The Behavioral Health Challenges of Mars Missions

National Academies of Sciences

Panel on Biological and Physical Sciences and Human Factors

Open Meeting #1

August 6th, 2024

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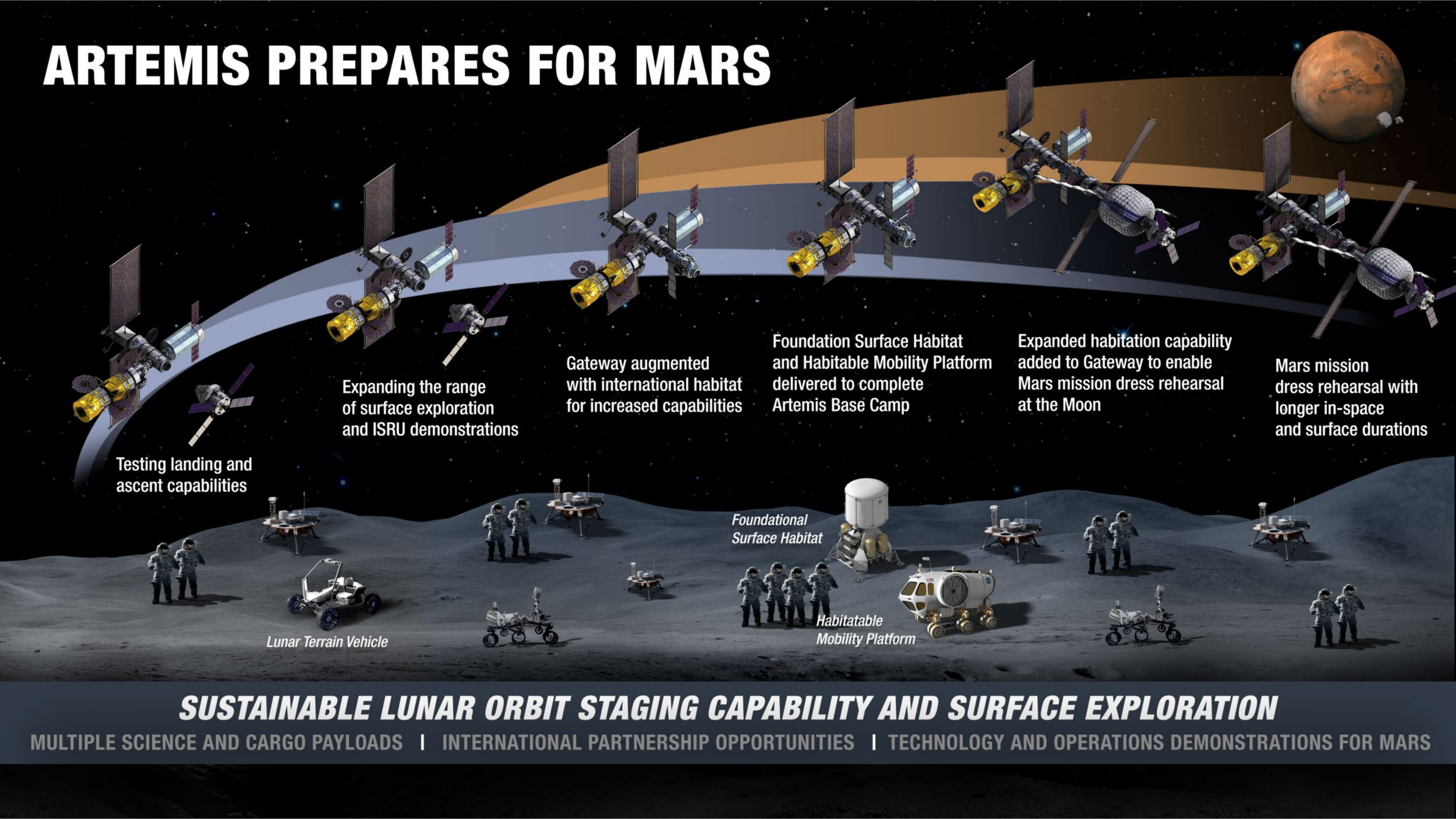
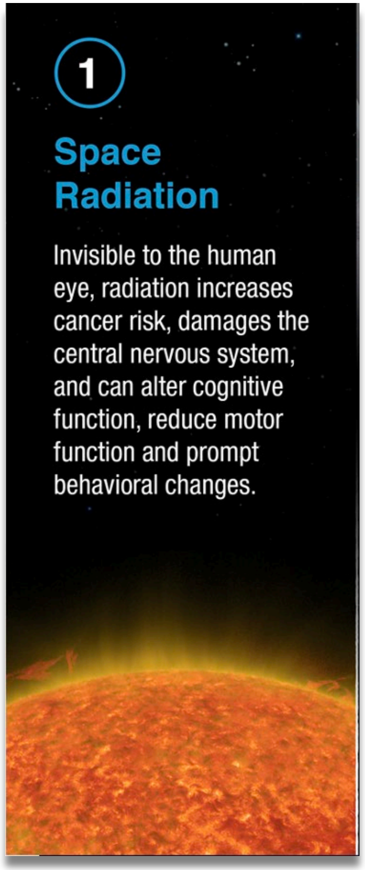
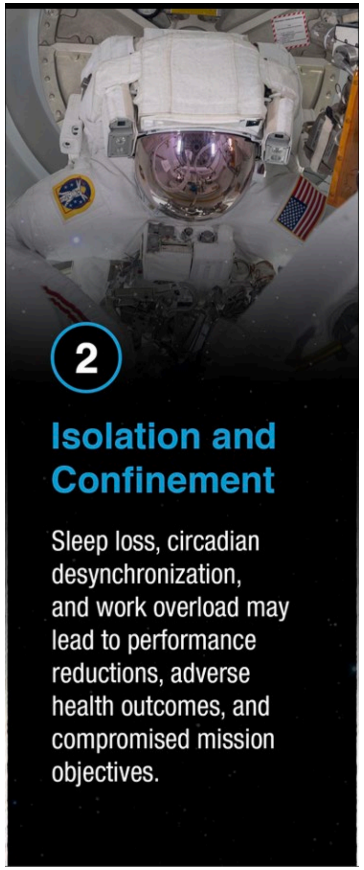
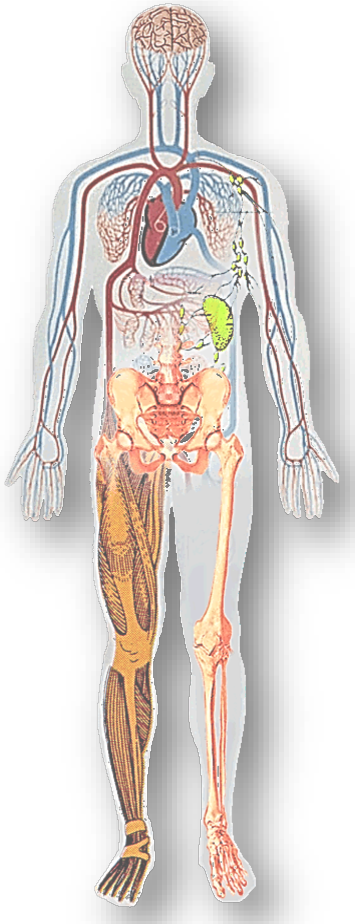
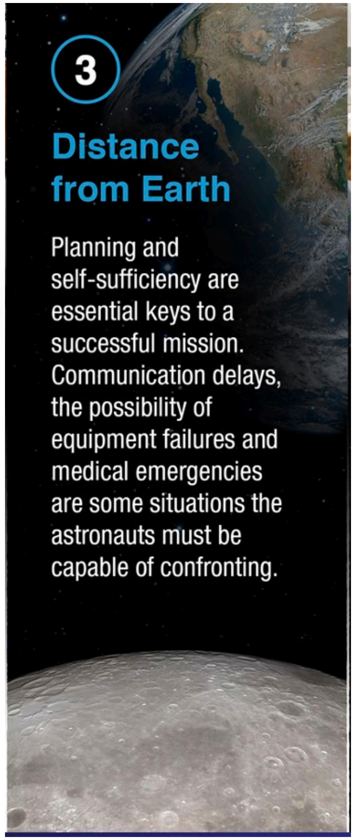

ARTEMIS PREPARES FOR MARS
Testing landing and ascent capabilities
Expanding the range of surface exploration and ISRU demonstrations
Gateway augmented with international habitat for increased capabilities
Foundation Surface Habitat and Habitable Mobility Platform delivered to complete Artemis Base Camp
Expanded habitation capability added to Gateway to enable Mars mission dress rehearsal at the Moon
Mars mission dress rehearsal with longer in-space and surface durations
Lunar Terrain Vehicle
Foundational Surface Habitat
Habitatable Mobility Platform
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

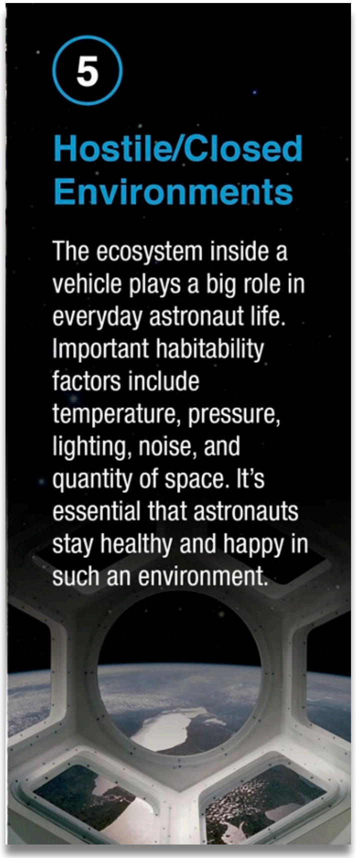
Hazards of Exploration Spaceflight











https://www.nasa.gov/hrp/hazards

Characteristics of NASA Human Research Program

Composed of Five *Elements*

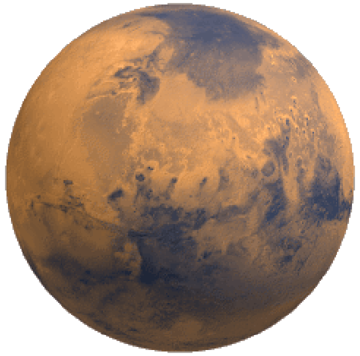
- Space Radiation
  - *Biological effects of radiation exposure – cancer*
- Human Health Countermeasures
  - *Physiological Changes*
- **Human Factors and Behavioral Performance (HFBP)**
  - *Individual and interpersonal outcomes*
  - *Interfaces between humans, vehicles & habitats*
- Exploration Medical Capability
  - *Medical care for deep-space missions*
- Research Operations and Integration
  - *Infrastructure for flight and analog experiments*

https://www.nasa.gov/hrp/hazards

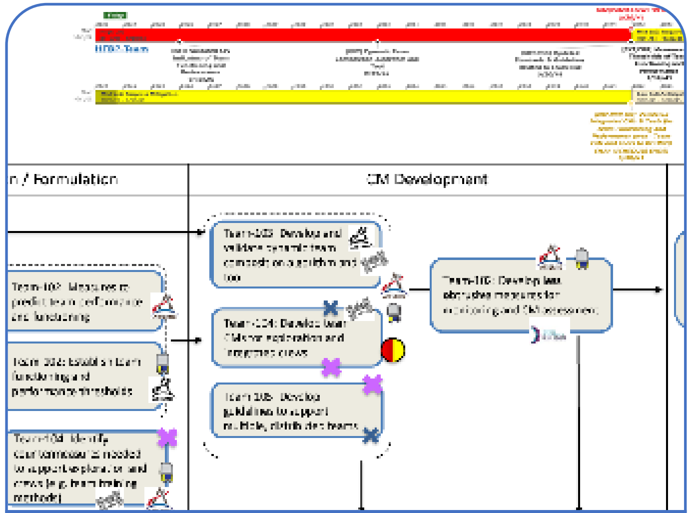
NASA Human Research Program (HRP)

Human Factors and Behavioral Performance (HFBP)

HFBP: Clarification Points



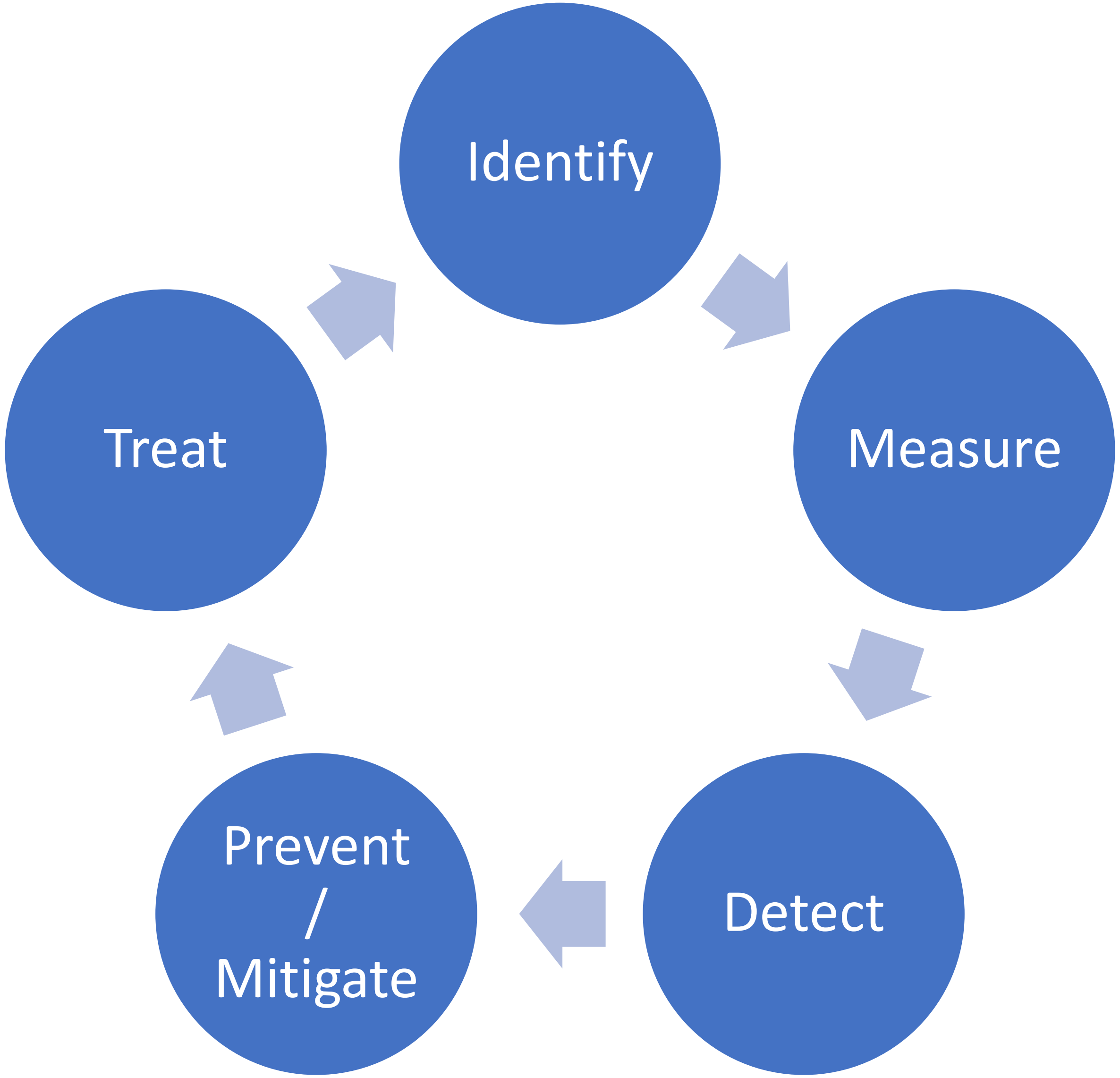
Medical Operations and Human Factors Practitioners



Human Research Program

Research Institutions/Labs

HFBP Approach – Behavioral Challenges of Future Missions



Moon2Mars Objectives

HBS-01-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-02-LM	**Evaluate and validate progressively Earth-independent crew health & performance systems and operations** with mission durations representative of Mars-class missions.
HBS-03-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.
OP-01-L	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-02-LM	**Optimize operations, training and interaction** between the team on Earth, crew members on orbit, and a Martian surface team **considering communication delays, autonomy level, and time** required for an early return to the Earth.
OP-06-L	**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-07-LM	**Validate readiness of systems and operations to support crew health and performance** for the initial human Mars exploration campaign.

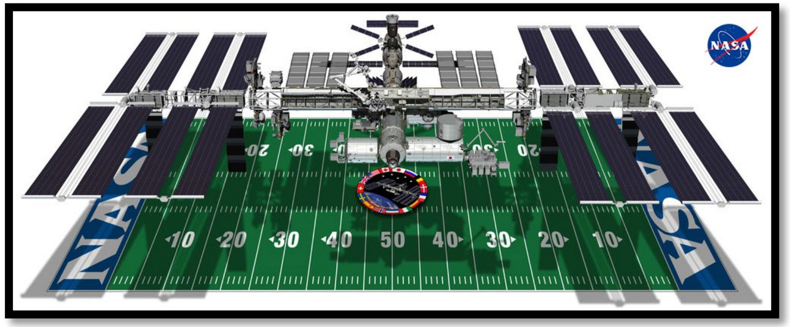
Behavioral Health and Performance

Current Operations

Low Earth Orbit

- Familiar duration and distance
- Real-time communications (ground ops, family, friends)
- Provision of crew care packages
- Evacuation options
- Windows for Earth-viewing
- Exercise variety & long regimens
- Large volume and private quarters
- Mostly six-month duration
- High tempo & shifting operations
- Increasingly mixed crews

ISS



Near Term Exploration Missions

Short Duration Lunar

- Lunar missions around two weeks
- Loss of communication and delayed com (6-14 sec) with ground
- Limited re-supply
- Limited options for evacuation
- Windows for Earth-viewing
- Very limited food and exercise options
- Small volume and lack of privacy
- High-tempo, shifting schedules
- Increasingly autonomous operations, including during emergency
- Distributed teams

Orion Capsule

Gateway Habitat

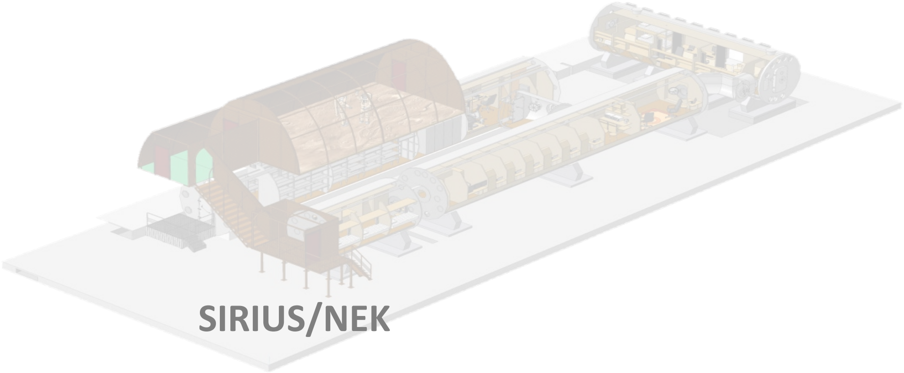
Future Exploration Class Missions

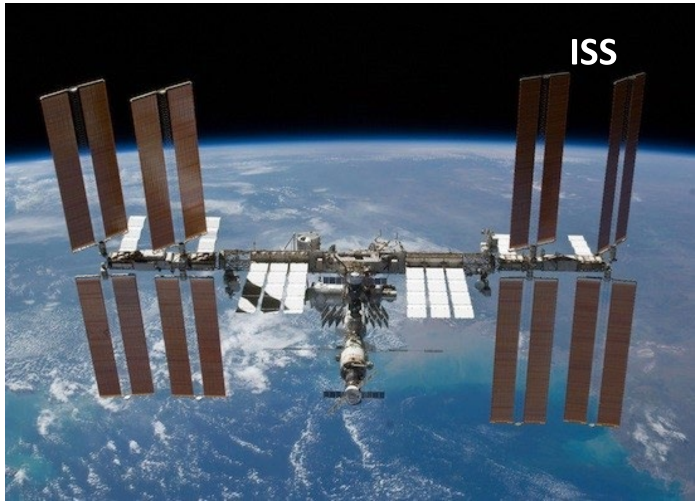
Mars

- Unprecedented duration and distance
- Loss of communication & delayed com (19 minutes) with ground
- No re-supply
- No options for evacuation
- Earth out of view; virtual windows
- Very limited food and exercise options
- Constrained volume & reduced privacy
- Periods of monotony with high-tempo situations; Mars sol
- Highly autonomous operations, including during emergency

Mars

Research Platforms





Behavioral Health and Performance Research in Current Spaceflight

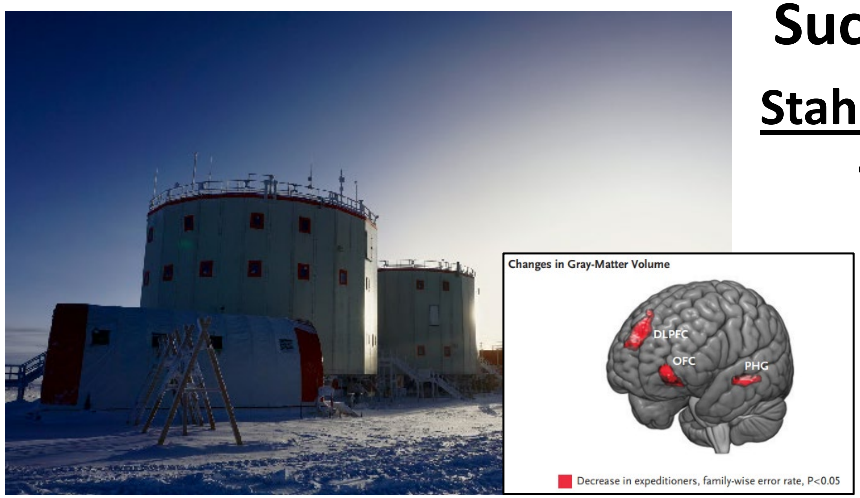
High performing crews completing very successful missions

- Average nightly sleep duration just over six hours per night (as measured objectively on ISS up to 2011) *Flynn-Evans et al. (2015)*
- Crew capable of achieving sufficient sleep in space, especially when their schedules afford adequate sleep *Flynn-Evans et al. (2023)*
- Reaction time measured by Psychomotor Vigilance Task (PVT) related to sleep and fatigue *Jones et al. (2022)*
- Docking sim performance related to sleep pressure *Petit et al. (2019)*
- Research evaluating other aspects of cognitive function suggests minimal changes *Strangman et al. (2015); Tays et al. (2021)*
- Fine motor changes during gravitational transitions *Holden et al. (2019)*
- Evidence of neurostructural changes; limited functional changes *(Roy-Oreilly et al., 2021; Roberts et al., 2020, 2017; Kopplemans et al., 2022, 2016)*
- Self-reported stress increases over mission duration for some crew members, particularly during second half of mission *Dinges et al. (2017); Jones et al. (2024); Dev et al. (2024)*
- Journaling reveals very positive experience overall *Stuster (2010); Stuster (2016)*

Limitations (relative to generalizing to Mars)
Close proximity to Earth

- Real-time communication
- Crew care packages
- Dynamic composition
- Earth in view
- Radiation

Analogs - What Are We Learning for Exploration?



Successful missions with healthy crew ~ signs of increased risk

Stahn et al. (2019) Neurostructural changes following 14-Month Winter-Over

- Reductions in hippocampal volume of the dentate gyrus
  - Associated with lower cognitive performance in tests of spatial processing and selective attention (no decreases in performance on other cognitive tests)
  - Associated with reductions in BDNF concentrations

Alfano et al. (2021) Decrease in Positive Adaptation & Increase in Poor Self- Regulation Nine-Month Winter-Over

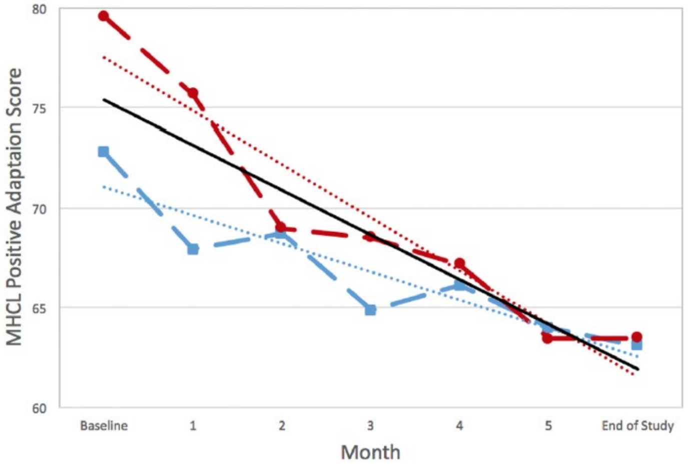
Mental Health Check List (MHCL)

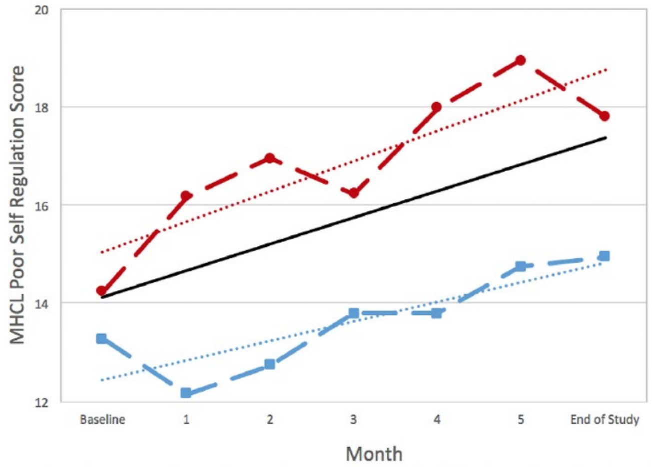
Measure consists of 23 individual items (e.g., “effective”, “racing thoughts”) that ‘load’ on 3 primary categories: **Positive Adaptation**, **Poor Self-Regulation**, and **Anxious Apprehension**.

Physical Symptoms Checklist

Positive Emotion Strategies

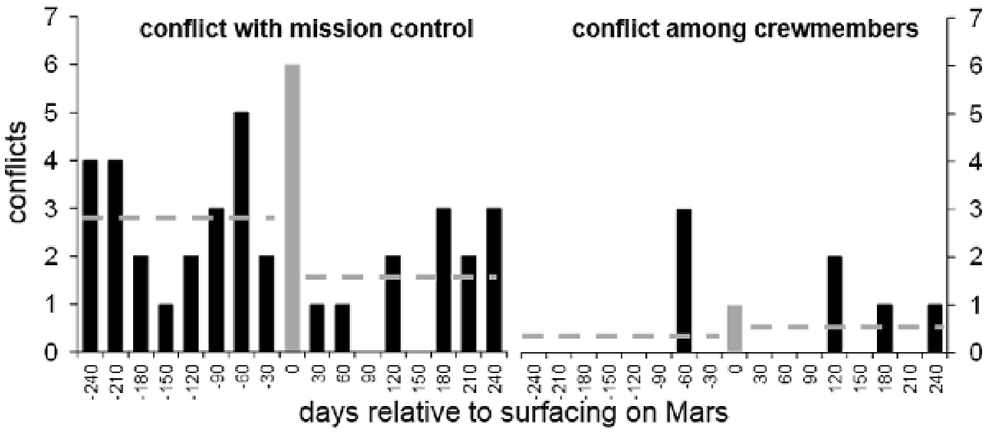
DHEA and Cortisol

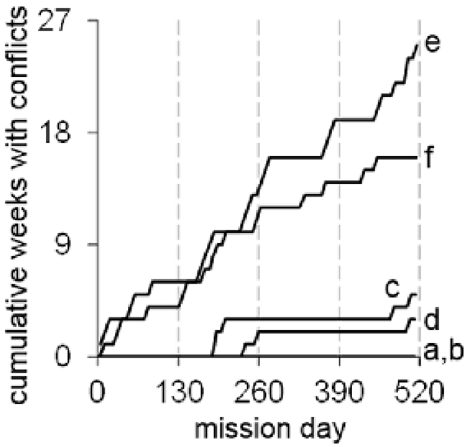


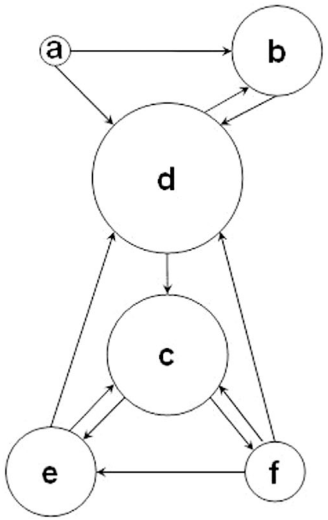


Analogs - What Are We Learning for Exploration?

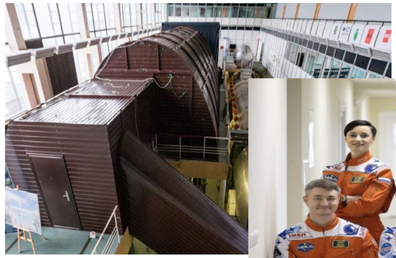
Basner et al. (2014) Increased conflict and isolation over time 520-day mission







Lungeanu et al. (2023) Declines in Relationships in ~ 250-day mission



Surveys of network relationships:

- Motivation: "Who kept your taskforce motivated?"
- Leadership: "Who did you rely on for leadership?"
- Hindrance: "Who makes tasks difficult to complete?"
- Viability: "With whom would you want to go on a 3-yr mission?"

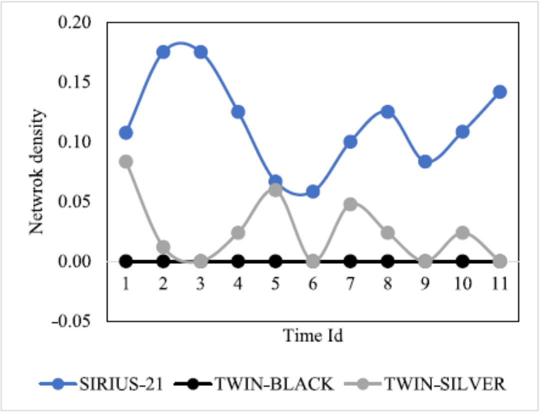


Fig. 6. Network density for hindrance relation.

In comparison to control teams, SIRIUS-21 crew exhibited:

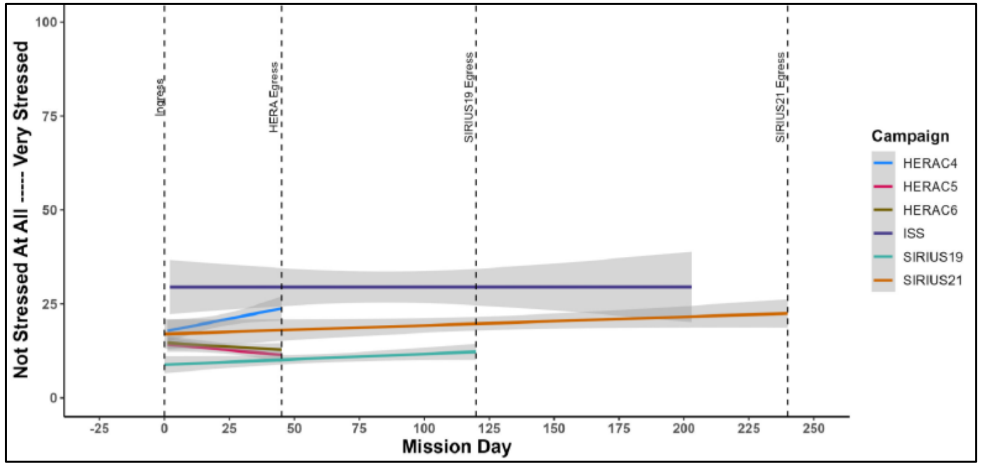
- **more motivating relationships**
- **more hindrance relationships**
- **fewer viable relationships**
- **sustained subgrouping** following off-nominal event

Analogs - What Are We Learning for Exploration?

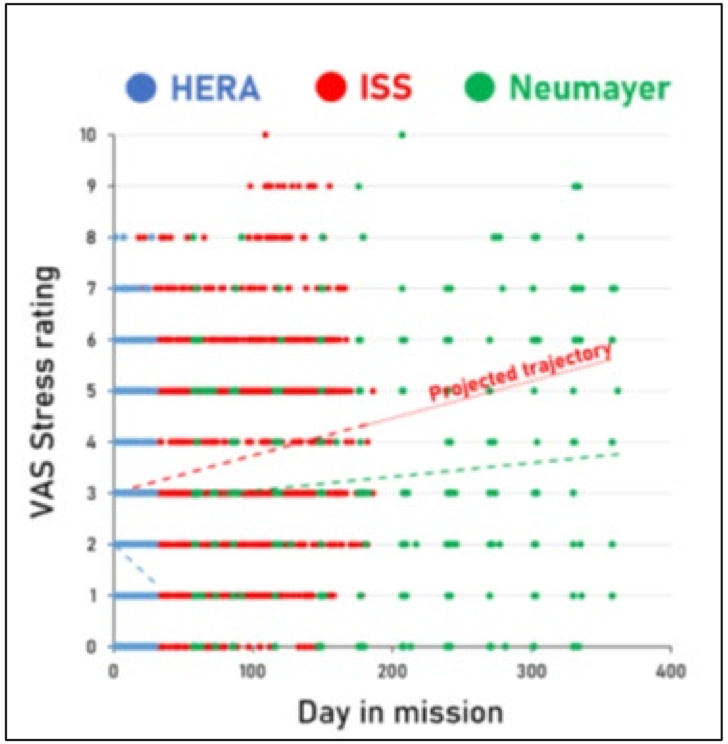
Limitations of Analog Research

- Small n
- Measurement limitations
- Generalizable to exploration?
- Generalizable to astronauts?

VAS Stress Ratings



Dev et al. (2024)



Jones et al. (2024)

- **Radiation exposure?**

Combined Effects: Sleep Fragmentation and Radiation Exposure

Sleep Fragmentation Exacerbates Executive Function Impairments Induced by Low Doses of Si Ions

Richard A. Britten,[a,b,c,d,1] Arriyam S. Fesshaye,[a] Vania D. Duncan,[a] Laurie L. Wellman[c,e] and Larry D. Sanford[c,e]

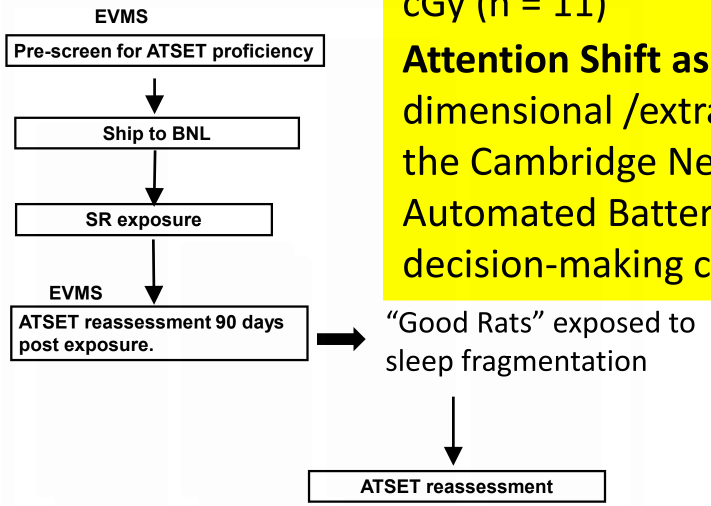
RADIATION RESEARCH **194**, 116–123 (2020)
0033-7587/20 $15.00

DOI: 10.1667/RADE-20-00080.1

Si Radiation

Whole-body irradiation with 600 MeV/n Si ions 5 cGy (n = 11)

Attention Shift assay modeled after the intra-dimensional /extra-dimensional component of the Cambridge Neuropsychological Test Automated Battery (CANTAB) – testing complex decision-making cognitive function



ATSET – attentional set-shifting
ATRC – attempts to reach criteria
SR – space radiation
EVMS – Eastern Virginia Medical school
BNL – Brookhaven National Laboratory

Sleep fragmentation exacerbates executive function impairments induced by protracted low dose rate neutron exposure

Richard A. Britten, Vania D. Duncan, Arriyam S. Fesshaye, Laurie L. Wellman, Christina M. Fallgren & Larry D. Sanford

Received 25 Jul 2019, Accepted 29 Oct 2019, Accepted author version posted online: 14 Nov 2019, Published online: 06 Dec 2019

Download citation https://doi.org/10.1080/09553002.2019.1694190

INTERNATIONAL JOURNAL OF RADIATION BIOLOGY
https://doi.org/10.1080/09553002.2019.1694190

Sleep Fragmentation Chamber (Lafayette Instrument Co., Lafayette, IN)

Neutron Radiation

The rats were exposed to neutrons for 15.9–18.3 h/day, N.30), total neutron dose: 18 cGy

SD – Simple Discrimination
CD – Compound Discrimination
CDR – Compound Discrimination Reversal
IDS – Intra Dimensional Shift
IDR – Intra Dimension Reversal
EDS – Extra Dimensional Shift
EDR – Extra Dimensional Reversal

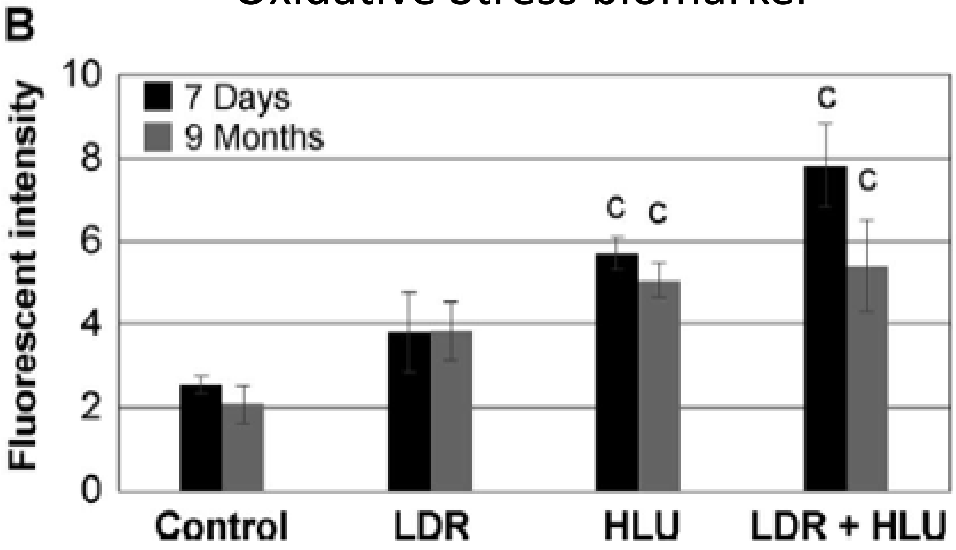
Sleep Fragmentation

Rats placed in Sleep Fragmentation chamber, Active/Sleep (Dark/Light), Sleep time 2 mins, Allows dozing but not deep (REM) sleep.

1. Under rested wakefulness conditions, no significant effect of Si or low dose neutron radiation
2. After sleep fragmentation rats showed a significant performance effects
   - for the IDR, and EDS stages of the ATSET test after Si radiation
   - for the IDR stage of the ATSET test after low dose neutron radiation
   - IDR deficits are not typically induced after SR exposure

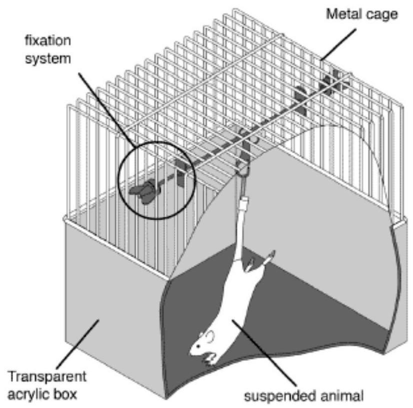
Combined Effects: Space Radiation and Altered Gravity

Oxidative Stress biomarker

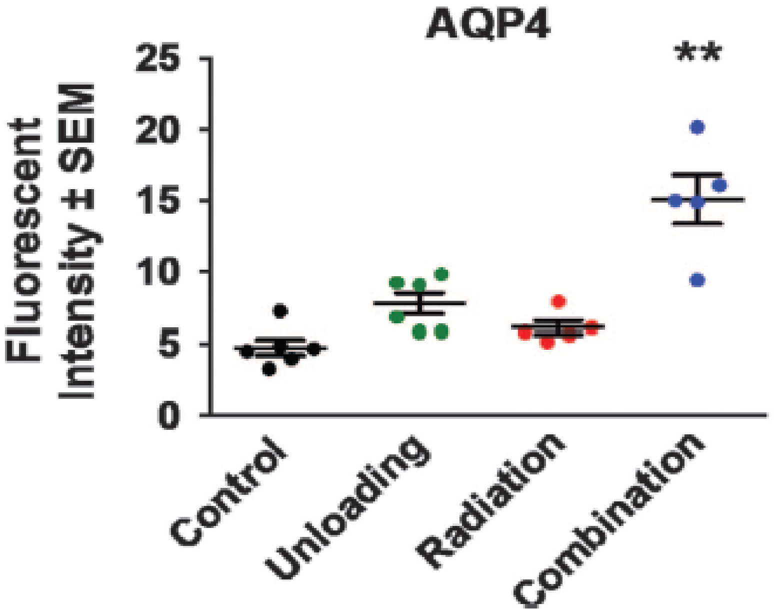


4-hydroxynonenal (4-HNE) staining in the hippocampus (panel B) at 7 days or 9 months.

Hind Limb Unloading



BBB biomarker



Water transporter aquaporin 4, astrocyte foot / endothelium interface marker at 9 months.

Stressors:

- Low dose gamma radiation (LDR)
- Hindlimb unloading (HLU)
- Combination of both for 3 weeks

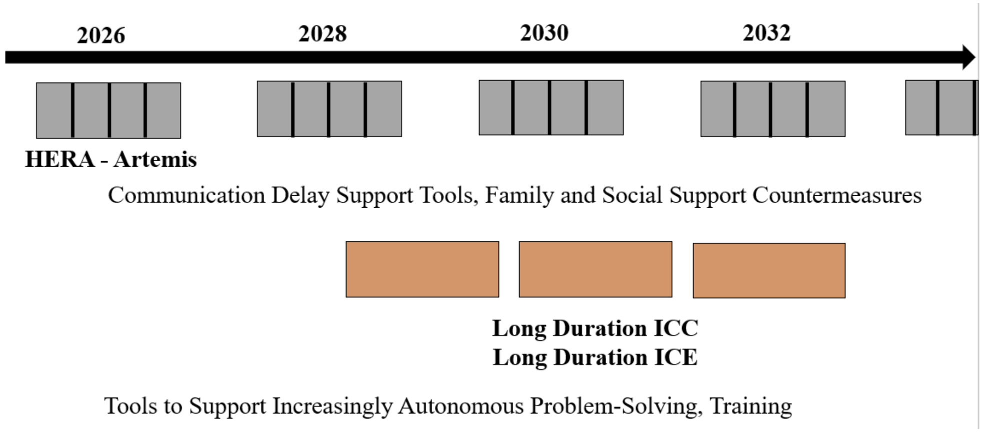
Measurements of LDR+ HLU Effects on:

- Mouse Brain Oxidative Stress increases (4-HNE)
- Blood Brain Barrier modified (AQP4)
- Microvessel changes

Mao et al. (2016), Bellone et al. (2016)

Efforts to Address Limitations

- Efforts underway to increase analog fidelity
- Support multiple efforts and increase n
  - Collaborating with other disciplines, agencies
- Target astronaut-like individuals



- Radiation: Animal to Human Translation
  - Soliciting research on animal-to-human translation
  - Align measures
  - When possible, evaluate pathways/mechanisms relative to performance outcomes
  - Future approaches: Validation plan includes irradiating rodent returning from space/microgravity

Research in Transit and on Surface of Mars

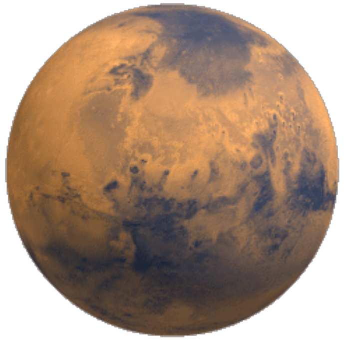
Measure and mitigate the effects of risk factors – unique to Mars, individually and/or in combination

Transit to Mars:

- Weightlessness
- Extended duration in isolation and confinement
- Increasing levels of autonomy driven by distance from earth and resulting communication delays
- Increasing exposure to galactic cosmic radiation
- Vehicle interfacing and maintenance
- Progressively Earth-out-of-view

On surface:

- Gravitational transitions at landing – from weightlessness to partial gravity
- Prolonged duration in isolation and confinement with reduced and delayed ground communication
- Increasing (and cumulative) exposure to galactic cosmic radiation
- Sunlight on Mars – reduced short wavelength light, less bright than Earth
- 24 hour and 39-minute day-night cycle impacts to crew and mission control
- Living and working in partial gravity – implications for sleep stations, work surfaces
- Vehicle subsystem interface and maintenance (e.g. plant systems, exercise)
- Surface hazards including extreme temperatures dust storms



Research in Transit and on Surface of Mars

Relative to these risk factors/stressors, measure behavioral and performance outcomes through multi-modal assessments - individual performance, individual-individual "team" performance, and individual to vehicle/interface performance

Example behavior and performance outcomes

- Cognitive function
- Emotion regulation
- Psychosocial adaptation
- Team functioning, including team cohesion, communication, cooperation
- Operational performance, including:
    - Problem solving, creativity, task completionEgress
    - EVAs

Other levels of measurement, to be collected concurrently:

- Blood biomarkers
- Neurostructural changes (if feasible – at minimum, pre and post)

Multi-modal assessments that include subjective & objective measures can also assess countermeasure effectiveness

Example countermeasures:

- In-mission training protocols, adaptive training;
- Communication protocols with ground and family support, given extended com delay;
- Augmented food system (e.g. plants), exercise capabilities, lighting, sleep stations, and other risk mitigation strategies

Conclusion

- Future exploration missions will introduce new hazards/stressors to individual and team behavioral health and performance
- Spaceflight studies in current ISS operations highlight the importance of nominal schedules, workload, habitability/environmental countermeasures; and that the current selection process and BHP operations support, facilitated by low earth orbit, is very effective
- Research in terrestrial analogs have shown that in context of future exploration missions, other aspects of behavioral health and performance (e.g. emotion regulation, social aspects), may be impacted
- Rodent research is underway to further characterize potential combined effects of exploration risk factors and radiation
- Future studies will increasingly focus on countermeasure effectiveness
- Limitations with current analogs exist
- Efforts are underway to attempt to address these limitations