

# Briefing to the Human Exploration and Operations Advisory Committee

July 25, 2016

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Division Director



SPACE LIFE AND PHYSICAL SCIENCES RESEARCH AND APPLICATIONS

# SLPSRAD Alignment with the NASA Strategic Plan



*Objective 1.1: Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration*

*Objective 1.2: Conduct research on the ISS to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity.*

# SLPSRAD Research and Application Focus Areas



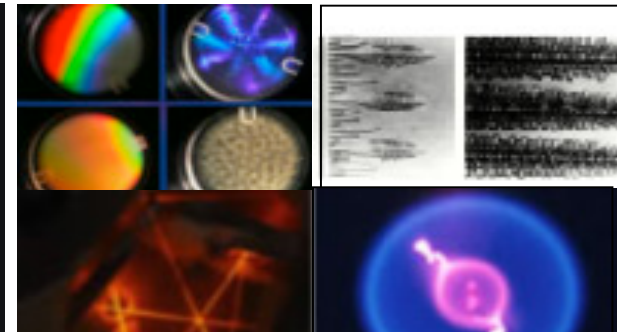
**Space Biology**

- Uses the space environment to enhance understanding of the response of living organisms and biological processes to spaceflight conditions.
- Works toward an understanding of the requirements of terrestrial life in non-Earth environments. Provides access to model biomedical research systems.



**Human Research**

- Develops scientific and technological foundations for a safe, productive human presence in space for extended periods.
- Focuses on investigating and mitigating the highest risks to human health and performance in order to enable safe, reliable, and productive human space exploration.



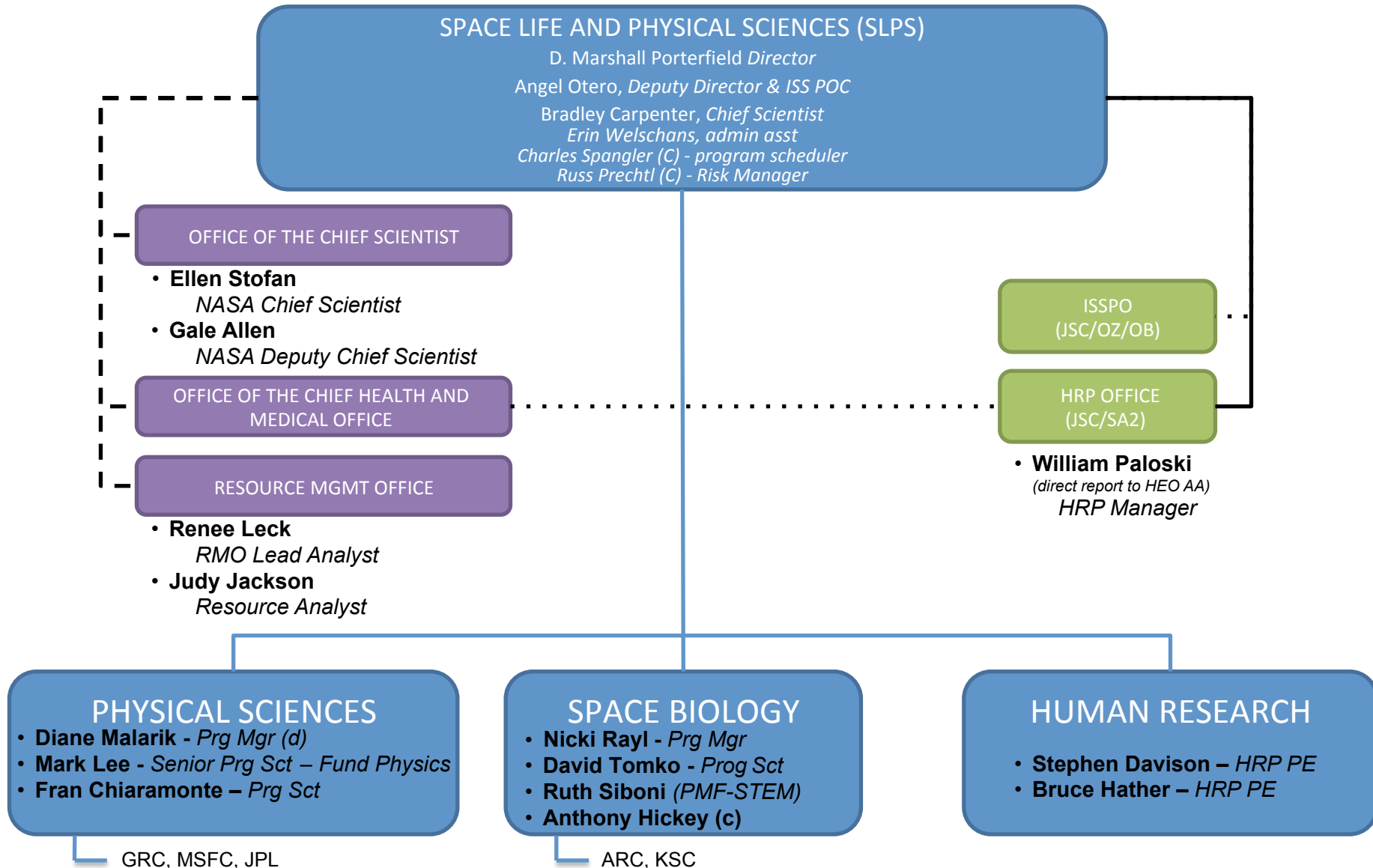
**Physical Sciences**

- Conducts fundamental and applied research in space to explore the processes that form materials and determine the performance of fluid, thermal, and combustion systems.
- Builds engineering knowledge to enable the design of fluid, thermal, and chemical process devices for future space exploration systems.

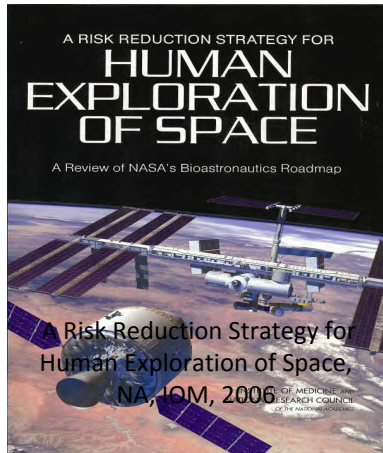
We apply this knowledge and technology to improve our Nation's competitiveness, education and the quality of life on Earth.



# SLPSRA Organizational Chart



# Human Research Program



## Risk Reduction for Human Exploration of Space

“Human space flight remains an endeavor with substantial risks, and these **risks must be identified, managed, and mitigated** appropriately to achieve the nation’s goals in space.”

### Mission

- Enable space exploration beyond low Earth orbit by reducing the risks to human health and performance through a focused program of basic, applied, and operational research

### Goals

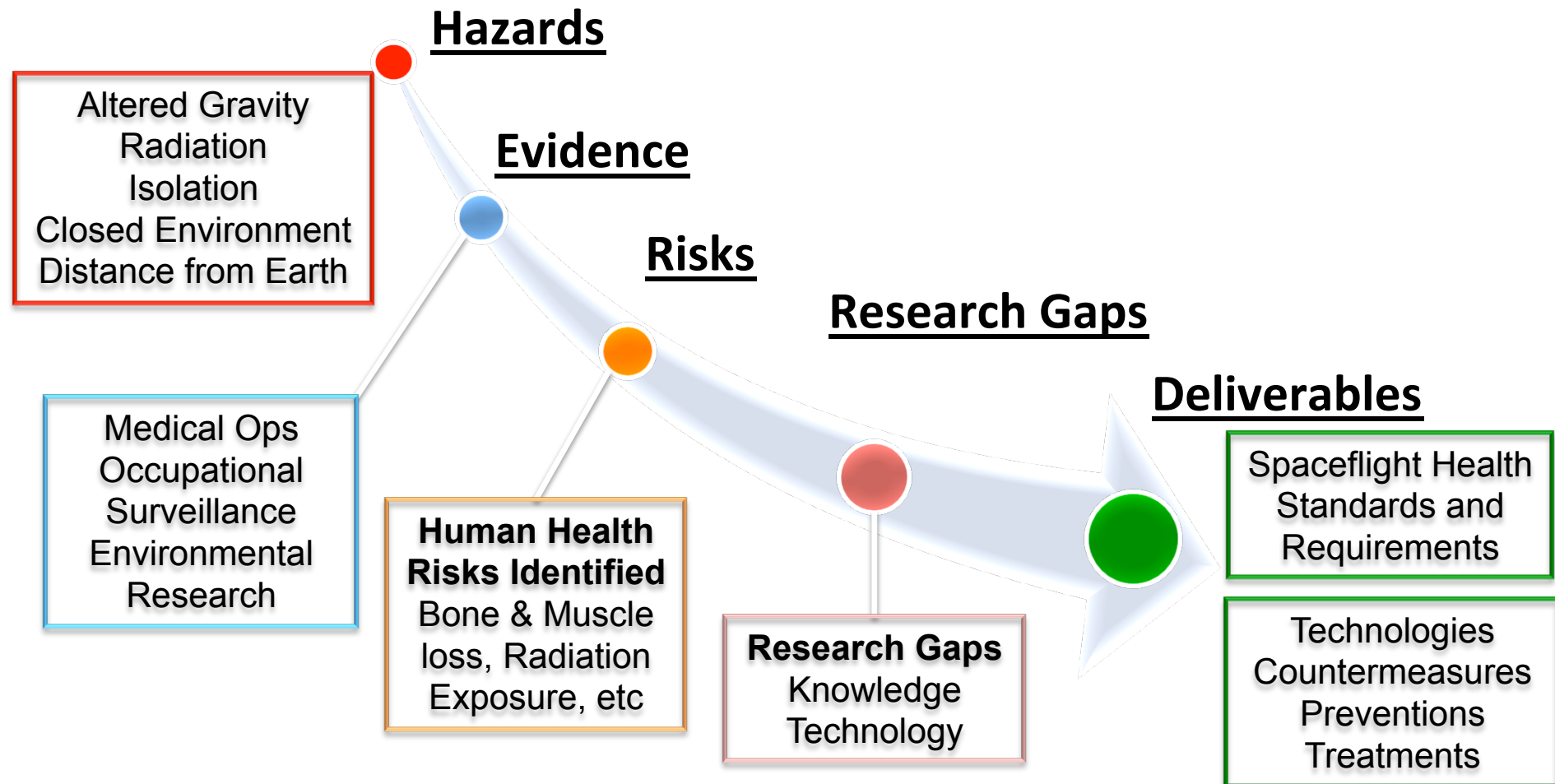
- Perform research necessary to understand human health risks and develop countermeasures
- Develop and validate technologies and tools that serve to characterize and/or reduce medical risks
- Enable development of human spaceflight medical and performance standards



# Risk-based Human Health Framework



Enable Successful Space Exploration by Mitigating the Risks of Spaceflight



# Human Research Program



## Science Management and Program Integration Office

Program Planning, Integration/Control, Peer Review, Task/Risk Management, Data Archive/Sharing

## Space Radiation Element

Recommendations to permissible exposure limits, assessment/projection tools/models of crew risk from radiation exposure, and models/tools to assess vehicle design for radiation protection

## Human Health Countermeasures Element

Integrated physiological, pharmacological/nutritional countermeasures suite, development and assessment of medical standards, vehicle and spacesuit requirements to meet physiological needs

## Exploration Medical Capabilities Element

Medical care and crew health maintenance technologies (monitoring, diagnostic, treatment tools/techniques); medical data management; probabilistic risk assessment; informatics development

## Behavioral Health & Performance Element

Behavioral health and performance monitoring tools/countermeasures (sleep/circadian; neurobehavioral; psychosocial), crew composition, selection, assessment, and training capabilities

## Space Human Factors & Habitability Element

Anthropometry, display/control, usability, cognition, habitability, lighting, ergonomics; adv. food development; dust characterization/toxicology testing, microbiological hazards characterization

## ISS Medical Projects Element

Research integration and operations: ISS, Flight Analog facilities

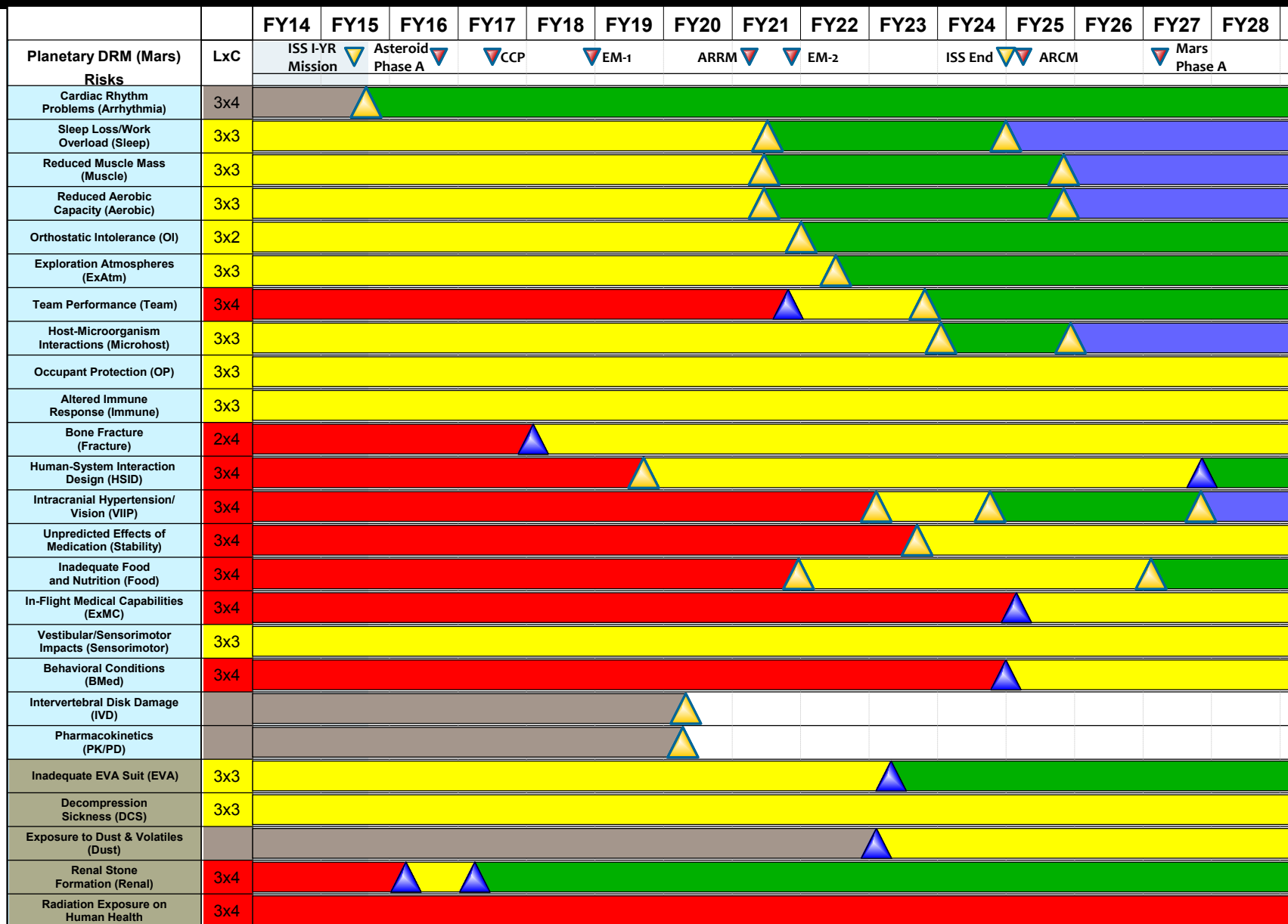
## National Space Biomedical Research Institute

Cooperative agreement to pursue research that extends the HRP portfolio





# Integrated Path to Risk Reduction, Revision C (2015)



- Uncontrolled
- Partially Controlled
- Controlled
- Optimized
- Insufficient Data

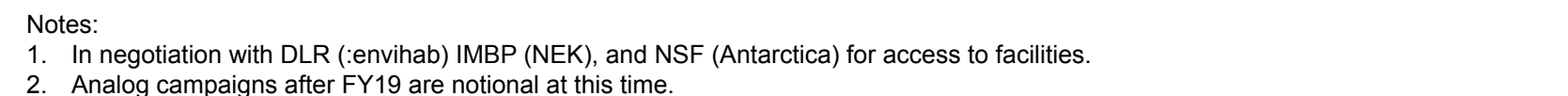
- Assumptions:**
- 450 crew hrs/ Increment pair
  - 3 crew/ Increment pair
  - 6 month missions

Updated  
6/10/15

ISS Required ISS Not Required

Milestone Requires ISS

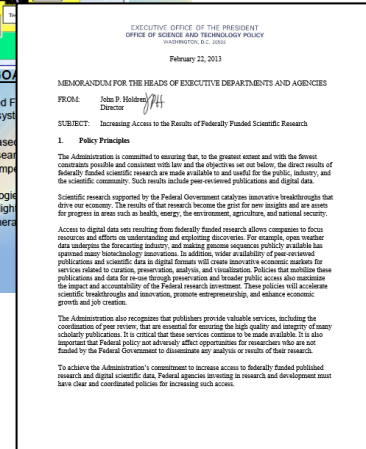
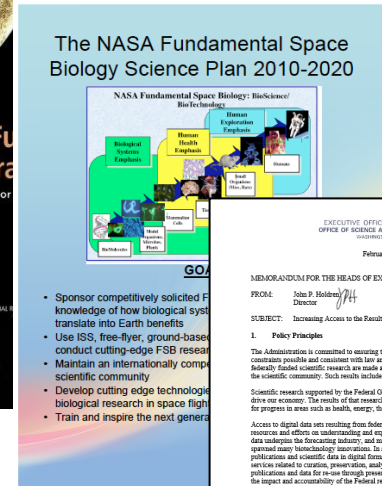
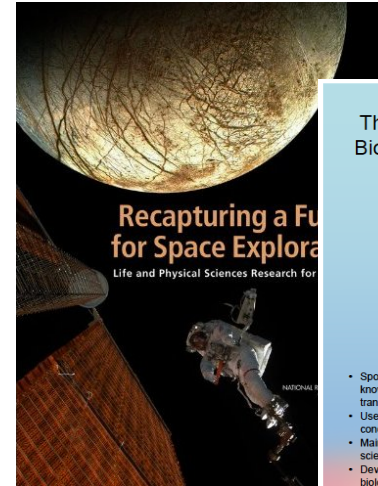
Milestone Shift



# Biological and Physical Sciences



- NRC Decadal Survey
- BPS Integrated Science Plan
- Executive Order, “Increasing Access to the Results of Federally Funded Scientific Research”
- International Collaboration



# Strategy vs Logistics



“Amateurs talk strategy, professionals talk logistics” – *attributed to Omar Bradley*

- A serious practical obstacle to the execution of a BPS research strategy is the limited crew time available for NASA-sponsored basic research

## Increment 45/46 Research Plan Baseline

NASA/CASIS Research Plan:	Prime Requested	Prime Adjusted A
National Lab (NLO) / CASIS	389.26	291.75
NASA Research - HRP	414.32	289.40
NASA Research - Non HRP <sup>1</sup>	314.34	0.00
Tech Demo	83.41	6.00
Cold Stowage	40.75 <sup>2</sup>	57.26
Other IP Agreements <sup>3</sup>	25.41	25.41
<b>Totals</b>	1267.49	669.82
<b>Total NASA Allocation:</b>	--	652.50

## Increment 47/48 Research Plan Baseline

NASA/CASIS Research Plan:	Prime Requested	Prime Baselined
National Lab (NLO) / CASIS	348.92	348.92 <sup>3</sup>
NASA Research - HRP	255.73	255.73
NASA Research - Non HRP	346.05	12.67 <sup>3</sup>
Tech Demo	200.86	99.83
Cold Stowage <sup>1</sup>	40	33.81
Other IP Agreements <sup>2</sup>	50	39.66
<b>Totals</b>	1224.98	790.62
<b>Total NASA Allocation:</b>		782.09

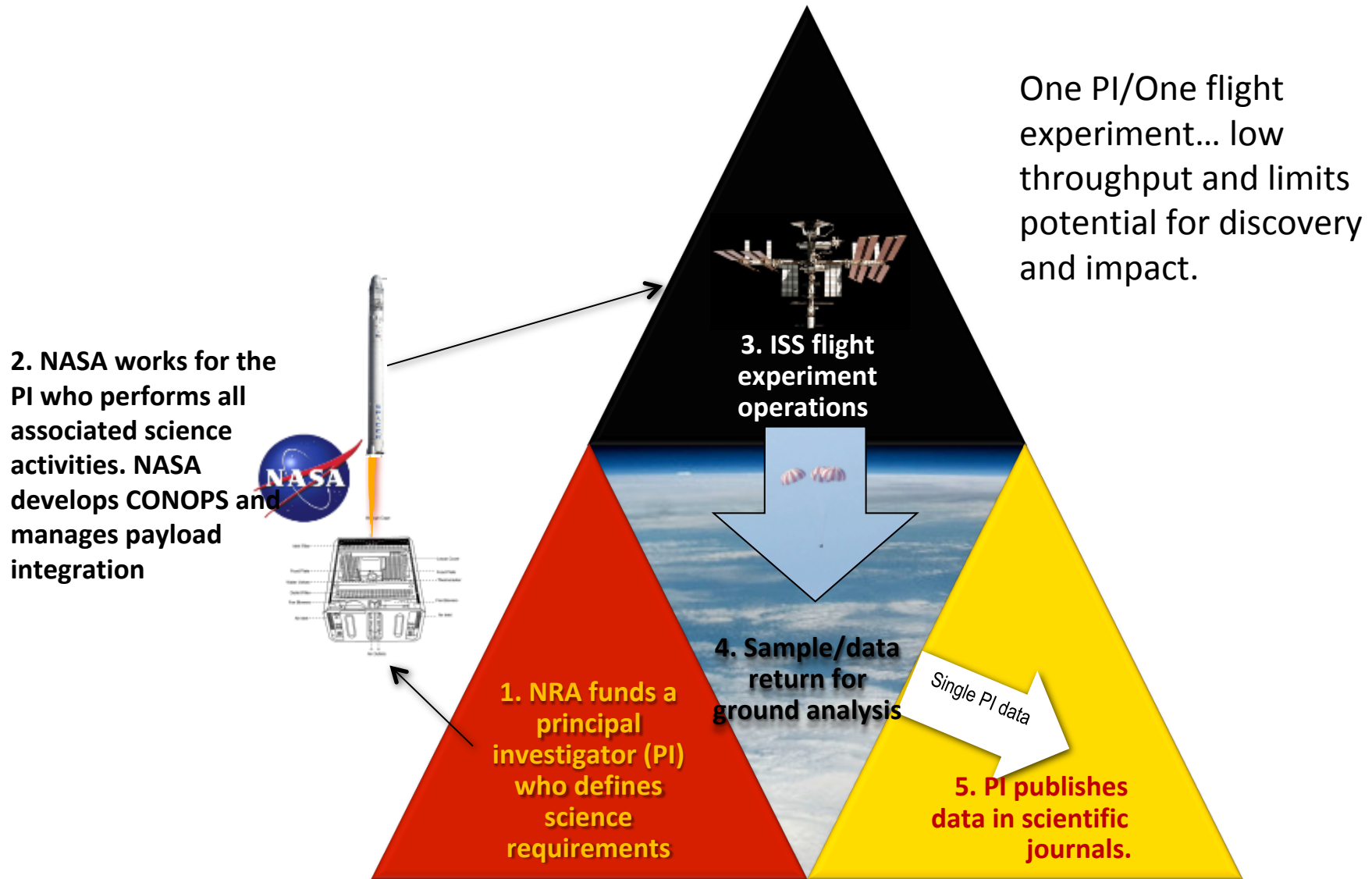
- The lack of crew time for BPS research has driven a search for more efficient approaches to engage to research community in flight experiments

- Open Science is a paradigm shift away from the traditional approach of enabling science for one specific Principal Investigator (PI) at a time.
- Open Science does not eliminate the traditional Flight PI role, but allows us to enhance science returns by having multiple investigators on the ground accessing the flight data for advanced modeling and analysis – enabling development next generation science
- Our vision: implement Open Science initiatives across the SLPS portfolio.

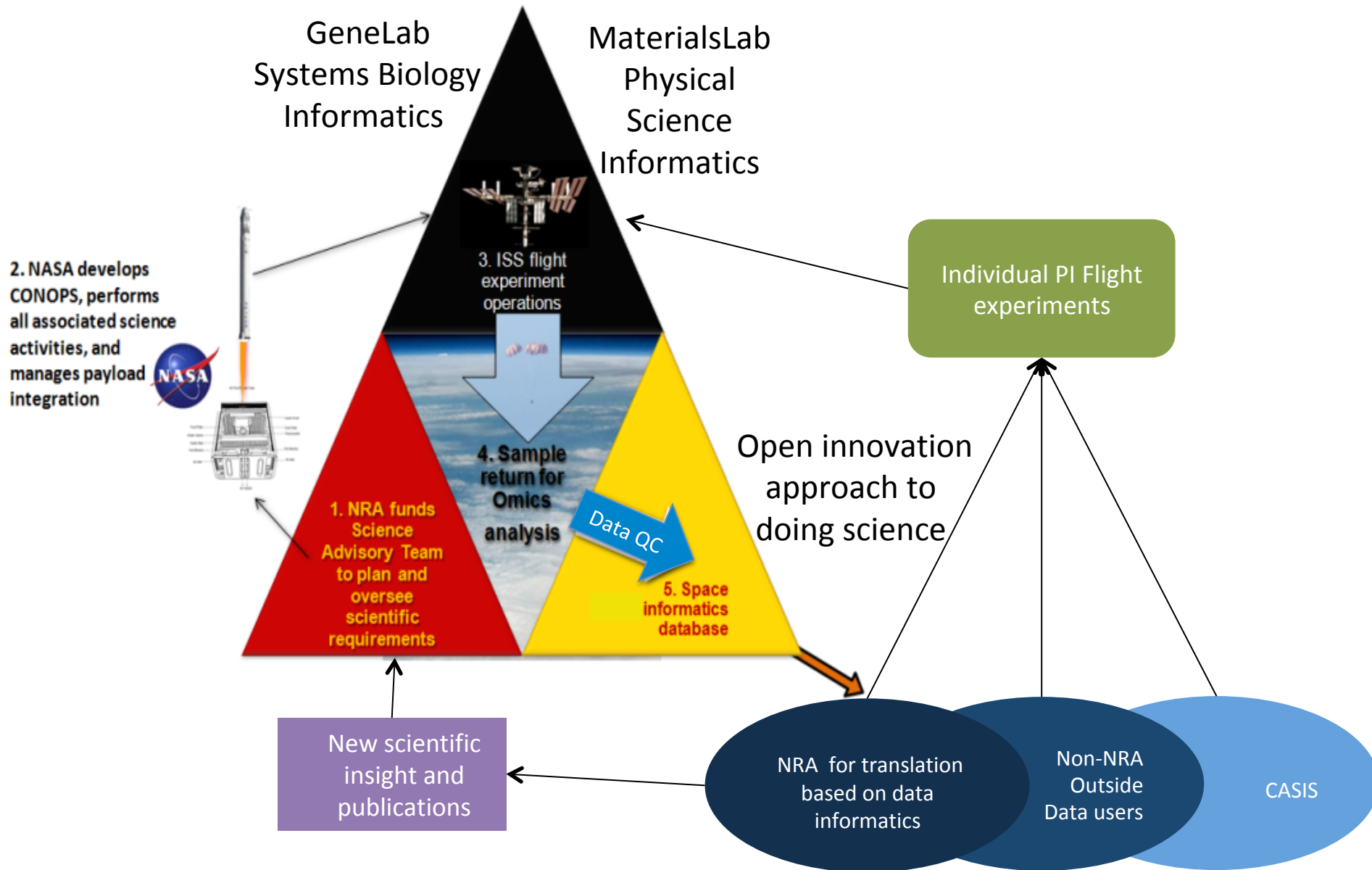
## **Initial Pathfinders:**

- GeneLab (Space Biology)
- MaterialsLab (Physical Sciences)
- Implementation of these pathfinders is bound by our budget

# Traditional Approach to Flight Research



# Open Science can allow many investigators to participate in flight experiments





- The Open Science approach is intended to enhance the scientific return from ISS during its operating timeline and beyond
- SLPS is poised to implement the initial phases of Open Source with the geneLAB and materialsLAB pathfinders
- Full implementation of these beyond their initial the initial phase will depend on performance and budget

# GeneLab Strategic Plan



To address these recommendations of the NRC Decadal Survey, the Space Life and Physical Sciences Research and Applications Division of NASA's Human Exploration and Operations Mission Directorate has initiated a transition to an *Open Science architecture to increase research opportunities*, and is developing the *GeneLab Platform based on highly leveraged and integrated bioinformatics analytics*.

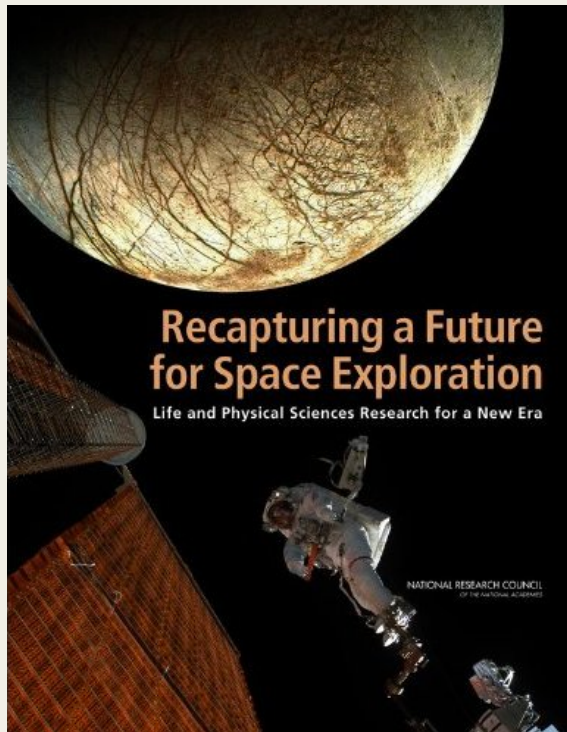
-GeneLab Strategic Plan, 2014



# Recommendations from the 2011 Decadal Survey



**“In the past decade, major conceptual and technological advances in genetics, molecular conservation, and genome sequencing have considerably expanded the scope and depth of developmental biology in ways that will significantly enhance the ability to uncover fundamental biological principles governing how bodies and brains organize, develop, maintain, and adapt under the constant force of gravity.”**



**“High priority studies include: developmental programming, epigenetics, and omics *systems biology* approaches”**

“Spaceflight experiments offer unique insights in the the role of forces omnipresent on Earth (but absent in orbital flight). Such spaceflight experiments would place gravitational biology at the leading edge of modern developmental and evolutionary science”

A strategy that would benefit all research areas “Creation of robust databases that could be used for extramural scientist to address research questions”

# Project Goals for GeneLab



“The GeneLab Project is a new ***systems approach*** to space biology research and International Space Station utilization based on high content bioinformatics analytics operating under open science and open data policies.”

## GeneLab Project Goals / Level 0 Requirements

1. “Develop an integrated repository and bioinformatics data system for analysis and modeling “
2. “Enable the discovery and validation of molecular networks that are influenced by space conditions through ground-based and flight research using next-generation omics technologies”
3. “Engage the broadest possible community of researchers, industry, and the general public to foster innovation”
4. “Strengthen international partnerships by leveraging existing capabilities and data sharing “

-GeneLab Strategic Plan, 2014

[Comment #3]



# Implementation of GeneLab

## Phased Implementation 2014-2021

Begin  
Implementation

Full  
Implementation

We are here

**Phase 1**  
Searchable Data  
FY2014 –2015

**Phase 2**  
Data Exchange  
FY2015-2016

**Phase 3**  
System Integration  
FY2017 – 2018

**Phase 4**  
Implementation  
FY2019 – 2021

### Data Systems

- **System Requirements & Architecture**
- **Public Website**
- **Searchable Data Repository**
- Requirements Level 1

### Science

- Omics Center Selection
- Protocol Development
- Data analysis validation
- Initiate ground controls
- Collaborate with two manifested flight experiments
- SDT Solicitation for Dedicated Flight

### Data Systems

- Link to Public Databases via Federation stds.
- Beta space- bio-informatics system

### Science

- Omics Center Selection
- Data analysis from initial studies
- Science Definition Teams Identified
- Outreach Program Plan

### Data Systems

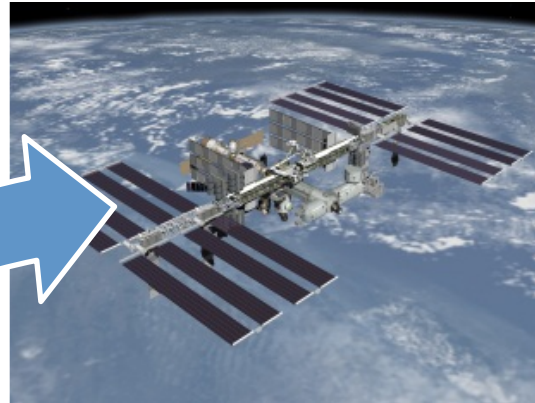
- Integrated Platform across model organisms
- Build Community via collaborative science analysis & modeling

### Science

- Continue ground controls and process enhancement
- Engage with Scientists external to NASA as part of Outreach Program
- Dedicated flight experiments

- Full science community engagement
- Analysis and modeling
- Ongoing dedicated flight experiments
- Website and platform sustaining activities
- Continuous improvement

# A New Generation of Materials Science Experiments onboard ISS



## Engineering-Driven Science

## Industry

## Academic institutions

DOD

## Other Government agencies

## International partners

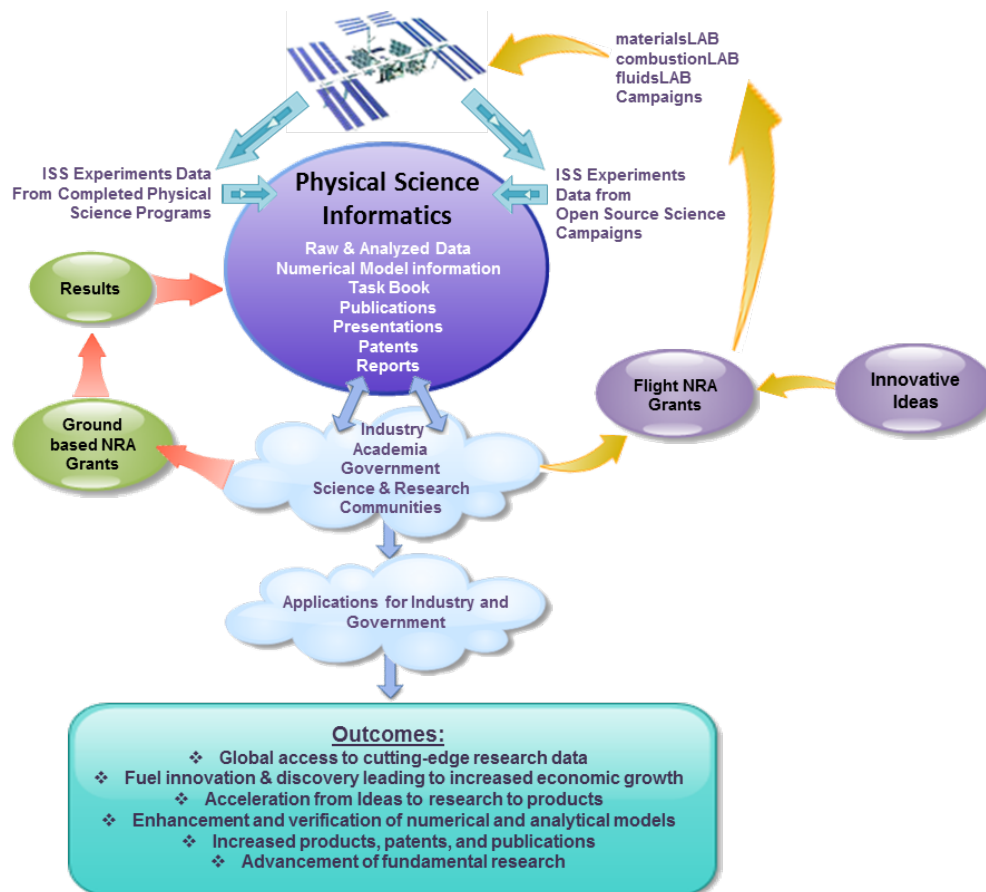
**NASA**

CISIS

# MaterialsLab - Vision



Fully utilize ISS as national laboratory to conduct microgravity materials science and disseminate data into open source informatics, to accelerate revelation of materials science mysteries, develop engineering need-driven higher-performing materials for NASA and the nation, and enhance STEM education.



- Access to global science/engineering community
- Simultaneous rapid multiplicative investigations
- Break-through scientific advance of real value
- World-wide STEM education opportunity
- Low cost and high-throughput research
- Use of existing facilities as much as possible
- Minimum Astronaut intervention and time
- Visible, applicable, and high return on investment
- Industry-driven engineering fulfillment
- Potential of discovering higher-performing material

# NASA and NIST MOU



## Objective

- A cooperative endeavor to support NASA's MaterialsLab microgravity materials science program and materials research conducted on the International Space Station (ISS).
- Facilitate collaboration between the NASA microgravity materials science program and the NIST Material Measurement Laboratory (MML) materials measurement science programs.
- Accelerate the development of U.S. industry innovative materials and processes through critical experiments that evaluate predictive models. Essential data is needed for modeling of materials behavior that supports the Materials Genome Initiative (MGI).

2014 Materials Genome Initiative Strategic Plan - A Strategy to Accelerate Cutting-Edge Materials Innovation, December 04, 2014

## NIST

- Promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

## Materials Genome Initiative: A Renaissance of American Manufacturing

- To accelerate the pace of discovery, development, and deployment of advanced materials in US manufactured goods.

## MOU Status

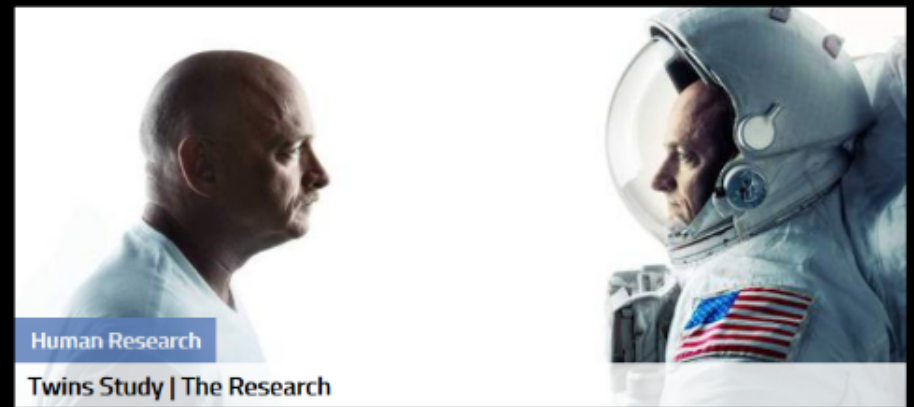
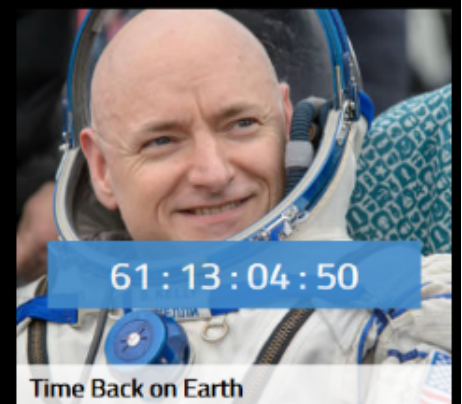
- MOU language agreed to by NASA & NIST, signed by Bolden/Mays.

*These goals will enable the transfer and commercialization of Federally-developed materials-related research and technology to promote U.S. innovation and industrial competitiveness.*

# 2016 Science Highlights



## *One Year Mission*



# ISS One-Year Mission



- Completed One-year Mission on March 1
  - Mission Successful and Benefits of US/Russian Collaborative Work Realized
  - Astronaut Scott Kelly set the record for the longest duration American space mission (340 days)
  - Research Data Collection to Continue Over the Next Year
  - Future One-year Missions Currently Under Study
- One-year Mission Joint Research Plan Completed
  - Physical and Functional Performance Assessments
  - Behavioral Health Studies and Ocular Health Monitoring
  - Metabolic and Immune System Studies
  - Microbial Population Changes
  - Long-Duration Mission Human Factors Studies
- US/Russian Fluids Shift Experiment
  - Most complex biomedical experiment implemented on ISS
  - Experiment could only be undertaken using both US and Russian hardware, subjects, and crew time
  - Studies body fluids redistribution during long-duration missions that may cause the visual changes in crewmembers



# One-Year Mission: Research Objectives



**Functional:** assess changes in crew member performance (strength/endurance/coordination/balance) using operational functional tasks after one-year in a low-gravity environment



**Behavioral Health:** study psychological effects of long-duration spaceflight on crew members by conducting cognition tests, neuromapping studies, sleep monitoring, journaling analyses and a reaction self-test



**Visual Impairment:** examine ocular health changes using ultrasound and high-fidelity optical coherence tomography imaging



**Metabolic:** study immune system function, salivary markers, biochemical profiles, and biological markers of oxidative/inflammatory stress.



**Physical Performance:** assess exercise effectiveness focusing on changes to bone density and structure, muscle strength, and the cardiovascular output over time in a weightless environment



**Microbial:** investigate changes in the microbiome of crewmembers.



**Human Factors:** examine how astronauts interact with their environment aboard the International Space Station focusing on fine motor performance, habitability, and training.

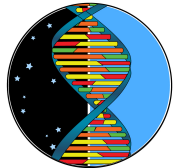
# Twins Study



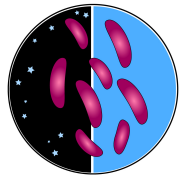
- Twins Study (Scott and Mark Kelly)
  - ISS Sample Collection Completed
  - Post Flight Sample Collection to Continue Over the Next Year
- Objective was to Begin Examining Next Generation Genomics Solutions to Mitigating Crew Health and Performance Risks
  - Personalized countermeasures approaches
- Twins Study National Research Team will Examine
  - Genome, telomeres, epigenome
  - Transcriptome and epitranscriptome
  - Proteome, Metabolome, Microbiome
  - Physiology and Cognition
- Significant Privacy and Ethics Issues
  - NASA is developing new genomics policy (modeled after NIH policy) that addresses informed consent, data privacy approaches, and genetic counseling on consequences of discovery (individual, family)



# Twins Study: Research Objectives



**Molecular/Omics:** investigations will look at the way genes in the cells are turned on and off as a result of spaceflight; and how stressors like radiation, confinement and microgravity prompt changes in the proteins and metabolites gathered in biological samples like blood, saliva, urine and stool.



**Microbiology/Microbiome:** explore the brothers' dietary differences and stressors to find out how both affect the organisms in the twins' guts.



**Human Physiology:** investigations will look at how the spaceflight environment may induce changes in different organs like the heart, muscles or brain.

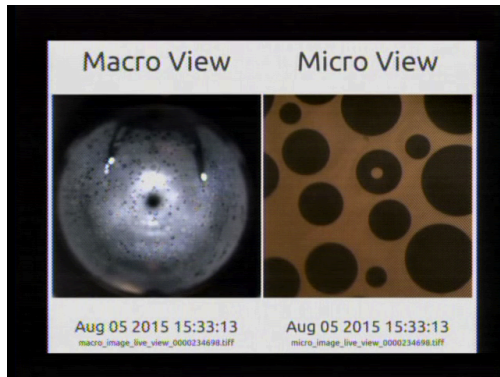


**Behavioral Health:** characterize the effects spaceflight may have on perception and reasoning, decision making and alertness.

# 2016 Science Highlights



## Observation and Analysis of Smectic Islands in Space (OASIS)



Pore emulsions



Emulsions form compact aggregates

OASIS observes the various aspects of liquid crystals behavior in microgravity such as overall fluid motion, diffusion (the movement of particles from an area of high concentration to low concentration) and the merging of liquid crystal film layers called islands. 2016 research found novel, unpredicted behavior of liquid crystals.

PI: Noel Clark, University of Colorado (NAS, APS Buckley Prize in Condensed Matter Physics)

Co-Investigators: Joseph MacLennan, Ph.D., University of Colorado, Boulder, CO

Matt Glaser, Ph.D., University of Colorado, Boulder, CO

Ralf Stannarius, Ph.D., Magdeburg University, D39106 Magdeburg, Germany

Alexandr Levchenko, Ph.D., Russian Academy of Sciences, Moscow, Russia

Vladimir Dolganov, Ph.D., Russian Academy of Sciences, Moscow, Russia

Pavel Dolganov, Ph.D., Russian Academy of Sciences, Moscow, Russia

Efim Kats, Ph.D., Russian Academy of Sciences, Moscow, Russia

Coming in 2017



# ***Cold Atom Laboratory***

## ***Exploring the Quantum Universe***



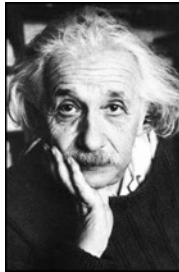
# Context: A Brief History of Cold



*The quest for ever-colder temperatures has been an important theme in physics for over a hundred years....*



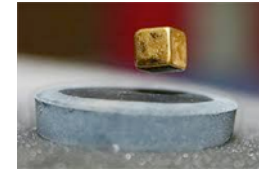
1892-Sir James Dewar  
invents the Dewar flask;  
Liquefies hydrogen



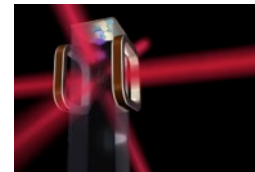
1924-Bose and  
Einstein develop  
theory of Bose-Einstein  
Condensate



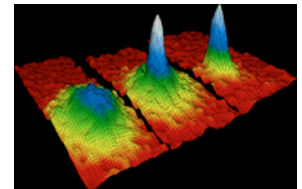
1937 Superfluidity  
discovered



1987-High-Temperature  
Superconductivity



1980's-Laser cooling developed



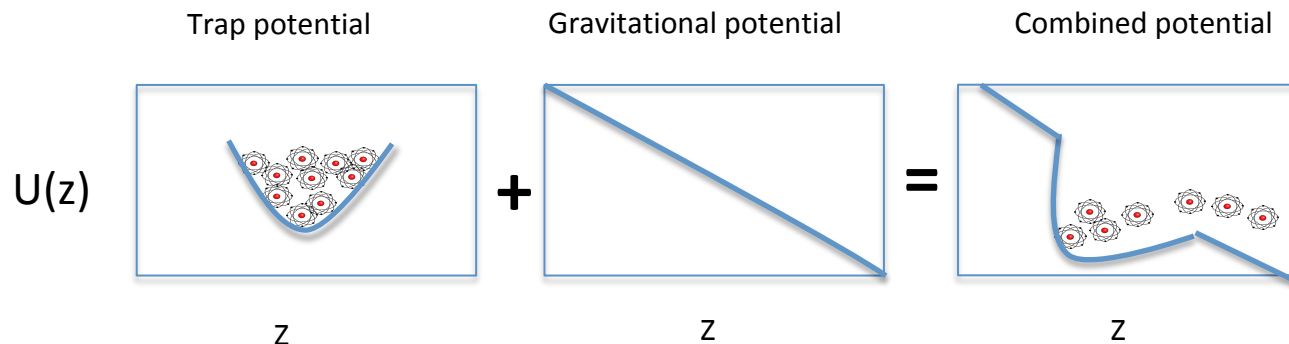
1995 BEC finally observed

“Sir James Dewar  
Is a better man than you are.  
None of you asses  
Can liquefy gases...”

*...leading to profound insights into nature, and  
myriad new technologies*

# Why Ultra-cold atoms in Space?

- Microgravity offers the possibility of dramatically reducing the forces needed to confine an ultra-cold sample of atoms
  - Enables us to achieve a new regime of ultra-low temperatures
- Ultra-cold samples created by CAL can float unconfined for long periods, nearly fixed relative to the apparatus
  - Enables searches for very weak interactions between atoms
  - Enables greatly enhanced sensitivity for quantum sensor applications
- Absence of density stratification and separation of mixtures of different species



**The International Space Station is the ideal location for studies of ultra-cold atoms in a regime that can not be accessed on Earth**

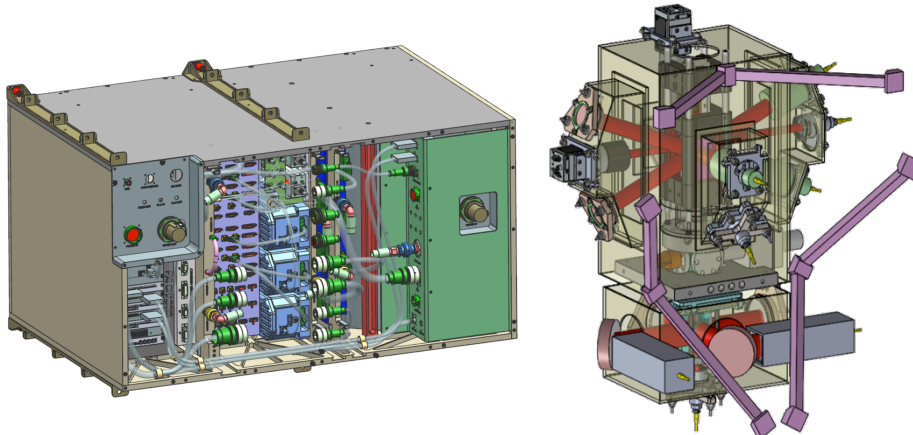
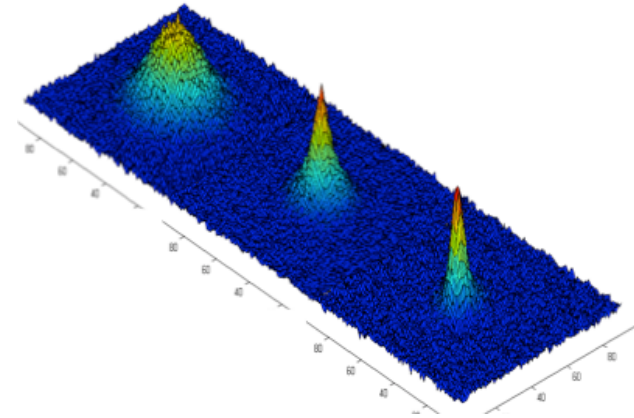
# CAL Science Impact



***The Cold Atom Laboratory will give scientists access to an unexplored quantum realm...***

- A realm in which temperatures can be orders of magnitude below that achievable on Earth
- A facility in which ultra-cold quantum gases float unconfined for long periods, allowing unprecedented measurement precision free from the distortion of Earth's gravity
- An atom interferometer that can contribute to the measurement of dark energy
- Technology Demonstration for ultra-stable clocks, high precision inertial sensors, and quantum computing

*The coldest spot in the known universe...*



Exploring this realm will help scientists to answer some of the most fundamental questions in science:

**How does complexity arise in the universe?**

**What is the nature of dark energy?**

**Did Einstein have the last word on gravity?**

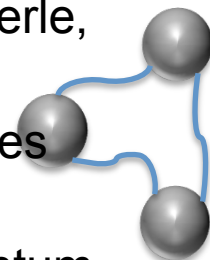
**How did the universe begin?**

**How do high temperature superconductors work?**

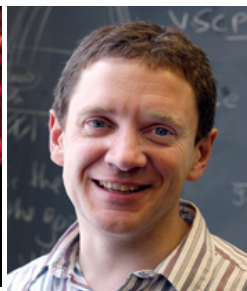
# CAL1 Flight Investigations



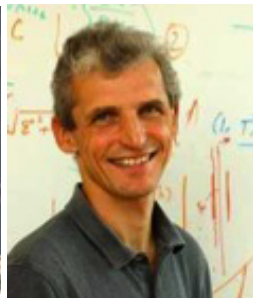
- Zero-G Studies of Few and Many Body Physics (PI E. Cornell)
- Atom interferometry Will Pave the Way for Definitive Space-based Tests of Einstein's Theory of General Relativity (PI N. Bigelow, Co-PI W. Ketterle, Co-PI W. Phillips)
- Microgravity dynamics of bubble-geometry Bose-Einstein condensates (PI Nathan Lundblad)
- Fundamental Interactions of Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment (PI Jason Williams)
- Development of Atom Interferometry Experiments for the International Space Station's Cold Atom Laboratory (PI Cass Sackett)



*E. Cornell*



*N. Bigelow*



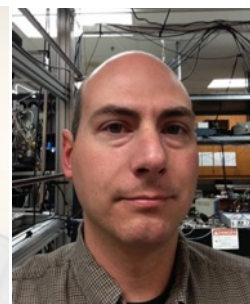
*W. Ketterle*



*W. Phillips*



*N. Lundblad*



*J. Williams*



*C. Sackett*

**The Three Nobel Laureates on the CAL Science Team**

# Additional Upcoming Research



- Advanced Plant Habitat – To ISS late FY17
- Continue “Pick and Eat” Veggie Campaigns
- GeneLab Open Science Campaigns
- US/ Russian Rodent Research collaborative investigations
- Fruit Fly Lab 2 & 3
- Cool Flames Investigation
- ACME and SoFIE Combustion projects (10+ PI's)
- MaterialsLab Phase 1 Investigations
  - Thermophysical Properties (NIST)
  - Cement (CASIS highlight at ISS R&D)
  - Brazing
  - Solidification Microstructures
  - Freeze-casting
  - Biofilms
  - Liquid Crystals
- Zero Boil Off Experiment
- Alternative Vehicle initiatives (BO New Shepard, X-37, DragonLab, etc.)

