hypervelocity Free Flight
80x120 Wind Tunnel
Astrobiology Institute
Quantum Computing
LADEE

NASA Ames Research Center

Space Biology at NASA Ames

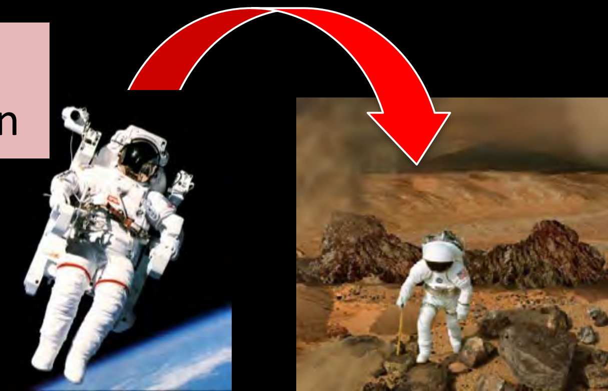
What is Space Biology?

Hypothesis-driven, discovery-based biological science in space and associated technology development

Why do we do it? So We Can:

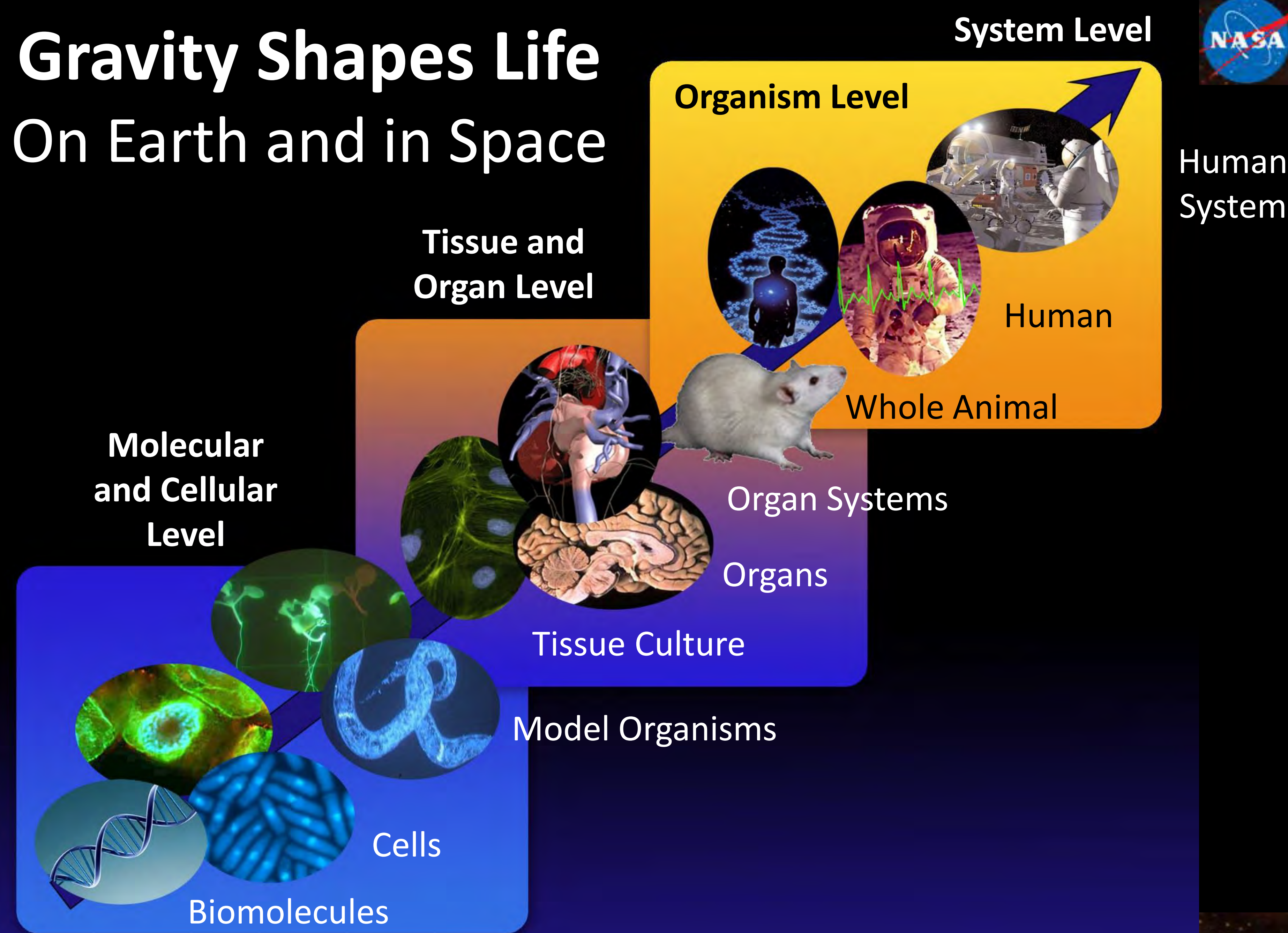
- Travel further than we've ever been and live safely beyond the protection of Earth
- Discover how gravity and space shape life, and
- Enable breakthroughs to improve life on Earth

Enabling Exploration

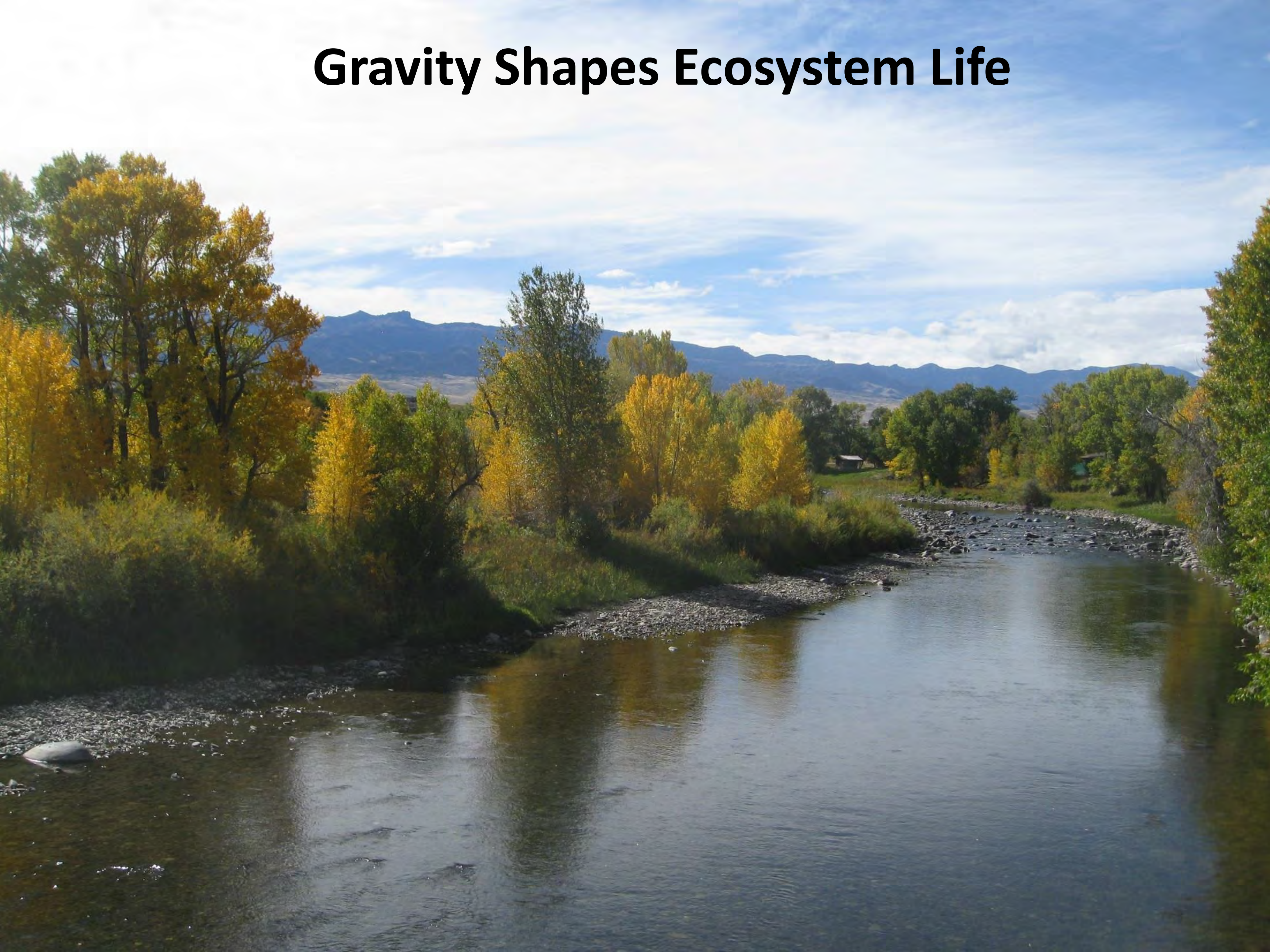


Making New Discoveries

Improving Life on Earth


Gravity Shapes Life
On Earth and in Space
System Level
Organism Level
Human System
Human
Whole Animal
Tissue and Organ Level
Organ Systems
Organs
Tissue Culture
Molecular and Cellular Level
Model Organisms
Cells
Biomolecules

Gravity Shapes Ecosystem Life



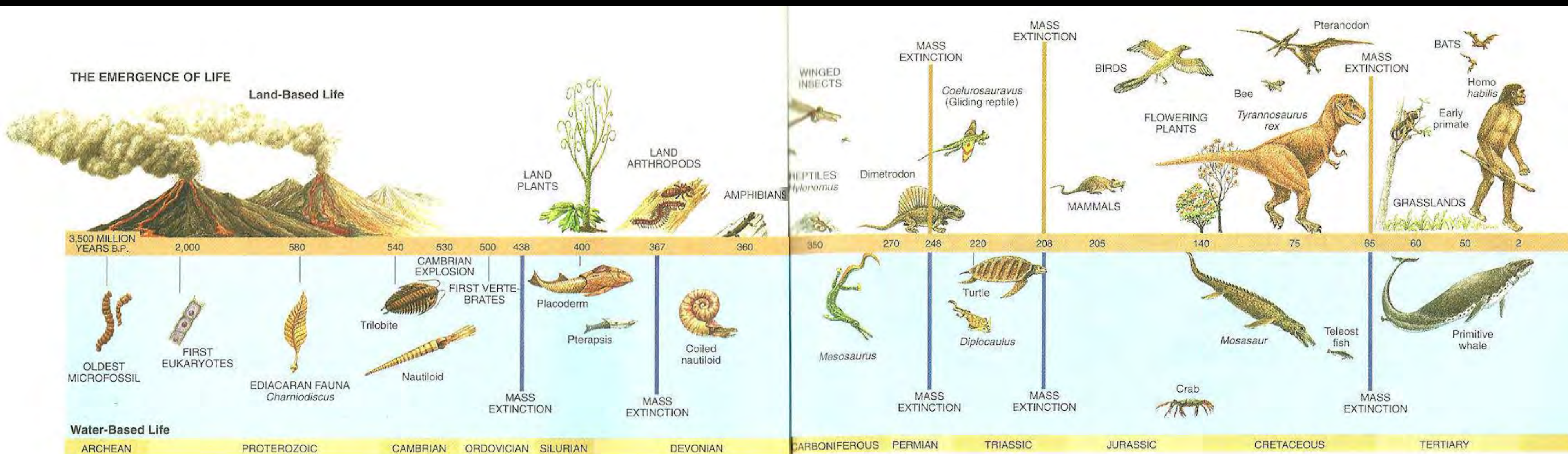

Gravity Moves
Mountains

Gravity Carves Canyons


Gravity Shifts The Sea

Gravity Drives Weather and Climate

For approximately 3.5 Billion years, the ever-constant 9.8 m/s^2 acceleration of gravity has shaped every aspect of life on Earth



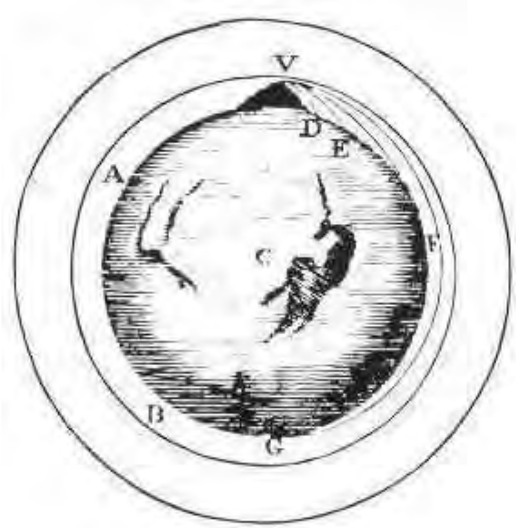
https://universe-review.ca/F10-multicell01.htm

Everything Changes for Life in Space

Forces In Life

- In space, changes in the physical environment are at the root of all known biological adaptations
- Many physical influences directly affect biological systems:
  - Acceleration Fields: Loading and Unloading
  - Hydrostatic Pressure, Buoyancy and Sedimentation
  - Convective Flow of Gasses and Liquids
  - Surface Tension
  - Space Radiation
  - Other: Temperature, Atmospheric Pressure and Atmospheric Composition

“Microgravity” in Orbit Is Not Absence of Gravity



Isaac Newton, ***Principia Mathematica*** (1687)

Earth Orbital Velocity

$$v = \sqrt{\frac{GM}{r}} = \sim 17{,}000 \text{ miles/hr}$$

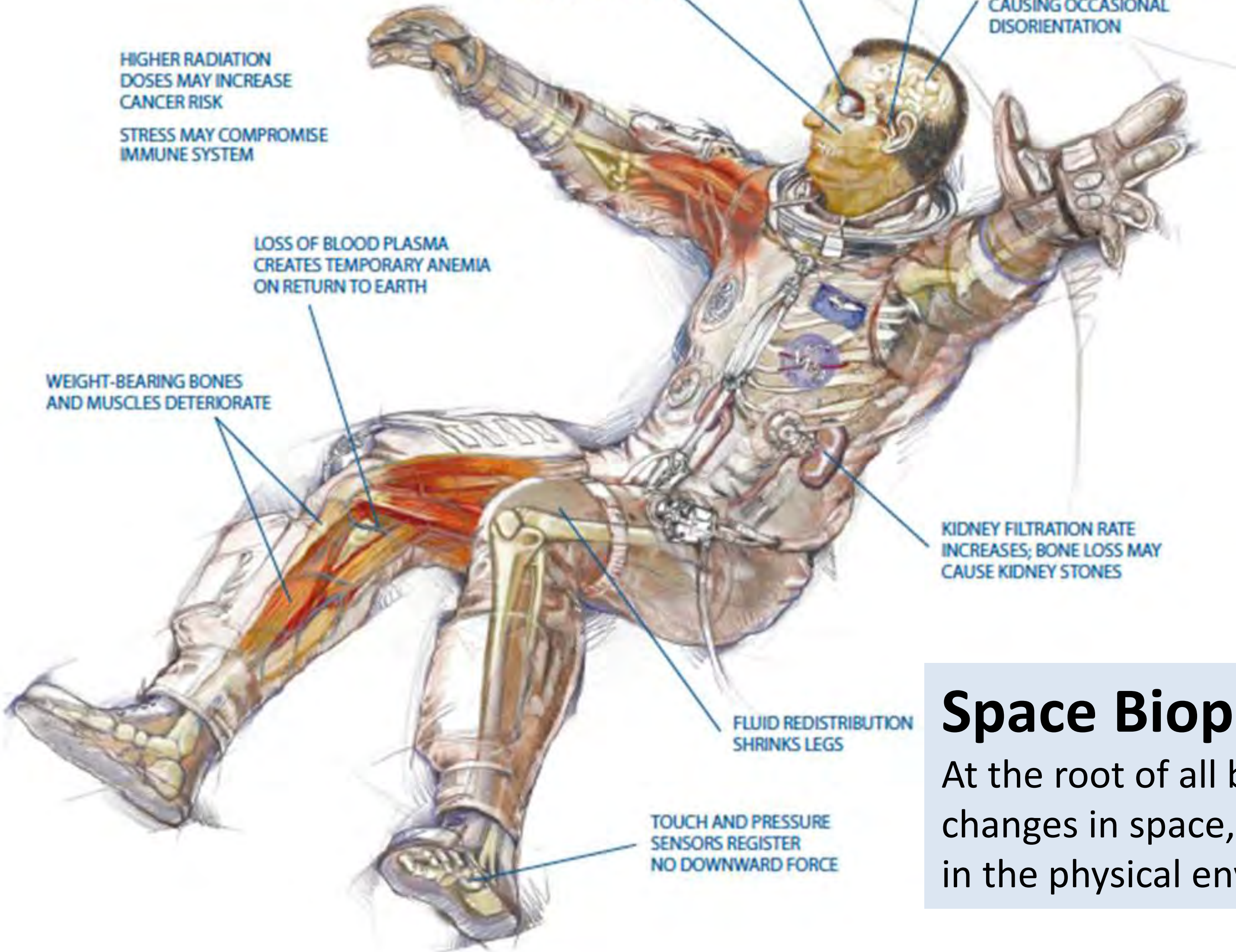
v = Velocity (m/s)
M = Mass (5.972×10^{24} kg)
r = radius (6371000 + 400000 m)
G = Gravitational Constant (6.67384×10^{-11} $m^3/(kg \cdot s^2)$)

Edward White during Gemini 4 performing EVA; he was the first American to “walk” in space (June 1965)

Gravitational Acceleration At the Space Station

$$a = G\frac{M_e}{r^2} = 8.69 \text{ m/s}^2$$

Weightlessness and the Human Body



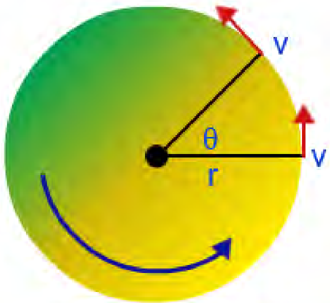
Space Biophysics

At the root of all biological changes in space, are changes in the physical environment

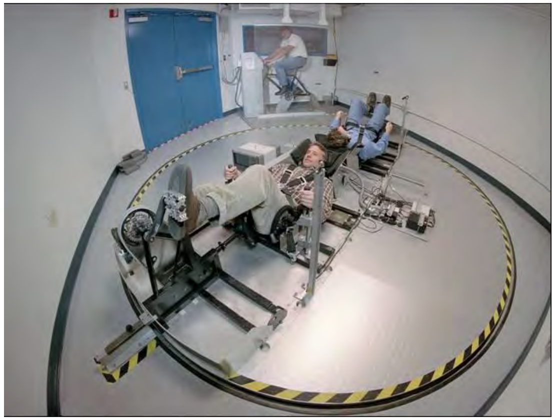
Figure from the article by Ronald J. White, "Weightlessness and the Human Body," Scientific American, Sept. 1998

Acceleration Fields: Loading and Unloading

- Linear Acceleration
- Angular Acceleration
- Vibration



$\omega = \frac{v}{r}$ $\alpha = \frac{d\omega}{dt}$



Shuttle 3*g*L:2*g*R

Soyuz 4*g*L:4*g*R

Moon 1/6*g*

Mars 3/8*g*

Hydrostatic Pressure, Buoyancy and Sedimentation

Buoyant Force

Force due to Acceleration = Gravity Force - Buoyancy Force - Drag Force

Sedimentation velocity by Stoke's Law

The fastest settling particles are huge, heavy, spherical molecules. The slowest settling particles, which sometimes cannot be settled accurately or properly, are tiny, light, irregularly shaped molecules.

Complications for Biology

Flocculation, or "clumping," of particles into spherical shapes

Autocoagulation due to mineral or chemical traits inherent in the particle

http://www.rpi.edu/dept/chem-eng/Biotech-Environ/SEDIMENT/sedsettle.html

BUOYANT FORCE

$$F_G = (\rho_P - \rho)\, g\, V_P$$

- ρ_P: density of particle
- ρ: density of fluid
- g: gravitational constant
- V_P: volume of particle

DRAG FORCE

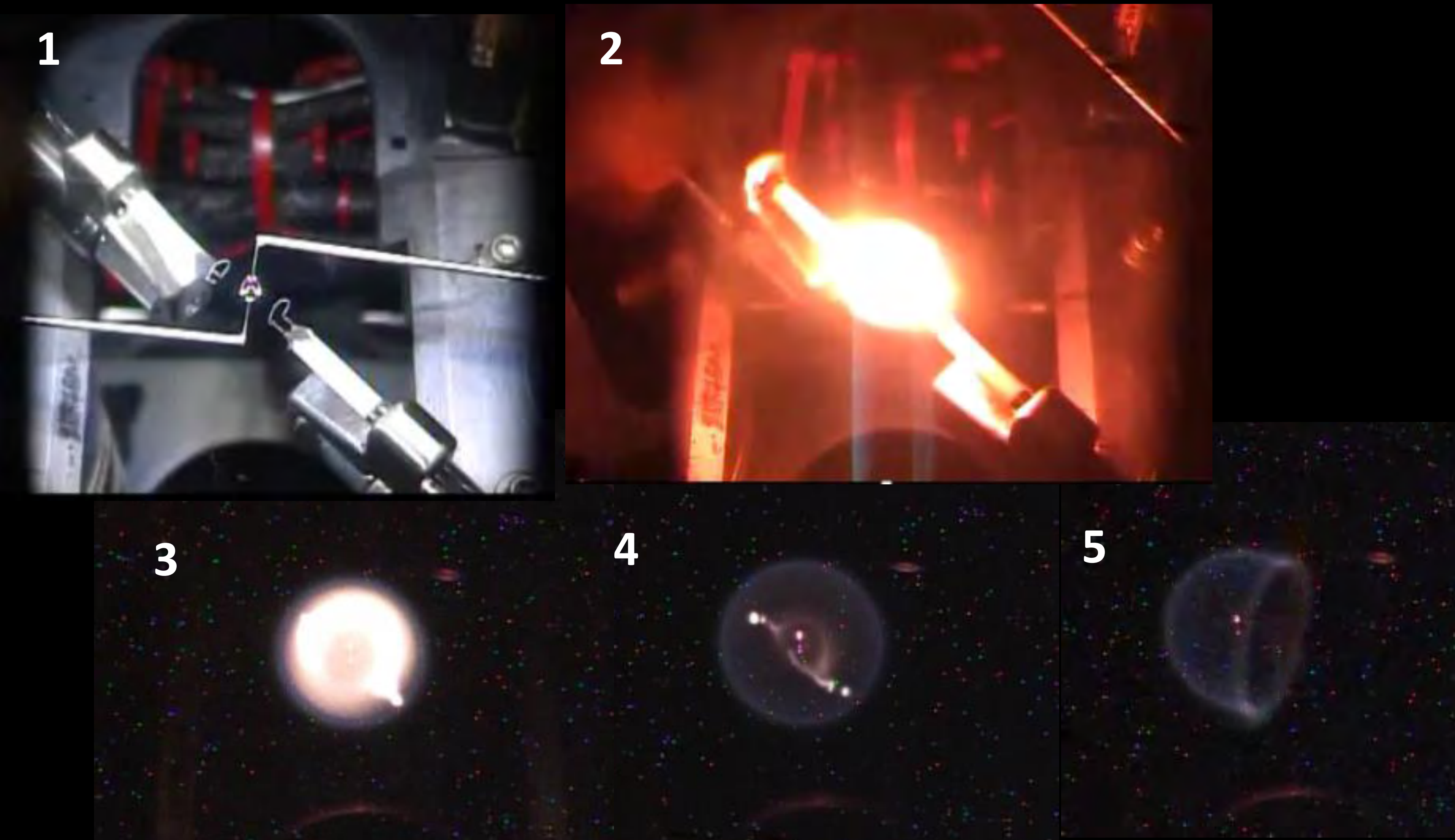
$$F_D = \frac{C_D A_P \rho v_S^2}{2}$$

- C_D: drag coefficient
- A_P: area of particle
- ρ: fluid
- v_S: settling velocity

$$v_S = \frac{g(\rho_P - \rho) D_P^2}{18\mu}$$

- μ: fluid viscosity
- D_P: particle diameter

Convective Flow of Gasses and Liquids

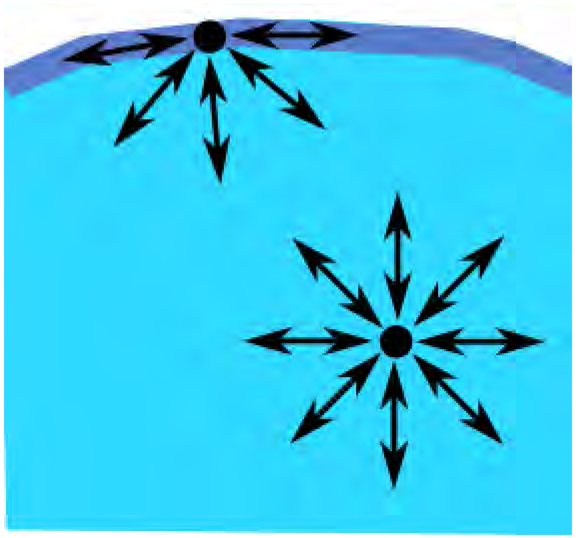


Flame Extinguishment Experiment - 2 (FLEX-2)

http://www.nasa.gov/mission_pages/station/research/experiments/480.html

Surface Tension and Biophysics in Space

Surface Tension

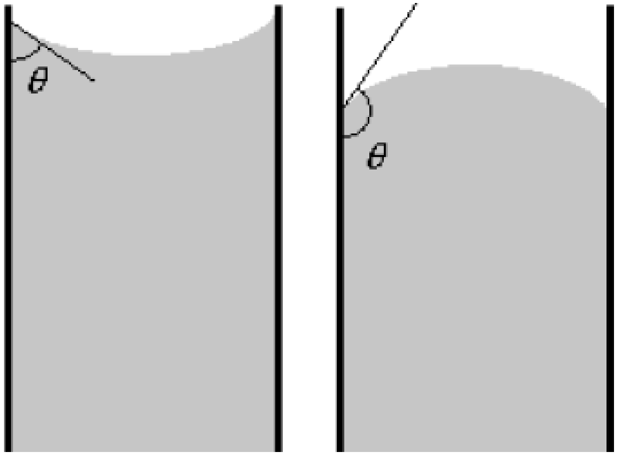


Public domain, from Wikipedia.org

Surface tension (γ) is defined as the ratio of the surface force (*F)* to the length (*d)* along which the force acts

$$\gamma = F / d \text{ (dyne/cm)}$$

Contact Angle



Public domain, from Wikipedia.org

Contact angle is related to the liquid-solid surface tension (γ_{ls}) and the liquid-gas surface tension (γ_{lg})

$$\gamma_{ls} = -\gamma_{lg} \cos(\theta)$$

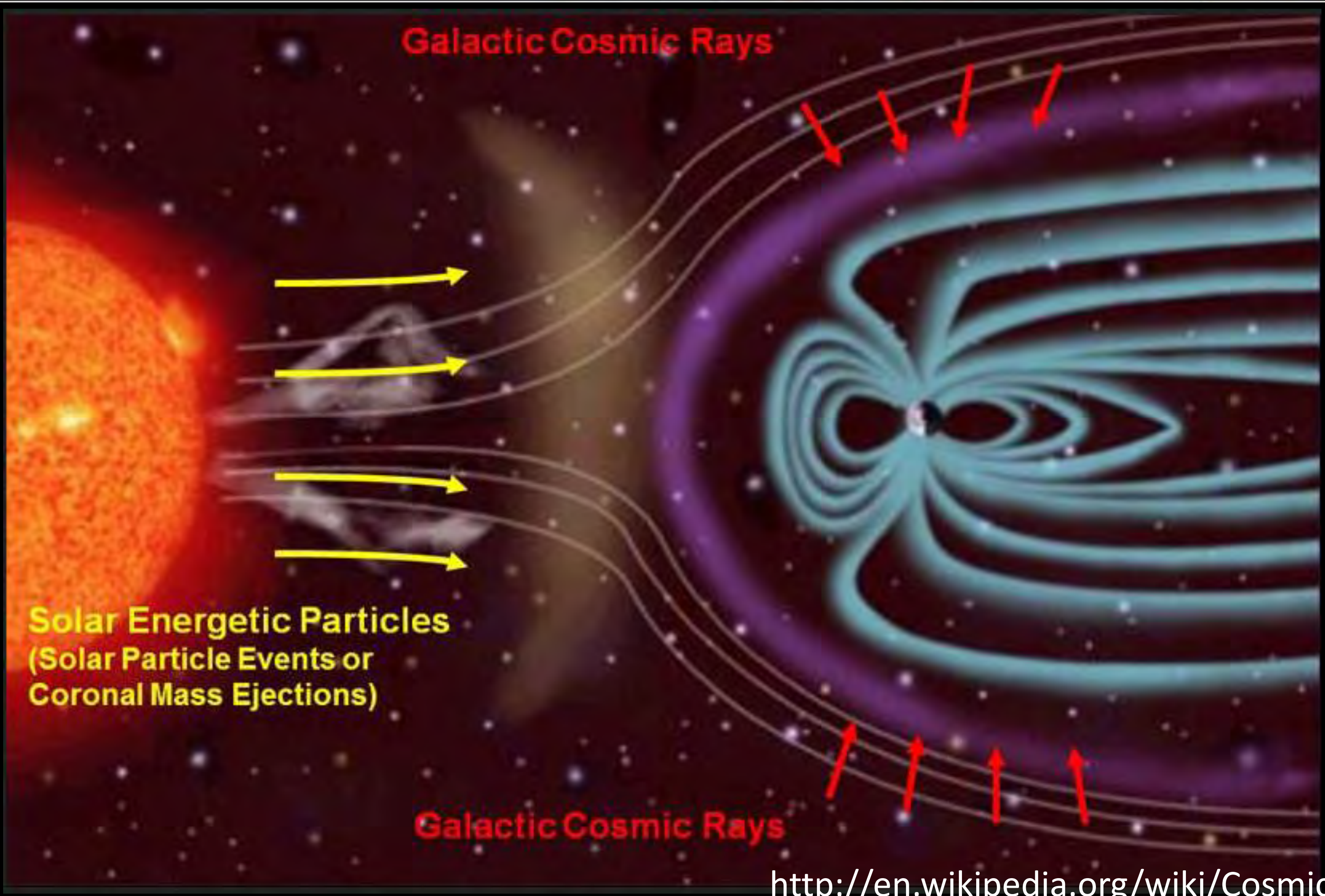
about education http://physics.about.com

Drinking Tea in Space

Astronaut, Don Pettit, takes advantage of capillary flow from surface tension to drink a cup of tea on ISS

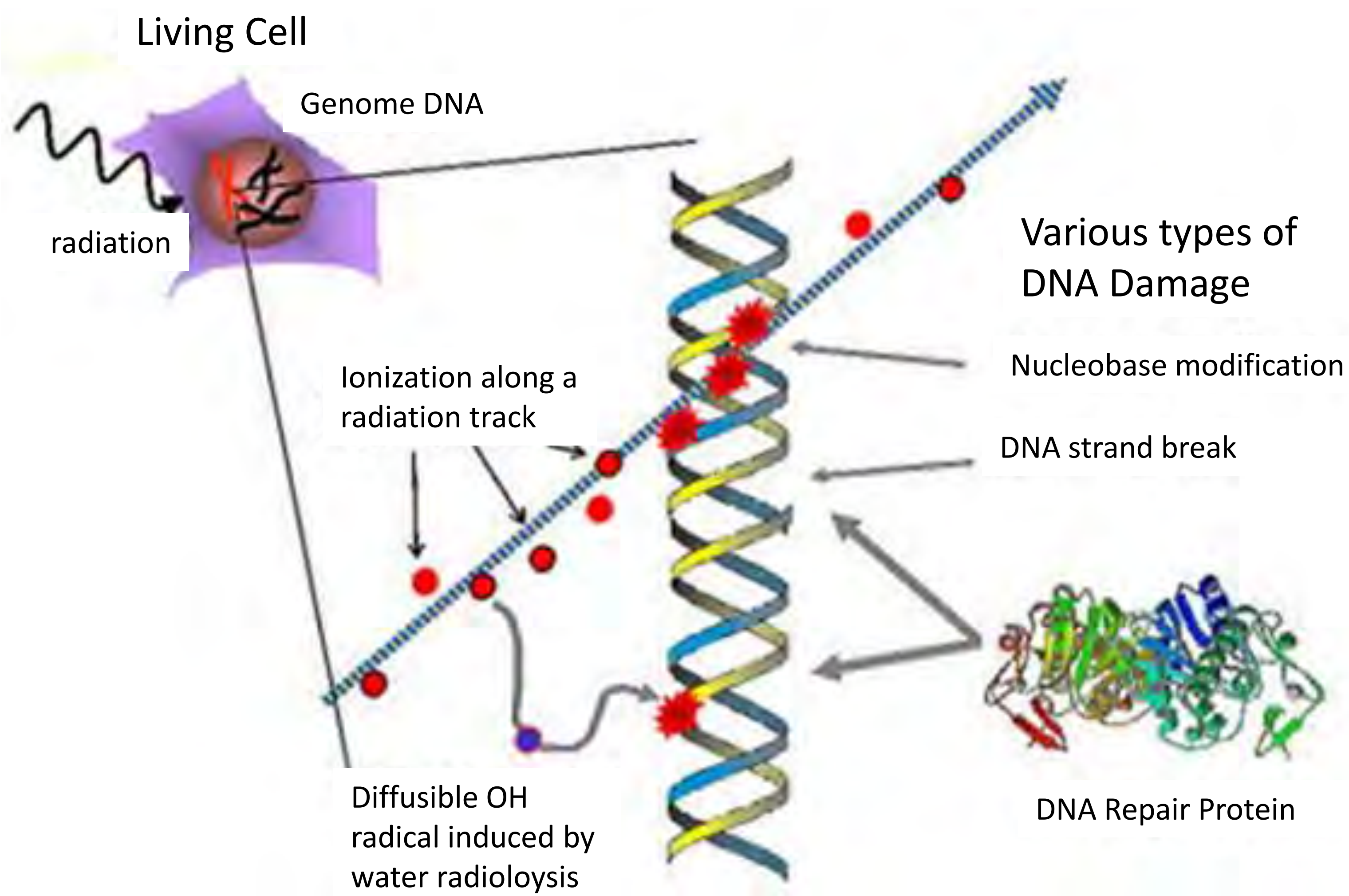
http://www.geek.com/news/how-do-astronauts-drink-tea-with-capillary-action-tea-cups-of-course-1509793/

Space Radiation



http://en.wikipedia.org/wiki/Cosmic_ray

Space Radiation Damage to DNA and its Enzymatic Repair



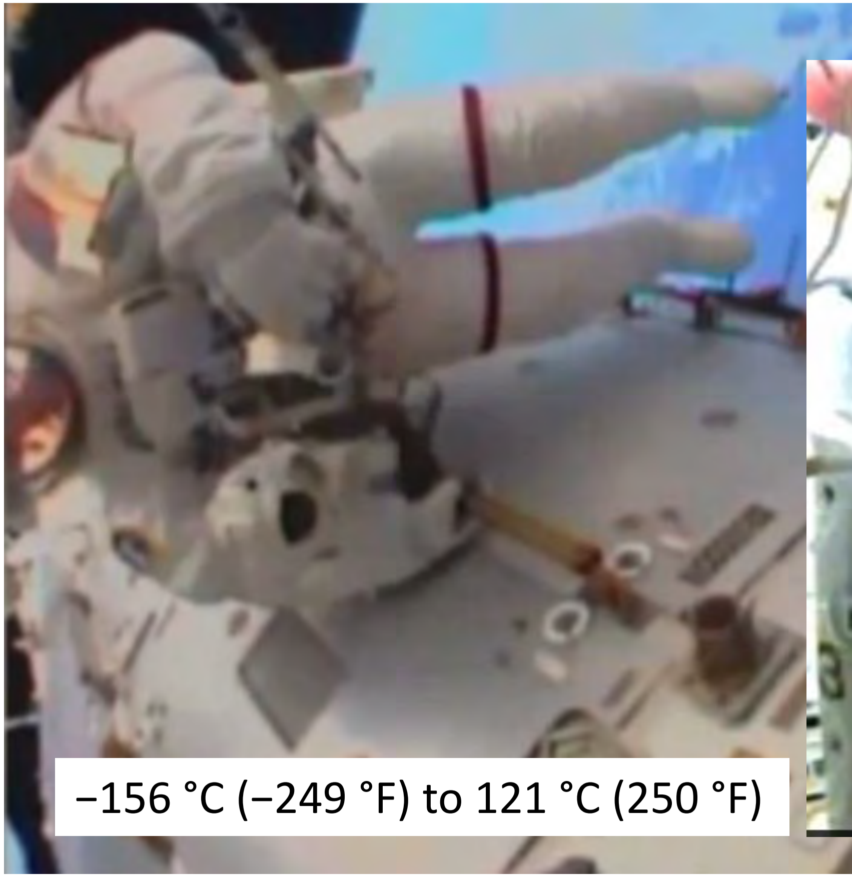
http://asrc.jaea.go.jp/soshiki/gr/eng/mysite6/index.html


ROLL

Temperature, Pressure, Atmosphere

10.2 psi (6,100ft) atmosphere in EMU

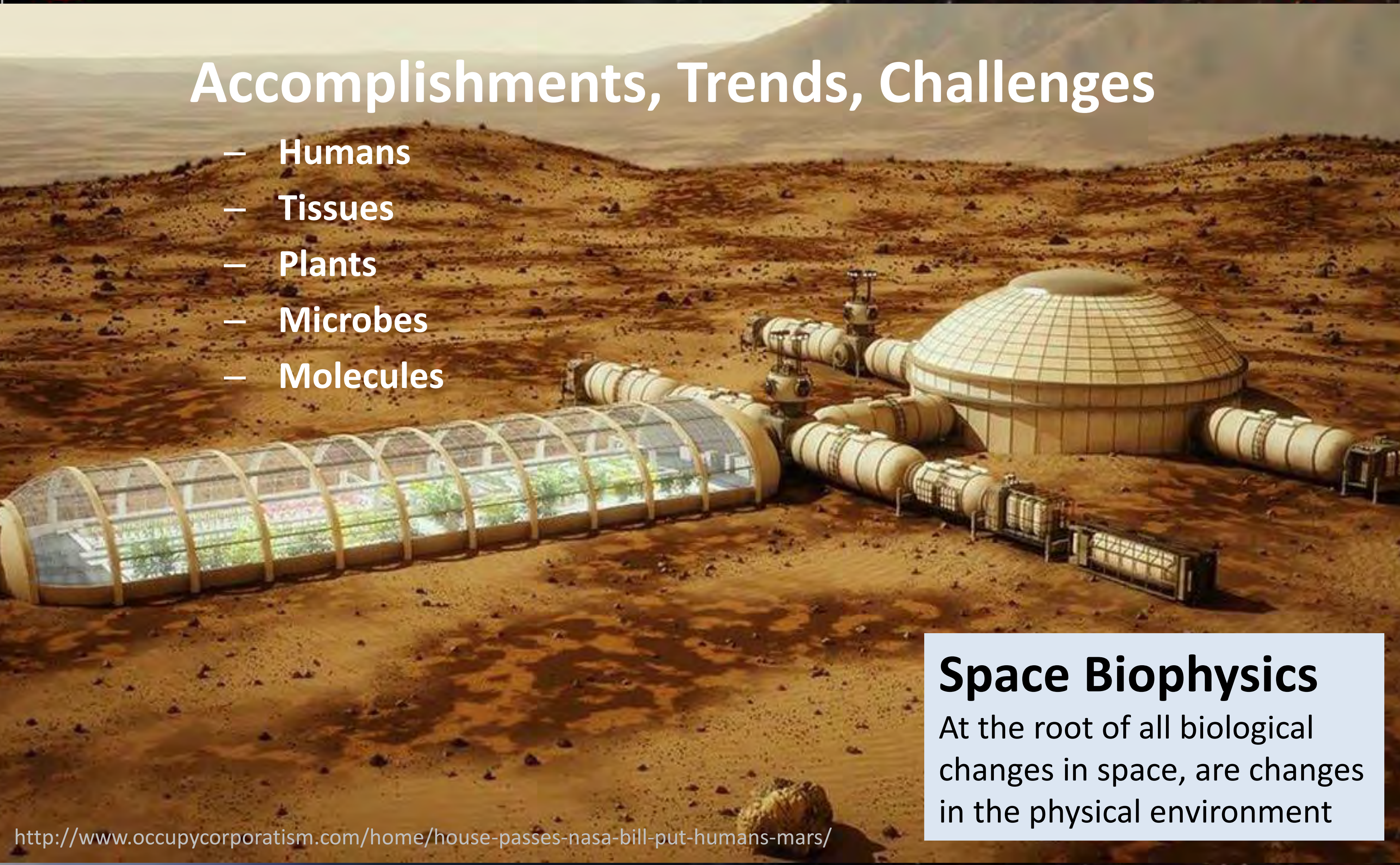
100% Oxygen



14.7 psi (sea level) atmosphere in ISS

21% Oxygen, 78% Nitrogen 3K-10K ppm CO2

Italian astronaut Luca Parmitano discovered water accumulation in the helmet of his spacesuit and needed to return to the ISS (July 2013)



Accomplishments, Trends, Challenges

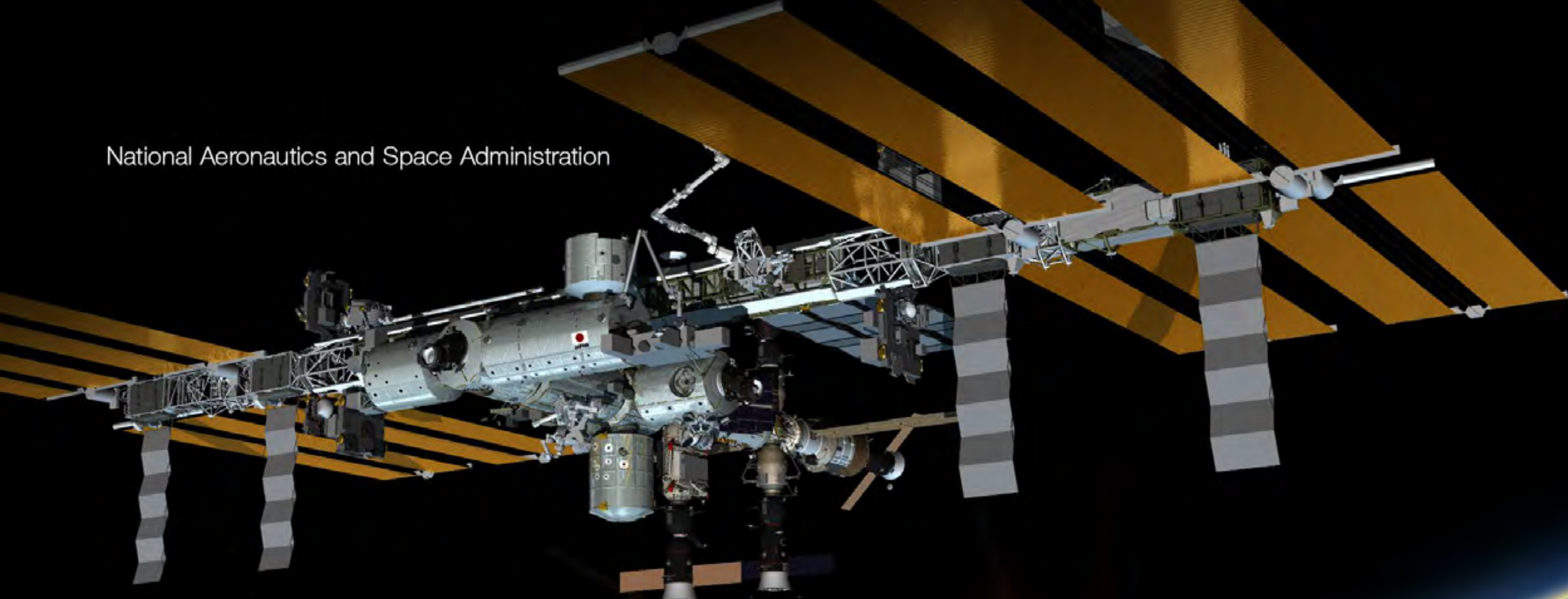
- Humans
- Tissues
- Plants
- Microbes
- Molecules

Space Biophysics

At the root of all biological changes in space, are changes in the physical environment

http://www.occupycorporatism.com/home/house-passes-nasa-bill-put-humans-mars/

National Aeronautics and Space Administration



Space Biophysics:

Accomplishments, Trends, Challenges

Human Systems Biology

Accomplishments in Space Biophysics: Human Systems Biology

Human Research Roadmap

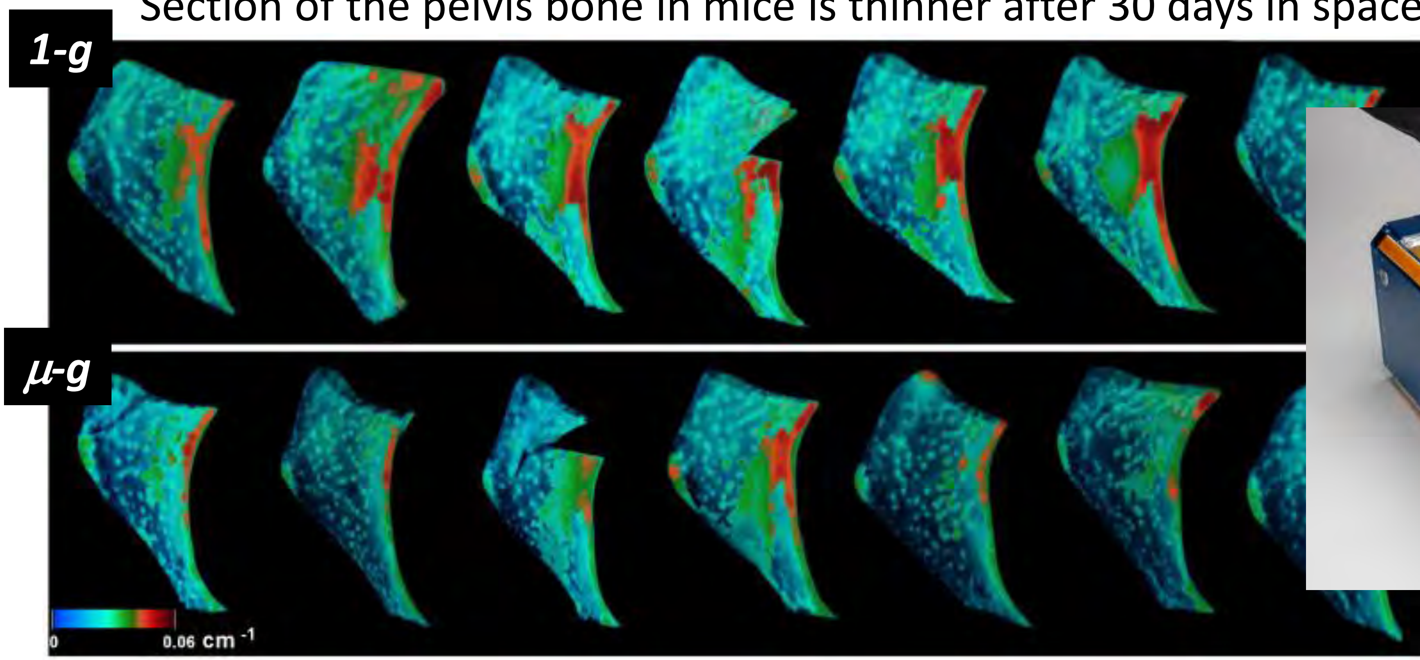
http://humanresearchroadmap.nasa.gov/

Accomplishments in Space Biophysics: Human Systems Biology

Bone

Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density will stabilize at a lower level, or continue to diminish. It is also unknown if fractional gravity, present on the moon and Mars would mitigate the loss.
http://humanresearchroadmap.nasa.gov/Evidence/reports/Bone%20Fracture.pdf

Section of the pelvis bone in mice is thinner after 30 days in space



ISS Rodent Habitat

Blaber *et. al.*, ***PLoS ONE*** 8(4): e61372. doi:10.1371/journal.pone.0061372

Accomplishments in Space Biophysics: Human Systems Biology

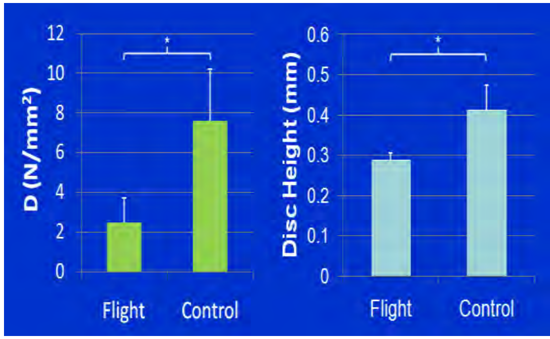
Animal Research in Space Applied to Human Health

- ***"Spaceflight impairs the ability of the cerebral circulation to precisely control brain blood flow." Bion - M1***

  - **M. Delp's results with mice flown for 30d on Bion-M1 suggests a mechanism that may contribute to the temporary or permanent vision problems experienced by ISS astronauts**. (S. Sofronova et al. Spaceflight on the Bion-M1 Biosatellite Alters Cerebral Artery Vasomotor and Mechanical Properties in Mice, J. Appl. Physiol, in press Jan. 2015)

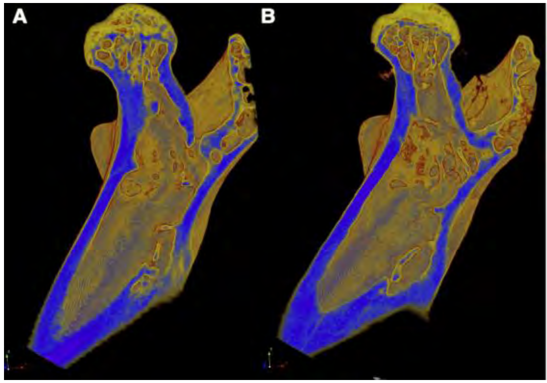
- ***"Microgravity effectively diminished biomechanical properties of caudal discs" Bion - M1***

  - **A. Hargens' results with mice on the Bion-M1 mission indicate that the deleterious effects on the caudal discs in the spine may underlie cervical versus lumbar disc herniation rates that are observed among astronauts. Future studies are warranted to explore the rate and effect of recovery post landing, i.e., are the effects of spaceflight reversible?** (J. Bailey et al, Effect of microgravity on the biomechanical properties of lumbar and caudal intervertebral discs in mice. J. Biomechanics, 47:2983-2988:2014)



- ***Mechanical unloading of mammalian tissues in microgravity can inhibit tissue growth and regeneration mechansms. STS-131***

  - **E. Blaber's results with mice flown on STS-131 indicate that the process of hematopoietic mesenchymal stem cell differentiation in bone marrow is profoundly altered under conditions of reduced mechanical load in microgravity, and a broad down-regulation in marrow differentiation capacity.** (E. Blaber et al. Mechanical unloading of bone in microgravity reduces mesenchymal and hematopoetic stem cell-mediated tissue regeneration.Stem Cell Res. 13:181-201:2014)



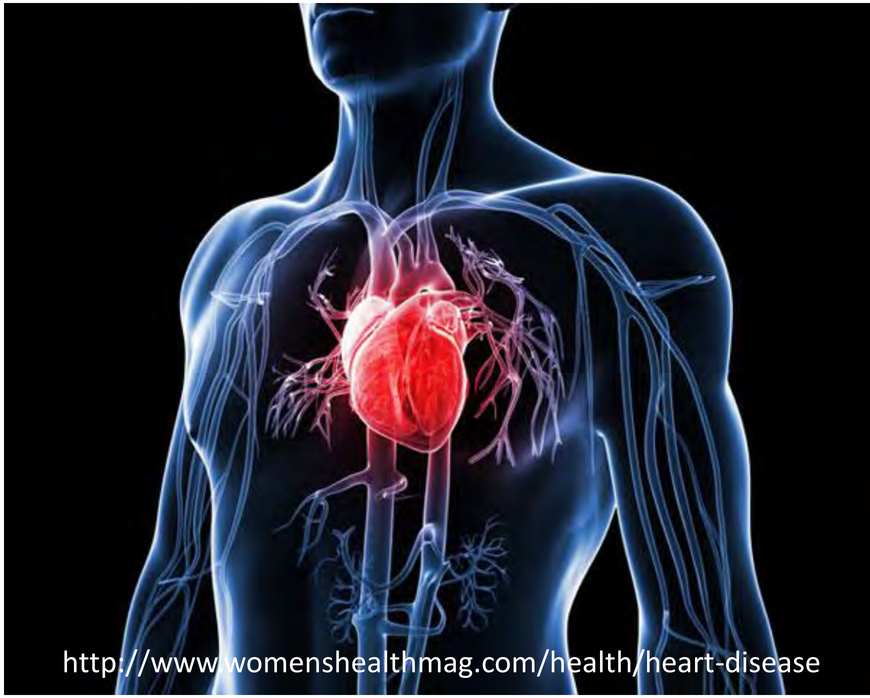
Muscle

There is growing research suggesting that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and structural and metabolic alterations during space flight. However, the relationships between in-flight exercise, muscle changes and performance levels are not well understood.

http://humanresearchroadmap.nasa.gov/Evidence/reports/Muscle.pdf

Dan Burbank on ARED

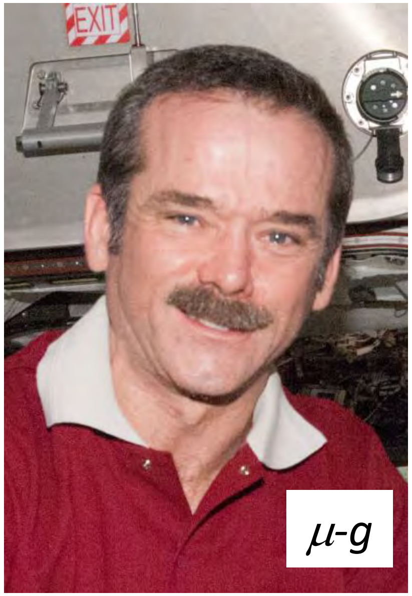
Suni Williams on TVIS



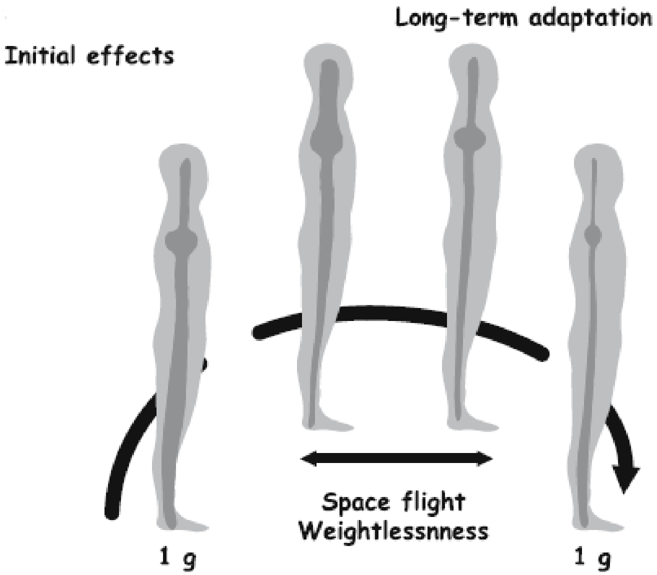
Heart Muscle: the most-altered in space

Fluid Shift

Postflight orthostatic intolerance, the inability to maintain blood pressure while in an upright position, is an established, space-flight-related medical problem. Countermeasures have been identified and implemented with some success (fluid loading, compression garments) or are being evaluated (midodrine & others). Completion of these efforts is essential for determining what preventive measures should be used to combat orthostatic intolerance during future long-term missions in LEO or to the Moon and Mars.
http://humanresearchroadmap.nasa.gov/Evidence/reports/Orthostatic.pdf



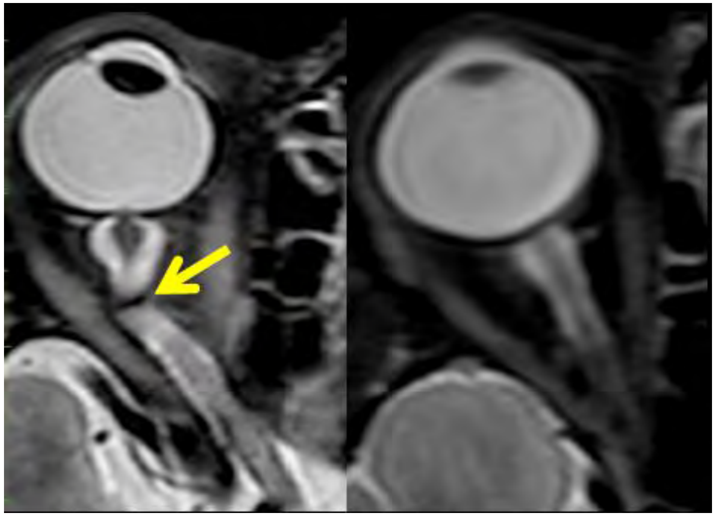
Chris Hadfield



Pavy-Le Traon et. al, Eur J Appl Physiol, 2007
DOI 10.1007/s00421-007-0474-z

Visual Impairment and Intracranial Pressure (VIIP)

Case reports of edema, globe flattening, papilledema, choroidal folds & optic nerve sheath abnormalities affecting vision in astronauts



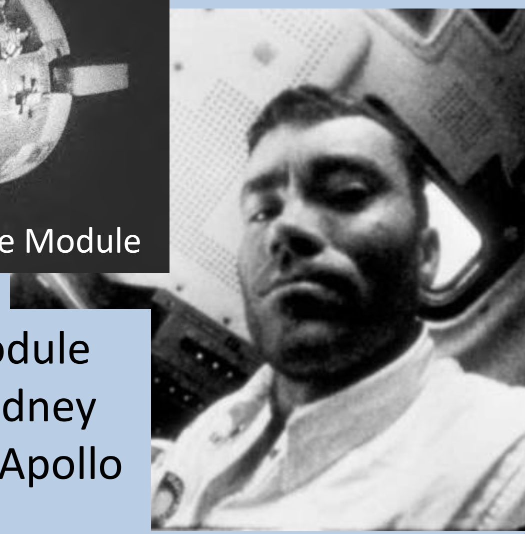
MRI (R+30 days) from long-duration spaceflight. Optic nerve kink on left (arrow). Control on right.

Mader et. al., ***Ophthalmology*** *2011;118:2058–2069*
doi:10.1016/j.ophtha.2011.06.021

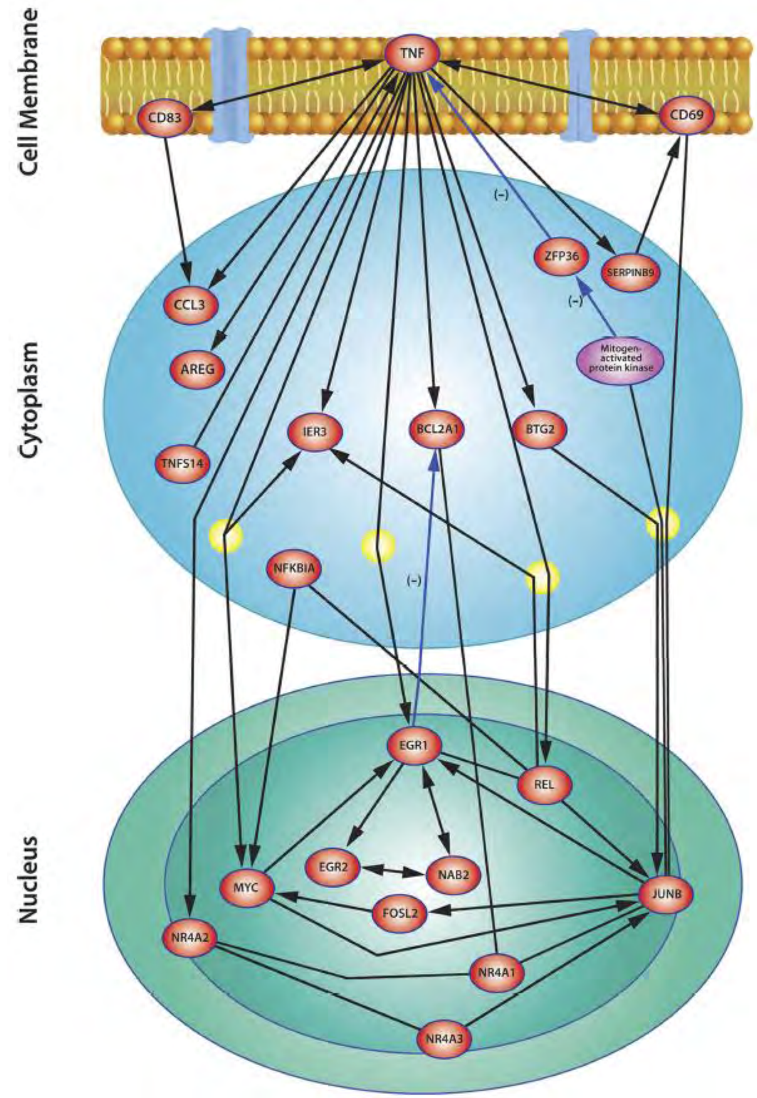
Using the Advanced Diagnostic Ultrasound in Microgravity (ADUM), ISS Expedition Commander Leroy Chiao performs an ultrasound examination of the eye on Flight Engineer Salizhan Sharipov (NASA)

Immune System Function

Apollo 13 Damaged Service Module



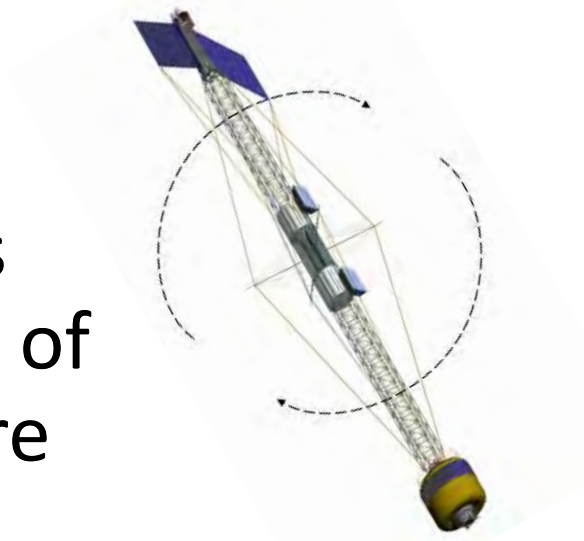
Fred Haise, lunar module pilot, contracted a kidney infection during the Apollo 13 mission (1970)



Pathway analysis of genes significantly inhibited in μg-activated samples by twofold or more compared with activation in 1g.

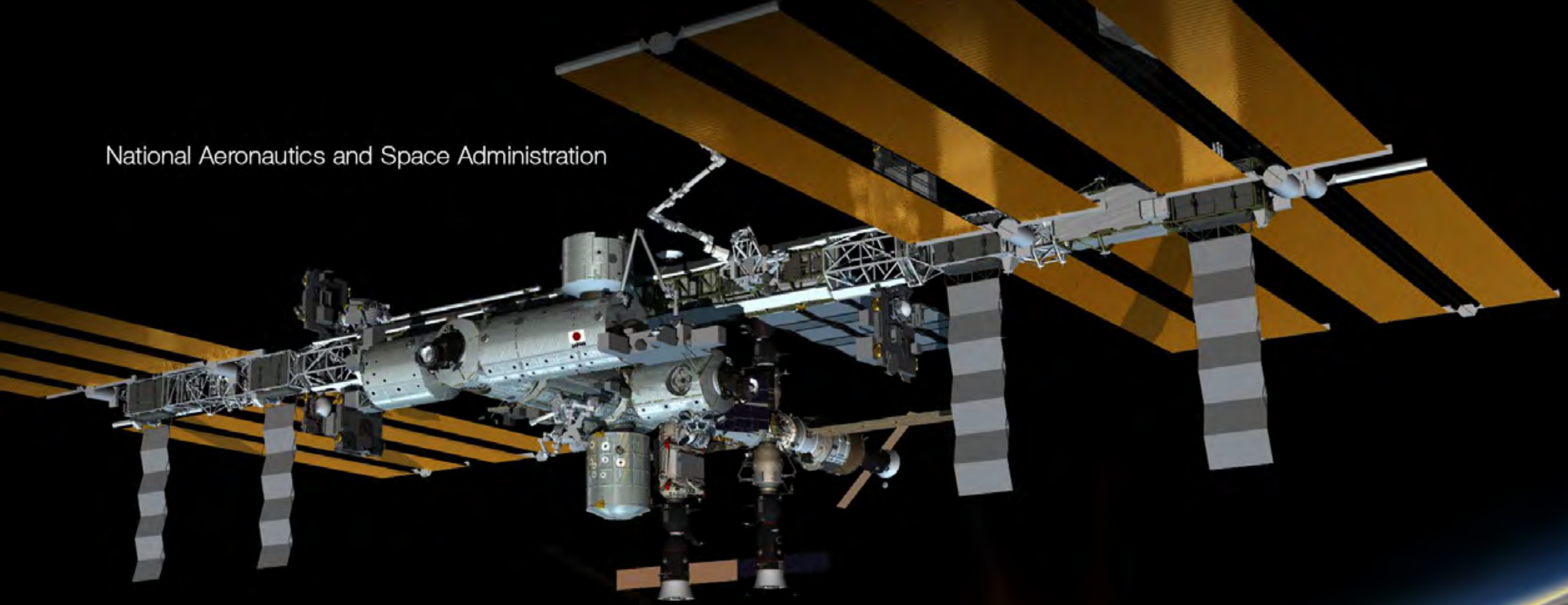
Chang et. al., 2012, J. Leuk. Biol, doi:10.1189/jlb.0312157

Challenges in Space Biophysics: Human Systems Biology



- Individualized Countermeasures
- Separation of the physical changes related to microgravity from those of radiation, pressure and atmosphere
- Understanding artificial gravity as a multi-system countermeasure
- Understanding the long-term effects of partial gravity and microgravity at the systems biology level

National Aeronautics and Space Administration



Space Biophysics:

Accomplishments, Trends, Challenges

Tissue Biology

Rotating Wall Bioreactor

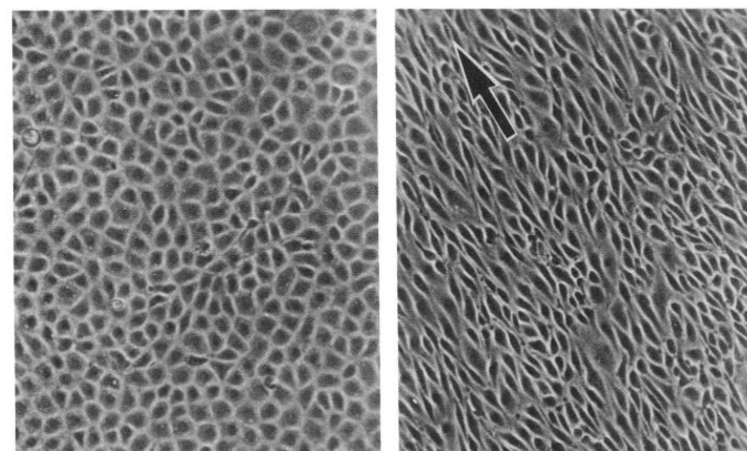
David Wolf fixes the rotating bioreactor in space

Endonovo Therapeutics

Rotating Wall Bioreactor

Fluid Sheer and micro-gravity effects at the cellular level

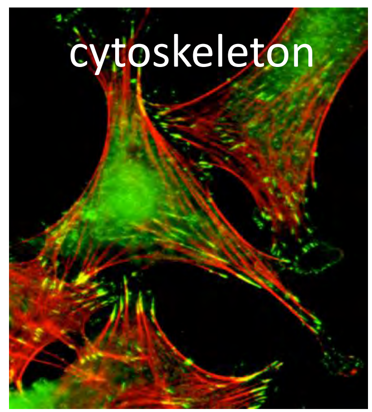
Confluent bovine aortic endothelial Cells exposed to fluid shear stress



Davies et. al., 1986, ***Proc. Natl. Acad. Sci.*** (**83**)2114-2117

Mechanisms of Stem Cell Differentiation and Proliferation in Microgravity

Microgravity alters stem cell-based tissue regenerative health, including, osteogenesis (bone), hematopoiesis (blood), and lymphopoeisis (immune) which can lead to degenerative health effects in space.
Blaber et. al., 2014, ***Stem Cells Dev.***
doi: 10.1089/scd.2014.0408



Quad Tissue Culture Module Assembly (QTCMA) 5 on ISS Expedition 4, used to grow human cells on ISS. Courtesy image from Marshall Space Flight Center (NASA ISS004E5210)

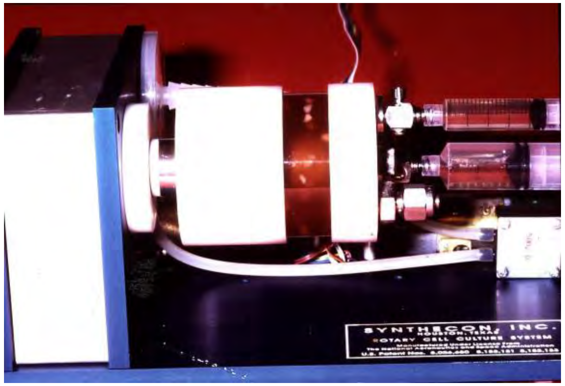
NASA Bioculture System (left) will be used to support a variety of cell culture research on ISS

Complex 3D Tissue Culture in Microgravity

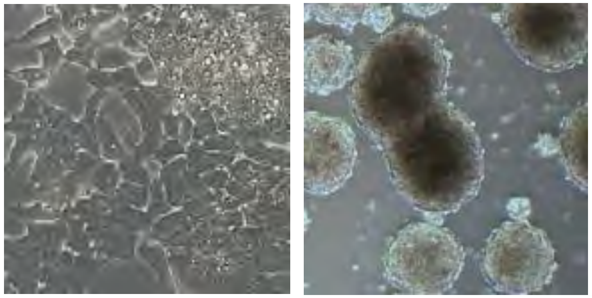
Problem and Solution in Space: Gravity limits the generation of large size organized cell cultures due to fluid shear. The absence of these physical forces in microgravity permits investigations of how different cell types freely associate to form complex multicellular structures.

Relevance of the Research: investigations of heterotypic cellular self-organization will provide invaluable insight into the governing principles that regulate ex vivo complex tissue formation and organ bioengineering.

- Microgravity may be a key tool that facilitates tissue engineering of complex 3D organs
- Microgravity may be used to develop better tissue models for drug development and studies of Earth-based diseases involving complex heterotrophic tissues such as cancer.



NASA. Image shows blocks of human lymphoid tissue being cultured in the Rotating Wall Vessel system.



Mouse Embryonic Stem Cells (left) differentiated into embrioid bodies (right) in space (Blaber et. al., 2014, ***Stem Cells Dev.*** doi: 10.1089/scd.2014.0408).

Challenges in Space Biophysics: Tissue Biology

Image credit: Wyss Institute.

- 3D tissue and organ culture
- Uncovering the underlying physical principles of aging

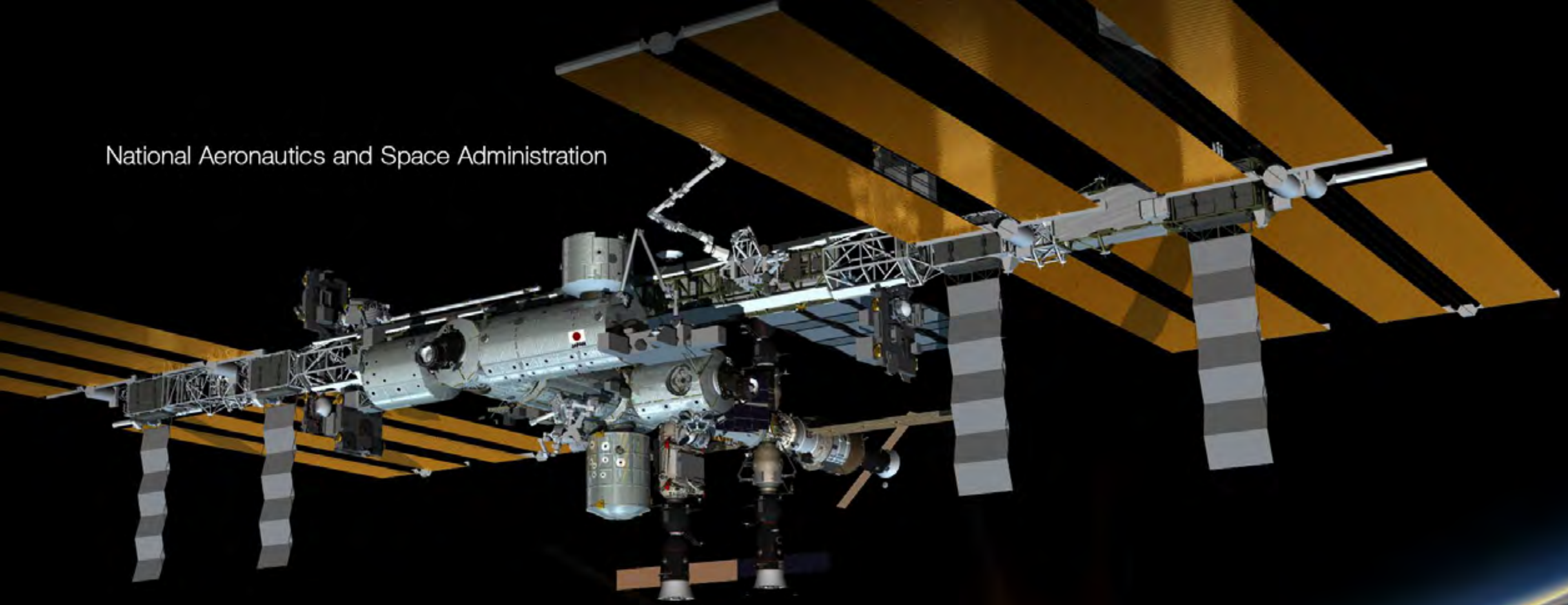
The abnormal physiology that manifests itself in healthy humans during their adaptation to the microgravity of space has all the features of accelerated aging.

The convergence of the disciplines of aging, along with gravitational and space physiology is advancing the understanding and prevention of modern lifestyle medical disorders.

Vernikos and Schneider, 2010, ***Gerontology*** 56(2):157-66. doi: 10.1159/000252852

Population Aging Research Center

National Aeronautics and Space Administration



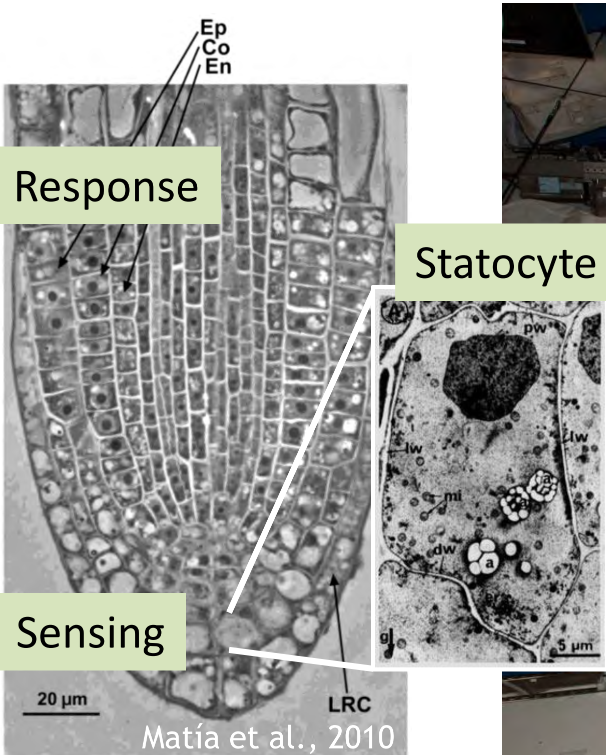
Space Biophysics:

Accomplishments, Trends, Challenges

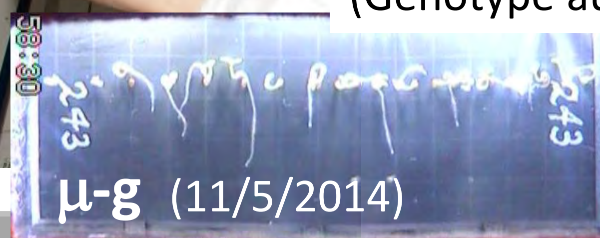
Plant Biology

Accomplishments in Space Biophysics: Plant Biology and Physiology

Accomplishments in Space Biophysics: Plant Biology, Gravity Sensing and Response



(Genotype aux 1.7 @ 88hr post hydration)



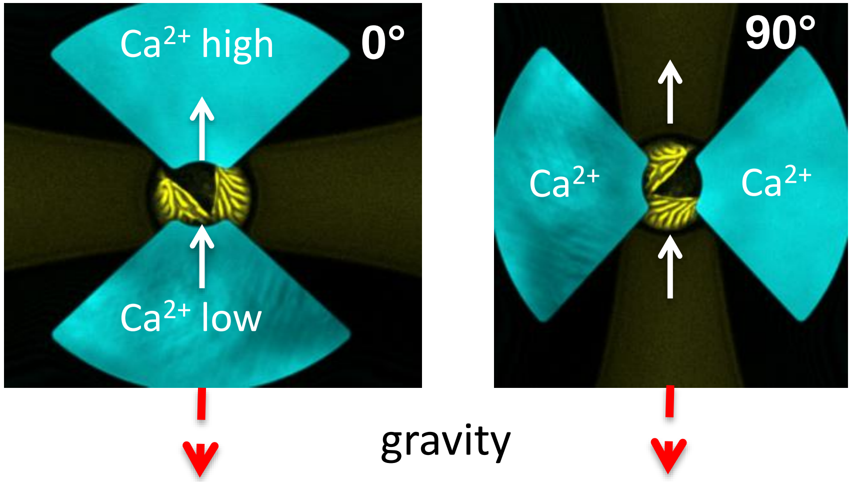
F. Javier Medina
Centro de Investigaciones Biológicas (CSIC)
Madrid, Spain

John Z. Kiss
University of Mississippi, USA

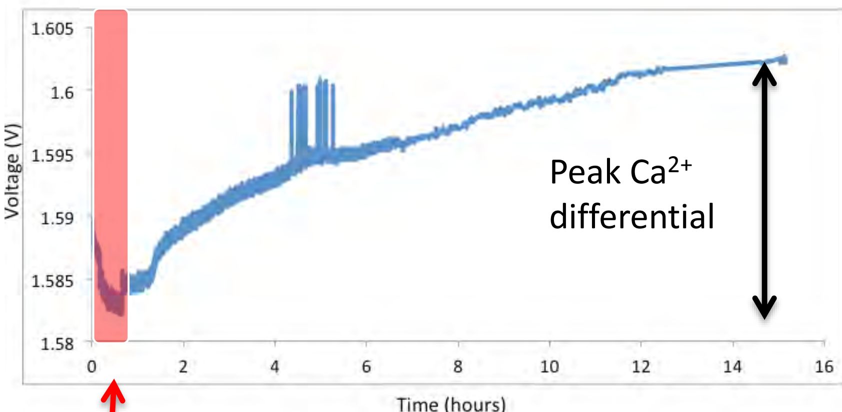
Trends in Space Biophysics: Plant Biology, CubeSat for Gravity Perception

Jenna L. Rickus, Purdue University
Stanley Roux, University of Texas

Spores coupled to electrodes in BioCD

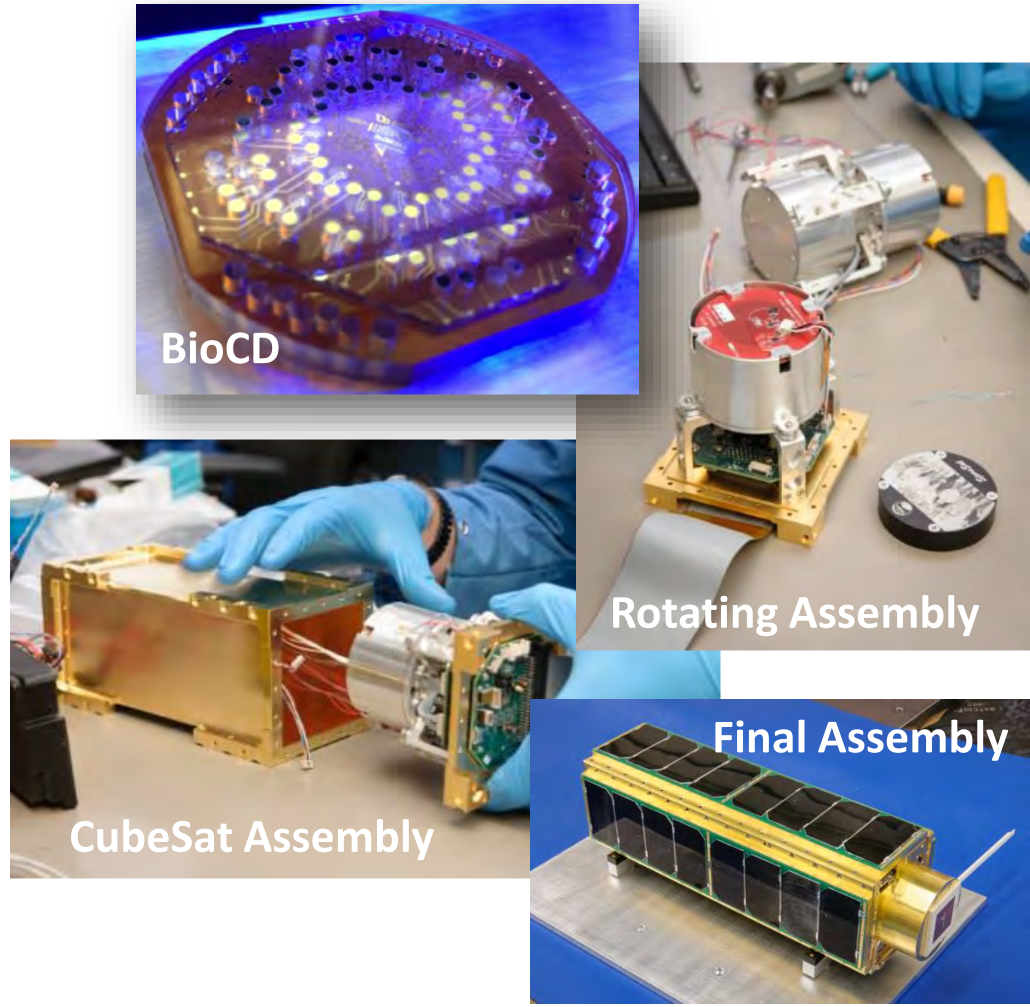


characteristic curve germinated spore

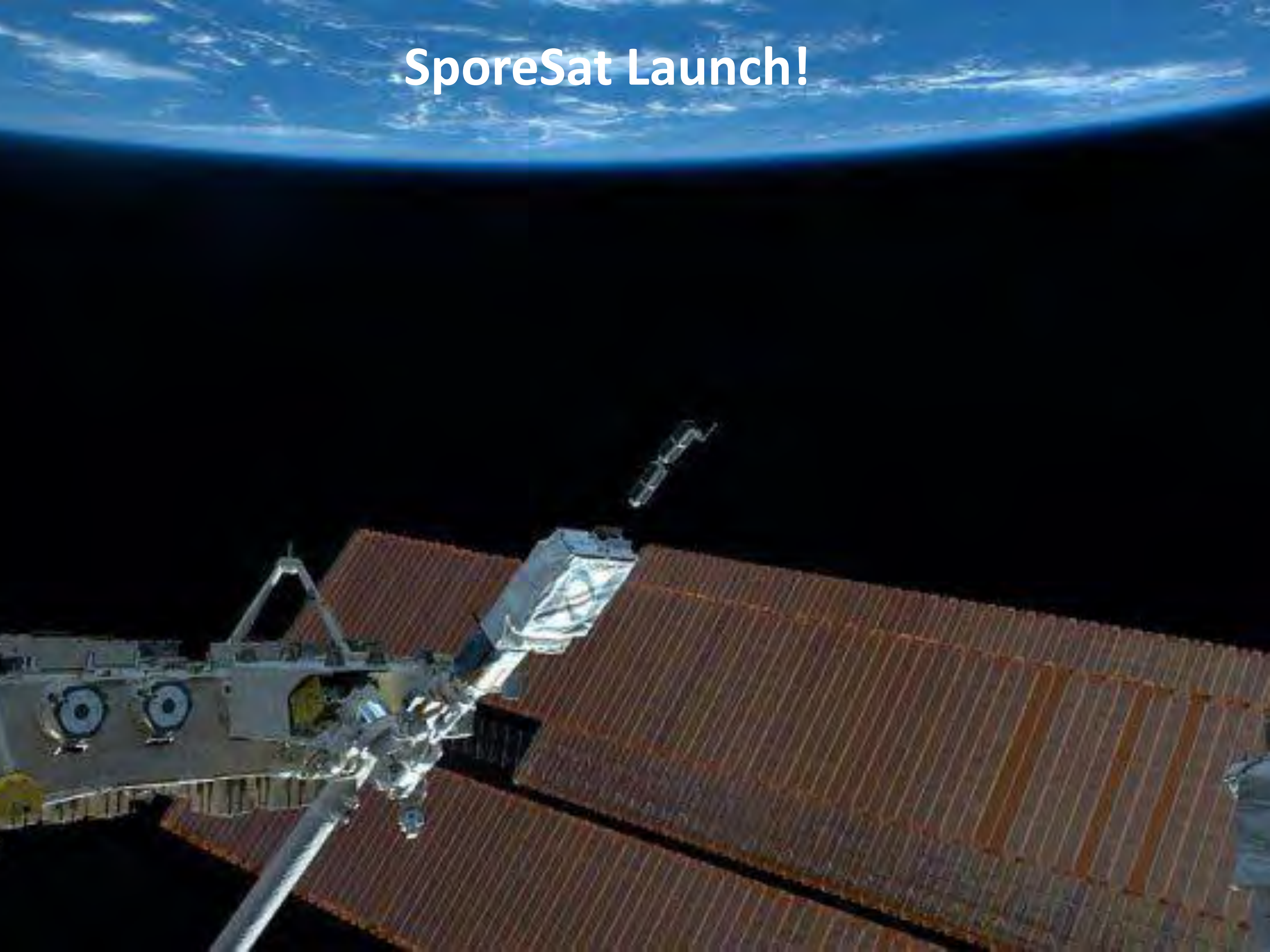


light

Calcium Current Signal



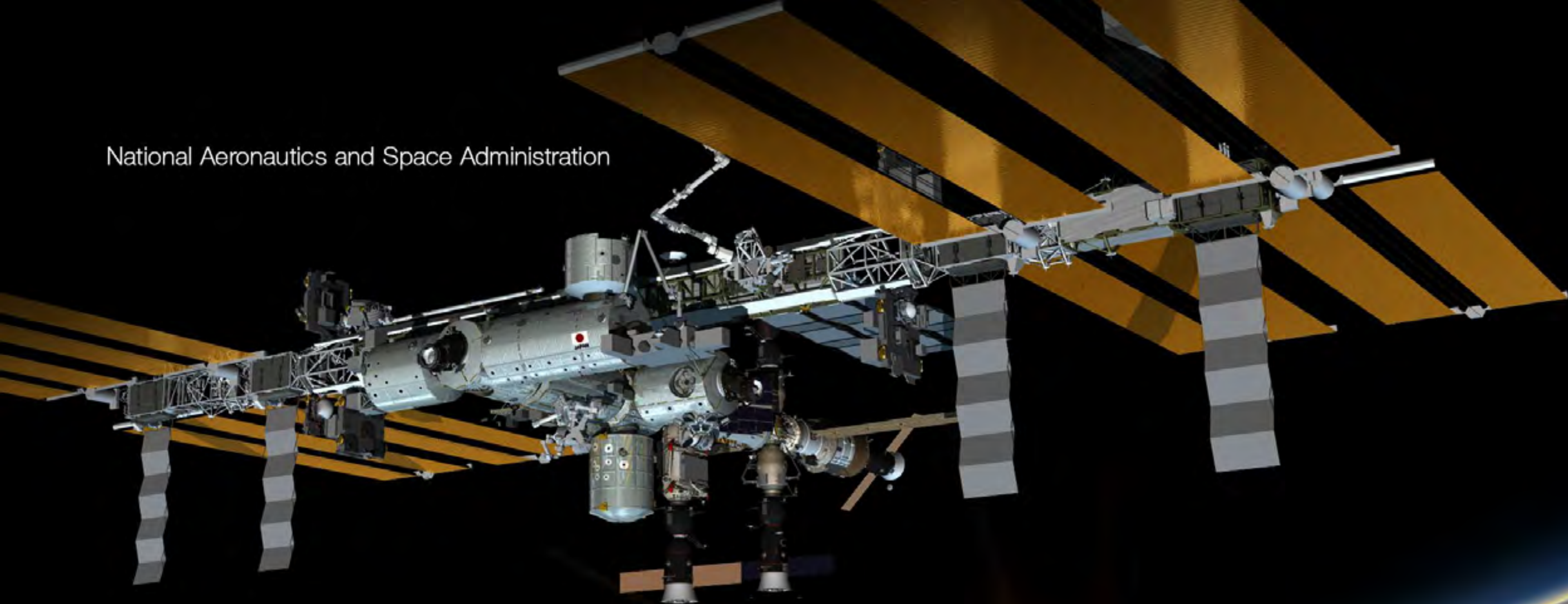
SporeSat Launch!



Challenges in Space Biophysics: Plant Biology

Bioregenerative life support as a combined physical and biological system with robust capability for long term space exploration

Credit: Pat Rawlings / NASA



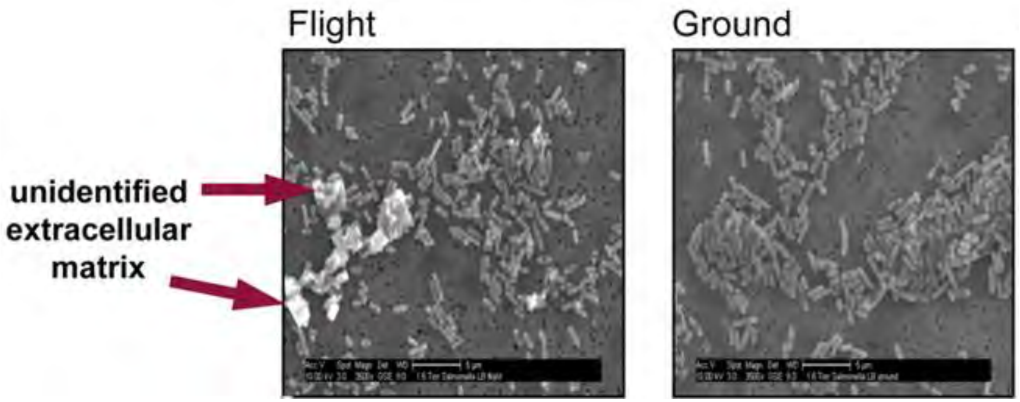
Space Biophysics:

Accomplishments, Trends, Challenges

Microbiology

Accomplishments in Space Biophysics: Microbial Virulence

Space flight alters gene expression and virulence in the bacterium, *Salmonella typhimurium,* and reveals a role for global regulator Hfq



Wilson, 2007, ***PNAS* 104**(41) 16299–16304, doi: 10.1073/pnas.0707155104

Mouse Immunology-2 Spaceflight Experiment

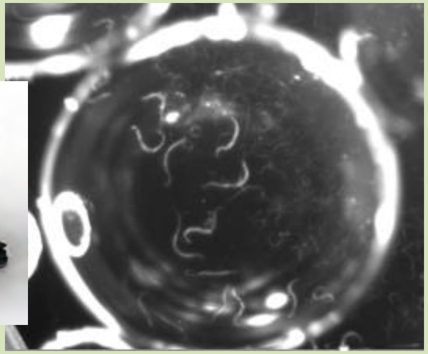
PI: Robert Garofalo, UTMB Galveston

Mice flew on the Space Shuttle Discovery (STS-133) and were subjected to 12.8 days of micro-gravity. After return to Earth, animals from all groups were infected with RSV or control. 1 day after infection we observed remarkable neutrophils response for the RSV-infected mice from the FLT group compared with the ground controls infected groups. (manuscript submitted for publication)

Micro-5 Experiment: Bacterial Infection of C. elegans worm in space

PI: Cheryl Nickerson, Arizona State University

Micro-5 Flight Hardware (BioServe)



C. Elegans and bubble formation needed to be fixed

Accomplishments in Space Biophysics: Microbes and Biofilms

Microgravity changes biofilms and biofilm-forming bacteria and fungi:

- Spaceflight Increases Biofilm Formation
- Spaceflight Alters Biofilm Architecture
- Cell Motility Affects Spaceflight Biofilm Formation
- Oxygen and Nutrient Availability Affect Biofilm Formation

Collins et. al., 2013, ***PLoS ONE* 8**(4): doi:10.1371/journal.pone.0062437)

Experiments in the absence of gravity on the ISS coupled to microfluidic experiments on earth will allow each of these mechanisms to be tested

Example of biofilm in water system
http://wellness-24.blogspot.com/2011_10_01_archive.html

Image credit: *Nicola Stanley-Wall, University of Dundee*

Image credit: *Photo Researchers Inc.*

Trends in Space Biophysics: Microbial Observatory

MO-1A Sampling Onboard the ISS:
Air Sampling-Harmony (N2) 3/15

Trends in Space Biophysics: Microbial Observatory

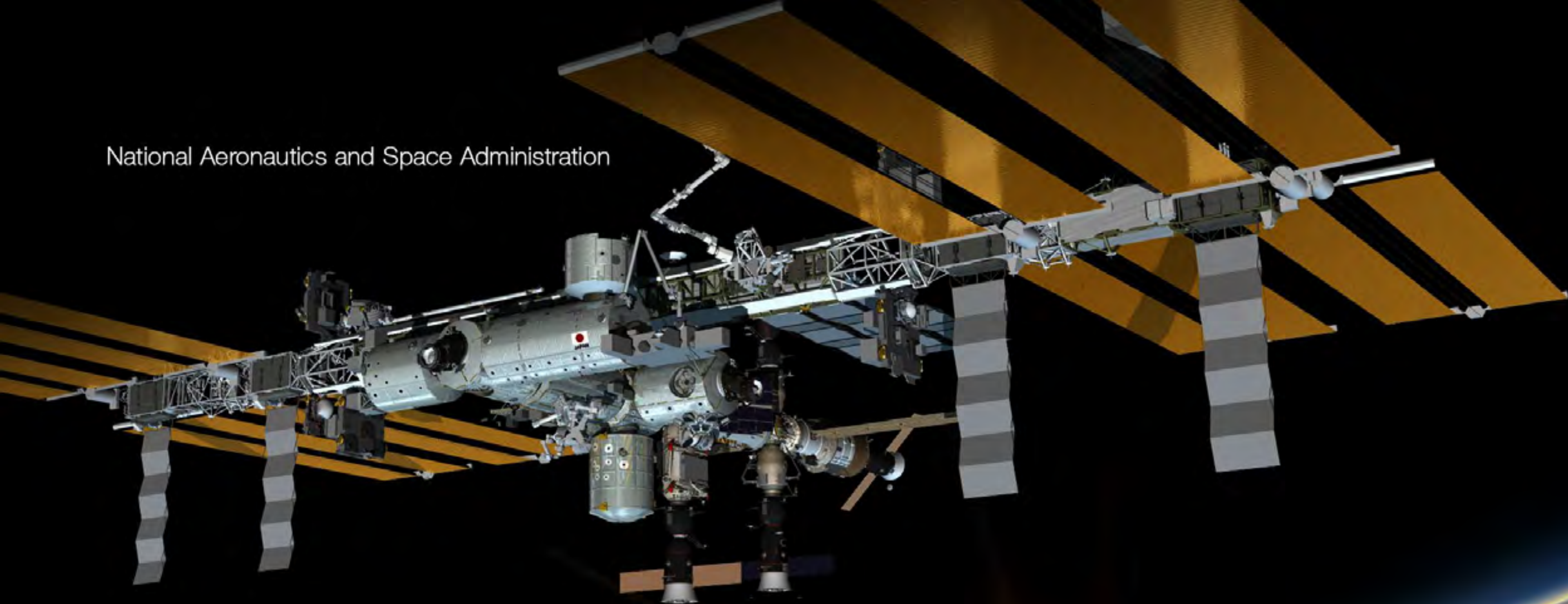
MO-1A Sampling Onboard the ISS:
Surface Sampling Dining Table-
Tranquility (N3) 3/15

Challenges in Space Biophysics: Microbiology

- **Microbial Evolution in Space?**
- **Impact of Microbial Evolution on Human Exploration**

Mars One/Bryan Versteeg

National Aeronautics and Space Administration

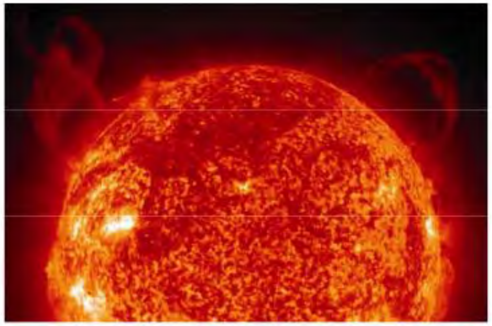


Space Biophysics:
Accomplishments, Trends, Challenges

Molecular Biophysics

Accomplishments in Space Biophysics: Molecular Biophysics, Space Radiation

Risk of Acute or Late Central Nervous System Effects from Radiation Exposure



Risk of Acute Radiation Syndromes Due to Solar Particle Events

Risk of Degenerative Tissue or Other Health Effects from Radiation Exposure

Risk of Radiation Carcinogenesis

http://humanresearchroadmap.nasa.gov/evidence/reports

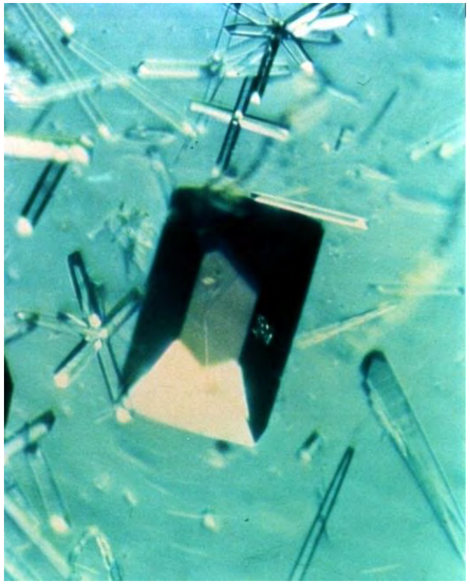
Accomplishments in Space Biophysics: Molecular Biophysics, Protein Crystal Growth

Comparative analysis of thaumatin crystals grown on earth and in microgravity.

- 16-day Life and Microgravity Spacelab (LMS), which flew June 20-July 7, 1996, aboard Space Shuttle Columbia (STS-78
- Using otherwise similar crystallizing conditions, the space crystal showed a nearly 25% larger volume compared to its earth-grown counterparts and yielded nearly twice the crystalline order.

Ng et. al., 1997 , Acta Crystallogr D Biol, Nov 1;53(Pt 6):724-33

Protein Crystal Growth Porcine Elastase.



This enzyme is associated with the degradation of lung tissue in people suffering from emphysema. It is useful in studying causes of this disease. Principal Investigator on STS-26 was Charles Bugg.

DeLucas et. al., 1991, J Crystal Growth 110, 302-311

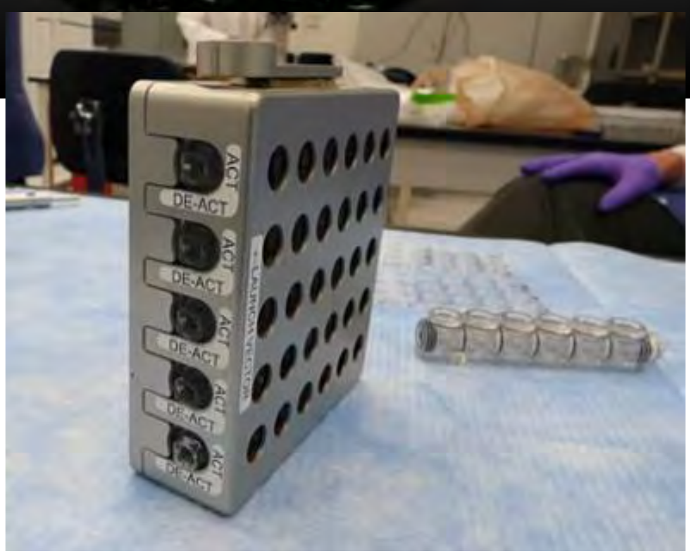
Space Station Live: Protein Crystal Growth for Treatment of Immunological Disorders

Monoclonal Antibodies

SpaceX-3 Mission

- Uniform temperature gradient in microgravity reduces convective flow due to density gradients
- Crystal structures grow and do not sediment in microgravity, allowing for larger high-quality crystals to form
- The PI team will measure particle size distribution and crystal purity.

Published on Mar 27, 2014



GeneLab and Space Bioinformatics

There are many Laws of Physics

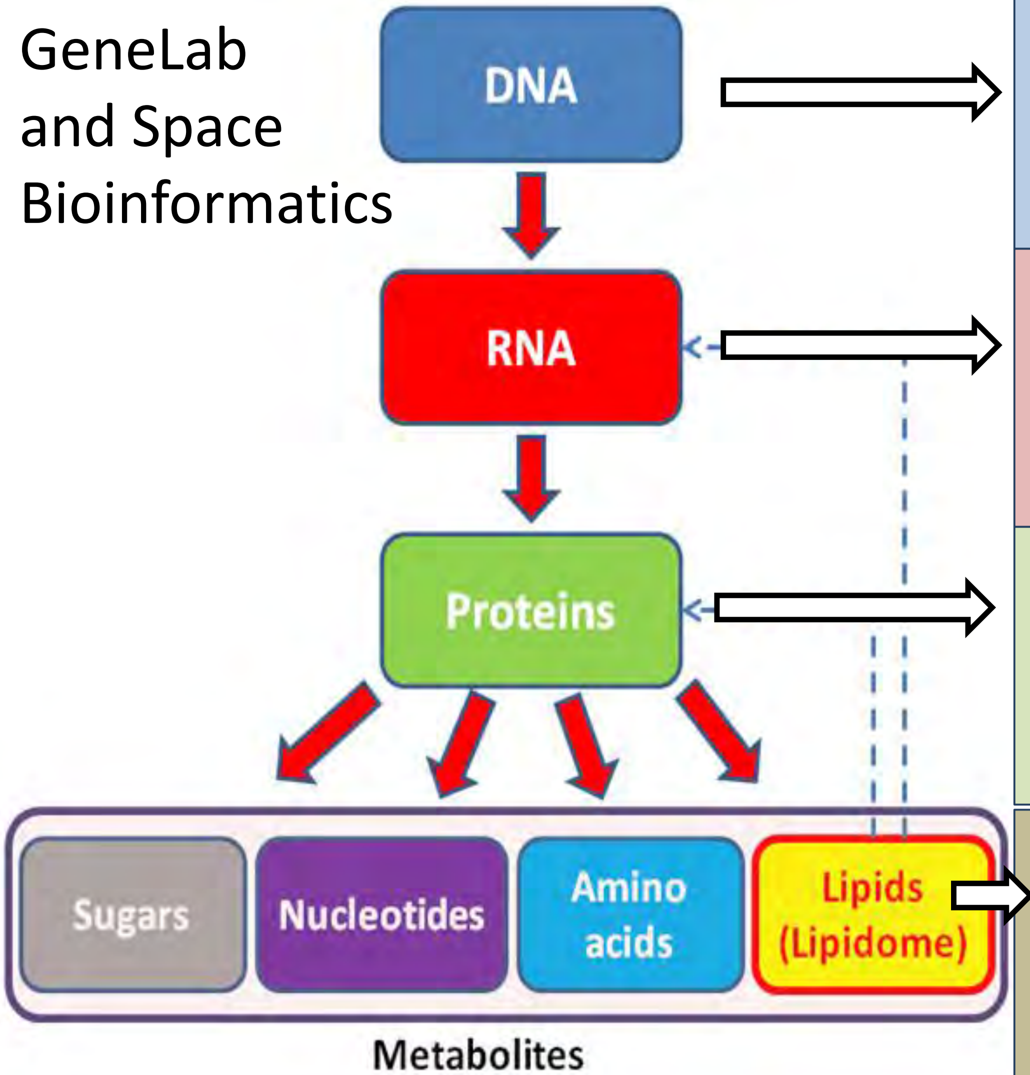
Are there any Laws of Biology?

The First? Law of Biology…

DNA is transcribed to RNA, which is translated to protein which, through chemical interactions, cause transcription, translation and DNA replication to continue and repeat all the processes of biology

Trends in Space Biophysics: Molecular Biophysics

GeneLab and Space Bioinformatics



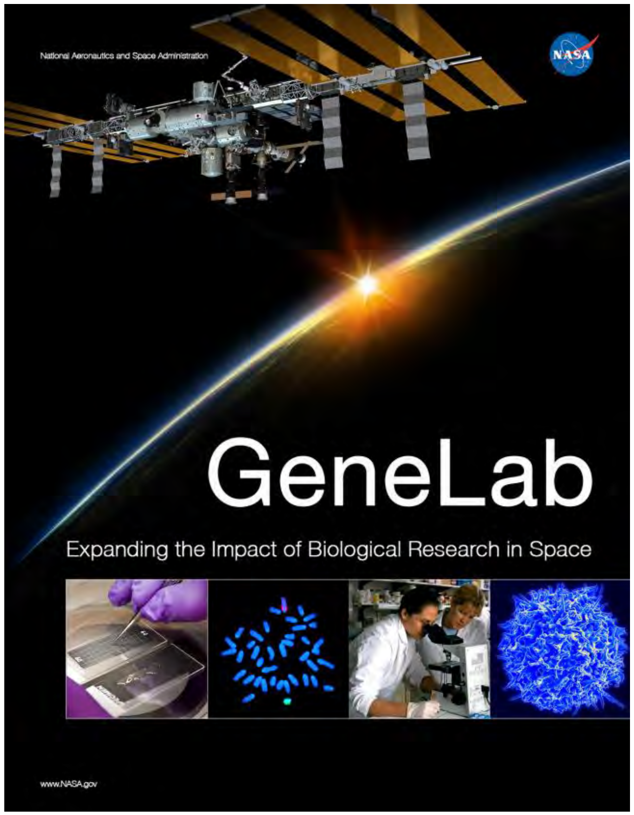
- DNA damage and repair
- Mutation leading to disease or disfunction
- Evolutionary adaptation over many generations
- Epigenetic changes passed down to progeny

- Adaptation to changes in the environment through changes in gene expression
- Changes in growth and development due to environmental conditions that alter the course of gene expression during life

- Proteins expressed to adapt to the space environment change the way a cell functions
- Increased or decreased protein expression will change the balance of cellular function

- Physical changes in space can alter the availability of nutrients and signaling molecules
- Adaptation to space can alter the compliment of metabolites and create feedback loop to other omics systems

GeneLab and Space Bioinformatics



GeneLab Strategic Plan

http://genelab.nasa.gov/resources/GeneLabStrategicPlan_Baseline_2014.pdf

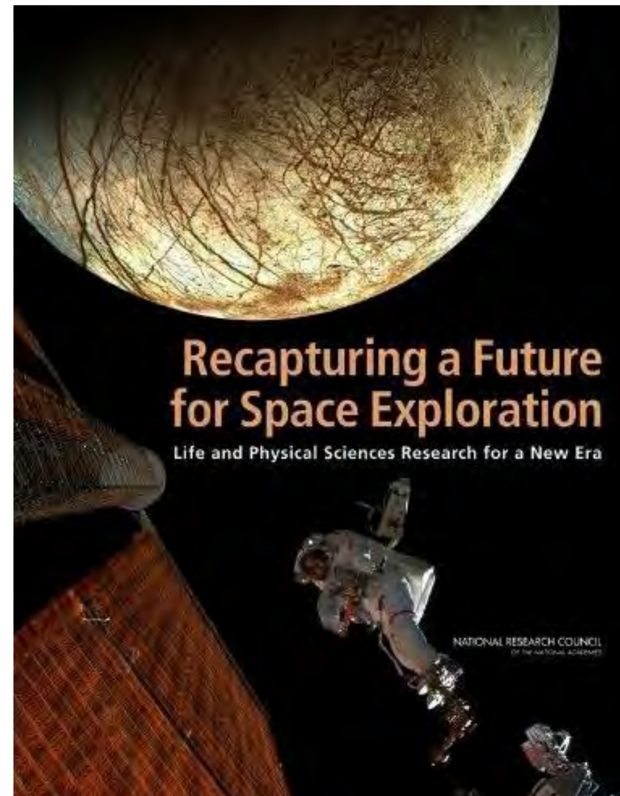
- GeneLab will use an integrated multi-omics approach requiring the development of new bioinformatic technologies to deliver a next-generation system to approach spaceflight biological research
- GeneLab will enable community-driven reference experiments to generate standard, common, and open reference datasets to act as a powerful resource for scientific throughput and innovation
- GeneLab will maximize the scientific return on investment and maximize the use of the ISS given the limited number of biological research opportunities in space
- The open science of GeneLAb will expand the number of researchers in the community, bringing new ideas and innovation to space biology research, while enabling discovery and advances for both NASA Exploration and Earth-based benefit

Trends in Space Biophysics: Space Radiation

- Emphasis should be placed on increasing information comparing biological effects at various LET values and at low doses (low particle fluences) and low dose rates (fluxes). To enhance an understanding of whole-body and whole-organism effects, studies in cellular systems need to continue to progress to animal studies.

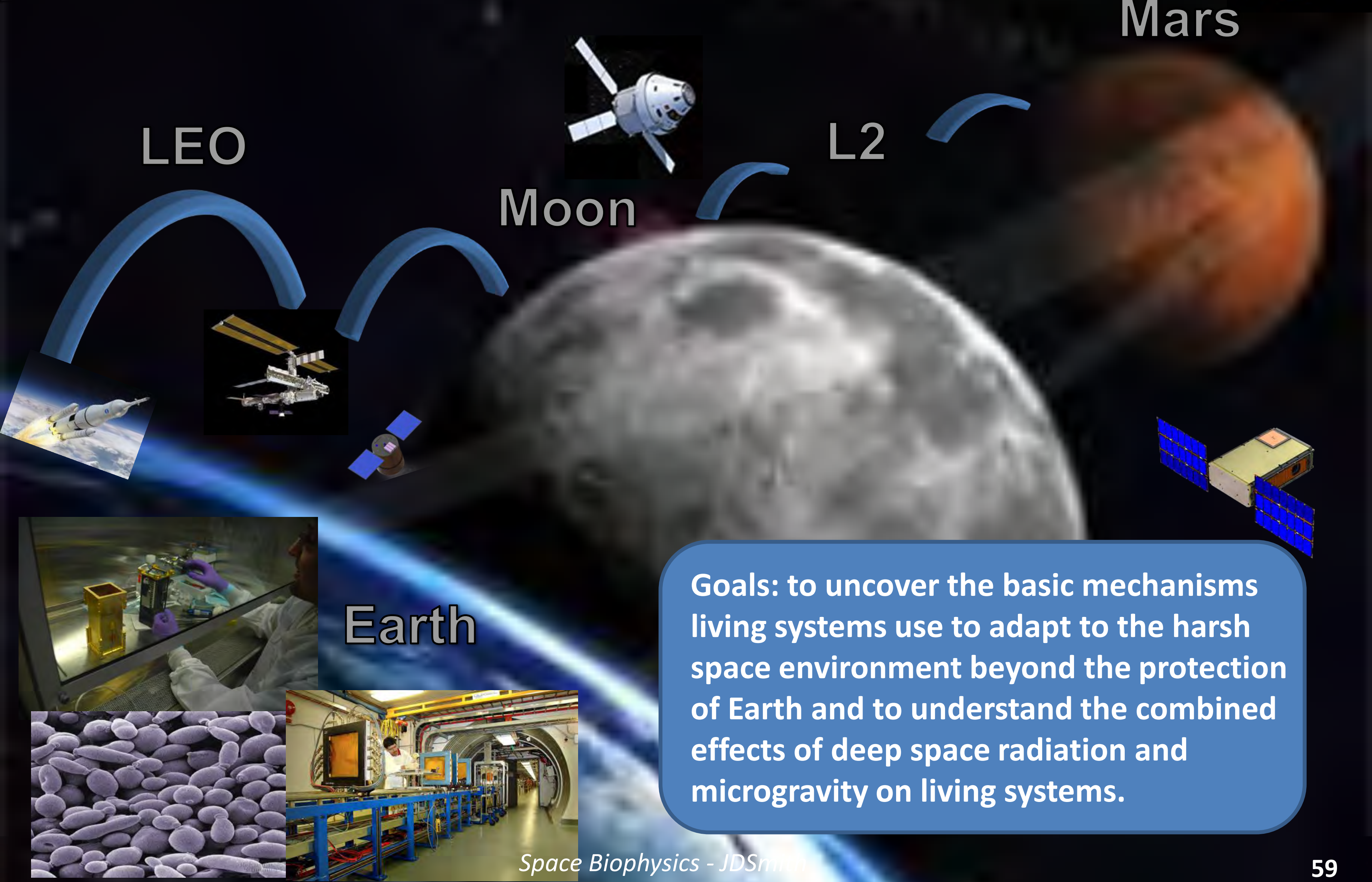
- Radiation studies should include the development of an understanding not only of short-term effects that might hamper a mission (acute radiation toxicities) but also of long-term consequences (carcinogenesis, heart disease, neurologic dysfunction, and others) that might affect astronauts after they return.

- A clearer understanding is needed of the effects of mixed fields composed of radiation of varying LETs, mixed effects of radiation and other stressors, and possible use of countermeasures.



http://www.nasa.gov/exploration/library/esmd_documents.html.

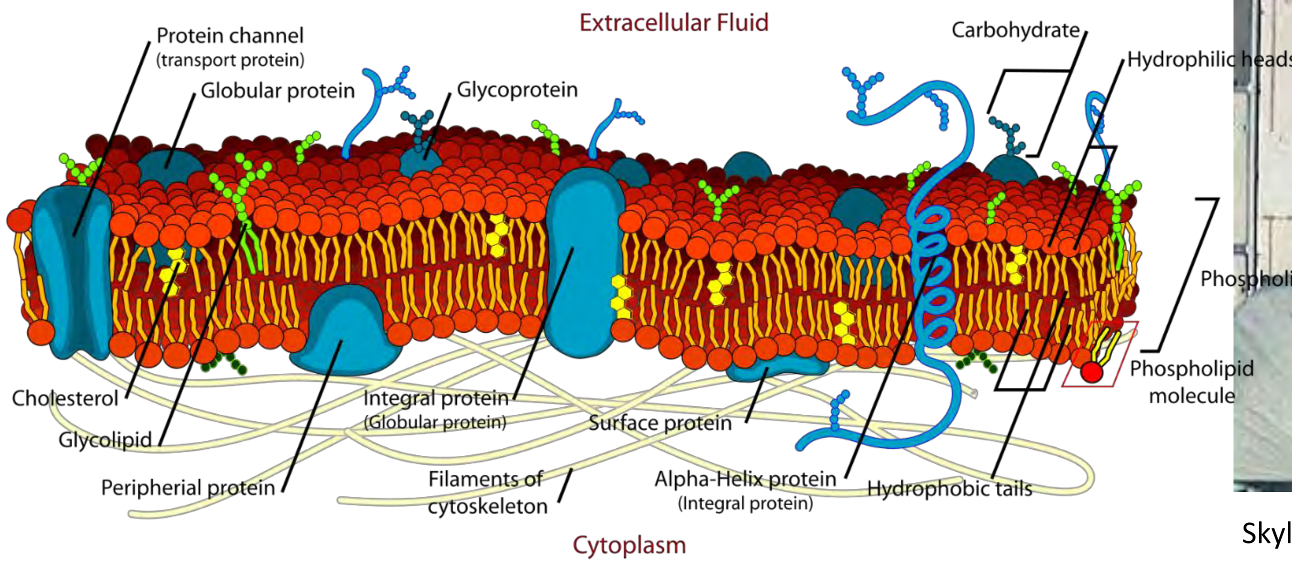
Trends in Space Biophysics: Life Beyond LEO Science Campaign



Goals: to uncover the basic mechanisms living systems use to adapt to the harsh space environment beyond the protection of Earth and to understand the combined effects of deep space radiation and microgravity on living systems.

Challenges in Space Biophysics: Molecular Biophysics

- Membrane Protein Crystallization
- Membrane Biophysics in Space
- Biological Countermeasures to Space Radiation
- Molecular Simulation of Life Without Gravity



http://en.wikipedia.org/wiki/Cell_membrane

Skylab 2 Commander Charles Conrad submits to a dental examination by Medical Officer Joseph Kerwin in the Skylab Medical Facility

The Future of Human Space Exploration
NASA's Building Blocks to Mars

Every aspect of NASA's Building Blocks to Mars involves interactions between physical and human systems

U.S. companies provide affordabl access to l Earth orb

As we send people further into space for longer durations, we must uncover the fundamental physical processes that affect life in space to fully-understand the biological risks to Exploration and how they can be addressed

ing Mars her deep space destinations

Space Biophysics
Hypothesis, Theory or Law?

At the root of all biological changes in space, are changes in the physical environment

Return: hours

Earth Reliant

Return: days

Proving Ground

ons: 2 to 3 years
Return: months

Earth Independent

Space Biology Inspiring the Next Generation: SLSTP and NPP

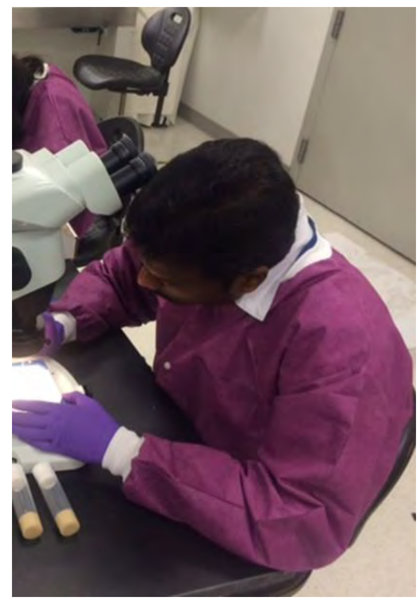
Space Life Sciences Training Program

- Re-initiated as a pilot program in 2013
- Full program in 2014

SLSTP goal is to train our next generation of scientists and engineers and enable NASA to meet future research and engineering challenges in the space life sciences

NASA Postdoctoral Program

Postdoctoral fellows spend 1-3 years working alongside NASA investigators who are engaged in ongoing fundamental space biology research



Space Biology Inspiring the Next Generation:
Students and Fellows Across the Nation

- **Space Biology Research Engages Undergraduate, Graduate and Postdoctoral Fellows at Universities Across the Nation**

- **<u>Space Biology currently supports about 75 competitively-funded grants</u>**

- **<u>71 students participated in Space Biology research during 2014</u>** (reported by 20 PIs who responded to the poll):
  - 43 students were directly supported with space biology grant funding (11 Undergraduate, 22 Graduate, 7 Postdoctoral Fellows and 3 High School)
  - 28 students worked on Space Biology grants with salary paid from sources other than the Space Biology grants (9 Undergraduate, 11 Graduate and 8 Postdoctoral Fellows)

Space Biology and Physical Sciences Resources

- NASA Task Book

  Grants 1995-Present

https://taskbook.nasaprs.com/Publication/welcome.cfm

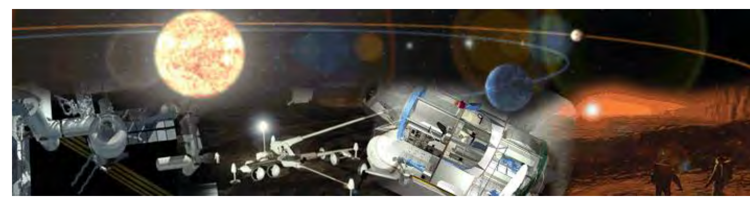
- NSPIRES

  NASA Research Announcements

http://nspires.nasaprs.com/external/

- Human Research Roadmap

  NASA Research Announcements



http://humanresearchroadmap.nasa.gov/

- Space Biosciences Division

http://www.nasa.gov/ames/research/space-biosciences/

Opportunities, Fellowships, Careers

OSSI One Stop Shopping Initiative NIFS
Recruiting NASA Interns, Fellows and Scholars

https://intern.nasa.gov/ossi/web/public/main/

OSSI is a NASA-wide system for the recruitment, application, selection and career development of under-graduate and graduate students

Greenville IN
http://www.techshot.com/

Lexington KY
http://www.kentuckyspace.com/

Lafayette, IN
http://www.purdue.edu/discoverypark/psf/

Boulder CO
http://www.colorado.edu/engineering/BioServe/

American Society for Gravitational and Space Research
Biological and Physical Sciences
Bridging Earth and Space
https://www.asgsr.org/

Questions?