National Aeronautics and Space Administration

Changing Risk in Human Spaceflight

Drivers for Healthcare Automation and Vehicle Integration

March 7, 2018

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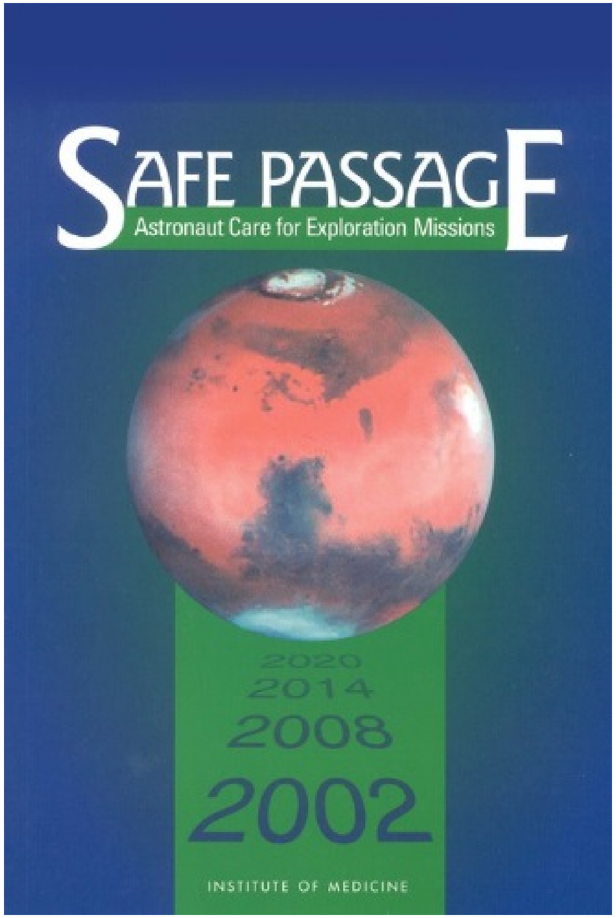
Element Scientist, Exploration Medical Capabilities

Safe Passage



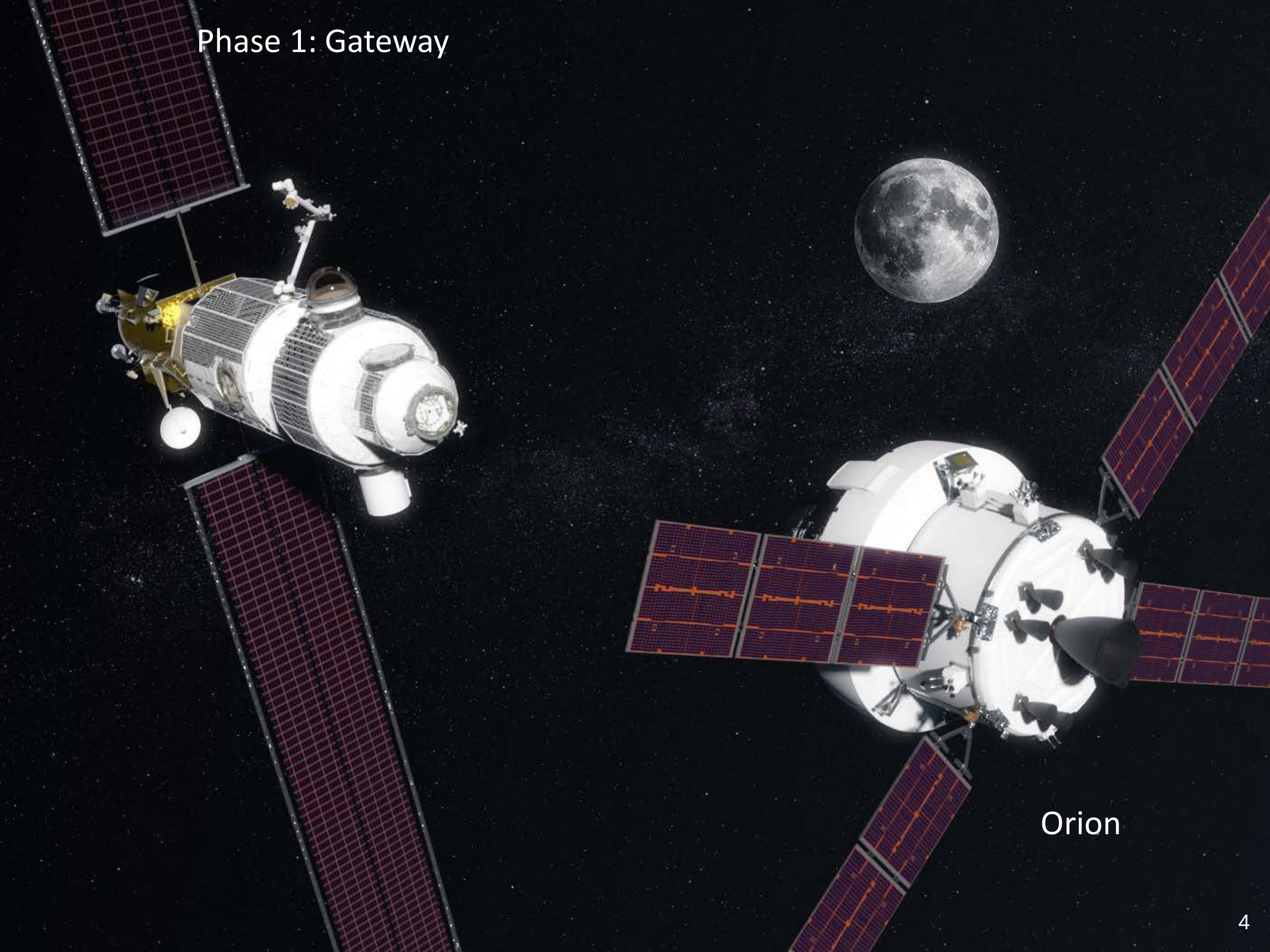
- *From Conclusion 6:*
- *“The human being must be integrated into the space mission in the same way in which all other aspects of the mission are integrated.”*

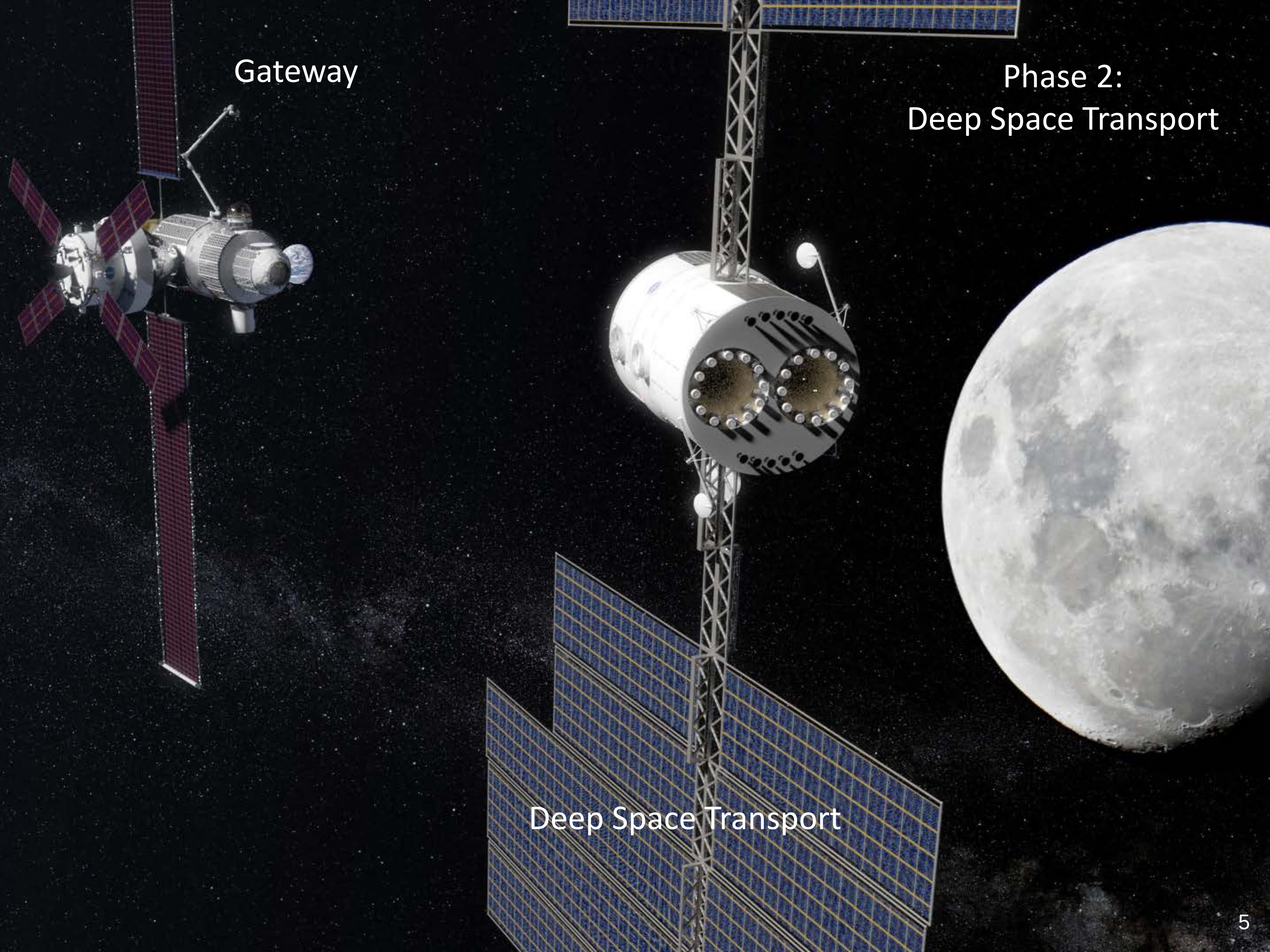
Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit, Board on Health Sciences Policy and I. O. Medicine, *Safe Passage: Astronaut Care for Exploration Missions*, Institute of Medicine of the National Academies Press, 2001.

Outline

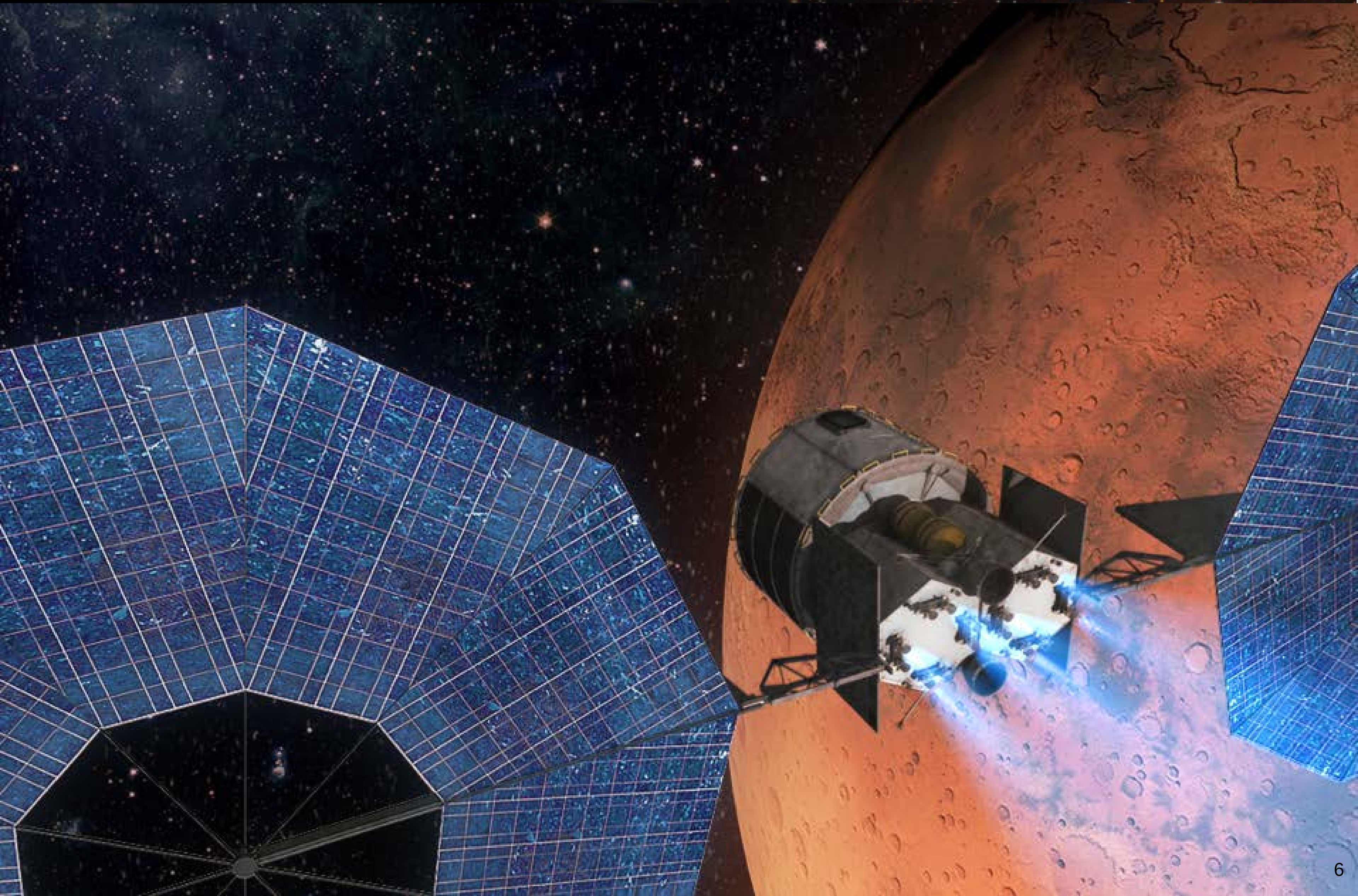
- **Where NASA is headed?**
- **What kind of risk does that incur?**
- **PHM is part of the solution**
- **The larger context**
  - Medical Data Architecture
  - Medical Systems Engineering
  - Vehicle and Mission Integration
- **What are the obstacles?**
  - Data limitations
  - **Evidence-based** predictive analytics
  - Program Expectation and System Integration

Phase 1: Gateway



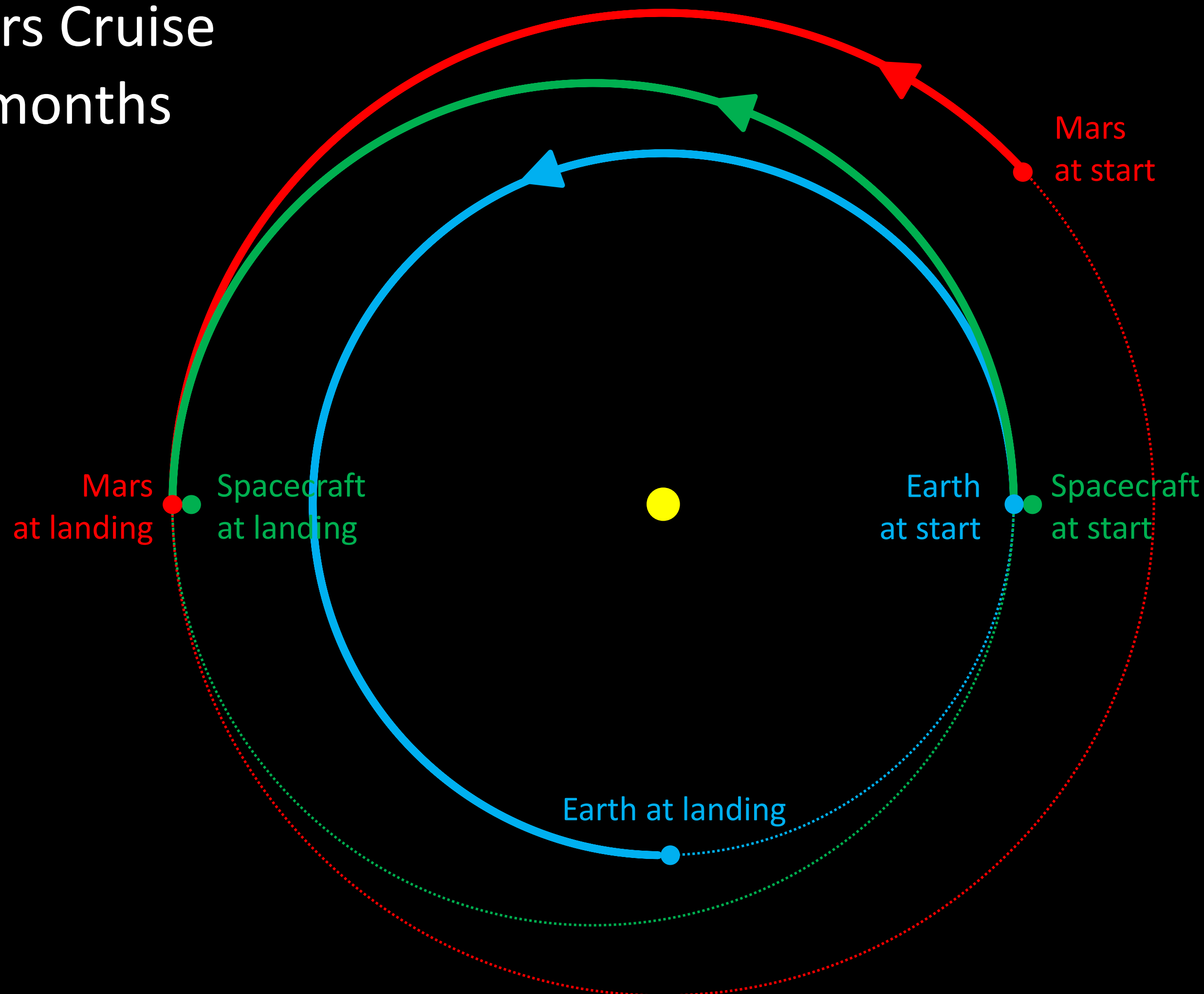

Gateway
Phase 2:
Deep Space Transport
Deep Space Transport

Mars Transit



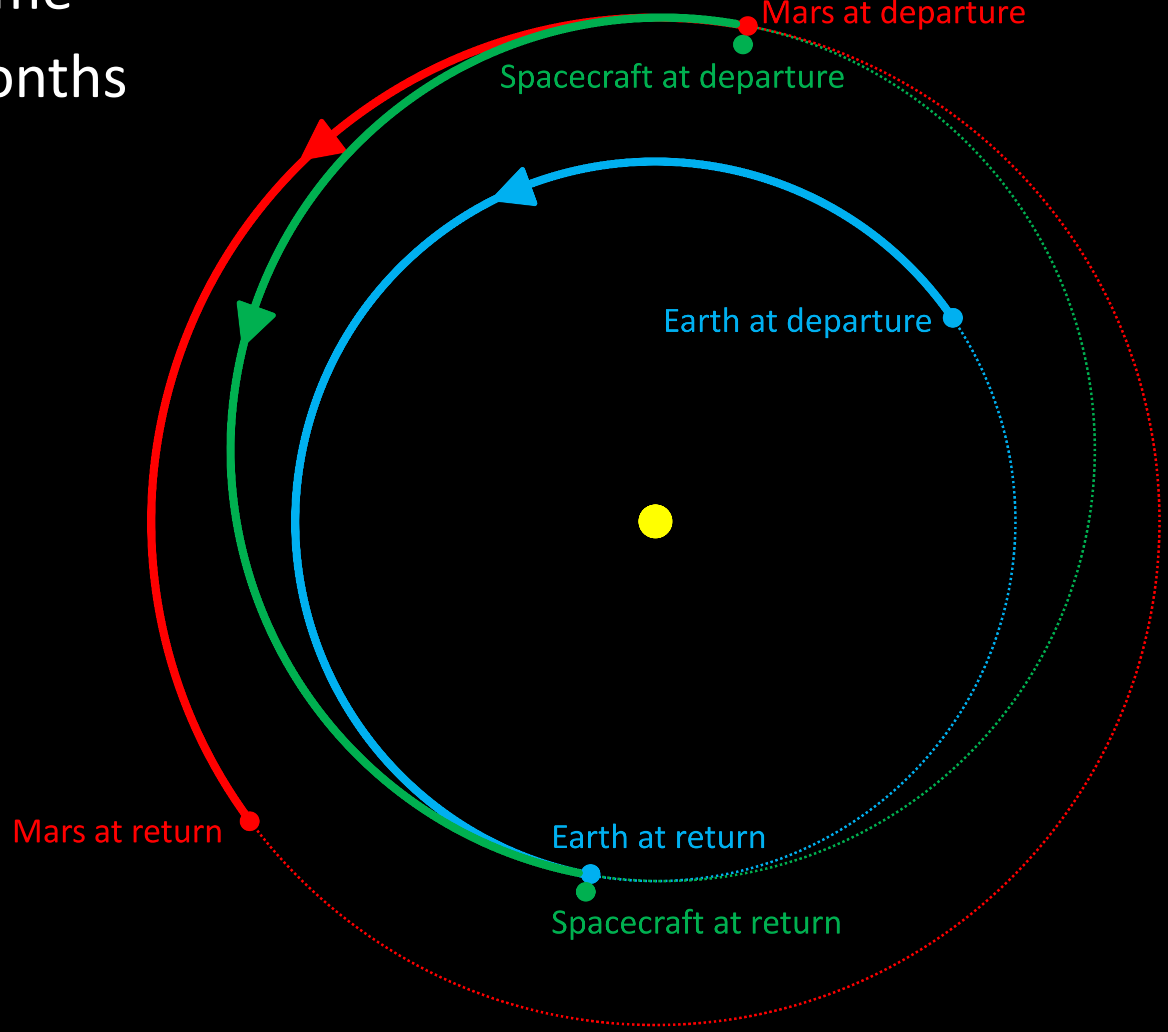
Trans-Mars Cruise

About 9 months



Coming Home

About 9 months



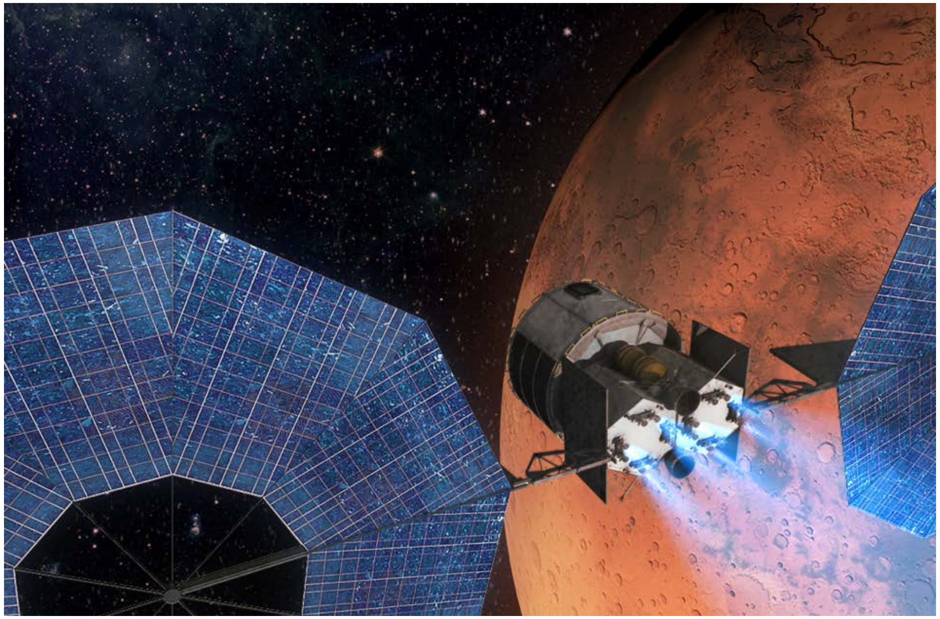
S. Love, E. Nelson, Mars Mission Concept of Operations, Aug 2016

- Unlike the reactive approach being currently employed in the space medicine domain, the suggested PHM-based concept is about real-time monitoring of the healthy crew, where the monitoring is augmented with predictive diagnostic capabilities.

- Given the limited responses on health compromises during exploration-class space missions and the uncertainty inherent to the missions, the ability to predict versus react can mean the difference between mission success and mission failure.

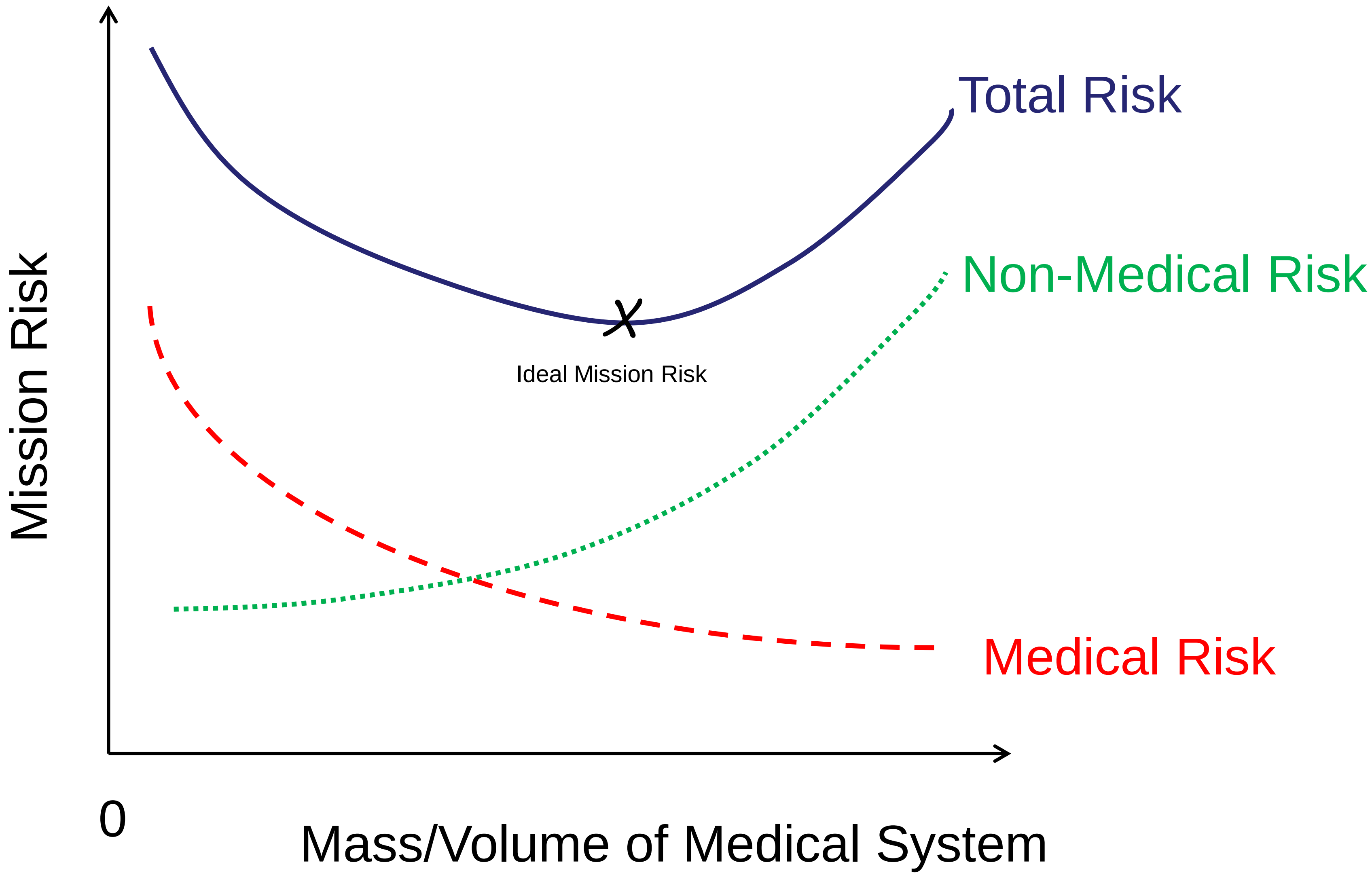
Fink et al. IEEE 2014

How well can we use what we already know?



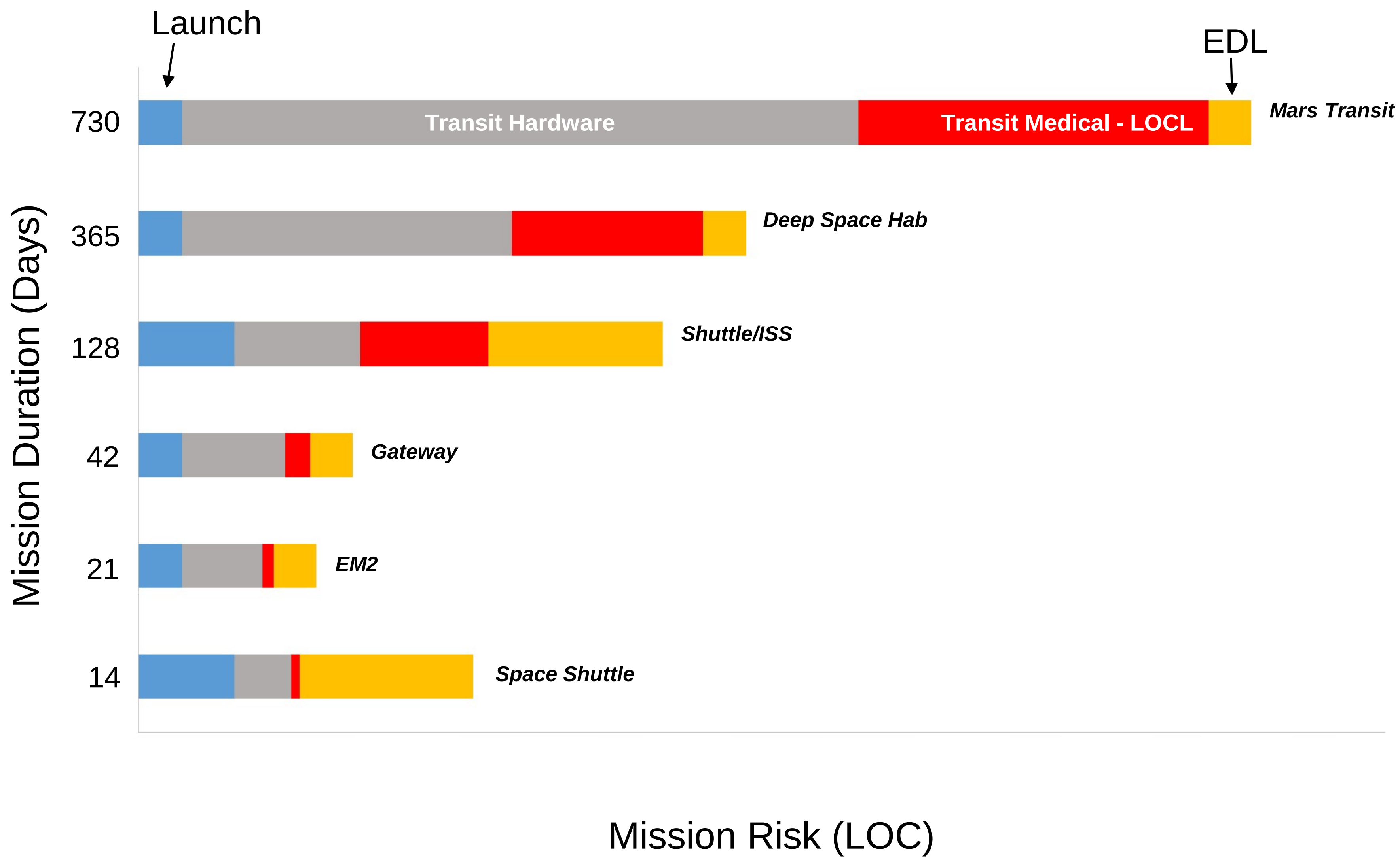
- Real Time Communications
- Medical Evacuation Capability
- Consumables Resupply

Medical and Non-medical Risk



Notional

Changing Mission Risk

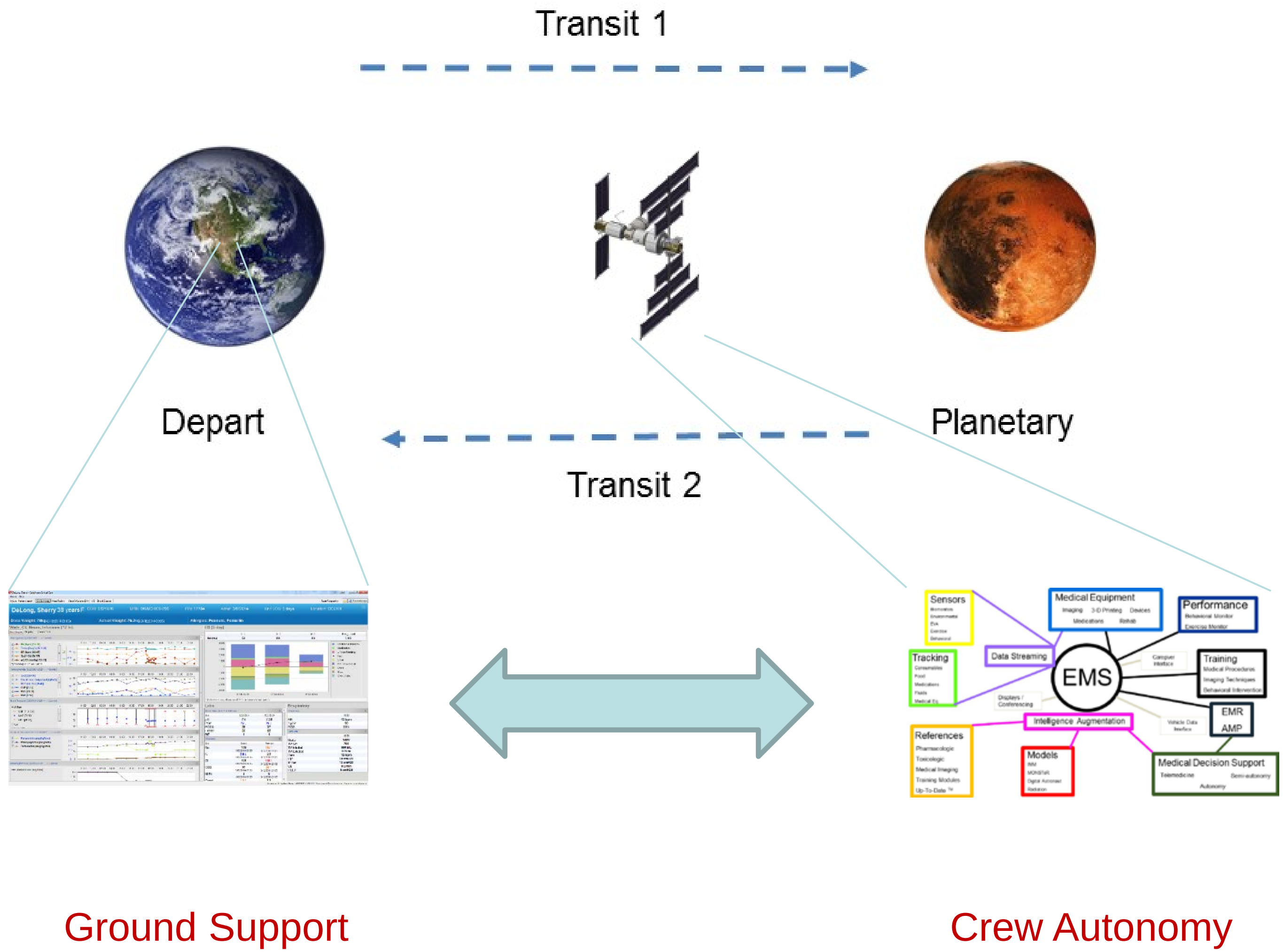


PHM techniques

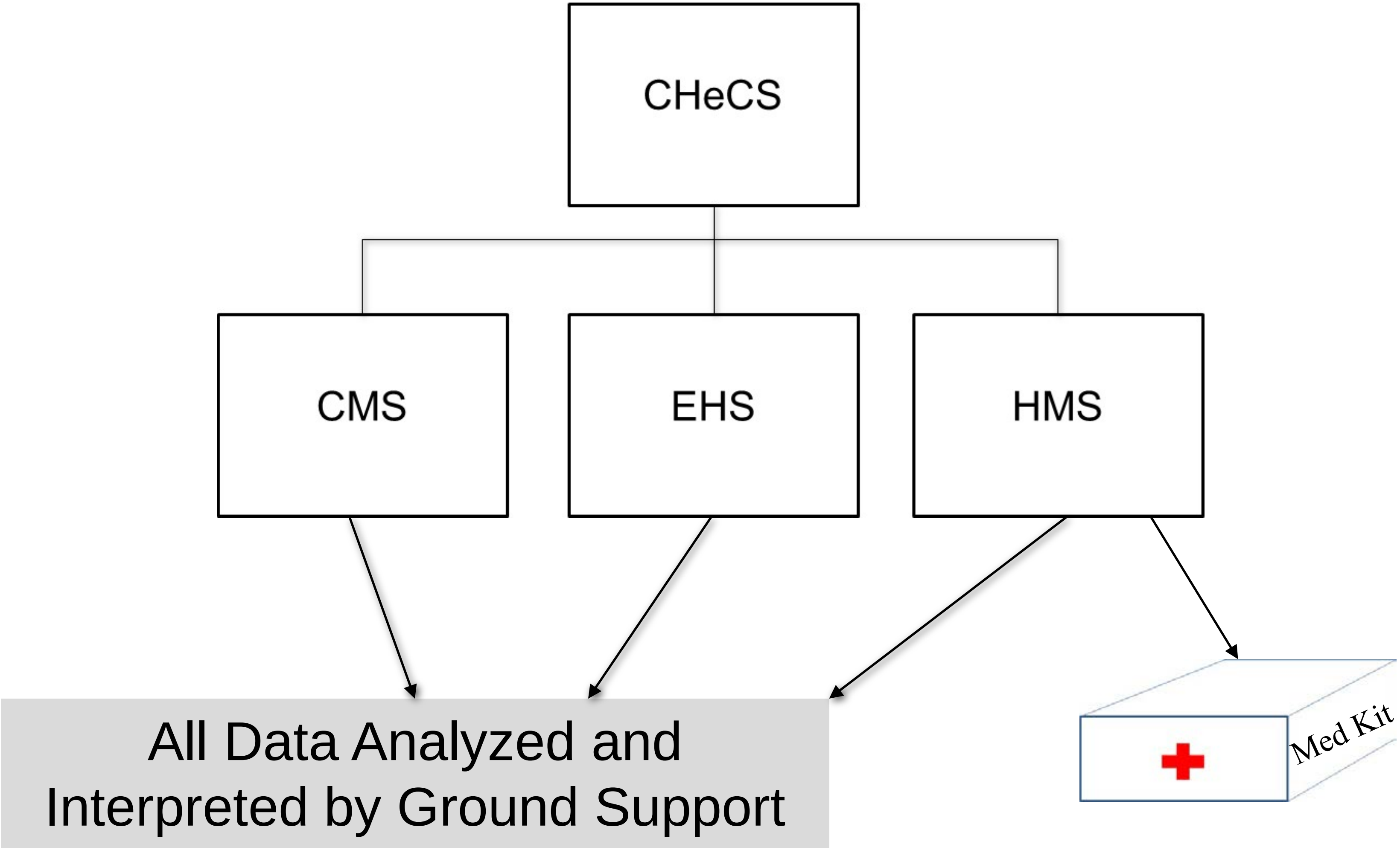
- Proven engineering techniques, data analysis, and statistical methods to astronaut health maintenance in order to translate complex data into accurate knowledge and informed actions;
- Methods for in-situ monitoring of astronaut health using unobtrusive and non-invasive sensors/devices;
- Implementation of telemetry and data processing concepts to improve health care delivery;
- Data-driven approaches, algorithms and models for large-scale health data processing and extraction of features of interest;
- Identification and analysis of precursors on health compromise;
- Statistical techniques and machine learning methods for diagnostics and prognostics;
- Environment anomaly detection.

Fink et al. IEEE 2014

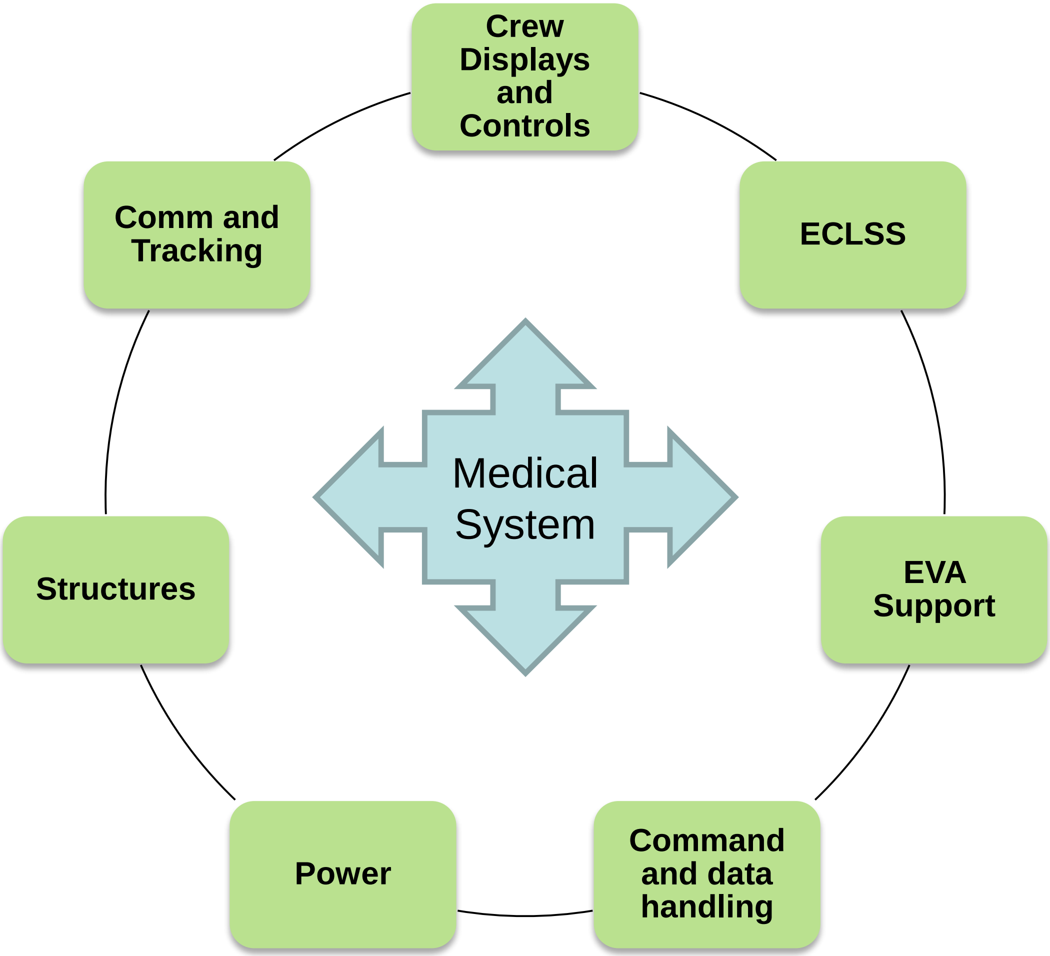
Implementation requires a Human System



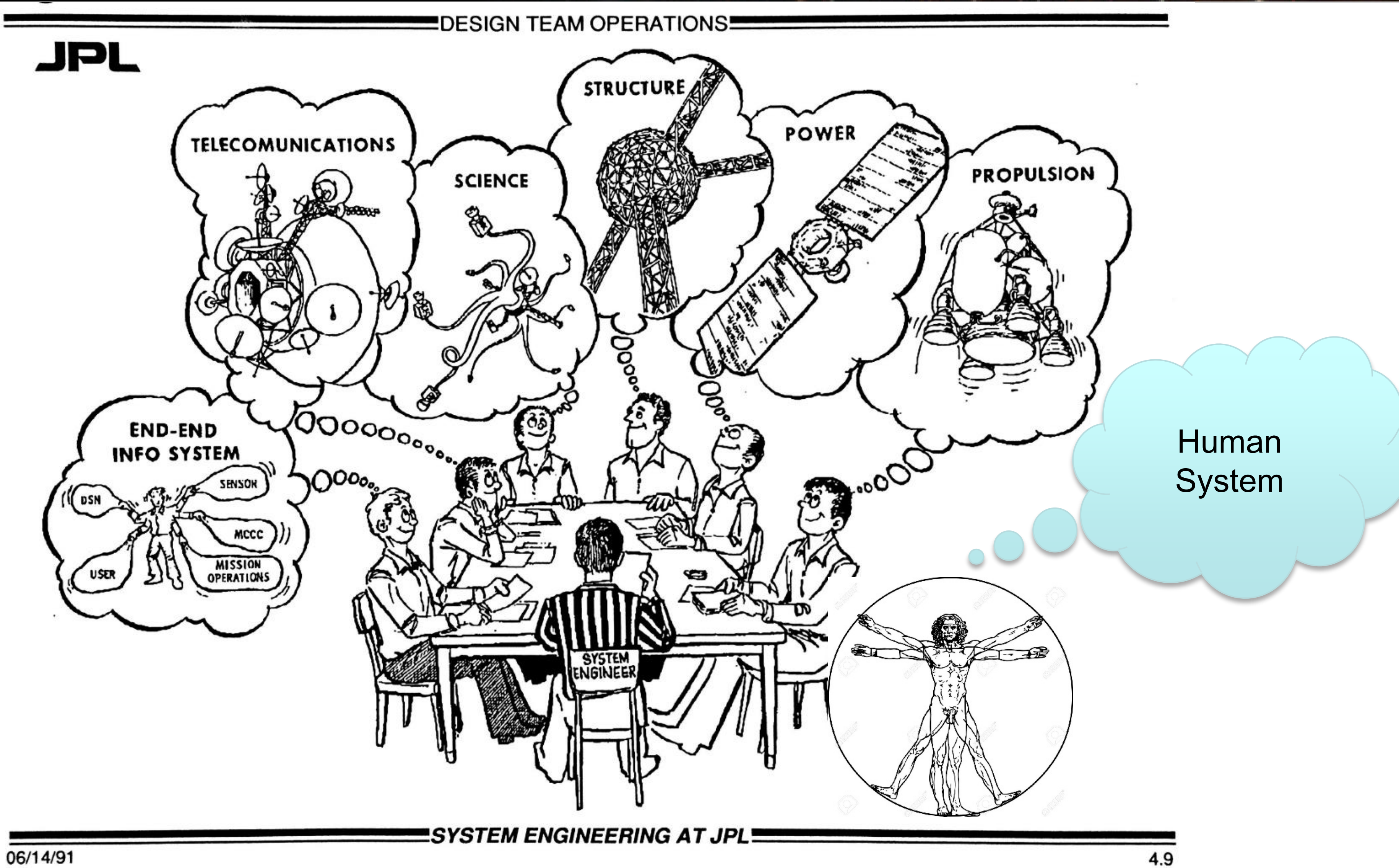
International Space Station



Example Interfaces with the Flight System



Medical Systems Engineering



From "System Engineering at JPL" training course material, June 1991.

NASA Engineering Life Cycle

NASA Life-Cycle Phases	Approval for Formulation	Formulation	Approval for Implementation	Implementation			
Project Life-Cycle Phases	**Pre-Phase A:** Concept Studies	**Phase A:** Concept & Technology Development	**Phase B:** Preliminary Design & Technology Completion	**Phase C:** Final Design & Fabrication	**Phase D:** System Assembly, Integration & Test, Launch & Checkout	**Phase E:** Operations & Sustainment	**Phase F:** Closeout
Project Life-Cycle Gates & Reviews	KDP A MCR	KDP B SRR SDR	KDP C PDR	KDP D CDR SIR	KDP E ORR FRR	KDP F	

*See 7120.5E for acronym definitions

Crew Health and Performance System Must…

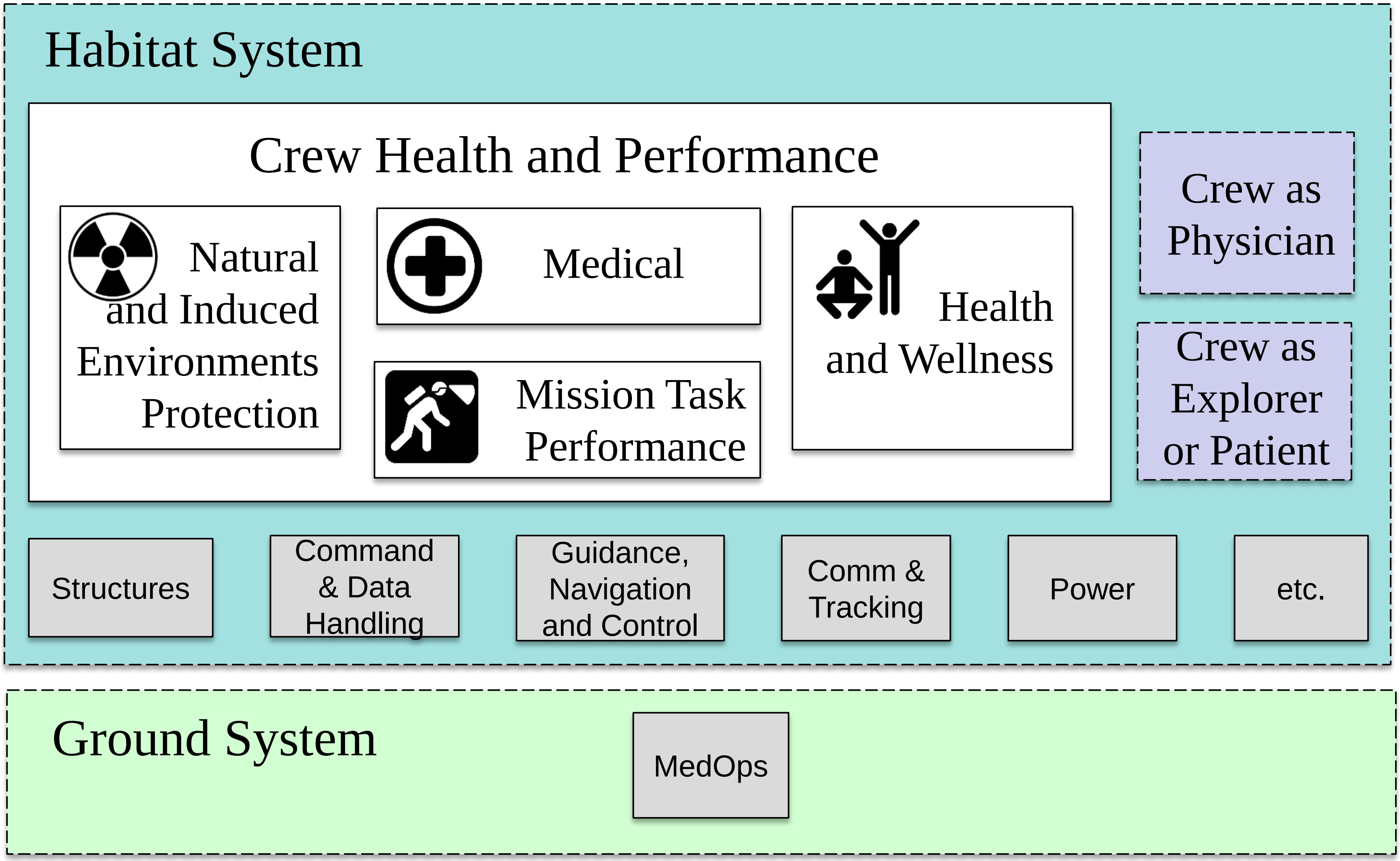
- **Protect from environmental hazards**
  - Radiation protection
  - Noise, vibration, CO_2, etc.

- **Keep healthy crew well**
  - Exercise
  - Other physiological countermeasures
  - Food
  - Behavioral health

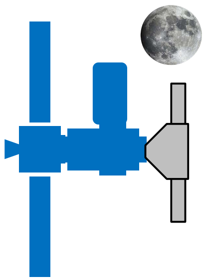
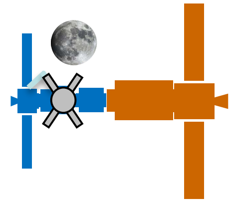
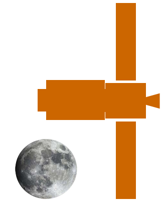
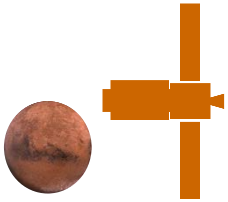
- **Prevent, diagnose, treat, manage long-term health care**
  - Data system
    - Medical Data Capture
    - Medical Training
  - Medical devices
  - Medical supplies

- **Support crew to accomplish mission tasks**
  - Procedures
  - Training
  - User interfaces

Vehicle/Mission Architecture Integration



Stepwise Progression

Gateway 2024	Deep Space Transport 2027	Precursor 2029	Mars 2033
			

Human System Requirements

Test System Data Management

Ground Optimize for 42 Day Mission

Deploy System Data Handling

Initial Ground Operations Changes

Exercise Deep Space Comm, Autonomy, and Decision Paths

Deploy Revised Ground Ops

Optimally Autonomous Crew

Redefined Ground Operations Paradigm

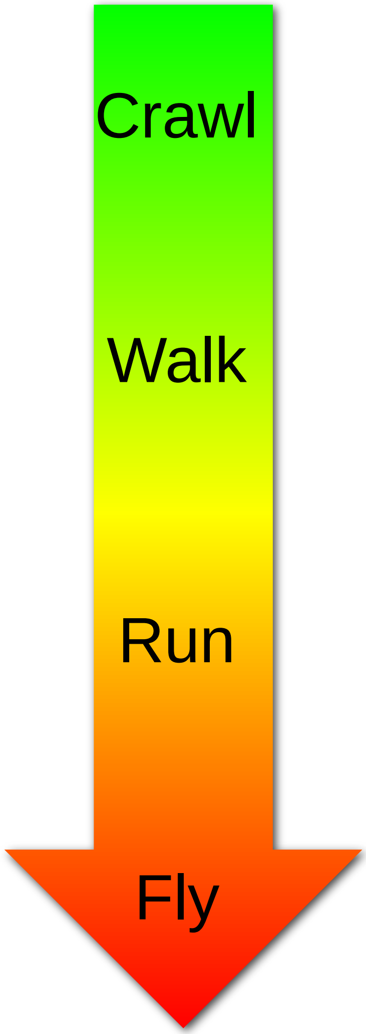
Ground System Requirements

- Given the limited responses on health compromises during exploration-class space missions and the uncertainty inherent to the missions, the ability to predict versus react can mean the difference between mission success and mission failure.

Fink et al. IEEE 2014

Medical Support Capability

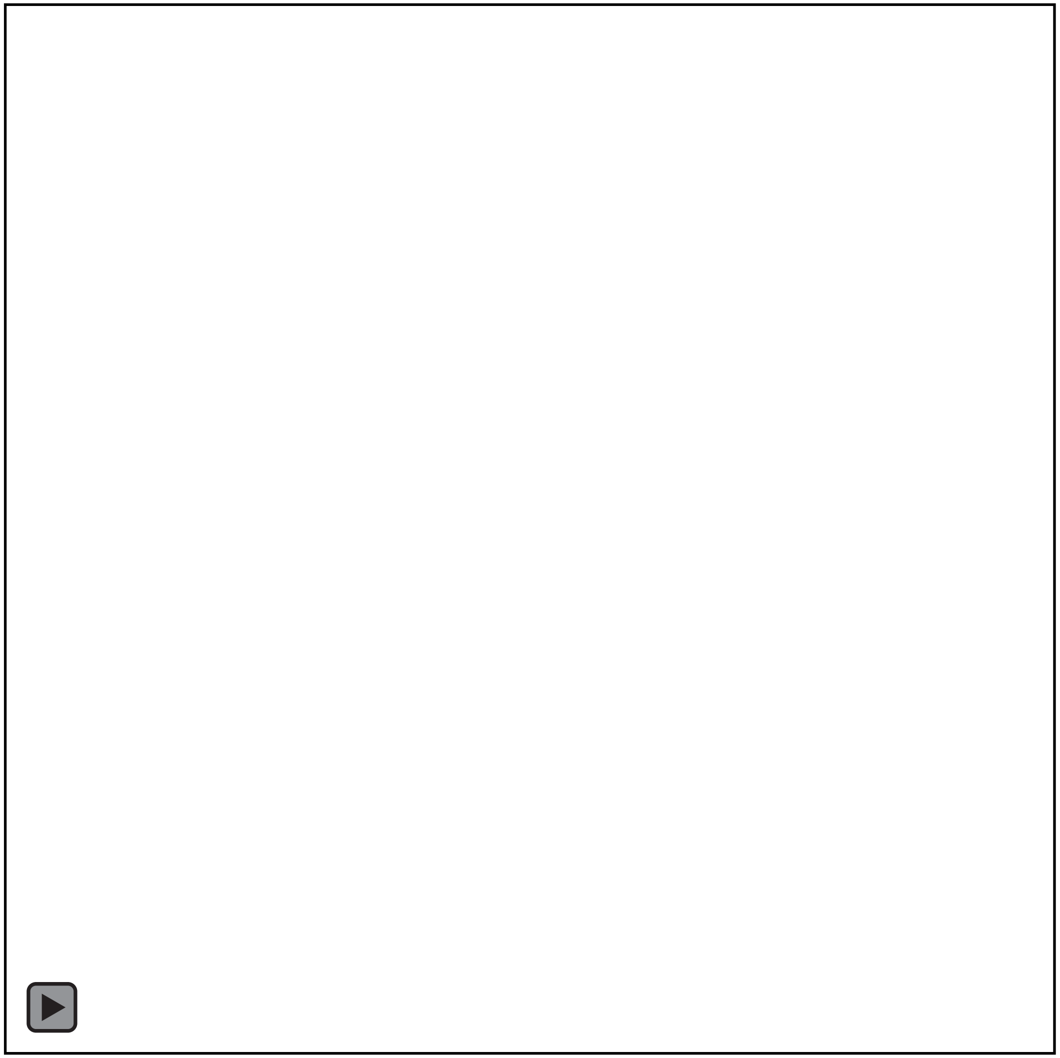
- **Preventive Care**
- **Knowledge Support/Known Algorithm Provision**
- **Automated Image/Data Analysis**
- **Differential Diagnosis Generation**
- **Condition Specific Guidance**
- **Integrative Health Prediction**
- **Full AI**



- Physicians are fond of saying, the only unambiguous diagnosis is death. Everything else is typically subject to argument. That is why a big data approach must be cautious to use relevant data and interpret the data correctly. Not to speak about making predictions outside of what has been quantified.

Popov et al. 2016

What could go wrong?

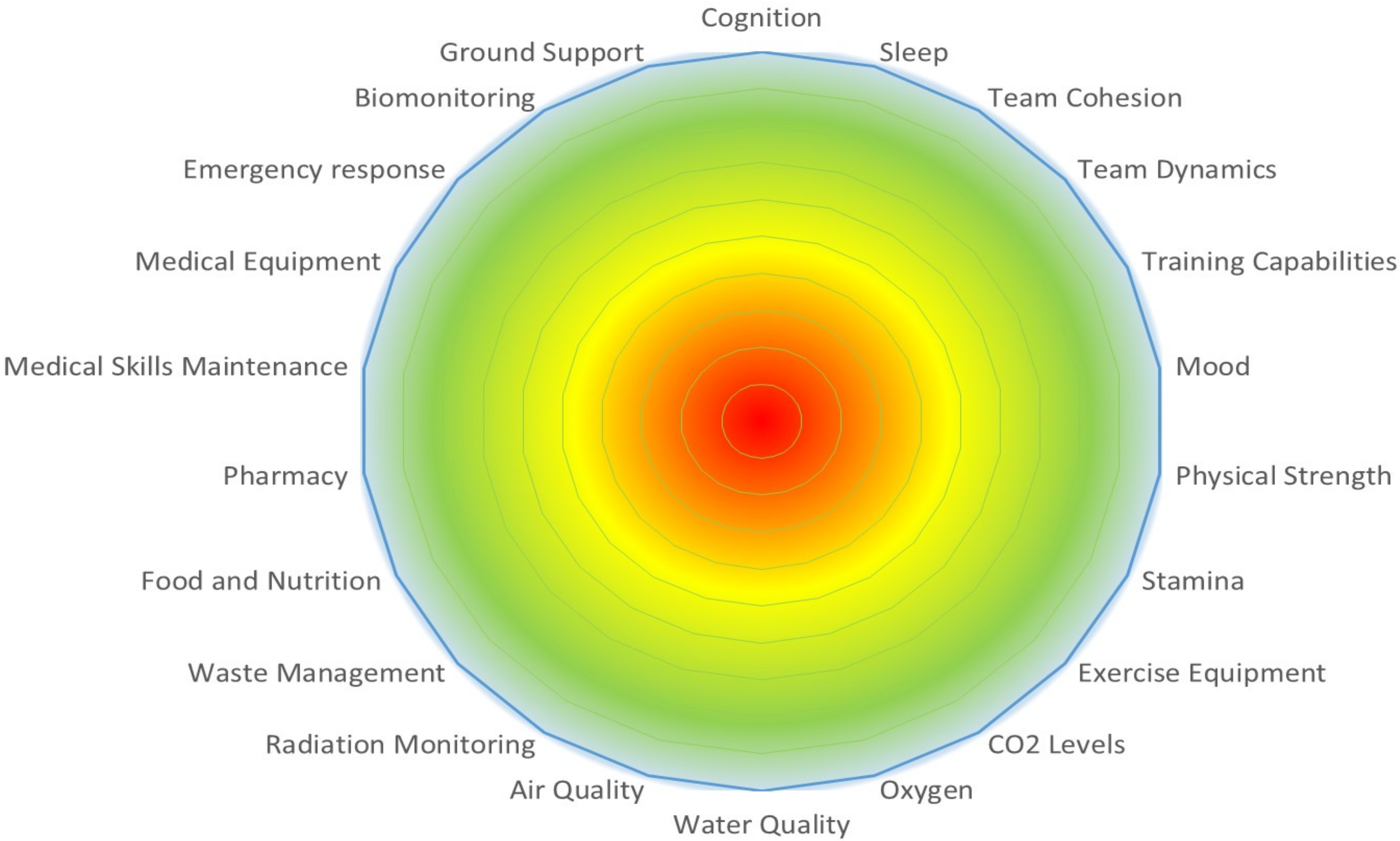


Determination of the mission-specific effects and other relevant stressors, alone and in combination, on the general psychological and physical well-being of an astronaut. Emphasis should be on determining the extent to which such stressors constitute a risk to mission success

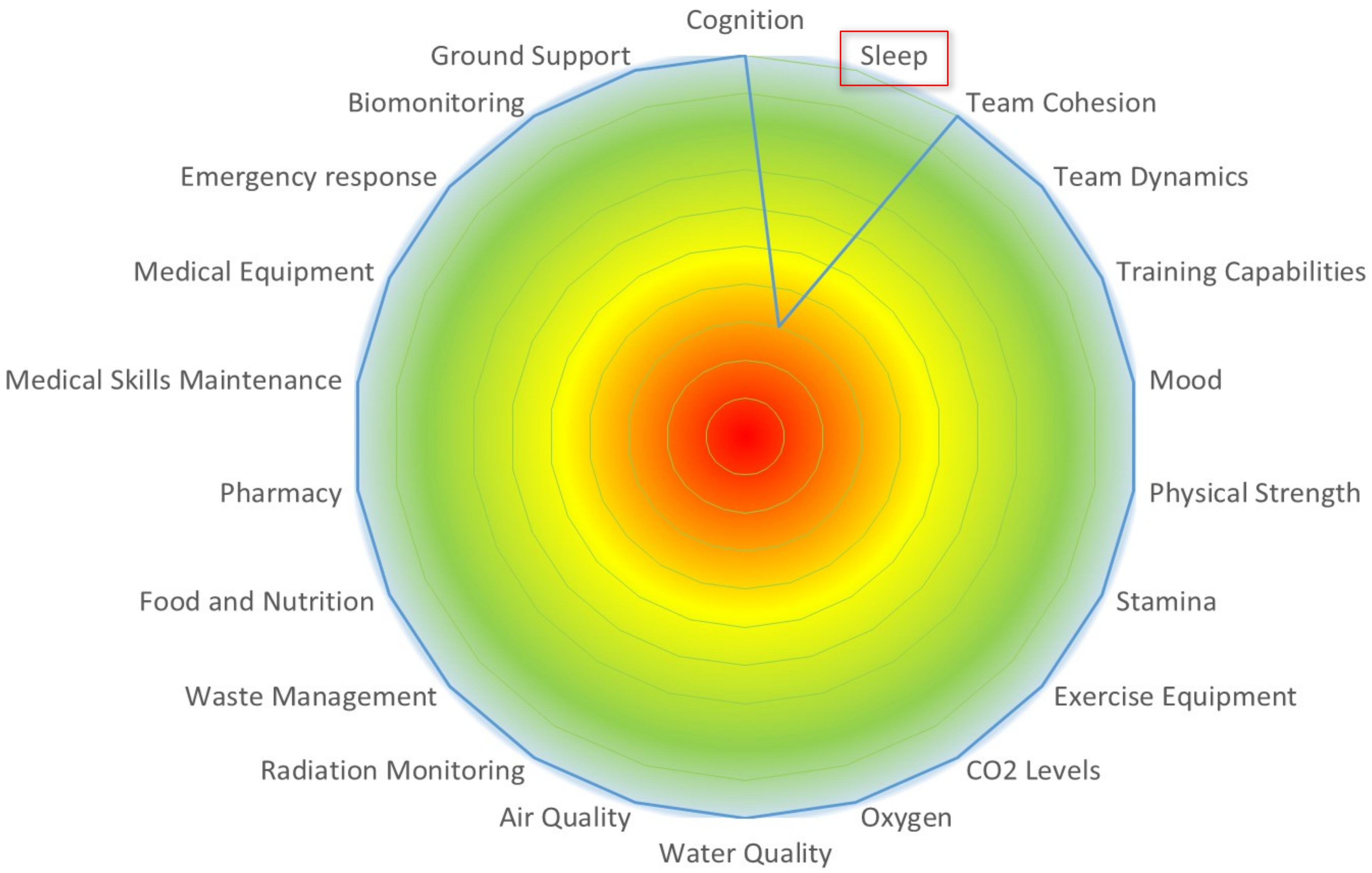
To assess the effects of environmental factors on crew health and to enable early detection of negative trends a real-time monitoring is required. The monitoring challenge is to provide not only valid and reliable data, but also data sensitive to potentially subtle physiological and neuropsychological deficits caused by the stressors.

Popov et al. 2016

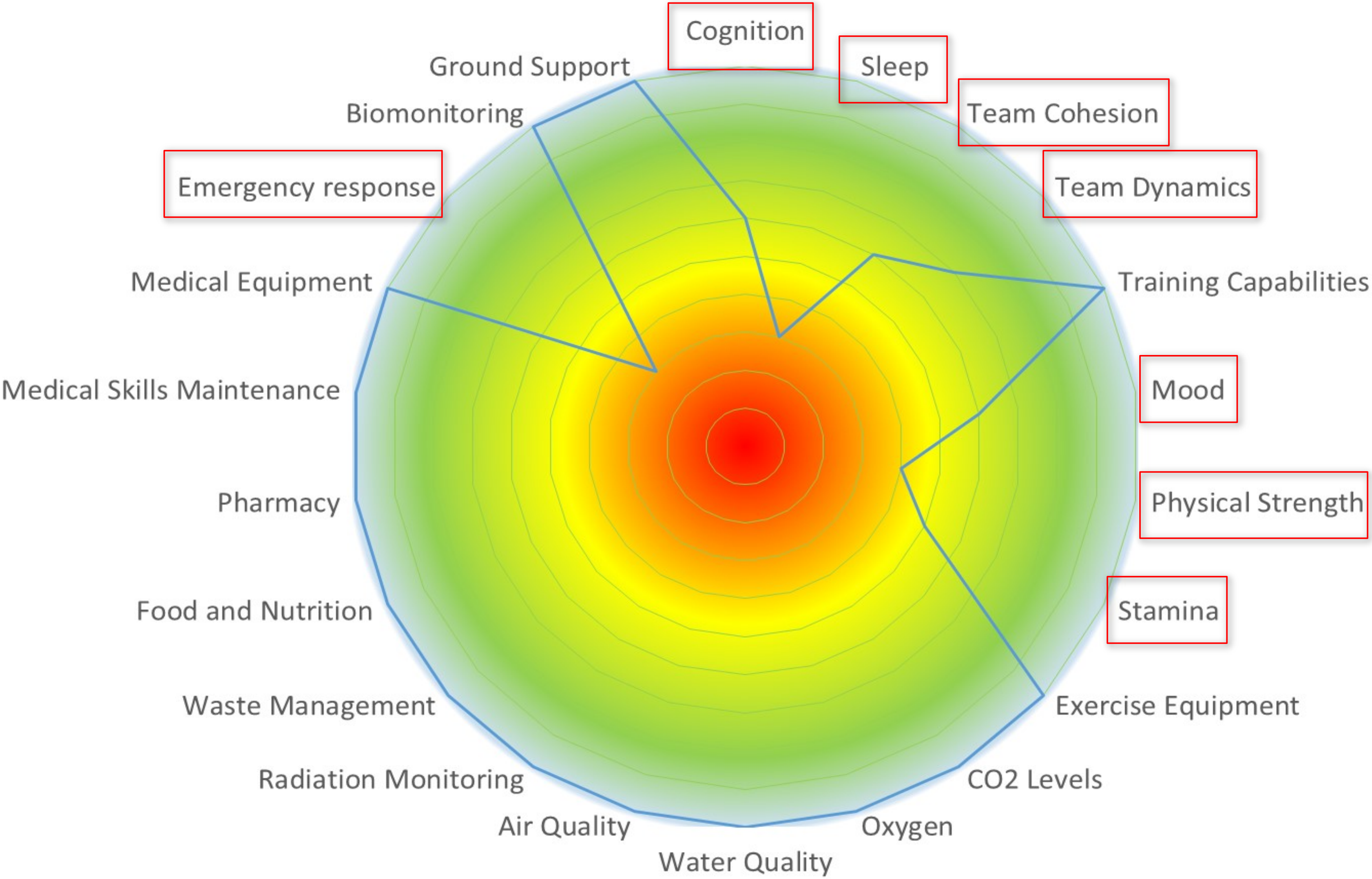
Human System Performance



System Performance Threatened by Sleep Deficit



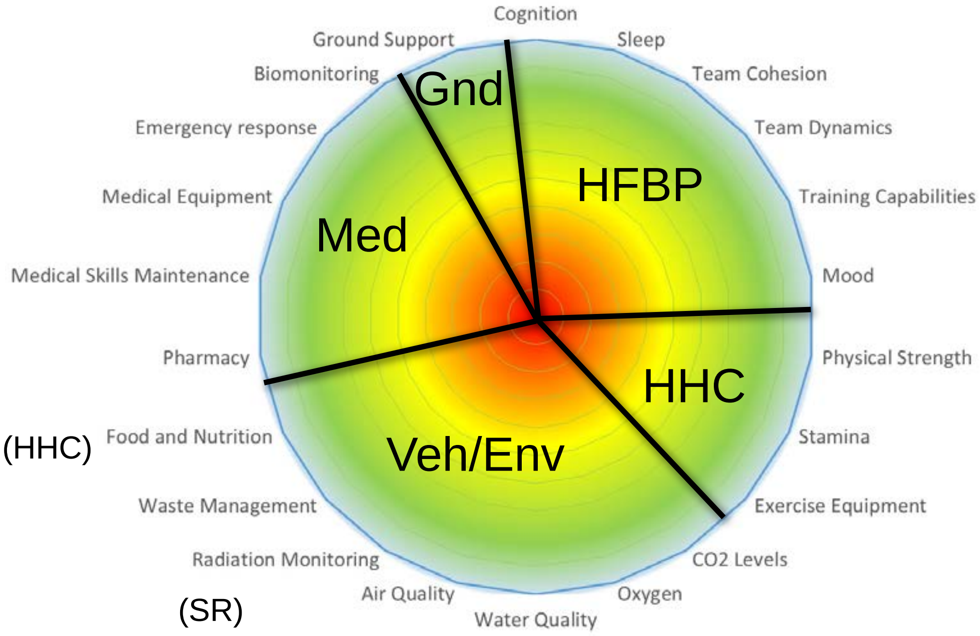
Sleep Deficit Affects Other System Aspects



Cross Collaboration Priorities

- **How do we monitor the human system state to enable prediction and prevention of medical issues?**
- **How do we model Human Performance so that we can plan for systems that optimize that?**
- **How do we balance medical specific training/understanding with the larger mission training needs?**

Medical is a small part of the **Crew Health and Performance** System



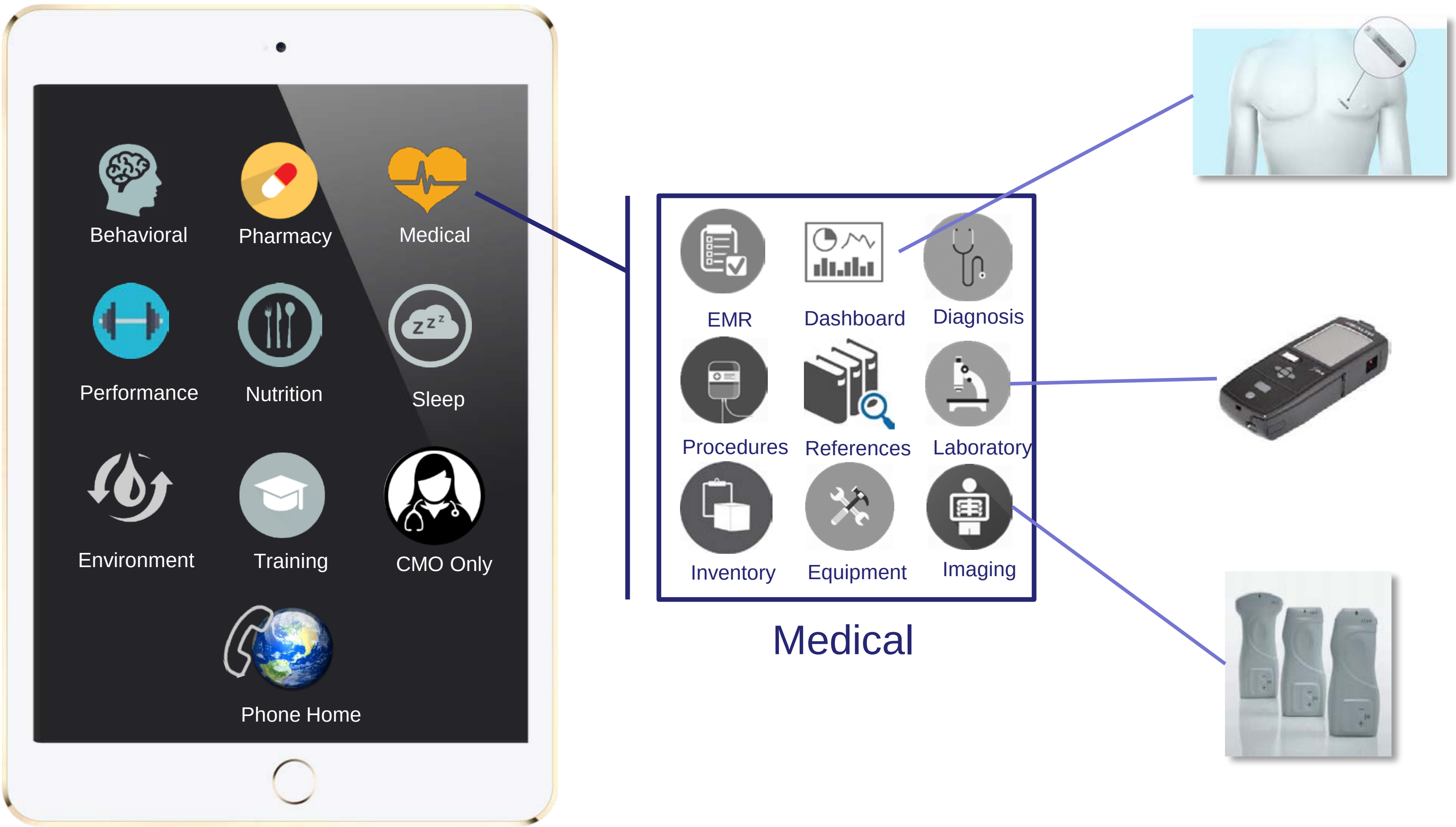
- COTS hand-held reportable smart devices with increased capability and reduced mass, volume, and power make the technology implementation feasible for the crewed vehicles, expected to be used for more advanced missions.

- What happened when we put iPads on the ISS?

A PHM-type system vision

The Human System Data Architecture

These technologies exist today



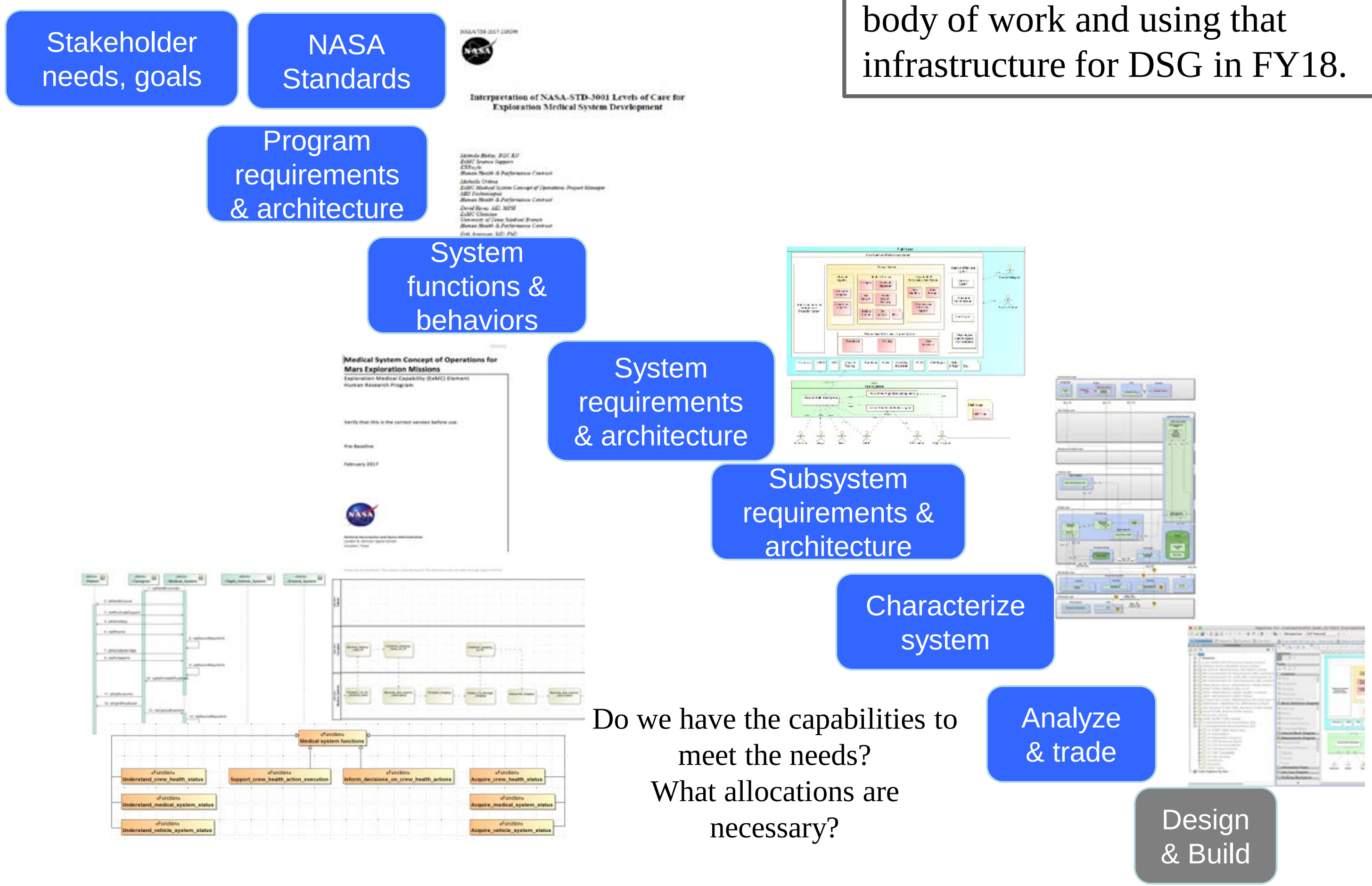
Notional

PHM Must Complement The Paradigm

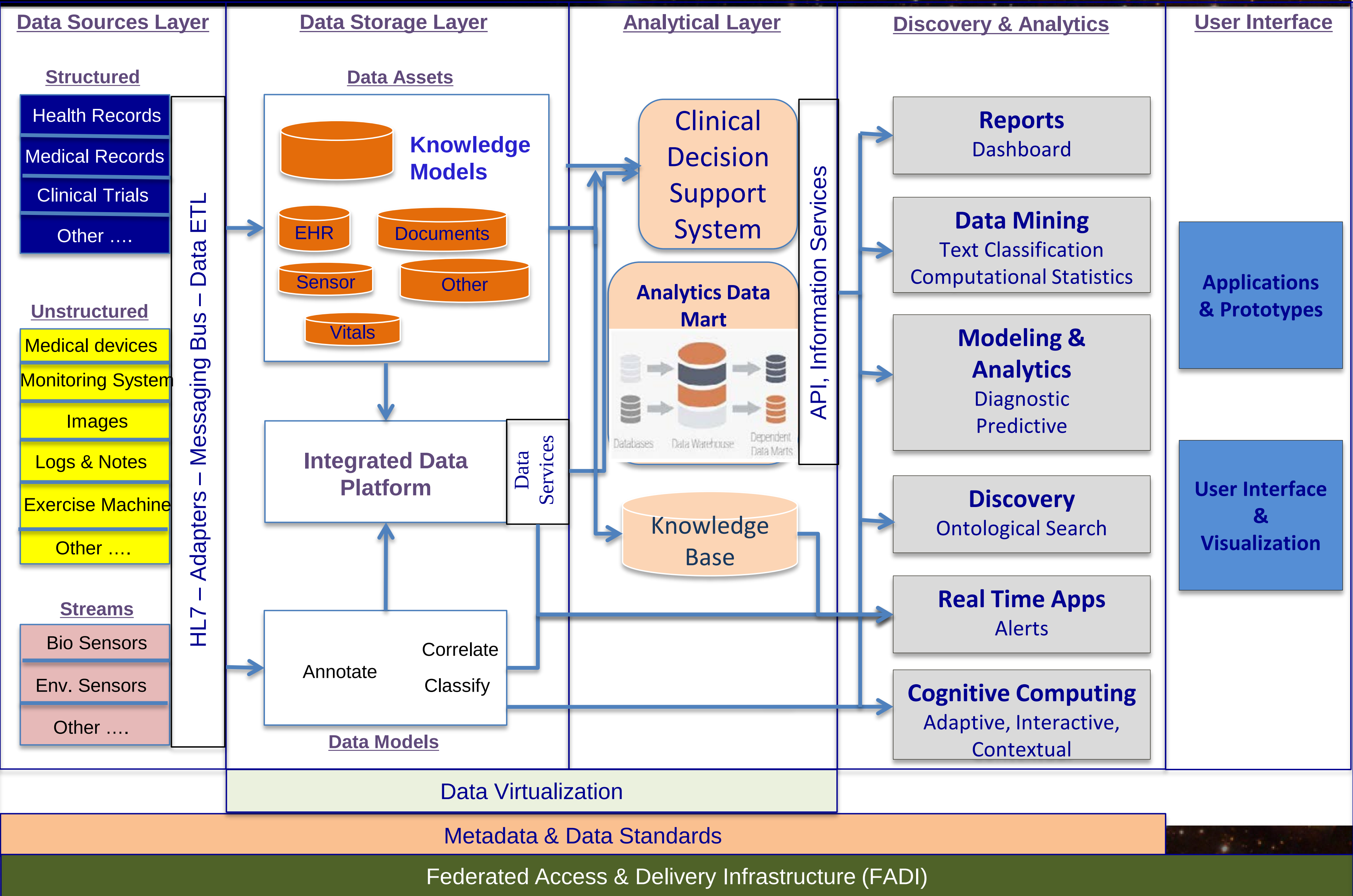
- Conception of Medical and Performance Operations
- Quantification of Medical and Performance Risk
- Data Systems Development
- Human Systems Engineering for Vehicle and Mission Integration

The Requirements Process

Began with DST (Mars transit) to develop body of work and using that infrastructure for DSG in FY18.



Where are we today?



Provision of Training and Crew Support

MENU | COMfORT | Baseline | Date: 2/9/2017 | ID: 9201 | NOTES | EXIT

FUNDOSCOPY | OBJECTIVE | FOUNDATION | SETUP | EXAM PROCEDURE | QUIZ | REFERENCE

Eye Anatomy | CellScope Use | Taking Images | Eye Pathology

Taking a Good Image: Composition

Tips for good composition:

To move the optic disc down the subject needs to look up.

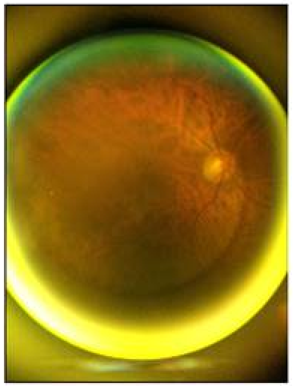
To move the optic disc right the subject needs to look right.

In a good composition the optic disc is centered.

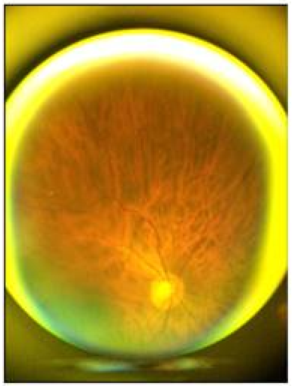
Good composition

Bad composition

In poor composition, the optic disc is not centered or not visible.



Bad composition
Optic disc is too far right



Bad composition
Optic disc is too low

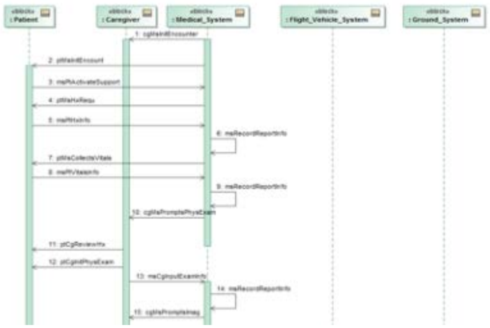
PREVIOUS | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 | NEXT

but I think it would help us be more efficient.

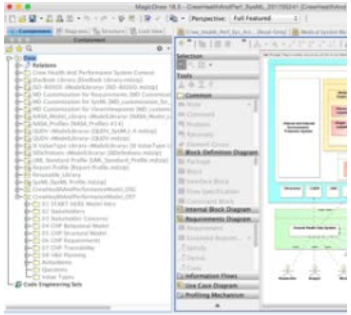
Remote -> Autonomy

Augmented Reality Training
Tietronix

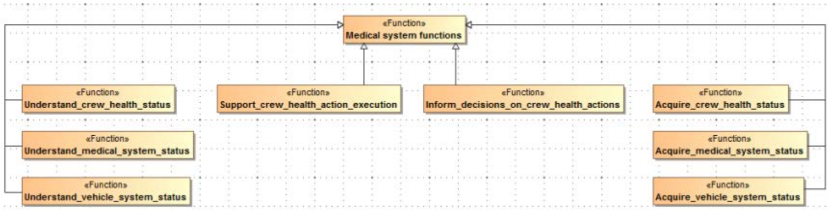
Medical Data Architecture and Systems Engineering



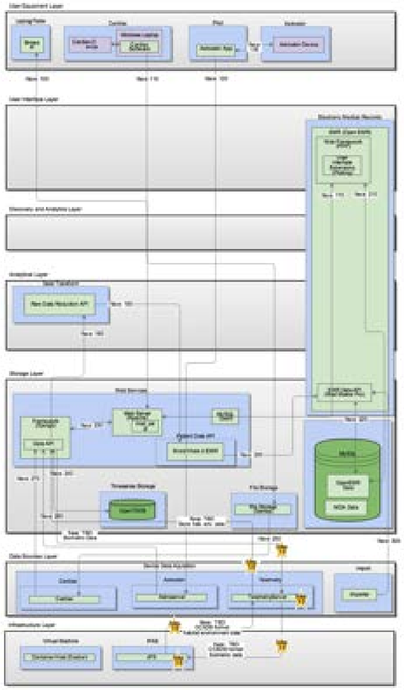
Interaction Diagrams



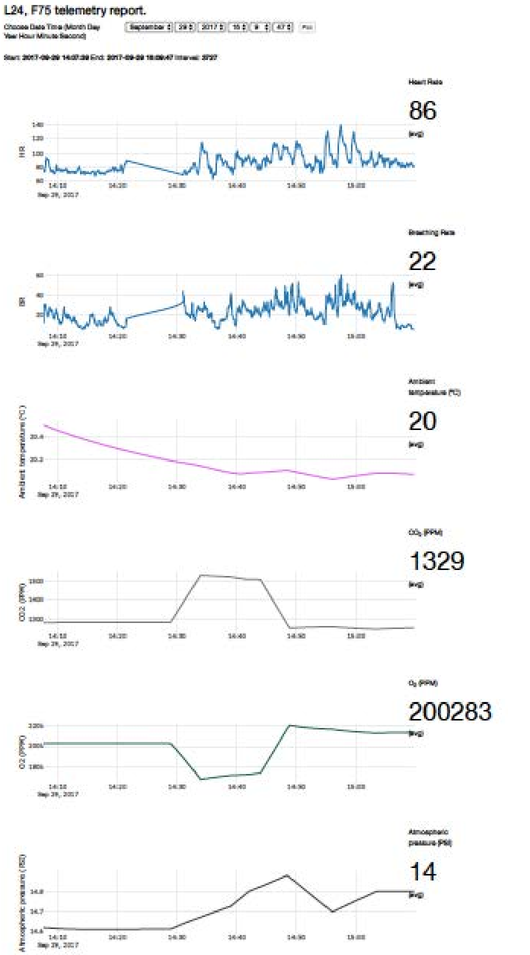
Nested Model Tree



Functional Decomposition



MDA Architecture



Data Sent/Collective by MDA System via Telemetry with CFS (CCSDS Protocol)

Conclusions

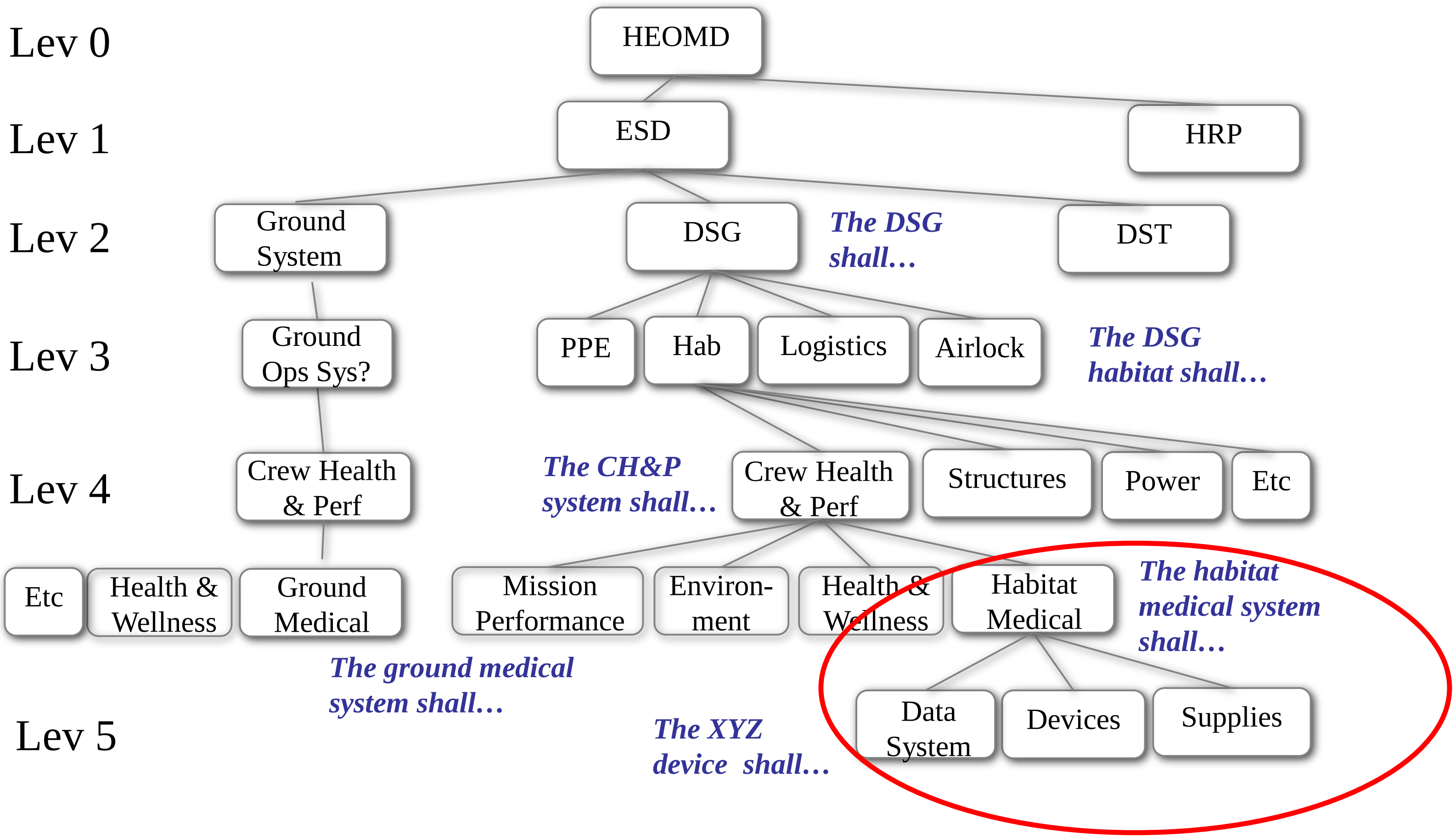
- **PMH is the future of human spaceflight.**

- **The goals of the discipline complement ongoing work at NASA that targets the Exploration Missions.**
  - Program expectation for integration with vehicle and mission
  - Medical Data Architecture
  - Systems Engineering Pathway

- **Evidence Base Challenges**
  - What do we need to bring?
    - What do we monitor?
    - How do we validate predictive capability?
  - Big Data Analytics
    - How do we build the evidence base that we trust?
    - Analogs first – Testing and Evaluation Pathway

BACKUP

NOT Official – best guess on requirements context



27Apr17 crew note from HMS-ULTRSND-SCAN-CMO:

You know what would really help us? If we had pictures of a "perfect case" for each type of image. Given the time lag between ground and ISS - and the minute adjustments we are making for the correct image- the ground is like "3 seconds ago". If we had a picture of what we should make each image look like, we will print it out and have it above the machine so we can more quickly get to what you want and then stabilize for the ground to catch up. I think it will also help cosmonauts considerably given the high amount of commanding/translation. Just a thought - but I think it would help us be more efficient.

- PHM concepts are the future

- Systems engineering for CHP needs requires early integration with vehicle and respect for the engineering design life cycle.

Table 1. PHM-based Healthcare Concept vs. Conventional Medicine

The PHM-based Healthcare Concept	Conventional Medicine
Focus on keeping astronaut healthy by predicting a deterioration or impairment in his/her health before a sign is detected or a symptom is manifested	Focus on detected signs and manifested symptoms in order to diagnose a medical condition, disease or disorder
Real-time 24/7 streaming, monitoring and processing	One-off, snapshots made in doctor's office
Astronaut generated data	Doctor ordered data
Individualized	Population-based
Panoramic	Data limited
Condition Based Maintenance (CBM)	Diagnosis-based treatment
Evidence-based health maintenance	Diagnostics and treatment limited to experience and knowledge of healthcare provider
Used in conjunction with COTS wireless sensor network communicating with custom smartphone-based (e.g., [4]) or tablet-based (e.g., [6]) apps, reasonably priced	Expensive, Big-Ticket Technologies
Intuitive and customizable dashboard-based interface with user-friendly language designed for astronaut as the only end-user	Medical language and an interface designed for healthcare professional
Astronaut healthcare autonomy paradigm, rather than the tele-medicine one	Medical Paternalism
Astronaut edited and owned his/her CEHR	Non-shared EHR that owned by healthcare provider
Astronaut engagement	Compliance with healthcare provider directives