National Aeronautics and Space Administration

# Human Research Program

National Academies, Space Studies Board
Committee On Biological and Physical Sciences In Space

Steve Davison

14 December 2016

# Overview and Status

# Research to Enable Space Exploration

Human travelers to Mars will experience unprecedented physiological, environmental, and psychosocial challenges that could lead to significant health & performance decrements in the absence of effective mitigation strategies.

Success of any human mission to Mars may hinge on the ability of NASA to develop and implement such strategies.

NASA's Human Research Program is responsible for identifying those strategies.

# Compare Going to Mars to Where We Are Today with ISS

**228,000,000 kilometers**

**~1 – 1.5 years transit time, ~2 – 3 years mission time**

Communications (up to 42 minutes)

**~ 2 days transit time**

Communications (near real-time)

Crew exchanges

Crew supplies and logistics

Crew and atmosphere samples

Modified hardware

Emergency Crew Return

Trash

**“ recreate living on Earth capability”**

**390 kilometers**

**“extreme car camping in space”**

# Human Research Program Mission

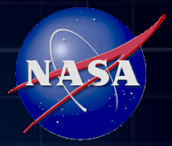
To enable space exploration beyond Low Earth Orbit
by reducing the risks to human health & performance
through a focused program of:

- Basic, applied, and operational research

Leading to the development and delivery of:

- Human health, performance, and habitability standards
- Countermeasures and other risk mitigation solutions
- Advanced habitability and medical support technologies

# Human Research Program Elements




**Program and Science Management 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

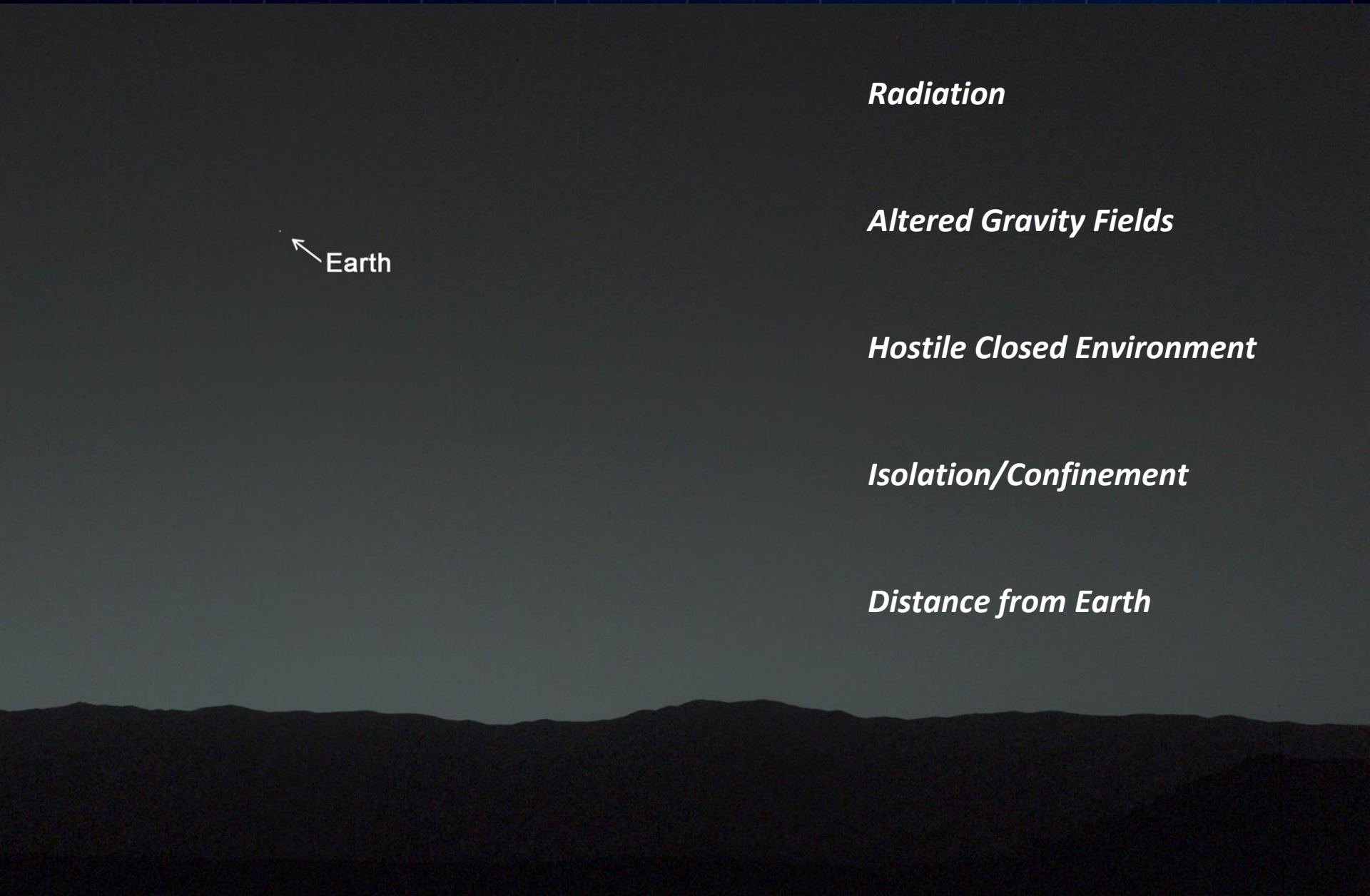
**ISS Medical Projects Element**

Research integration and operations: ISS, Flight Analog facilities

**National Space Biomedical Research Institute**

Cooperative agreement to pursue research that extends the HRP portfolio

# Crew Stressors in Deep Space Missions




*Radiation*

*Altered Gravity Fields*

*Hostile Closed Environment*

*Isolation/Confinement*

*Distance from Earth*

# HRP Aligns with Crew Stressors and Human Risks

| | | |
|---|---|---|
| **Human Health Countermeasures (HHC)** | → | **Altered Gravity Fields**<br>*Balance Disorders, Fluid Shifts, Visual Alterations, Cardiovascular Deconditioning, Decreased Immune Function, Muscle Atrophy, Bone Loss* |
| **Behavioral Health & Performance (BHP)** | → | **Isolation/Confinement & Altered Light-Dark Cycles**<br>*Behavioral & Performance aspects of isolation/confinement, Sleep disorders* |
| **Space Human Factors & Habitability (SHFH)** | → | **Hostile/Closed Environment**<br>*Vehicle Design, Environmental (CO2 Levels, Toxicology, Microbiology, Water), Food, Microbiome* |
| **Space Radiation (SR)** | → | **Space Radiation**<br>*Acute In-flight effects, Long-term cancer risk, CNS and Cardiovascular* |
| **Exploration Medical Capabilities (ExMC)** | → | **Distance from Earth**<br>*Autonomous medical care capacity (cannot come home for treatment), Communication Delays* |

**Note that effect severity generally increases with mission duration (i.e., time of exposure to stressor)*

# Element Consolidation

Rationale

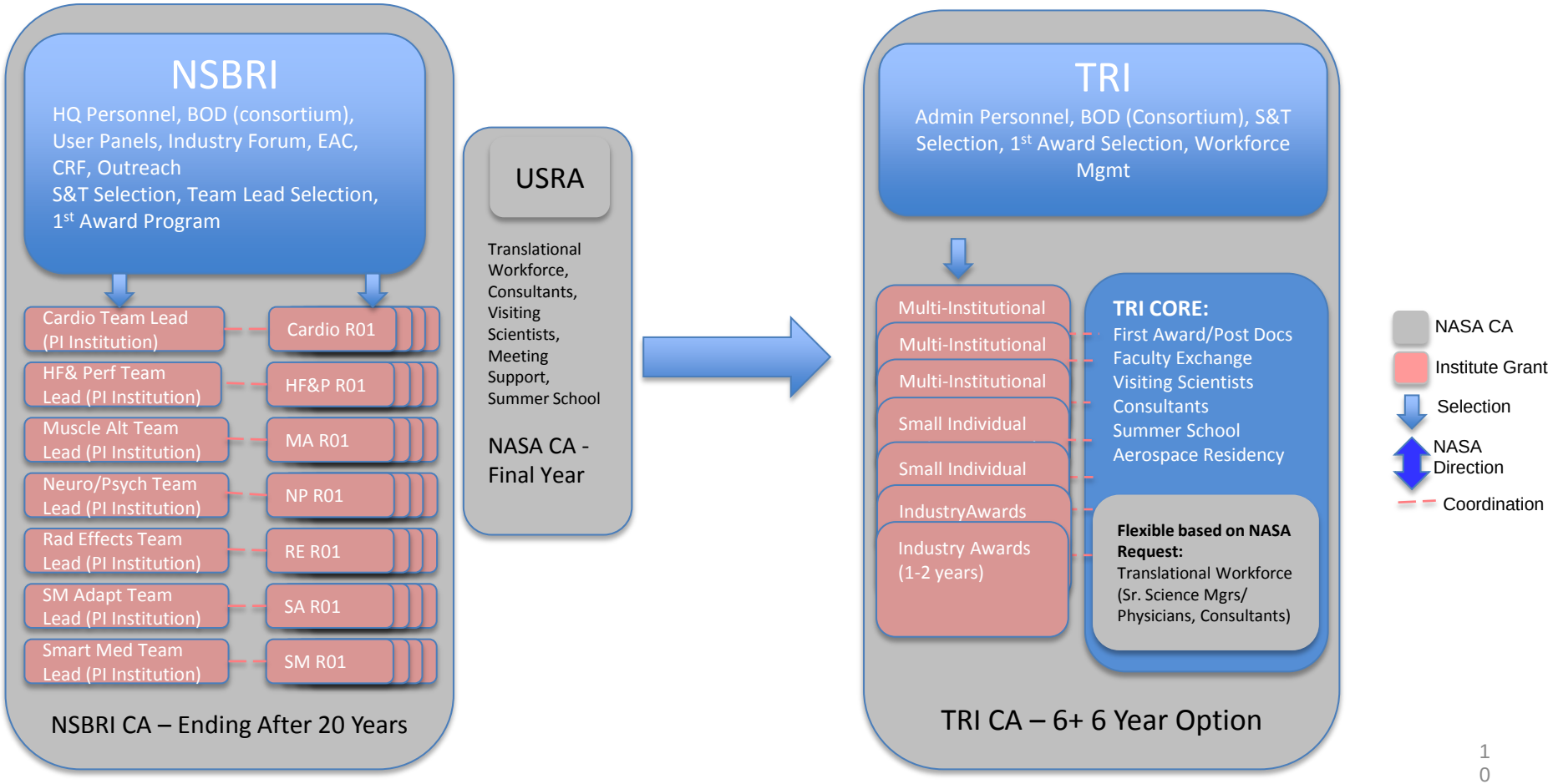
- Overlap in research studies
- Similar emphasis: improve crew performance and how to do operations better
- Required the same operational analogs to accomplish research

| | From: | | To: | | |
|---|---|---|---|---|---|
| | **Behavioral Health & Performance (BHP)** | **Space Human Factors & Habitability (SHFH)** | **Human Factors and Behavioral Performance (HFBP)** | **HHC** | **ExMC** |
| **Analogs** | ISS, HERA, HESTIA, NEK, Antarctic | ISS, HERA, HESTIA, NEK, Antarctic | ISS, HERA, HESTIA, NEK, Antarctic | | |
| **HSRB Risks** | **SLEEP** | **FOOD** | **SLEEP** | **Microhost** | **DUST** |
| | **TEAM** | **HSID** | **TEAM** | **FOOD** | |
| | **BMED** | **OP** | **BMED** | | |
| | | **DUST** | **HSID** | | |
| | | **Microhost** | **OP** | | |

# Translational Research Institute (TRI)

Research Emphasis: Characterized by Discipline Team Leads, RO1-Type Grants, and Lower-TRL Projects

Emerging Scientific/Technical Capability Emphasis: Characterized by Multi-Disciplinary, Multi-Institutional Team Grants, Technology Funneling Process, Higher-TRL Deliverables, and close coordination with NASA Risk Custodians to Transition Results,



# Translational Research Institute (TRI)

- Advantages to NASA

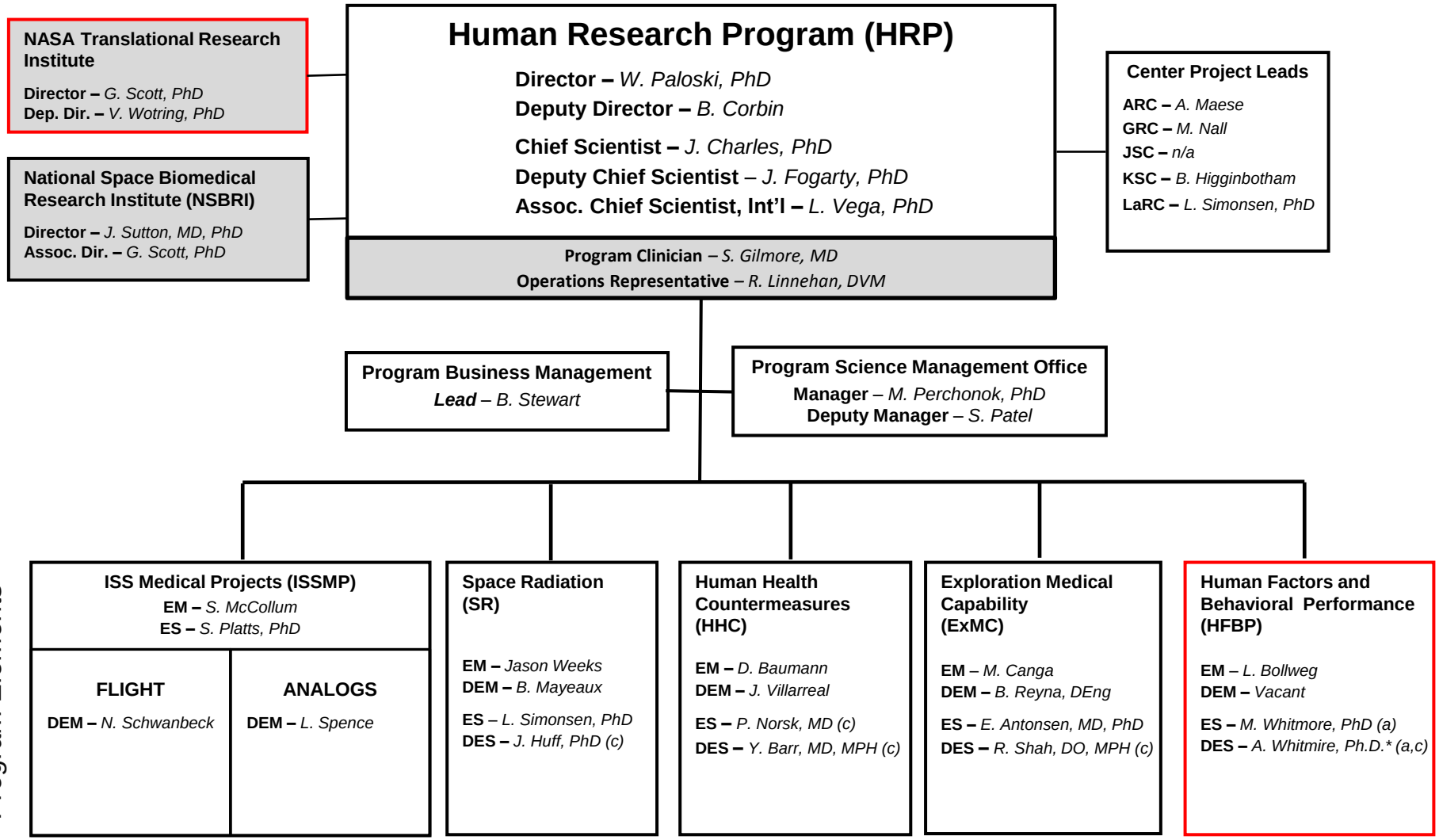
  - Complements NASA research by investing in areas not on critical path to risk reduction – allows investment in higher risk, potentially higher payoff research

  - Academic institution affiliations (BCM, MIT, CalTech) are more in tune with emerging biomedical research and technologies that may provide accelerated or break-through solutions

  - Institute has greater access to early career investigators and mechanisms to support post-doc fellows, visiting scientists and faculty exchange programs

  - Provides flexible approach to future NASA in-house technical capabilities, ensuring ongoing exposure to cutting-edge research and methodologies through faculty exchange and translational workforce

# HRP Organization




(c) = contractor

(a) = acting

**EM** = Element Manager
**DEM** = Deputy Element Manager
**ES** = Element Scientist
**DES** = Deputy Element Scientist

# Internal Integration and Coordination

**OCHMO/HMTA and OCS**
- Medical and Science Policies

**Advanced Exploration Systems**
- Space Radiation Shielding/MSL RAD
- NASA Space Radiation Lab. Upgrade
- Crew Mobility Systems & EVA Surface Suit
- Habitat Testing: volume, Ops concepts, design
- Interface Display & Control Unit Studies
- HERA Mission Tasks/Fidelity: Flight Simulator

**Crew Health & Safety (ISS Med Ops)**
- VIIP, CO2 levels, Exercise Studies
- Astronaut Occupational Surveillance
- Crew Health Risk Assessment
- Cognitive Function and Measures
- Space Radiation Protection (SRAG)
- LSAH Database

**Science Mission Directorate**
- Solar System Explor. Rsrch. Virtual Inst. (SSERVI)
- Space Radiation Environment
  - LRO-CRaTER radiation measurements
  - SEP monitoring/characterization
  - MSL-RAD measurements of radiation during transit & on the surface of Mars

**ISS Program**
- MHRPE: ISS One-year Mission
- Russian collaborations (Field Test, Fluid Shifts)
- MARES Research (ESA/US/Roscosmos)
- Miniature Exercise Device (MED) Testing
- ARED Platform
- Technology Demonstrations

**Orion**
- EM2 objectives in work
- Vibration validation assessments (EM1)
- E-Procedure Validation (EM2)
- Food System Mass Reduction
- Exercise hardware
- Human Testing using Orion seat and suit prototypes

**Space Technology Mission Directorate**
- SBIR (Integral part of HRP's R&T Plan): Ocular Flow, Drug Stability, Exercise
- Thick Radiation Shielding Project
- NASA Space Radiation Lab. Upgrade
- Biomedical Technology Development/ISS Demo

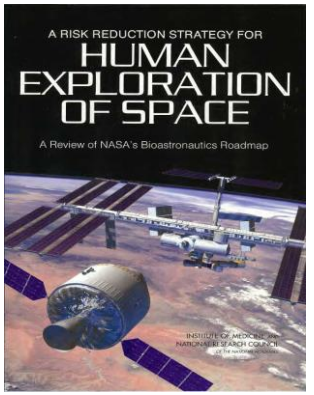
**Space Biology**
- Advanced Food: Pick & Eat Veggies
- Microbial Assessment/Observatory
- Translational Research Roadmap
- Gene Lab and Bioinformatics
- Artificial Gravity Studies
- Joint selections: food, physiology, virulence, microbial
- LSDA Database

# External Research Community

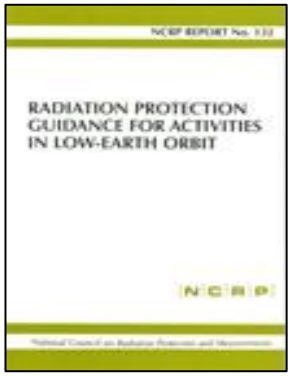
- **Strategic Planning**
  - National Academies (IOM, NRC)
    - Risk Reduction Strategy for Human Exploration of Space
    - Review of HRP Evidence Base and Merit Review Process
  - National Council on Radiation Protection (NCRP)
  - NASA Advisory Committee (NAC)
  - Annual Standing Review Panels (SRP)

- **Science Planning**
  - Research and Clinical Advisory Panels for Visual Impairment, Space Radiation Health, Bone Health
  - Papilledema & VIIP, Telemedicine, Osteoporosis & Bone Summits
  - Lunar Atmospheric Dust Toxicity Assessment Group
  - Decompression Risk Review, Dental Working Group
  - Acute Risk Radiation Workshop, CNS Research Panel
  - Habitable Volume Workshop

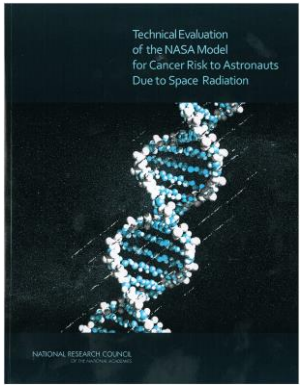
- **Research Implementation**
  - National Research Solicitations
    - HERO Crew Health and Performance NRA
    - Space Radiobiology NRA
  - Graduate Student and Post-Doctoral Programs



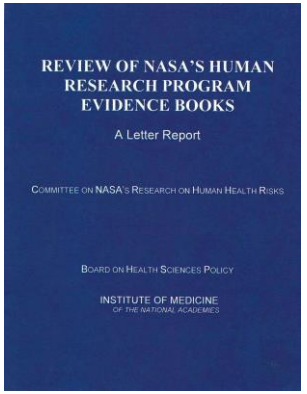

A Risk Reduction Strategy for Human Exploration of Space




National Council on Radiation Protection & Measurement




NRC Report on NASA Cancer Risk Models




IOM Review of NASA's Human Research Program Evidence Books

# External Interfaces/Collaborations


ROSCOSMOS

esa

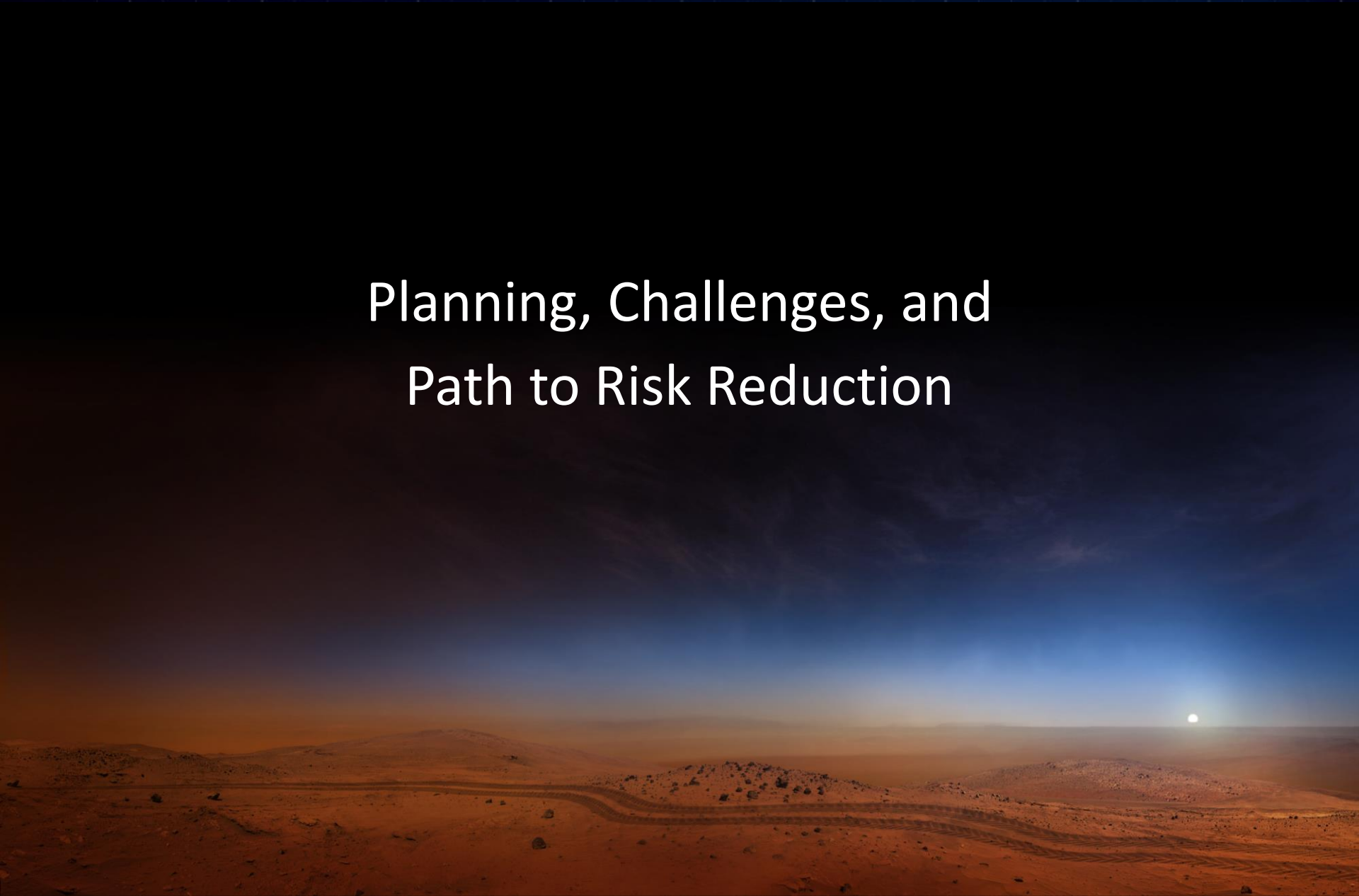
JAXA

CSA ASC

# Program Approach Summary

- Enable NASA human exploration goals by conducting flight and ground research to mitigate highest risks to human health and performance on current and future exploration missions
- Fully utilize ISS research and operational capabilities to mitigate human health space exploration risks to an acceptable level
- Establish research priorities consistent with guidance from the National Academies, other external independent reviews, and Health and Medical Technical Authority (HMTA) assessments
- Implement an open competitive solicitation process and independent, external scientific peer review to ensure highest quality research investigations
- Leverage resources and expertise through collaborative research with other NASA programs, international partners, and other US agencies
- Review portfolio regularly to rebalance work and ensure ISS research subjects are efficiently utilized to mitigate highest risks to human health

# Planning, Challenges, and Path to Risk Reduction



# Integrated Planning Framework

**HRP works within an integrated framework to mitigate human health & performance risks**


- **Office of the Chief Health and Medical Officer (OCHMO)**
  - Medical Policy, Health and Performance Standards, Bioethics (IRB, ACUC, Risk Threshold), Health and Medical Technical Authority (HMTA), Human System Risk Board (HSRB)
- **Crew Health and Safety (CHS)**
  - Medical Operations and Occupational Health (career health care/post career monitoring)
- **Human Research Program (HRP)**
  - Research necessary to understand and reduce health and performance risks in support of space exploration

# Human Risks of Spaceflight
## Grouped by Hazards – 30 Risks

### *Altered Gravity Field*

1. Spaceflight-Induced Intracranial Hypertension/Vision Alterations
2. Renal Stone Formation
3. Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations Associated with Space Flight
4. Bone Fracture due to spaceflight Induced changes to bone
5. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance
6. Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
7. Adverse Health Effects Due to Host-Microorganism Interactions
8. Urinary Retention
9. Orthostatic Intolerance During Re-Exposure to Gravity
10. Cardiac Rhythm Problems
11. Space Adaptation Back Pain

**Concerns**

1. Clinically Relevant Unpredicted Effects of Meds
2. Intervertebral Disc Damage upon re-exposure to μg
3. Health/Performance impacts of White Matter Hyperintensities

### *Radiation*

1. Adverse Health Outcomes and Performance Decrements resulting from Space Radiation Exposure(cancer, cardio & CNS)

### *Distance from Earth*

1. Adverse Health Outcomes & Decrements in Performance due to inflight Medical Conditions
2. Ineffective or Toxic Medications due to Long Term Storage

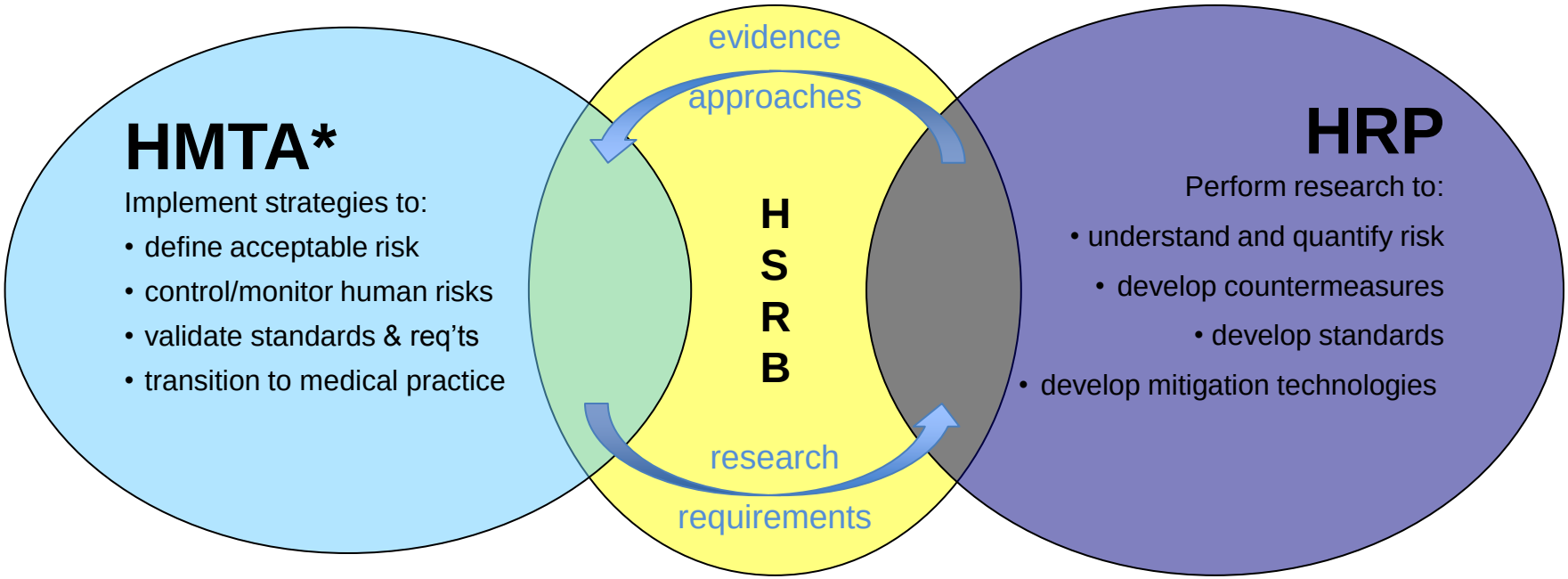
### *Isolation*

1. Adverse Cognitive or Behavioral Conditions & Psychiatric Disorders
2. Performance & Behavioral health Decrements Due to Inadequate Cooperation, Coordination, Communication, & Psychosocial Adaptation within a Team

### *Hostile/Closed Environment-Spacecraft Design*

1. Acute and Chronic Carbon Dioxide Exposure
2. Performance decrement and crew illness due to inadequate food and nutrition
3. Reduced Crew Performance and of Injury Due to Inadequate Human-System Interaction Design (HSID)
4. Injury from Dynamic Loads
5. Injury and Compromised Performance due to EVA Operations
6. Adverse Health & Performance Effects of Celestial Dust Exposure
7. Adverse Health Event Due to Altered Immune Response
8. Reduced Crew Health and Performance Due to Hypobaric Hypoxia
9. Performance Decrements & Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, & Work Overload
10. Decompression Sickness
11. Toxic Exposure
12. Hearing Loss Related to Spaceflight
13. Injury from Sunlight Exposure
14. Crew Health Due to Electrical Shock

# Human System Risk Board (HSRB)




**NASA Health & Medical Technical Authority*

***Human System Risk Board***

- *HMTA/Space Medicine (chair)*
- *HRP/Human Research*
- *Environmental Science*
- *Human Factors Engineering*
- *Space Flight Operations*
- *Crew Office*

# Human Risks Disposition for all Design Reference Missions

| | In Mission Risk - Operations | | | | | | Post Mission Risk - Long Term Health | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Human System Risks 07/01/15 | Low Earth Orbit | Low Earth Orbit | Deep Space Sortie | Lunar Visit/Habitation | Deep Space Journey/Habitation | Planetary | Low Earth Orbit | Low Earth Orbit | Deep Space Sortie | Lunar Visit/Habitation | Deep Space Journey/ Habitation | Planetary |
| | 6 Months | 12 Months | 30 Days | 1 year | 1 Year | 3 years | 6 Months | 12 Months | 30 Days | 1 year | 1 Year | 3 years |
| VIIP | A | A | A | A | RM | RM | A | A | A | A | RM | RM |
| Renal Stone Formation | A | A | A | A | RM | RM | RM | RM | RM | RM | RM | RM |
| Inadequate Food and Nutrition | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Space Radiation Exposure | A | A | A | A | A | TBD* | A | A | A | RM | RM | RM |
| Medications Long Term Storage | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Acute and Chronic Carbon Dioxide | A | A | A | A | RM | RM | A | A | A | A | A | A |
| Inflight Medical Conditions | A | A | A | RM | RM | RM | A | A | A | RM | RM | RM |
| Cognitive or Behavioral Conditions | A | RM | A | RM | RM | RM | A | A | A | A | A | RM |
| Bone Fracture | A | A | A | A | A | RM | A | A | A | A | A | A |
| Human-System Interaction Design | A | A | A | RM | RM | RM | A | A | A | A | A | A |
| Team Performance Decrements | A | A | A | A | RM | RM | A | A | A | A | A | A |
| Cardiac Rhythm Problems- Under Review | A | A | A | A | RM | RM | A | A | A | A | A | A |
| Reduced Muscle Mass, Strength | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Reduced Aerobic Capacity | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Sensorimotor Alterations | A | A | A | RM | RM | RM | A | A | A | A | A | RM |
| Injury from Dynamic Loads | A | A | RM | RM | RM | RM | A | A | RM | RM | RM | RM |
| Sleep Loss | A | A | A | A | RM | RM | A | A | A | A | RM | RM |
| Altered Immune Response | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Celestial Dust Exposure | N/A | N/A | TBD | A | TBD | TBD | N/A | N/A | TBD | A | TBD | TBD |
| Host-Microorganism Interactions | A | A | A | A | A | RM | A | A | A | A | A | RM |
| Injury due to EVA Operations | A | A | A | RM | A | RM | A | A | A | RM | A | RM |
| Decompression Sickness | A | A | RM | A | RM | A | A | A | A | RM | A | RM |
| Toxic Exposure | A | A | A | A | A | A | A | A | A | A | A | A |
| Hypobaric Hypoxia | RM | RM | A | RM | RM | RM | RM | RM | A | RM | RM | RM |
| Space Adaptation Back Pain | A | A | A | A | A | A | N/A | N/A | N/A | N/A | N/A | N/A |
| Urinary Retention | A | A | A | A | A | A | A | A | A | A | A | A |
| Hearing Loss Related to Spaceflight | A | A | A | A | A | A | A | A | A | A | A | A |
| Orthostatic Intolerance | A | A | A | A | A | A | A | A | A | A | A | A |
| Injury from Sunlight Exposure | A | A | A | A | A | A | A | A | A | A | A | A |
| Electrical shock | A | A | A | A | A | A | A | A | A | A | A | A |

A – Accepted RM- Requires Mitigation

Green – low/very low consequence Yellow – low to medium consequence Red – high consequence

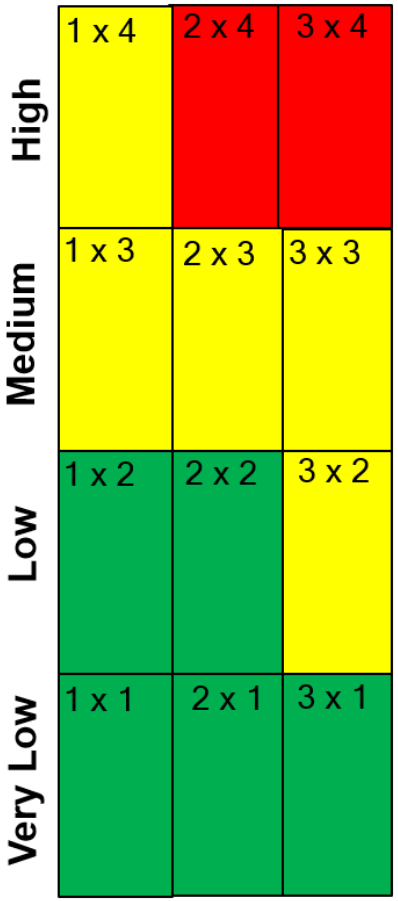
# Human System Risk Board

## Likelihood vs Consequence

### Consequence
**Mission Health and Performance (OPS)**

| | |
|---|---|
| High | Death or permanently disabling injury to one or more crew (LOC) OR Severe reduction of performance that results in loss of most mission objectives (LOM) |
| Medium | Significant injury, illness, or incapacitation – may affect personal safety OR Significant reduction in performance results in the loss of some mission objectives |
| Low | Minor injury/illness that is self-limiting OR Minor impact to performance and operations- requires additional resources (time, consumables) |
| Very Low | Temporary discomfort OR Insignificant impact to performance and operations - no additional resources required |

CM = Countermeasure
LOC = Loss of Crew
LOM = Loss of Mission




### Consequence
**Long Term Health (post mission) (LTH)**

| | |
|---|---|
| High | • Unknown and improbable return to baseline (requires drastic intervention surgery & therapy)<br>• Major impact on quality of life (permanent reduced function, premature death) |
| Medium | • Return to near baseline requires extended medical intervention w/ known clinical methods/technologies (pharmaceuticals, etc.)<br>• Moderate impact on quality of life |
| Low | • Return to baseline values within 1 year with nominal intervention (time, exercise, nutrition, lenses)<br>• Negligible effect on quality of life |
| Very Low | • Return to baseline values within 3 months with limited intervention<br>• No effect on the quality of life |

**Quality of Life** is defined as impact on day to day physical and mental functional capability and/or lifetime loss of years

# Research Planning Foundation


**Evidence Basis**
Medical Ops
Occupational Surveillance
Environmental
Research

**Research Gaps**
Knowledge
Technology

## HRP Key Deliverables

- **Knowledge/Evidence to Assess Human Health and Performance Risks**
- **Validated Health, Medical, Human Performance, and Environmental Standards**
  - ✧ Fitness-for-Duty Standards
  - ✧ Permissible Outcome Limits (POL)
  - ✧ Permissible Exposure Limits (PEL)
- **Validated Countermeasures, Technologies, and Risk Mitigation Approaches**
- **Recommended Approaches to Minimizing Mission Resource Requirements**

# Research Planning Cycle

**Evidence Base – Flight and Ground**
- Research
- Clinical
- Operational experience

*Reviewed by IOM*

**Human Health & Performance Risks**

*HSRB Evaluates Risk Posture*

**Exploration Missions & Architectures**

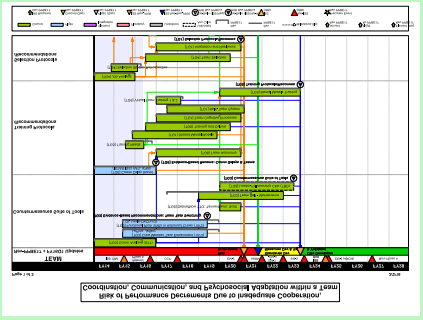
**NASA Spaceflight Human System Standards**

*Reviewed by Standing Review Panels*

**Research Gaps**

Prioritization/Implementation Constrained by
- Customer need dates
- Budgets
- Research platform availability

**Integrated Research Plan**



**Solicitations & Directed Research**

*Peer Review*

**Results and Deliverables**
- Mitigate Risks
- Inform Standards
- Countermeasures
- Medical Technologies

*Customer Review*

# HRP PI Tasks and NRA Solicitations

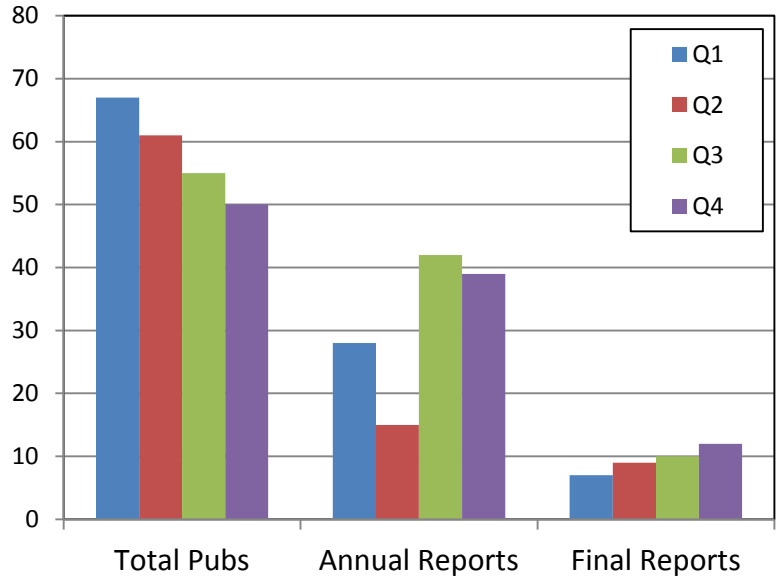
- FY 16 Metrics
  - 307 Tasks, 32 States, 255 PIs, 118 Institutions
- Human Exploration Research Opportunities (HERO) Solicitation

| HERO | Appendix | Release Date | Step-1 Received | Step-2 Received | Peer Review Date | Selection Date | # Proposals Awarded | Notes |
|---|---|---|---|---|---|---|---|---|
| 2015 | A - C | 7/31/2015 | 184 | 116 | Feb-16 | Apr-16 | 25 | • NASA/NSBRI |
| | D | 7/31/2015 | NA | 15 | Jan-16 | Apr-16 | 3 | • Artificial Gravity (Cells and Rodents)<br>• 2 joint selections SB |
| | E | *Planned for 2/1/2016* | NA | NA | NA | NA | NA | • Radiobiology NRA<br>• Cancelled due to budget cuts |
| | F | 9/14/15 | 13 NOIs | 13 | Apr-16 | May-16 | 4 NASA and 2 DLR | • ILSRA (HERA) |
| | G | 12/1/2015 | 28 | 25 | May-16 | Nov-16 | 4 | • Artificial Gravity (:envihab) |
| 2016 | A | 7/28/2016 | 65 | TBD | Feb-17 | Apr-17 | TBD | • Limited to Omnibus<br>• HFBP, HHC, and SR opted out due to budget cuts |
| | B | 9/1/2016 | 60 | TBD | Feb-17 | Apr-17 | TBD | Flagship |
| | C | 3/15/2017 | | | Aug-17 | Oct-17 | TBD | Flagship |
| 2017 | A | 7/31/2017 | | | Feb-18 | Apr-18 | TBD | Flagship |
| | B | 7/31/2017 | | | Feb-18 | Apr-18 | TBD | Omnibus |

Awarded  Recently Released  Planned Solicitation

# FY16 Publication Metrics

## Number of Publications




## High-Impact Factor Publications (JIF > 5)

1. Cabahug-Zuckerman, Pamela, Dorra Frikha-Benayed, Robert J. Majeska, Alyssa Tuthill, Shoshana Yakar, Stefan Judex, and Mitchell B. Schaffler. “Osteocyte Apoptosis Caused by Hindlimb Unloading Is Required to Trigger Osteocyte RANKL Production and Subsequent Resorption of Cortical and Trabecular Bone in Mice Femurs.” ***Journal of Bone and Mineral Research*** 31, no. 7 (July 2016): 1356–65.
2. Crucian, Brian, Smith Johnston, Satish Mehta, Raymond Stowe, Peter Uchakin, Heather Quiriarte, Duane Pierson, Mark L. Laudenslager, and Clarence Sams. “A Case of Persistent Skin Rash and Rhinitis with Immune System Dysregulation Onboard the International Space Station.” ***The Journal of Allergy and Clinical Immunology*** 4, no. 4 (August 2016): 759–62.e8.
3. Delp, Michael D., Jacqueline M. Charvat, Charles L. Limoli, Ruth K. Globus, and Payal Ghosh. “Apollo Lunar Astronauts Show Higher Cardiovascular Disease Mortality: Possible Deep Space Radiation Effects on the Vascular Endothelium.” ***Scientific Reports*** 6 (July 2016): 29901.
4. El-Ashmawy, Mariam, Melissa Coquelin, Krishna Luitel, Kimberly Batten, and Jerry W. Shay. “Organotypic Culture in Three Dimensions Prevents Radiation-Induced Transformation in Human Lung Epithelial Cells.” ***Scientific Reports*** 6 (August 19, 2016).
5. Feger, Bryan J., J. Will Thompson, Laura G. Dubois, Reddy P. Kommaddi, Matthew W. Foster, Rajashree Mishra, Sudha K. Shenoy, et al. “Microgravity Induces Proteomics Changes Involved in Endoplasmic Reticulum Stress and Mitochondrial Protection.” ***Scientific Reports*** 6 (September 27, 2016): 34091.
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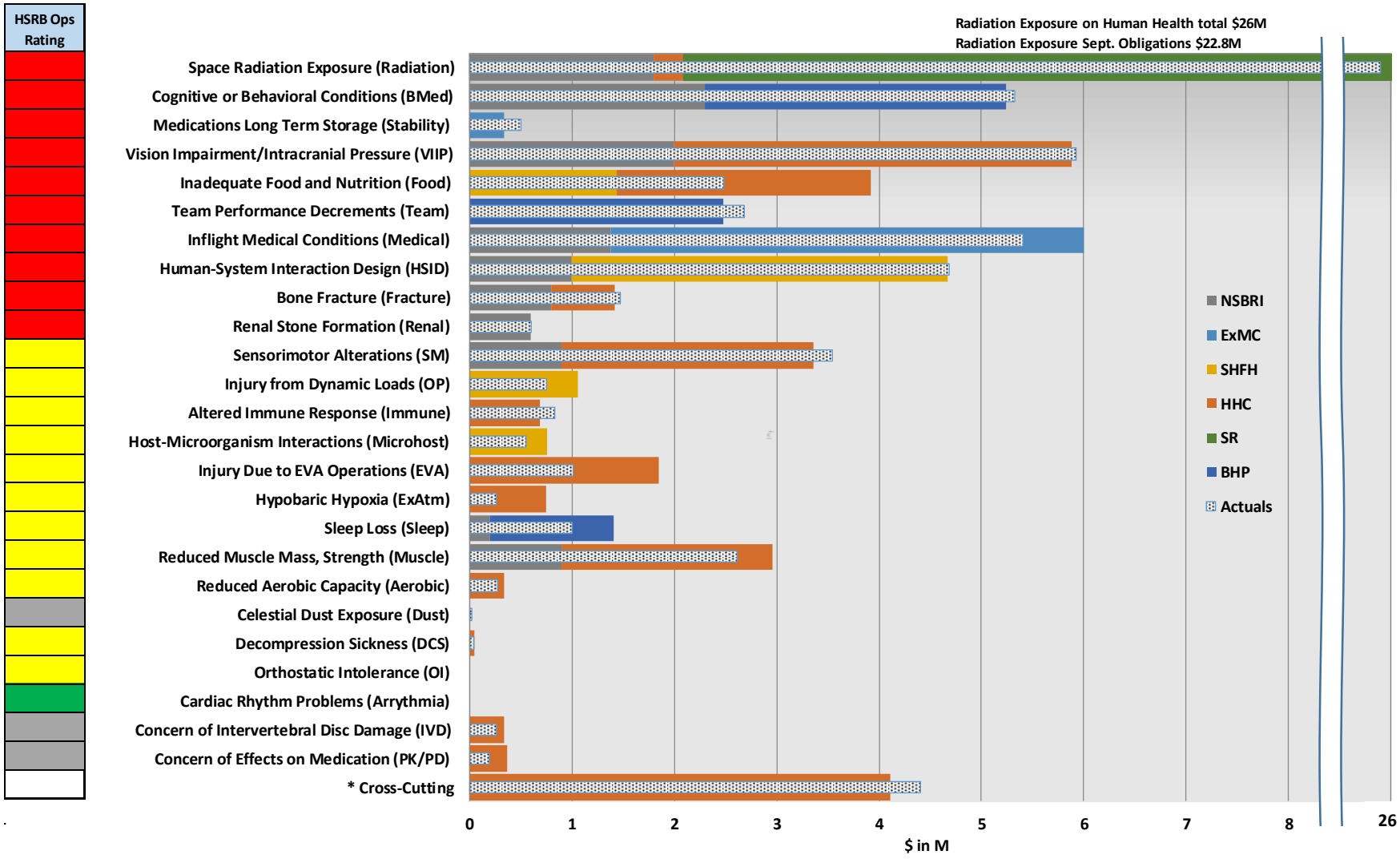
# HRP R&D Investment by Risk



# ISS Research Planning: Critical to Mitigating Mars Mission Human Health and Performance Risks


Medical Imaging


Cardiovascular Function Experiment


Muscle Physiology Facili


Bone Loss Countermeasure


Fluid Shift Experiment


Nutritional Requirements


Ocular Surveillance Flight Study


Physiological Changes/Exercise Countermeasures


Crew Sleep/ Performance


Immunological Changes

HRP is a high priority for NASA science payloads aboard ISS.

Each USOS crewmember participates in 10-15 separate experiments.

# ISS Research Flight Planning: Limited Subjects

## HRP ISS Research Tactical Flight Plan (FY16 Q4 Update)

| Experiment Name | Sponsor | Subjects Req'd | Subjects thru 45S | Req R+0/1 | I47/48 | I49/50 | I51/52 | I53/54 | I55/56 |
|---|---|---|---|---|---|---|---|---|---|
| Flight | | | | | 46S & 47S | 48S & 49S | 50S & 51S | 52S & 53S | 54S & 55S |
| Biochemical Profile/Smith | HHC | N/A | 12 | Yes | 3 | 3 | 3 | 3 | 3 |
| Bisphos. (Control)/LeBlanc, Matsumoto | HHC/IP | 10 | 9 | | 1 | | | | |
| Body Measures/Rajulu | HFBP | 9 | 7 | | 1 | 1 | | | |
| Cardio Ox/Lee | HHC | 12 | 9 | | 3 | 1 | | | |
| Dose Tracker/Wotring | ExMC | 24 | 2 | | 2 | 2 | 3 | 2 | 3 |
| Field Test/Reschke (p/p) | HHC | 15 | 1 + 2[1YM] | Yes | 2 | 2 | 1 | 1 | 2 |
| Fine Motor Skills/Holden | HFBP | 8 | 4 | Yes | 2 | 2 | 1 | | |
| Fluid Shifts/Stenger, Hargens, Dulchavsky | HHC | 10 (5 USOS) | 2 (1 USOS) | Yes | 4 (2 USOS) | 4 (2 USOS) | | | |
| Functional Immune/Crucian | HHC | 10 | - | Yes | | 1 | 1 | 1 | 2 |
| Habitability/Thaxton | HFBP | 6 | 3 | | 2 | 1 | | | |
| Intervert. Disc Damage/Hargens (p/p) | HHC | 12 | 6 | | | 1 | 3 | 2 | |
| Lighting Effects/Brainard, Lockley | HFBP | 6 | - | | | 1 | 2 | 2 | 1 |
| Medical Consumables Tracking/Zoldak | ExMC | N/A | - | | | Launch Install/Batt Change | | | |
| NeuroMapping/Seidler | HHC+HFBP | 13 | 3 + 1[1YM] | | 2 | 1 | 2 | 1 | 2 |
| Repository/McMonigal | HHC | N/A | 44 | | 3 | 3 | 3 | 3 | 3 |
| Rx Metabolism/Wotring | HHC | 6 | - | | | | | 1 | 2 |
| Sprint (Active)/Ploutz-Snyder | HHC | 12 | 7 | Yes | 1 | 0 | 1 | 1 | 1 |
| Telomeres/Bailey (p/p for Inc 45/46 and after) | HHC | 10 | 4 | | 3 | 3 | | | |
| Behavioral Core Measures/Dinges | HFBP | 2 | - | | | | | | |
| Occupant Protection/Newby (post only) | HFBP | TBD | - | | | | | | |
| One Carbon Poly/Smith (p/p) | HHC | 20[P] | - | | | | | | |
| Pick & Eat Veggie/Massa | HFBP | TBD | - | | | | | | |
| Standard Measures/TBD | HRP | N/A | - | | | | | | |
| Vertebral Strength/Weaver (p/p) | HFBP | 9[P] | - | | | | | | |

Baselined Flights/Approved Complements/Consented Crew

Projected Flight Opportunity

Crew Interest/Pending Signed Consent Forms

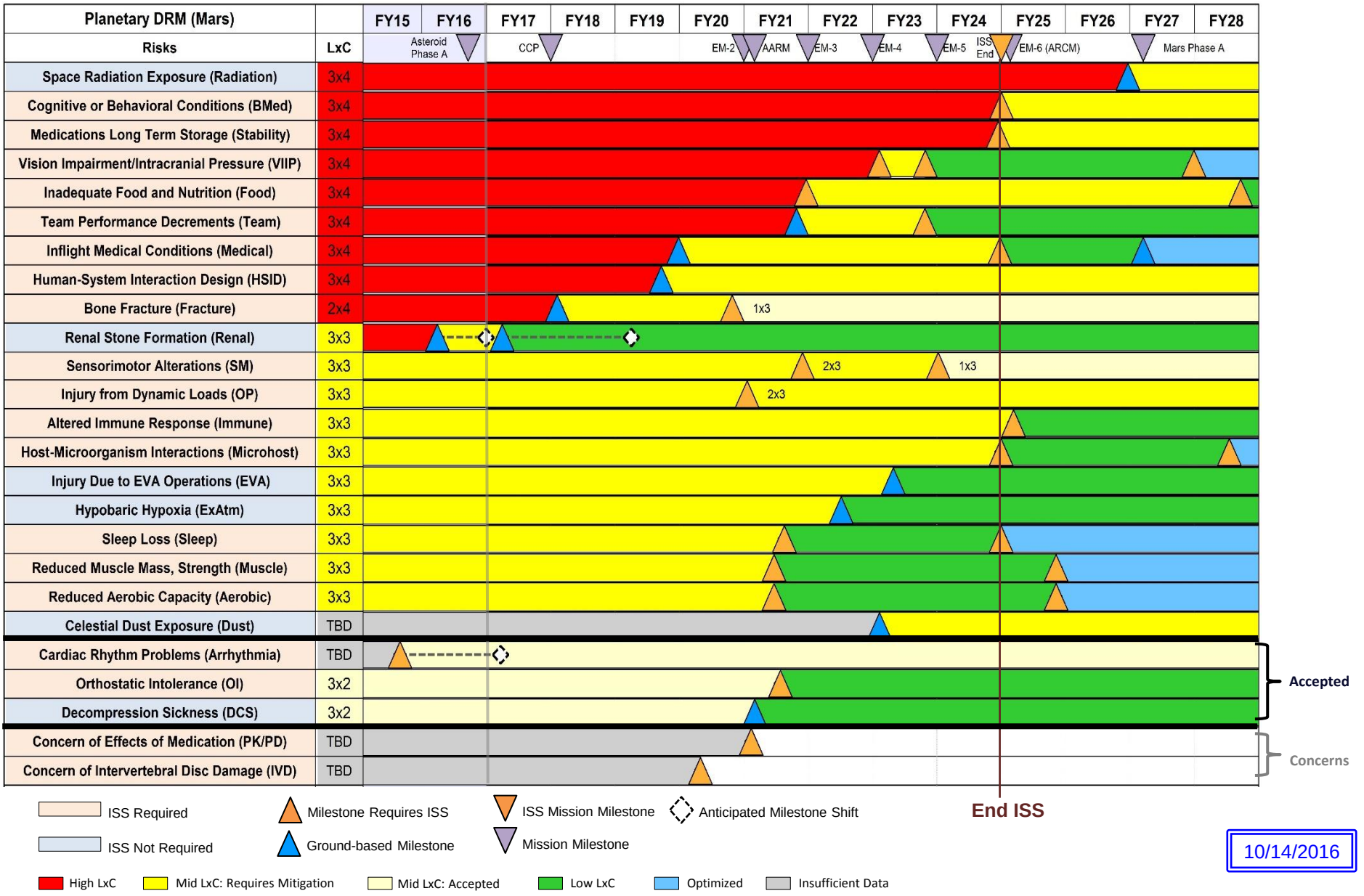
Feasibility Assessment In Work/Pending Select for Flight

* = Does not count toward N shown

P = Prospective subjects only

1YM = 1YM Subjects that do not count towards study N

# HRP Integrated Path to Risk Reduction (Mars)




10/14/2016

# HRP Risk Mitigation Maturation Plan

**~2035–20nn**

Fine-tune mitigation approaches

- Exploration vehicles
- Planetary surfaces

**~2021–2030**

Validate mitigation approaches

- Orion
- Deep-space hab
- Lunar surface (?)

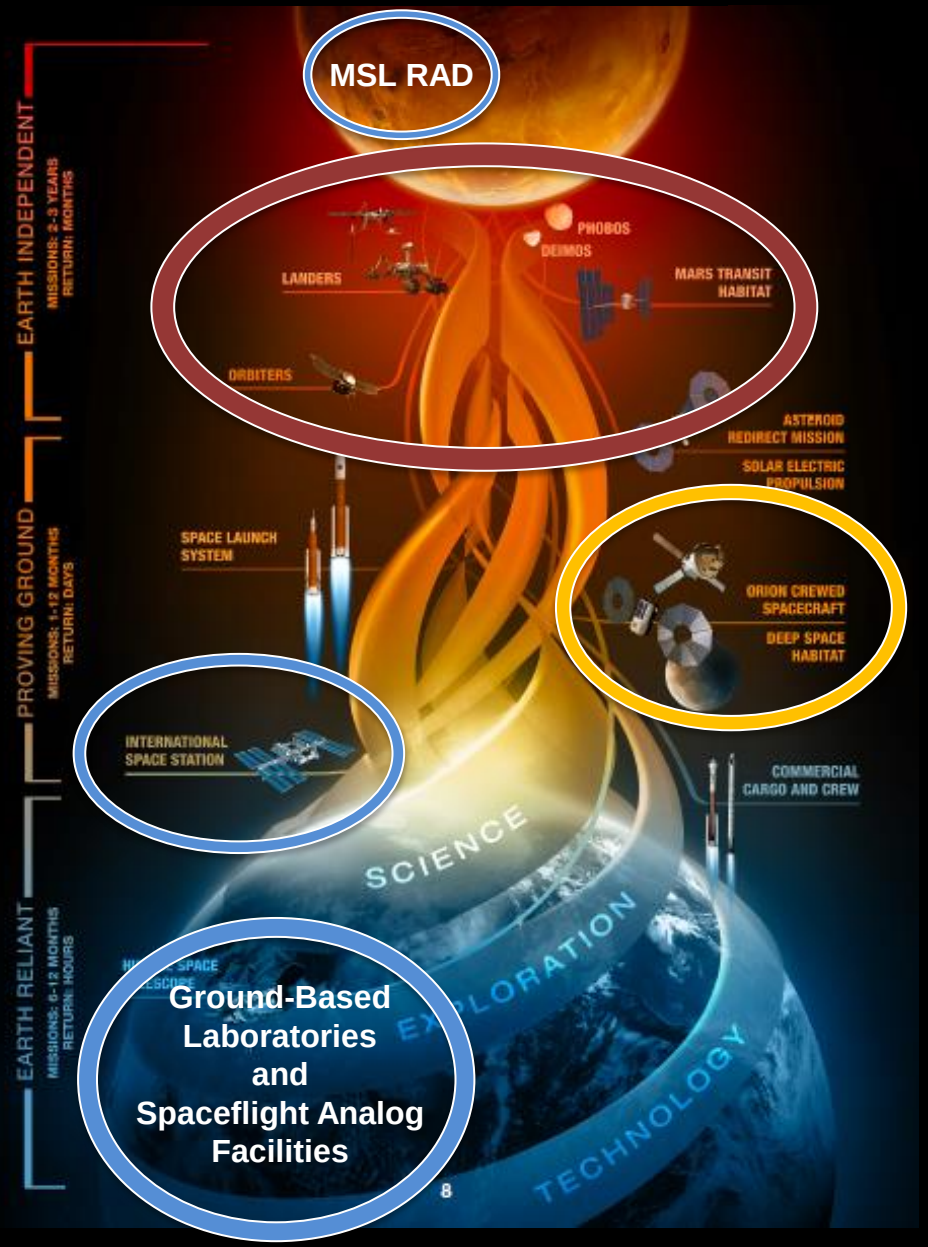
Inform exploration system designs

**Now–2024** (+/-)

Develop/test mitigation approaches

- ISS
- Spaceflight analog facilities
- Ground-based laboratories

Inform deep-space hab designs



# Research Planning: InterAgency Collaboration

- Department of Energy (DOE)/NASA on NASA Space Radiation Laboratory (NSRL)
  - NSRL is a multidisciplinary accelerator-based center that provides charged particles for space radiation research including radiobiology studies on carcinogenesis, Central Nervous System (CNS) and degenerative tissue effects; shielding materials, radiation sensitivity of electronics and nuclear physics measurements for model benchmarking; heavy ion radiotherapy.
  - Three modes of operation are available: single species and mono-energetic beams, Solar Particle Event (SPE) simulator and Galactic Cosmic Ray (GCR) simulator.

- National Science Foundation (NSF)/NASA on Polar Biomedical Research
  - Provide important operational research data to NASA and NSF Polar Program including improved protocols, technology, equipment, training, countermeasures and procedures for planning and operations in the extreme environments.
  - Human performance research in Antarctic Polar Stations can provide real operational experience with environmental stressors similar to those found in spaceflight. The remote location, extreme isolation, and confinement of polar station crew make it a unique and ideal operational analog to undertake translational research that addresses crew performance risks associated with long-duration space missions.

- NASA/Naval Submarine Medical Research (NSMRL) Laboratory Agreement
  - High performance operational teams, like those on U.S. submarines and NASA flight crews, face common issues. Among the most important of these issues is maintaining effective operational team performance during prolonged stressful missions.
  - The Submarine Team Behavior Tool (STBT) has previously been effective as an assessment mechanism for submarine and mariner operational teams to assess a team's operating resiliency level through observation of behaviors. The primary focus of the proposed research would be testing this tool's applicability to NASA crew during simulated space missions.

# Research Planning: InterAgency Collaboration

- Department of Defense (DoD)-Natick/NASA on Advanced Food Technology
  - NASA and DOD (U.S. Army Soldier Systems Center- Natick) are working on a common goal to produce nutritionally balanced, high-calorie meal bars using a novel ultrasonic process that reduces volume of the bars while providing a longer quality shelf life.
  - This high-calorie meal bar project is part of a mass/volume reduction for exploration food systems, including Orion program requirement of a 10% reduction in food system mass.

- NASA/NIH Memorandum of Understanding (In Development)
  - MOU sets forth a framework of cooperation between NIH/NASA on space and Earth related biomedical research that benefits health on Earth & enables space exploration.
  - Objective is to establish collaborative science planning and cooperative support in areas of mutual research and to provide investigators greater access to NASA's and NIH's unique biomedical specialty-focused Institutes, Centers, and research facilities. Where appropriate, investigators will have greater access to NASA's unique scientific experimentation platforms during space flight missions.

- DOD/NASA/VA Collaboration (In Development)
  - NASA, DoD, and the VA Medical S&T Interchange meeting to discuss medical research, technologies and practices of mutual interest and to explore opportunities for collaborations.
  - Focused on deployable medical capabilities and behavioral research including: medical simulation for training; medical qualifications and training content for trainers as well as deployed personnel; research on medical technologies and bio-marker indices for various states (includes states of stress, rates of recovery, and disease manifestation).

# Progress

# Circadian Regulation via Lighting

## “Real Work Underway To Keep Mars Travelers Alive”

**The clock is running on ISS testing for Mars missions**

*Oct 19, 2016 Frank Morring, Jr. | Aviation Week & Space Technology*

Astronaut Kate Rubins recently installed new lighting in the International Space Station (ISS) crew quarters that could help her successors in space survive a mission to Mars. Known as a solid-state lighting assembly (SSLA), the device emits light in wavelengths that can be tuned to help space travelers get a better night’s sleep. The SSLA is a simple example of the complex testing underway on the ISS as NASA and its international partners prepare for eventual human travel to Mars.

*Michael Fincke holding a General Luminaire Assembly (GLA) in Node 2.*

## Solid State Lighting Assembly (SSLA)

- Energy efficient, longer life span, no toxic mercury vapor.
- Excellent, bright light for visual performance and color discrimination.
- Suppresses melatonin to better manage circadian rhythms.
- Provides spectral adjustments to aid sleep and circadian disruption.
  - Blue shifts for the morning
  - Red shifts for the evening

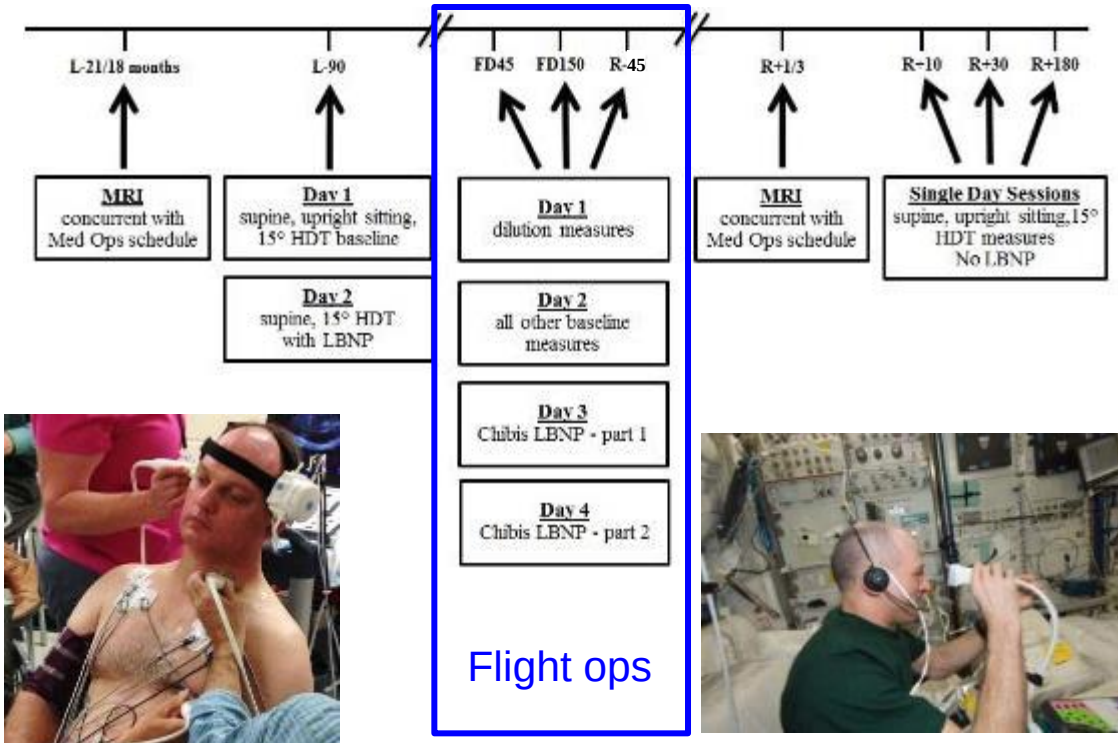

*Flight unit Solid State Lighting Module (SSLM)*

## Delivery and Testing Aboard ISS

- 7/8/16: 1st 4 SSLAs launched on SpX-9
- 10/5/16: Kate Rubins installed 3 SSLAs in Crew Quarters
- 11/15/16 Lighting Effects Flight Study begins on 49S
- 12/?/16: Next 11 SSLAs launch on HTV6

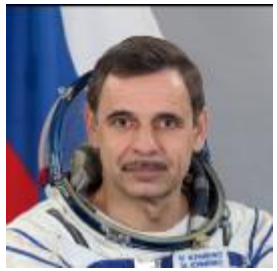
*Brainard GC, et al. Solid-state Lighting for the International Space Station: Tests of Visual Performance and Melatonin Regulation. Acta Astronautica. 2012 November; 92(1): 21-28. DOI: 10.1016/j.actaastro.2012.04.019.*

# VIIP Studies–Fluid Shifts Experiment







## Challenge: Russian Segment Ops

- Obtaining Agency-level Int'l Agreements
- Coordinating activities across NASA/Roscosmos
  - Hardware certification and testing activities
  - Simulation development planning
  - Real-time crew scheduling of US and Russian crew
- Consenting and training Russian crewmembers for NASA-sponsored science activities
- Procedure/Remote Guidance translation capability an unknown commodity

# U.S./Russian Field Test Studies

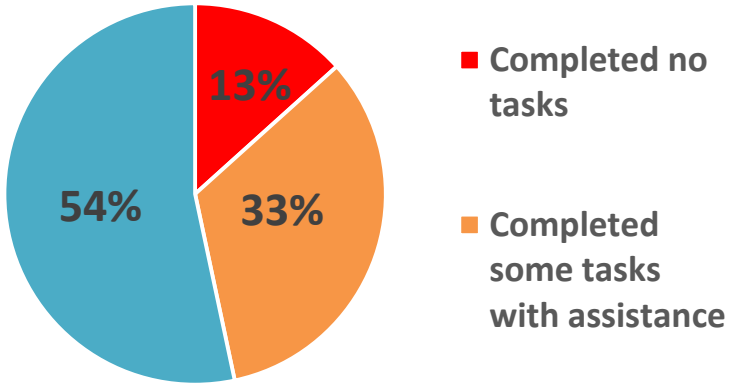
# US/Russian Field Test Experiment

## Operational Implications of Sensorimotor Dysfunction after G-transitions

- Postural and gait instability
- Visual performance changes
- Manual control disruptions
- Spatial disorientation
- Motion sickness

## Pilot Field Test
## Expeditions 34S – 40S (N=15)
## Medical Tent or Kazakhstan Airport

1. Every returning crewmember exhibits vestibular/cerebellar sensorimotor symptoms.
2. Every crewmember experiences some reentry or landing motion sickness.
3. Considerable variance across crewmembers' functional performance.
4. Multiple test sessions on R+0 appears to be beneficial in enhancing readaptation.



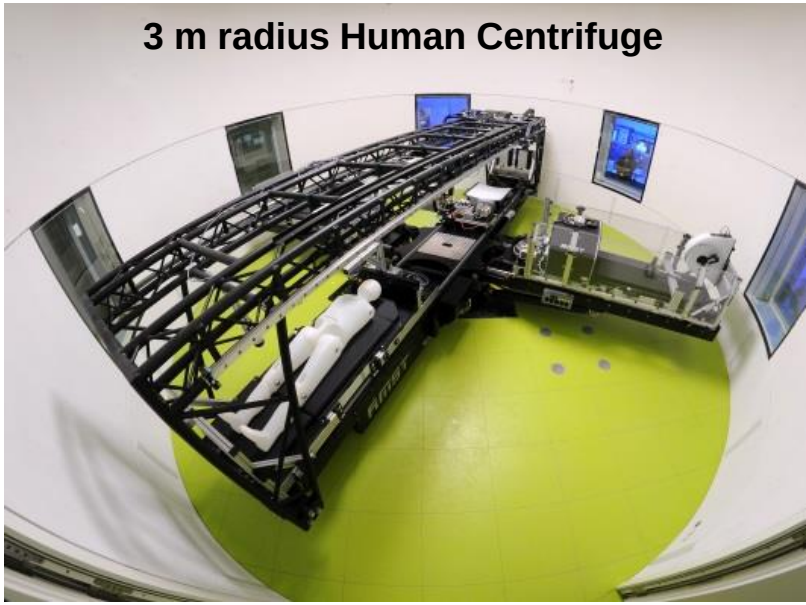

**No subject was able to complete the full test without assistance.**

# Joint NASA/ESA AG-Bedrest Solicitation

**Physiological and Behavioral Responses in Humans to Intermittent Artificial Gravity during Bed Rest**

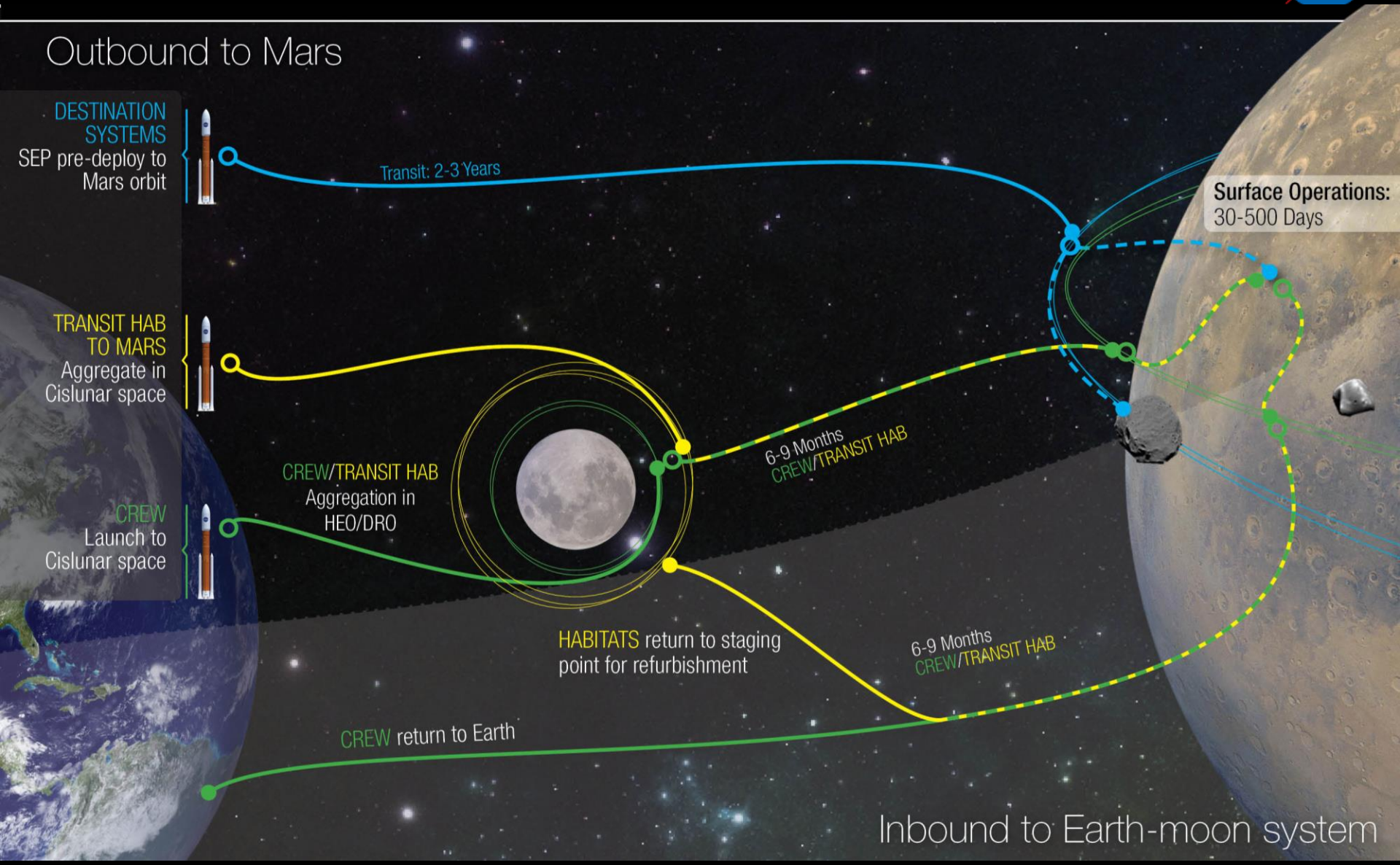
*Research to be carried out during two 60-day bedrest campaigns at the DLR's :enviHab facility in Cologne, Germany (2017, 2018).*

- Coordinated solicitations
- Common peer review (NRESS)
- Coordinated selections to maximize scientific gain
- Shared facility costs
- International Investigator Working Group: data sharing and coordinated publications




| | SM1 | CV3 | VIIP1 | M23 | Osteo4 | AGEGap1 | AGEGap3 | AGEGap4 |
|---|---|---|---|---|---|---|---|---|
| NASAEAGBRED009E | X | X | X | | | X | X | X |
| NASAEAGBRED020 | X | X | | | | X | X | X |
| NASAEAGBRED011 | X | | | | | X | X | X |
| NASAEAGBRED013 | | | | | X | X | X | X |
| ESAEAGBRED014 | X | | | | | X | X | X |
| ESAEAGBRED031 | | X | | | | X | X | X |
| ESAEAGBRED013 | X | | | X | | X | X | X |
| ESAEAGBRED017 | | | | | | X | X | X |
| ESAEAGBRED018 | | | | X | | X | X | X |
| ESAEAGBRED018 | | | | | X | X | X | X |
| ESAEAGBRED005 | | | | | | X | X | X |
| StandardEMeasures | X | X | X | X | X | X | X | X |


# Extrapolation Issue

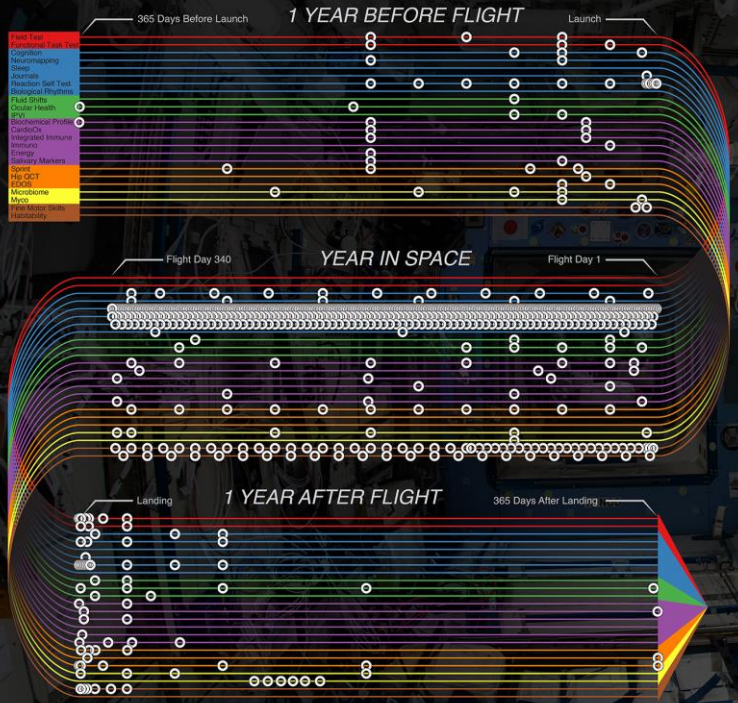



How confidently can we extrapolate our current 6-month experience to 30-month deep space missions?

National Aeronautics and Space Administration

# ONE YEAR in SPACE
# THREE YEARS of SCIENCE

Through research on astronaut Scott Kelly in seven major areas, we will improve our understanding of how the human body reacts to long-duration spaceflight. Testing began one year before his launch, intensified during his 340 days in space, and will continue for a year — or longer — after his return to Earth. Each line below represents one of the investigations for the Year in Space, and the circles indicate data collection points such as blood draws, ultrasound scans and cognition tests. The results of this research will help prepare us for future voyages beyond low-Earth orbit.




**FUNCTIONAL INVESTIGATIONS *(Field Test, Functional Task Test)*:** Can Scott perform tasks such as walking or opening a spacecraft hatch after landing? It's a lot harder after a year in microgravity!

**BEHAVIORAL HEALTH *(Cognition, Neuromapping, Sleep, Journals, Reaction Self Test, Biological Rhythms)*:** Has living in space affected Scott's psychological health? Stressful environments can impair cognitive performance.

**VISUAL IMPAIRMENT *(Fluid Shifts, Ocular Health, IPVI)*:** Has Scott's vision been impaired? Fluid shifts in microgravity can put pressure on the optical nerves.

**METABOLIC INVESTIGATIONS *(Biochemical Profile, CardioOx, Integrated Immune, Immuno, Energy, Salivary Markers)*:** How is Scott's immune system? He even got a flu shot while he was in space!

**PHYSICAL PERFORMANCE *(Sprint Study, Hip QCT, EDOS)*:** How strong are Scott's bones, muscles and cardiovascular system? The body deconditions in microgravity, so astronauts exercise two hours each day.

**MICROBIAL INVESTIGATIONS *(Microbiome, Myco)*:** Will Scott's microbiome change in space? Environmental changes affect Earth's organisms and ours, too.

**HUMAN FACTORS *(Fine Motor Skills, Habitability)*:** Will Scott's fine motor control diminish? Fine motor skills are important for controlling spacecraft.

Some investigations may collect data beyond the one-year post-flight mark. Learn more about each investigation represented above at: www.nasa.gov/1ym/research

INTERNATIONAL SPACE STATION
OFF THE EARTH, FOR THE EARTH

# Summary of Follow-On 1YM Plans

## Operations Implementation Strategy

- 5 follow-on 1YM: 2 crewmembers each (1 Russian, 1 USOS); N=10
- 10 concurrent 6 month missions (6MM); 1-2 crewmwmbers; N=10-20
- 5 concurrent extended (30-45d) Soyuz taxi missions (6WM): 2 crewmembers each; N=10

## Research Focus

- Medical events (validate incidence, standards, diagnostic & therapeutic tools)
- Physiological deconditioning (validate countermeasure efficacy)
- Behavior & Performance (validate standards, monitoring, countermeasures)

## Research Implementation Strategy

- Three tier research plan
  - Standard measures/occupational surveillance, on all crew: 6WM, 6MM, 1YM
  - Expanded versions of 6MM studies in current portfolio
  - Open (international) solicitation for focused studies
- Fully integrated joint Multi-lateral research program
  - All MHRPE Partners have agreed in principle
  - International subject (crew), hardware, and data sharing agreements in development
  - International research solicitation to be developed

# Omics/Personalized CMs–Twins Study

## Twins Study (Scott and Mark Kelly)

- ISS Sample Collection Completed
- Post Flight Sample Collection Completed

## Objective

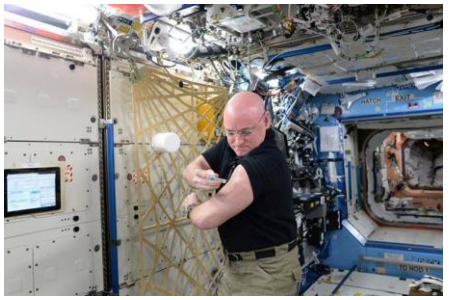
- Begin to examine next generation genomics solutions to mitigating crew health and performance risks: Personalized countermeasures

## Twins Study National Research Team Examined

- 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)



**Preliminary Results Expected at HRP IWS** (January 2017)

# **NASA Space Radiation Lab (NSRL)** DOE/BNL

Began testing GCR simulator during Fall 2016 run.


- Simulates the space radiation environment- high energy ion beams ($H^+$, Fe, Si, C, O, Cl, Ti, etc.) individually or together.
- Beam line, target area, dosimetry, biology labs, animal care, scientific, logistic and administrative support
- 3 experimental campaigns per year
- Space Radiation Summer School

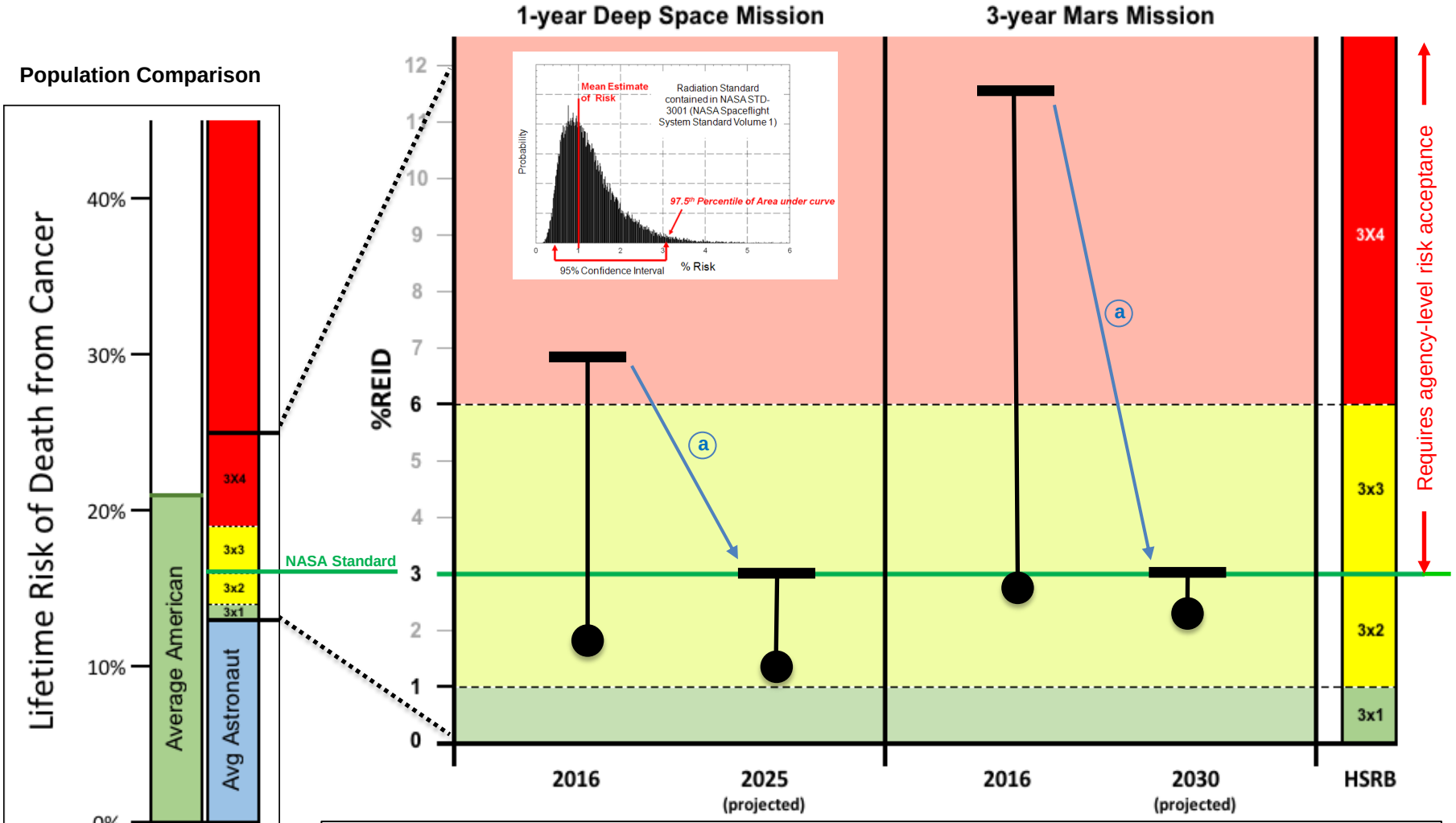
**NSRL Beam Line**

Images Courtesy of Brookhaven National Laboratory (BNL)

# Space Radiation Health Risks

| Health Risk Areas | Status |
|---|---|
| **Carcinogenesis**<br>Space radiation exposure may cause increased cancer morbidity or mortality risk in astronauts | ➢ Cancer risk model developed for mission risk assessment<br>➢ Model is being refined through research at NASA Space Radiation Laboratory (NSRL)<br>➢ Health standard established |
| **Acute Radiation Syndromes from SPEs**<br>Acute (in-flight) radiation syndromes, which may be clinically severe, may occur due to occupational radiation exposure | ➢ Acute radiation health model has been developed and is mature<br>➢ Health standards established<br>➢ Risk area is controlled with operational space radiation monitoring & shielding mitigations |
| **Degenerative Tissue Effects**<br>Radiation exposure may result in effects to cardiovascular system, as well as cataracts<br><br>**Central Nervous System Risks (CNS)**<br>Acute and late radiation damage to the central CNS may lead to changes in cognition or neurological disorders | ➢ Non-cancer risks (**Cardiovascular and CNS**) are currently being defined<br>➢ Research is underway at NSRL and on ISS to address these areas<br>➢ Appropriate animal models needed to assess clinical significance |

# Radiation Cancer Risk Mitigation Status




**NASA Standard:** 3% Risk of Exposure Induced Death (**REID**) at upper 95% Confidence Interval (CI) applied to individual over NASA career. [NASA Standard 3001: Space Flight Human-System Standard, Volume 1: Crew Health, rev. A]

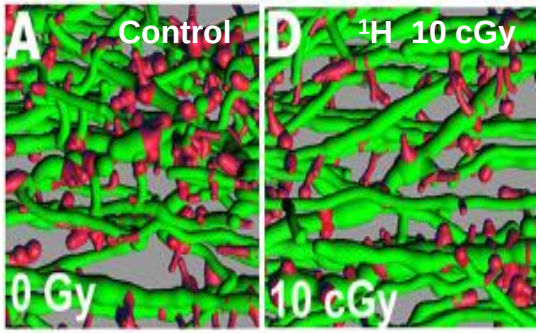
**Conservative REID estimate** (35 yo female; solar min): median (●) and 95% CI associated with single mission for dates shown.

(a) Based on projected improvements in terrestrial medical care, reductions in risk assessment model uncertainties, and development of radioprotectant countermeasures.

# NASA Space Radiation Laboratory (NSRL) Research

## Central Nervous System (CNS) Effects from Space Radiation

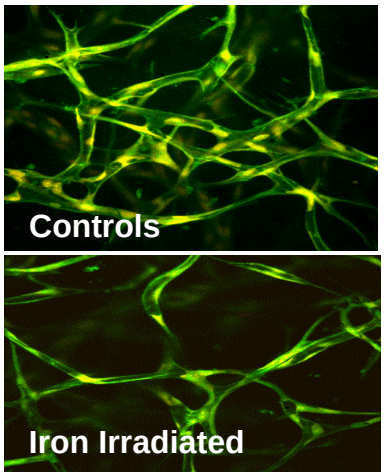
- Research with animal models shows changes to the CNS at exposure levels in range of concern to NASA
- Current research is focused on establishing significance, mechanistic basis, and of dose thresholds for these effects
- Major uncertainty in how to extrapolate results from animals to humans
- NCRP Committee (Radiation Exposures in Space and the Potential of Central Nervous System Effects) will provide guidance on future research




*Structural Changes in Neurons: Dendritic spines (red) are lost after 10 cGy of protons*

## Cardiovascular Effects from Space Radiation

- Current research is focused on understanding and quantifying the risk of cardiovascular effects at space-relevant exposures
- Establish whether a dose threshold exists, influence of dose-rate, and establish individual sensitivity
- Necessity for life span studies in appropriate animal models




*Vasculature damage: μm of vessel per cell after protons or Fe (C. Geard Columbia U)*

# NCRP Committee Reports on CNS effects Commentary # 25. Feb. 2016

**Radiation Exposures in Space and the Potential for Central Nervous System Effects from Radiation During Space Activities Phase I: Overview –Committee SC-1-24**

Phase I objective is to determine if there is evidence indicating that detrimental effects of radiation on CNS function may be significant and to determine if there is sufficient information available to support a second phase study. Findings:

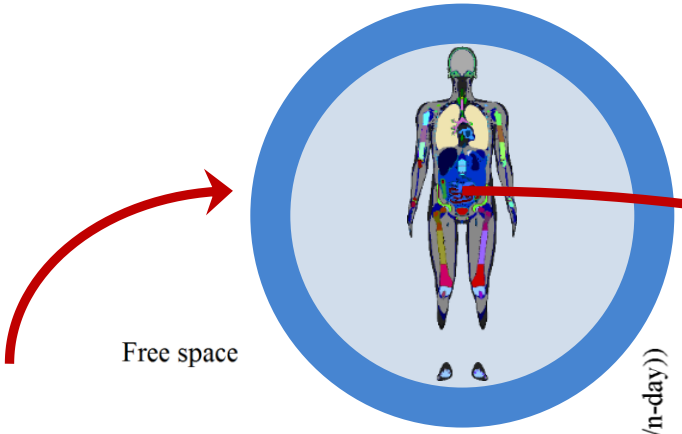
- Exploration mission relevant doses of HZE particles in animals, environmental exposure to other radiation insults, and clinical effects of therapeutic radiation exposure suggest that significant alteration in brain function can occur due to exposure to radiation.
- There is more than sufficient evidence that exploration mission relevant doses of HZE particles can cause significant alteration in animal brain function.
- Animal research addressing cell and molecular basis of risks and behavioral outcomes is needed to relate to both simple and complex behaviors relevant to the human risks
- The nature of CNS damage is significantly different than for cancer [cancer primarily involves deoxyribonucleic acid (DNA) changes (mutagenesis)] and therefore effects on the CNS may require a different approach to characterizing radiation exposure
- Mechanisms may be entirely different than for cancer and may require different approaches to dosimetry and risk mitigation
- Other sources of stress during space missions may mask radiation-induced CNS effects
- More research is needed to characterize the interaction of radiation exposure with other aspects of crew-member environment (e.g., sleep, lighting, exercise, diet)

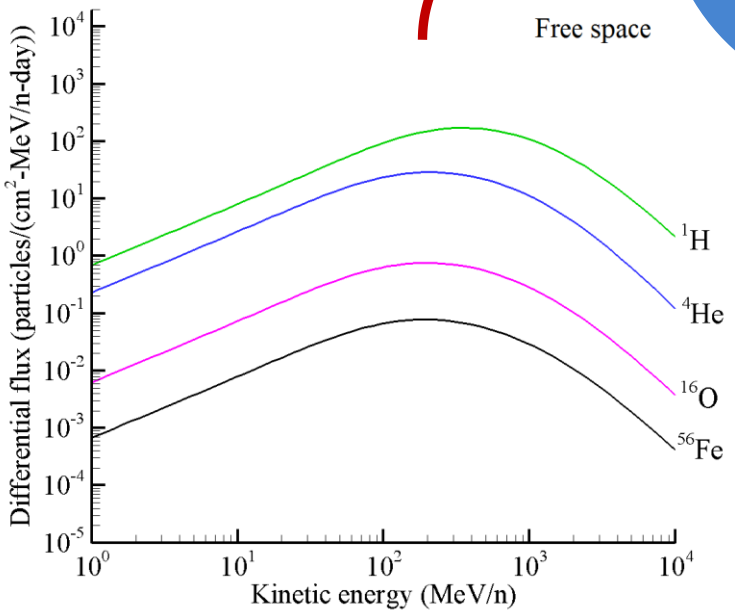
**Proposed 3-yr. follow-on Phase 2 proposal entitled "Radiation Exposures in Space and the Potential of Central Nervous System Effects" report expected in 2018.**

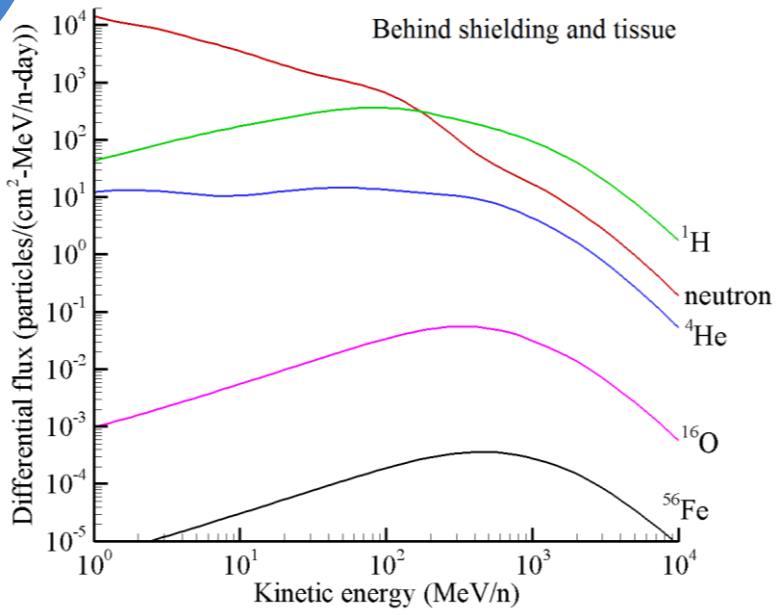
# External and Internal Fields

The external field is modified as it passes through shielding and tissue

- Slowing down due to atomic processes
- Attenuation and breakup of heavy ions due to nuclear collisions
- Secondary particle production (especially neutrons)






***Selected particle spectra in free space (left) and behind 5 g/cm² of aluminum and 30 g/cm² of water (right) during solar minimum.***

# Isolation and Confinement Analogs

**HERA:**
3-4 Missions/yr
4 Crew
14, 30, 45 d

**NSF:**
Multiple Stations
winter overs+

**IMBP/NEK:**
4, 8, 12 month

# Human Exploration Research Analog (HERA)

HERA 2016 Campaign

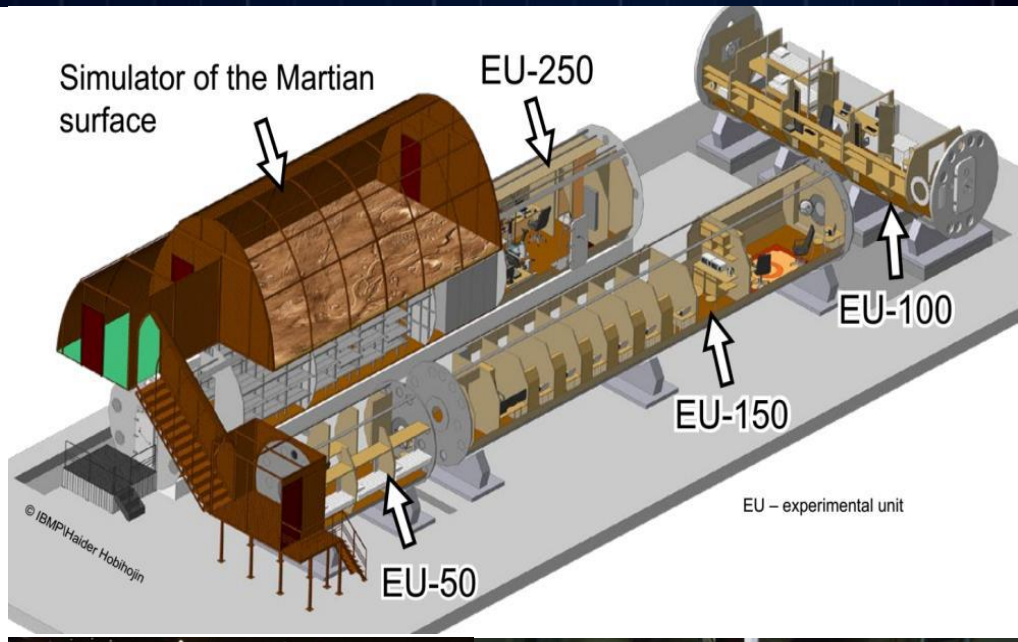
- Four 30-day missions
- 4 crewmembers
- Completed 22 studies including 3 from DLR
- Moving to 45-day campaigns in 2017



# **NEK** (RAS/IMBP, Moscow, Russia)

NASA/IMBP Collaborative on NEK Isolation Studies

- Joint two-week shake-down study is planned for fall 2017 to allow for testing of equipment, infrastructure, and operational processes.
- Research program may contain studies from both sides, as well as other partners to test the data handling and sharing processes.
- Studies performed by the crew of 4-6 volunteers recruited from participating partners.
- Potential four-month mission is being planned for 2018 with a multinational crew of six.
- Considering future 8-month and 12-month missions.

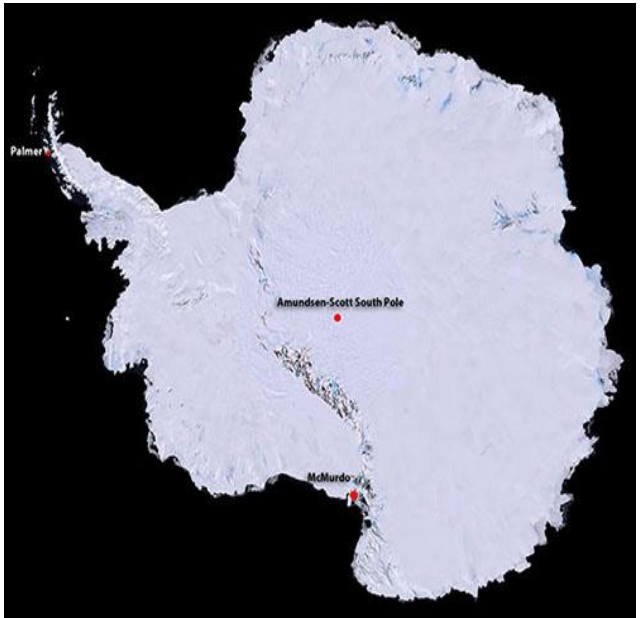



# **Antarctic Stations** NSF

- Highest priority HRP study was accepted by NSF is scheduled to begin during winter-over in February 2017 and will include approximately 110 U.S. Antarctic program volunteers located at the McMurdo and South Pole stations.
  - "Characterizations of Psychological Risk, Overlap with Physical Health, and Associated Performance in Isolated, Confined, and Extreme (ICE) Environments," Dr. Candice Alfano, UH
  - Goal is to refine a checklist to be used to provide an efficient means of monitoring signs and symptoms that a behavioral condition may be developing. Therefore, allowing early detection and early intervention.

- Antarctica (White Mars) is an excellent operational analog because you can't walk off the ice whether you're having a health, behavioral health or a personal issue, you're not going anywhere.
  - Similar challenges: months without seeing the sun; with the same crew; without shipments of mail or fresh food; isolation, absence of family and friends; and lack of new sensory inputs

**NSF/ South Pole Station**



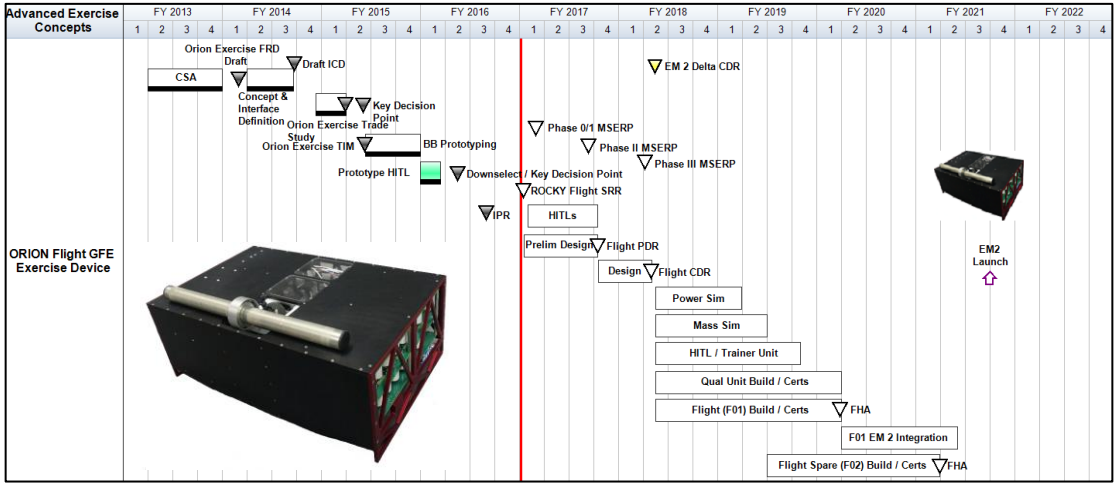
# MPCV Exercise Device (ROCKY*) Status

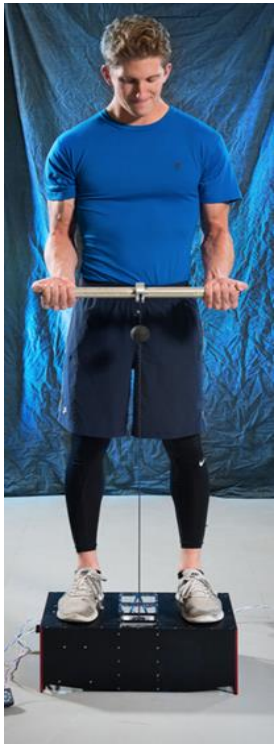
## Design/Capabilities

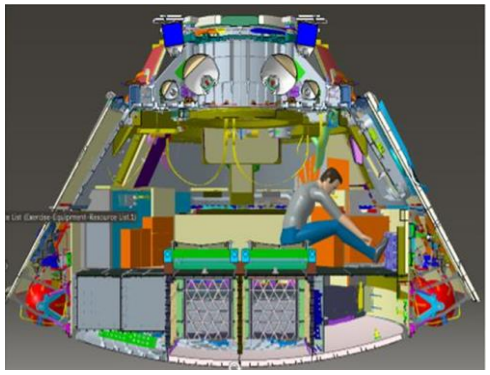
- Servo-motor controlled, single cable exercise system
- Provides resistive loads up to 400 lbf at velocities up to 2 m/s
- Software-modifiable exercise loading profiles
  - Inertial characteristics of free weights for resistive training
  - Oar/boat loading dynamics for aerobic (rowing) training
  - Custom profiles for eccentric overloading, weight racks, etc.
- Capacitor bank allows unpowered operation in rowing mode

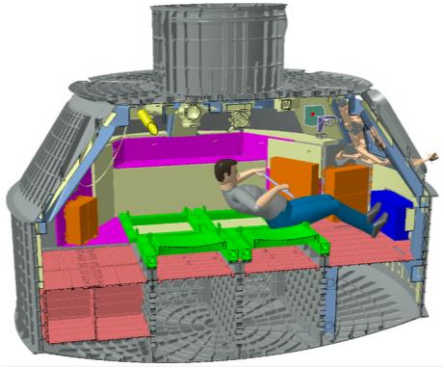
## Status

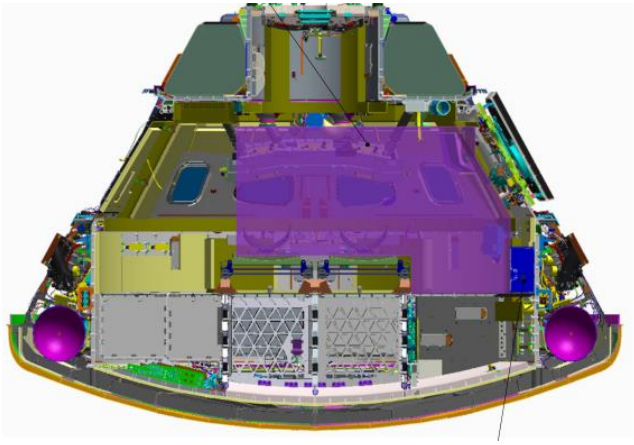
- 10/18/16: SRR held at GRC
- 11/22/16 (NET): RID Review Board









**Resistive Overload Combined with Kinetic Yo-yo*

# Deep Space Exercise Device (ATLAS*) Status

## Objectives:

- Develop exercise CM hardware for exploration
- Base on effective ISS exercise CM hardware suite
- Minimize mass, power, volume and highly
- Maximize reliability, versatility, and effectiveness

## Development Approach:

- Leverage the MPCV/ROCKY, MMED2, and SBIR efforts
- Demonstrate/validate on ISS asap (NET 2019)
- TTO to augment/replace ARED after initial valid

Design Goal: ATLAS will exceed ARED capabilities at 1/10 of its mass and volume

## Design Specification Goals:

| | |
|---|---|
| Accommodation (carrier) | ISS |
| Up-mass (lbm) | 200 lbm target |
| Stowed Volume ($ft^3$) | 3.0 $ft^3$ target |
| Peak Power (W) | 480 W target |
| Life Cycle Count | 750,000 cycles / year |
| Launch / Increment | Year 2019 |

***note: HULK and/or NGRED to be made available for BAA habitat testing.***

***NGRED Prototype***

***HULK Prototype***

***ATLAS Flight Concept***

*Advanced Twin Lifting and Aerobic System

# Renal Stone Formation Risk Mitigation

**Risk of renal stone formation/development is elevated during and early after flight**

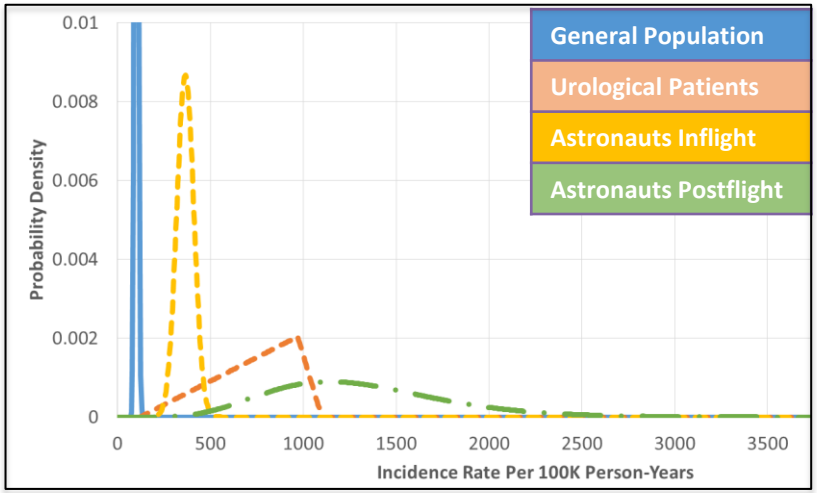
- Fluid redistribution, bone loss, muscle atrophy, diet

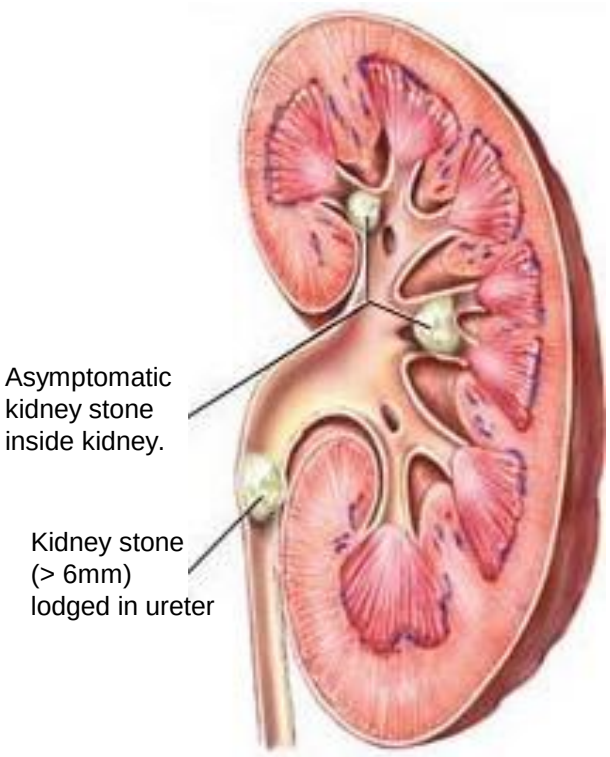
**Current Risk Mitigation Strategy**:

- Preflight ultrasound screening
- In-flight prevention: resistive exercise, increased fluid intake, appropriate diet
- Oral Calcium citrate

**Future Risk Mitigation Research Goals:**

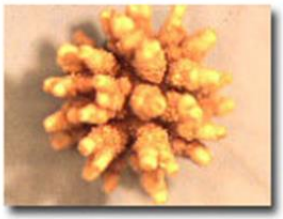
- Flexible Ultrasound System (FUS) to provide clinical grade imaging of asymptomatic stones.
- FUS to provide therapeutic modalities:
  - Moving a kidney stone away from the ureters
  - Moving a kidney stone lodged in the ureter
  - Non-invasively breaking-up a kidney stone.





Misery


Agony

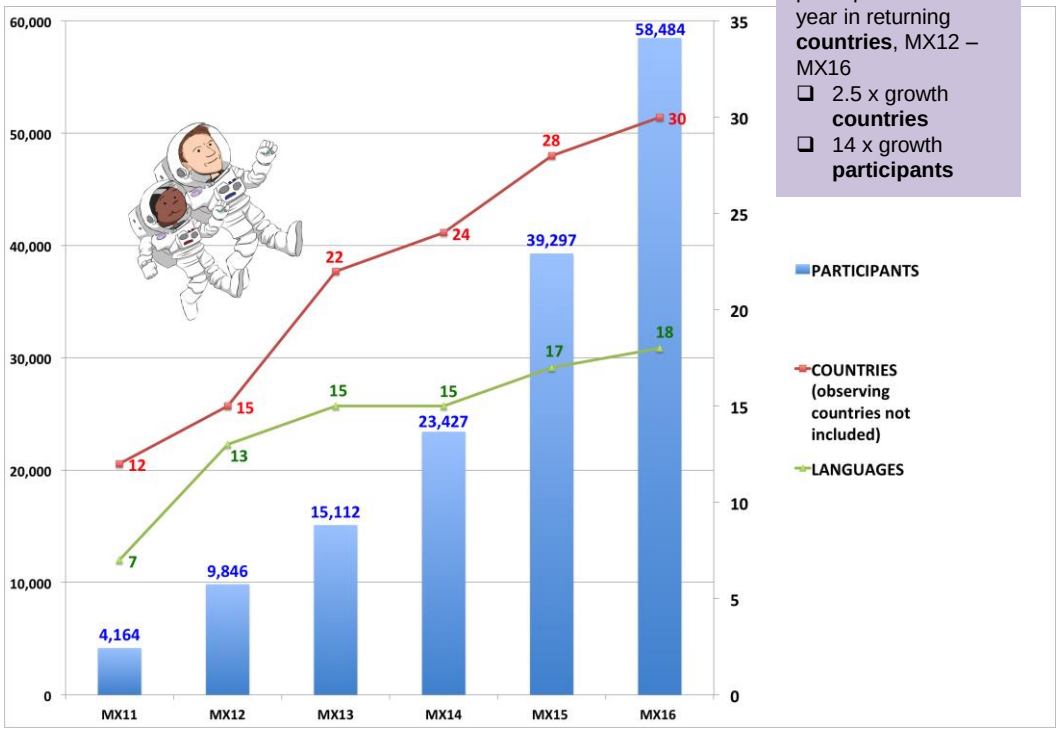
FUS moving stone in ER patient.


Ultrasound testing aboard ISS

# Engagement and Communications

## Train Like an Astronaut /Mission X

- **Mission X 2016 (MX16) International Fitness Challenge**
  - MX16 Walk To The Moon Challenge closed with 30 countries, four observing countries, and nearly 60K participants, Apr 28.
  - MX16 Team USA Closed with a virtual tour of JSC, May 13.
  - MX16 Face-to-Face meeting in Vienna, Austria with the largest number (16 of 30) countries participating, Jun 1-3.




Growth of participants each year in returning **countries**, MX12 – MX16
- ❑ 2.5 x growth **countries**
- ❑ 14 x growth **participants**

## research to outreach

- **Omics Exploring Space Through You Series**
  - Conclusion video 8 of 8 in the series and story were posted in conjunction with Twins Day, Aug 5. http://www.nasa.gov/content/exploring-space-through-you-omics


**Analog Mission Webpage**
Completed HRP/HEO Analog Missions webpage phase 1 and featured on the HRP website, Jul 7. Phase 2 to be released Nov 2017.
http://www.nasa.gov/analogs

# Human Research Roadmap:

## A Risk Reduction Strategy for Human Space Exploration

- HRP uses an Integrated Research Plan to identify the approach and research activities planned to address these risks
- http://humanresearchroadmap.nasa.gov/