Human Research Gaps for Moon and Mars



Steering Committee for a Science Strategy
for the Human Exploration of Mars

David Baumann
Director, Human Research Program
April 25, 2024

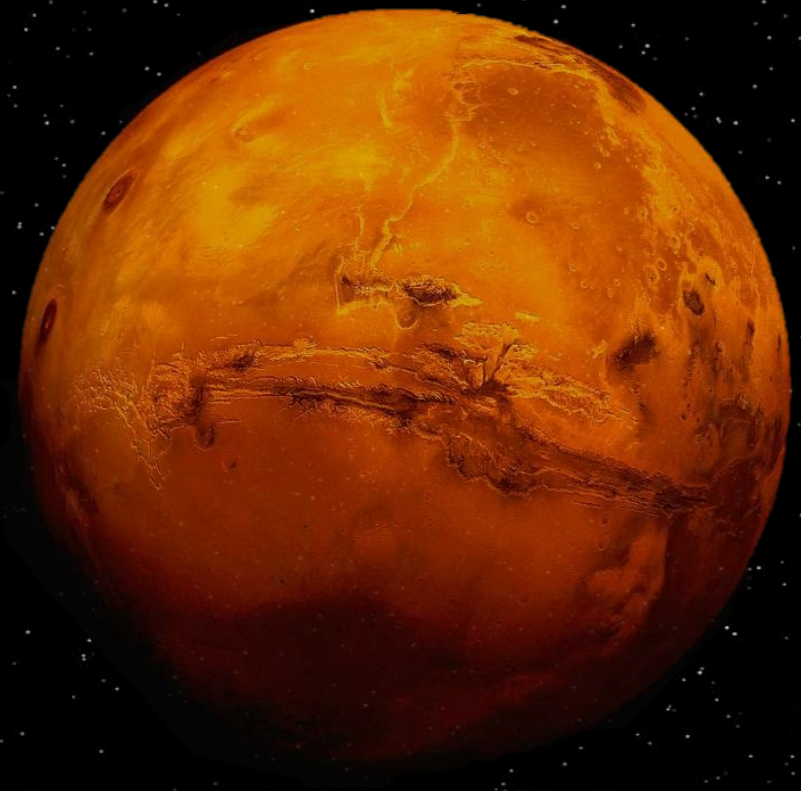


HRP Presentation to the NAS

- HRP Overview
- Lunar and Mars Gaps
- Research to Get to Mars
- Research to Do on Mars

Human Research Program Mission

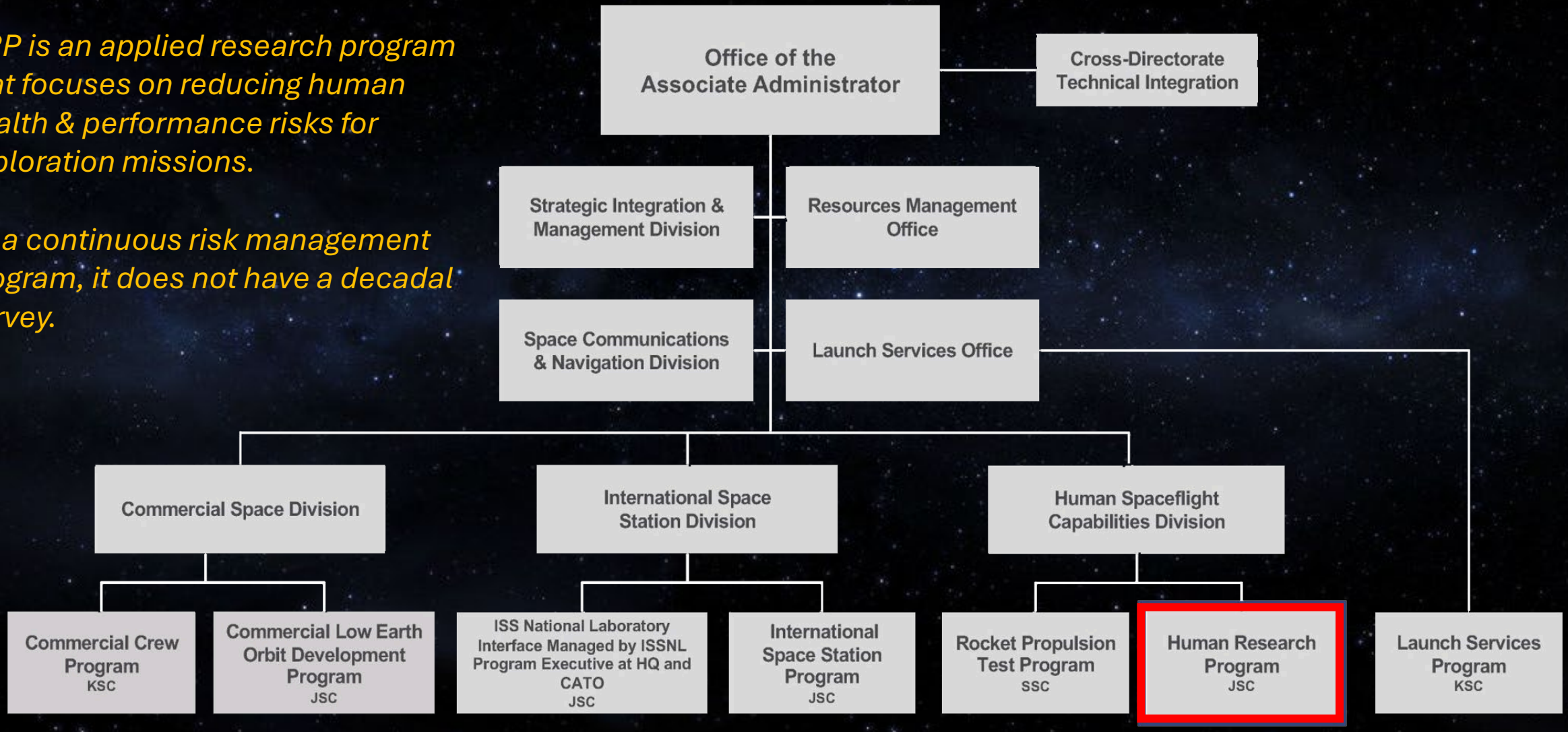
To enable space exploration beyond low Earth orbit by reducing the risks to human health & performance



Space Operations Mission Directorate

HRP is an applied research program that focuses on reducing human health & performance risks for exploration missions.

As a continuous risk management program, it does not have a decadal survey.



HRP Elements Overview



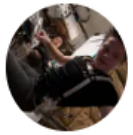
Exploration Medical Capability

Pushes the boundary of space medical systems to help take care of current and future astronauts.



Human Factors and Behavioral Performance

Characterizes and manages behavioral health effects of long-duration space missions



Human Health Countermeasures

Assesses the effects spaceflight has on the human body and develops safeguards to deal with those changes.



Space Radiation

Ensures that crewmembers can safely live and work in space without exceeding acceptable radiation health risks.



Research Operations and Integration

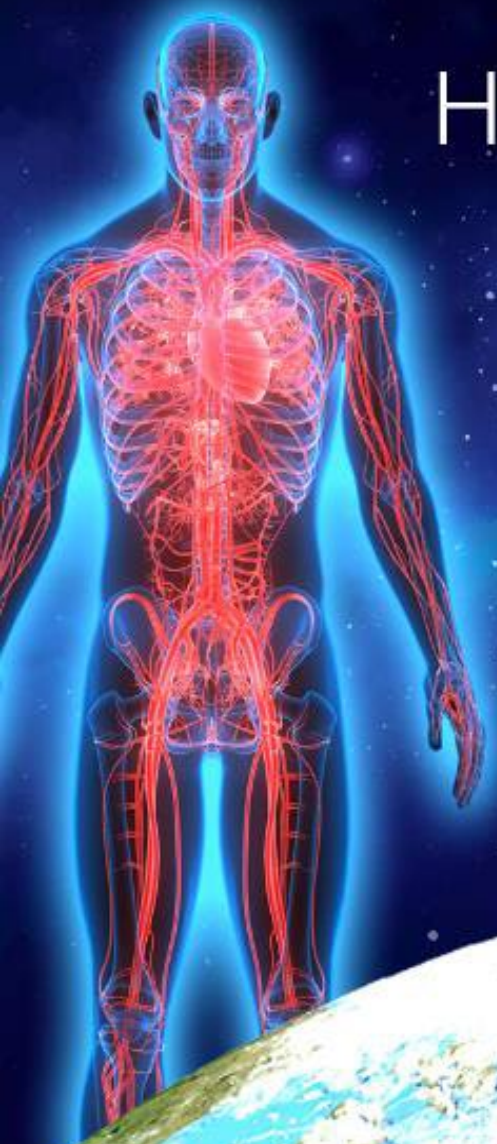
Plans, integrates, and implements services for HRP research in Earth-based simulations, the International Space Station, and other platforms.

National Aeronautics and Space Administration

NASA

Human Research Program

STEPS TO MARS



EARTH:

Simulated spaceflight hazards in Ground Analogs | :envihab | Antarctic Stations | NEK | HERA | Space Radiation Lab

LOW EARTH ORBIT:

International Space Station – A unique testbed to study micro-gravity and environment hazards, with varying mission durations

LUNAR MISSIONS:

Decreasing Earth-dependence around and on the lunar surface. Provides insight into deep space radiation, behavioral health, and gravity transitions

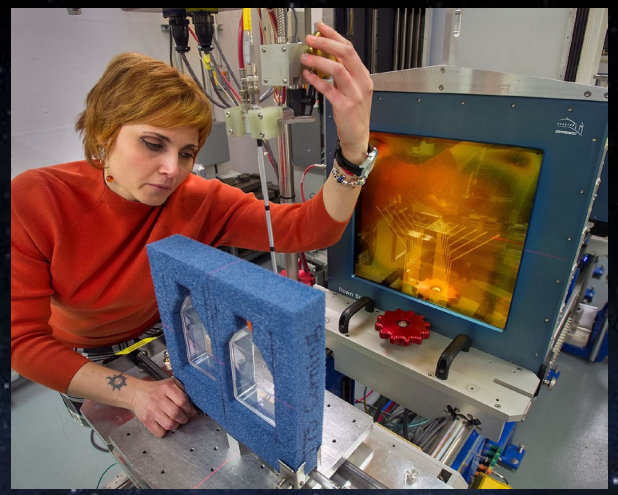


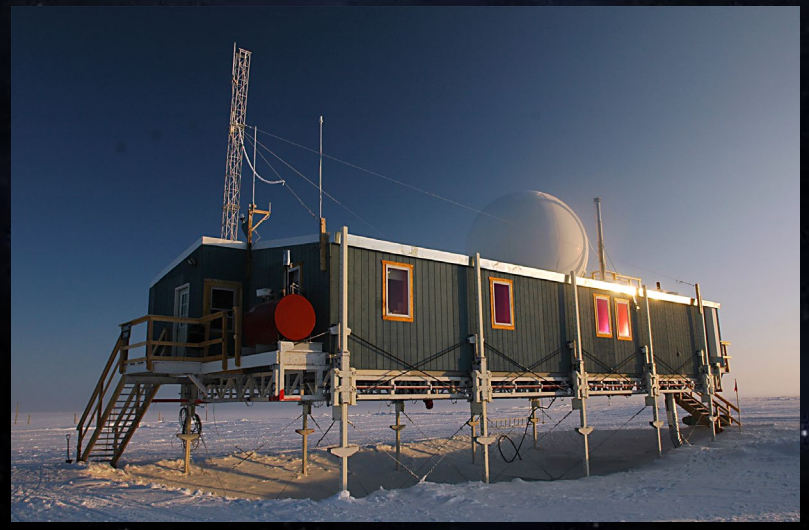


Steps to Mars: Ground Analogs













Steps to Mars: LEO Spaceflight Missions

Increment 69



Mar 2023 to Sep 2023

Increment 70



Sep 2023 to April 2024

Frank Rubio



>1 year in space
Sep 2022 – Sep 2023

Steps to Mars: Commercial Space Missions

SpaceX Inspiration4



September 16-18, 2021

Axiom 2



May 21 – May 31, 2023

Axiom 3



Jan 18 – Feb 9, 2024

Steps to Mars: Commercial LEO Destination Partners











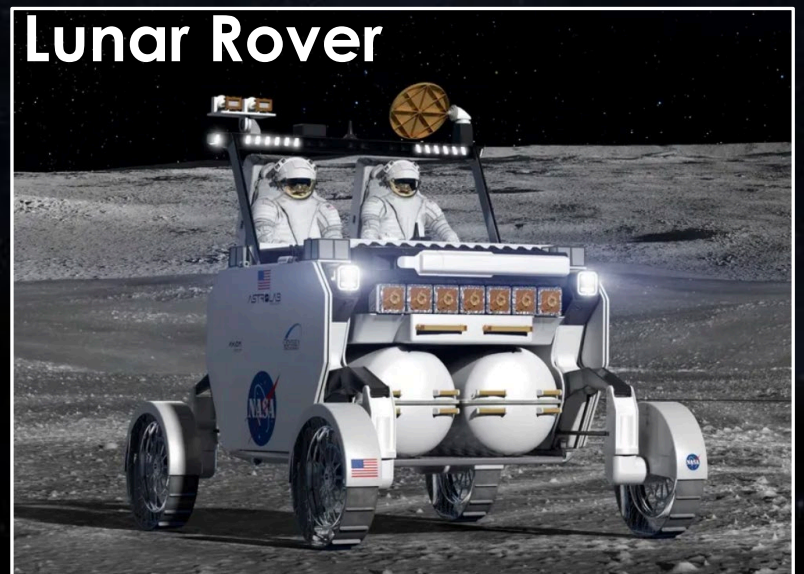


Steps to Mars: Artemis









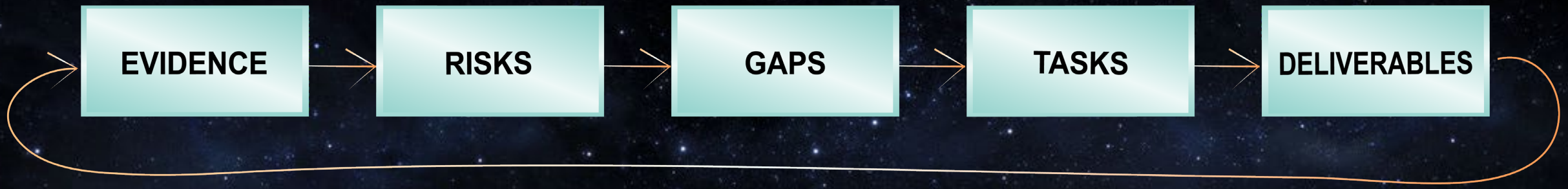


Human Research Roadmap

https://humanresearchroadmap.nasa.gov/

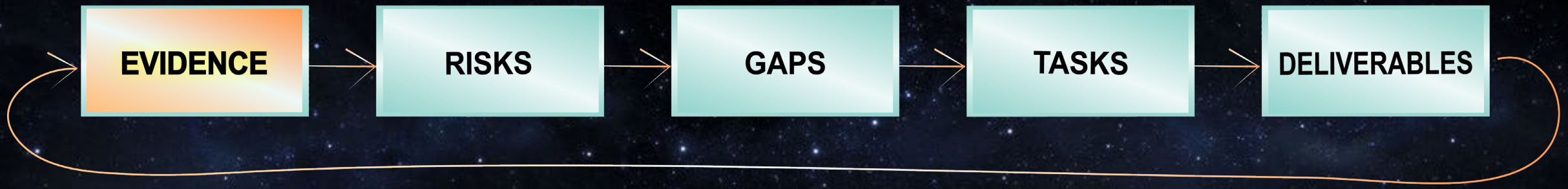


HRP's Applied Research Program Architecture



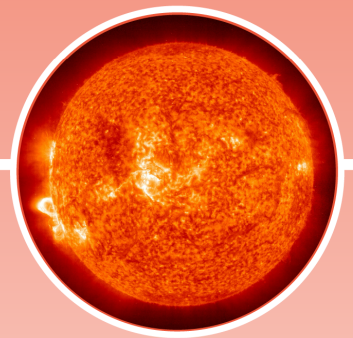
Continuous Risk Management

HRP's Applied Research Program Architecture



Continuous Risk Management

Evidence: Hazards and Risks of Human Spaceflight



Space Radiation

- Radiation Carcinogenesis
- Non-Ionizing Radiation



Isolation & Confinement

- Inadequate psychosocial adaptation within a team
- Adverse cognitive or behavioral conditions



Distance from Earth

- Inflight medial conditions
- Inadequate human systems integration architecture
- Inadequate food and nutrition
- Ineffective or toxic medications



Lack of Gravity

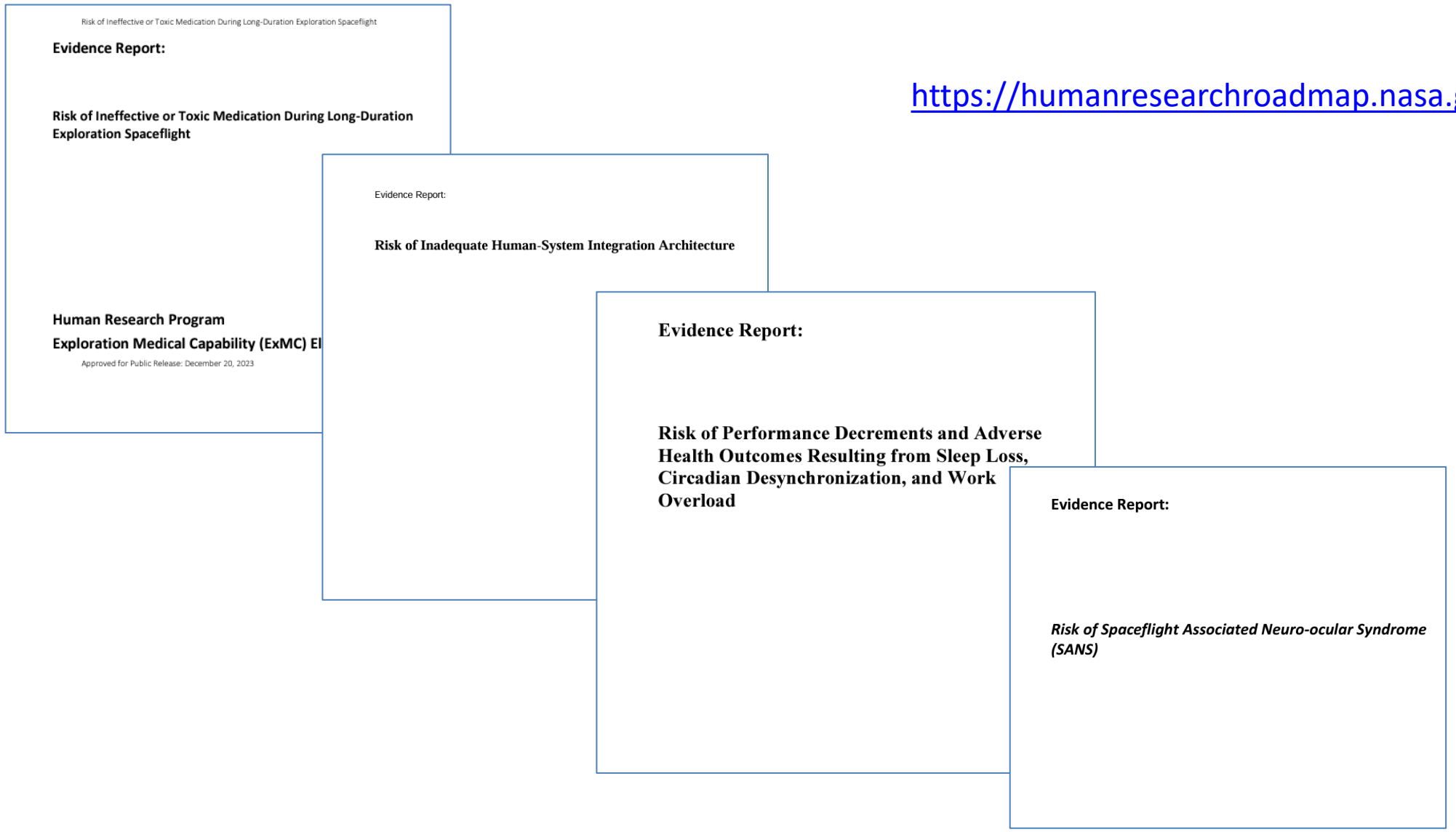
- Reduced muscle size
- Bone fracture
- Sensorimotor alterations
- Host-microorganisms interactions
- Orthostatic intolerance
- Cardiac rhythm problems
- Renal stone formations
- Reduced aerobic capacity
- Cardiovascular adaptions
- Urinary retention
- Crew egress
- SANS



Hostile/Closed Environment

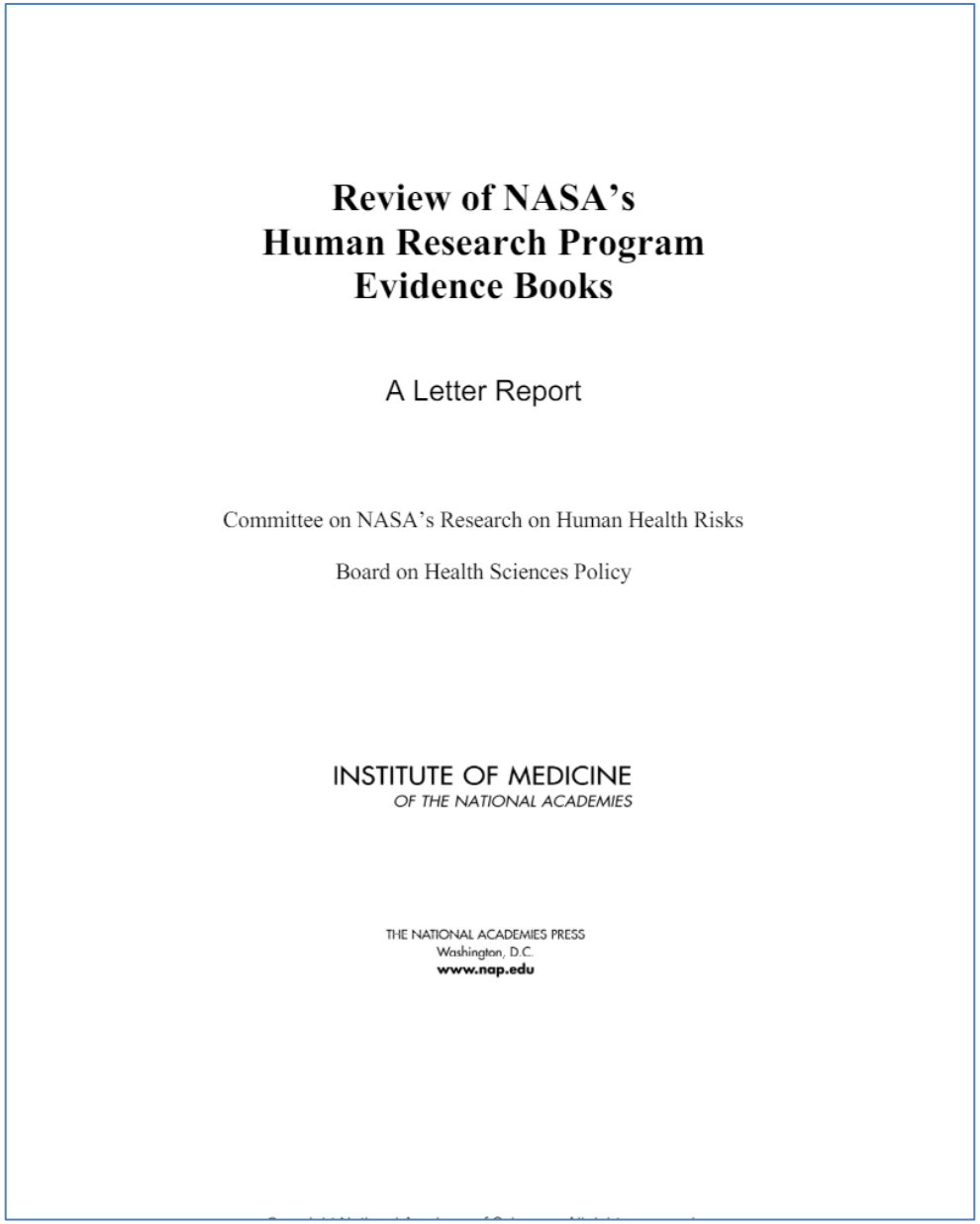
- Toxic exposure
- Hypoxia
- Decompression sickness
- Celestrial dust exposure
- Carbon dioxide exposure
- Electrical shock
- Sleep loss
- Hearing loss
- Altered immune response
- Reduced EVA performance
- Injury from dynamic loads

HRP Evidence Reports for Individual Risks (Examples)



https://humanresearchroadmap.nasa.gov/Evidence/

Institute of Medicine
Review of HRP Evidence Reports in starting in 2008



Review of NASA's Human Research Program Evidence Books

A Letter Report

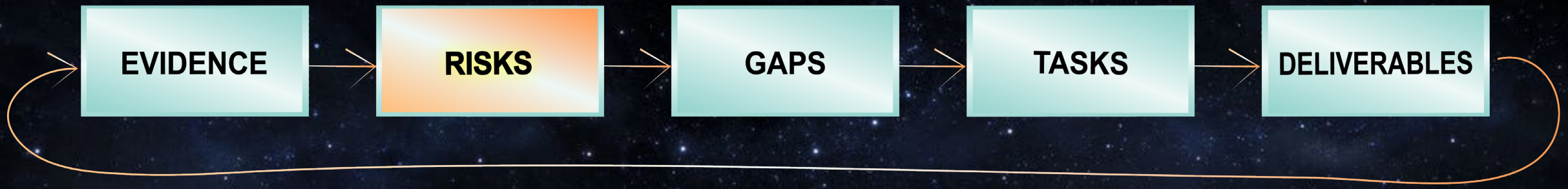
Committee on NASA's Research on Human Health Risks

Board on Health Sciences Policy

INSTITUTE OF MEDICINE
OF THE NATIONAL ACADEMIES

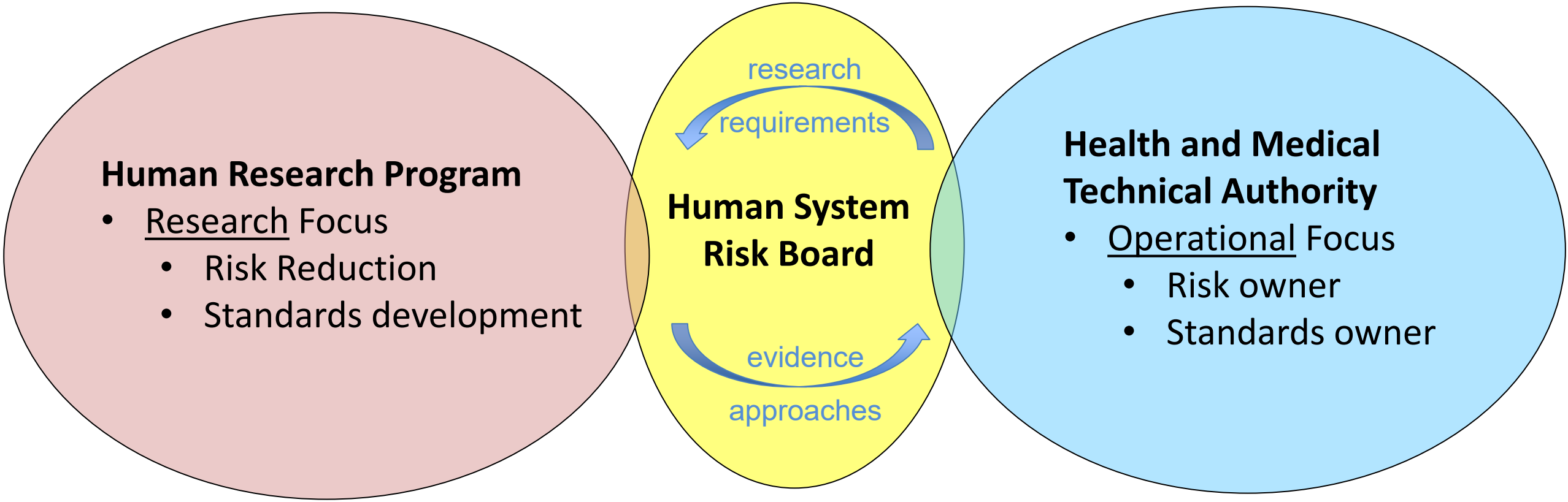
THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

HRP's Applied Research Program Architecture



Continuous Risk Management

Continuous Risk Management for the Human System
Human System Risk Board (HSRB)



HSRB Risk Ratings (HRP "requirements")



High Priority Mitigation target

Medium Priority Mitigation target

Low Priority Mitigation target


P.S.I.


P.S.I.

Mars Path to Risk Reduction

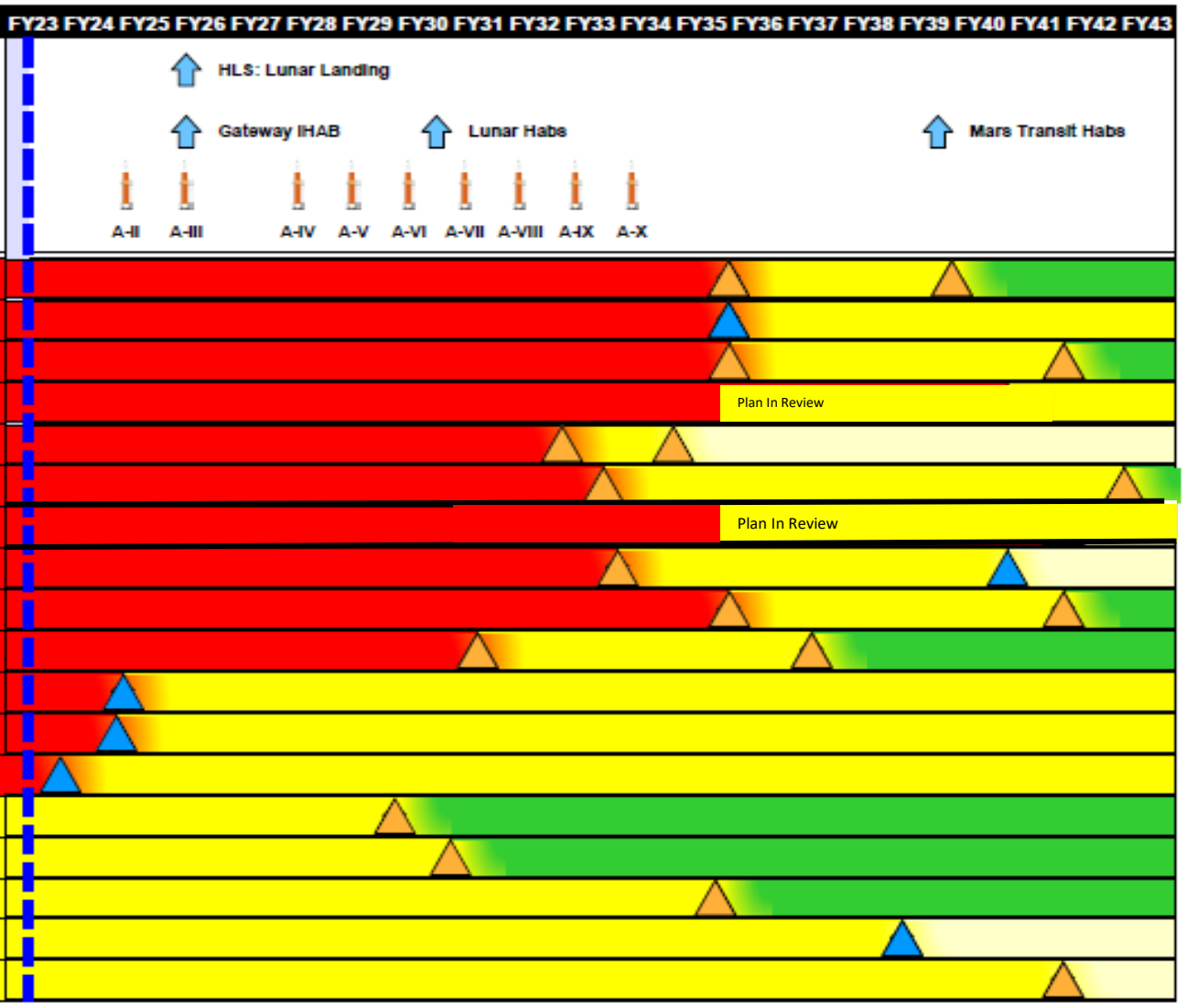
High Priority

Medium Priority

Low Priority

HRP Mars iPRR PPBE25 BASELINED

Unique ID	Exploration DRMs / Exploration Mission Milestones (HRP Delivery Dates) / RISKS	Artemis Launche LxC
1	Spaceflight Associated Neuro-ocular Syndrome (HHC-SANS)	3x4
2	Celestial Dust Exposure (ExMC-Dust)	4x4 *
3	Cardiovascular Adaptations (HHC-Cardiovascular)	4x4 *
4	Cognitive or Behavioral Conditions (HFBP-BMed)	5x3 *
5	Injury from Dynamic Loads (HFBP-Dynamic Loads)	3x4
6	Bone Fracture (HHC-Bone Fracture)	4x4 *
7	Team Performance Decrements (HFBP-Team)	3x4
8	Human Systems Integration Architecture (HFBP-HSIA)	5x3 *
9	Injury Due to EVA Operations (HHC-EVA)	3x4
10	Inadequate Food and Nutrition (HHC-Food and Nutition)	3x4
11	Medical Conditions In-Mission Long Term Health (ExMC-Medical Conditions)	5x4 *
12	Ineffective or Toxic Medications (ExMC-Pharm)	5X3*
13	Renal Stone Formation (ExMC-Renal Stone)	4x4*
14	Altered Immune Response (HHC-Immune)	3x3
15	Host-Microorganism Interactions (HHC-Microhost)	3x3
16	Vestibular Sensorimotor Impacts (HHC-Sensorimotor)	4x2 *
17	Space Radiation Carcinogenesis (SR-Carcinogenesis)	3x3
18	Sleep Loss and Circadian Misalignment (HFBP-Sleep)	3x3



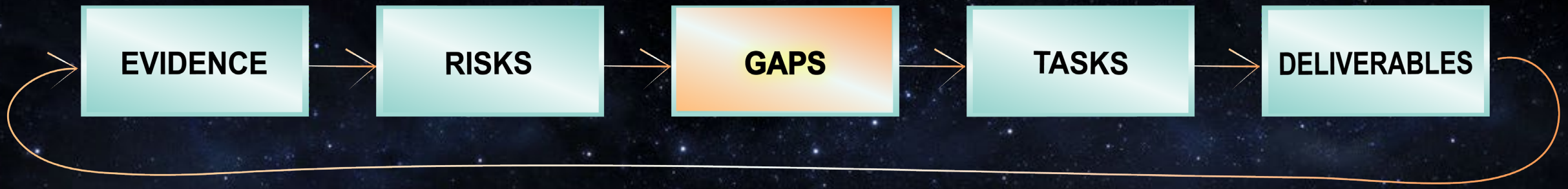
Risk Class: ISS Required
Completed (PRR-Color Change) Shift
Optimized
Risk Class: ISS Not Required
High LxC
Insufficent Data
* (Asterisk) Updated to New HSRB LxC 5x5 Scale

Milestone: Requires LEO Platform
Mid LxC: Requires Mitigation
Exploration Mission Milestone

Ground Based: Milestone
Mid LxC: Accepted
Mission Date

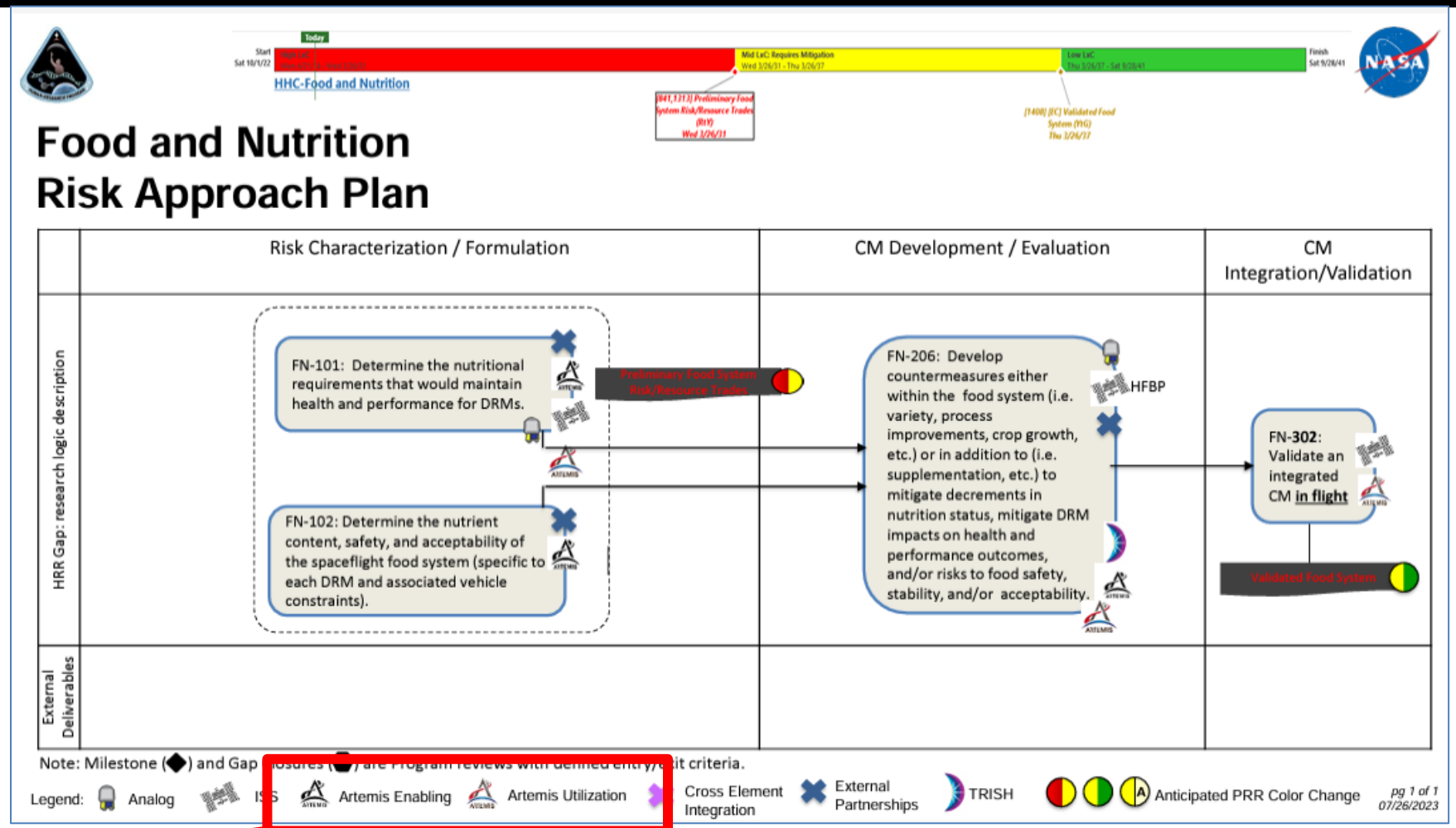
Anticipated (PRR-Color Change) Shift
Low LxC

HRP's Applied Research Program Architecture



Continuous Risk Management

Decomposition of Human Health Risks into Research Gaps



Artemis Enabling Artemis Utilization

Artemis Enabling = Lunar Gaps
Artemis Utilization = Mars Gaps

Top Crew Health and Performance System Capability Gaps for Mars



Earth-Independent Human Operations



Mars Duration Food System



Mars Duration Effects on Human Physiology



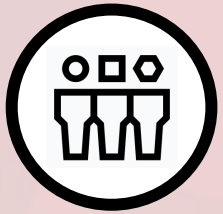
Risk Mitigations for Vehicle Atmospheres



Computational Injury & Anthropometric Models



Exploration Exercise Countermeasures

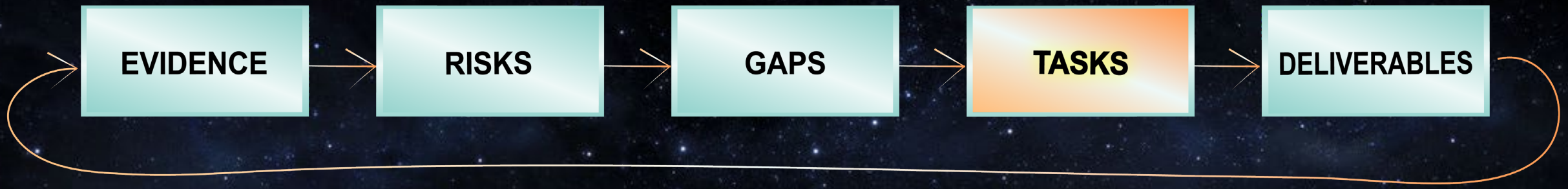


Understanding Individual Variability in Spaceflight



Sensorimotor Countermeasures

HRP's Applied Research Program Architecture



Continuous Risk Management

Top Crew Health and Performance System Capability Gaps for Mars

Earth-Independent Human Operations

Mars Duration Food System

Mars Duration Effects on Human Physiology

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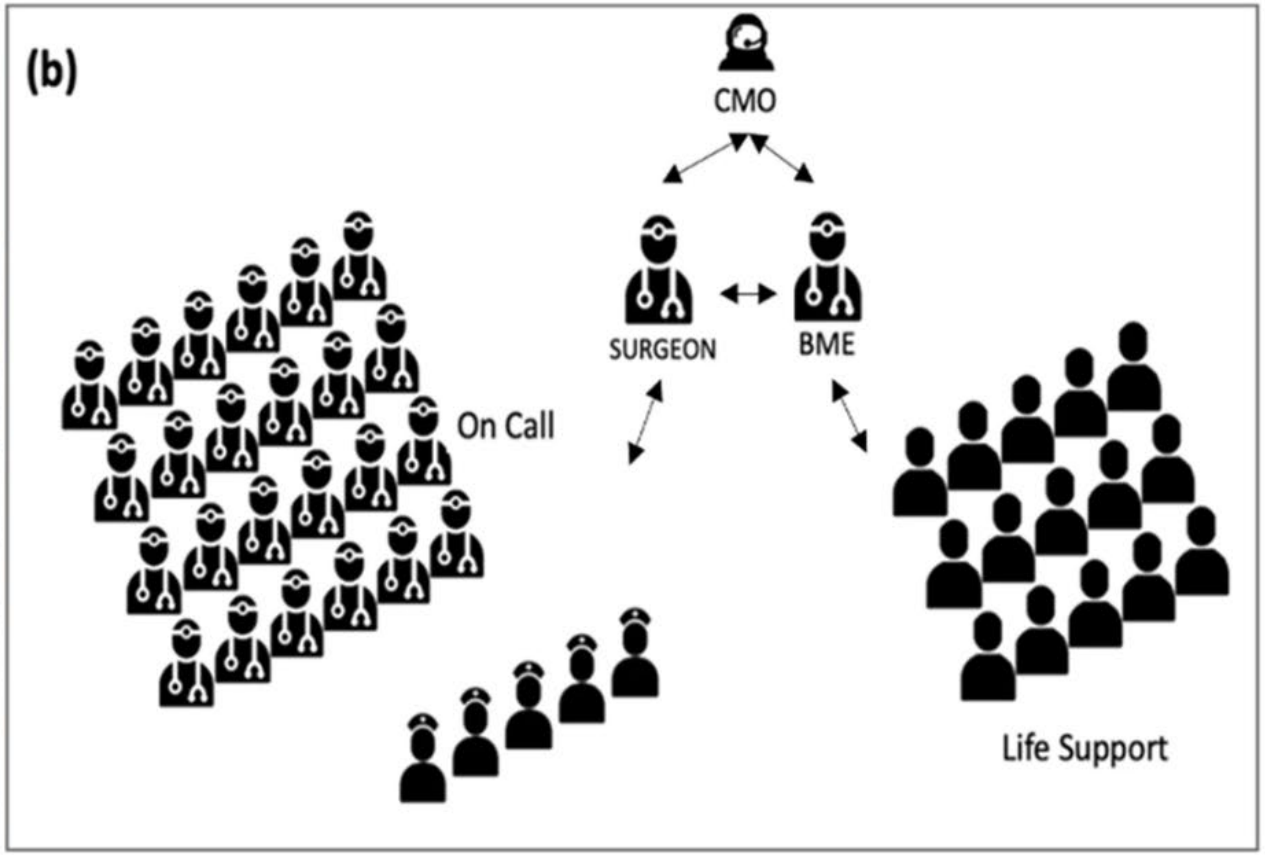
Medical Risk Increases with Distance from Earth

International Space Station → Gateway → Lunar Surface → Mars Transit

CURRENT STATE	EXPLORATION CLASS MISSION
• 180-day to 360 -day mission duration	• 650-day to > 900 -day mission duration
• Strong consumables resupply	• Zero consumables resupply
• Real-time communications	• No real-time communications
• Regular sample returns to Earth	• No sample returns to Earth
• Emergency evacuations possible	• No evacuations possible
• Relatively large internal volume	• (Likely) much smaller internal volume
• Limited onboard medical care (Earth -reliant)	• Expanded onboard medical care (crew/vehicle -reliant)

Example: Earth Independent Medical Operations





ISS Mission Control can communicate directly with the ISS Crew Medical Officer (CMO) along with a team of ground specialists

Isolation, Confinement and Communications Delay Analogs

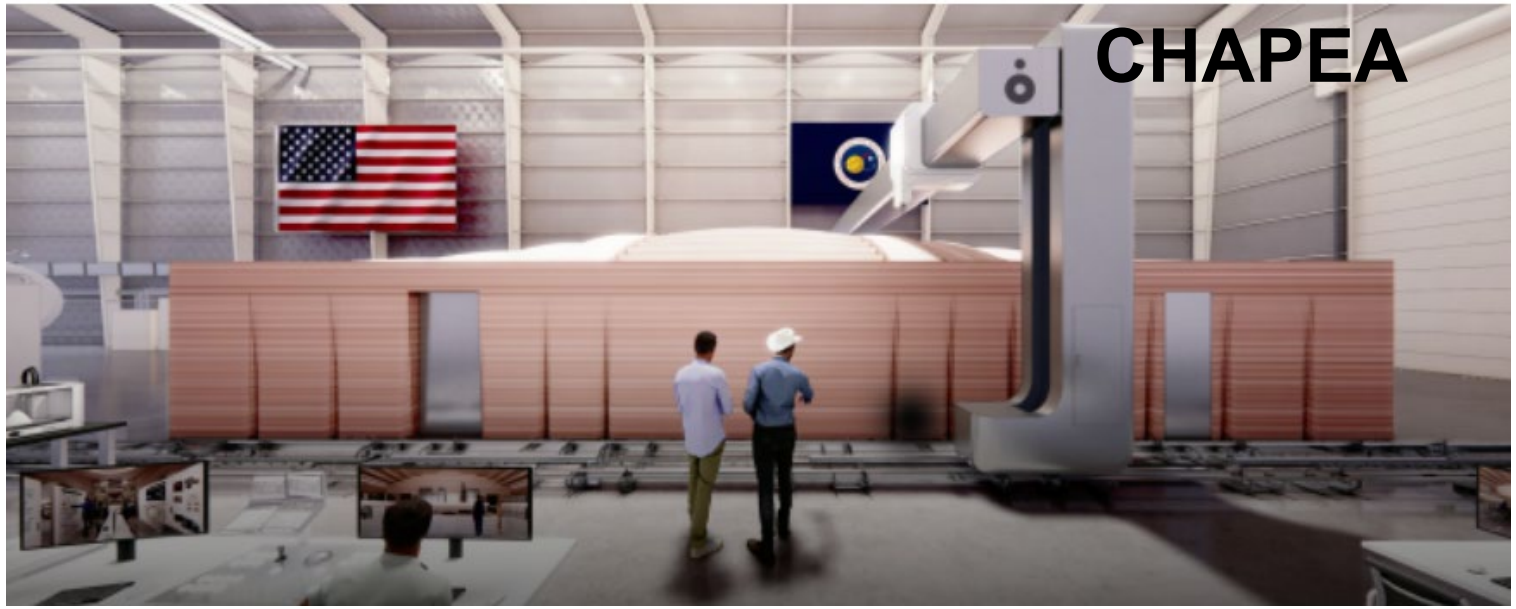


HERA

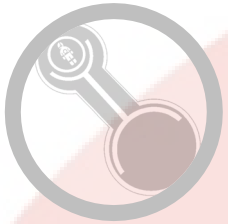
- Isolated, confined & controlled
- 45-day missions
- Variable crew autonomy
- Standard MCC-crew interactions

CHAPEA

- Isolated & confined
- 378-day missions
- High crew autonomy
- Minimal MCC-crew



Top Crew Health and Performance System Capability Gaps for Mars



Earth-Independent Human Operations



Computational Injury & Anthropometric Models



Mars Duration Food System



Exploration Exercise Countermeasures



Mars Duration Effects on Human Physiology



Understanding Individual Variability in Spaceflight



Risk Mitigations for Vehicle Atmospheres



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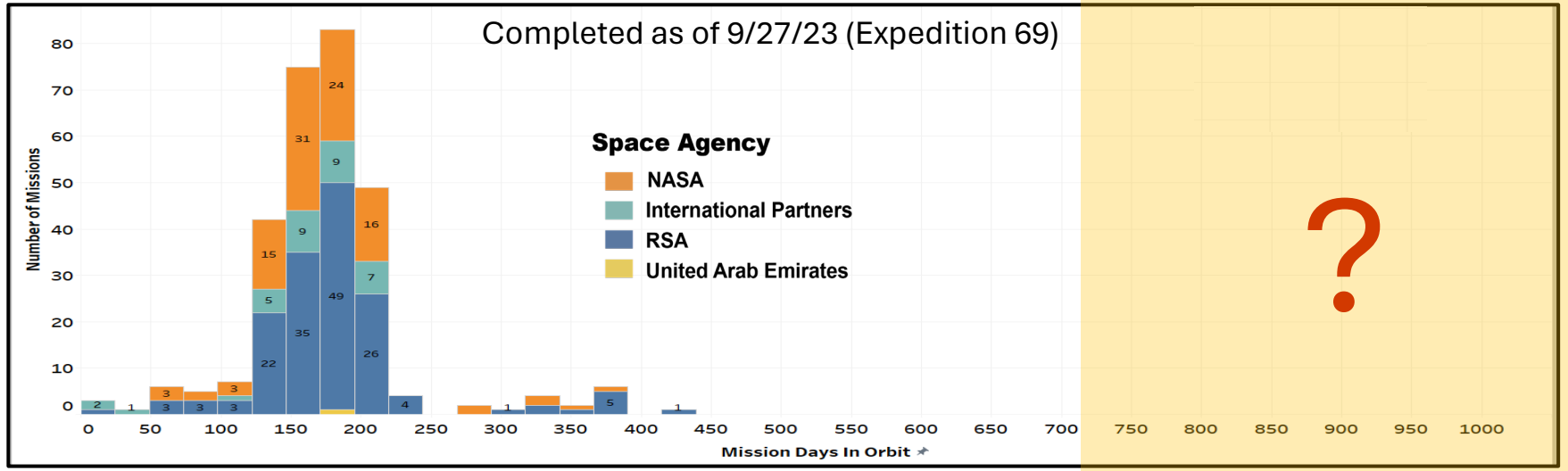
Limited Extended-Duration Data Creates Large Unknowns

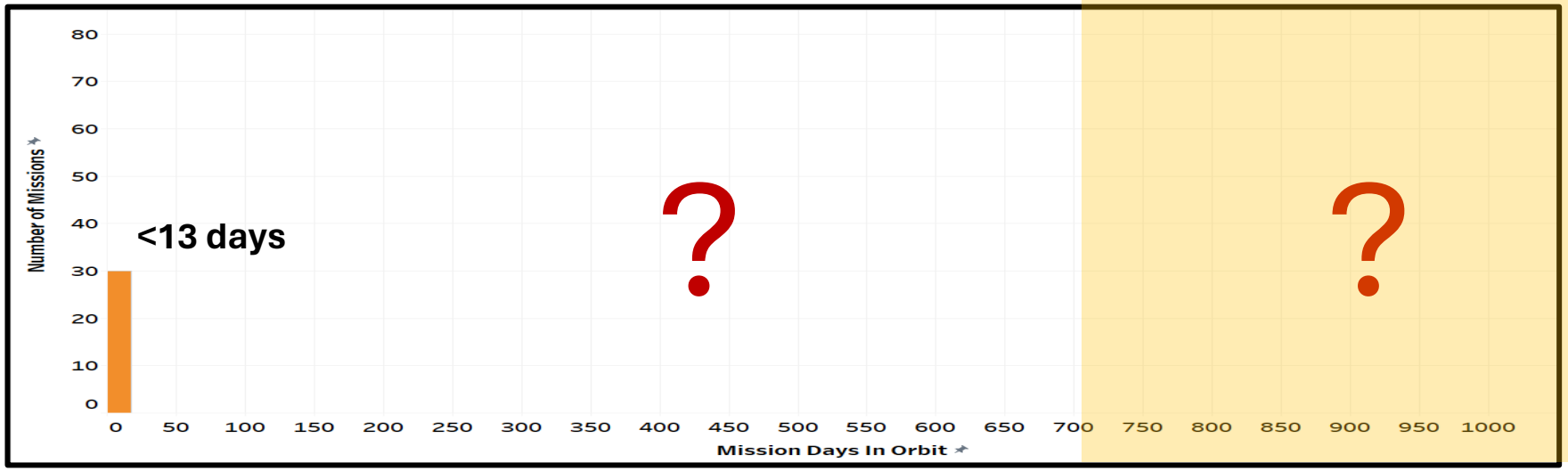
LEO Conditions
(ISS/MIR/Salyut)

Deep Space/Lunar Conditions
(Apollo)

Number of Missions by Length

Mars durations

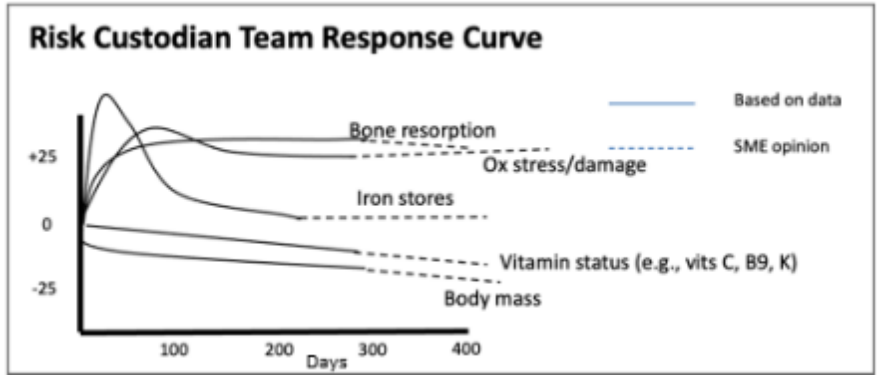




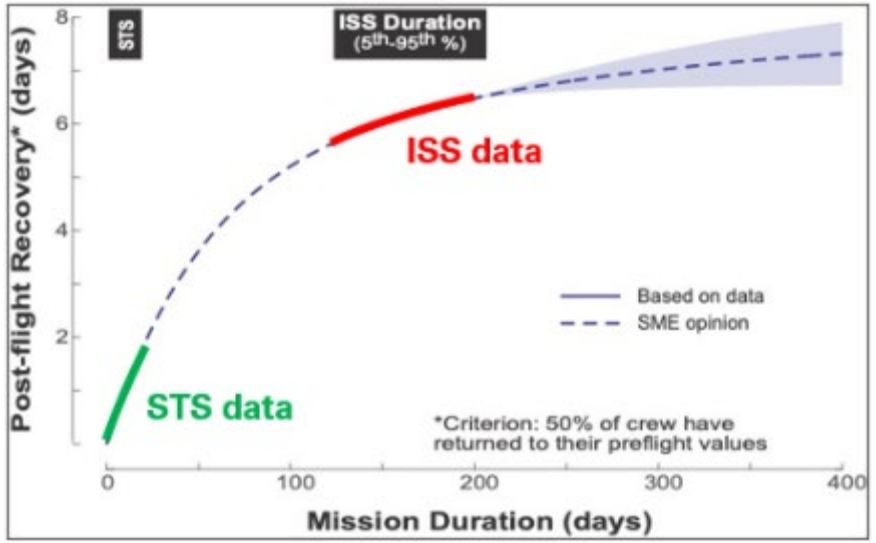
Time Course Spaceflight Changes

Appears to Generally Plateau by 6 months

Nutrition

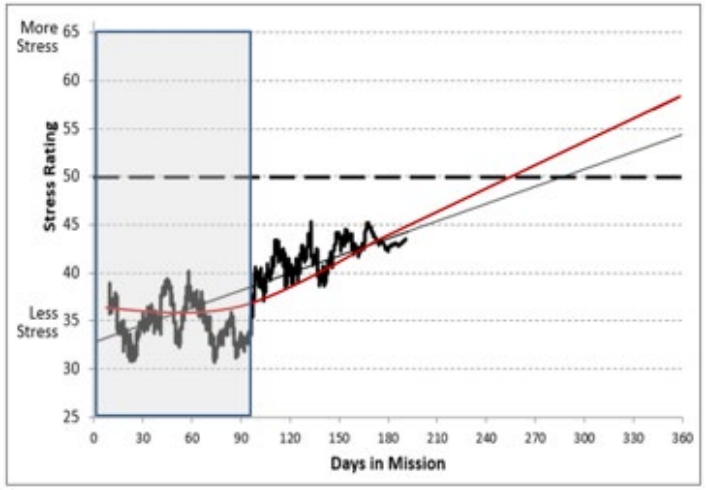


Sensorimotor

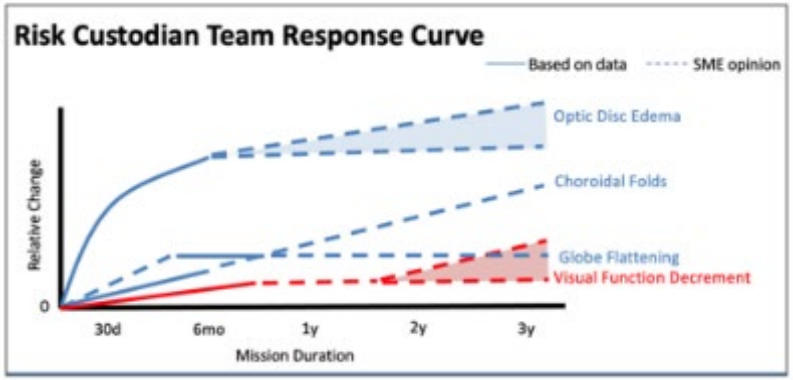


Does not Plateau by 6 months in some crewmembers

Stress

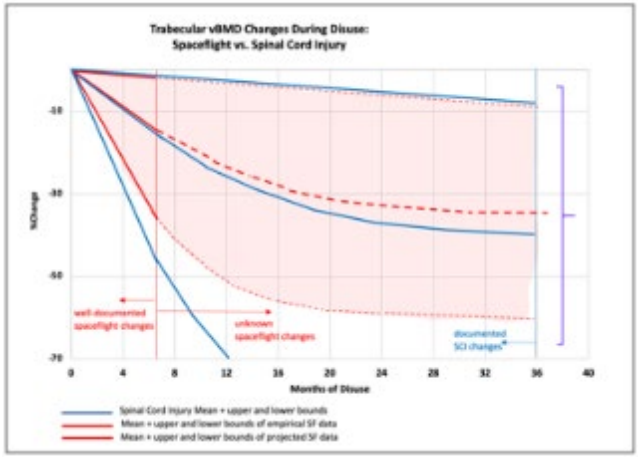


Spaceflight Associated Neuro-ocular Syndrome (SANS)

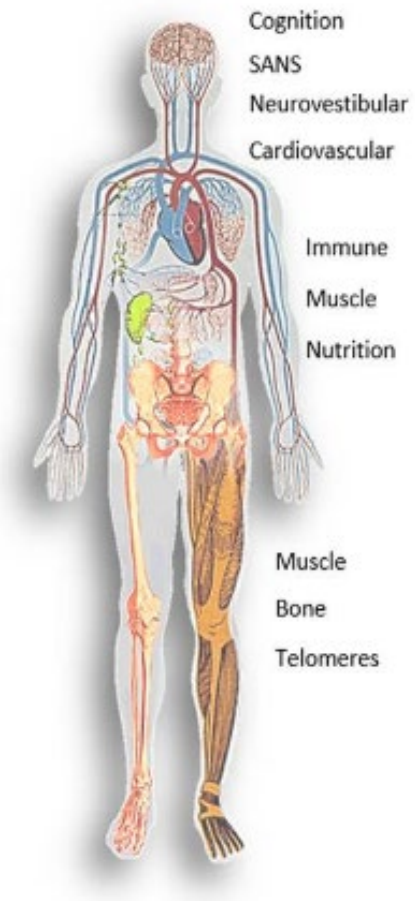


Unknown

Bone Quality



Complement of Integrated Protocols for Human Exploration Research



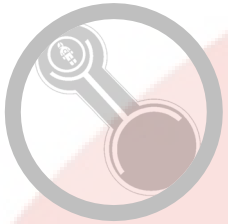
The CIPHER **integrated** protocol is composed of **14 multi-disciplinary, multi-national investigations** that have been integrated into a **single research complement** that addresses over **20 Human System Spaceflight Risks.**

Mars-forward use of ISS to measure the time course of **physiological and psychological adaptations** to spaceflight to reduce crew health & performance risks during multi-year deep space exploration missions.

Designed to be conducted on 30 crew members of varying mission durations, but categorized into three subject pools:

- **Short**: 30 to 105 days
- **Standard**: 106 to 239 days
- **Extended**: 240+ days

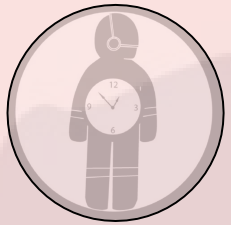
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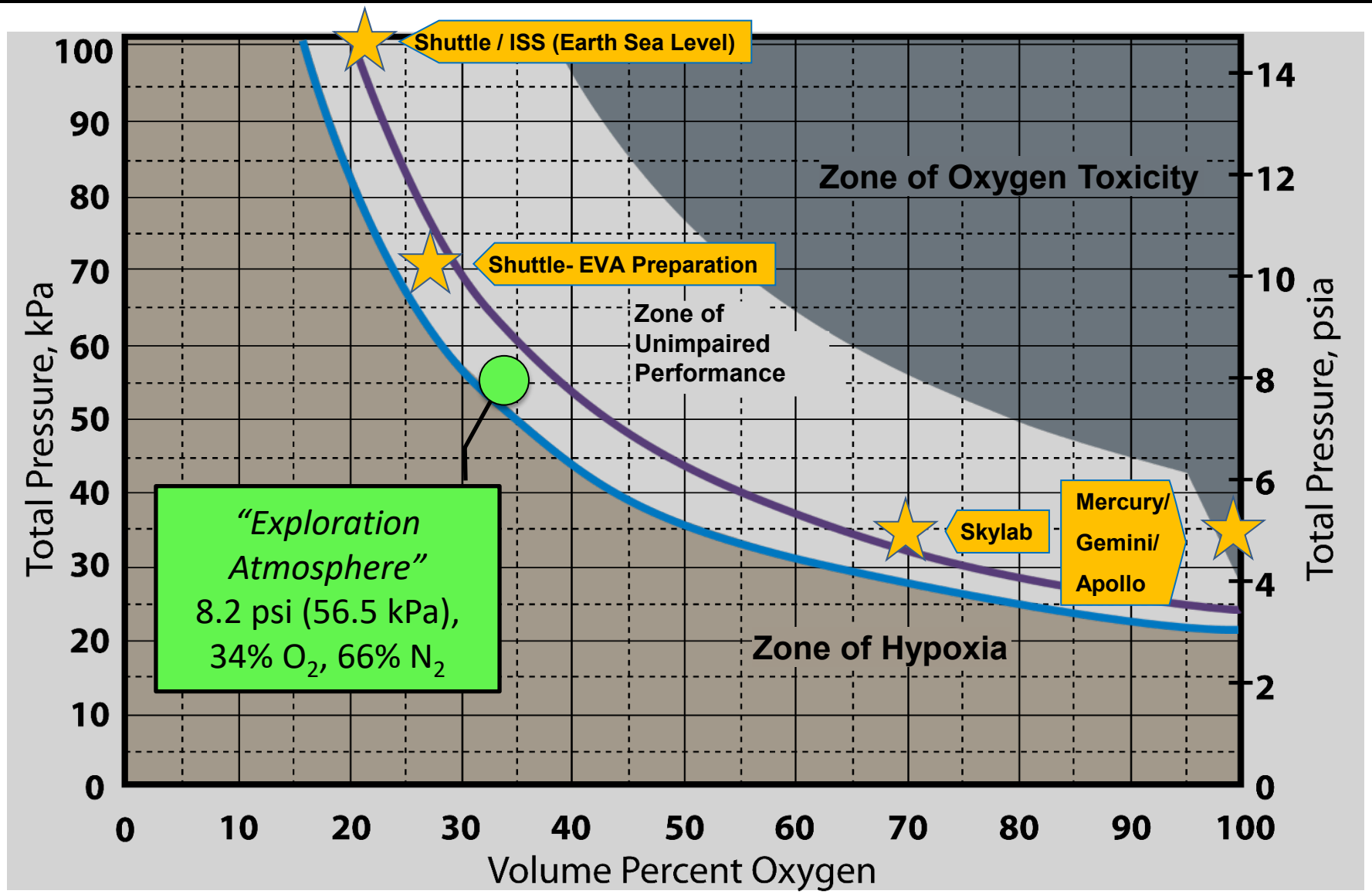


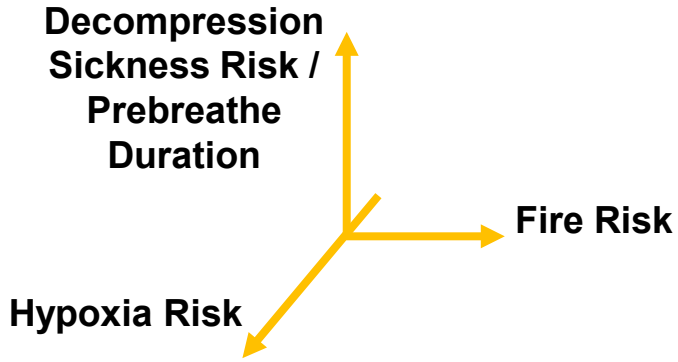
Understanding Individual Variability in Spaceflight



Sensorimotor Countermeasures

Spacecraft Atmospheres





Historical Designs

Normoxic (Sea Level) Equivalent Alveolar Oxygen

1829 m (6000 ft.) Equivalent Alveolar Oxygen

For high-frequency EVA

NASA/TP-2010-216134: Recommendations for Exploration Spacecraft Atmospheres - The Final report of the NASA Exploration Atmospheres Working Group. D. L. Henninger, Chair

Rationale for Exploration Atmosphere

- Multidisciplinary Working Group recommendation to adopt 8.2 psia / 34% O2 as a capability for future missions involving high frequency EVA[4]
- Provided recommendations for Human research studies, materials flammability, life support, EVA systems

Saturation Atmosphere	Microgravity Prebreathe* (h:mm)	Estimated Planetary Prebreathe*
14.7 psi, 21% O2	4:00	6:30-7:00 [5]
10.2 psi, 26.5% O2	0:40	3:00-3:30 [6]
8.2 psi, 34% O2	**0:00-0:15**	**0:20** [7,8]
5.0 psi, 100% O2 (Apollo, Gemini)	0:00	0:00

***Assume 6hr EVA @ 4.3 psia**

Unvalidated (i.e., not yet available for flight use)

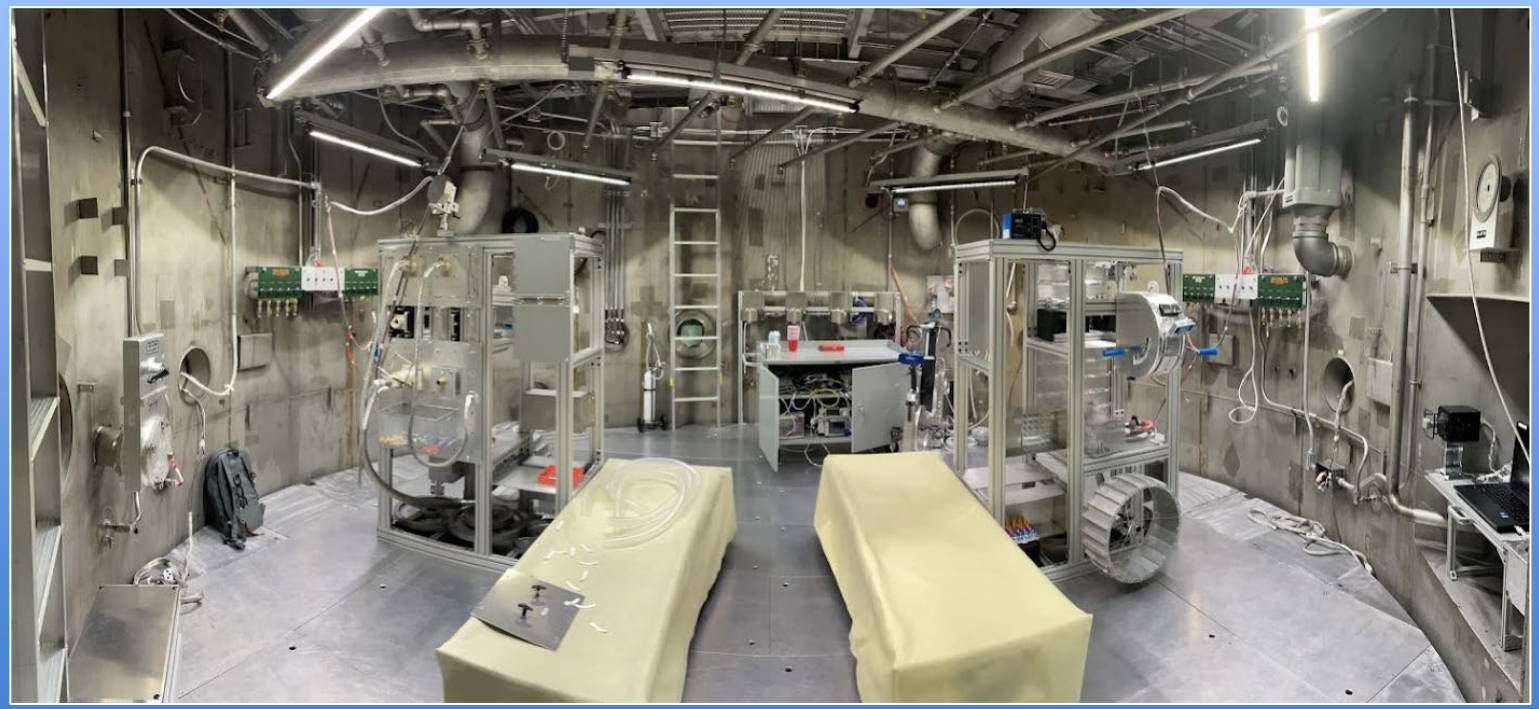
Validated via Ground Testing



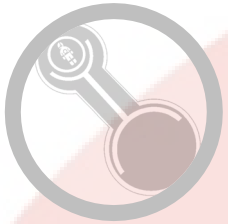
[4] NASA/TP-2010-216134/JSC 63309, Recommendations for Exploration Spacecraft Atmospheres - The Final report of the NASA Exploration Atmospheres Working Group
[5] Abercromby et al. *"Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report"*, 2018 NASA Technical Report
[6] Abercromby, et al. *"Using the Shuttle Staged Prebreathe Atmosphere and Variable Pressure Spacesuits for Exploration Extravehicular Activity"*, 2018 AsMA.
[7] Abercromby et al. *"Modeling Oxygen Prebreathe Protocols for Exploration EVA Using Variable Pressure Suits"*, 2017 AsMA.
[8] Abercromby et al. "Modeling a 15-min extravehicular activity prebreathe protocol using NASA 's exploration atmosphere (56.5 kPa/34% O2)", Acta Astronautica, 109 (2015), pp.76-87.

Exploration Atmosphere Testing in JSC's 20 ft Chamber





Top Crew Health and Performance System Capability Gaps for Mars



Earth-Independent Human Operations



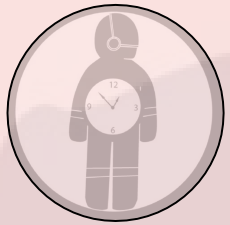
Computational Injury & Anthropometric Models



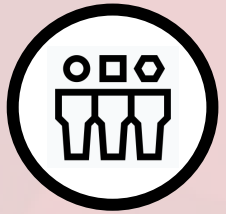
Mars Duration Food System



Exploration Exercise Countermeasures



Mars Duration Effects on Human Physiology



Understanding Individual Variability in Spaceflight

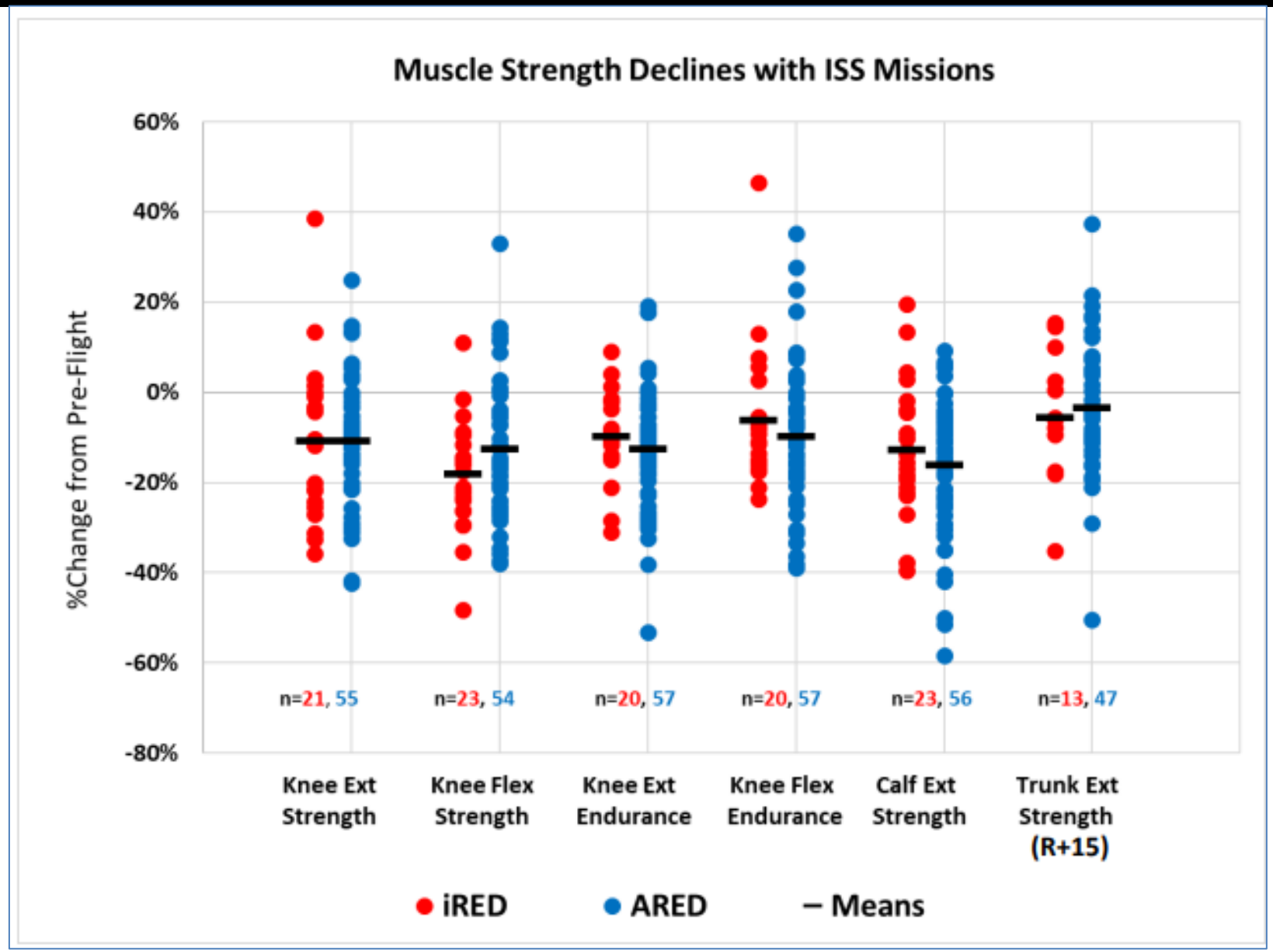


Risk Mitigations for Vehicle Atmospheres

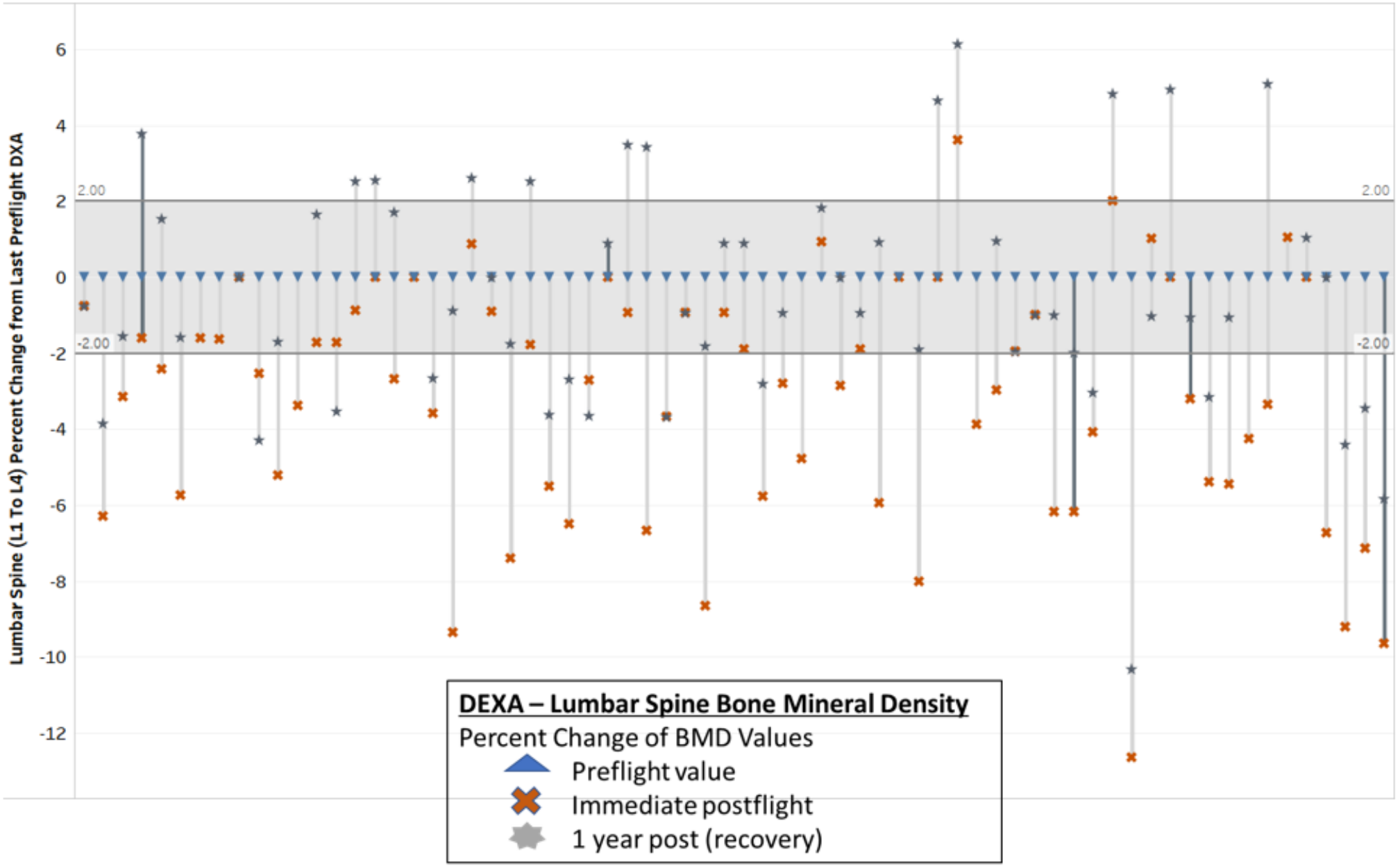


Sensorimotor Countermeasures

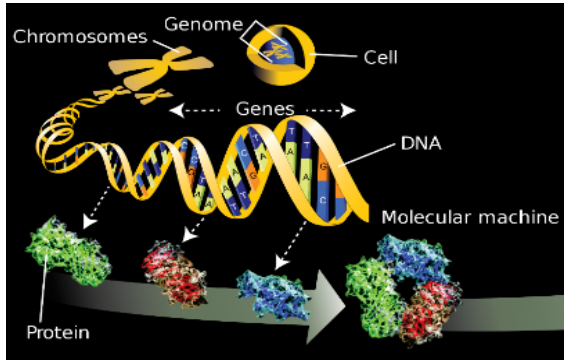
Example of Individual Variability in Spaceflight Physiology: Muscle



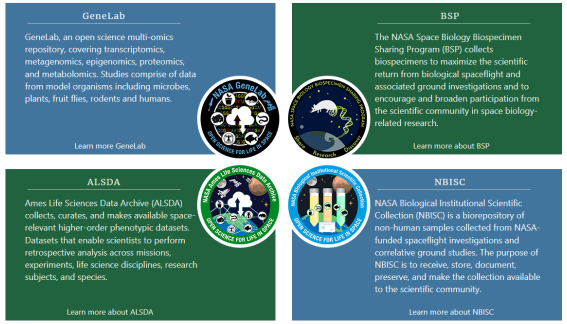
Duration vs. Individual Variability: Pre/Post Bone DXA measurements



Gathering and Making Datasets More Accessible for Analysis



NASA Omics Data Archive - https://www.nasa.gov/mission/station/research-explorer/investigation/?#id=8275
ISS flight study



NASA's Open Science Data Repository (OSDR) - https://osdr.nasa.gov/bio/

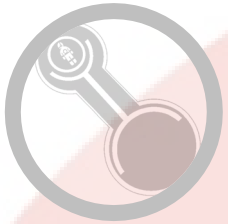
- **Genelab**
- **Biospecimen Sharing Program (BSP)**
- **Ames Life Sciences Data Archive (ALSDA)**
- **(NASA) Biological Institutional Scientific Collection (NBISC)**



NASA's Life Science Portal (NLSP) - https://nlsp.nasa.gov/explore/lsdahome

- **Life Science Data Archive**
- **Lifetime Surveillance of Astronaut Health**

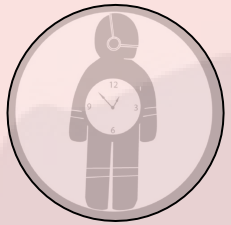
Top Crew Health and Performance System Capability Gaps for Mars



Earth-Independent Human Operations



Mars Duration Food System



Mars Duration Effects on Human Physiology



Risk Mitigations for Vehicle Atmospheres



Computational Injury & Anthropometric Models



Exploration Exercise Countermeasures



Understanding Individual Variability in Spaceflight



Sensorimotor Countermeasures

State-of-the-Art Landings on Earth After Six Months in Low Earth Orbit



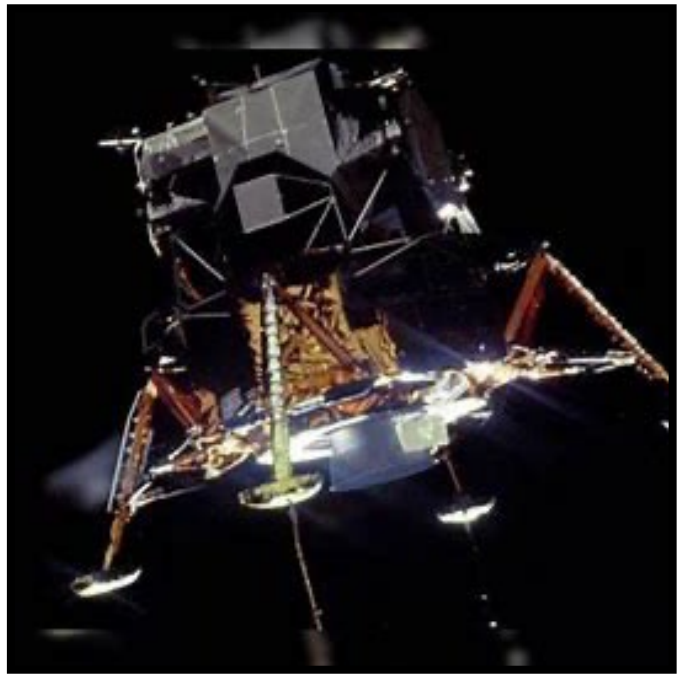




Mars Landing



Sensorimotor Capabilities Needed for Critical Activities



Manual Control

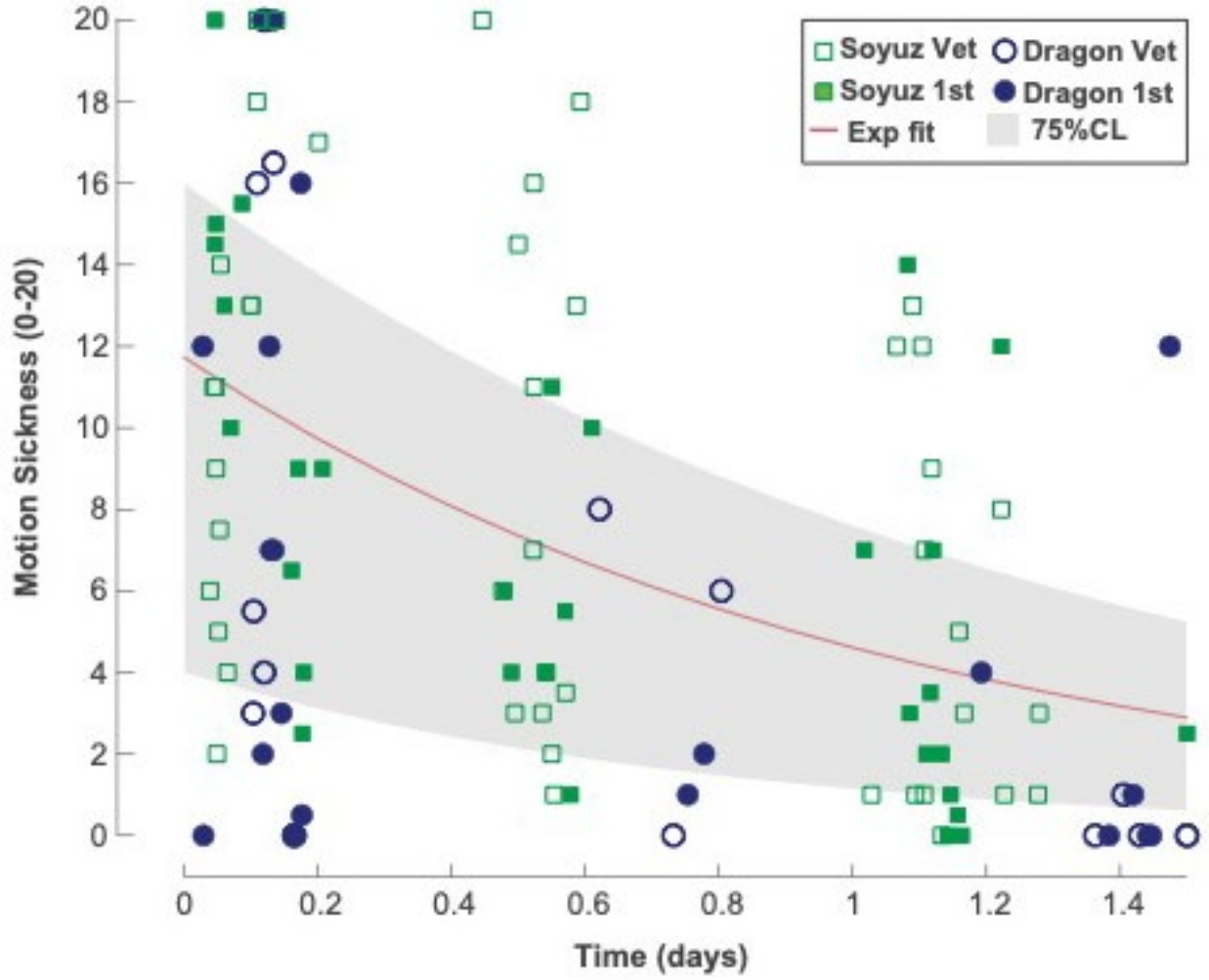


Early EVA

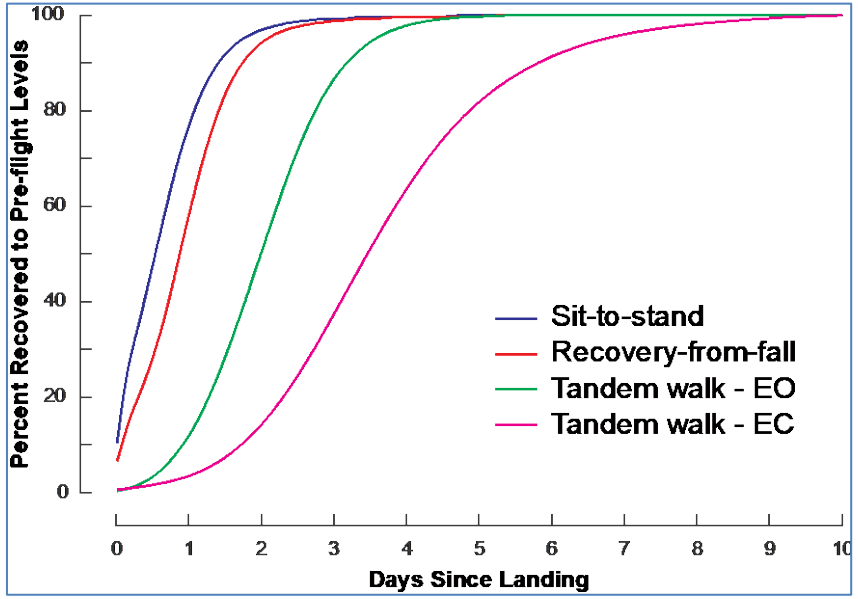


Crew Egress

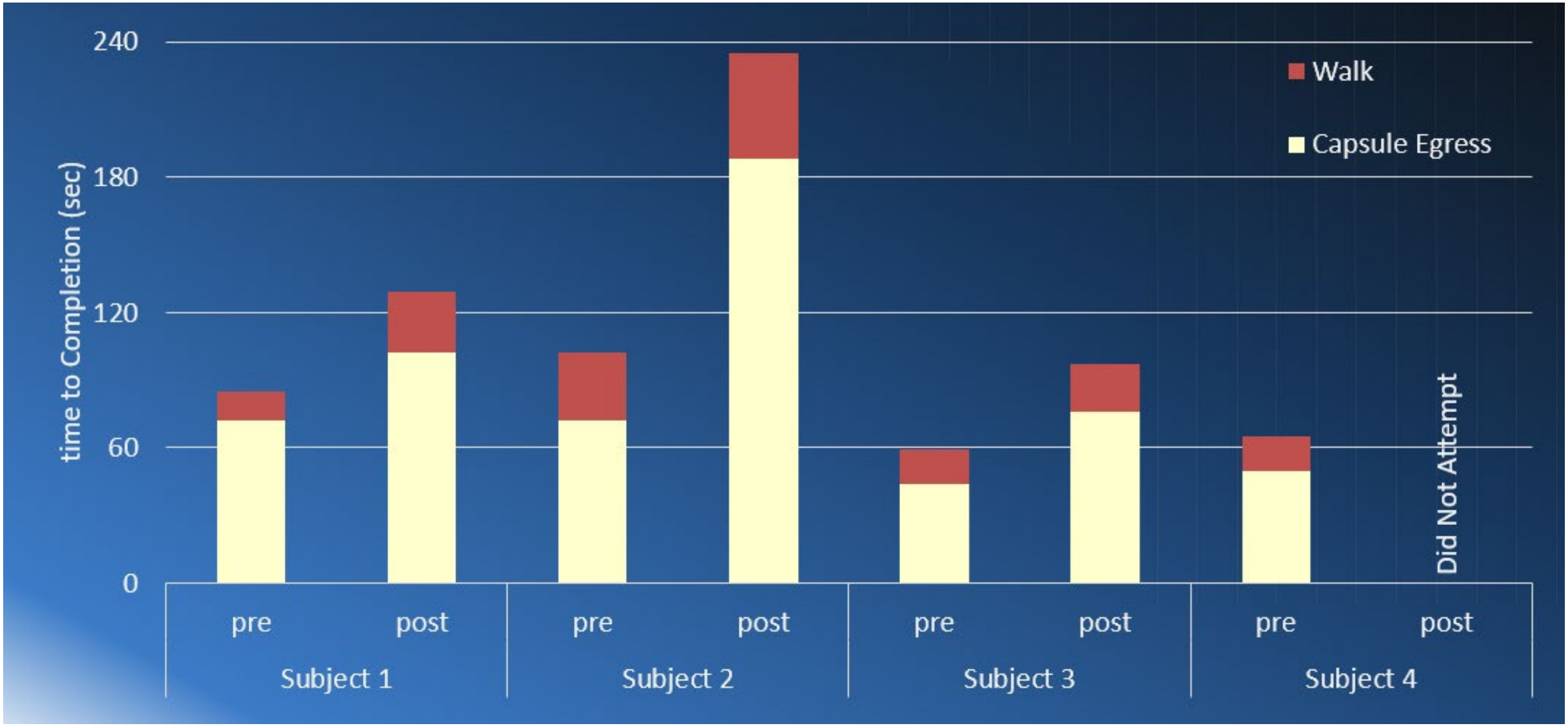
Sensorimotor Re-Entry Recovery



- Symptom severity highly variable across crewmembers
- Head movement wrt gravity are more provocative
- Recovery to baseline performance varies by task



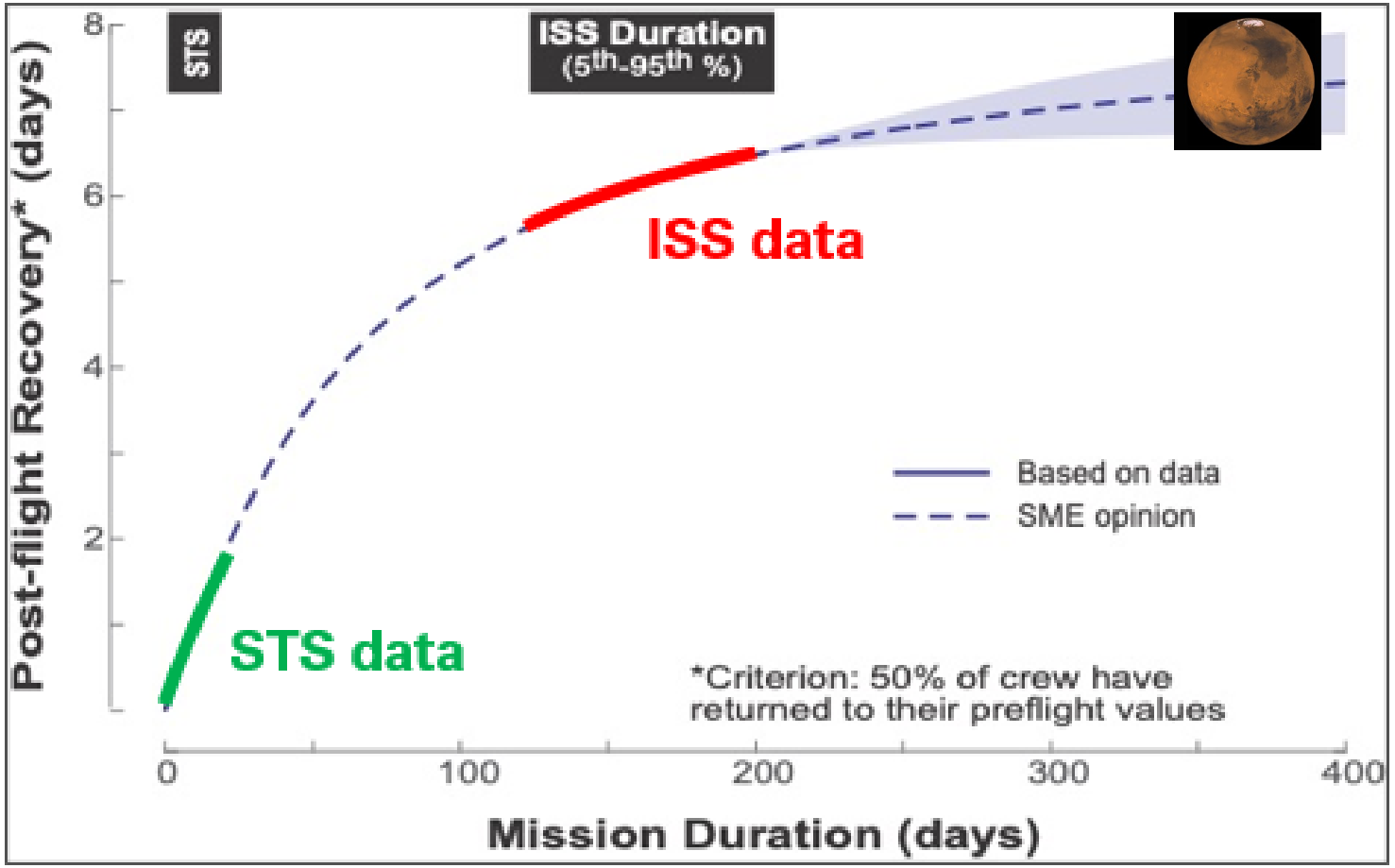
Mock-up Capsule Egress Results



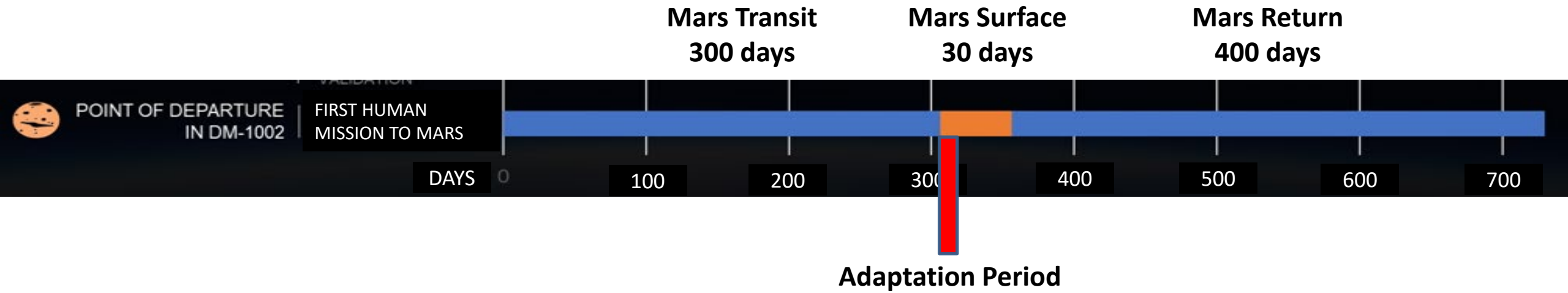
Postflight Recovery Curves for Sensorimotor Adaptation



Field Test was performed in the medical tents or rally airports as soon as possible after landings.



Example of a Mars Architecture Team timeline



Mars Architecture Team (MAT) is protecting **3-7 days** for Sensorimotor adaptation after landing on Mars for nominal EVAs

Depending on the Mars surface stay duration, that could represent a significantt percentage of the available planetary science timeline.

What are we doing to protect crews from radiation?
ALARA – As Low as Reasonably Achievable (GCR and SPEs)

Institutionalizing knowledge: NASA-STD-3001 standards and recent updates

1. **Galactic Cosmic Ray (GCR)** Shielding
2. Personal radiation exposure monitoring
3. Lifetime space radiation exposure limits (600mSv)
4. Design standards for **Solar Particle Events (SPE)** impacts and "storm shelters"
5. Real-Time Radiation Monitoring for Protection

Continue mitigation strategies: Space Radiation Research

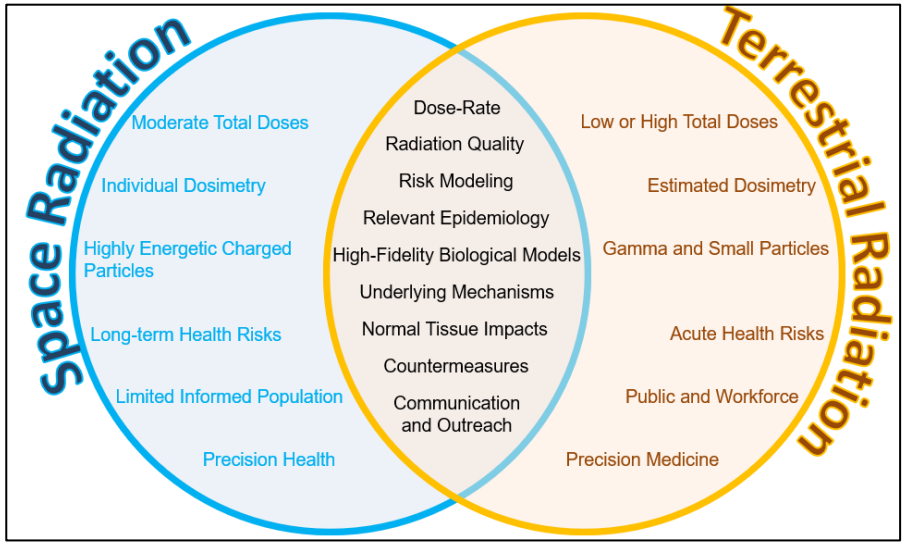
1. Characterize space environment on biology with GCR simulator
   - Dose Quality (Mixed Field GCR vs. Gamma)
   - Dose Rate (Dose provided over weeks vs. single exposure)
   - GCR Simulation in use since 2018 – first suite of studies starting to report results.
2. Leverages significant investment in **terrestrial radiation research** for **prevention, detection, treatment and personalized assessments**
3. Tools for **informed consent** for crews and agency decision makers
4. Improve SPE forecasting tools and technologies to minimize crew exposure levels

Providing recommendations to Agency: Mission Architecture Planning

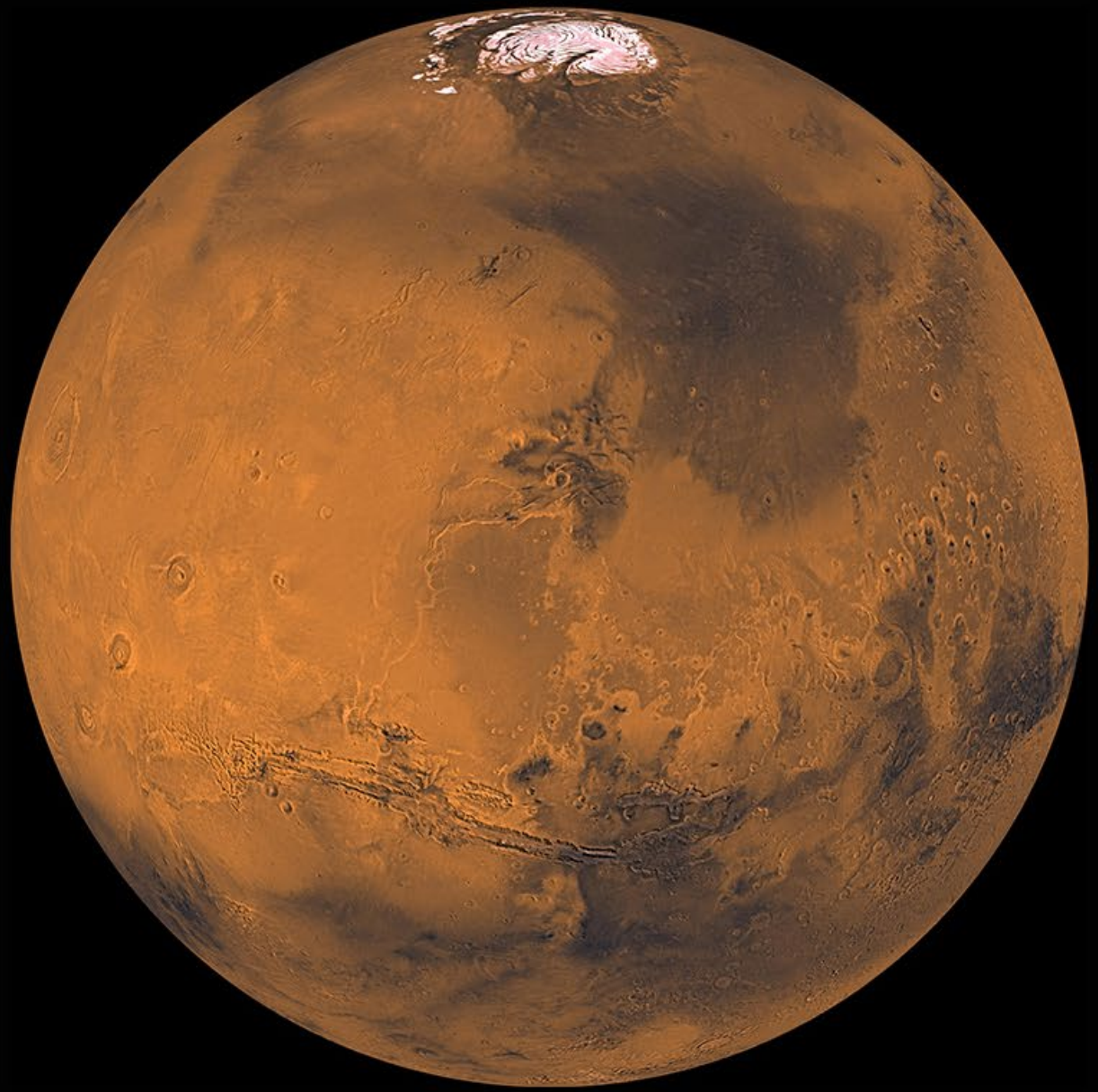
1. Fly during Solar Maximum
2. Fly shorter Missions



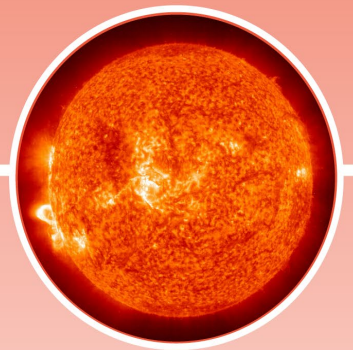
NASA's Space Radiation Laboratory (NSRL) provides the highest fidelity simulation of Galactic Cosmic Radiation (GCR) on Earth



Research on Mars



Artemis vs. Mars: 5 Hazards



Space Radiation

Longer exposure to deep space ionizing radiation.



Isolation & Confinement

Longer missions with same crew in same transit vehicle; majority of missions will be without views of the Earth



Distance from Earth

No resupply, multi-month/year return to Earth, longer communication delays, more crew and vehicle autonomy



Lack of Gravity

Longer periods in microgravity; partial gravity different; "heavier" EVA suit.



Hostile/Closed Environment

Different atmospheric pressure/partial pressure of oxygen (TBD), different microbial envirommment, limited food system, different exercise capability; Martian dust exposure.

Synergistic interaction of all five hazards acting on human body simultaneously

HRP Mars Goal & Objectives

Enable crews to thrive during Mars missions, protect their long-term health, and enable human exploration beyond Mars.

1. **Exploration Medical Operations**

   Validate Earth-independent crew health & performance systems and operations.

2. **Integrated Human System Performance**

   Validate countermeasures and characterize impacts to overall crew health & performance.

3. **Living Environment**

   Validate the interaction of exploration habitation systems, spaceflight hazards, and effects on crew health & performance.

4. **Special Task-Related Issues**

   Validate operational implementation of critical tasks, protocols, procedures, and human factors for adequate crew health & performance.

5. **Extended Mission Durations**

   Validate human system risk mitigation strategies in Mars-class duration missions and systems.

HRP & Planetary Science Collaborations

WHY:

NASA's Science Mission Directorate (SMD) is planning science objectives and related crew tasks/activities for Artemis and Mars missions. HRP is planning research tasks to enable human health and performance on Artemis and Mars missions. Collaboration allows for 1) potentially improved SMD crew tasks and mission timelines, and 2) more refined/accurate HRP research tasks.

HOW:

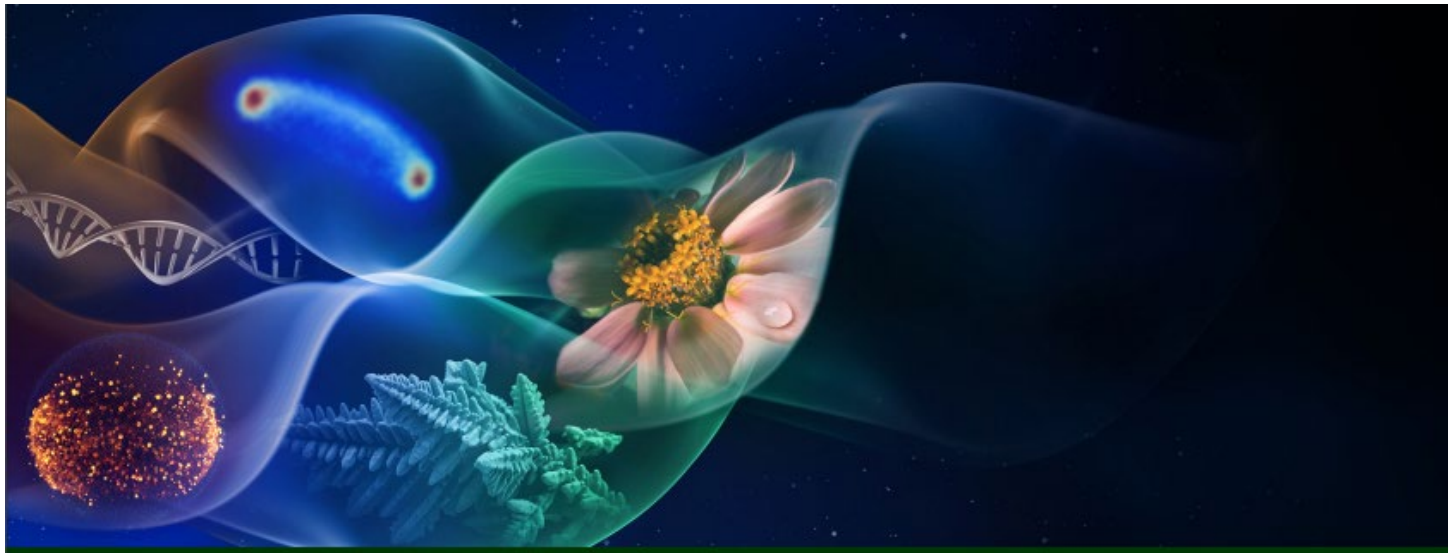
1. SMD is presenting to HRP this spring to brief EVA planned activities and sampling strategy.
2. Deeper dive/targeted presentations by SMD to HRP's Scientists every quarter.
3. HRP 2025 Investigator's Workshop proposed plenary by SMD
4. Cross-participation or observation in each other's analog missions (where applicable)

WHAT:

1. HRP refined research tasks to enable SMD science on Artemis & Mars missions
2. Ground analogs collaboration ideas

M2M strategy: HRP-Specific Objectives





Human and Biological Science (HBS)

Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, to support safe, productive human space missions, and to reduce risks for future exploration.

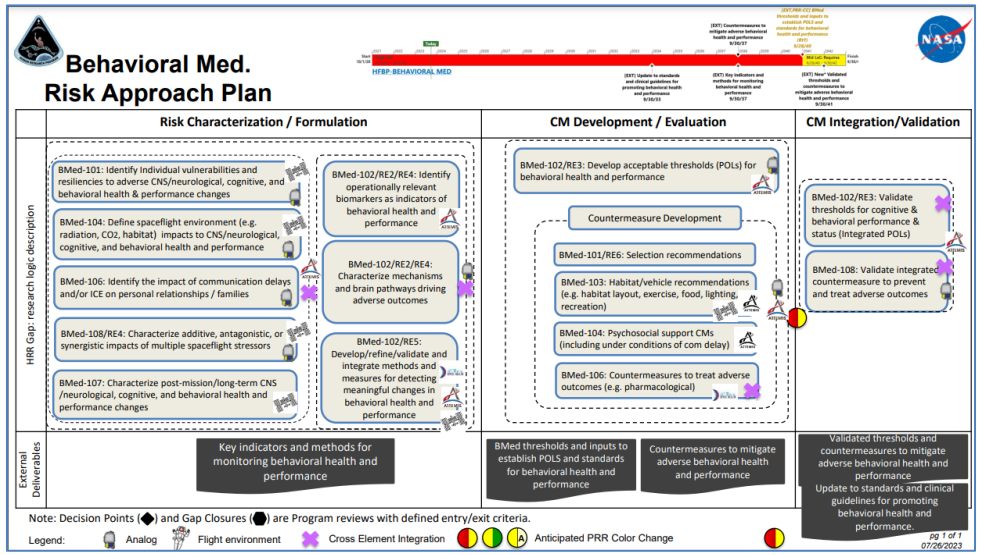
HBS-1[LM]:	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
HBS-2[LM]:	Evaluate and validate progressively Earth-independent crew health and performance systems and operations with mission durations representative of Mars-class missions.
HBS-3[LM]:	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.

https://www.nasa.gov/sites/default/files/atoms/files/m2m_strategy_and_objectives_development.pdf

HRP M2M Iterative Strategy:

Enable and Utilize Artemis Missions as a Mars Testbed to Characterize and Mitigate Human System Risks

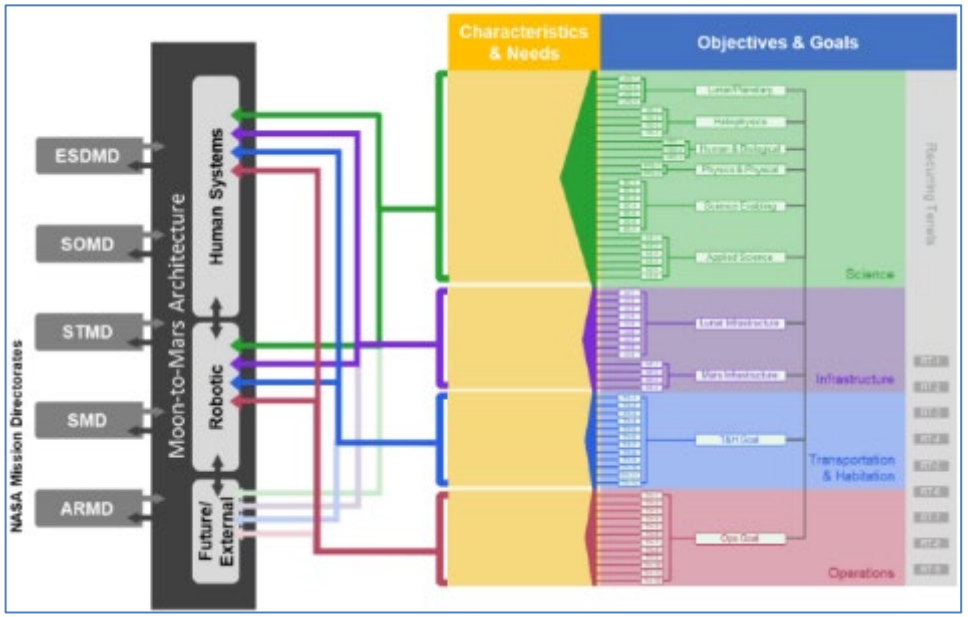
HRP Risk Approach Plans (RAPs)



Decompose into RAPs

Inform Architecture

M2M Architecture Definition Document



HRP Risk Approach Plans (RAPs) serve as both an ADD decomposition and an input

Moon2Mars Architecture Objectives for Crew Health and Performance

OBJ	DESCRIPTION
OP-1L	Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the Moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.
OP-6L	Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.
OP-7LM	Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.
HBS-01LM	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
HBS-02LM	Evaluate and validate progressively Earth-independent crew health & performance systems and operations with mission durations representative of Mars-class missions.
HBS-03LM	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.

Recommended reading and additional resources

- **Moon2Mars Human Health white paper**
  - https://www.nasa.gov/wp-content/uploads/2024/01/human-health-and-performance.pdf
- **NASA Office of the Chief Health and Medical Officer (OCHMO) Technical Briefs**
  - https://www.nasa.gov/ochmo/health-operations-and-oversight/hsa-standards/ochmo-technical-briefs/
- **Human research roadmap websites (evidence, risks, gaps, risk approach plans)**
  - https://humanresearchroadmap.nasa.gov/
- **HRP Evidence reports**
  - https://humanresearchroadmap.nasa.gov/Evidence/
- **Annual Human Research Program Investigator Workshop**
  - https://www.nasa.gov/hrp-iws-2024/

- **My email**
  - david.k.baumann@nasa.gov



Questions?

