National Aeronautics and Space Administration

Space Life and Physical Sciences Research and Applications (SLPSRA)

NASA Advisory Council for HEOMD
March 28, 2017

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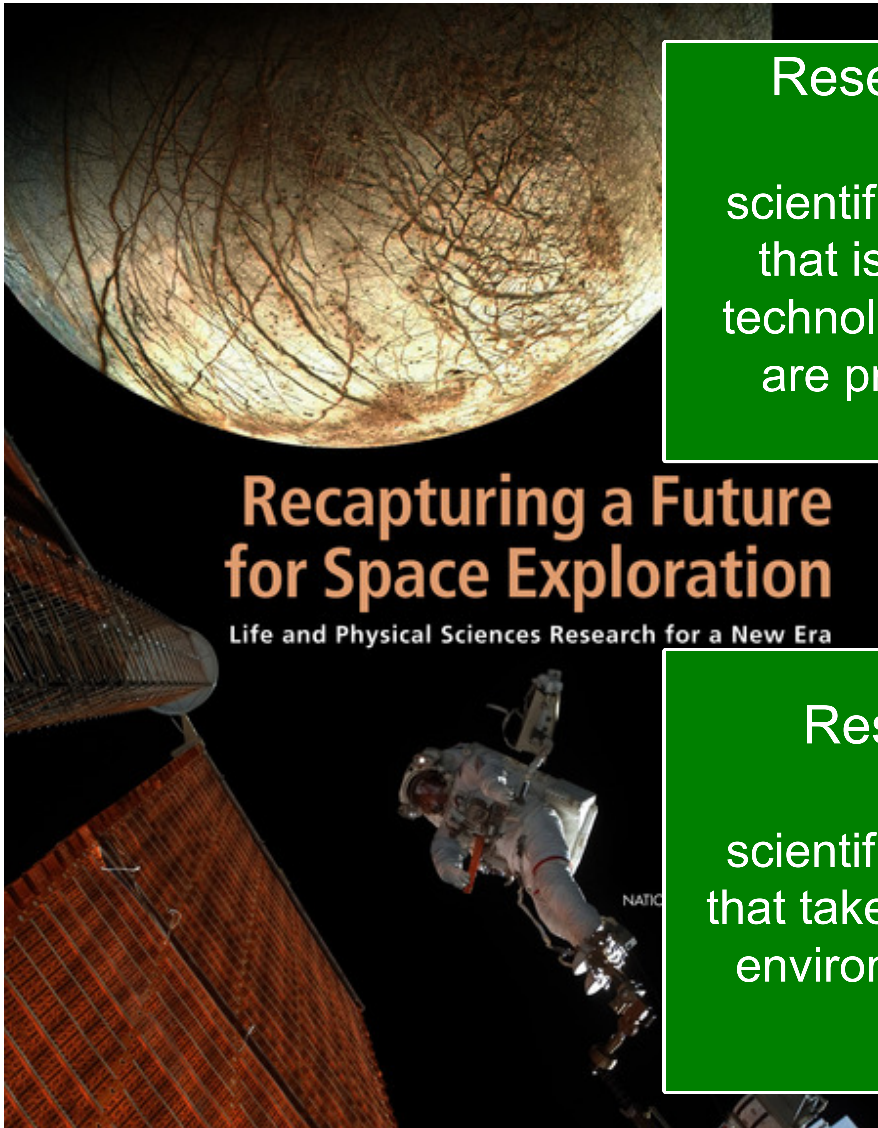
Director, Space Life and Physical Sciences
Human Exploration & Operations Mission Directorate

Research Portfolio Guided by Decadal Survey



Research that enables space exploration:

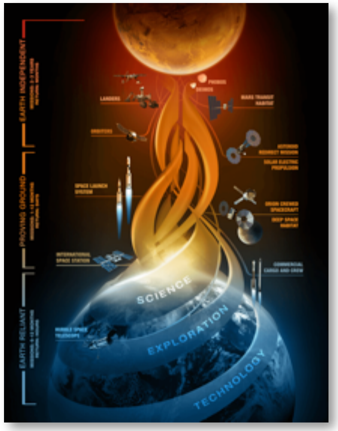
scientific research in the life and physical sciences that is needed to develop advanced exploration technologies and processes, particularly those that are profoundly affected by operation in a space environment.

Research enabled by access to space:

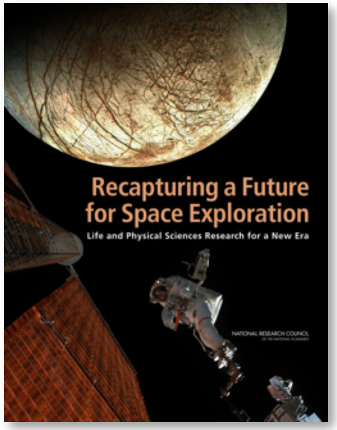
scientific research in the life and physical sciences that takes advantage of unique aspects of the space environment to significantly advance fundamental scientific understanding

SLPSRA Purpose

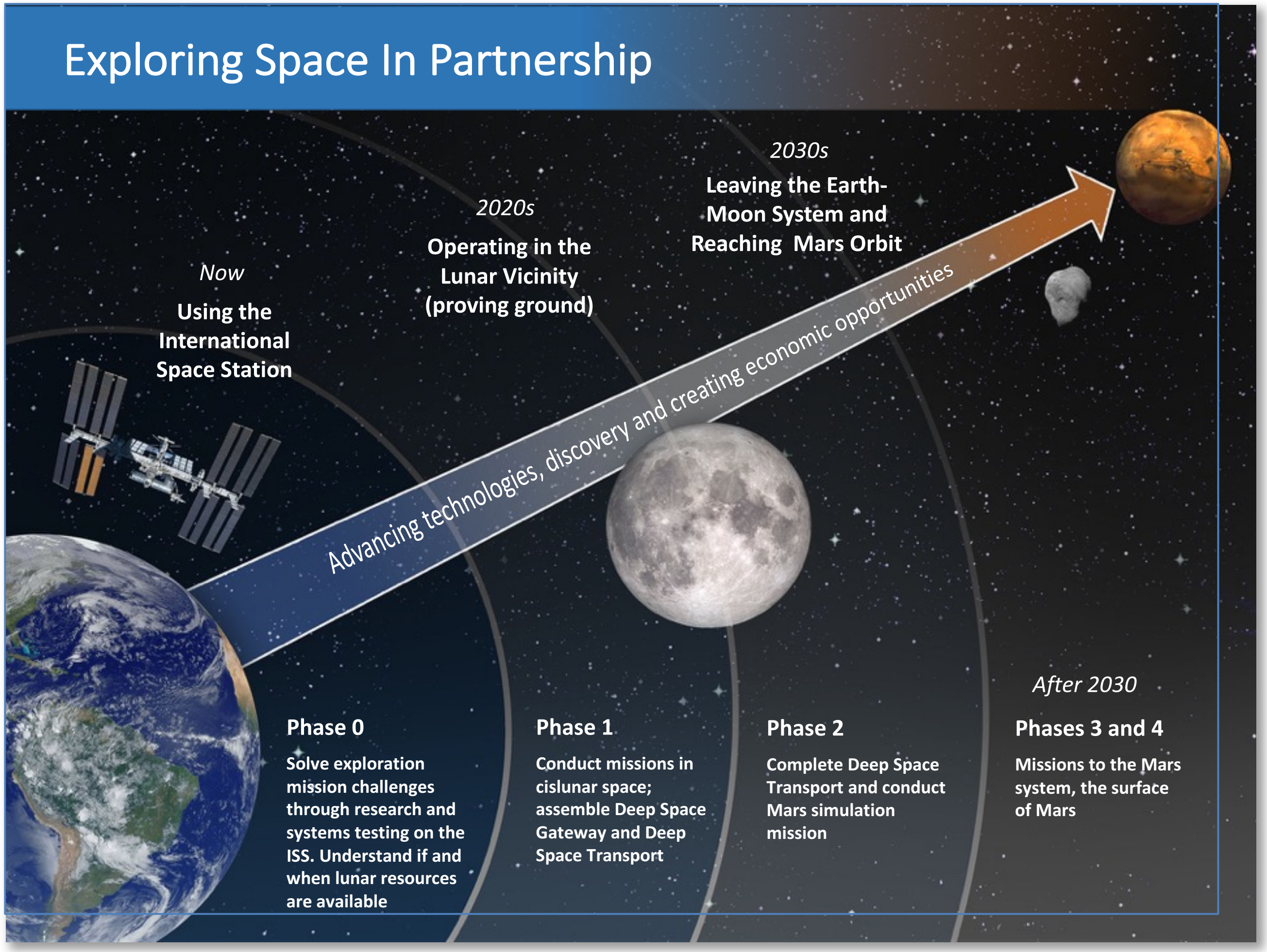
- **Vision**
  - We lead the space life and physical sciences research community to enable space exploration and benefit life on Earth



- **Mission**
  - **Enable exploration** to expand the frontiers of knowledge, capability, and opportunity in space
  - **Pioneer scientific discovery** in and beyond Low Earth Orbit to drive advances in science, technology, and space exploration to enhance knowledge, education, innovation, and economic vitality



For Exploration Beyond LEO



Enabling Exploration

Examples:

- **Human Research &**
- **Plant Science**
- **Gravitational Biology**
- **Combustion**
- **Fluid Physics**

Implementation: Open Science

- Maximize community participation in the formulation of investigations where feasible
  - Co-Principal Investigator Teams
  - Topical Teams
  - Science Definition Teams
- Disseminate and reuse data, tools, and samples post-project
  - Timely data deposition
    - With space flight metadata
    - With unique analysis tools
  - Platforms
    - GeneLab
    - Physical Science Informatics
    - Life Sciences Data Archive

Implementation: Partnerships

- Enrich content
  - Needed to Enable Exploration (Pull)
    - E.g., Advanced Exploration Systems, Space Technology Mission Directorate
  - Needed to Pioneer Scientific Discovery (Adopters)
    - E.g., CASIS, NIH, NIST, NSF, other government agencies; international partners; industry

- Facilitate execution
  - Access new platforms
  - Leverage SLPSRA resources

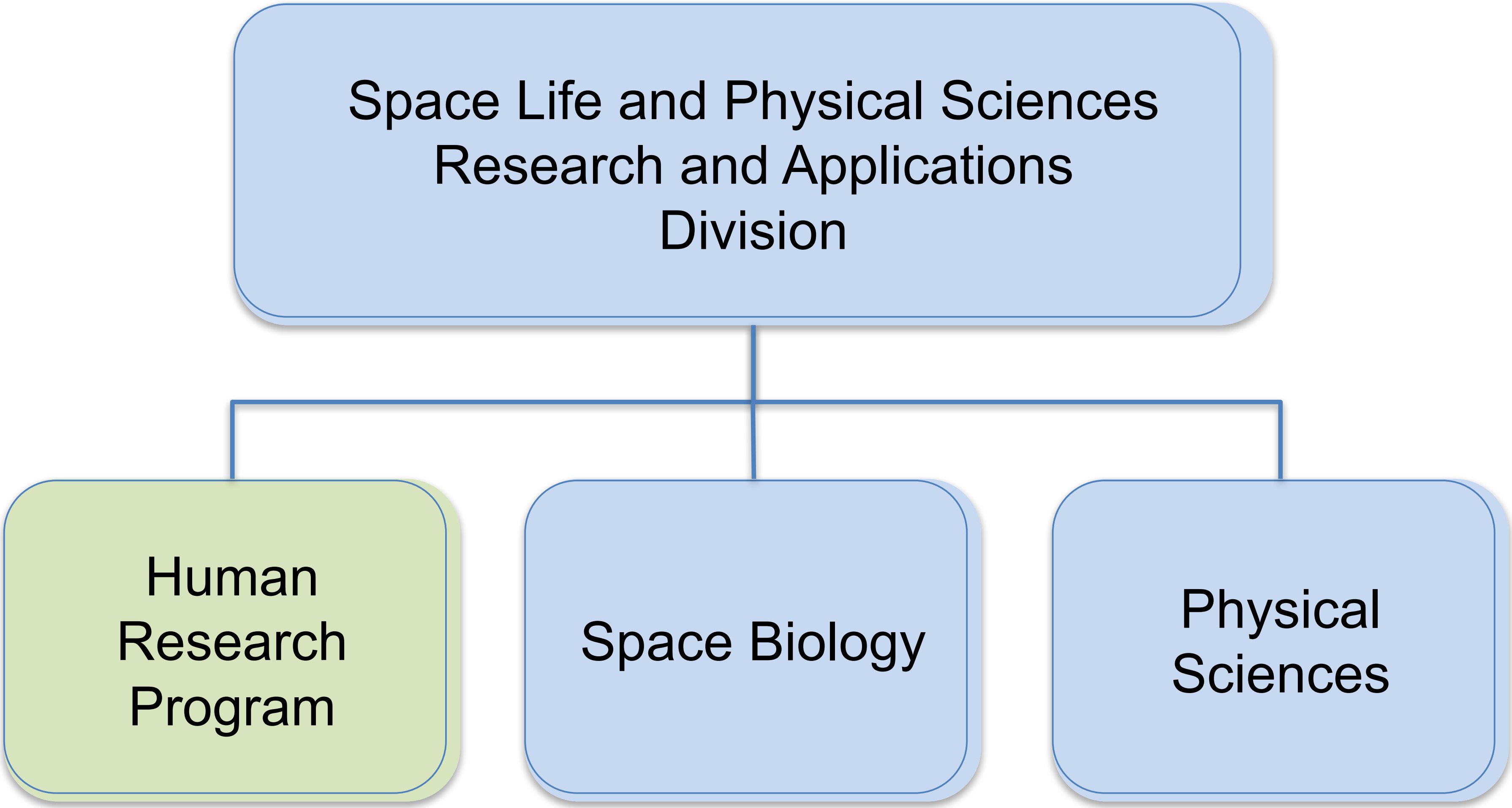
Capitalizing on resources in LEO and below

- **Space Stations**
  - International Space Station
  - International partner space station(s)?
  - Commercial space station(s)?
- **Free Fliers**
  - Other government agencies
  - Commercial
  - International partners
- **Sub-orbital**
  - Crewed flights
  - Sounding rockets
  - Balloons
  - Parabolic aircraft
- **Ground research**

Enabling Exploration

Pioneering Scientific Discovery

- Other government agencies
- Commercial
- International partners


Space Life and Physical Sciences Research and Applications Division
Human Research Program
Space Biology
Physical Sciences

Summary of Human Risks of Spaceflight
Grouped by Hazards – 30 Human Risks, 2 Concern/Watch list Items

Altered Gravity Field

Primary Effect

1. **Spaceflight-Induced Intracranial Hypertension/Vision Alteration**
2. Urinary Retention
3. **Space Adaptation Back Pain**
4. Renal Stone Formation
5. **Risk of Bone Fracture due to spaceflight Induced bone changes**
6. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance
7. **Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity**
8. Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations associated with space flight.
9. **Cardiac Rhythm Problems**
10. Orthostatic Intolerance During Re-Exposure to Gravity
11. **Crew Adverse Health Event due to Altered Immune Response**
12. Adverse Health Effects due to Alterations in Host Microorganism Interaction

Concerns/Watch list

1. **Concern of Clinically Relevant Unpredicted Effects of Medication**
2. **Intervertebral Disc Damage**

Radiation

Primary Effect

1. **Risk of Space Radiation Exposure on Human Health**

Distance from Earth

Primary Effect

1. **Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities**
2. Risk of Ineffective or Toxic Medications due to Long Term Storage

Isolation

Primary Effect

1. **Risk of performance decrements due to adverse behavioral conditions**

Hostile/Closed Environment-Spacecraft Design

Primary Effect

1. **Toxic Exposure**
2. Acute and Chronic Carbon Dioxide Exposure
3. **Hearing Loss Related to Spaceflight**
4. Probability of mild Acute Mountain Sickness (AMS) in astronauts resulting in reduced crew performance prior to adaptation to a mild hypoxia.
5. **Injury and Compromised Performance due to EVA Operations**
6. Decompression Sickness
7. **Injury from Sunlight Exposure**
8. Incompatible Vehicle/Habitat Design
9. **Risk of Inadequate Human-Machine Interface**
10. Risk to crew health and compromised performance due to inadequate nutrition
11. **Adverse Health Effects of Lunar (Celestrial) Dust Exposure**
12. Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload
13. **Injury from Dynamic Loads**
14. Risk of electrical shock

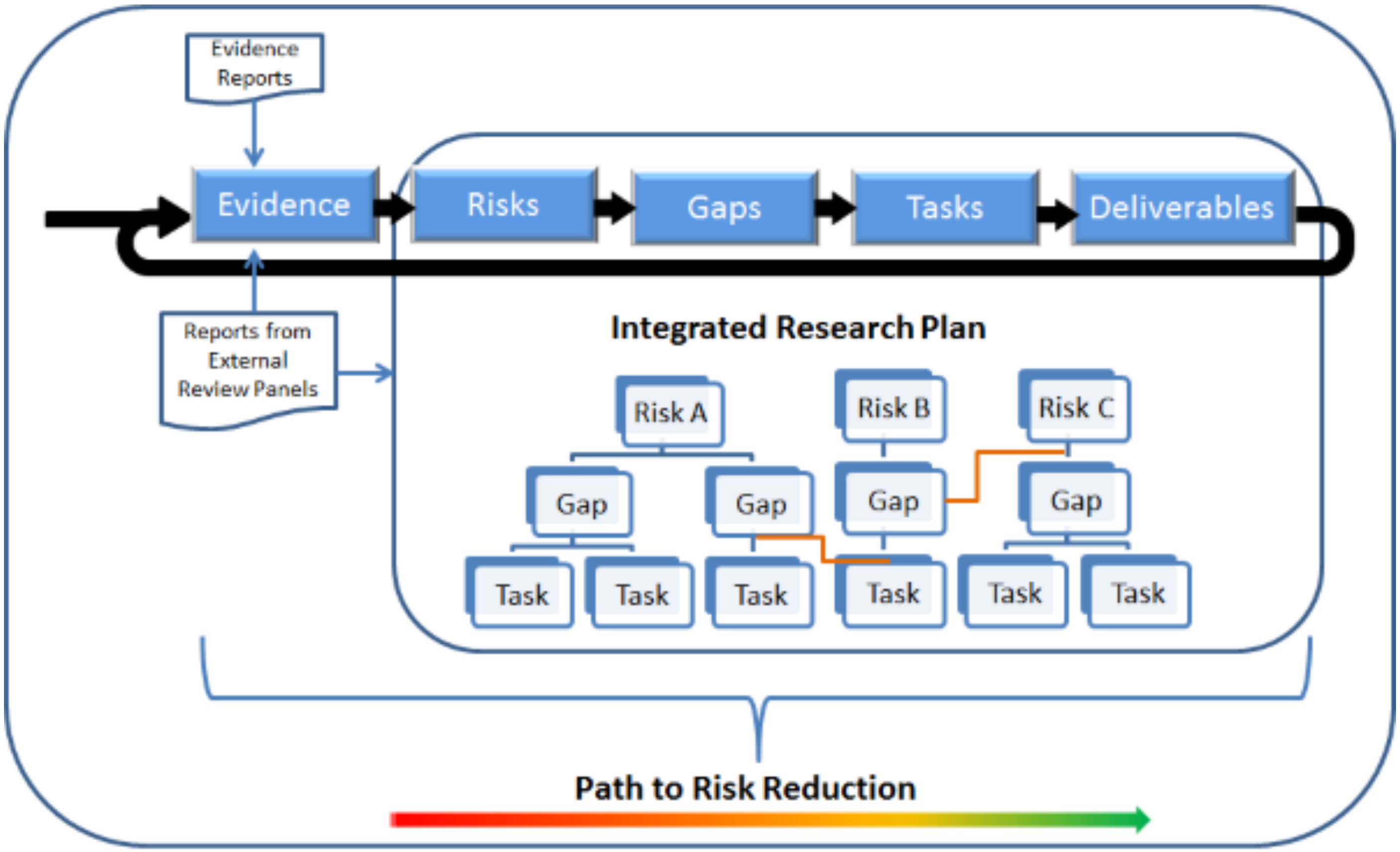
★	NASA-STD-3001, VOLUME 1, CREW HEALTH
★	NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH
	Clinical Practice Guidelines

★ Standards in process of review/change/addition

HMTA list in revision 2014

Human Research Program

- Focused on understanding and reducing risks to crew health and performance in exploration missions

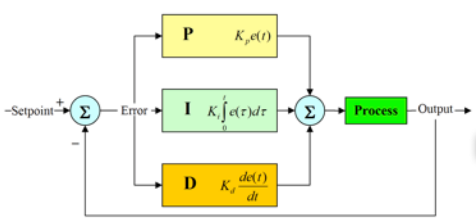


Human Research Roadmap

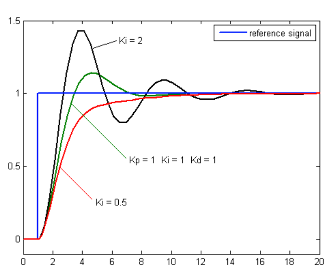
Life science differs from engineering

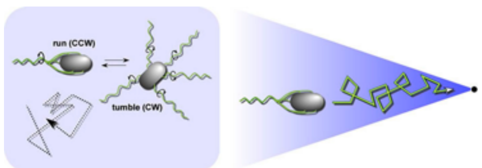
Engineers…	Life Scientists…
…design their systems	…reverse engineer Nature to understand the system
…use quality controlled components	…study diverse individuals with diverse components
…use established frameworks to employ physical laws	...discover concepts and qualitative relationships before developing quantitative understanding
…design PID controllers	…discover biased walks in chemotaxis

design

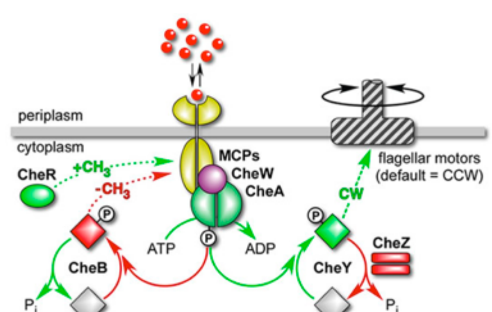


behavior





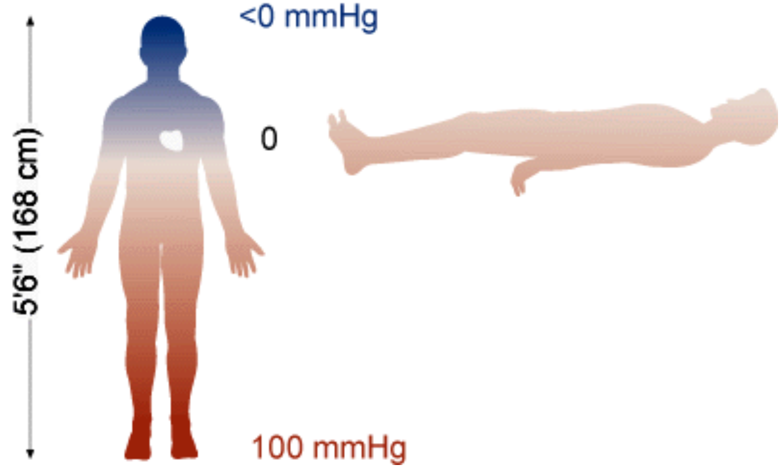
behavior



design

Example: Cardiovascular

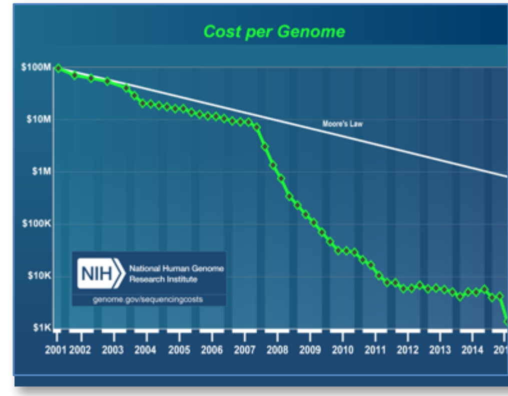
- Accommodations to weightlessness cause problems upon return to 1-g
  - Plasma volume (orthostatic intolerance)
    - 0-g -> cephalad fluid shift -> 1-2 L fluid excretion
    - Baroceptor reflex deconditions in 0-g
    - Insufficient volume and reflex for 1-g
  - Red blood cell mass (aerobic capacity)
    - 1-2 L fluid excretion -> increased hemocrit -> decreased EPO production -> decreased RBC production -> restored hemocrit

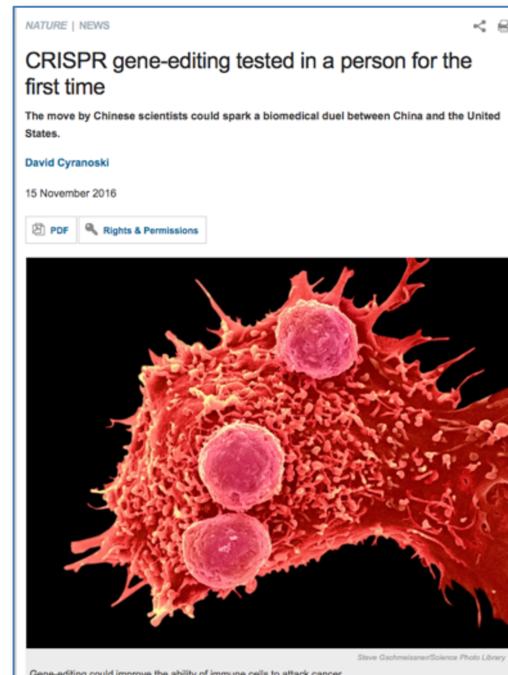


- Countermeasures prevent problems upon return to 1-g
  - Orthostatic intolerance countermeasures
    - Lower body negative pressure
    - Occlusion thigh cuff
    - Fluid load
    - Compression garments
    - Liquid cooling garment
  - Aerobic capacity countermeasures
    - Treadmill and cycle ergometer
    - 15% reduction in VO_2max remains

Dramatic Advances in Biotechnology

- Molecular data collection (omics)
  - Cost of sequencing the human genome has been falling much faster than Moore's Law
- Modeling systems biology
  - Capitalizing on Moore's Law and omics
- Manipulation of organisms
  - This generation may see human directed evolution of humans




NATURE | NEWS

CRISPR gene-editing tested in a person for the first time

The move by Chinese scientists could spark a biomedical duel between China and the United States.

David Cyranoski

15 November 2016

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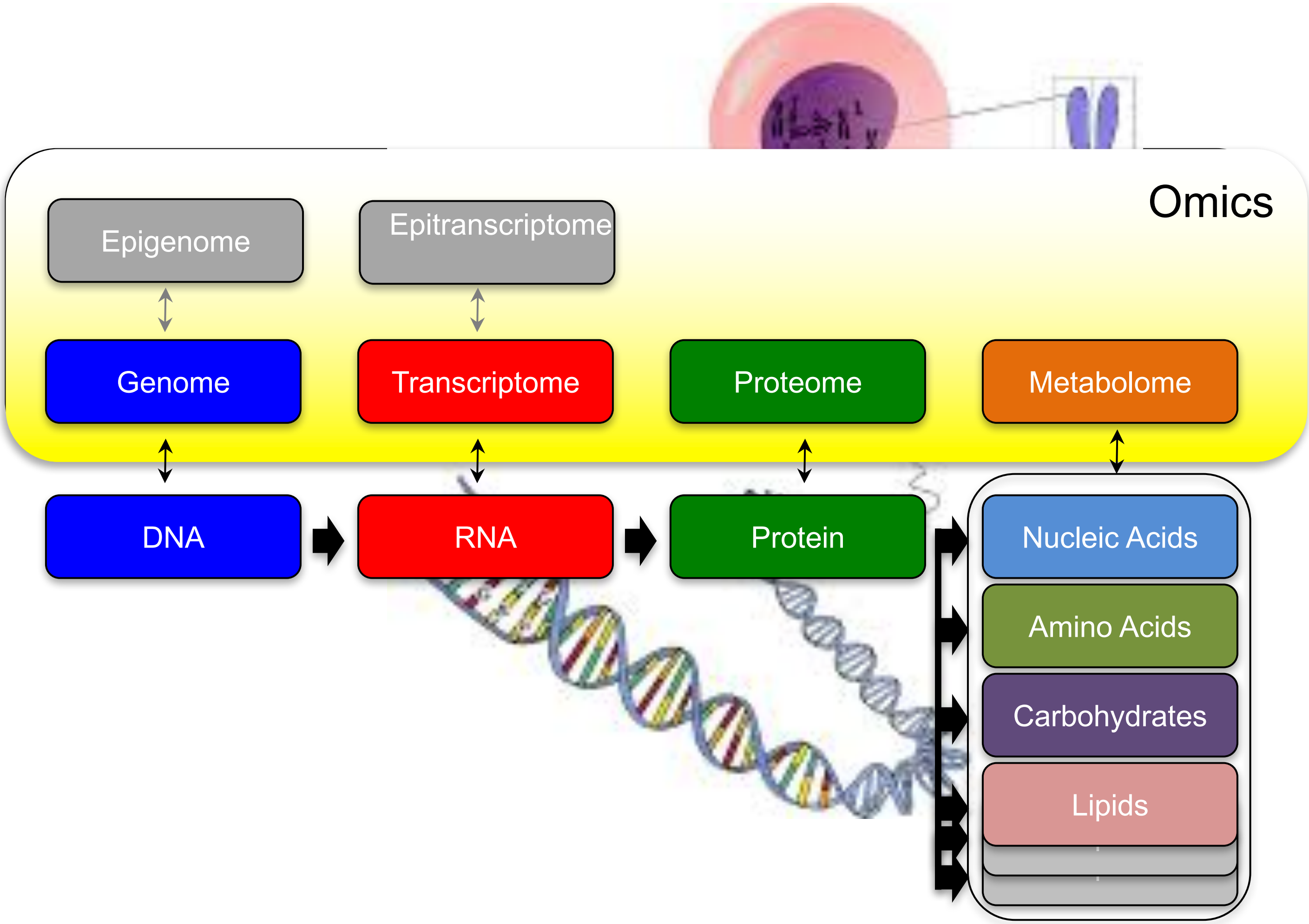
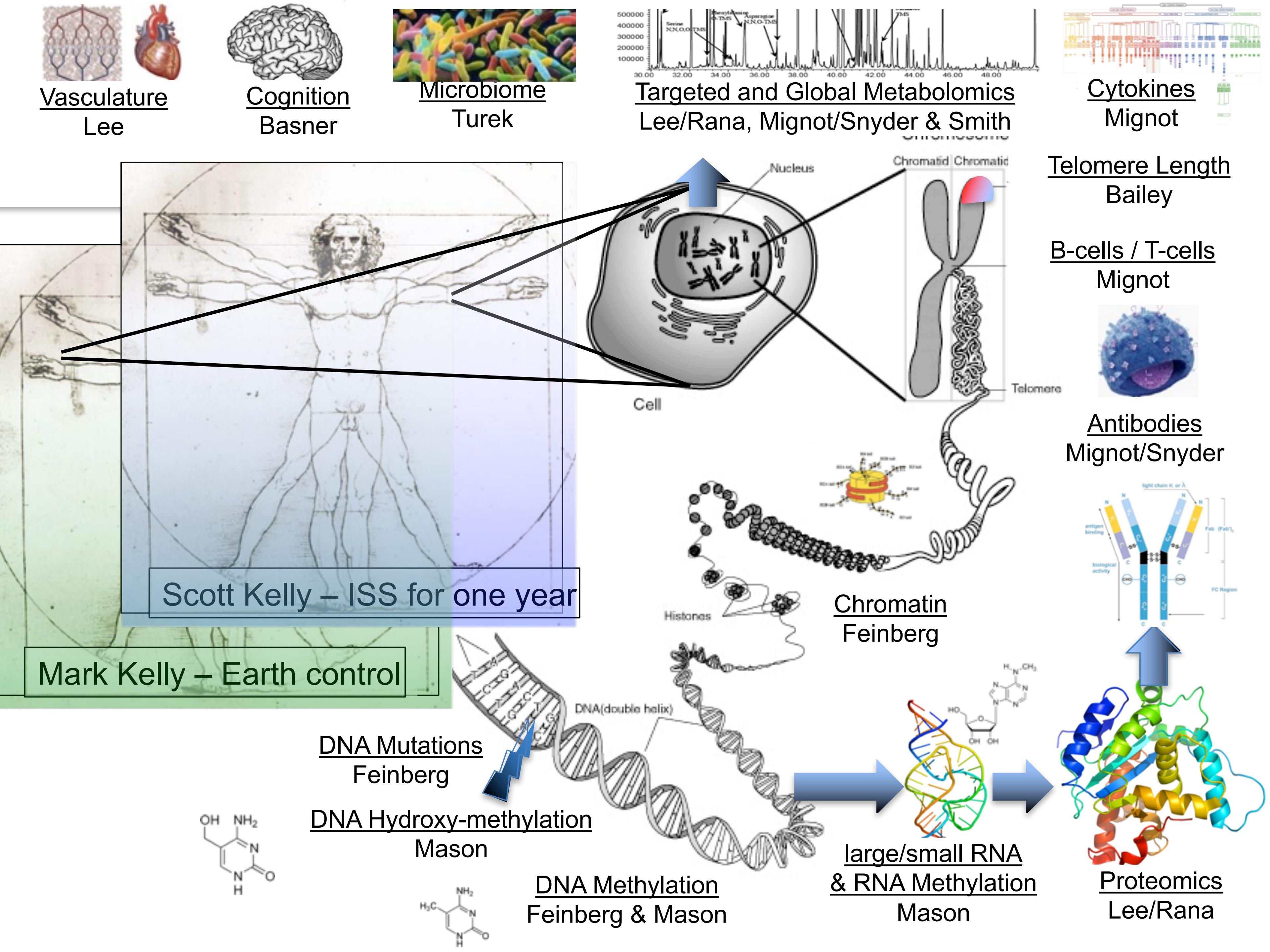
Steve Gschmeissner/Science Photo Library

Gene-editing could improve the ability of immune cells to attack cancer.

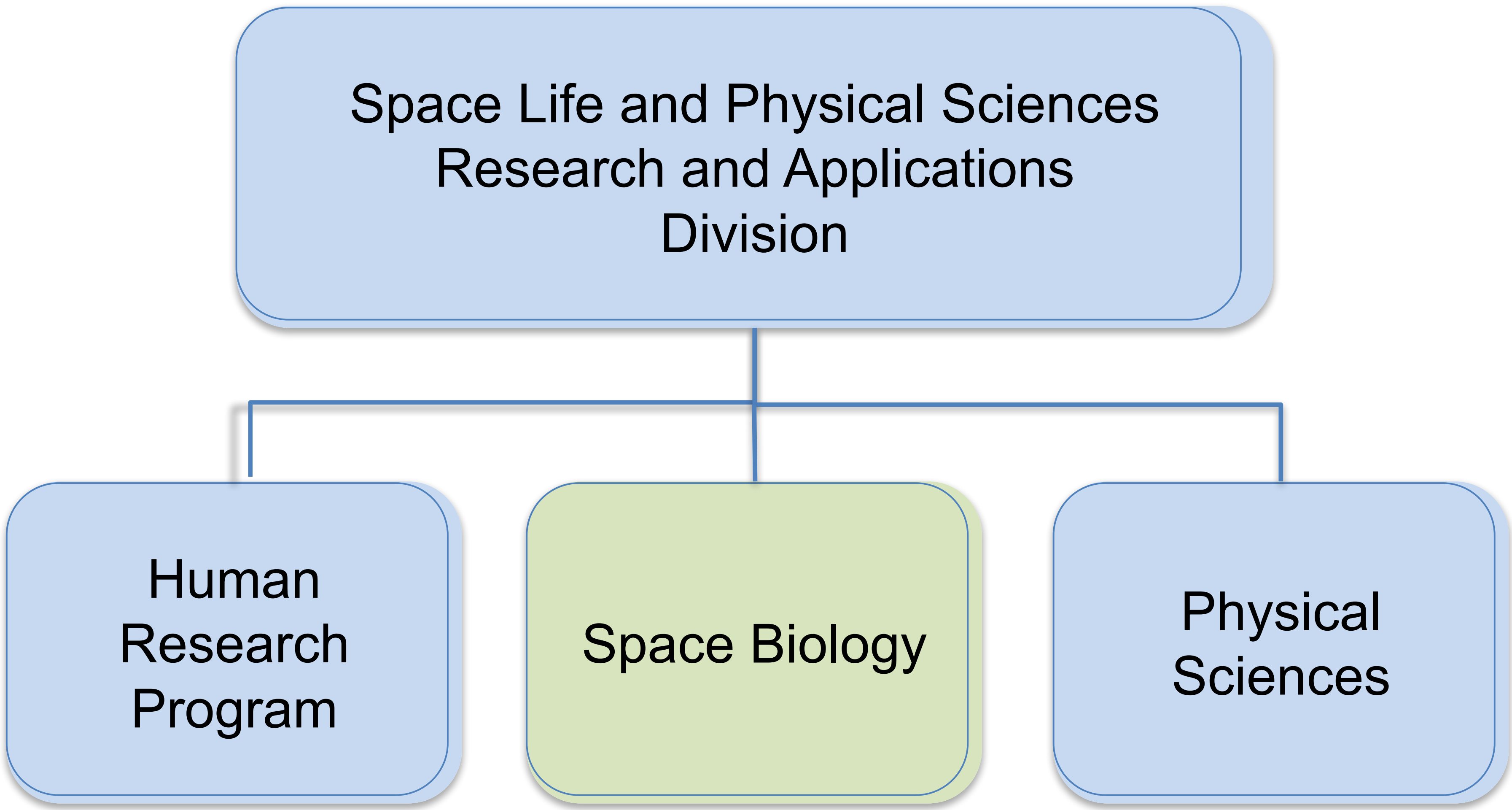
Example: The Twins Study- a Chance in a Lifetime

What is Omics?





Vasculature
Lee
Cognition
Basner
Microbiome
Turek
Targeted and Global Metabolomics
Lee/Rana, Mignot/Snyder & Smith
Cytokines
Mignot
Telomere Length
Bailey
B-cells / T-cells
Mignot
Antibodies
Mignot/Snyder
Nucleus
Chromatid Chromatid
Telomere
Cell
Scott Kelly – ISS for one year
Mark Kelly – Earth control
Chromatin
Feinberg
Histones
DNA(double helix)
DNA Mutations
Feinberg
DNA Hydroxy-methylation
Mason
DNA Methylation
Feinberg & Mason
large/small RNA
& RNA Methylation
Mason
Proteomics
Lee/Rana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The Fundamental Question of Space Biology

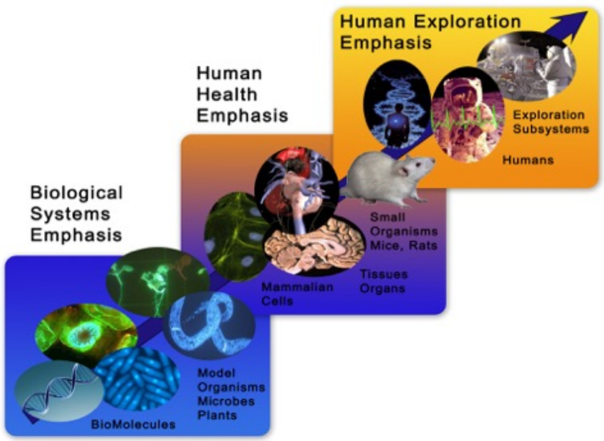
- For ~3.5 billion years, the constant acceleration of gravity has shaped every aspect of Earths' biosphere, from the origin to evolution and sustainment of life

- Space Biology seeks answers to one of the most fundamental questions of life:

What happens to life from Earth, beyond Earth?

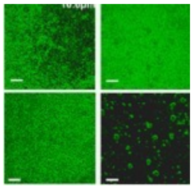
Space Biology Purpose and Goals

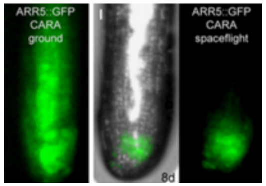
- Purpose: provide new knowledge about how biological systems respond and adapt to spaceflight, particularly altered gravity and radiation, with a focus on new knowledge and technologies that might be translated into useful tools for human exploration.
- Goals:
  - Create new knowledge of how biological systems adapt to space that can benefit space exploration missions and provide Earth applications
  - Conduct cutting-edge Space Biology research that answers NRC Decadal Survey recommendations
  - Leverage and amplify findings from ISS and other Space Biology research using state-of-the art omics, molecular/systems biology tools and GeneLab
  - Engage and build a more robust, internationally competitive U.S. Space Biology community

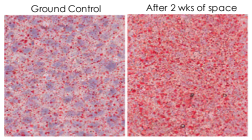


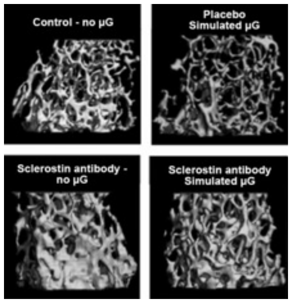
Space Biology Areas of Study

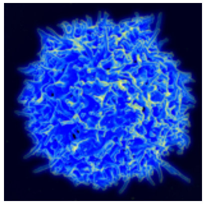
	Decadal Survey Recommendations
P1	ISS Microbial Observatory: long-term, multigenerational studies
P2: Microbial	Microbe growth and physiology
P2: Plant	Plant growth and physiology
P3	Roles of microbe-plant systems in long-term advanced life support systems
AH2	Preservation/reversibility of bone structure and strength
AH3	Bone loss studies of genetically altered mice
AH4	Osteoporosis drug tests in animal models
AH5	Underlying mechanisms regulating skeletal muscle protein balance
AH7	Daily recruitment of flexor and extensor muscles of the neck, trunk, arms, and legs
AH8	Basic mechanisms, vascular/interstitial pressures (Starling forces)
AH9	Microgravity and partial g (3/8 or 1/6 g) enabling levels of work capacity.
AH10	Integrative mechanisms of orthostatic intolerance (both 1 g and 3/8 g)
AH14	Mechanism(s) of changes in the immune system; multiple organ systems
AH15	Perform mouse studies of immunization and challenge on the ISS
AH16	Multigenerational studies; develop rodent breeding habitat for space
CC2	Is artificial gravity needed? Establish dose-response relationships
CC8	Expand animal use for radiation research
CC10	Gender Differences











Recent results: Veggie-03A

- Shane Kimbrough, expert gardener
- Six Red Romaine lettuce plants grown
- Tested the repetitive harvest technique ‘Cut-and-Come-Again’
- Four harvest events took place (12/2, 12/9, 12/23, and 12/28)
  - two for crew consumption
  - one for science samples
  - final harvest that split between the two
- The Crew enjoyed the harvest bounty together for each harvest
- Science Samples slated to return on SpaceX-11

- Follow on
  - Second VEGGIE unit
  - Advanced Plant Habitat
    - Launch in 2017
    - Tight control of growth parameters

Media releases…Veggie Nov 2016-Jan 2017

Veggie featured in KSC Spaceport Magazine
November 2016 issue: 1) Students plant seeds to help NASA farm in space (page 24); and 2) Third lettuce crop begins growing aboard station (page 26).
January 2017 issue: Space gardener Shane Kimbrough enjoys harvests.

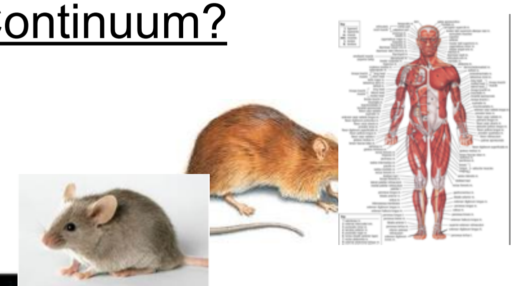
Veg-03A News Releases:
http://www.ign.com/articles/2016/12/19/nasa-successfully-grows-lettuce-in-space
http://www.nextgov.com/health/2016/12/video-nasa-harvests-another-round-veggies/133933/
http://www.floridatoday.com/story/tech/science/space/2016/12/23/come-again-ksc-space-lettuce-iss-menu/95792038/
https://www.nasa.gov/feature/space-gardener-shane-kimbrough-enjoys-first-of-multiple-harvests

Veg-03A in the Social Media:
https://www.facebook.com/ESAThomasPesquet/videos/549820178560793/
https://twitter.com/Thom_astro/status/809840103942197248
https://twitter.com/ISS_Research/status/804781200627920897

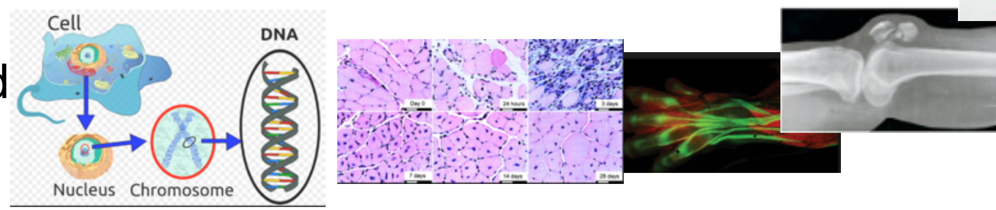
Veg-03A on Inside KSC
KSC UB-A Engineer Nicole Dufour hosted a segment of Inside KSC about the Veg-03 experiment on the ISS. Scientists at Kennedy Space Center watched intently as NASA astronauts aboard the ISS started growing red romaine lettuce in space this week. Link at https://www.youtube.com/watch?v=mq0R-PlcqAk&feature=youtu.be

Space Biology: Gravity as A Continuum

<u>Elucidating the Gravity Dose Response Curve: Threshold or Continuum?</u>

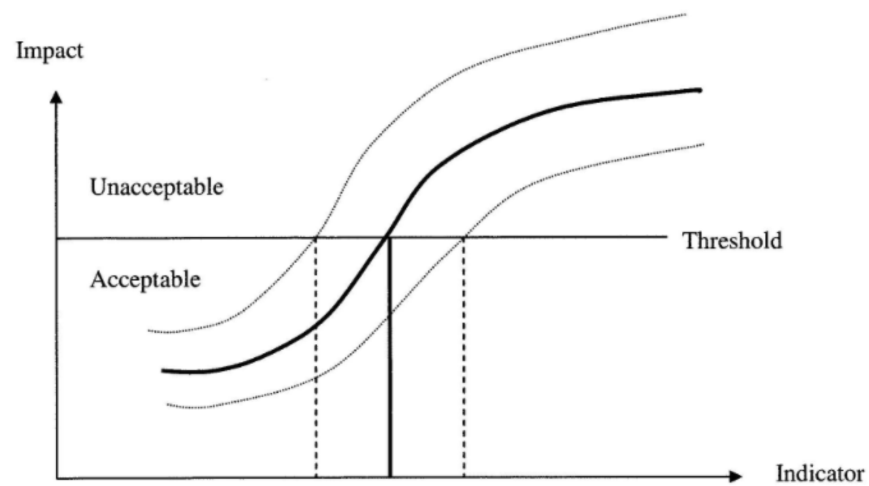


- Gravity induces biological responses at the gene expression, cellular, systems and whole organism level
- The dose response curve of any of these responses is not fully characterized



- It is not known if responses are a continuum or are based on reaching thresholds
- Its is not known if responses require continuous or intermittent exposures
- It is not known if the sensitivity/dose response changes during developmen

<u>Gravity as a Continuum</u> will support ground and flight research on a variety of organisms to elucidate the dose response curve and mechanisms of adaptation across a gravity spectrum from 0g to >2+g



Space Life and Physical Sciences Research and Applications Division

- Human Research Program
- Space Biology
- Physical Sciences

Physical Sciences Research

Combustion Science
- Spacecraft fire safety
- Droplets
- Gaseous – Premixed and Non-Premixed
- Solid Fuels
- Supercritical reacting fluids

Biophysics
- Biological macromolecules
- Biomaterials
- Biological physics
- Fluids for Biology

Fluid Physics
- Adiabatic two-phase flow
- Boiling and Condensation
- Capillary flow and Interfacial phenomena
- Cryogenic storage and handling

Materials Science
- Glasses and Ceramics
- Granular Materials
- Metals
- Polymers and Organics
- Semiconductors

Complex Fluids
- Colloids
- Foams
- Gels
- Granular flows
- Liquid crystals

Fundamental Physics
- Space Optical/Atomic Clocks
- Quantum test of Equivalence Principle
- Cold atom physics
- Critical point phenomena
- Dusty plasmas

Physical Sciences and the Decadal Survey

	Decadal Survey Recommendations
FP1	Research on complex fluids and soft matter
FP2	Understanding of the fundamental forces and symmetries of nature
FP3	Research related to the physics and applications of quantum gases
FP4	Investigations of matter near a critical phase transition
AP1	Reduced-gravity multiphase flows, cryogenics and heat transfer database and modeling
AP2	Interfacial flows and phenomena
AP3	Dynamic granular material behavior and subsurface geotechnics
AP4	Development of fundamentals-based strategies and methods for dust mitigation during advanced human and robotic exploration of planetary bodies
AP5	Experiments on the ISS to understand complex fluid physics in microgravity
AP6	Fire safety research to improve methods for screening materials for flammability and fire suppression in space environments
AP7	Combustion processes research, including reduced-gravity experiments with longer durations, larger scales, new fuels, and practical aerospace materials relevant to future missions
AP8	Research on numerical simulation of combustion to develop and validate detailed single phase and multiphase combustion models for interpreting and facilitating combustion experiments and tests
AP9	Reduced-gravity research on materials synthesis and processing and control of microstructure and properties
AP10	Development of new and advanced materials
AP11	Fundamental and applied research to develop technologies that facilitate extraction, synthesis, and processing of minerals, metals, and other materials available on extraterrestrial surfaces

Physical Sciences and the Decadal Survey

	Decadal Survey Recommendations
TSES1	Conduct research to address issues for active two-phase flow relevant to thermal management (T1)
TSES2	Conduct research on advanced insulation materials research, active cooling, multiphase flows, and capillary effectiveness, as well as active and passive storage, fluid transfer, gauging, pressurization, pressure control, leak detection, and mixing destratification
TSES3	Enhance surface mobility
TSES4	Develop and demonstrate technologies to mitigate the effects of dust on extravehicular activity systems and suits, life support systems, and surface construction systems
TSES5	Define requirements for thermal control, micrometeroid and orbital debris impact and protection, and radiation protection for extravehicular activity systems, rovers, and habitats and develop a plan for radiation shelters
TSES6	Conduct research for the development and demonstration of closed-loop life support systems and supporting technologies
TSES7	Develop and demonstrate technologies to support thermoregulation of habitats, rovers, and spacesuits on the lunar surface
TSES8	Perform critical fire safety research to develop new standards to qualify materials for flight and to improve fire and particle detectors
TSES9	Develop a standard methodology for qualifying fire suppression systems in relevant atmospheres and gravity levels and would benefit from strategies for safe post-fire recovery
TSES10	Conduct research to allow regenerative fuel cell technologies to be demonstrated in reduced-gravity environments
TSES11	To support the development of new energy conversion technologies, research should be done on high-temperature energy conversion cycles, device coupling to essential working fluids, heat rejection systems materials, etc.
TSES12	Research is needed on high-temperature, low-weight materials for power conversion and radiators and on other supporting technologies
TSES13	Development and demonstration of ascent and descent system technologies are needed
TSES14	Research is required to support the development and demonstration of space nuclear propulsion systems
TSES15	Research is needed to identify and adapt excavation, extraction, preparation, handling, and processing techniques for a lunar water/oxygen extraction system

Cool Flames Investigation (CFI)

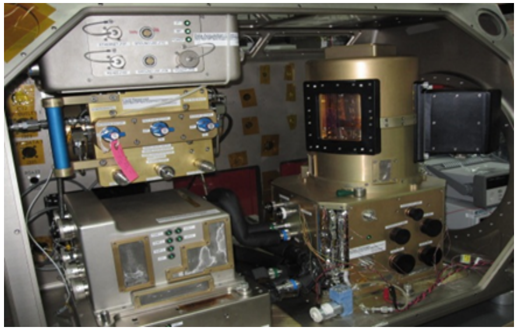
- Objective:
  - To investigate the structure and dynamics of the coo l flame mode of droplet burning – an environment in which the flame was thought to be extinguished until the discovery on the ISS.

- Relevance/Impact:
  - Fundamental Science – cool flame chemistry not well understood; current modeling does not accurately predict cool flame mode of combustion
  - Applications
    - Increase efficiency through advanced low temperature internal combustion engines
    - Reduce emissions with understanding of low temperature chemistry
    - Increase safety on Earth and in spacecraft
  - In collaboration with Russian scientists

Zero Boil-Off Tank (ZBOT)

- Objective:
  - Investigate mass and thermal transport and phase change aspects of cryogenic tank pressurization and pressure control in microgravity

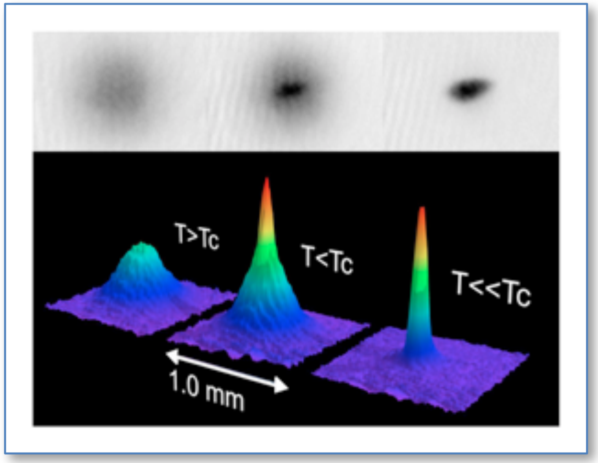
- Relevance/Impact:
  - Optimize development of zero boil-off pressure control, an OCT roadmap Mars mission-enabling technology.
  - Conserve propellant through active mixing and cooling of the fluid without venting
  - Increase design reliability by providing microgravity data for improved CFD models
  - In collaboration with STMD's Evolvable Cryogenics (eCryo) program

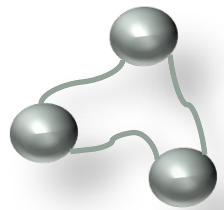


Simulation shows in microgravity non-condensable driven Marangoni convection prevents rapid spread of cold jet around the ullage thus impeding rapid ullage pressure reduction and control.

Cold Atom Laboratory (CAL)

- Bose Einstein condensation (BEC) occurs at $T = 10^{-8}$ K atoms share the same wave function
  - Many body physics
  - Test Einstein Equivalence Principle
  - Search for dark matter, dark energy
- Microgravity enables
  - Reduced temperature ($T = 10^{-12}$ K)
  - Increased interaction time (10 s)
  - Bias free symmetric trap
- High and low resolution imaging allow scientists to view atom clouds from 2 directions
- 7 funded awards
  - Universities, government labs, and NASA
  - Includes 3 Nobel Laureates
- Launch 2017
- Follow on research planned
  - National Science Foundation
  - DLR





Conclusion

- SLPSRA continues to implement an updated interpretation of the Decadal Survey to shape current and future content
  - Enable exploration (emphasis on R&TD pull)
  - Pioneer scientific discovery (emphasis on subsequent Adopters)
- Open Science and partnerships are key to implementation
- Risks of human spaceflight are being better understood and mitigated
- Scientific papers aligned with the Decadal Survey are being published and the results shared at national conferences
- Efforts continue to cultivate opportunities to
  - Enable exploration
  - Identify potential adopters of LEO for research