Science on the International Space Station

National Research Council
Aeronautics and Space Engineering Board
22 April2015

Julie A. Robinson, Ph.D., Chief Scientist, International Space Station

Overview

- Research Demand and Development of ISS as a National Laboratory
- New Facilities and Initiatives
  - Model Organisms
  - One-year Expedition & Twin Study
- Scientific Impact
  - Publications
  - Applications & Benefits

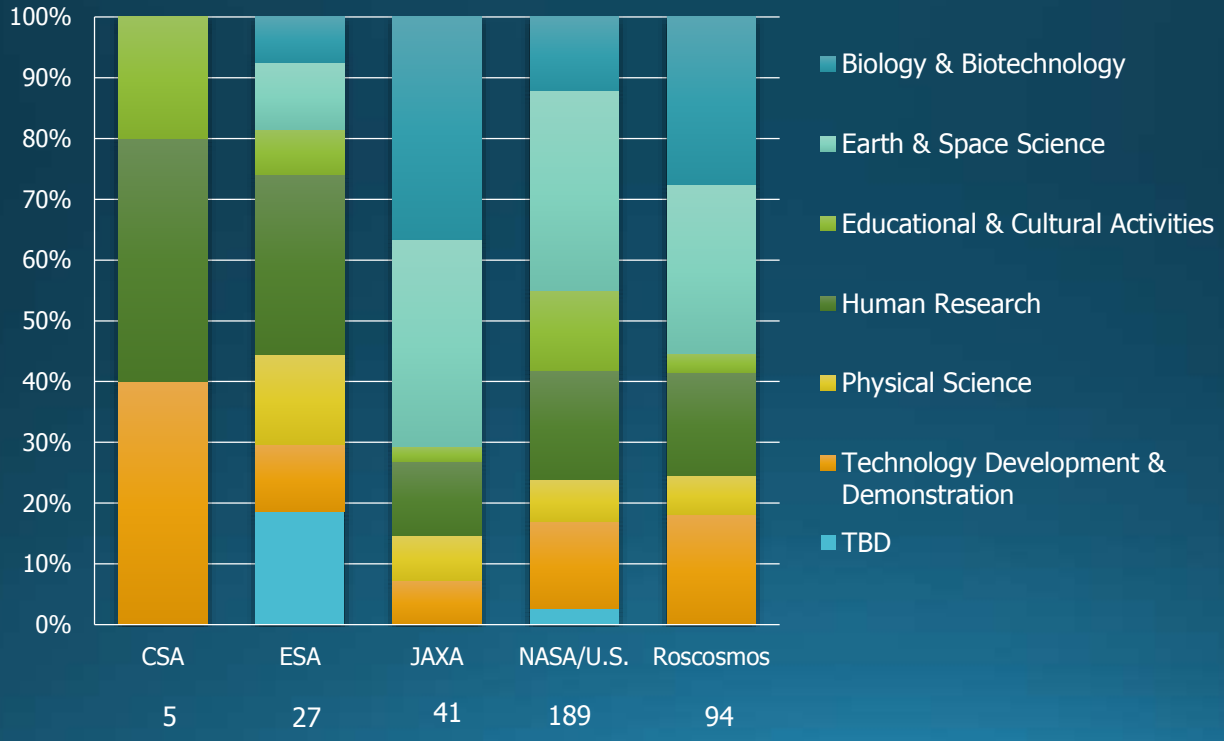
ISS Research Statistics *(Working data through Feb 28, 2014)*

Number of Investigations for 43/44 : 356

- 189 NASA/U.S.-led investigations
- 167 International-led investigations
- 95 new investigations

Total to Date--Expeditions 0-40*

- Over 800 investigators represented
- Over 1100 scientific results published
- 1765 individual investigations

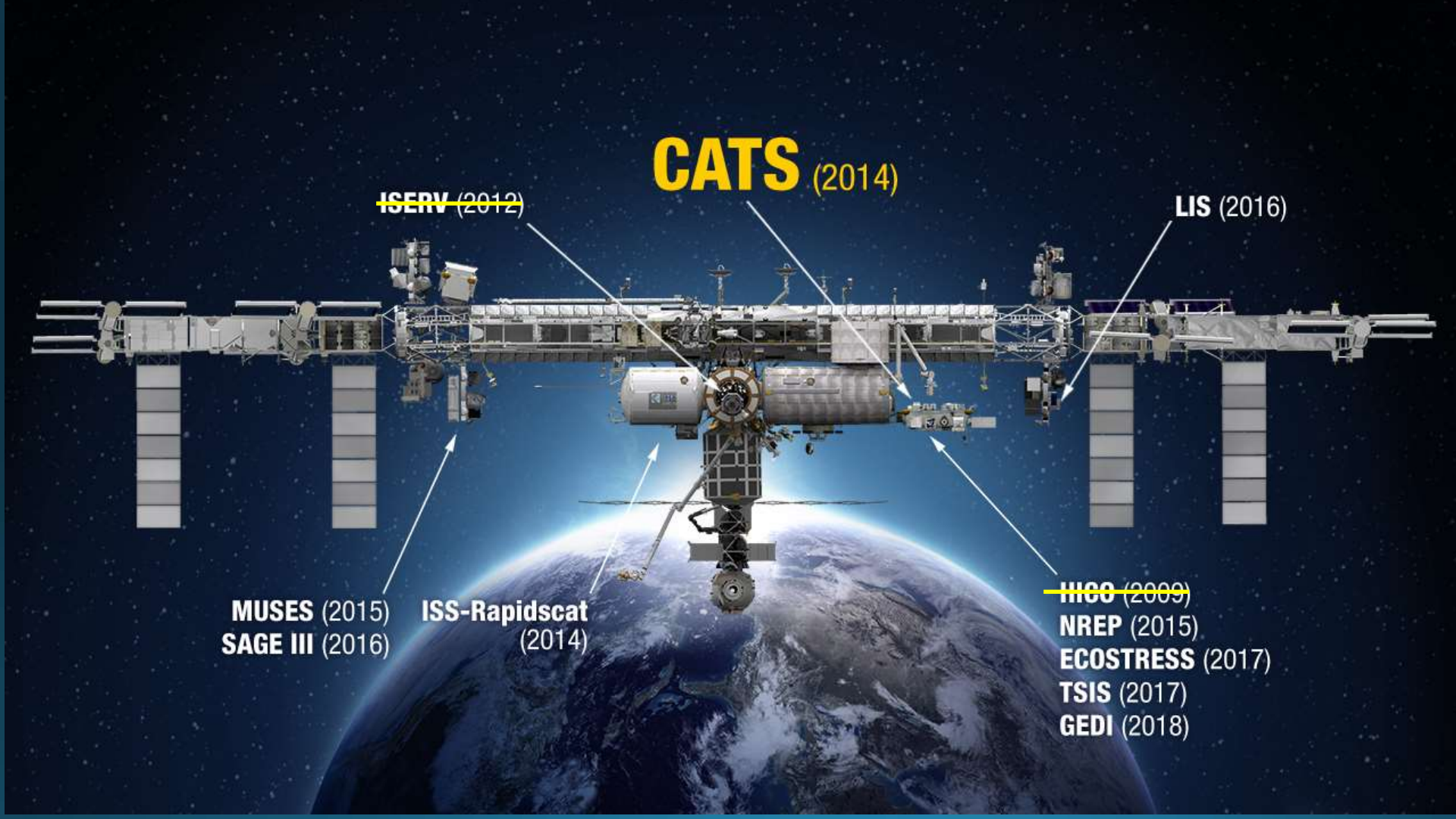


ISS Research and Education
Expeditions 0-38 (Through September 2014)

83 countries and areas

ISS Occupancy Highlights *(data as of February 2014)*

- Internal Occupancy 81%
  - Express racks: will launch additional Express to support small payloads in 2017
  - Microgravity Sciences Glovebox: oversubscribed, will launch a 2nd glovebox to deconflict life and physical sciences
- Crew time heavily oversubscribed
  - Human research and rodent research demand is high, and is crewtime intensive
  - National Laboratory/CASIS demand has grown to fully use the 50% allocation granted in the NASA Authorization of 2010 for crewtime beginning in late 2015, requiring a replanning of NASA-funded research
  - 4th crew member (with commercial crew ~2017) will almost double crew time for research
- External Occupancy (instruments for astrophysics and Earth Science)
  - CATS (Cloud Lidar) and Rapidscat (Scatterometer) launches in 2014
  - 3 sites left after the end of the year (SAGE, NVP, STP-H5), 70%
  - Only 2 sites available in 2017

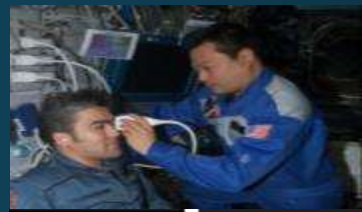

CATS (2014)
~~ISERV~~ (2012)
LIS (2016)
MUSES (2015)
SAGE III (2016)
ISS-Rapidscat (2014)
~~HICO~~ (2009)
NREP (2015)
ECOSTRESS (2017)
TSIS (2017)
GEDI (2018)

What are we doing on ISS today?

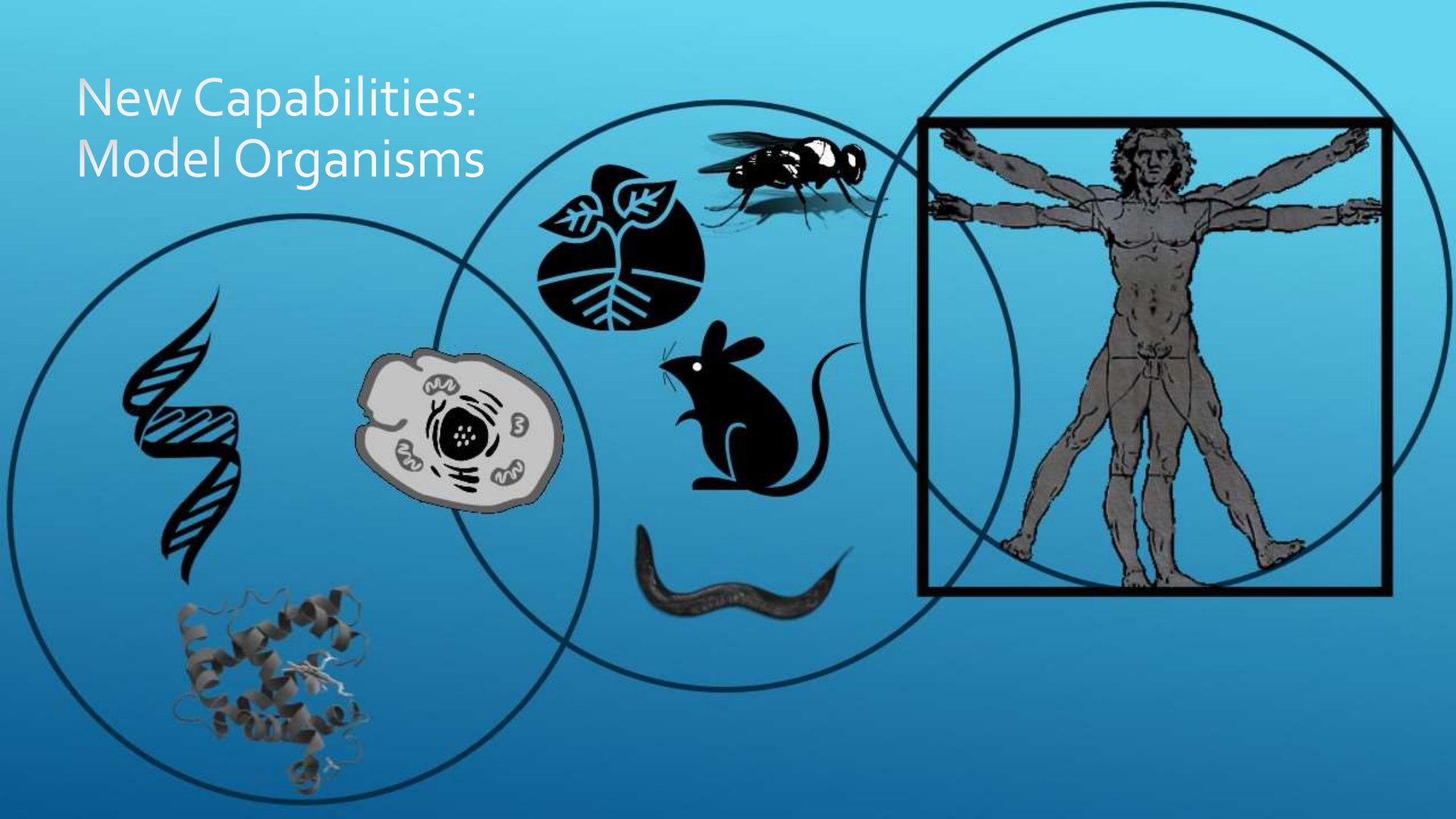
National Lab (CASIS)

NASA Exploration

- Biology and Biotechnology
- Physical Sciences
- Biomedical Human Research
- Tech Demos
- Astrophysics*
- Earth and Space Sciences



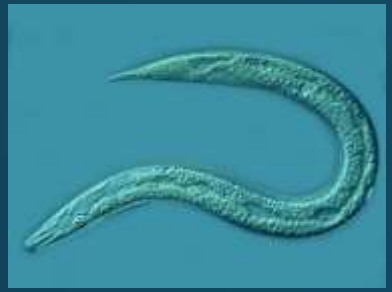
New Capabilities: Model Organisms



Model Organisms on ISS, Examples from 2014-2015

Worms (C elegans):

- **"Epigenetics" (Sx-5, JAXA)** studies impacts of microgravity on basic DNA across multiple cell generations.
- **"Nematode Muscle" (Sx-6, JAXA)** studies muscle atrophy molecular mechanisms *(muscle)*.



- **"Micro 5" (Spx-5, NASA)** infects C elegans with Salmonella typhimurium and follows the survival of the C. elegans on orbit *(immune)*.

Rodents:

Rodent Reearch-2 (Sx-6, NASA, National Lab)

- Immune system response under simulated infection *(immune, NASA)*.
- Effects on intracranial pressure *(vision, NASA)*.
- Bone remodeling with periodic measures throughout the flight (*CASIS-sponsored*)

Fruit Flies (Drosophila):

Fruit Fly Lab-01 (Spx-5, NASA) hoped to study microbial interaction, microgravity, and radiation on fruit flies on ISS *(immune), hardware failure, reflight planned in replacement hardware*.

Plants (Arabadopsis):

Plant Gravity Sensing 1&2 (Spx-4, -6 NASA) studies the structures involved in calcium signaling required for plant growth under various microgravity conditions (*optimal plant growth)*.

Studying model organisms in space contributes to understanding basic processes that can also be applied on Earth, such as treatments for disease, improvements for injured or aging populations, and innovative agricultural processes.

First Flight of Rodent Research System

"The lack of an animal facility for rodents on the ISS suitable for long-duration studies on adult animals is a major research impediment that will hamper the ability to obtain information important for maintaining astronaut health and fitness for duty." - *NRC Decadal Survey, 2011.*

- **"Rodent Research-1"** September-November 2014
  - 10 "NASA" mice dedicated to evaluation of hardware and on-orbit operations (Launched and samples returned on SpaceX-4).
  - 10 "National Laboratory" mice: Pharmaceutical company evaluating muscle atrophy (Launched on SpaceX-4, samples returned on SpaceX-5)
  - On orbit dissections, tissue sharing, evaluation of data retrieval from returned frozen carcasses

ISS One-Year Mission

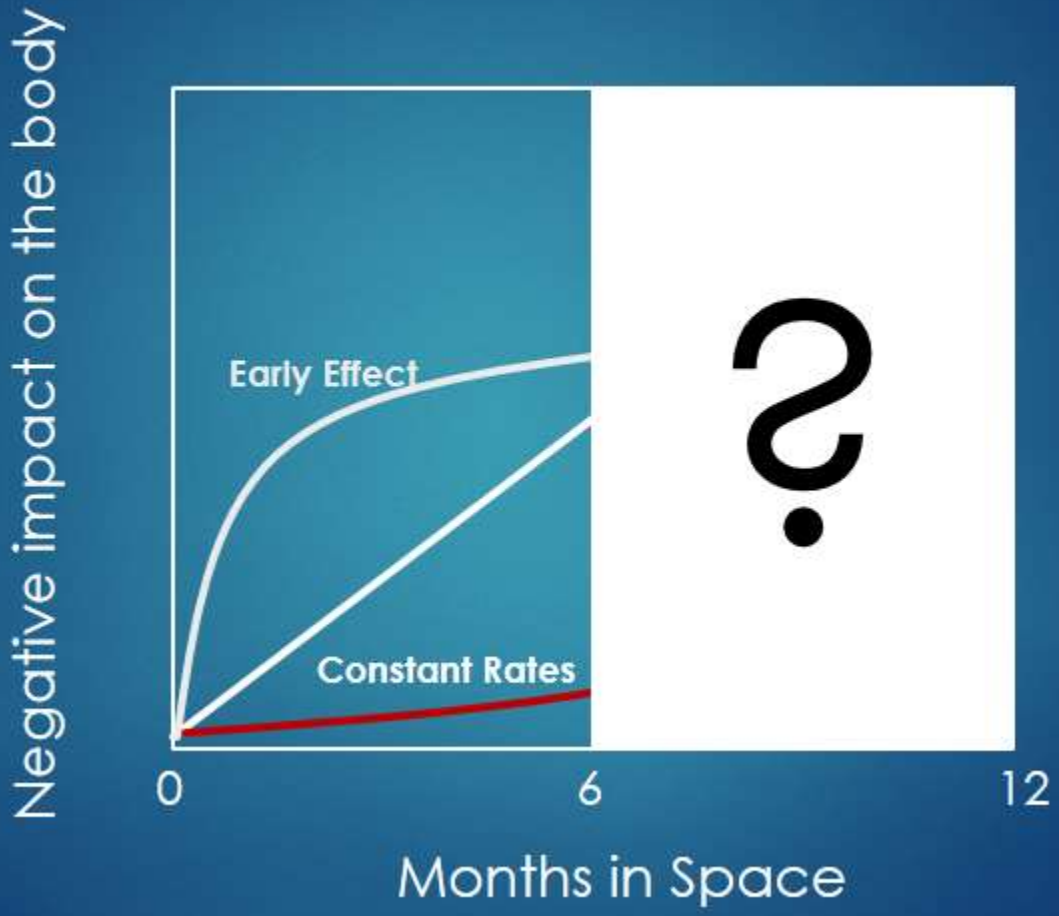
http://www.nasa.gov/exploration/humanresearch/index.html

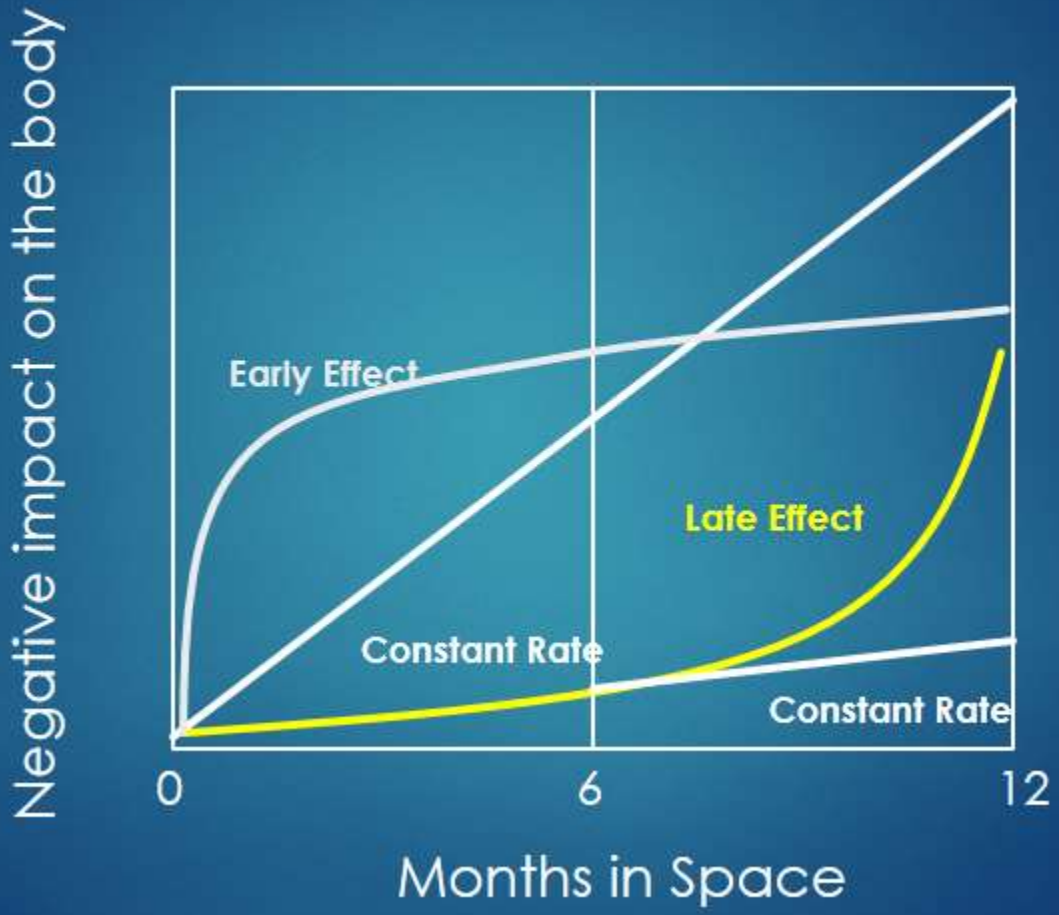
Physiological Response to Spaceflight

Astronauts experience a spectrum of adaptations in flight and postflight

Balance disorders
Cardiovascular deconditioning
Decreased immune function
Muscle atrophy
Bone loss

- Neurovestibular
- Cardiovascular
- Bone
- Muscle
- Immunology
- Nutrition
- Behavior
- Radiation


Negative impact on the body
Early Effect
Constant Rates
?
0
6
12
Months in Space


Negative impact on the body
Early Effect
Late Effect
Constant Rate
Constant Rate
0
6
12
Months in Space

Months	14	13	12	11	10
#	1	1	2	1	1
Year	1994-1995	1998-1999	1987-1988	1987	1992

Valeri Polyakov

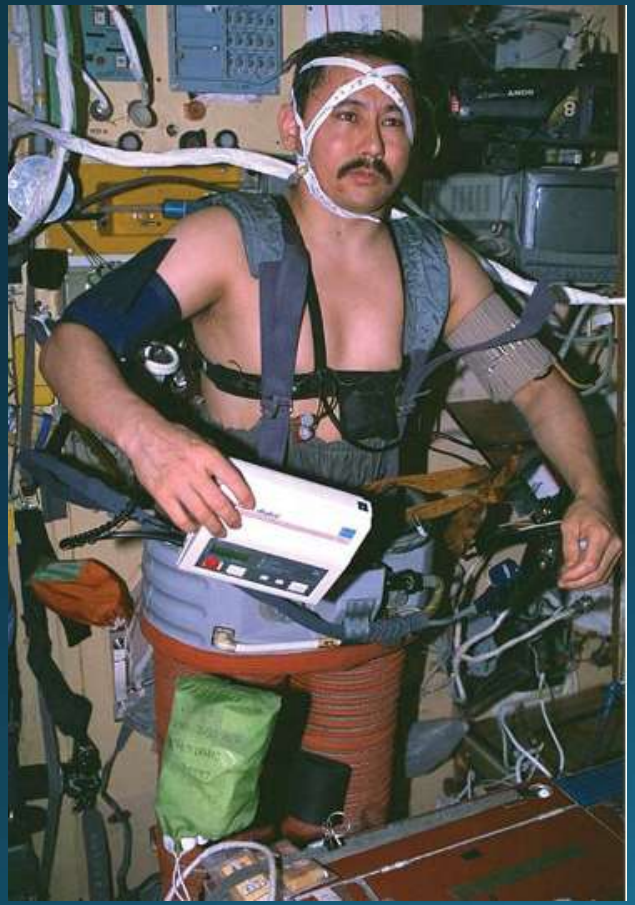
Sergei Avdeyev

Vladimir Titov

Musa Manarov

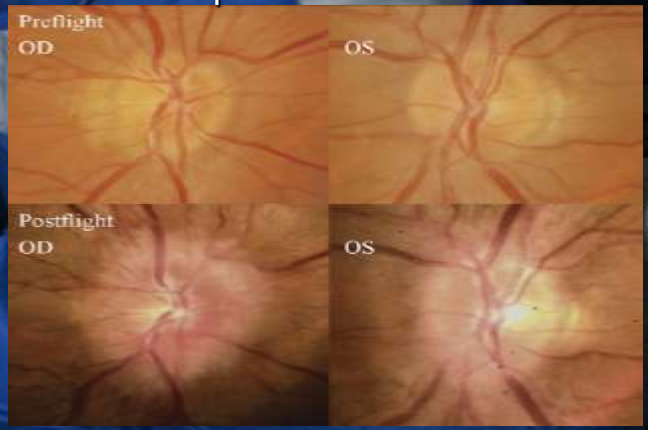

KELLY · КОРНИЕНКО
YEAR IN SPACE - ГОД В КОСМОСЕ
ISS 43 • 44 • 45 • 46 МКС

Highlight: Fluid Shifts Investigation



Highlight Ocular Health

Optic Disc Edema



Journal of Nutrition, Zwart, et. al February 2012
Ophthalmology, Mader, et. al October 2011

Source: ISS Program Scientist, NASA

MEET THE TWINS UNLOCKING THE SECRETS OF SPACE

BY JEFFREY KLUGER

PHOTOGRAPHS BY MARCO GROB FOR TIME

time.com/meet-the-twins-unlocking-the-secrets-of-space/

"Twins" Investigations begin integrated human omics studies in space

Susan Bailey, Colorado State University, Differential effects on telomeres and telomerase in twin astronauts associated with spaceflight

Andrew Feinberg, Johns Hopkins University School of Medicine, Comprehensive whole genome analysis of differential epigenetic effects of space travel on monozygotic twins

Christopher Mason, Weill Medical College of Cornell University, The Landscape of DNA and RNA Methylation Before, During, and After Human Space Travel

Scott Smith, NASA Johnson Space Center, Biochemical Profile: Homozygous Twin control for a 12 month Space Flight Exposure

Emmanuel Mignot, Stanford University School of Medicine, HERO Twin Astronaut Study Consortium (TASC): Immunome Changes in Space

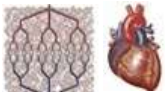
Stuart Lee, Wyle Laboratories, Metabolomic And Genomic Markers Of Atherosclerosis As Related To Oxidative Stress, Inflammation, And Vascular Function In Twin Astronauts

Brinda Rana, University of California, Proteomic Assessment of Fluid Shifts and Association with Visual Impairment and Intracranial Pressure in Twin Astronauts

Mathias Basner, University of Pennsylvania School of Medicine, HERO Twin Astronaut Study Consortium (TASC) Project: Cognition on Monozygotic Twin on Earth

Fred Turek, Northwestern University, HERO Twin Astronaut Study Consortium (TASC) Project: Metagenomic Sequencing of the Bacteriome in GI Tract of Twin Astronauts

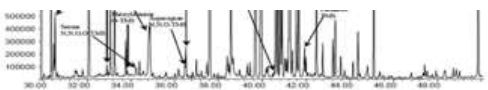
Michael Snyder, Stanford University, HERO Twin Astronaut Study Consortium (TASC) Project: Longitudinal integrated multi-omics analysis of the biomolecular effects of space travel



Vasculature
Lee

Cognition
Basner

Microbiome
Turek



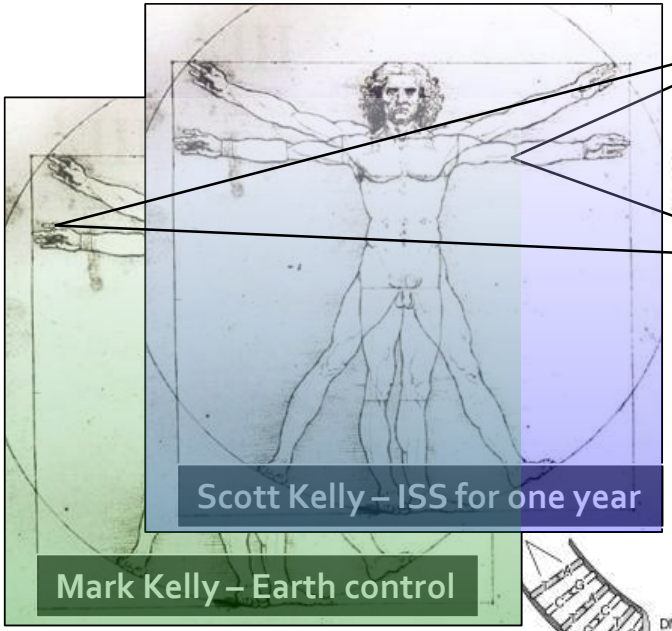
Targeted and Global Metabolomics
Lee/Rana, Mignot/Snyder & Smith

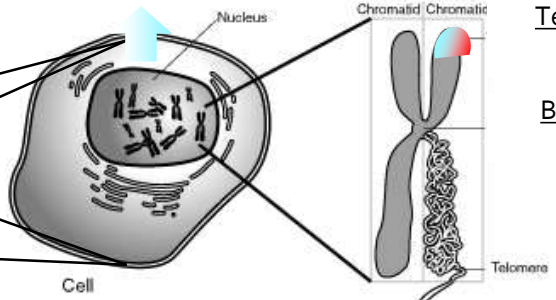
Cytokines
Mignot

Telomere Length
Bailey

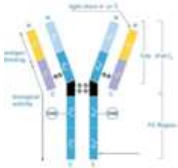
B-cells / T-cells
Mignot

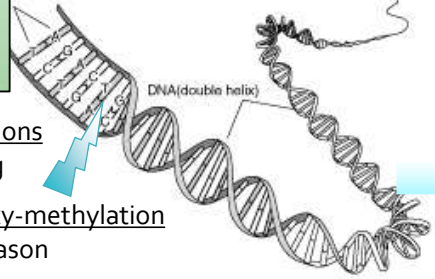
Antibodies
Mignot/Snyder





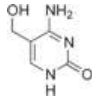
Chromatin
Feinberg



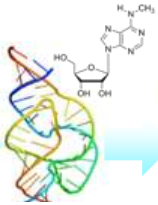


DNA Mutations
Feinberg

DNA Hydroxy-methylation
Mason



DNA Methylation
Feinberg & Mason

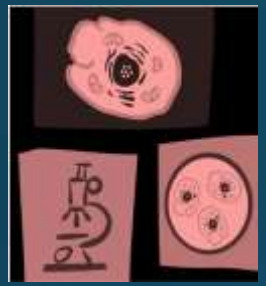


large/small RNA
& RNA Methylation
Mason

Proteomics
Lee/Rana

Key Clusters of Research Results over the past 2 years: Discoveries and Applications

Medicine

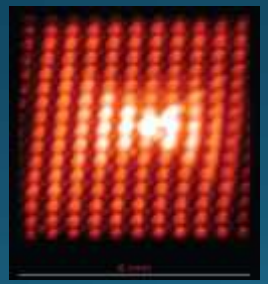


Cell Biology

Protein Crystals

Disasters

Combustion



Nanomaterials

Alloys

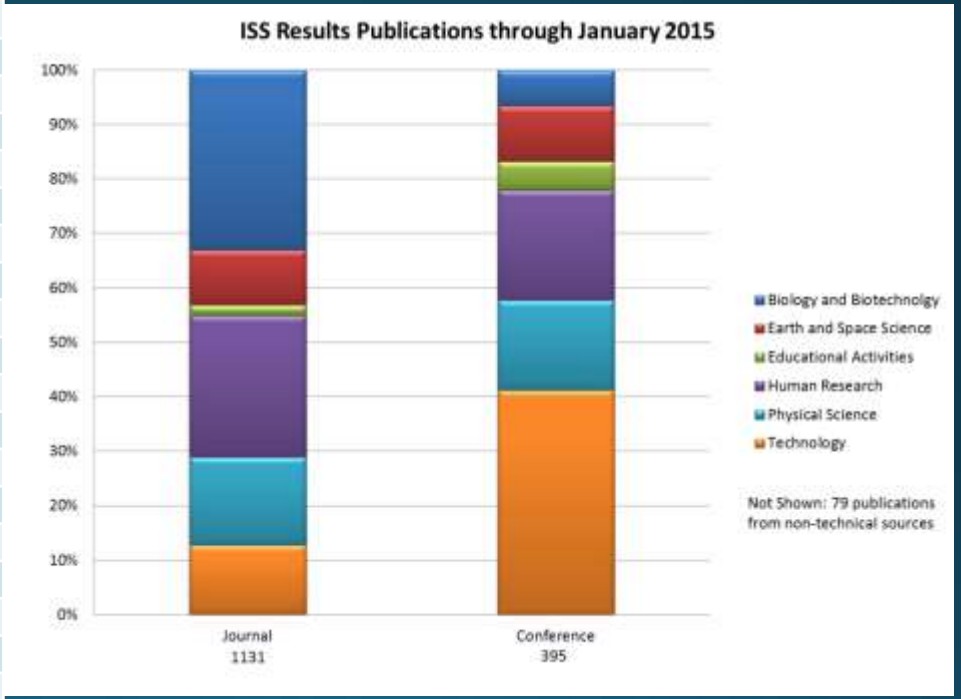
Robotics

Top 20 Journals with ISS Results*

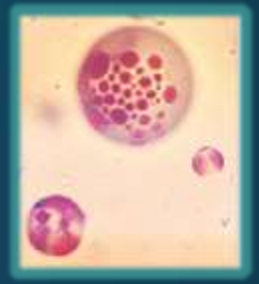
Nature
Proceedings of the National Academy of Sciences of the United States of America
Science
PLOS ONE
Physical Review Letters
Journal of Biological Chemistry
Journal of Neuroscience
Journal of Geophysical Research
Chemical Communications +
Physical Review D
Advanced Materials
Geophysical Research Letters
Langmuir
Journal of Chemical Physics
Chemistry – A European Journal +
Physical Review E
NeuroImage
The Astrophysical Journal
Journal of Physical Chemistry B
Oncogene

*Journals are listed in Eigenfactor® order.

+Denotes new Journal to top 20 List since the Expeditions 0-38 report.



Example of Pathway from Bench to Bedside



What was done in space:

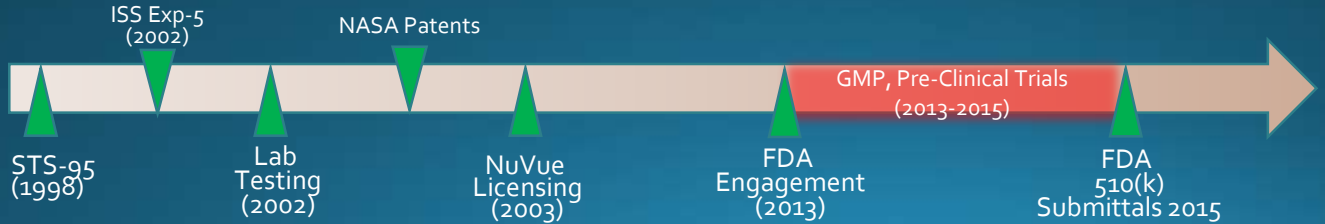
- The NASA Microencapsulation processing system (MEPS) was flown on STS-95 (1998) and ISS Expedition 5 (2002), where the unique behavior of fluids in microgravity led to improvements in microcapsule development.
  - *Microcapsule technology has been tested by many researchers on Earth as a form of cancer treatment by directly injecting microcapsules into tumor sites without the toxic effects of systemic chemotherapy, but several disadvantages have restricted the use of this technology in cancer treatment.*

What spaceflight enabled:

- The space flight results led to the development of a ground-based version of the system (called the Pulse Flow System (PFS)) for Earth-based manufacturing of commercial-scale quantities of the desirable microcapsules that showed significant improvements in treating tumors in laboratory animals.
  - *13 NASA US patents were filed, and are currently licensed to NuVue Therapeutics, Inc.*

What's happening now:

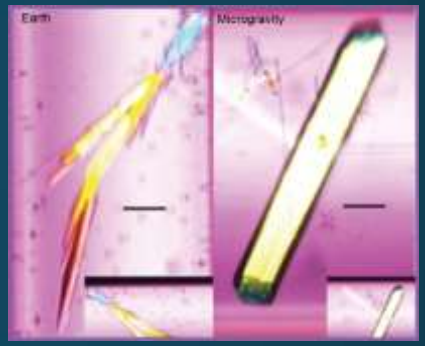
- The MEPS team is currently working closely with the FDA towards three 510(k) applications as visualization markers:
  - Imaging Marker-Microcapsules ("Biopsy Site Marker") for the visualization of tumor tissue sites, (pre and post surgical)
  - Microcapsule Fiducial Imaging Markers for measuring tumor regression
  - Microcapsule Tissue Markers for Magnetic Resonance Imaging compatibility (this was recommended by FDA)
- Results from these studies will also advance development of the chemo markers for future FDA approval



Example of Pathway from Bench to Bedside

What was done in space:

On ISS, Japanese scientists crystallized a protein (H-PGDS) involved in the progression of Duchenne Muscular Dystrophy complexed to its known oral inhibitor (HQL-79) in an effort to grow a 3-dimensional crystal structure that could provide insight on how to improve the inhibitor in Duchenne patients.



What spaceflight enabled:

Lack of sedimentation and convection in microgravity led to the 3-dimensional crystal growth that allowed scientists to identify an improved complex structure and an associated water molecule that was not previously known. Researchers used this discovery to developed an even more potent form of HQL-79 inhibitor for Duchenne in laboratory testing.

What's happening now:

Principal Investigators are studying the effects of the improved inhibitor in pre-clinical studies on animals. Beagle pups treated with the improved inhibitor has shown improvements in slowing the progression of Duchenne.

ISS Benefits for Humanity, 2nd Edition

JULY 2015 release planned

Human Health

Earth Observation & Disaster Response

Innovative Technology

Global Education

Economic Development of Space

http://www.nasa.gov/stationbenefits

ISS Research & Technology

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