

# Human Research Program Update

WH Paloski, PhD, Director

*CBPSS Virtual Fall Committee Meeting*

October 27, 2020



# Agenda



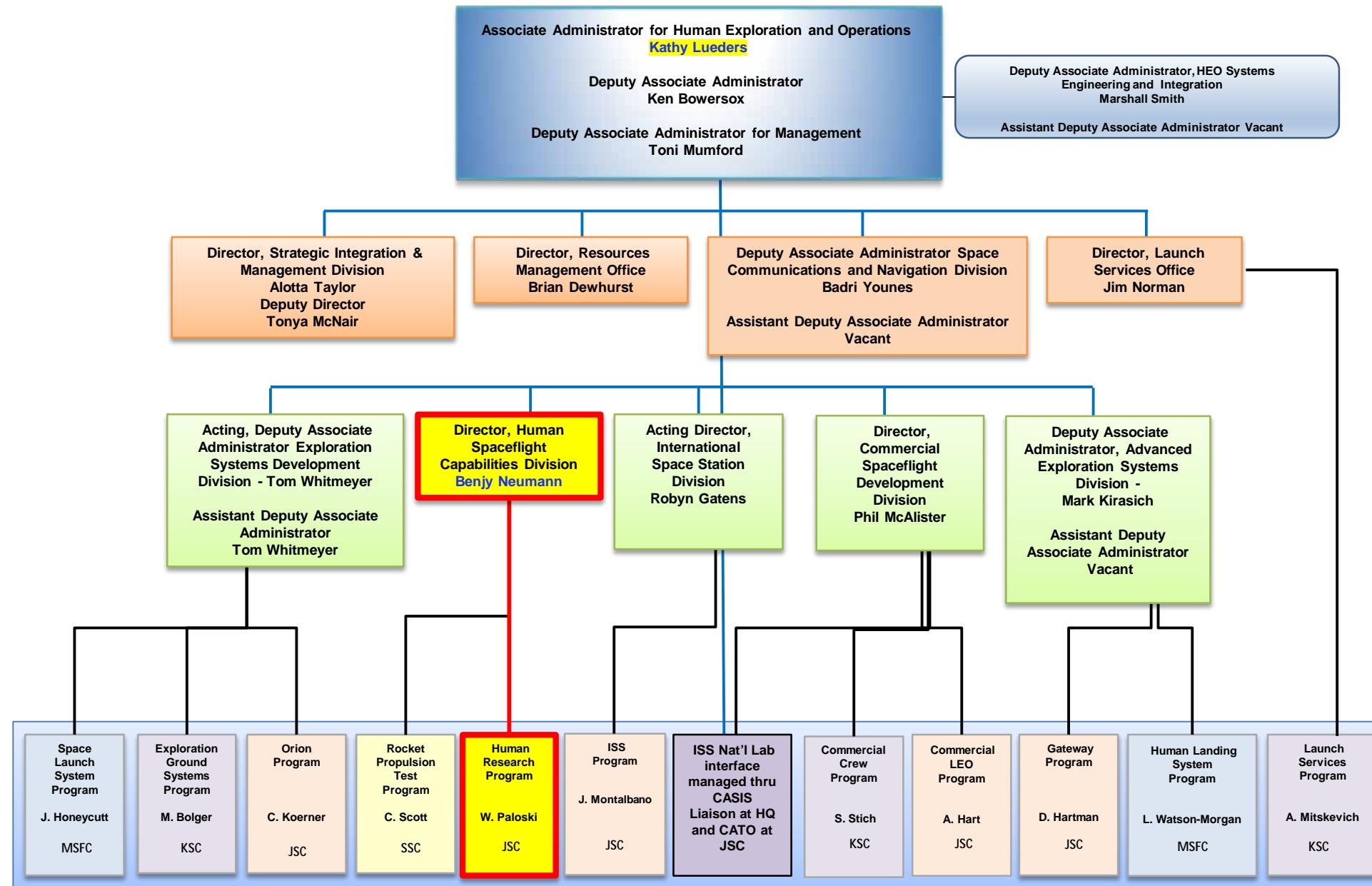
- Status, Planning, Research Accomplishments
- Insight on Coordination with BPS
- Trends, Forecasting Science Directions in the Community
- Challenges of Interest for the Decadal Survey
- Discussion and Q&A



# Status, Planning, Research Accomplishments



# NASA HQ/ Human Exploration and Operations (HEO) Mission Directorate



# HRP Functional Organization



## Human Research Program (HRP)

Director: W Paloski, PhD

### Program Management

Deputy Director: D Baumann

PSMO Manager: M Canga

Resources Lead: L Price

Agreements: L McCullough

### Program Science

Chief Scientist: J Fogarty, PhD

Deputy Chief Scientist: S Platts, PhD

Assoc. Chief Scientist: L Vega, PhD

Comm/Outreach: C Lloyd, PharmD

### Translational Research Institute For Space Health (TRISH)

Director: D Donoviel, PhD

Assoc. Director: J Hury

### Cross-Cutting Projects

ARC, GRC, JSC, KSC, LaRC

### Research Elements

#### Exploration Medical Capabilities

### Element Management

Manager: N Fleming

Deputy Mgr: J Sotomayor (rotation)

#### Human Factors & Behavioral Performance

Manager: A Allcorn

Deputy Mgr: S Ahsan

#### Human Health Countermeasures

Manager: L Bollweg

Deputy Mgr: R Schulte

#### Space Radiation

Manager: J Weeks

Deputy Mgr: N Meyer

### Operations Elements

#### Research Operations & Integration

Manager: S McCollum

Deputy Mgr Flight: N Schwanbeck

Deputy Mgr Analogs: K Pido

#### Space Radiation

See Above

### Element Science

Scientist: K Lehnhardt, MD

Deputy Sci: B Easter, MD

Scientist: T Williams, PhD

Deputy Sci: S Whitmire, PhD

Scientist: P Norsk, MD

Deputy Sci: Vacant

Scientist: R Elgart, PhD

Deputy Sci: J Zawaski, PhD

### HSRB Risk Content

Medical Renal Pharm Fracture Dust

BMed Team HSIA OP Sleep

SANS Food & Nutrition Immune Microhost EVA  
SM DCS ExATM Muscle Aerobic CVD

Cancer

### Facility Responsibilities

Flight: ISS, Orion, Gateway, ECM, HLS, Lunar Surface,  
Mars Transit/Surface

Analogs: HERA, NEK, envihab, Antarctic

Analogs: NSRL

### Business Planning

### Content Planning

# 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:

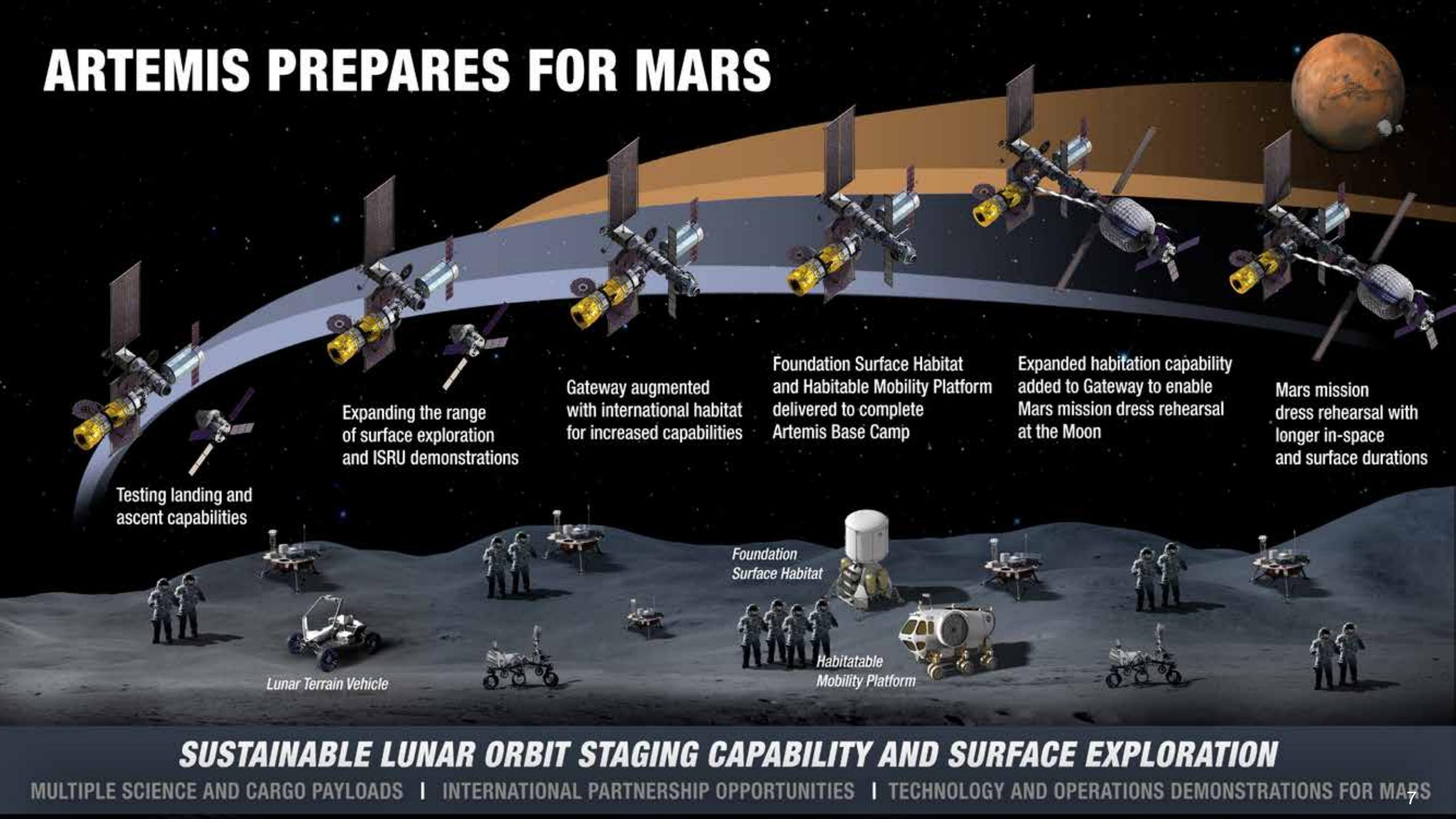
- **Basic, applied, and operational research**

leading to the development and delivery of:

- **Knowledge** relevant to crew health and performance
- Human health, performance, and habitability **Standards**
- Risk mitigation solutions, including **Countermeasures**
- Advanced habitability and medical support **Technologies**



# ARTEMIS PREPARES FOR MARS



# Deep Space Stressors to Human Health & Performance



Earth

*Altered Gravity Fields*

*Hostile Closed Environment*

*Radiation*

*Isolation/Confinement*

*Distance from Earth*

# Integrated Human Health & Performance Effects

## *Isolation/Confinement*

Behavioral aspect of isolation ♦ ♦

Sleep disorders ♦ ♦ ♦

## *Distance from Earth*

Communication delay ♦ ♦ ♦

Autonomous medical care ♦ ♦ ♦

Emergency evacuation ♦ ♦ ♦

Resupply/prepositioning ♦ ♦ ♦

## *Radiation Effects*

Acute, in-flight effects ♦ ♦

CNS and Cardiovascular ♦ ♦

Long-term cancer risk ♦

## *Altered Gravity Fields*

Bone Demineralization ♦

Muscle Atrophy ♦

Cardiovascular Deconditioning ♦

Fluid Shifts & Visual Alterations ♦

Disorientation & Balance Disorders ♦ ♦

## *Hostile Closed Environment*

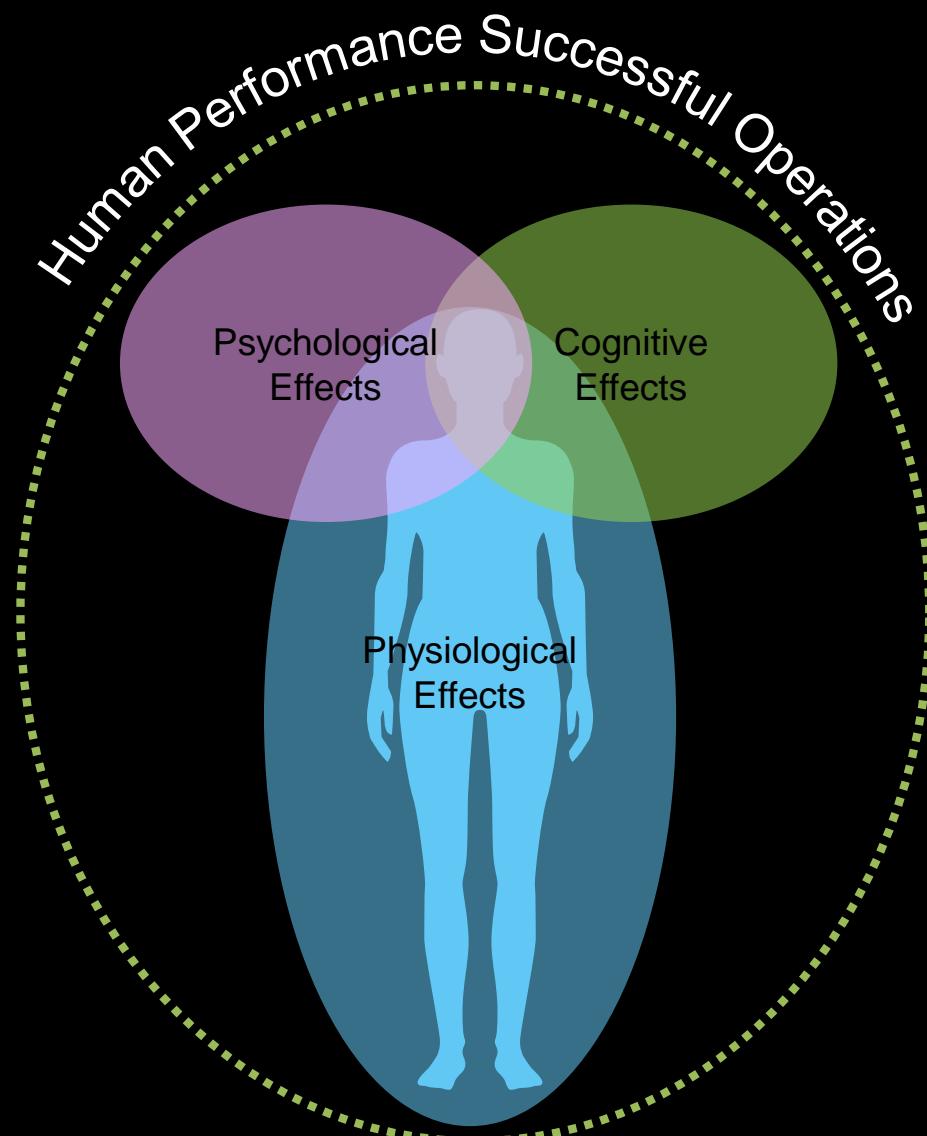
Vehicle Design (mass, power, volume) ♦ ♦ ♦

Human-system interactions ♦ ♦

Air, water, food/nutrition ♦ ♦ ♦

Toxic Exposures ♦ ♦ ♦

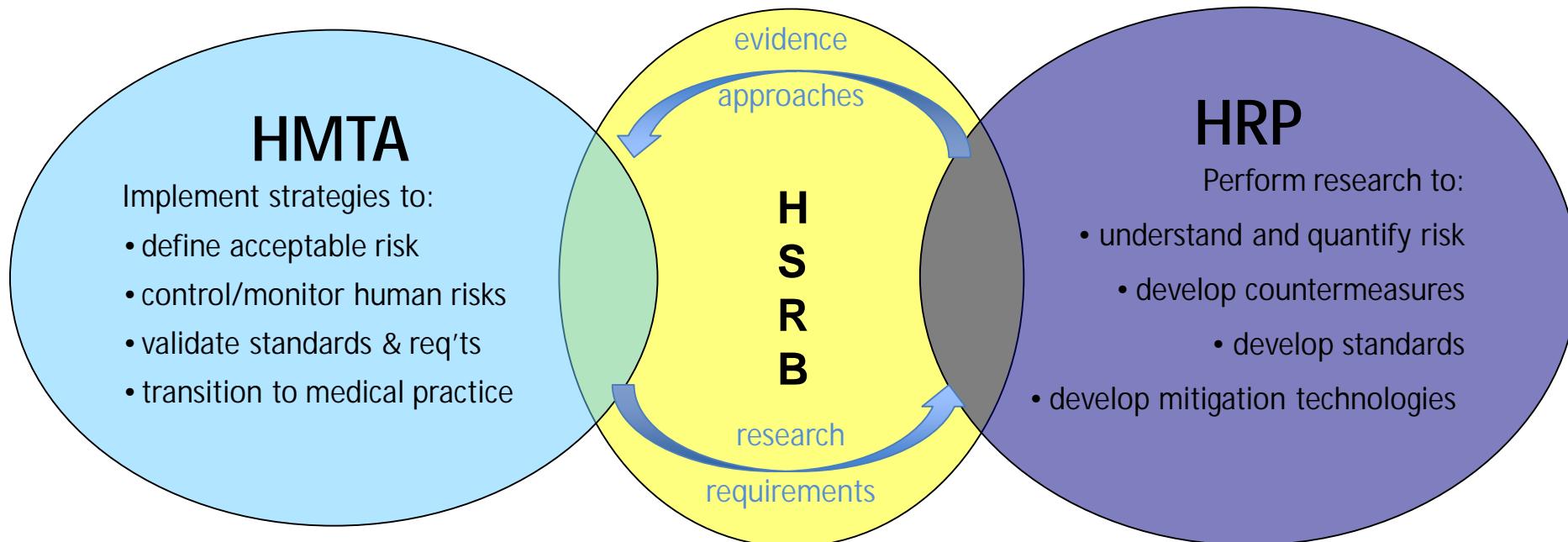
Microbiome ♦ ♦ ♦



# Human System Risk Board



Provides independent assessment of crew health and performance risk status for various design reference missions of interest to NASA.



## Human System Risk Board Membership

- HMTA Delegate for Human Spaceflight Risk Reduction Management (chair)
- JSC Chief Medical Officer
- Biomedical Research and Environmental Sciences, Division Chief
- **HRP Chief Scientist**
- Assistant Director for Exploration Development Support

- HH&P Director
- Space Medicine Operations, Division Chief
- **HRP Program Director**
- CH&S Manager
- Lead Epidemiologist

# Human System Risk Summary – Risks by Hazard



Last Updated: 14 October 2020

## Radiation

< Radiation Carcinogenesis (LTH)

Non-Ionizing Radiation

## Distance from Earth

< Inadequate Human Systems Integration Architecture

< Inflight Medical Conditions

< Inadequate Food and Nutrition

< Ineffective or Toxic Medications

## Isolation and Confinement

< Cognitive or Behavioral Conditions

< Psychosocial Adaptation within a Team

## Altered Gravity

< Spaceflight Associated Neuro-ocular Syndrome - SANS (LTH)

< Renal Stone Formation

< Cardiac Rhythm Problems

< Sensorimotor Alterations

< Host-Microorganism Interactions

< Bone Fracture

Urinary Retention

< Reduced Aerobic Capacity

< Reduced Muscle Size, Strength

< Orthostatic Intolerance

< Cardiovascular Health and Performance

< Venous Thromboembolism (CONCERN)

## Hostile Closed Environment

< Carbon Dioxide Exposure

< EVA Operations

< Injury from Dynamic Loads

< Hypoxia

< Decompression Sickness

< Sleep Loss

< Altered Immune Response

Electrical Shock

Hearing Loss Related to Spaceflight (LTH)

## Toxic Exposure

< Celestial Dust Exposure

LEO		Lunar Orbital		Lunar Orbital +Surface		Mars	
<30d	30d-1yr	<30d	30d-1yr	<30d	30d-1yr	<1yr	1-3yr
A	RC	A	RC	A	RC	RM	RM
A	A	A	A	A	A	AO	AO
AM	AM	RM/Standard Refinement	RM	RM	RM	RM	RM
A	A	A	RM	A	RM	RM	RM
A	A	A	RM	A	RM	RM	RM
A	A	A	A	A	A	A	RM
AM	RM	AM	RM	RC	RM	RM	RM
AM	AM	AM	RM	AM	AM	RM	RM
A	A	A	A	AM	AM	RM	RM
A	A	A	AM	AM	AM	RM	RM
AM	AM	AM	AM	AM	AM	AM	RM
A	AO	AO	AO	AO	AO	AO	AO
A	A	A	A	A	A	A	A
A	AM	AO	AM	AO	AM	AM	AM
A	AM	AO	AM	AO	AO	AO	AO
A	AM	AO	AM	AO	AM	AM	AM
A	AM	AO	AM	AO	AO	AO	AO
A	AM	AO	AM	AO	AO	AO	AO
TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
A	A	A	A	A	A	RM	RM
A	A	A	A	AO	AO	RM	RM
A	A	RM	RM	RM	RM	RM	RM
AM	AM	AM	AM	AM	AM	AM	RC
A	A	RM	RM	RM	RM	RM	RM
AO	AO	AO	AO	AO	AO	AO	AO
AM	AM	AM	AM	AM	AM	AM	AM
A	AM	AM	AM	AM	AM	AM	AM
A	A	A	A	A	A	A	A
A	A	A	RC	A	RC	RC	RC
AM	AM	AM	AM	AM	AM	AM	AM
N/A	N/A	A	A	A	RM	N/A	TBD
ISS*		Planned Artemis Missions					

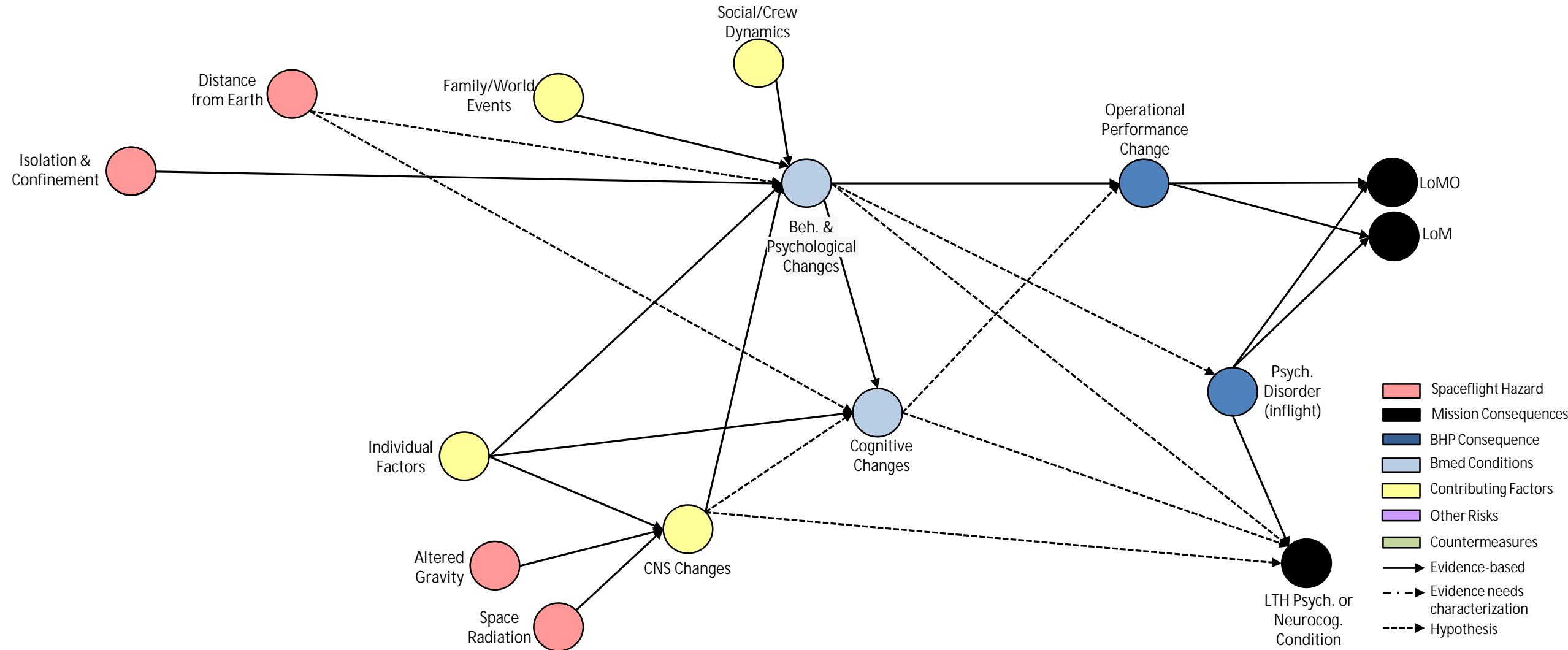
## Notes:

- Risk ratings are approved at the Human System Risk Board
- Risk ratings are for In-mission operations unless otherwise noted for Long-Term Health (LTH)
- Risk text color:
  - Current risk ratings
  - Risk update preparation in progress (will undergo CR)
  - Transferred to other risks, no longer appears in HSRB portfolio Risk ratings
  - To be proposed as a risk for HSRB approval
- Risk colors:
  - High LxC
  - Mid LxC
  - Low LxC
- Risk dispositions:
  - A Accepted
  - AM Accepted with Monitoring
  - AO Accepted with Optimization
  - RC Requires Characterization
  - RM Requires Mitigation
- < denotes specific risks that have HRP research investments

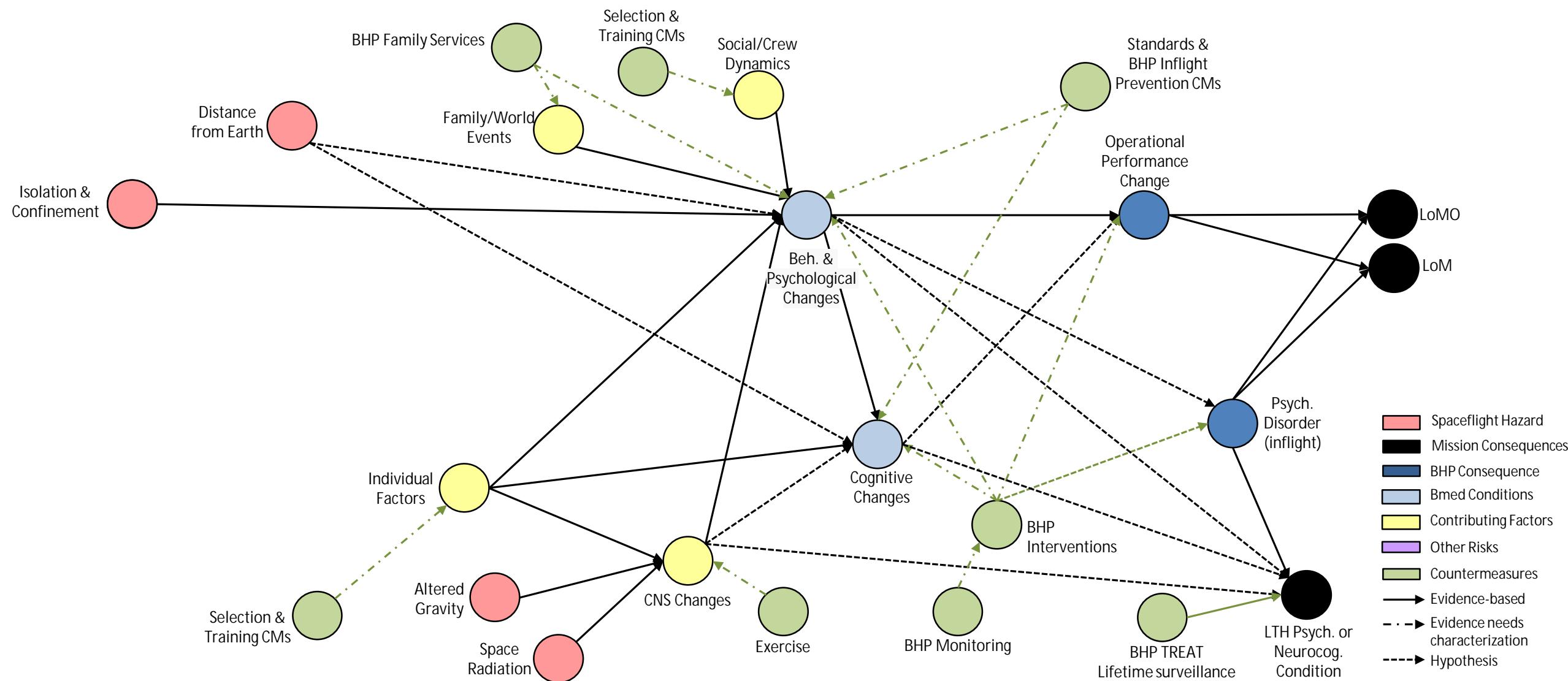
# HSRB: Directed Acyclic Graph for BMED\* Risk [basic]



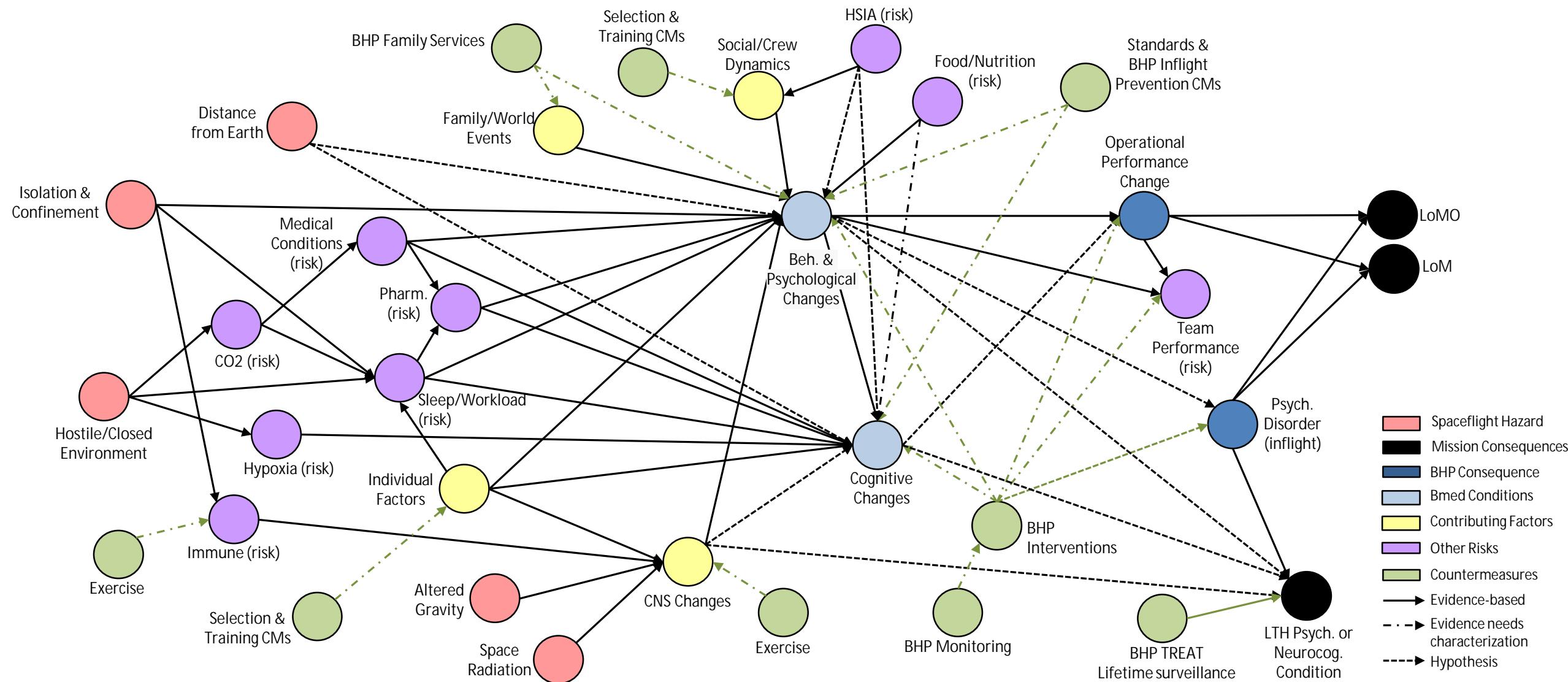
Directed acyclic graphs (DAGs) are used to model probabilities, connectivity, and causality.



# HSRB: Directed Acyclic Graph for BMED\* Risk [+countermeasures]



# HSRB: Directed Acyclic Graph for BMED\* Risk [+risk interactions]

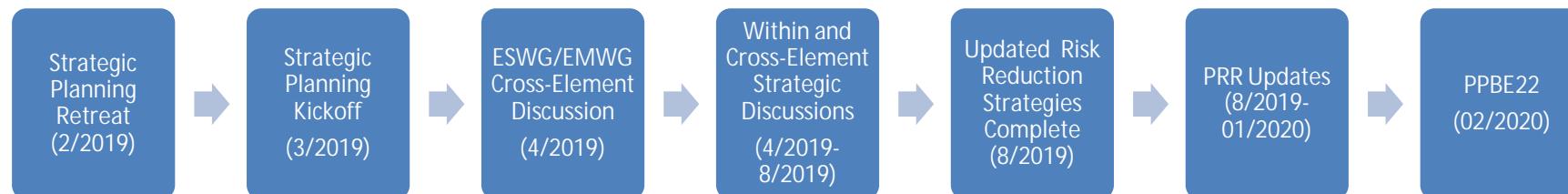


# HRP Major Strategy Changes 2019-2020

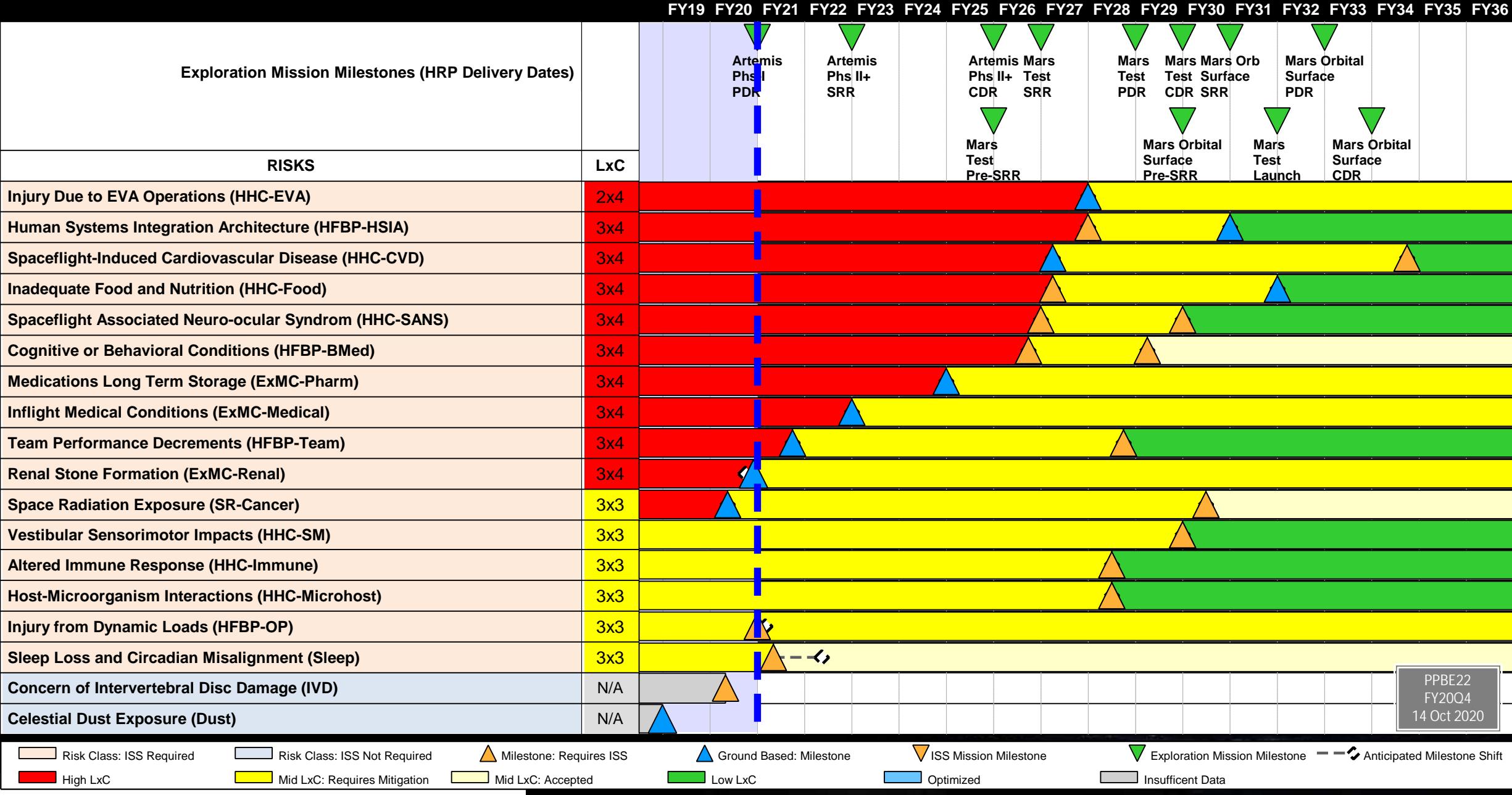


## Goal: position HRP to respond to changes in Exploration Planning

- Work *cross-element* and *cross-platform* to develop and validate strategic plans for each risk
- Consider how emerging exploration plans can best be used to:
  - relieve schedule for previously accelerated research areas
  - reinitiate delayed research with surface operations impacts
- Consider how emerging opportunities (e.g., Innovative use of ISS & CCP, ISS extension, Commercial LEO, lunar surface operations, etc.) can enhance risk reduction strategies. Incorporate new opportunities, as appropriate.
  - *LEO Transition Philosophy*: if it can be done in LEO, plan it in LEO, but do on ISS before 2024 if possible
- Assume 1-year Missions (1-year/6-month/6-week mission cadences) begin in 2021 and continue for 5 years.
- Update all ground analog needs to optimize risk mitigation outcomes
- Begin updating Gateway & Lunar Surface plans
  - Fold all required CTO's into baseline schedule and update tasks on Gateway that do not require "payload" capabilities
  - Identify as tasks on Gateway that would require "payload" capabilities (hardware or mass not part of the CHP system)



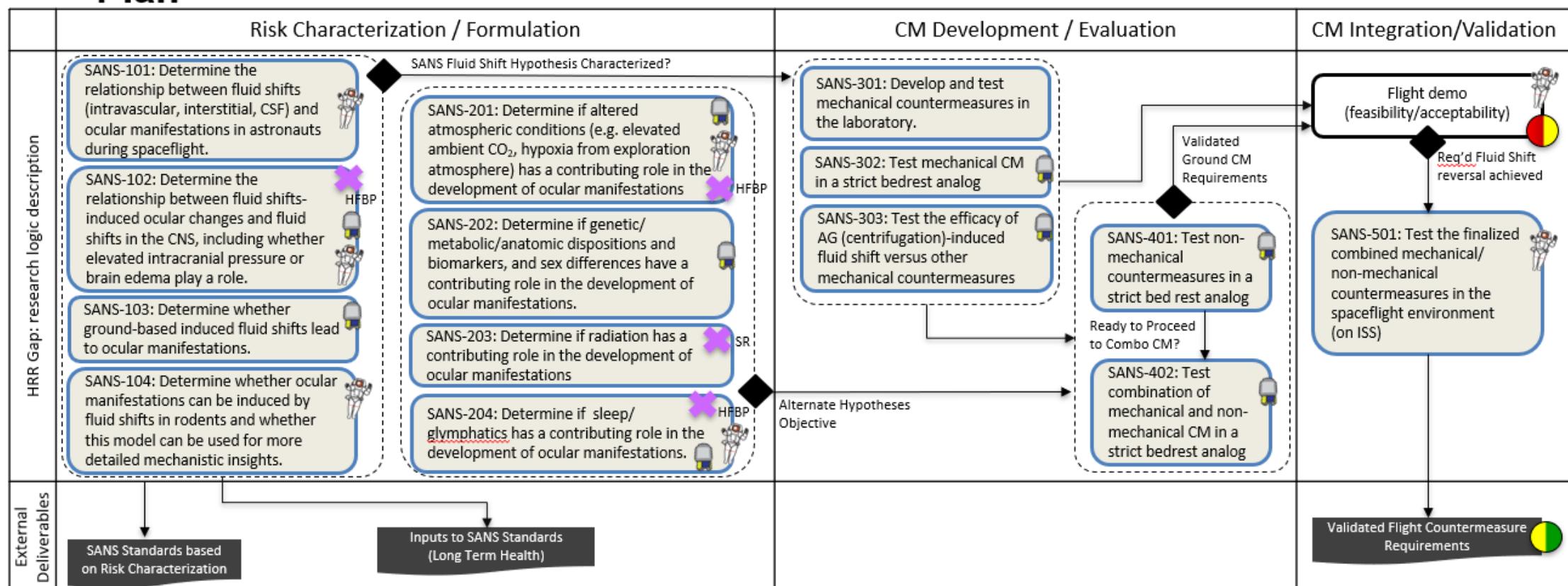
# 2020 HRP Integrated Path to Risk Reduction (Mars DRM)



# HRP Risk Approach Plan – SANS Risk Example



## SANS Risk Approach Plan



Note: Milestone (◆) and Gap Closures (●) are Program reviews with defined entry/exit criteria.

Legend: Analog Flight environment Cross Element Integration Anticipated PRR Color Change

# HRP Cross-Cutting Projects



**Cross-Cutting Projects** are established by the HRP Program Office to fill gaps, provide products, or otherwise support two or more elements. They are managed out of the PSM Office.

- **Space Biology and Translational Model Research (ARC)** – Identify methods to translate rodent research results/outcomes to associated human outcomes. Identify research within the Space Biology Program that can support translation into HRP risk reduction.
- **Standard Measures (JSC)** – Responsible for: coordination and implementation collection and analysis of the HRP standard measures across the approved platforms (e.g. flight studies, analog studies, etc.); Updating and providing inputs/updates to study related documents (e.g. IRB, TRR, protocols, debriefs, etc.); Oversee data collection methods and protocols.
- **ATLAS (GRC)** – Hardware development of compact device that could support resistive and aerobic exercise for exploration missions.
- **Computational Modeling (GRC)** – Application and development of computational models to characterize HRP risks; Development of computational model repository to house HRP developed models and facilitate reuse.
- **New: Systems Engineering/Computational Modeling of Food System (SCLT Support)**
- **New: Precision Health Initiative (aka Deep Phenotyping, Molecular Dosimetry)**
- **New: Systems Biology Translational Project**
- **New: Translational Radiation Research and Countermeasures Project**



# New: Precision Health Initiative (aka Deep Phenotyping, Molecular Dosimetry)



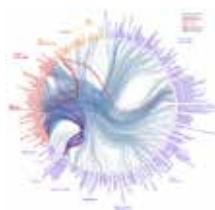
**Goal:** Empower state of the art biomedical analyses to establish mechanistic relationships between observed effects of spaceflight and their underlying biological processes.

**Method:** Create the framework for mapping an individual's molecular response to their physical manifestations in response to the complex environment of spaceflight. Establish a robust, systematic, and longitudinal data and sample archive capable of supporting an unlimited number of investigations.

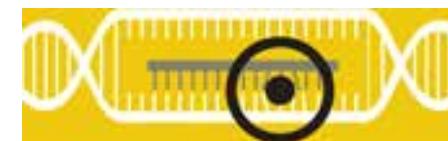
**Requirements:** Systematic, longitudinal acquisition of biological samples alongside biomedical, molecular, and environmental data



**HRP Spaceflight Standard Measures**  
Collection of biomedical and environmental data

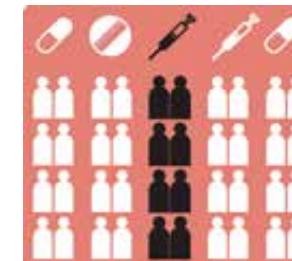


**Integrated Hazard Response**  
Multimodal analysis to determine individual response to spaceflight

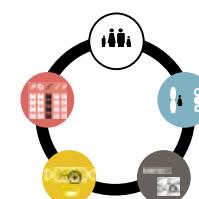


**Molecular Dosimetry**  
High resolution molecular data for detection of DNA damage due to spaceflight as an integrated hazard

Investment: \$2M/yr for 5 yrs



**HRP Spaceflight Omics Archive**  
Collection of biomedical samples and molecular data



**Data Integration**  
Cloud platform for archiving, managing, retrieving and integrating data

# New: Systems Biology Translational Project



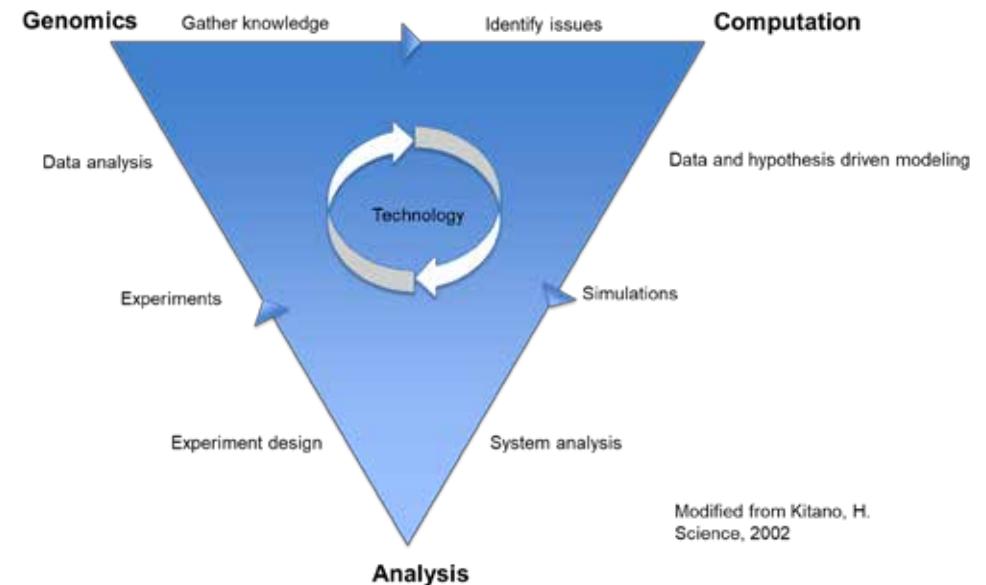
## Systems Biology Translational Project (joint with Space Biology)

Utilize bioinformatics and computational modeling to study data generated from previous and future investigations to evaluate changes in biological systems at a multi-level (e.g., cell, tissue, organism), multisystem (e.g., cardiovascular, renal, neural, immune), and multispecies perspective to better understand generalizable complex interactions among system responses to environmental stressors (CO<sub>2</sub>, radiation, G-level, microbiome, etc.).

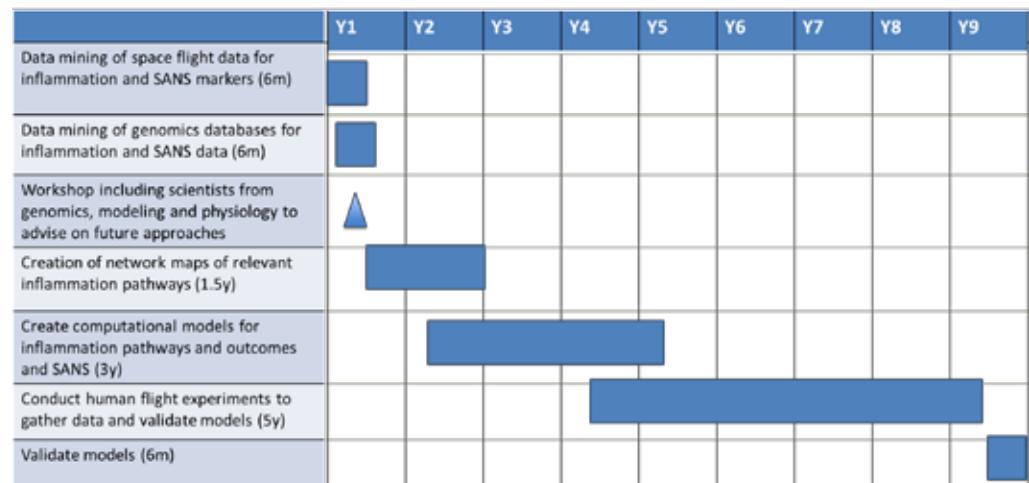
### Project Objectives

- The project will take a two pronged approach:
  - Develop and implement a research plan for a crosscutting spaceflight issue that is important for multiple risks - **inflammation**
  - Augment an already existing research plan - **SANS** - with applicable genomics and computational modeling to provide a full systems biology approach
- Fully integrate genomics, modeling and wet lab work (both human and animal models) into a holistic approach to space life sciences (**Space Biology collaboration**).
- Successfully translate animal work into application to the human (Space Biology collaboration).
- Identify key inflammatory pathway(s) that contribute to negative effects of spaceflight on the human body (**Space Biology collaboration**).
- Augment SANS research to create a systems biology approach.
- Create useful and applicable computational models that relate genomic data to physiological outcomes (**Space Biology collaboration**).

Investment: \$1.5M/yr for 5 yrs



Modified from Kitano, H.  
Science, 2002



# New: Translational Radiation Research and Countermeasures Project



## Project Objectives

- Translate radiation research results to humans using bioinformatics and computational modeling to link previous data generated to new sources of space relevant radiation exposure and new animal models, including human medical radiation exposure. Identify and develop preventative and in-mission therapies and integrated countermeasures (CMs).

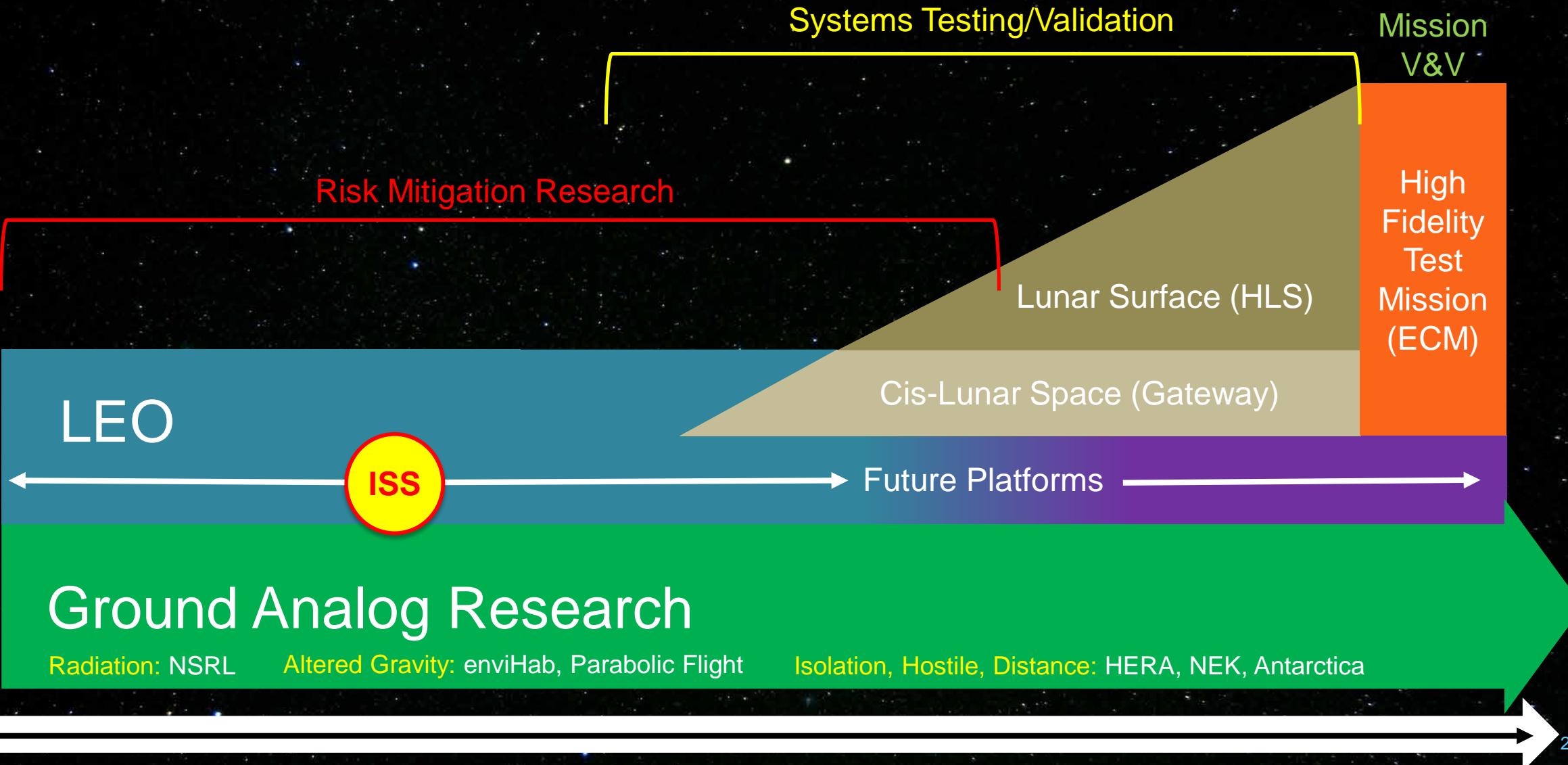
## Success Criteria

- Employ bioinformatics and computational biology to survey previous results; to link new sources of space relevant radiation exposure
- Develop computational and large animal models via use of mini pigs and NHPs to assess spaceflight radiation effects and translate findings between species
- Identification of pathway and biomarkers to inform selection of therapies/countermeasures and be used to assess efficacy
- Datamining effort coupled with computation biology/modeling to translate SR effects from rodents to humans, and identify and prioritize potential therapies and countermeasures
- In-vivo evaluation of ranked therapies and countermeasures
- Validate in-mission therapies and CMs

Investment: \$4.5M/yr for 5 yrs

# Integrated R&TD Strategy for Mars Mission Readiness

Research & Development Effort  
Exploration Science & Technology Demonstration



# Research Operations & Integration (ROI) Element



## Participating Centers: JSC

**Mission:** The Research Operations and Integration (ROI) Element plans, integrates, and executes HRP research tasks requiring access to space and flight analogs to address standards and/or reduce/eliminate human health and performance risks to enable Exploration mission success.

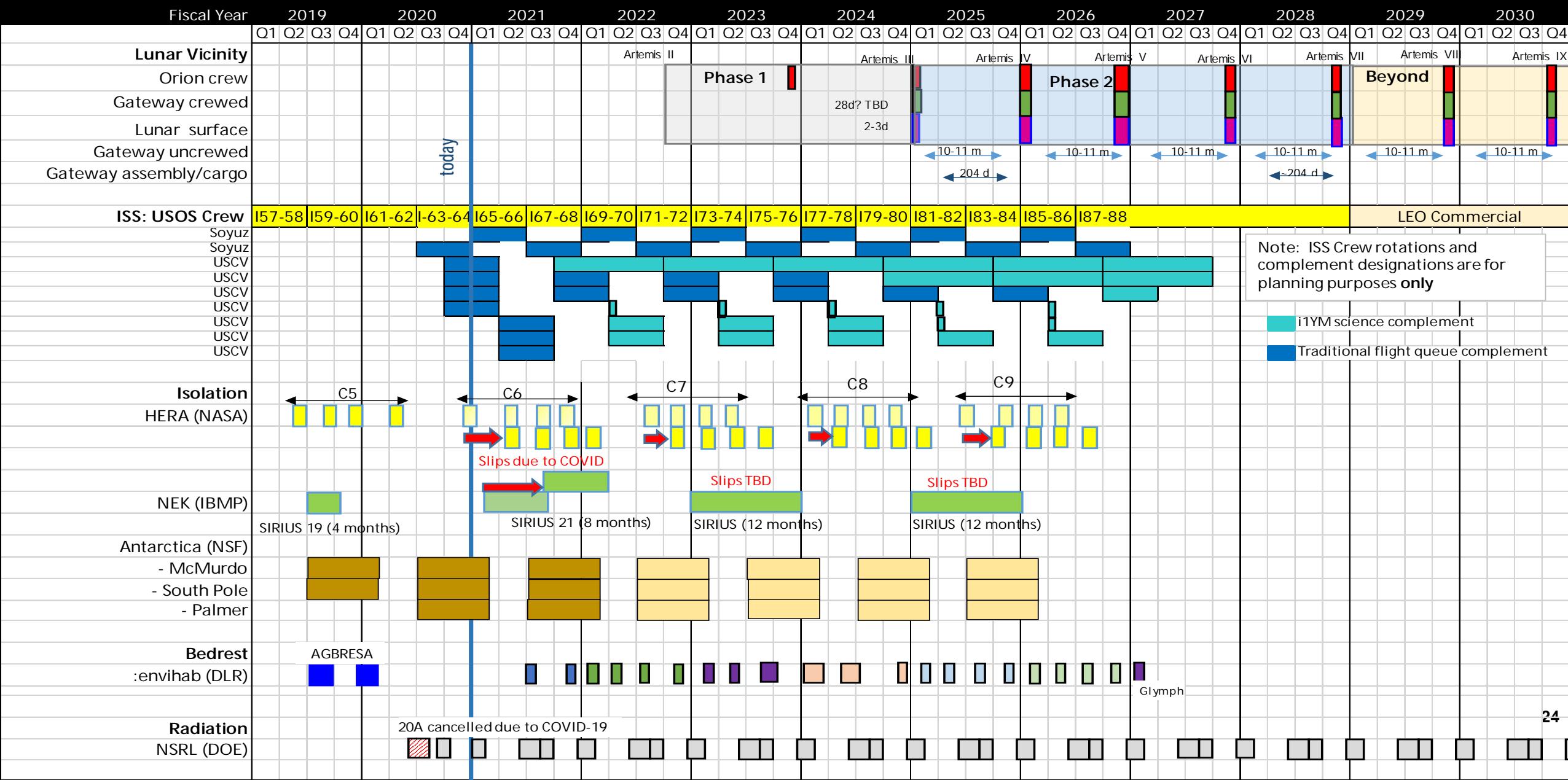
**Assigned Risks:** N/A

## Objectives:

- Facilitate access to International Space Station (ISS) and flight analog environments for HRP Elements and oversee the integration and operations of HRP research to maximize the use of these platforms.
- Manifest, integrate, operate and sustain human research hardware for use on ISS.
- Manage all aspects of mission planning and support for the Human Exploration Research Analog (HERA) (science integration, mission planning and support).
- Manage the contracts to procure access to additional analog environments
- Support International Partners in ISS and HERA research, per agency agreements



# Flight & Flight Analog Research Plans



# HRP FY20/21 Research Acquisition Status



HERO	Appendix	Release Date	Step 1 Received	Step 2 Received	Peer Review Date	Selection Date	# Planned Awards	# Actual Awards	Notes
2019	C	11/27/19	81	69	June-July 20	Sep-20	12-14	15	HHC, HFBP, and SR
	D	11/27/19	63	40	June-July 20	Sep-20	4-5	6	Omnibus
	E	3/31/20	28	20	Sep-Oct 20	Dec-20	TBD	TBD	Mars Adaptive Training-Integrative Knowledge System
	F	3/31/20	80	46	Sep-Oct 20	Dec-20	TBD	TBD	Omnibus
	G	6/15/20	2	1	Sep-20	Nov-20	1	TBD	Team (targeted) (NRESS will not be participating)
2020	A	7/31/20	TBD	TBD	Feb-21	Apr-21	1-2	TBD	Sensory Stimulation
	B	7/31/20	TBD	TBD	Feb-21	Apr-21	5-10	TBD	Omnibus
	C	Aug-20	TBD	TBD	Feb-21	Apr-21	TBD	TBD	Cortical Adaptation
TRISH	Title			Release Date	Step 1	Step 2	Selection Date	# Planned Awards	Notes
2020	2020 TRISH Postdoctoral Fellowship Solicitation TRISH-RFA-2001-PD			10/24/19	N/A	1/22/20	July 2020	4	Postdoctoral Fellowships
	Human-Based Models to Study Space Radiation and Countermeasures (TSRAD 2020)			1/8/20	2/14/2020	4/30/2020	August 2020	2-4 (\$1M ea)	Human-Based Models to Study Space Radiation and Countermeasures
	Faculty/Scientist Exchange Program: Space Health Swap			1/22/20	N/A	3/6/20	April 2020	2-4 (\$20K ea)	Scientists Exchange Program Swap postponed indefinitely due to COVID
	TRI-IND-2001 Industry Solicitation			3/9/20	N/A	6/26/20	September 2020	6 (\$250K ea)	Behavioral Health and Cognitive Performance Industry call
	BRASH 2101			10/1/20	12/11/20	3/20/21	August 2021	6-8	TBD
Topics to be determined									

# ISS Space Platform for HRP Studies



# Spaceflight Standard Measures



## Objectives

- To ensure that a minimal set of research measures, relevant to human spaceflight risks, is consistently captured from crewmembers until the end of the ISS
- The data from these measures are available to concurrent investigators via prospective data sharing, or to all investigators via a retrospective data request through the Life Sciences Data Archive
- *Spaceflight Standard Measures* will constitute a database for:
  - Providing context for data acquired by concurrent experiments
  - Supporting or developing hypotheses
  - Evaluating the effectiveness of various in-flight countermeasure profiles
  - Comparing population responses to various mission durations
    - Short: up to 105 days
    - Standard: 105-240 days
    - Extended: greater than 240 days



# CIPHER (Complement of Integrated Protocols for Human Exploration Research)

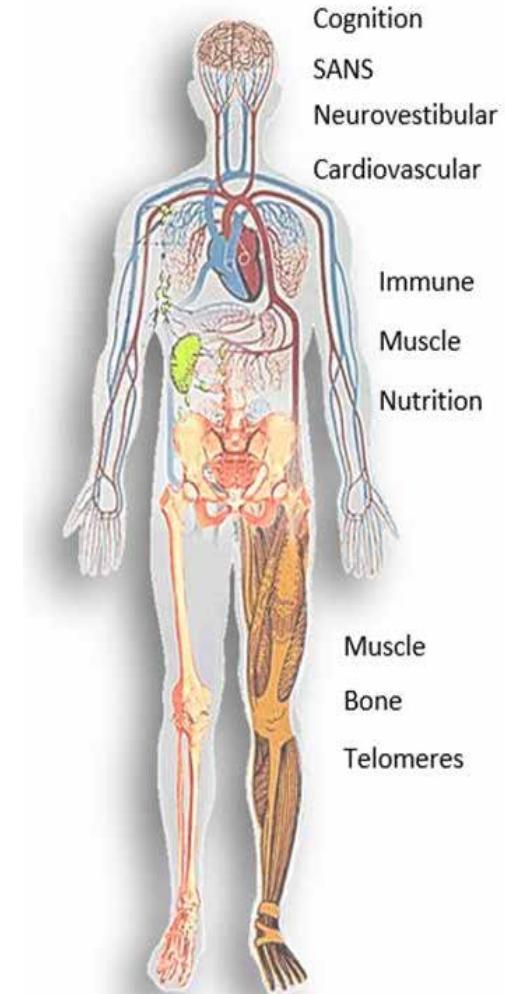


**CIPHER:** Most complex Human Research Project ever undertaken in space.

- 17 multi-disciplinary, multi-national investigations integrated into a single research complement.
- Mars-forward use of ISS to measure the time courses of **physiological and psychological adaptations** to spaceflight to inform crew health & performance risks during multi-year deep space exploration missions.
- Requires 30 participating crew members:



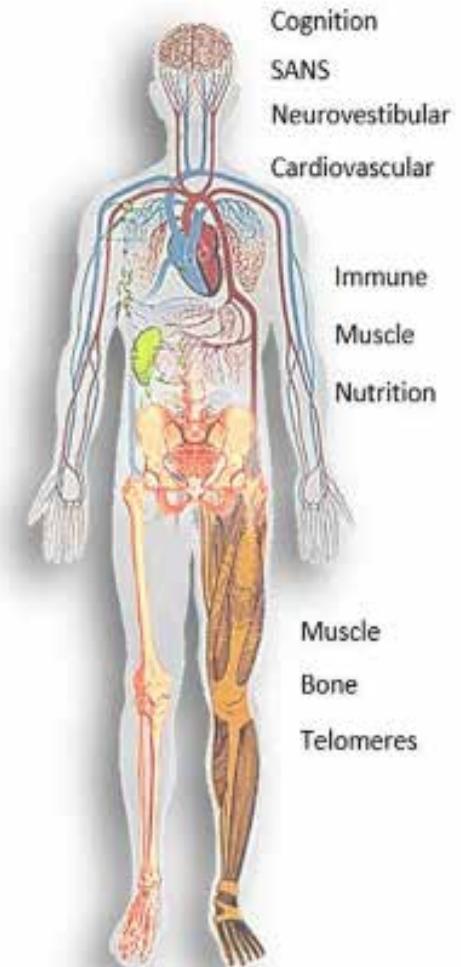
- First mission expected in late 2021



# CIPHER Selected Studies



PI	Investigation Title	Short Name
Arbeille, Philippe (CNES)	Preventive Medical Ultrasound Investigation of Organs Potentially Affected by Prolonged Exposure to Microgravity	Routine Ultrasound Assessment
Bailey, Susan	Telomeres and the One Year Mission Project	Telomeres 2
Basner, Mathias	Temporal Nature of Cognitive and Visuospatial Brain Domain Changes during Long-Duration Low-Earth Orbit Missions	Spatial Cognition
Bouxsein, Mary	Time Course of Spaceflight-Induced Adaptations in Bone Morphology, Bone Strength and Muscle Quality	Musculoskeletal Adaptations
Boyd, Steven (CSA)	The effect of long-duration space flight on bone microarchitecture and strength using three-dimensional high-resolution imaging	TBone2
Clement, Gilles	Spaceflight Standard Measures	Standard Measures
Downs, Meghan	Temporal changes in astronauts' muscle and cardiorespiratory physiology pre, during, and post spaceflight	Space Phys
Hughson, Richard (CSA)	Manifestations of spaceflight-induced sub-clinical cardiovascular disease as a long-term health risk	Vascular Calcium
Levine, Ben	Coronary Anatomy and Physiology during 1 year in Space and Risk of Atrial Fibrillation	Coronary Responses
Liphardt, Anna-Maria (DLR)	Joint health during a 1-year mission to the ISS - an assessment of exploration relevance.	Cartilage Health
Macias, Brandon	Investigating Structure and Function of the Eye	ISAFE
Matsuda, Chie (JAXA)	The Effect of Long-Duration Spaceflight on Renal Tissue Injury	Renal Tissue
Norcross, Jason	Validation of Fitness for Duty Standards Using Pre- and Post-Flight Capsule Egress and Suited Functional Performance Tasks in Simulated Reduced Gravity	Egress Fitness
Reschke, Millard	Neuro-Vestibular Examination During and After Spaceflight	Vestibular Health
Romanillo, Stephen	Evaluating Resistive Exercise as a Long-term Countermeasure for Spaceflight-induced Bone Loss Using Calcium Isotopes	Bone Health
Shelhamer, Mark	Assessment of Otolith Function and Asymmetry as a Corollary to Critical Sensorimotor Performance in Missions of Various Durations	Ocular Alignment
Shelhamer, Mark	TBD Data Integration Protocol	Data Integration
Zhang, Quan	Characterizing the Baselines of Sleep Quality, Cognitive / Operational Performance, Immune Function, and Intracranial Fluids for Deep Space Expeditions	NINscan



# ISS as a Deep Space Analog – ISS/HRP Accepted Use Cases FY20+



## Transit Durations (1-Year Missions):

- Science selected and will begin with crews launching NET Dec 2021 (\*crews starting CIPHER in Dec 2021 are expected to be 6-month duration)
- Longer durations do not provide additional insights into performance after landing on Mars

## Sensorimotor performance for deconditioned landings of long-duration crew:

- Quick-start of crew tele-robotic performance capabilities and fine motor skills on Kazakhstan returns (completed June 2019). Follow on study to collect additional data will start with Crew-2.
- 1-2 day landing simulation on Boeing CST-100 beginning on 3rd landing (TBD), 4x

## Medical autonomy:

- Autonomous Medical Officer Support (AMOS) – quick-start contingency operations without ground support (successfully completed Spring 2020)

## Operations Autonomy with Communications Delay:

- Comm delay capability available in September 2019
- HRP is not currently working on implementing any studies that require communication delay on ISS



# Extending ISS4Mars Concept to Gateway and Beyond

HRP led an ISLSWG Tiger Team to develop an integrated International set of Human Research Payloads for Gateway Initial Capability.

The product: a **comprehensive, coordinated and prioritized** suite of human research that represents multiple international research interests and an **integrated approach to utilizing Gateway's unique location**.

Tiger Team/ISLSWG down-select history: 32 candidates → 21 → 11				
	#	Lead Agency	Payload	Collaborating Agencies
Priority 1	1	NASA	Crew & Team Performance Measures	ESA, JAXA, CSA, ASI, CNES, DLR
	2	NASA	Spaceflight Standard Measures (subset of in-flight measures)	ESA, JAXA, CSA, ASI, CNES, DLR
	3	NASA	Pharmaceuticals (in GRAB bag)	ESA, JAXA, CSA, ASI, CNES, DLR
Priority 2	4	JAXA, CNES, NASA	Ultrasound	ESA, CSA, ASI, CNES, DLR
	5	CNES	EveryWear App	NASA, ESA, JAXA, CSA, ASI, DLR
Priority 3	6	NASA	Ophthalmic Measurements	ESA, JAXA, CSA, ASI, CNES, DLR
	7	ASI	IN-SITU	NASA, JAXA, CSA, CNES, DLR
Priority 4	8	ESA/CNES	TIME	NASA, CSA, ASI, DLR
	9	NASA	Dry Saliva Sampling Booklet	ESA, JAXA, CSA, ASI, DLR
	10	DLR	Non-Invasive Temperature Sensor	ESA, CSA, ASI, CNES
	11	ESA	Myotones	JAXA, CSA, ASI, CNES, DLR



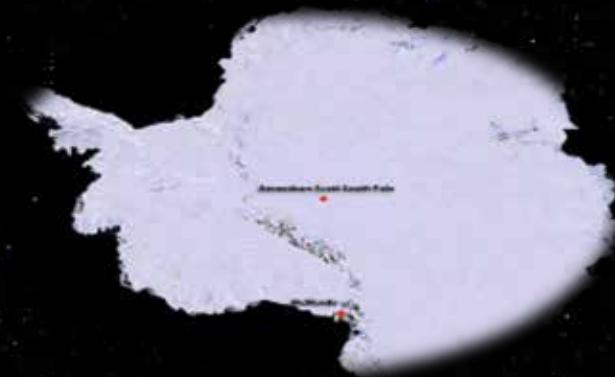
# Simulating Exploration Stressors on Earth



Isolation & Confinement,  
Distance From Earth



Hostile Environment,  
Isolation & Confinement,  
Distance From Earth



Radiation



Altered Gravity,  
Hostile Environment



# Isolation Analogs



## HERA

**Campaign 6 (2021-2022) - delayed due to COVID-19**

**Four 45-day missions with a crew of 4: 16 HRP studies (includes 8 new HRP studies)**

- Mission 1: ingress NET May 1
- Mission 2: ingress NET July 31
- Mission 3: ingress NET October 23
- Mission 4: ingress NET January 30, 2022

*\*dates may slip further due to Covid-19 impacts*



HERA

## Antarctica

**Partnership between NASA and the US National Science Foundation (NSF)**

- Winter-over 2020: two Immune studies
  - Palmer Station – Palmer Pilot study; 12 subjects enrolled. **Start delayed from March to June due to Covid-19** and will continue until early Dec. 2020.
  - McMurdo and Amundsen-Scott (South Pole) Stations – Antiviral Drug study; 35 total participants, completed data collection early Oct. 2020.
- Winter-over 2021: In discussions with NSF regarding new HFBP study



Palmer Station



Admumson-Scott Station



## NEK

**Partnership between NASA and IBMP**

- SIRIUS21 (8-month) mission: June 2021-January 2022
  - Seven HRP studies from SIRIUS19 and one new HRP study selected for SIRIUS21
  - **Mission start delayed from November 2020 due to Covid-19, dates may slip further**

# :envihab and NSRL



## :envihab

### **AGBRESA: 2x60-day AG Bedrest – Joint ESA/NASA completed Dec 2019**

- 60-day bed rest studies using the :envihab centrifuge (:envifuge) to study physiological and behavioral responses in humans to intermittent artificial gravity during 60-days HDT Bed Rest
- 3 NASA studies, 7 ESA studies
- Additional measures added for SANS due to early VaPER results

### **SANS Countermeasure Study in development with DLR**

- 6x30 day bedrest evaluating multiple SANS countermeasures
- 6 NASA studies, 6 DLR studies
- First 30-day campaign April 2021

## NSRL

### **NSRL-20A was cancelled due to COVID-19**

#### **Summer Run (NSRL-20B)**

- Began 1 June; ended 4 July
- **Modified to “ship and shoot” due to travel restrictions from COVID-19**

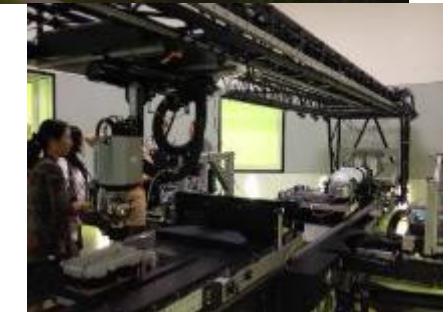
#### **Fall Run (NSRL-20C)**

- Began 5 October; will end 20 November
- **Modified to “ship and shoot” due to travel restrictions from COVID-19**

#### **FY21 and FY22 NSRL Planning**

- Spring Run (NSRL-21A) proposals received, and approvals are in work
- Call for proposals for 21B, 21C and 22A was released and proposals are due 18 November

## :envihab



# Exploration Medical Capabilities (ExMC) Element Highlights

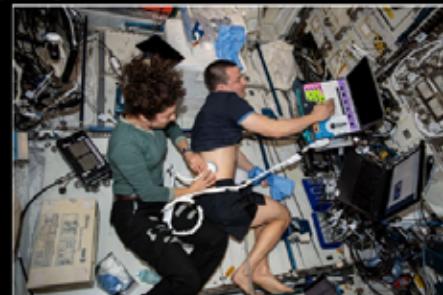


- **Participating Centers:** ARC, GRC, JSC, LaRC
- **Mission:** Advance medical system design and risk-informed decision-making for exploration beyond low Earth orbit to promote human health and performance in space.
- **Assigned Risks:** Medical, Pharm, Renal, Fracture, Dust
- **Objectives:**
  - Develop capabilities and countermeasures in support of human space exploration, focused on mitigating risks that negatively impact crew health and performance. Enable the definition and improvement of human spaceflight medical, environmental, and human system requirements.
  - Develop and demonstrate technologies that mitigate medical and environmental risks to the human system, reduce medical system resource requirements (mass, volume, power, data, etc.), and ensure effective crew health and performance integration across exploration mission systems.

## Autonomous Medical Officer Support (AMOS) Tech Demo – ISS Quick Start



- Crew used AMOS to perform ultrasound imaging of the bladder and kidneys, a complex imaging procedure, in **autonomous fashion with no preflight training and no support from the ground**
- **1<sup>st</sup> spaceflight performance** of fully autonomous, untrained imaging
- Major milestone in enabling medical capability for future exploration missions- could be used to streamline other procedures and reduce reliance on ground support for ongoing ISS missions
- Successfully collaborated with the ISS Program to develop a “quick-start” concept to use the ISS as an exploration analog to test progressively Earth-independent medical operations



## Medical Data Architecture (MDA) and Clinical Decision Support System (CDSS)

- **Executed MDA Test Bed 4** - exercise multiple layers of MDA/CDS functionality, illustrating the data pipeline from biosensor inputs to analysis and graphical visualizations to simple algorithms for proof-of-concept of CDS
- **MDA Architecture and Requirements recommendations delivered** to HRP and HHPD in July
  - Data architecture accepted as a critical component of an exploration CHP system
  - Working forward plan with HHPD, SCLT, and Gateway CHP System Manager to transition and progress MDA work
- **Authored CDSS ConOps** and received feedback from Dr. Tom Marshburn who felt that the “relevancy for space medicine is high”



# Human Factors & Behavioral Health (HFBP) Element Highlights



- **Participating Centers:** ARC, GRC, JSC
- **Mission:** The HFBP Element exists to characterize and mitigate the human factors and behavioral health and performance risks associated with the hazards of crewed spaceflight exploration missions, including isolation and confinement, exposure to deep space radiation, distance from earth, altered gravity fields, and hostile/closed environments.
- **Assigned Risks:** Behavioral Medicine, Sleep, Team, Human Systems Integration Architecture, and Occupant Protection
- **Objectives:**
  - Quantify the health and performance and human factors risks associated with human spaceflight exploration missions.
  - Develop countermeasures and technologies to prevent or mitigate adverse outcomes of human health and performance risks.
  - Develop methods and technologies to monitor and treat adverse outcomes of human health and performance risks.
  - Lead the development and execution of the CBS Integrated Research Plan which integrates tasks and deliverables across the HFBP, Space Radiation, and HHC.

## Hadron-Induced Impairment of Executive Function: Role of Perturbed Neurotransmission and the Exacerbating Impact of Sleep Deprivation.

Student Grant – (PI: Mayumi Machida; Dr. Britton's Lab)

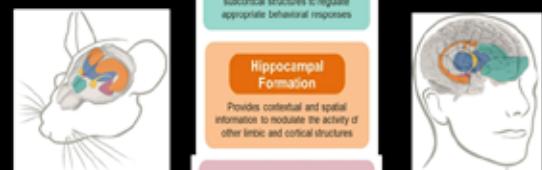
**Objective:** Develop the technical capability to simultaneously assess neural activity in multiple brain regions (neural network activity) of rats that are actively engaged in cognitive flexibility tasks.

### Return on Investment:

1. Developed a sequence recognition task – a touchscreen-based task known to activate the the corticolimbic (CLN) neural network: the hippocampus - amygdala – mPFC.
2. Established feasibility of obtaining high-quality LFP (local field potential) output data from, & quantifying coherence of activity across, the CLN nodes in actively performing rats.

### Relevance:

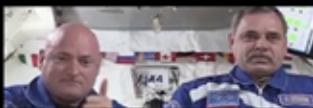
Consistent with CBS Integrated Risk Strategy, quantification of activity in Brain Performance Pathways during active performance of an operationally relevant task involving Executive Function. Provides model to characterize BMed risk of cognitive injury due to spaceflight hazards (induced by space radiation, isolation, confinement and altered gravity stressors).



Advances models for use of animals in Translational Research with BMed Risk in addressing potential synergistic impact of multiple spaceflight hazards.

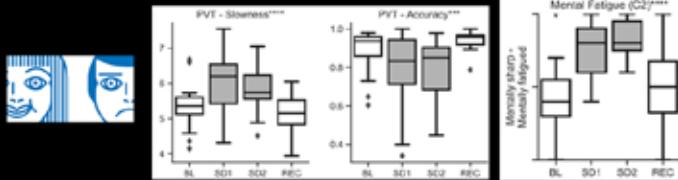
## Cognitive Performance During Confinement and Sleep Restriction in NASA's Human Exploration Research Analog (HERA) (PI: Basner)

- ❖ Sleep deprivation (~27h awake) and 1 day partial sleep restriction (~4h sleep) (Campaign 1)



- ❖ Reduced accuracy on facial emotion recognition test (both timepoints)

Operationally-relevant sleep restriction poses risk to attention and cognitive processing speed.



## Robust stability of trait-like vulnerability or resilience to common types of sleep deprivation in a large sample of adults (PI: Goel)

- ❖ Intra-person stability of neurocognitive responses to total sleep deprivation (36h awake) and partial sleep restriction (~3.5-4h nightly sleep over 5 days)
- ❖ Within-person PVT decrements robustly correlate with processing speed and working memory decrements

Neurocognitive risk/resilience to operationally-relevant sleep restriction and deprivation is a stable individual trait. Implications for predicting individual risk and personalizing fatigue management.

# Human Health Countermeasures (HHC) Element Highlights



- **Participating Centers:** ARC, JSC, GRC, KSC
- **Mission:**
  - Investigate and mitigate the highest exploration risks to astronaut health and performance.
  - Focus research questions on topics highly relevant to NASA's future activities.
- **Assigned Risks:** SANS, Food and Nutrition, CVD, Immune, Microhost, EVA, SM, ExATM, DCS, Fracture, Muscle, Aerobic
- **Objective:** Develop an integrated suite of physiological countermeasures for exploration missions that ensure the maintenance of crew health during all phases of the mission targeting human physiologic and required performance capabilities at risk from space flight missions.

### Cardio Ox Flight Study

Lee et al., *J. Appl. Physiol.*, 129:108-123, 2020. (IF = 3.14)

The Cardio Ox team recently reported that biomarkers of oxidative stress (e.g., oxidized LDL [ $\uparrow 25\%$ ], myeloperoxidase [ $\uparrow 75\%$ ]) and inflammation (TNF $\alpha$  [ $\uparrow 50\%$ ], VEGF-1 [ $\uparrow 85\%$ ]) in blood and urine were increased during spaceflight but, contrary to previous reports, ultrasound-derived indices of cardiovascular disease risk (i.e., cIMT, carotid stiffness) measured during and after spaceflight were not changed. Similarly, there was no clear effect of spaceflight on endothelial function measured after landing when most biomarkers of oxidative stress and inflammation had returned to their preflight levels. These astronauts will be followed for up to five years after their respective landings to determine if vascular changes are manifest during recovery from spaceflight.

*Forward work:* Determine if missions duration and exposure to deep space radiation augments the oxidative stress and damage effects as well as structural and functional health outcomes.

<https://doi.org/10.1152/japplphysiol.00550.2019>

### Vestibular-Cardiovascular Interaction

Desphande et al., *Aerospace Med. Hum. Perform.* 91:621-27, 2020 (IF = 0.889)

ISS subjects (n=13, Functional Task Test) experienced significant pre-to-post differences in postural control as well as in heart rate (HR) and blood pressure (BP) during prone-to-stand test. The novel finding was that these changes in postural stability (especially during dynamic head tilts) were significantly correlated to changes in HR and BP.

Pre-to-Postflight Change in HR (beats/min)	Pre-to-Postflight Change in SDT (%)
200	-100
250	-80
300	-60
350	-40
400	-20
450	0
500	20
550	40
600	60

Subjects who were less stable post-flight (lower "equilibrium" scores) experienced smaller HR increases when moving from the prone to standing position. Alternatively, the greater HR response in those who were more stable may reflect a greater vestibulo-sympathetic response during the an orthostatic challenge.



# Space Radiation (SR) Element Highlights

- **Participating Centers:** JSC, LaRC, ARC, GRC
- **Mission:** To ensure that crewmembers can safely live and work in space without exceeding acceptable radiation health risks.
- **Assigned Risks:** Cancer, Acute (also HHC/Cardio, HFBP/BMed)
- **Objectives:**
  - Ensure that NASA can safely live and work in the space radiation environment in support of current missions and enabling future exploration missions.
  - Perform radiobiological and physics research necessary to develop and validate human health standards.
  - Develop scientific basis to accurately quantify and mitigate health and performance risks from exposure to the space radiation environment.
  - Provide the data, computational tools, and methodologies required to evaluate protection strategies and accurately project risk.

## Particle radiation-induced dysregulation of protein homeostasis in primary human and mouse neuronal cells (PI: P Chang)

**RELEVANCE:** H, Si, or Fe-irradiation of mouse and human neuronal cell organoids show LET-dependent dysregulation of the ubiquitin-mediated protein targeting and damaged protein degradation system that may underlie memory impairment and late neurodegeneration.

- Three branches of the ubiquitin-based protein homeostasis system (K48, K11 & K63) were interrogated in neurospheres by LC-Mass spectrometry proteomics.
- Damaged protein recycling (K48) and intracellular receptor trafficking (K63) systems were dysregulated as a function of ion and cell type in mouse and human neurospheres as reported by increased levels of specific ubiquitin conjugates.
- Mouse striatum (cognition, voluntary movement) cells were prominently affected unlike cortical and mesencephalon (brain stem)-derived cells.
- Selected neural stem cell, DNA damage repair, and redox response markers were also elevated in irradiated cultures.

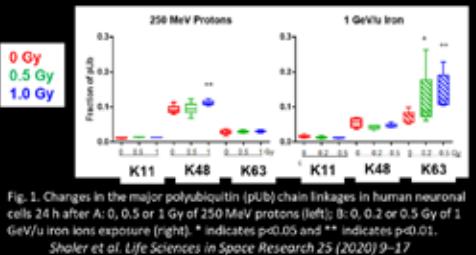


Fig. 1. Changes in the major polyubiquitin (pUb) chain linkages in human neuronal cells 24 h after A: 0, 0.5 or 1 Gy of 250 MeV protons (left); B: 0, 0.2 or 0.5 Gy of 1 GeV/u iron-ions exposure (right). \* indicates p<0.05 and \*\* indicates p<0.01.

Shaler et al. *Life Sciences in Space Research* 25 (2020) 9–17

## Genomic mapping in outbred mice reveals overlap in genetic susceptibility for HZE ion and $\gamma$ -ray induced tumors. PI: M. Weil – Colorado State University Fort Collins

**RELEVANCE:** Outbred mice irradiated to predicted carcinogenic saturation for  $\gamma$ -rays (3 Gy) or HZE ions (0.4 Gy) illuminate important differences in population and individual radiation risk assessment.

- Similar tumor spectrum and metastatic rate between all groups at population level as well as similar decreases in tumor latency following both radiation types suggests using epidemiological data from photon irradiated cohorts is valid for population risk estimation.
- Genetic background was primary component in determining radiation-induced histological tumor type, not radiation type. High incidence of specific tumor types within some families and not at all in others indicate **inherited susceptibility**.
- Identified susceptibility loci for specific tumor types shared by exposure types (e.g. thyroid adenoma, Harderian gland\*) or specific to HZE (Harderian gland\*)
- Increased risk in female mice due to loss of survival advantage following exposure unrelated to lung tumorigenesis.

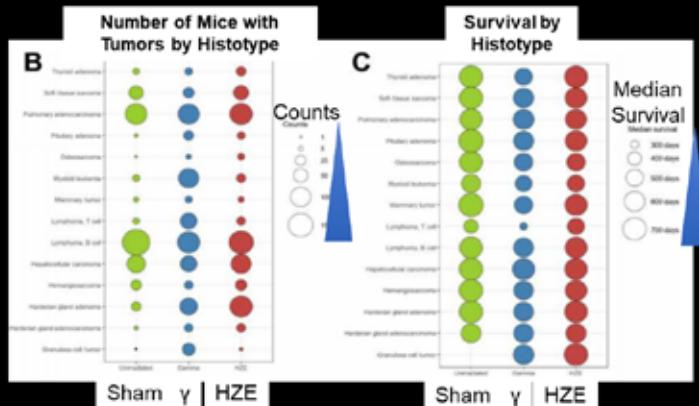


Fig. 1B,C. Comparison of HZE ion and  $\gamma$ -ray exposures on survival and tumor incidence in genetically diverse mouse populations.

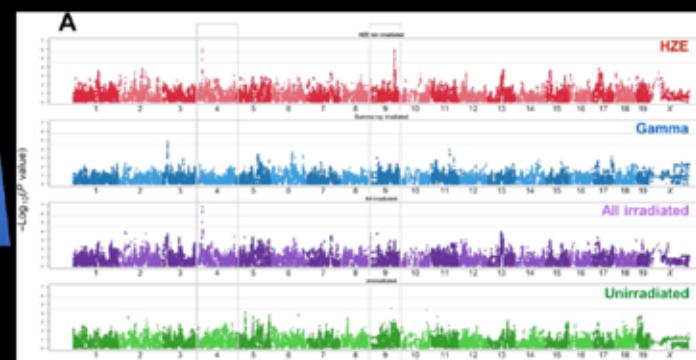


Fig. 4A. Genome-wide associations for Harderian gland adenocarcinomas identify QTL common to both irradiation groups and specific to HZE exposures.

Edmonson EF, et. al. *Sci Adv.* 2020 Apr; 6 (16): eaax5940.

## Mitigation of helium-irradiation-induced brain injury by microglia depletion (PI: Limoli)

**RELEVANCE:** Confirms and extends countermeasure approach using a microglia-depleting agent PLX5622 to protect against charged-particle induced cognitive impairment, neuronal structure and electro-physiological changes in mice

- The CSF-1R antagonist, PLX5622, depletes microglia from brain within ~ 3 days following oral administration without cognitive side effects.
- After 30 cGy whole body helium irradiation (400 MeV/n) PLX was administered chronically beginning 2 weeks post irradiation.
- Several cognitive, anxiety, depression tests were administered ~ 30 days post irradiation. PLX ameliorated radiation-induced impairments in memory tests but not anxiety & depression measures, nor most neuron morphological or electrophysiological features.
- Confirms previous studies by Rosi et al. that temporary post irradiation administration of agent can mitigate radiation-associate CNS impacts.

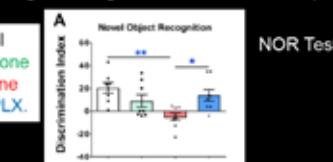


Fig. 2 Treatment with PLX5622 mitigates  ${}^4\text{He}$  irradiation-induced cognitive dysfunction shown here in Novel Object Recognition test. Data are mean  $\pm$  SEM (n = 8/group). P values two-way ANOVA. \*p < 0.05 and \*\*p < 0.01 versus 30 cGy w/ control chow.

Allen et al. (2020) *J Neuroinflammation* 17: 159.

# Translational Research Institute for Space Health (TRISH)

**Mission:** To lead a national effort in translating cutting edge emerging terrestrial biomedical research and technology development into applied space flight human risk mitigation strategies for exploration missions.



## TRISH: *Funding human health research for space.*

Partnering with NASA through a cooperative agreement, TRISH funds transformative human health technologies to predict, protect, and preserve astronaut physical and mental wellness during deep space exploration missions. We fund high-risk, high-reward, human health and performance solutions that can be adapted for use in space. Focused on early stage (proof of concept) and late stage (market-ready) research, TRISH stands apart from other funding organizations due to our high-risk tolerance, our flexible grant mechanisms, and our ability to connect researchers with NASA scientists and space analogs.

## The Ambidextrous Organization

- Corporate executives must constantly look backward, attending to the products and processes of the past, while also gazing forward, preparing for the innovations that will define the future. This mental balancing act is one of the toughest of all managerial challenges—it requires executives to explore new opportunities even as they work diligently to exploit existing capabilities ...
- [Successful ambidextrous] organizations separate their new, exploratory units from their traditional, exploitative ones, allowing them to have different processes, structures, and cultures; at the same time, they maintain tight links across units at the senior executive level.
- Such [organizations] allow executives to pioneer radical or disruptive innovations while also pursuing incremental gains.
- Almost every company needs to renew itself through the creation of breakthrough products and processes, but it shouldn't do so at the expense of its traditional business.

# TRISH Radiation Solicitation (TSRAD2020) Selections



This model uses normal human cells derived from single donor blood samples. Cells are de-differentiated into inducible pluripotent stem cells that can then be differentiated and made to form into variety of human organs on a chip. Bioengineering can mimic physiological and anatomical features of the target tissue (e.g., lung organoids can transport oxygen and carbon dioxide).

- First time that normal human cells/organoids will be exposed to simulated Mars-mission relevant space radiation
- Novel human model for radiation countermeasure testing
- Ability to compare radiation sensitivity and countermeasures responsiveness from different donors
  - Implication: One could personalize radiation countermeasures for each Mars astronaut
- Ability to compare radiation sensitivity across different human organ systems and effectiveness of countermeasures
- TSRAD projects collectively compare across different organ/cell types and conditions to find optimal settings
- TSRAD projects collectively represent several of the radiation sensitive organs and tissues of greatest concern for deep space

All data generated will be integrated into a data matrix model that will be used to build a sensitivity profile for each "astronaut avatar on a chip"

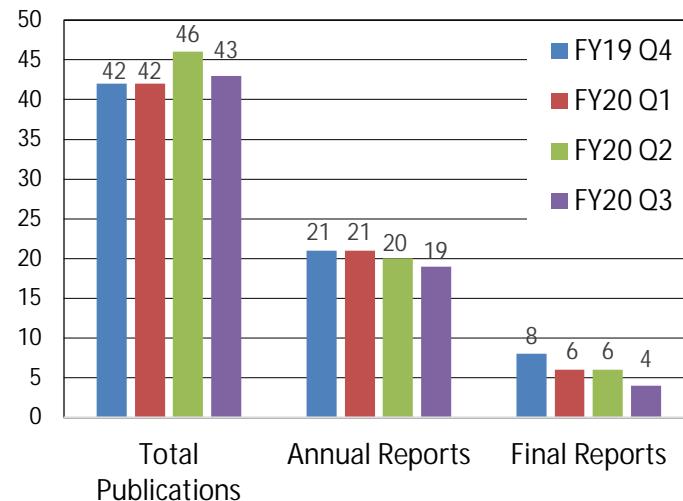
1. **Michael Weil, Ph.D.**; Colorado State University, Colorado  
*Effects of chronic high LET radiation on the human heart*
  - **Tissue Chip**. Complex cardiac model (both sexes); iPSC, deep dive on single organ model; peptide nucleic acid therapeutics, single-cell sequencing
2. **Gordana Vunjak-Novakovic, Ph.D.**; Columbia University, New York  
*Human multi-tissue platform to study effects of space radiation and countermeasures*
  - **Tissue Chip**. BM-liver-cardiac-vascular-immune linked system (both sexes); iPSC; nanoparticle drug delivery; circulating innate immune
3. **Sharon Gerecht, Ph.D.**; Johns Hopkins University, Maryland  
*Using human stem-cell derived vascular, neural and cardiac 3D tissues to determine countermeasures for radiation*
  - **Tissue Chip**. Vascular-cerebrovascular-cardiovascular; iPSC; modeling; inflammation emphasis, optogenetics, modular block for GCR, phantom modeling
4. **Sarah Blutt, Ph.D.**; Baylor College of Medicine, Texas  
*Use of Microbial Based Countermeasures to Mitigate Radiation Induced Intestinal Damage*
  - **Organoid**. GI; crypt stem cells; iPSC, deep dive on single organ model; supports microbial populations, crypt stem cell function, engineered microbes to enhance stem cell regeneration
5. **Mirjana Maletic-Savatic, M.D., Ph.D.**; Baylor College of Medicine, Texas  
*Counteracting space radiation by targeting neurogenesis in a human brain organoid model*
  - **Organoid**. Cerebral organoids (including microglia), neurogenesis, deep dive on single organ model; strongest brain model...neural stem cell renewal, strongest immune and inflammation proposal, microglia, electrical stimulation



# HRP Publication Metrics (7/1/2019 – 6/30/2020)



## Number of Publications



## HRP-funded research (FY20)

**224** Research Grants

**182** Principal Investigators

**108** Institutions in **26** states

Of the **224** Grants Awarded:

NASA – 38 (17%)

Academia – 143 (64%)

Other – 43 (19%)

## High-Impact Factor Publications – JIF > 9

1. Nangle SN, Wolfson MY, Hartsough L, Ma NJ, Mason CE, Merighi M, et al. The case for biotech on Mars. *Nat Biotechnol*. 2020 Apr;38(4):401–7.
2. Mishra B, Luderer U. Reproductive hazards of space travel in women and men. *Nat Rev Endocrinol*. 2019 Dec;15(12):713–30.
3. Fu Q, Shibata S, Hastings JL, Platts SH, Hamilton DM, Bungo MW, et al. Impact of Prolonged Spaceflight on Orthostatic Tolerance During Ambulation, and Blood Pressure Profiles in Astronauts. *Circulation*. 2019 Aug;140(9):729–38.
4. Frings-Meuthen P, Luchitskaya E, Jordan J, Tank J, Lichtinghagen R, Smith SM, Heer M. Natriuretic Peptide Resetting in Astronauts. *Circulation*. MAY 2020;141(19):1593–1595.
5. Edmondson EF, Gatti DM, Ray FA, Garcia EL, Fallgren CM, Kamstock DA, et al. Genomic mapping in outbred mice reveals overlap in genetic susceptibility for HZE ion- and  $\gamma$ -ray-induced tumors. *Sci Adv*. 2020 Apr;6(16).
6. Liu H, Begik O, Lucas MC, Ramirez JM, Mason CE, Wiener D, et al. Accurate detection of m6A RNA modifications in native RNA sequences. *Nat Commun*. 2019 Sep;10(1):4079.
7. Daley JM, Tomimatsu N, Hooks G, Wang W, Miller AS, Xue X, et al. Specificity of end resection pathways for double-strand break regions containing ribonucleotides and base lesions. *Nat Commun*. 2020 Jun;11(1):3088.
8. Noohi F, Kinnaird C, De Dios Y, Kofman I, Wood SJ, Bloomberg JJ, et al. Deactivation of somatosensory and visual cortices during vestibular stimulation is associated with older age and poorer balance. *PLoS ONE*. 2019 Sep;14(9).
9. Nelson ES, Myers JG Jr, Lewandowski BE, Ethier CR, Samuels BC. Acute effects of posture on intraocular pressure. *PLoS ONE*. 2020 Feb 6;15(2).
10. Robinson E, McKenna MJ, Bedford JS, Goodwin EH, Cornforth MN, Bailey SM, et al. Directional Genomic Hybridization (dGH) for Detection of Intrachromosomal Rearrangements. *Methods Mol Biol*. 2019 Jul;1984:107–16.
11. Banks S, Landon LB, Dorrian J, Waggoner LB, Centofanti SA, Roma PG, Van Dongen HPA. “Effects of Fatigue on Teams and Their Role in 24/7 Operations.” *Sleep Medicine Reviews* 48 (September 28, 2019): 101216.
12. Urbaniak C, Lorenzi H, Thissen J, Jaing C, Crucian B, Sams C, Pierson D, Venkateswaran K, Mehta. The influence of spaceflight on the astronaut salivary microbiome and the search for a microbiome biomarker for viral reactivation. *Microbiome*. 2020 Apr 20;8(1):56.
13. Silverman JD, Durand HK, Bloom RJ, Mukherjee S, David LA. “Dynamic linear models guide design and analysis of microbiota studies within artificial human guts.” *Microbiome*. 2018 Nov 12;6(1):202.
14. Ortega SB, Torres VO, Latchney SE, Whoolery CW, Noorbhai IZ, Poinsatte K, et al. B cells migrate into remote brain areas and support neurogenesis and functional recovery after focal stroke in mice. *PNAS*. 2020 Mar;117(9):4983–93.

A total of 36 publications had a JIF > 5

# Insight on Coordination with BPS



## Space Biology will continue to be an important partner to HRP

- Microbiome (crew and environment), plants (crops, psychological support), gravity as a continuum
- Genelab as a repository, Tissue Chip validation, pharmaceutical testing, ...

## We share investigators, partners, and platforms

## We continue to have regular discussions

- Seeking synergies
- Coordinating needs and interests
- Jointly soliciting/funding projects



# Trends, Forecasting Science Directions in the Community



## Autonomous Medical Operations

- Severe mass, power, volume, communication delays/restrictions; no resupply; 4 crewmembers
- Health monitoring, diagnostic capabilities, therapeutic capabilities; in situ analysis, pharmaceuticals, medical disposables, ...

## Behavioral Health and Performance in a Distant, Austere Environment

- Characterize and monitor operationally-relevant changes in individual and team behavior and performance; understand potential neuro-physiological underpinnings
- Countermeasures—team skills and task training protocols, sensory stimulation, environmental enrichment, social support
- Human Systems Integration throughout systems development, including adaptive technologies and cognitive aids

## Radiation Effects

- Translation of results from rodents to humans
- Countermeasures—pharmaceuticals, nutraceuticals, synergies with other stress responses?

## Physiological Effects

- SANS, nutrition, immune function/interactions with microbiome, monitoring, intervention, atmospheric composition
- Countermeasures—exercise, fluid shifting capabilities, pharmaceuticals, nutraceuticals, synergies with other stress responses?

## Synergistic Effects of Multiple Stressors

## Unknown Unknowns



# Challenges of Interest for the Decadal Survey



## HRP R&T Investment Priority Drivers

- Risk Color (HSRB)
- Scientific/technical challenge
- Need date (exploration schedules)
- Facility availability (ISS, HERA, NEK, enviHab, NSRL, Antarctic Stations, Parabolic Flight...)
- Budget availability (OMB, Congress, HEOMD)

## Areas of direct focus for HRP by Decadal Survey

- Insight into novel approaches, analog populations, research communities, etc. would be welcomed and valued

## Space Biology is an important partner to HRP (fundamental science, mechanisms, maturation)

- Microbiome (crew and environment), plants (crops, psychological support), gravity as a continuum
- Genelab as a repository, Tissue Chip validation, pharmaceutical testing, ...
- This synergistic relationship could be bolstered by recommendations in the Decadal Survey



# Discussion and Q&A



