Strategy for Risk Quantification of Spaceflight Crew Health and Performance Using Dynamic Probabilistic Risk Assessment

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- Quantifying Impact of Crew Health and Performance System on Human System Risks
- Proof-of-Concept Approach
  - Ensemble of “Mini-Models”
  - Demonstrate with 1 Capability / 9 Medical Risks
  - Low Credibility for Decision Making

Crew Health and Performance System

While there is no shared definition of a Crew Health and Performance System, the following are derived from the NASA Human Health, Medical, and Performance Spaceflight Standards.

These are intended to capture the cross-program functionality and capabilities needed to ensure the health and performance of the crew.

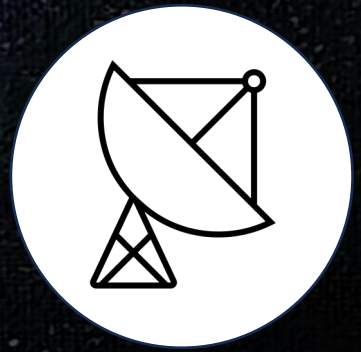
Countermeasures

Behavioral Health

Medical Capability

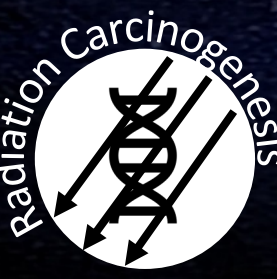
Environmental

EVA Health



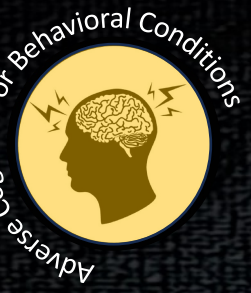
Ground Operations

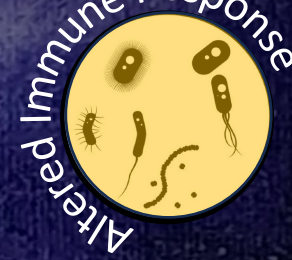
THE HUMAN SYSTEM RISKS

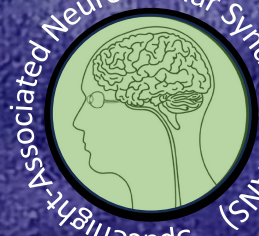


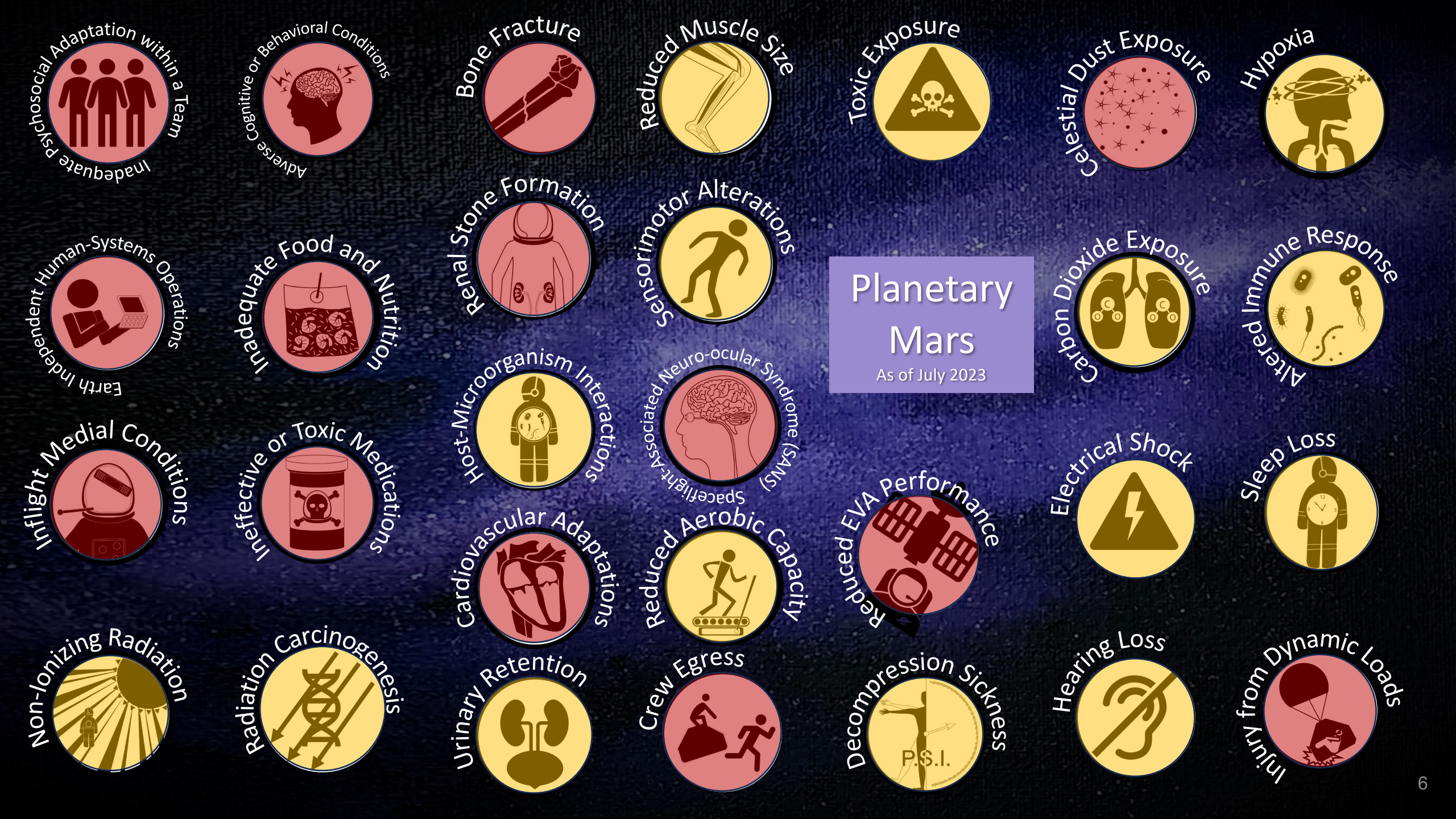
Lunar Orbital + Surface

As of July 2023





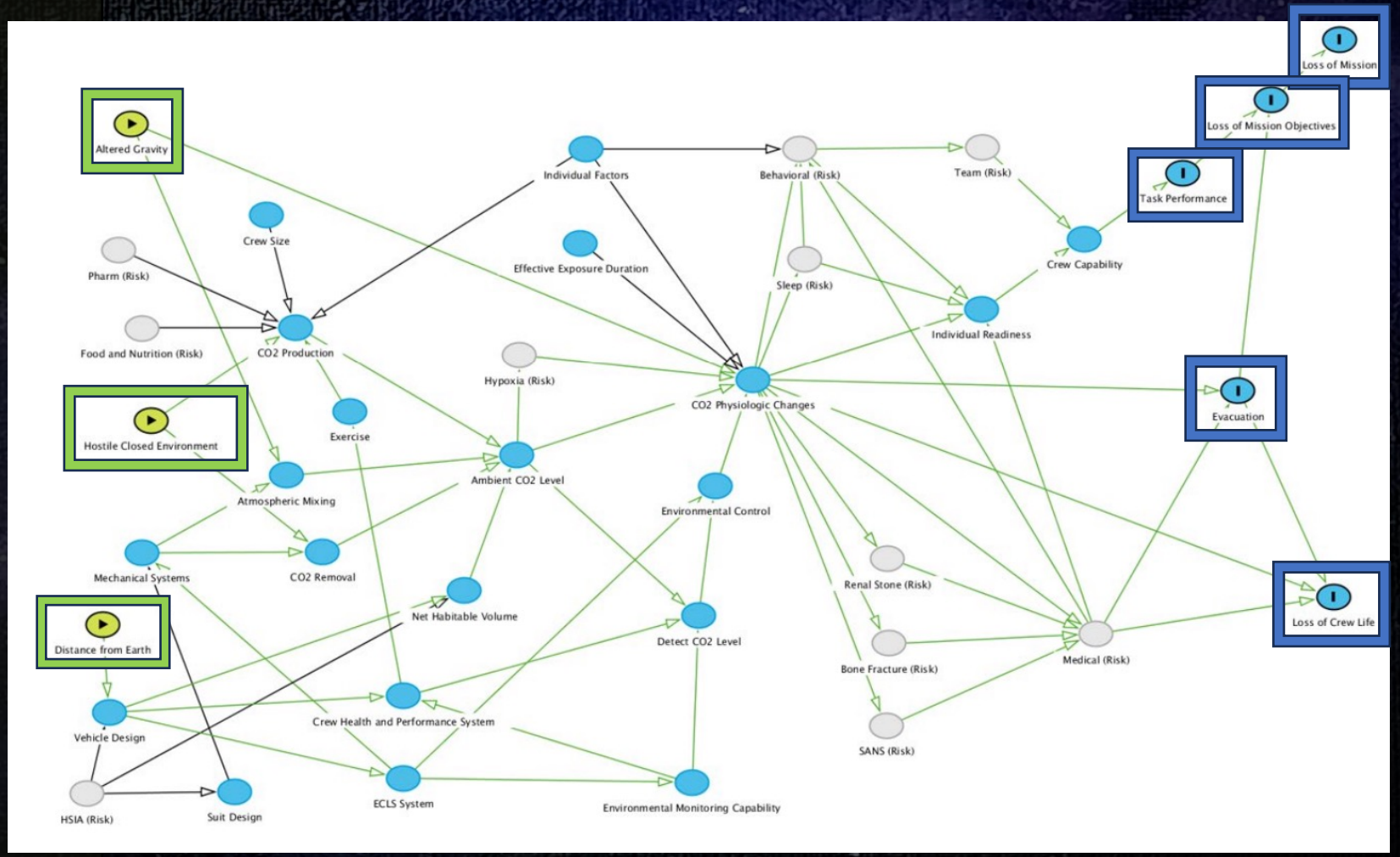


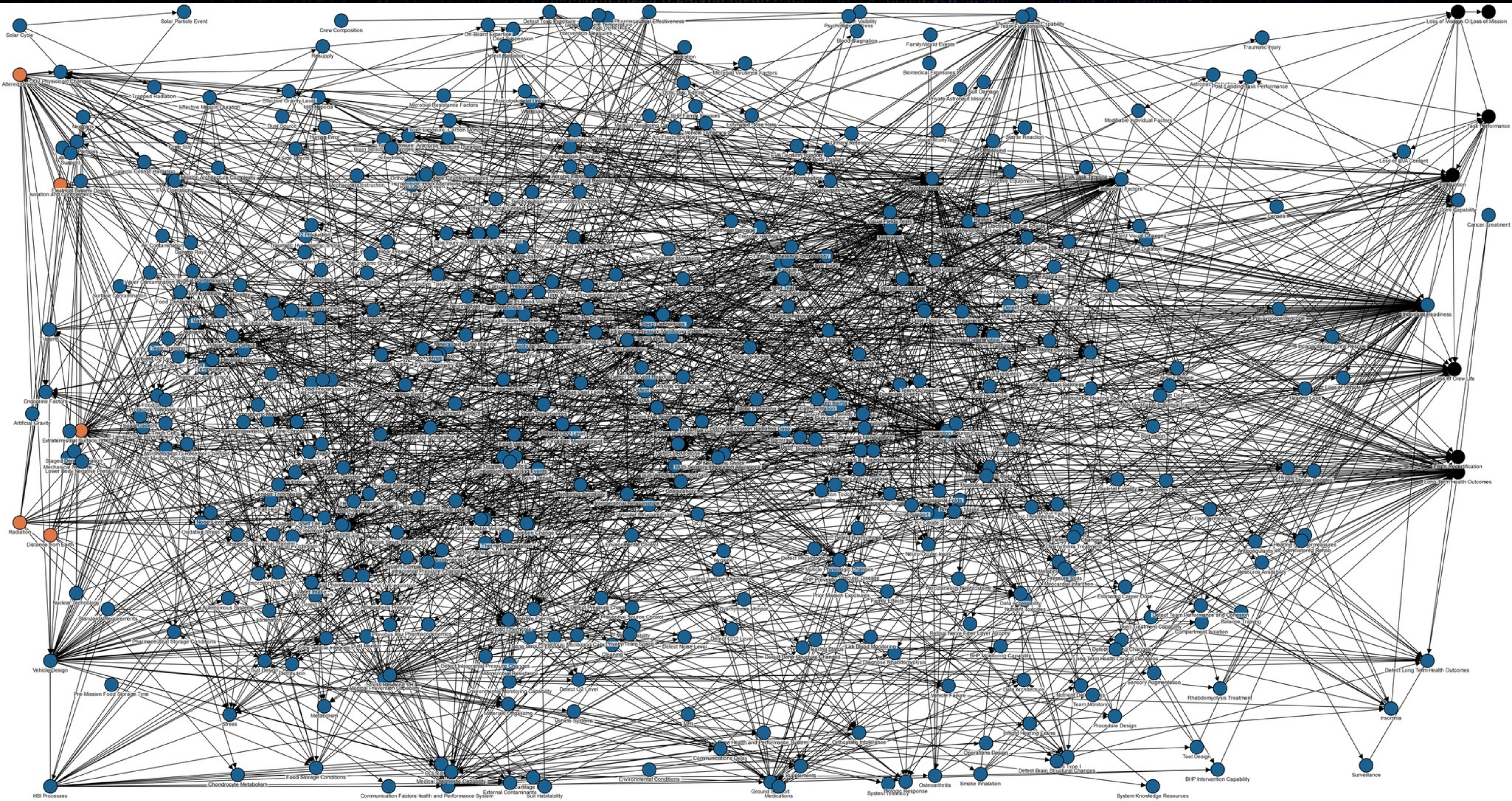

Inadequate Psychosocial Adaptation within a Team
Adverse Cognitive or Behavioral Conditions
Bone Fracture
Reduced Muscle Size
Toxic Exposure
Celestial Dust Exposure
Hypoxia
Earth Independent Human-Systems Operations
Inadequate Food and Nutrition
Renal Stone Formation
Sensorimotor Alterations
Planetary Mars
As of July 2023
Carbon Dioxide Exposure
Altered Immune Response
Inflight Medial Conditions
Ineffective or Toxic Medications
Host-Microorganism Interactions
Spaceflight-Associated Neuro-ocular Syndrome (SANS)
Electrical Shock
Sleep Loss
Cardiovascular Adaptations
Reduced Aerobic Capacity
Reduced EVA Performance
Non-Ionizing Radiation
Radiation Carcinogenesis
Urinary Retention
Crew Egress
Decompression Sickness
P.S.I.
Hearing Loss
Injury from Dynamic Loads

Directed Acyclic Graphs (DAGs)

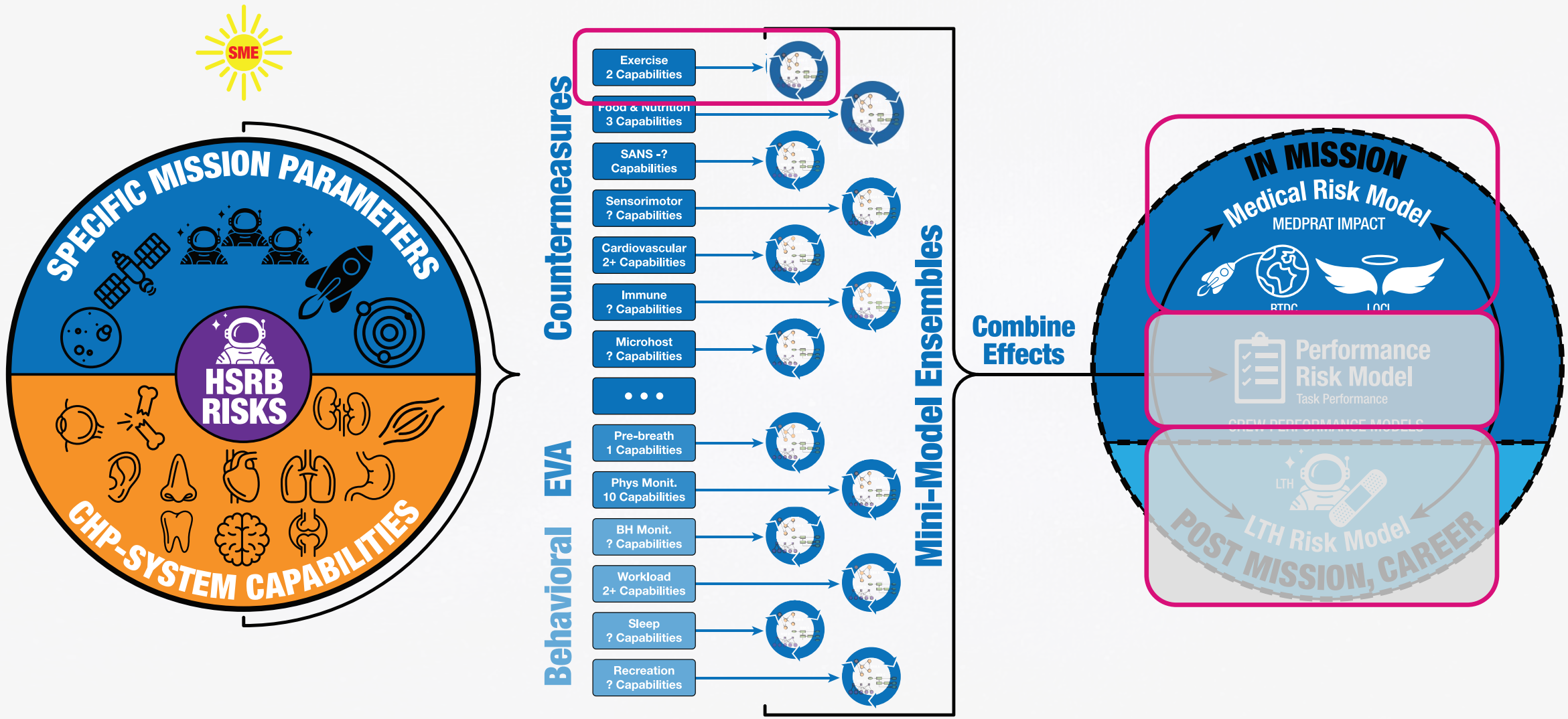
Each risk is accompanied by a DAG that describes how the spaceflight hazards and other factors are related to one another and lead to mission outcomes.

Risk of Nominal Acute and Chronic Ambient Carbon Dioxide Exposure in Crewed Vehicles (CO2 Risk)





Solar Cycle
Solar Particle Event
Crew Composition
Loss of Mission
Traumatic Injury
Family/World Events
Biomedical Exposures
Blood Stagnation
Microbial Virulence Factors
Altered Gravity Physiologic Changes
Trapped Radiation
Effective Mission Duration
Microbial Resistance Factors
Modifiable Individual Factors
Task Performance
Startle Reaction
Galactic Cosmic Radiation
Isolation and Confinement
Loss of EVA Content
Crew Capability
Cancer Treatment
Individual Readiness
Loss of Crew Life
Long Term Health Outcomes
Artificial Gravity
Endocrine Factors
Radiation
Distance from Earth
Nuclear Technology
Vehicle Design
Pharmaceutical Storage Conditions
Autonomous Systems
Pre-Mission Food Storage Time
Stress
Metabolism
HSI Processes
Chondrocyte Metabolism
Food Storage Conditions
Communication Factors
Suit Habitability
External Contaminants
Environmental Conditions
Communications Delay
Ground Support
Medications
Supplements
Osteoarthritis
Smoke Inhalation
System Knowledge Resources
Surveillance
Insomnia
Rhabdomyolysis Treatment
Detect Long Term Health Outcomes
Tool Design
BHP Intervention Capability
Procedure Design
Team Monitoring
Operations Design
Detect Brain Structural Changes
Orthostatic Intolerance
Vehicle Failure
Data Architecture
Sensory Augmentation
Compartment Isolation
Balance Training
Resource Availability
Detect O2 Level
Detect Noise Level
Resupply
Detect Radiation



Defines the context of the mission simulation

Defines the state of the CHP/Human interaction

Quantify the mission risk metrics

Exercise Proof-of-Concept

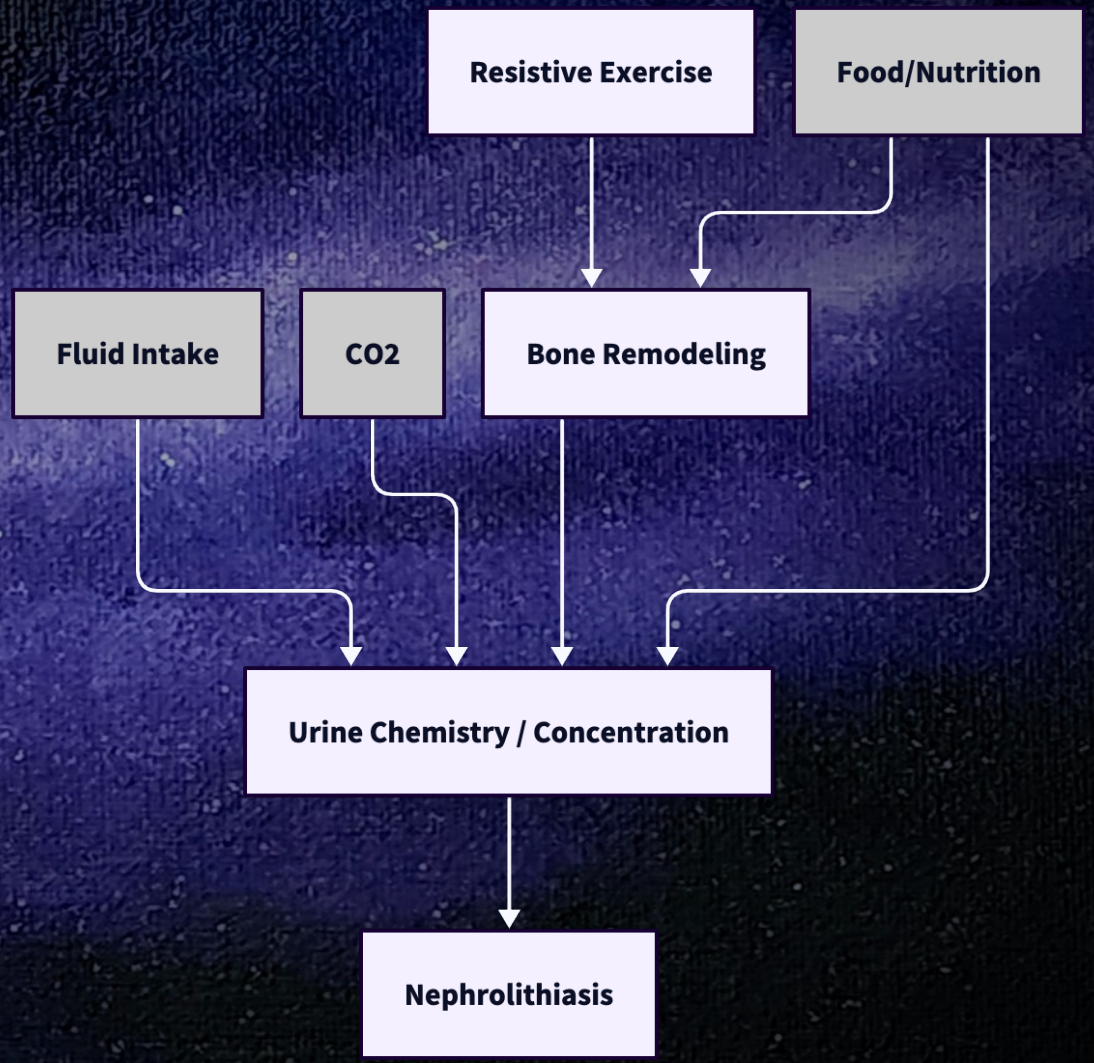
Exercise Proof-of-Concept: Renal Stone

We can make use of previously published models relating urine chemistry to renal stone risk.

Spaceflight data is available for the level of calcium in the urine pre- and in-flight with resistive exercise.

Spaceflight data is available for level of bone remodeling with and without effective resistive exercise.

We make the simplifying assumption that changes in urine calcium level from pre-flight to in-flight are solely attributable to bone remodeling.



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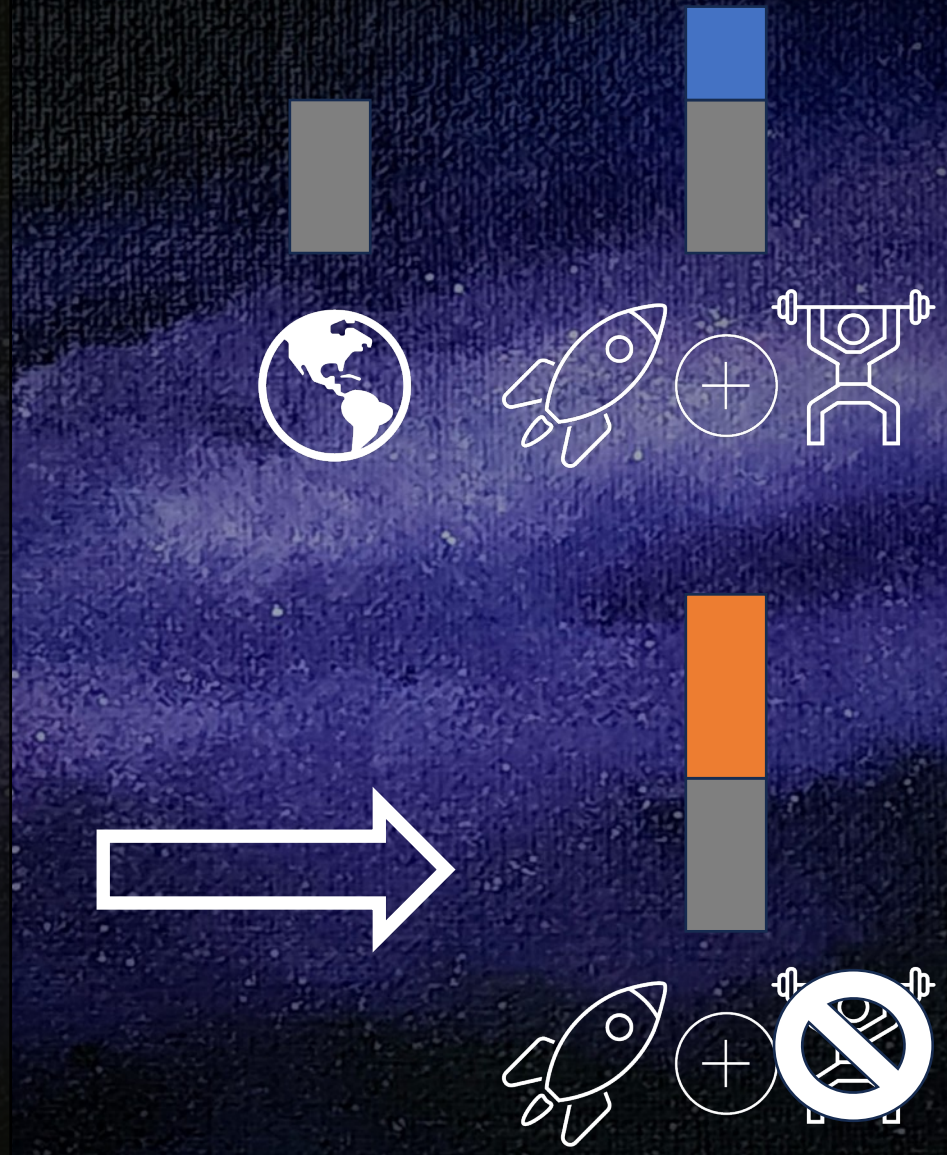


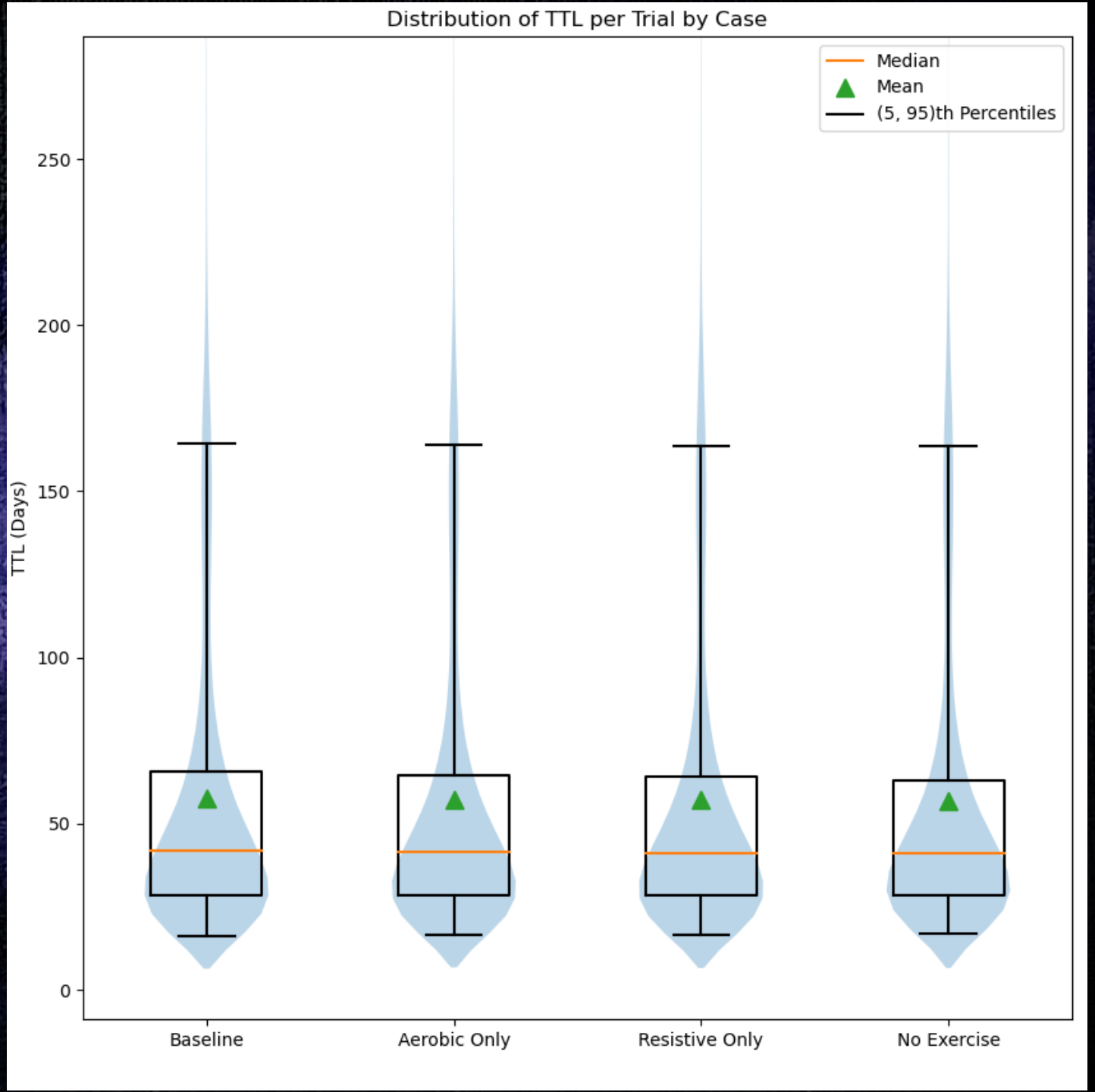
Outcome Risk Metrics: Task Time Lost (TTL)

A total of 32 parameters such as incidence rates and probability of best-case vs worst-case outcomes were adjusted.

We examine a Mars-Transit Analogue (MTA) case: a 250-day mission with 4 crew members.

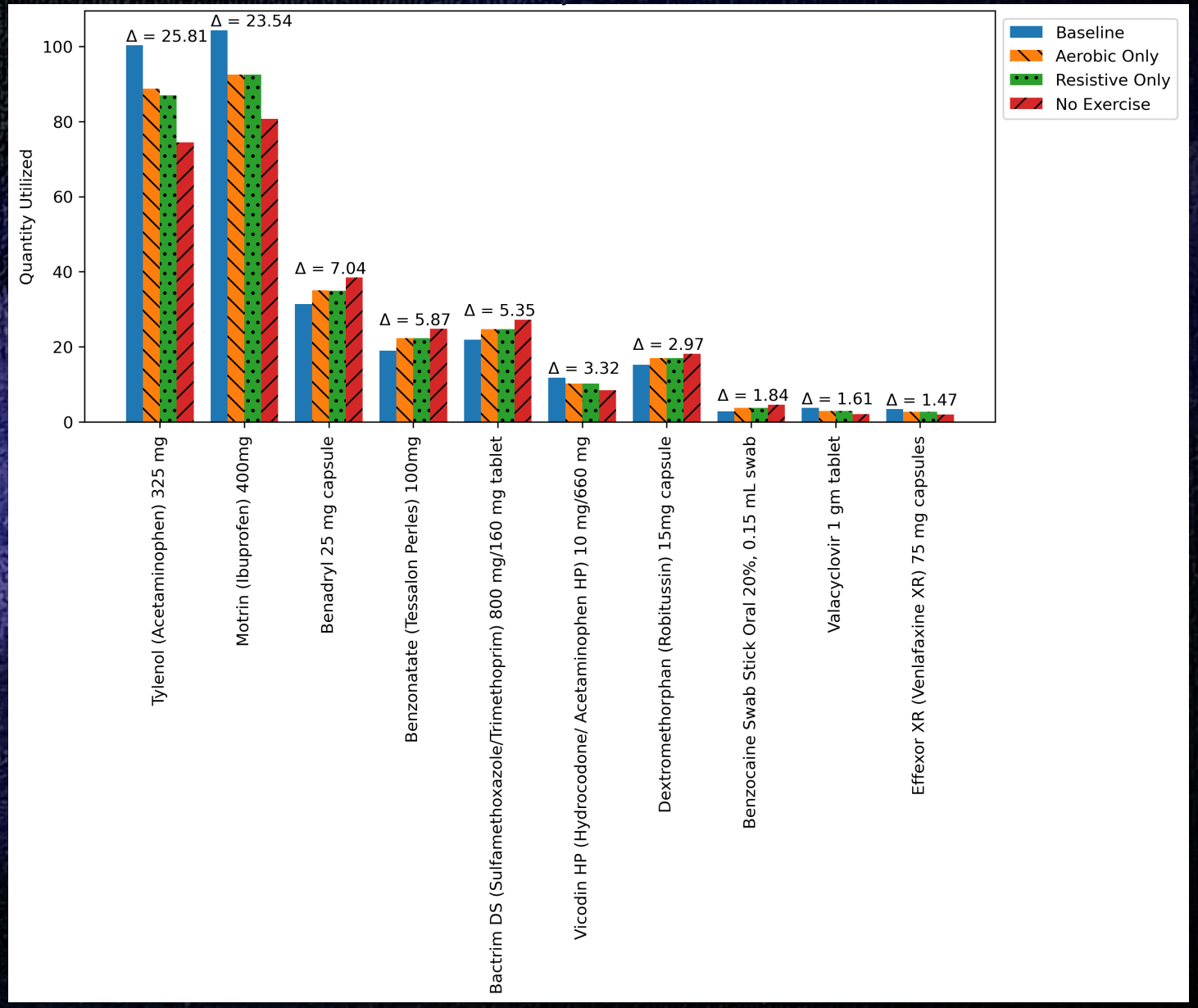
We observe a roughly 1-2% difference in TTL means across the four cases.

Other outcome metrics, such as Loss of Crew Life (LOCL) or Removal to Definitive Care (RTDC), are similar.



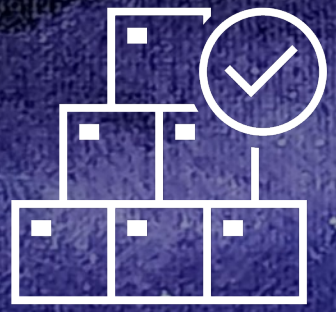
Outcome Risk Metrics: Resource Utilization

Large changes in both absolute and relative utilization of Medical Capability resources.



Proof-of-Concept Outcomes

Trade between
CHP Capabilities



Viability of
Integration Approach

Leverage Existing
Models and Data

Limitations

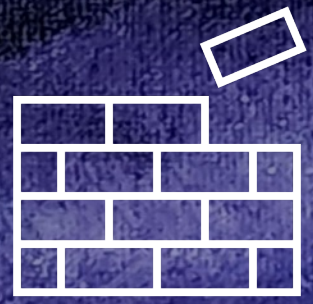
Missing
Critical Metrics

Data Quality

Model Verification
And Validation

Next Steps

Improvement of High-Influence Risks/Capabilities



Integration of New Risks/Capabilities

Integration of Long-Term Health and Performance

Thank You

Questions?