

# Medical Risks and Capabilities for Human Exploration Spaceflight

**Benjamin Easter, MD, MBA**

**Assistant Professor**

**Department of Emergency Medicine**

**University of Colorado School of Medicine**

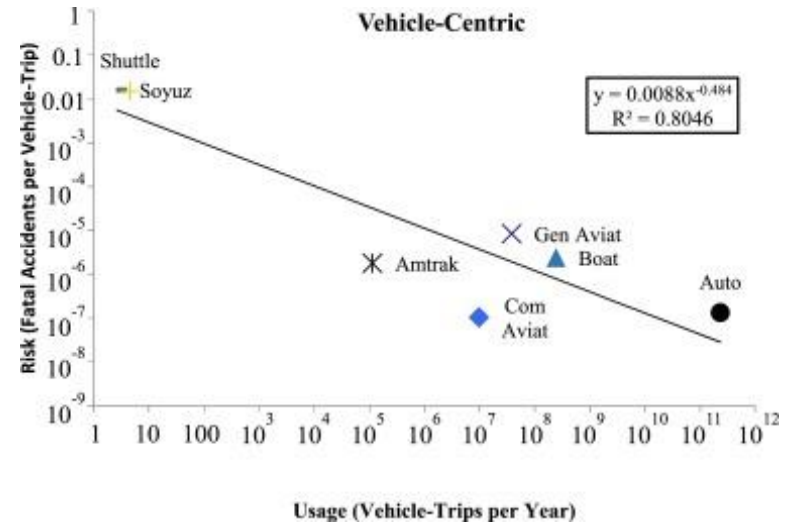
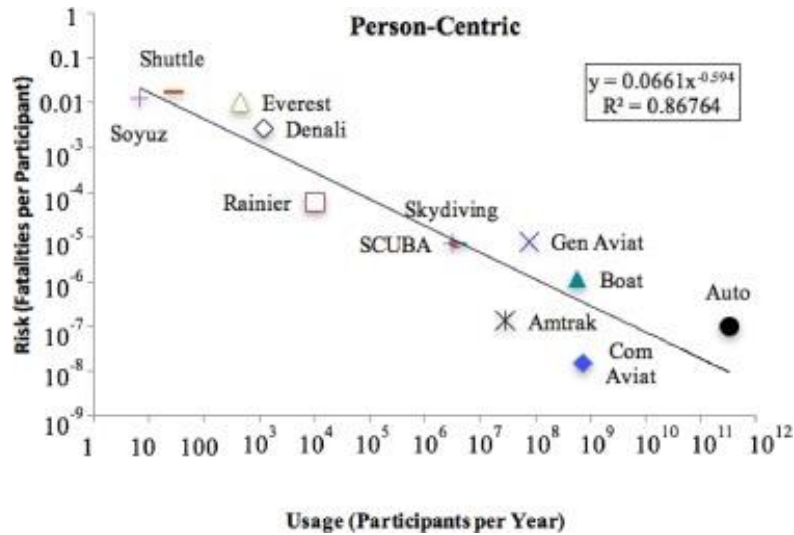
**Deputy Element Scientist**

**Exploration Medical Capability (ExMC)**

**NASA Human Research Program**

**Email: [benjamin.easter@nasa.gov](mailto:benjamin.easter@nasa.gov)**

# Risk of Human Spaceflight



# Outline

## Outline

- Historical spaceflight medical kits/systems
- Historical occurrence of medical conditions
- Upcoming missions and medical challenges
- Medical risk and spaceflight events
- Medical system and technology integration

## Objectives

- Describe the key principles of extreme environmental medicine
- Identify the challenges with telemedicine and remote medical support
- Analyze the steps necessary to increase clinical autonomy
- Outline how using systems engineering principles can improve medical system design

# Project Mercury



FIGURE 4.1. Mercury medical kits containing items such as antibiotics, decongestants, stimulants, electrode paste, and medications to treat nausea and diarrhea. (Photo courtesy of NASA)



FIGURE 4.2. Mercury medical kit containing items such as saline solution, bandages, stimulants, and decongestants (Photo courtesy of NASA)

# Gemini and Apollo

TABLE 4.1. Contents of the Gemini VII medical kit [10].

Medication	Indication	Dose	Amount
D-Amphetamine sulfate	Stimulant	5-mg tablets	8
Aspirin-phenacetin-caffeine	Pain	Tablets	16
Cyclizine HCl	Motion sickness	50-mg tablets	8
Diphenoxylate HCl	Diarrhea	2.5-mg tablets	16
Meperidine HCl	Pain	100-mg tablets	4
Methyl cellulose solution	Eye lubricant	15-ml bottle	1
Parenteral cyclizine	Motion sickness	45 mg (0.9-ml injector)	2
Parenteral meperidine HCl	Pain	90 mg (0.9-ml injector)	2
Pseudoephedrine HCl	Decongestant	60-mg tablets	16
Tetracycline HCl	Antibiotic	250-mg coated tablets	16
Tripolidine HCl	Decongestant	2.5-mg tablets	16



FIGURE 4.5. Apollo clinical physiological monitoring kit and emergency medical kit (Photo courtesy of NASA)



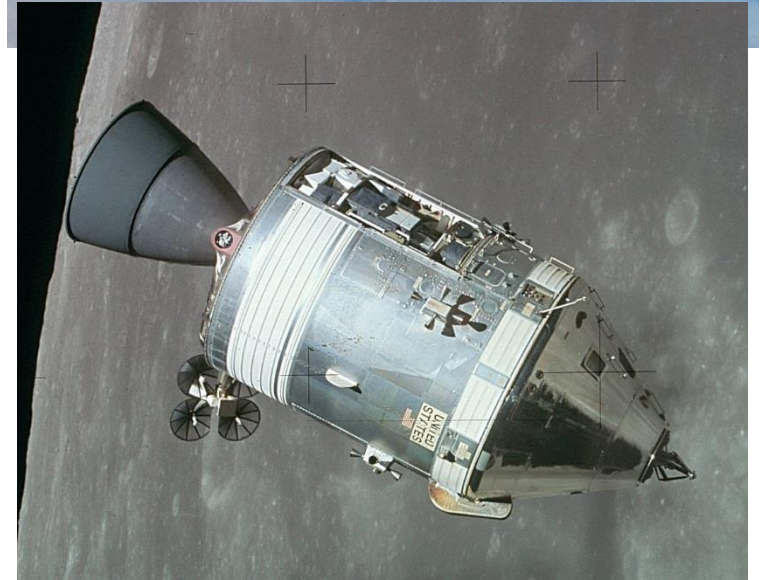
FIGURE 4.3. Apollo medical kit containing items such as skin cream, antibiotic ointment, nasal spray, band-aids, and stimulants (Photo courtesy of NASA)



FIGURE 4.6. Apollo emergency medical kit (Photo courtesy of NASA)



FIGURE 4.4. Apollo Command Module medical kit (Photo courtesy of NASA)



Principles of Clinical Medicine for Spaceflight  
Eds. Barratt, Pool, 2008

# Space Shuttle



FIGURE 4.7. Shuttle Orbiter Medical System. Following redesign in 2000, components include Saline Supply Bag, EENT Subpack, IV Administration Subpack, Trauma Subpack, Sharps Container, Drug Subpack, and Airway Subpack (Photo courtesy of NASA)



# Health and Medical on ISS

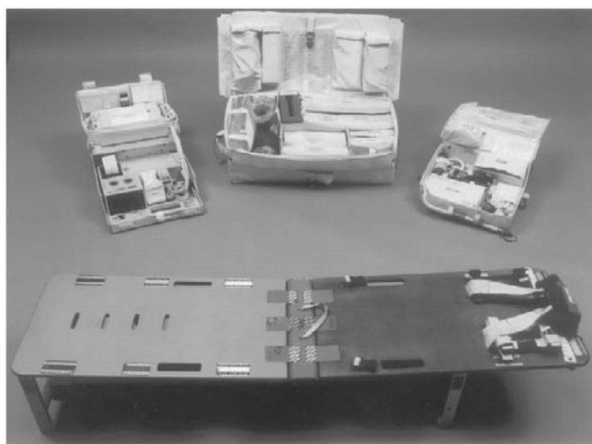
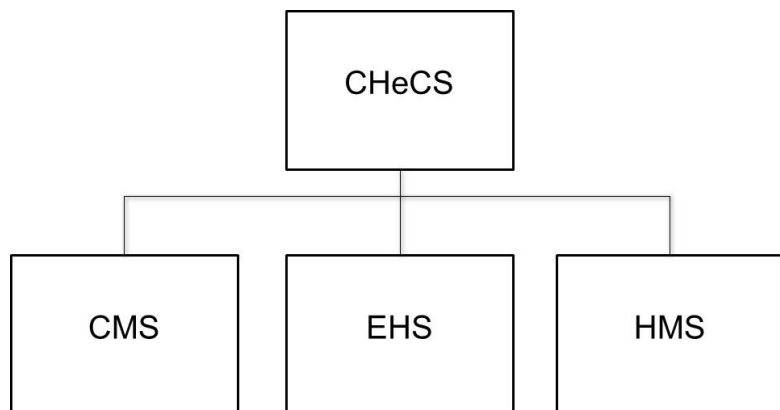


FIGURE 4.8. ISS Health Maintenance System. Components include (from left) defibrillator, Advanced Life Support Pack, Respiratory Support Pack, and Crew Medical Restraint System (Photo courtesy of NASA).

# Do we need medicine in spaceflight?

Medical Condition	Events	Medical Condition	Events
Allergic reaction (mild to moderate)	11	Mouth ulcer	9
Ankle sprain/strain	11	Nasal congestion (space adaptation)	389
Back injury	31	Neck injury	9
Back pain (space adaptation)	382	Nose bleed (space adaptation)	6
Barotrauma (ear/sinus block)	31	Otitis externa	3
Choking/obstructed airway	3	Otitis media	3
Constipation (space adaptation)	113	Paresthesias	26
Diarrhea	33	Pharyngitis	11
Elbow sprain/strain	12	Respiratory infection	33
Eye abrasion (foreign body)	70	Shoulder sprain/strain	22
Eye chemical burn	6	Sinusitis	6
Eye infection	5	Skin abrasion	94
Finger dislocation	1	Skin infection	13
Fingernail delamination (EVA)	16	Skin laceration	1
Gastroenteritis	4	Skin rash	94
Headache (CO2 induced)	20	Smoke inhalation	3
Headache (late)	49	Space motion sickness (space adaptation)	325
Headache (space adaptation)	233	Urinary incontinence (space adaptation)	5
Hemorrhoids	2	Urinary retention (space adaptation) – female	5
Herpes Zoster reactivation (shingles)	1	Urinary retention (space adaptation) – male	4
Indigestion	6	Urinary tract infection – female	5
Influenza	1	Urinary tract infection – male	4
Insomnia (space adaptation)	299	Visual impairment/increased intracranial pressure (space adaptation)	15
Insomnia (late)	133	Wrist sprain/strain	5
Knee sprain/strain	7		



# How is medical care provided in mission?

- Live remote guidance



- Live monitoring



- Store and forward

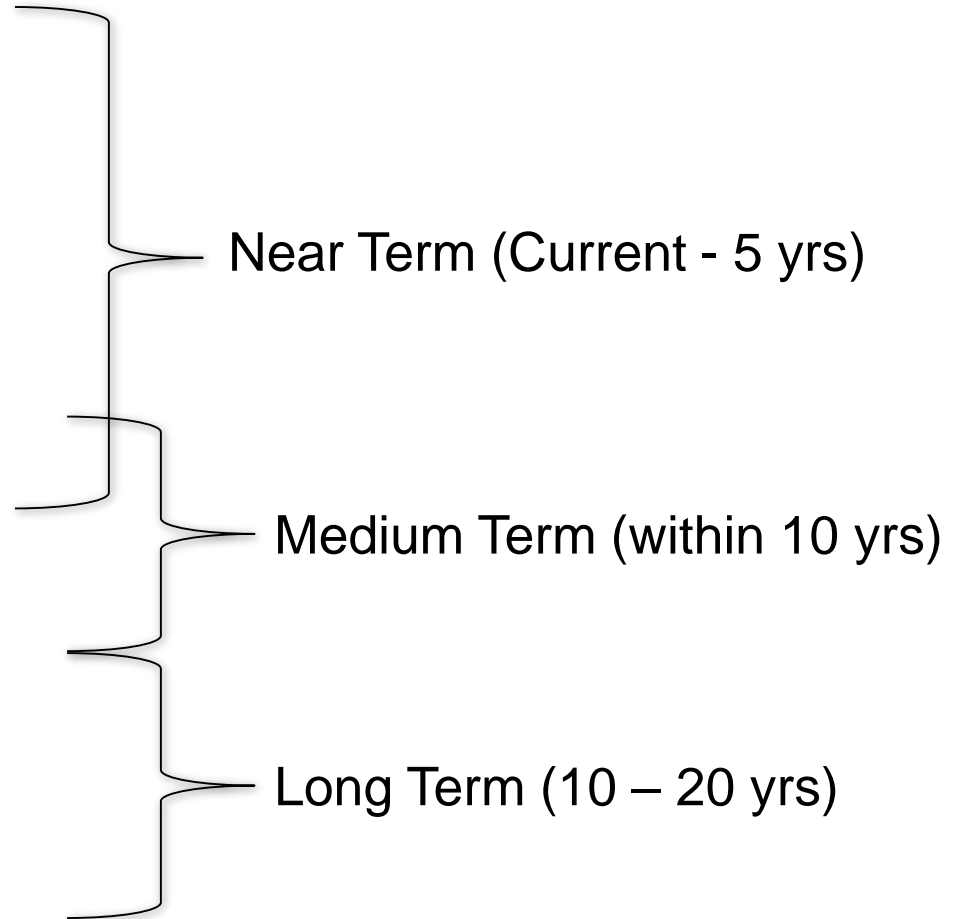




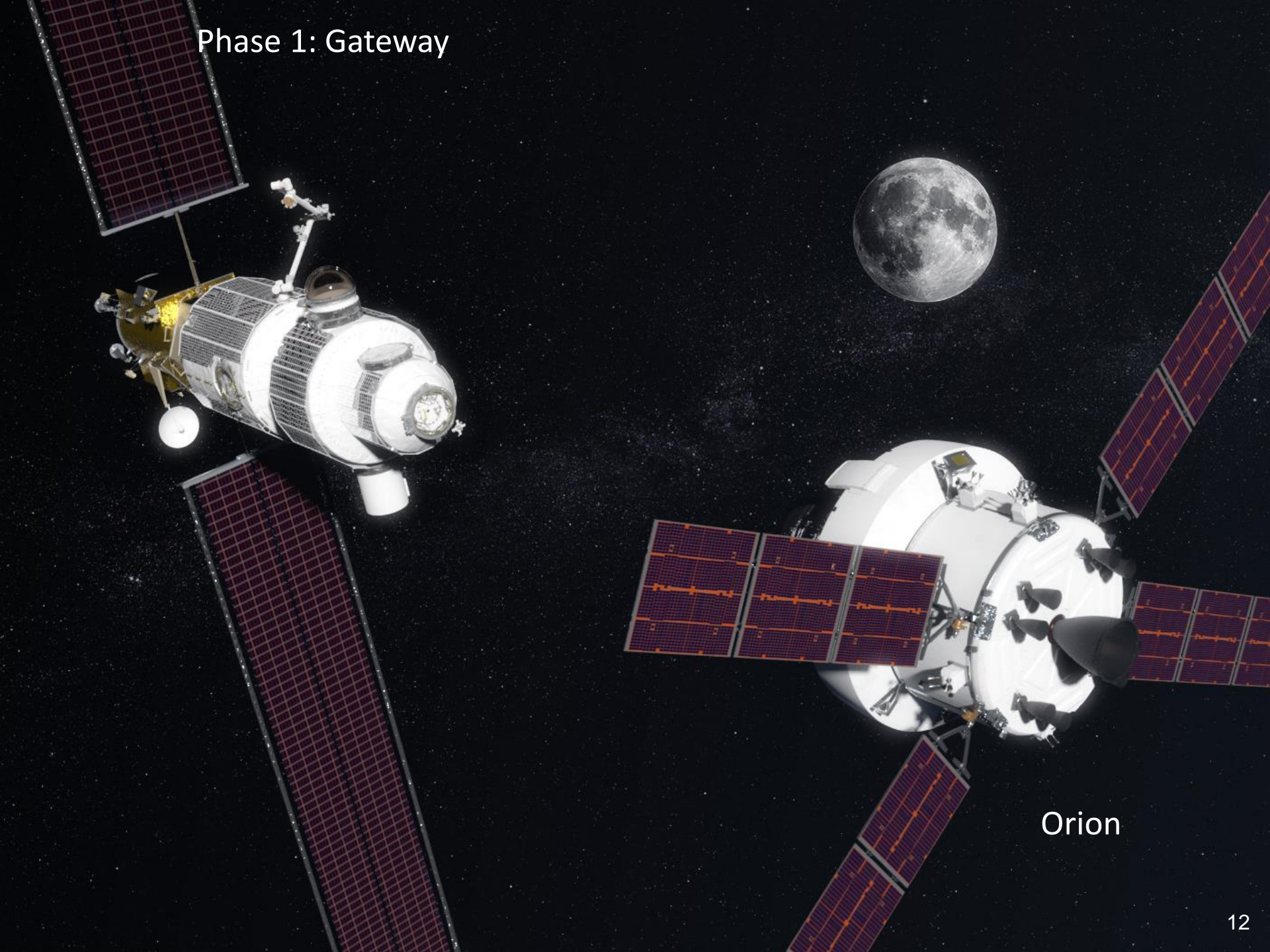
# **EXPLORATION SPACEFLIGHT**

# NASA Human Spaceflight Missions

- **Soyuz Launch and Landings**
- **International Space Station**
- **Commercial Crew Program**
- **Multi-Purpose Crew Vehicle**
- **Gateway Habitat**
- **Deep Space Transport**
- **Mars Missions**

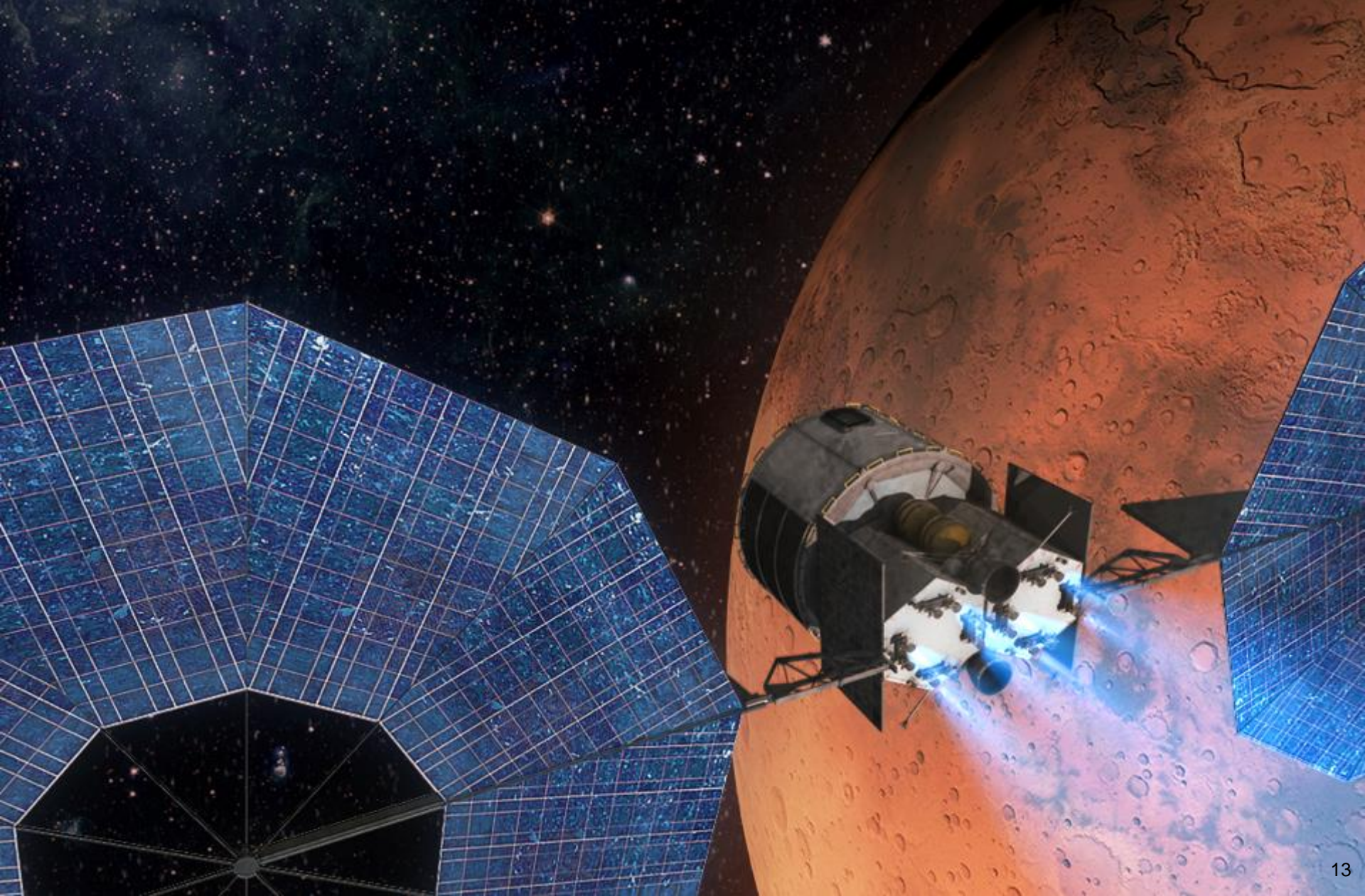


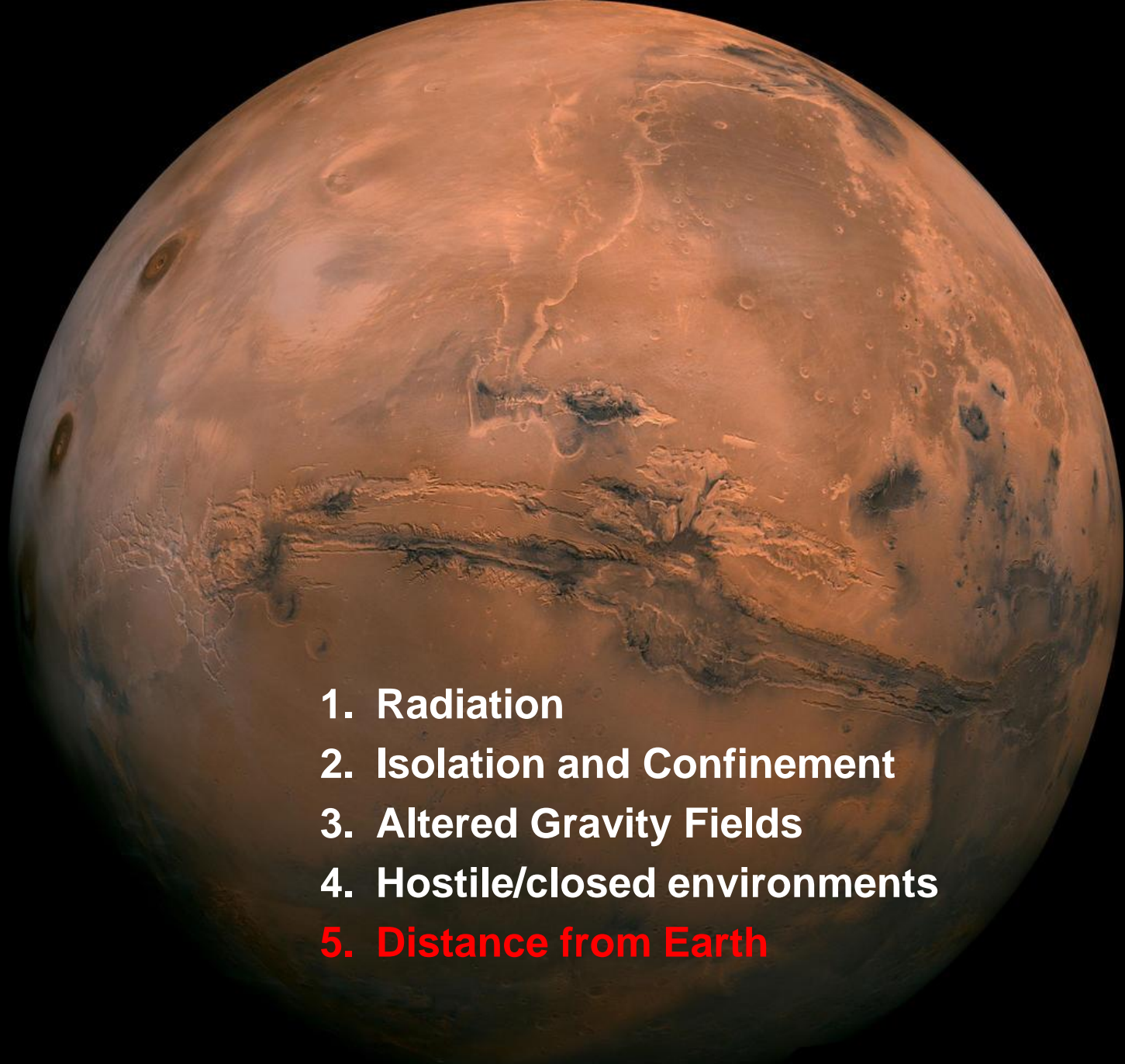
# Phase 1: Gateway



Orion


# What about Mars?





- 1. Radiation**
- 2. Isolation and Confinement**
- 3. Altered Gravity Fields**
- 4. Hostile/closed environments**
- 5. Distance from Earth**

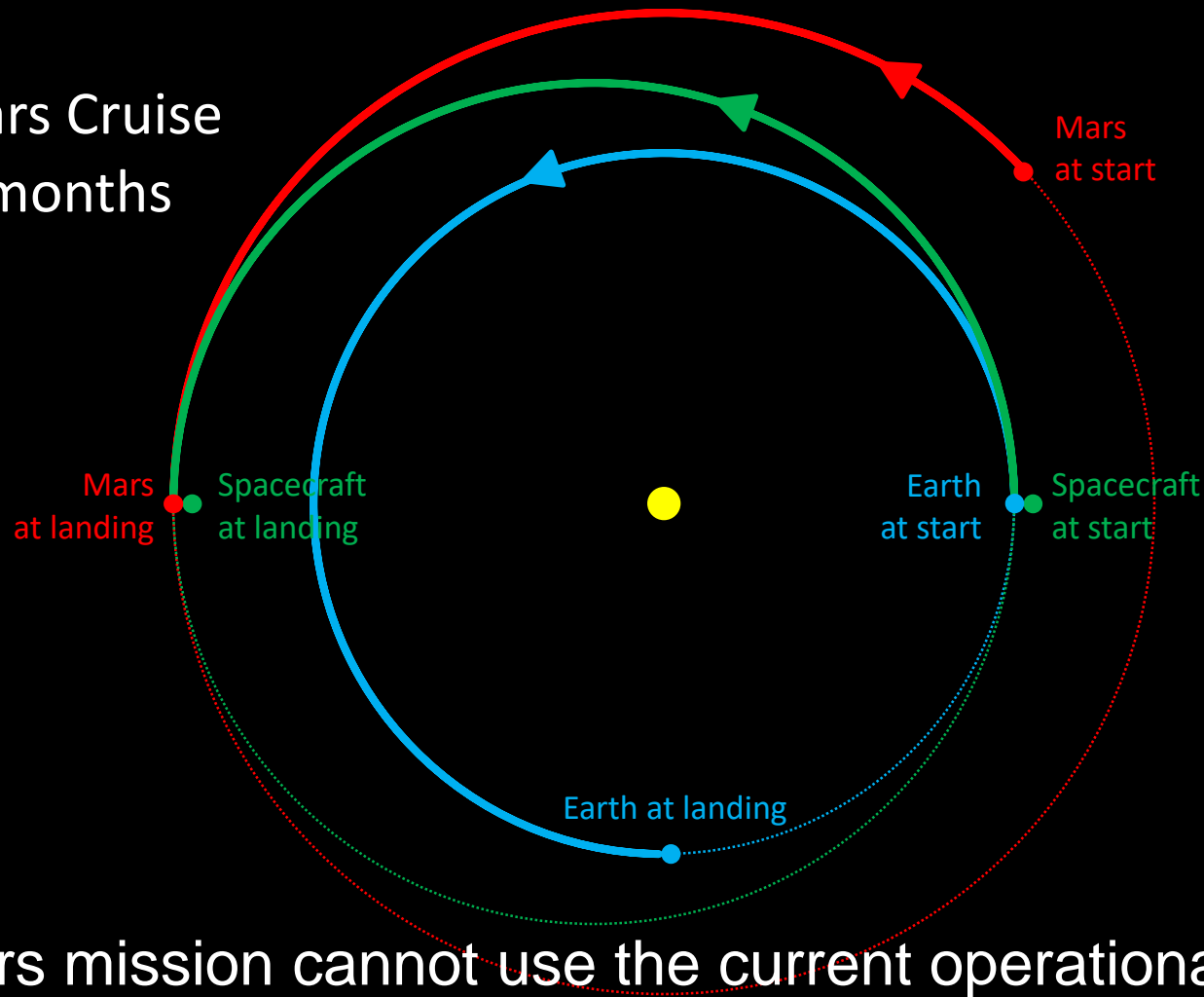
A Mars mission cannot use the current operational medical approach because that approach is dependent on **evacuation** for delivery of definitive care.

A dark, grayscale image of a Mars landscape. The foreground shows a silhouette of a mountain range. In the dark sky, a small white arrow points to a distant point labeled "Earth".

Earth

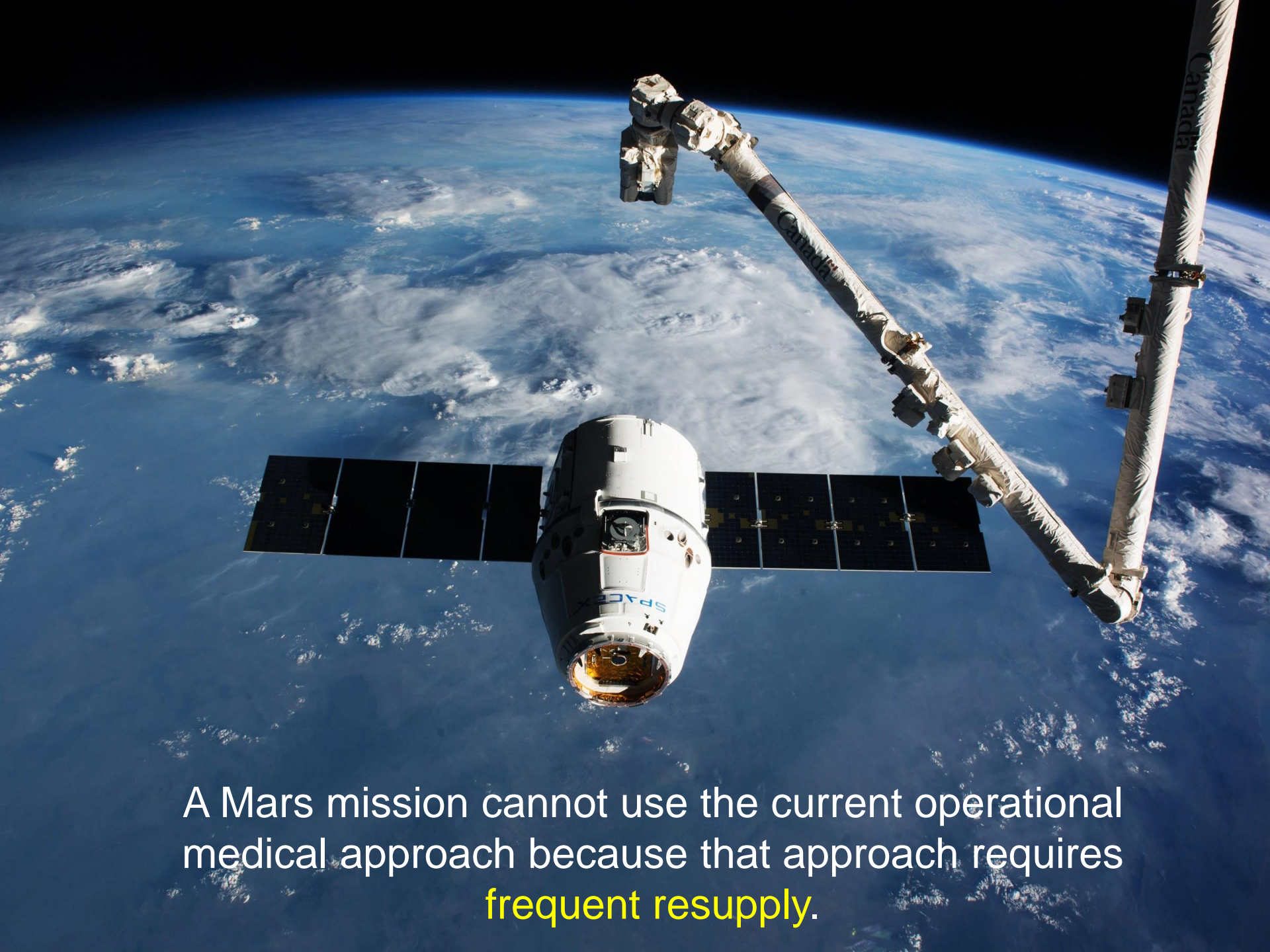
Access to the Deep Space Network for the vehicle may be as limited as 1 hour in a 24 hour period.

Trans-Mars Cruise  
About 9 months



A Mars mission cannot use the current operational medical approach because that approach is totally dependent on **real-time communication** with the ground.





A Mars mission cannot use the current operational medical approach because that approach requires frequent resupply.



A Mars mission cannot use the current operational medical approach because that approach requires **significant, continuous ground support.**

# Paradigm Shift

How do we scope a medical system to meet the needs of a planetary mission that is:

2-3 times as long as any prior mission

>500 times as far as any prior mission

Vehicle is committed after trans-Martian injection?

# **MEDICAL PROBABILISTIC RISK ANALYSIS**

# Exploration Medical Conditions

## SKIN

Burns secondary to Fire  
Skin Abrasion  
Skin Laceration

## EYES

Acute Glaucoma  
Eye Corneal Ulcer  
Eye Infection  
Retinal Detachment  
Eye Abrasion  
Eye Chemical Burn  
Eye Penetration

## EARS, NOSE, THROAT

Barotrauma (sinus block)  
Nasal Congestion (SA)  
Nosebleed (SA)  
Acute Sinusitis  
Hearing Loss  
Otitis Externa  
Otitis Media  
Pharyngitis

## DENTAL

Abscess  
Caries  
Exposed Pulp  
Tooth Loss  
Crown Loss  
Filling Loss

## CARDIOVASCULAR

Angina/Myocardial Infarction  
Atrial Fibrillation / Atrial Flutter  
Cardiogenic Shock secondary to Myocardial Infarction  
Hypertension  
Sudden Cardiac Arrest  
Traumatic Hypovolemic Shock

## GASTROINTESTINAL

Constipation (SA)  
Abdominal Injury  
Acute Cholecystitis  
Acute Diverticulitis  
Acute Pancreatitis  
Appendicitis  
Diarrhea  
Gastroenteritis  
Hemorrhoids  
Indigestion  
Small Bowel Obstruction

## Pulmonary

Choking/Obstructed Airway  
Respiratory Infection  
Toxic Exposure: Ammonia  
Smoke Inhalation  
Chest Injury

\*SA – Space Adaptation

## NEUROLOGIC

Space Motion Sickness (SA)  
Head Injury  
Seizures  
Headache  
Stroke  
Paresthesia  
Headache (SA)  
Neurogenic Shock  
VIIP (SA)

## MUSKULOSKELETAL

Back Pain (SA)  
Abdominal Wall Hernia  
Acute Arthritis  
Back Injury  
Ankle Sprain/Strain  
Elbow Dislocation  
Elbow Sprain/Strain  
Finger Dislocation  
Fingernail Delamination (EVA)  
Hip Sprain/Strain  
Hip/Proximal Femur Fracture  
Knee Sprain/Strain  
Lower Extremity Stress fracture  
Lumbar Spine Fracture  
Shoulder Dislocation  
Shoulder Sprain/Strain  
Acute Compartment Syndrome  
Neck Injury  
Wrist Sprain/Strain  
Wrist Fracture

## PSYCHIATRIC

Insomnia (Space Adaptation)  
Late Insomnia  
Anxiety  
Behavioral Emergency  
Depression

## GENITOURINARY

Abnormal Uterine Bleeding  
Acute Prostatitis  
Nephrolithiasis  
Urinary Incontinence (SA)  
Urinary Retention (SA)  
Vaginal Yeast Infection

## INFECTION

Herpes Zoster (shingles)  
Influenza  
Mouth Ulcer  
Sepsis  
Skin Infection  
Urinary Tract Infection

## IMMUNE

Allergic Reaction  
Anaphylaxis  
Skin Rash  
Medication Reaction

## ENVIRONMENT

Acute Radiation Syndrome  
Altitude Sickness  
Decompression Sickness (EVA)  
Headache (CO<sub>2</sub>)

# Spaceflight Medical Risk

Medical Risk

~100 Medical Conditions

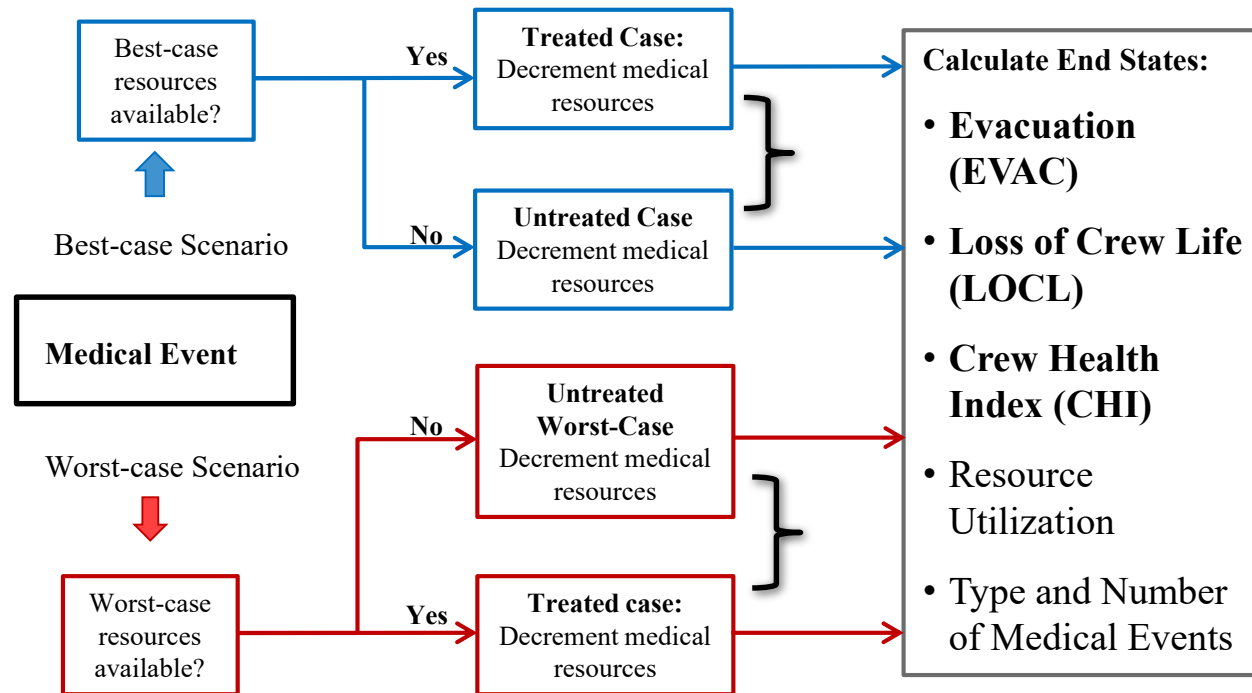
Medical Conditions for which we have not planned.

# Extrapolating Medical Risk



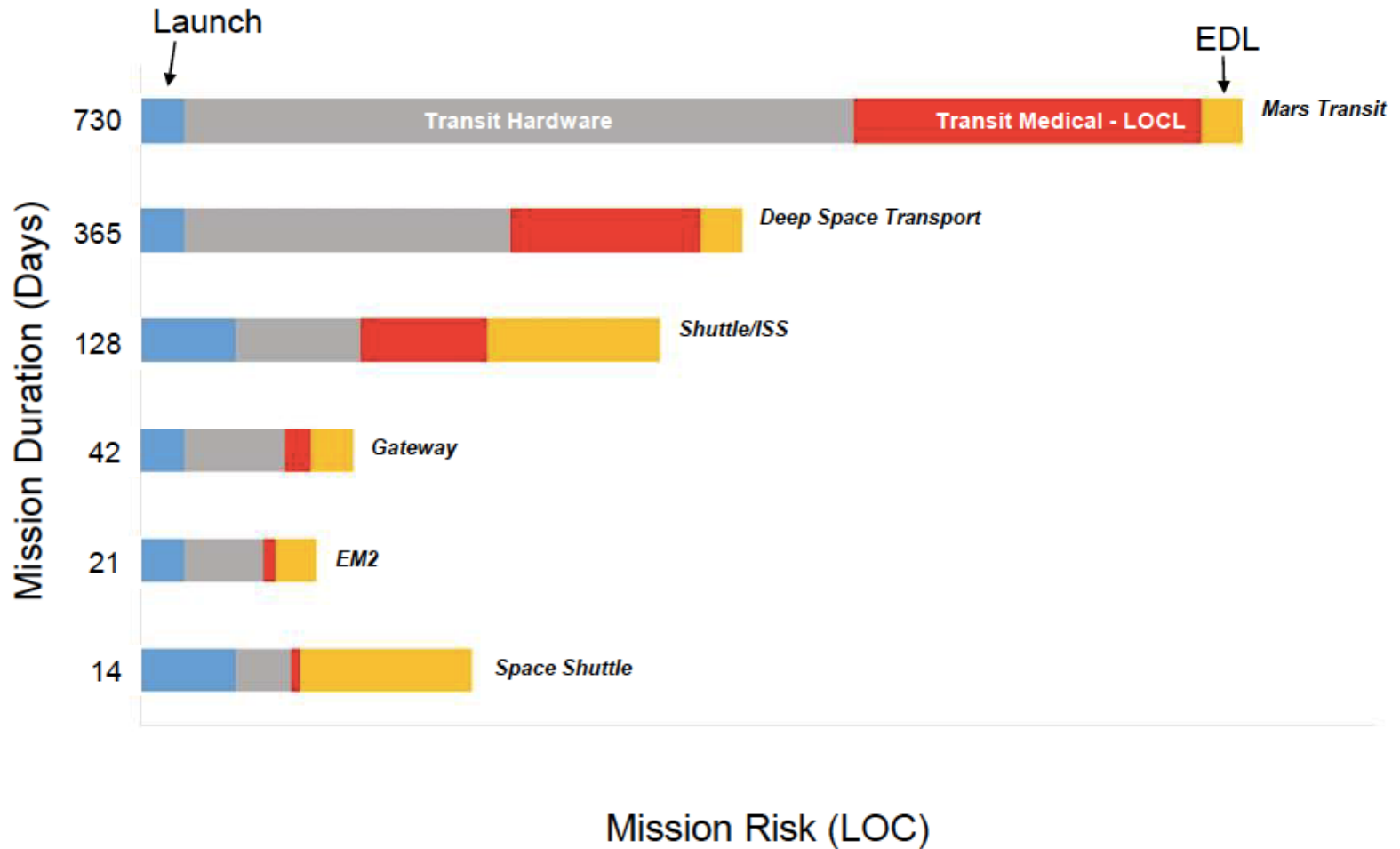
- **Lack of single source for data**
- **Flight data- high internal validity, small volume**
- **Analog data- Lower validity, higher volume**
- **Expert opinion**

# Probabilistic Risk Assessment





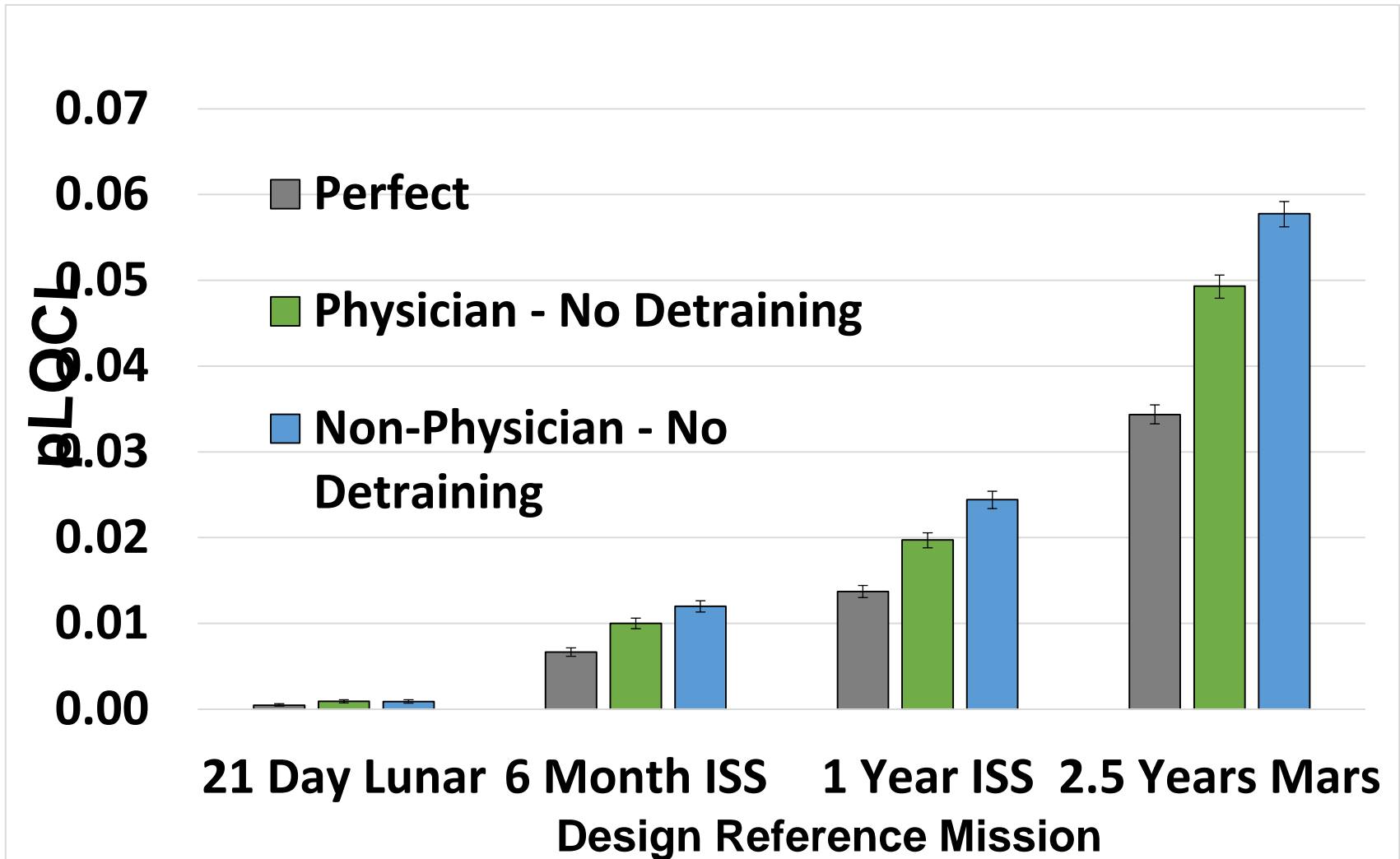
# Proportion of Mission Risk attributable to Medical



# Some IMM Assumptions...

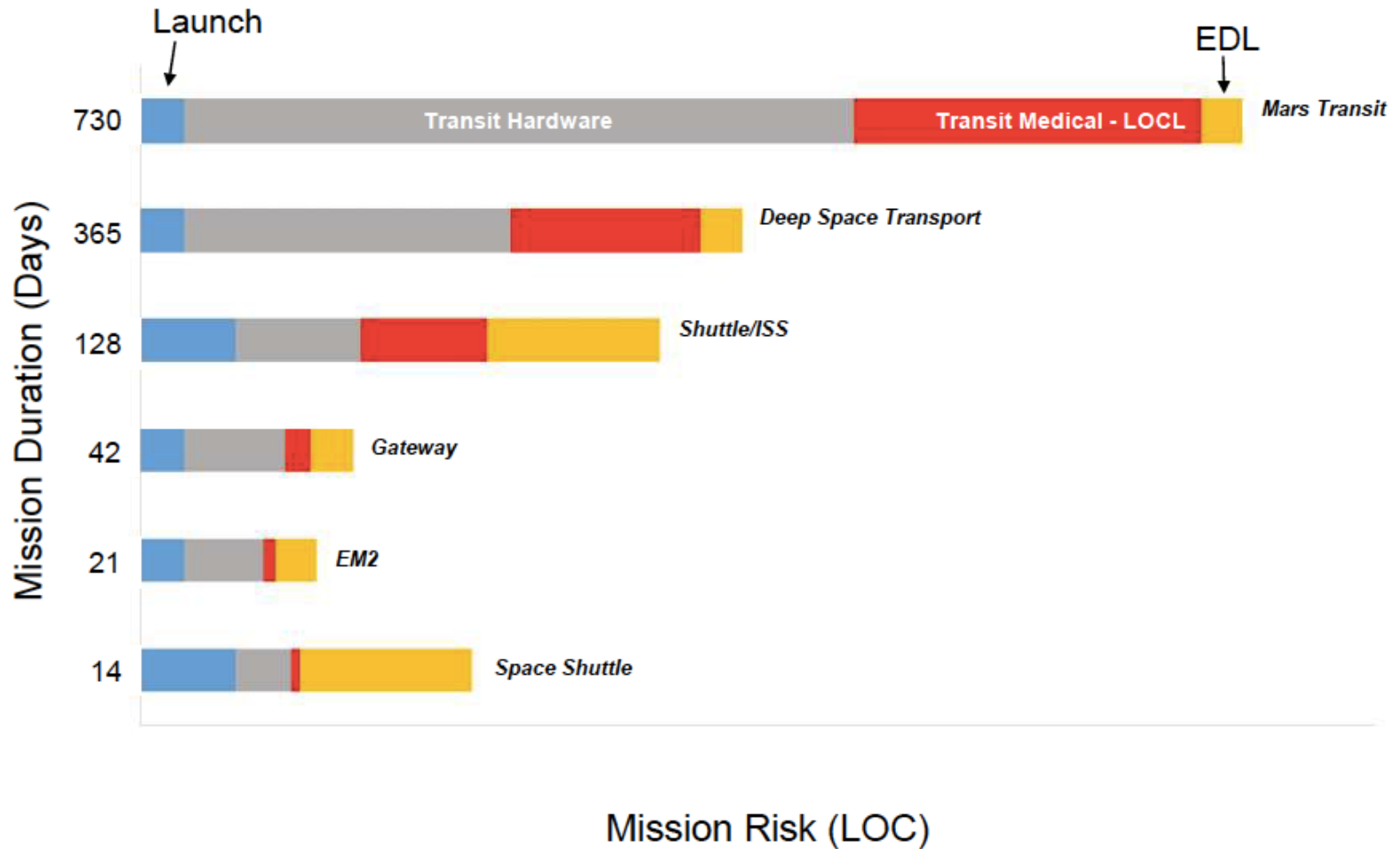
1. **All diagnoses are 100% accurate.**
2. **All events receive appropriate treatment.**
3. All meds and equipment are 100% reliable and effective.
4. All events respond as they would terrestrially.
5. **No mistakes in medical procedures (regardless of training)**
6. Power, water, oxygen unlimited

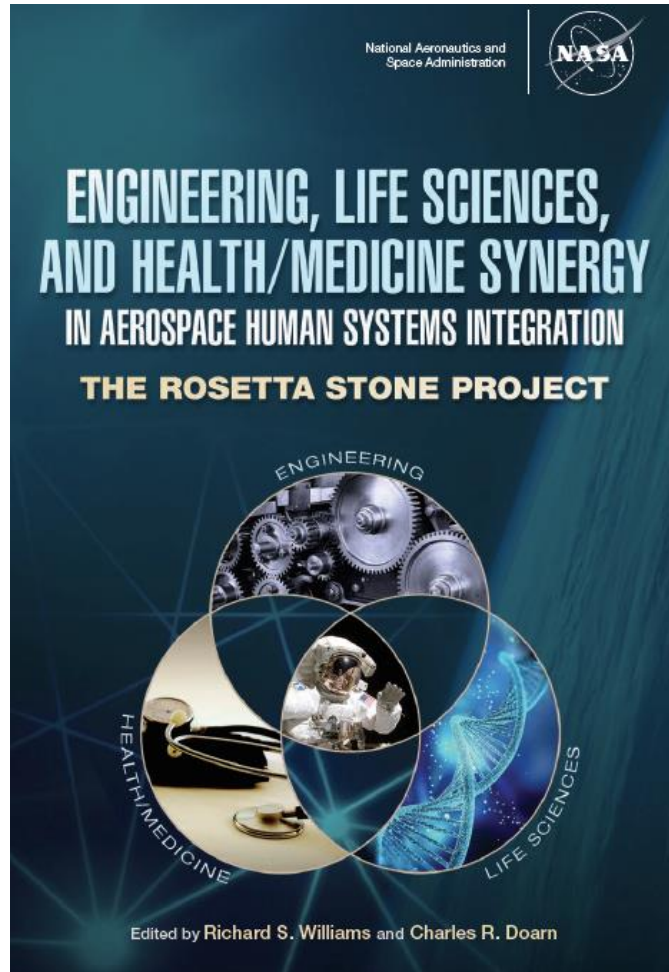
# PRA Estimates of Loss of Crew Life



Slide courtesy of E Kerstman

# Proportion of Mission Risk attributable to Medical





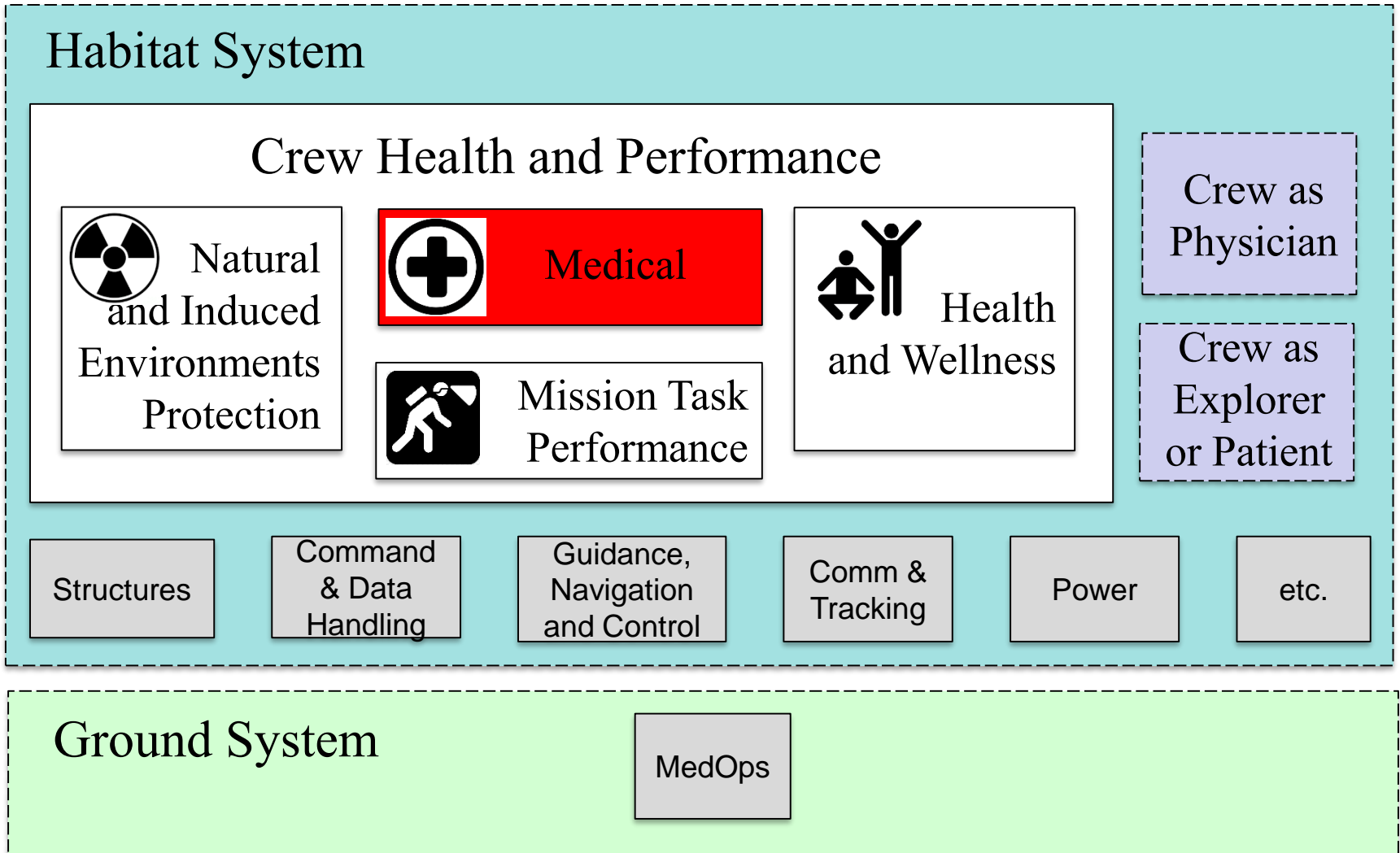
“...[The] assumption has been that **risk of vehicle system malfunction far outweighs the risk of human system failure**...NASA buys down the risk of failure of the human system through rigorous selection of individuals designed to minimize medical issues and optimize available capability in flight.”

NASA SP-2017-0633



# **CREW HEALTH AND PERFORMANCE SYSTEM**

# Vehicle/Mission Architecture Integration



# Crew Health and Performance System Must...

- **Protect from environmental hazards**

- Radiation protection
- Noise, vibration, CO<sub>2</sub>, 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



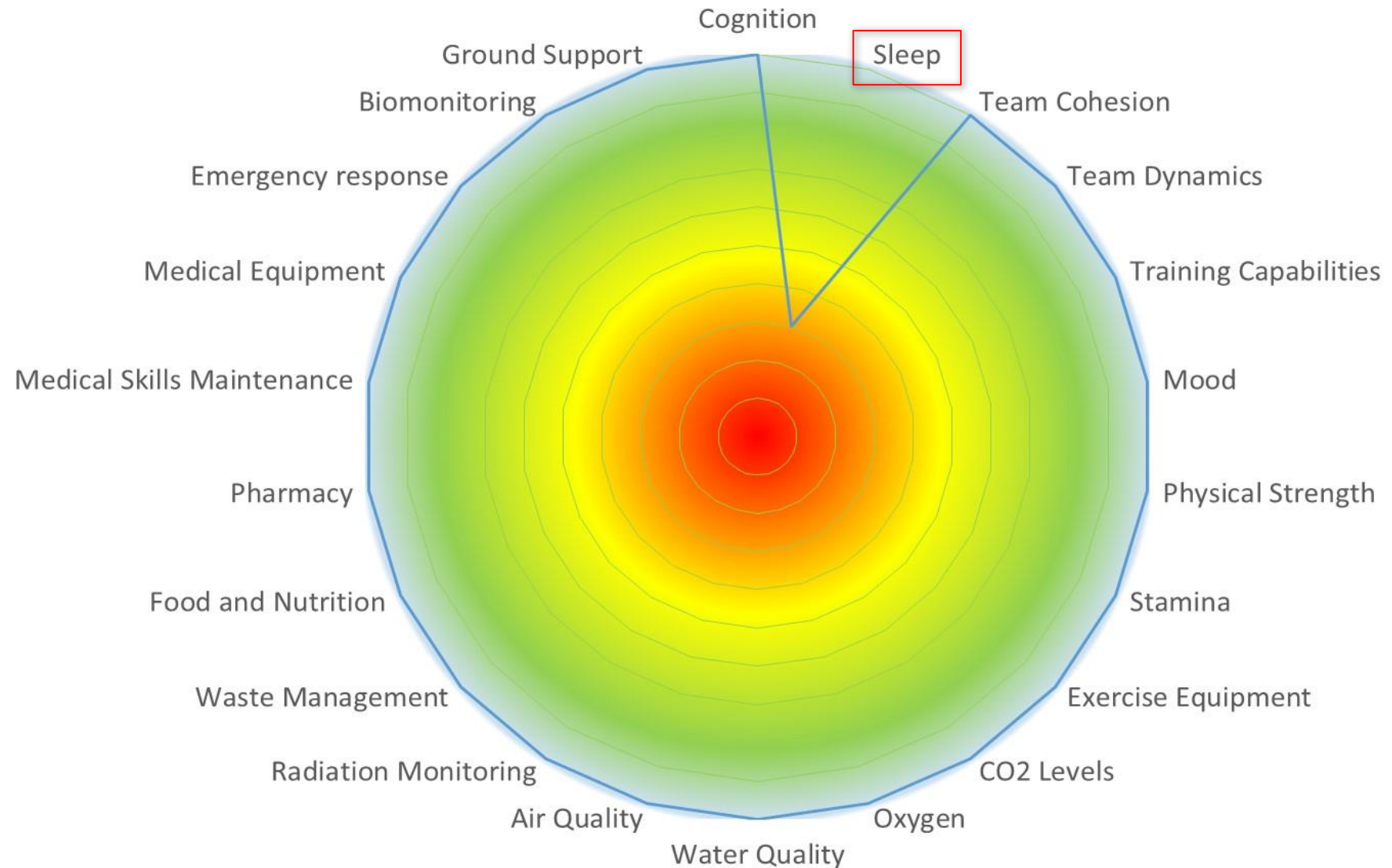
- **Support crew to accomplish mission tasks**

- Procedures
- Training
- User interfaces

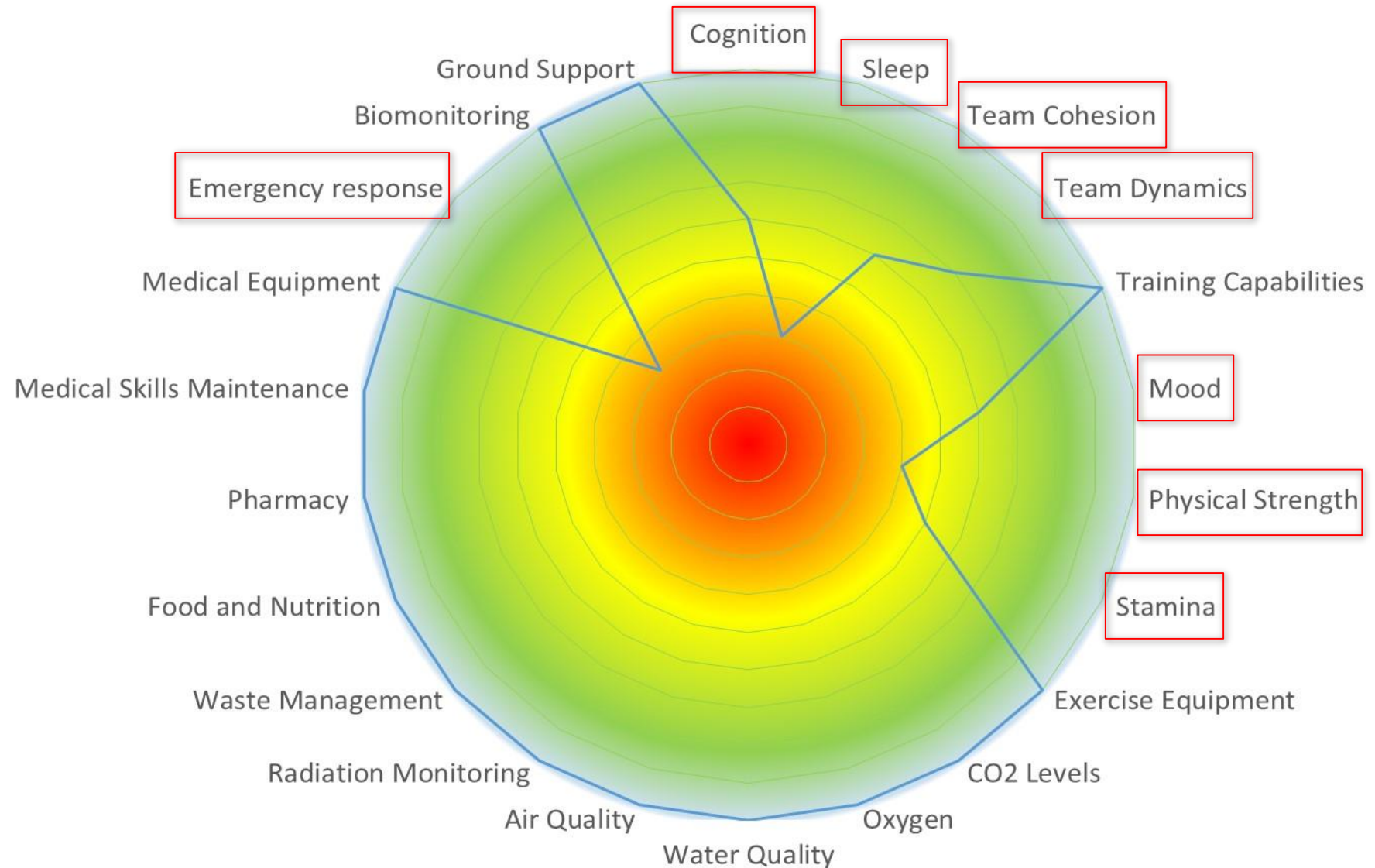




# System Performance Threatened by Sleep Deficit



# Sleep Deficit Affects Other System Aspects



# Translate Medicine to Engineering

Stakeholder needs, goals

NASA Standards



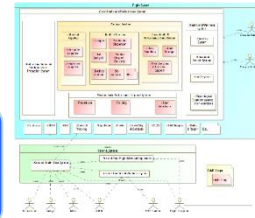
Interpretation of NASA-STD-3001 Levels of Care for Exploration Medical System Development

Program requirements & architecture

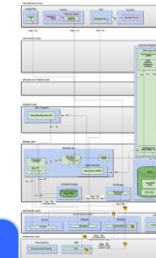
Melinda Reiter, BS, DPT  
EMSC System Support  
EMSC-02  
Human Health & Performance Center  
Mikaela O'Brien  
EMSC Medical System Concept of Operations Project Manager  
EMSC-02/03/04/05  
Human Health & Performance Center  
David Brown, MS, DPT  
EMSC Clinician  
University of Texas Medical Branch  
Human Health & Performance Center  
Rich Anderson, MS, PhD

System functions & behaviors

System requirements & architecture

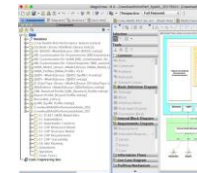


Subsystem requirements & architecture

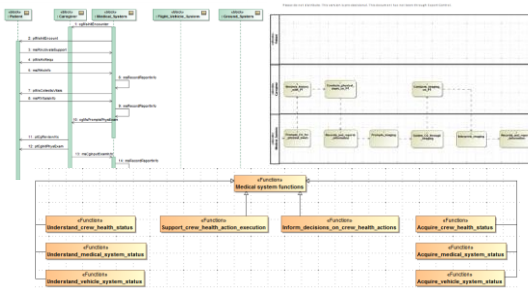


Characterize system

Analyze & trade

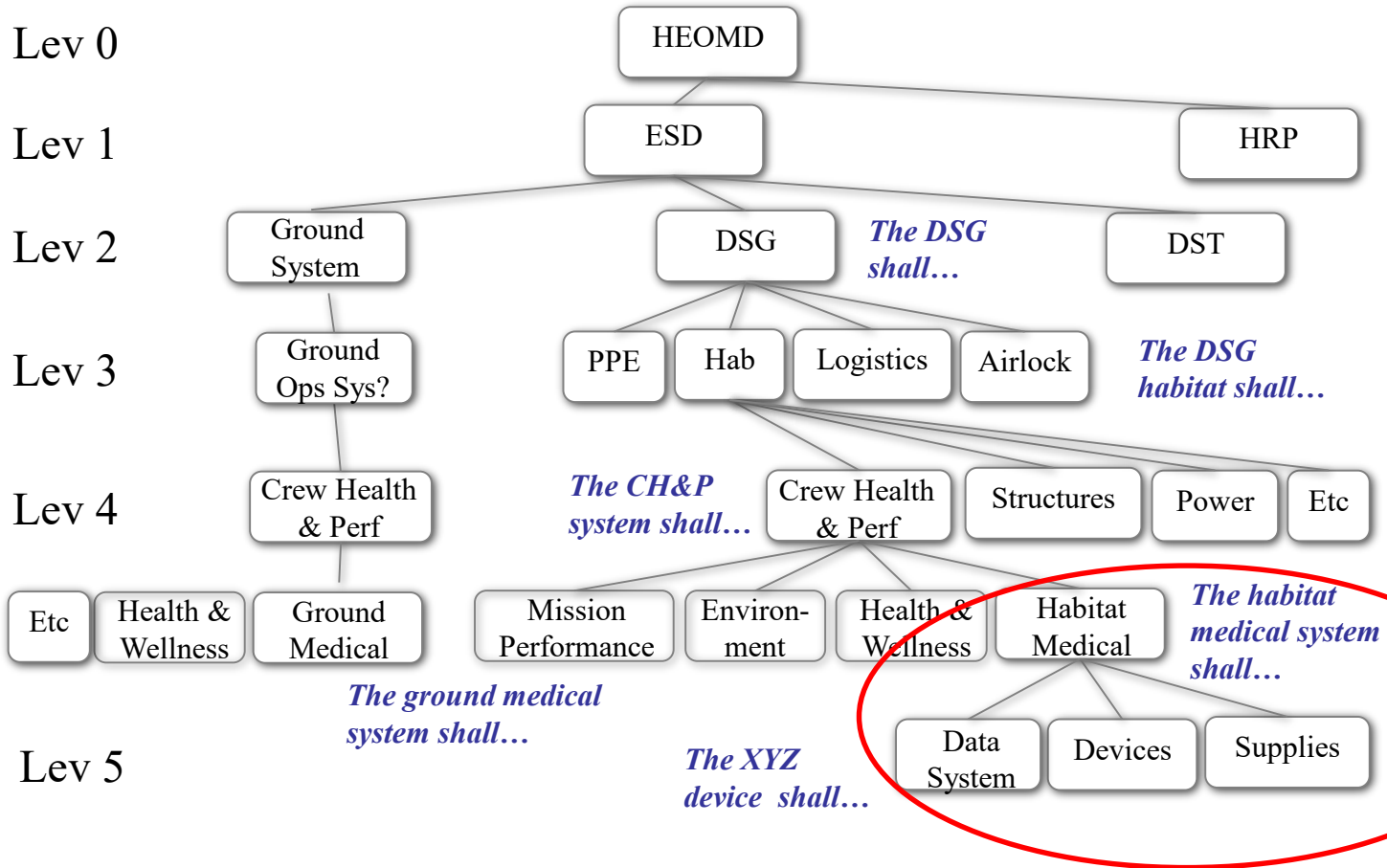


Design & Build



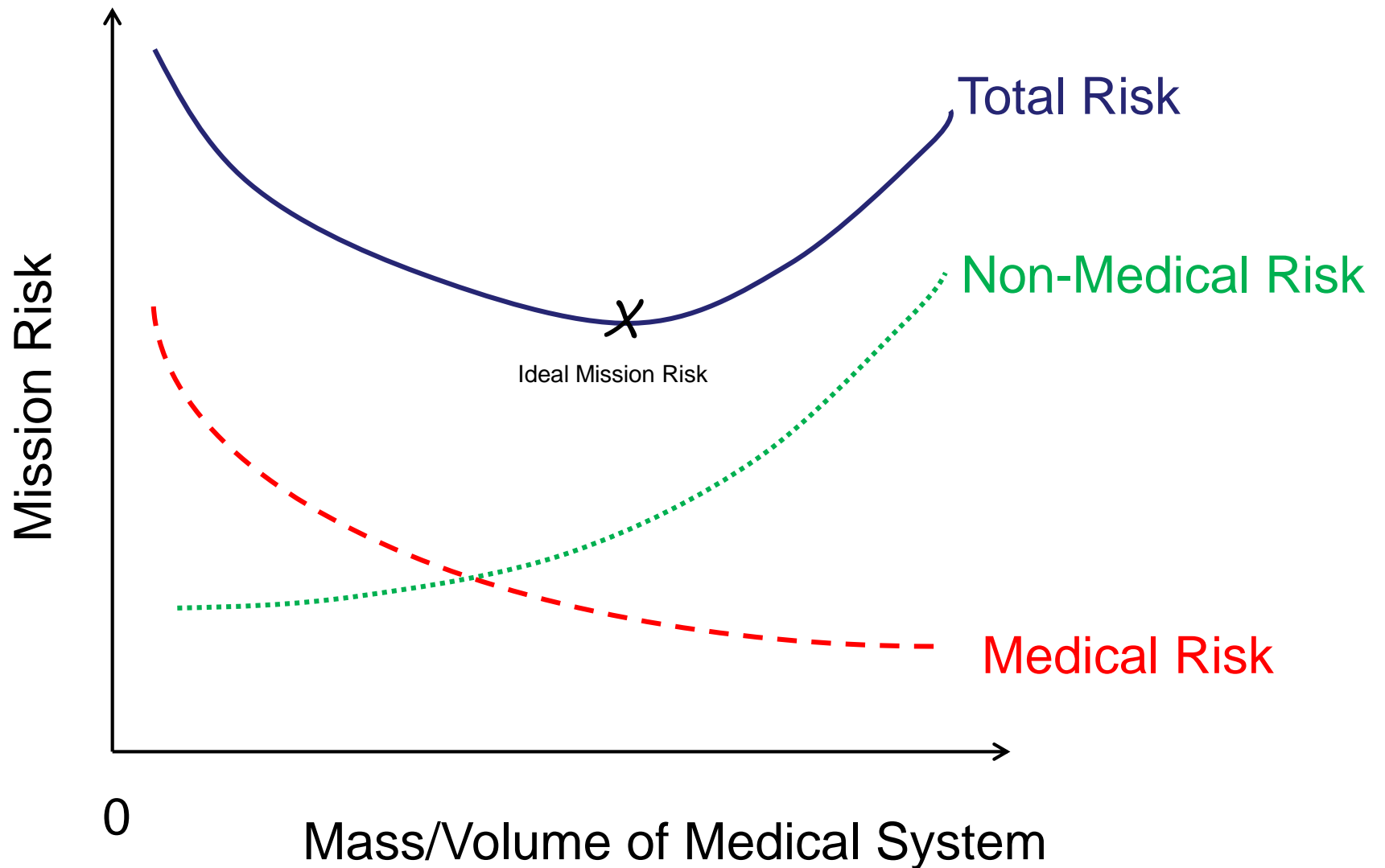
Do we have the capabilities to meet the needs?  
What allocations are necessary?

# NOT Official – best guess on requirements context



# TRADE SPACE ANALYSIS

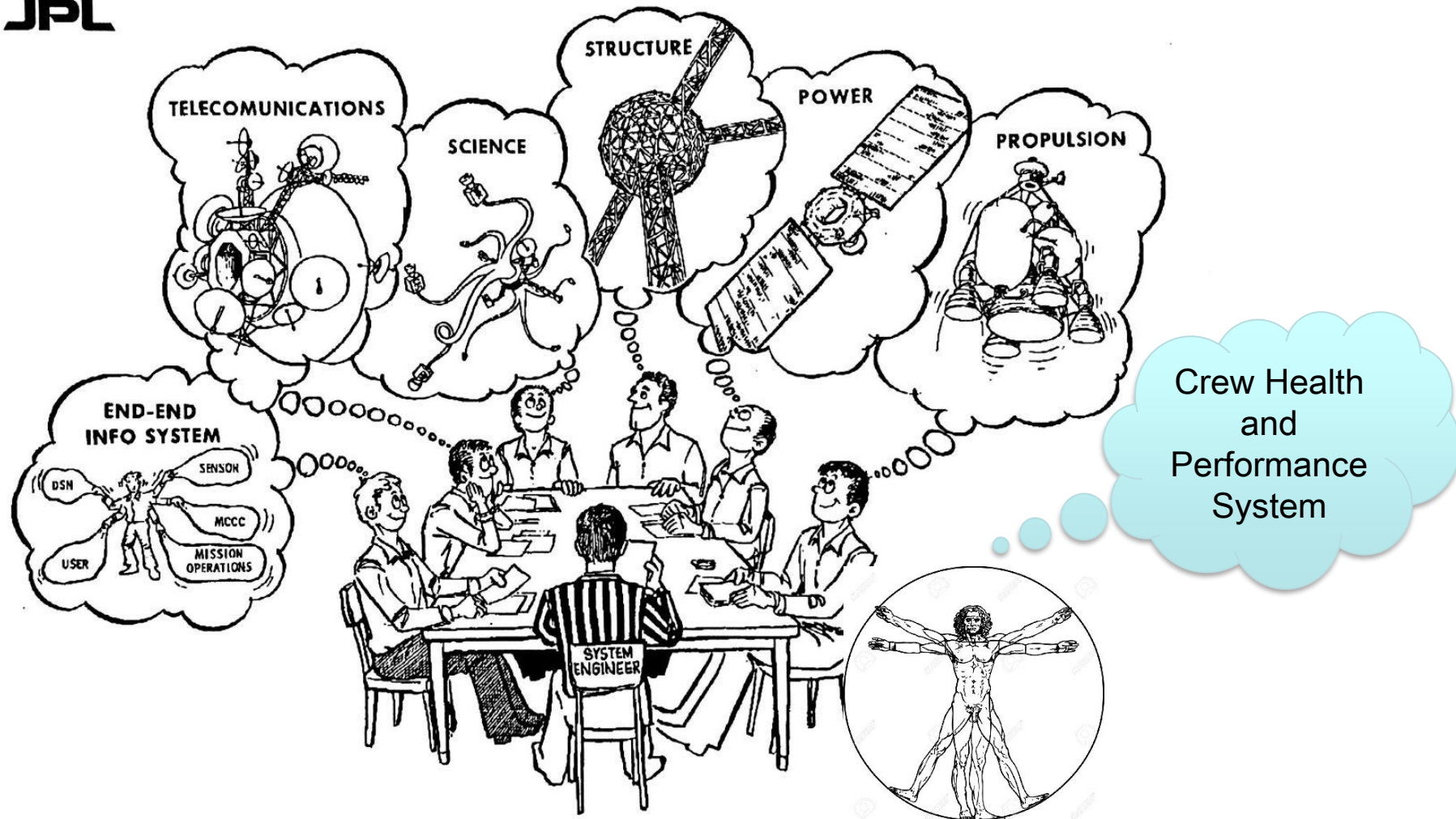
# Medical and Non-medical Risk



# Medical Systems Engineering

DESIGN TEAM OPERATIONS

JPL



SYSTEM ENGINEERING AT JPL

06/14/91

4.9



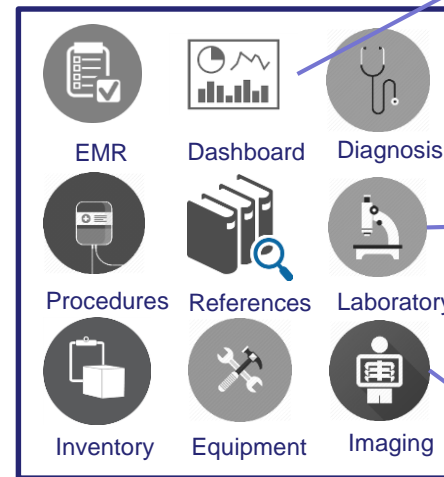
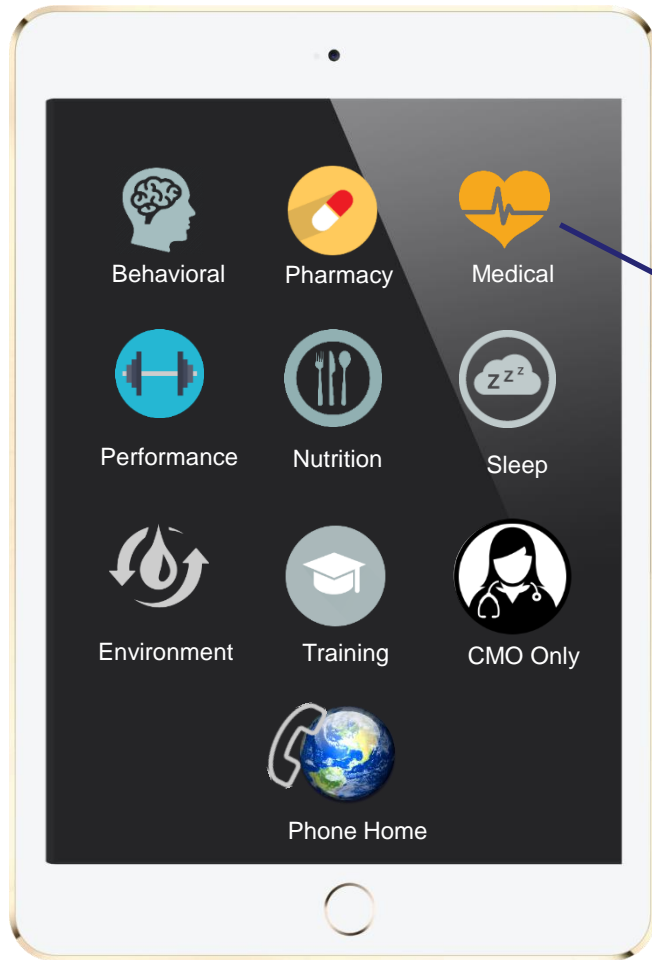
# **MEDICAL DATA ARCHITECTURE**



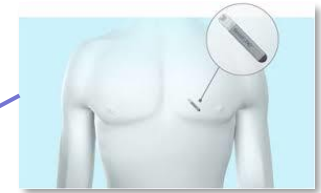
# We're not bringing an Intensive Care Unit but...

Crew Health and Performance System

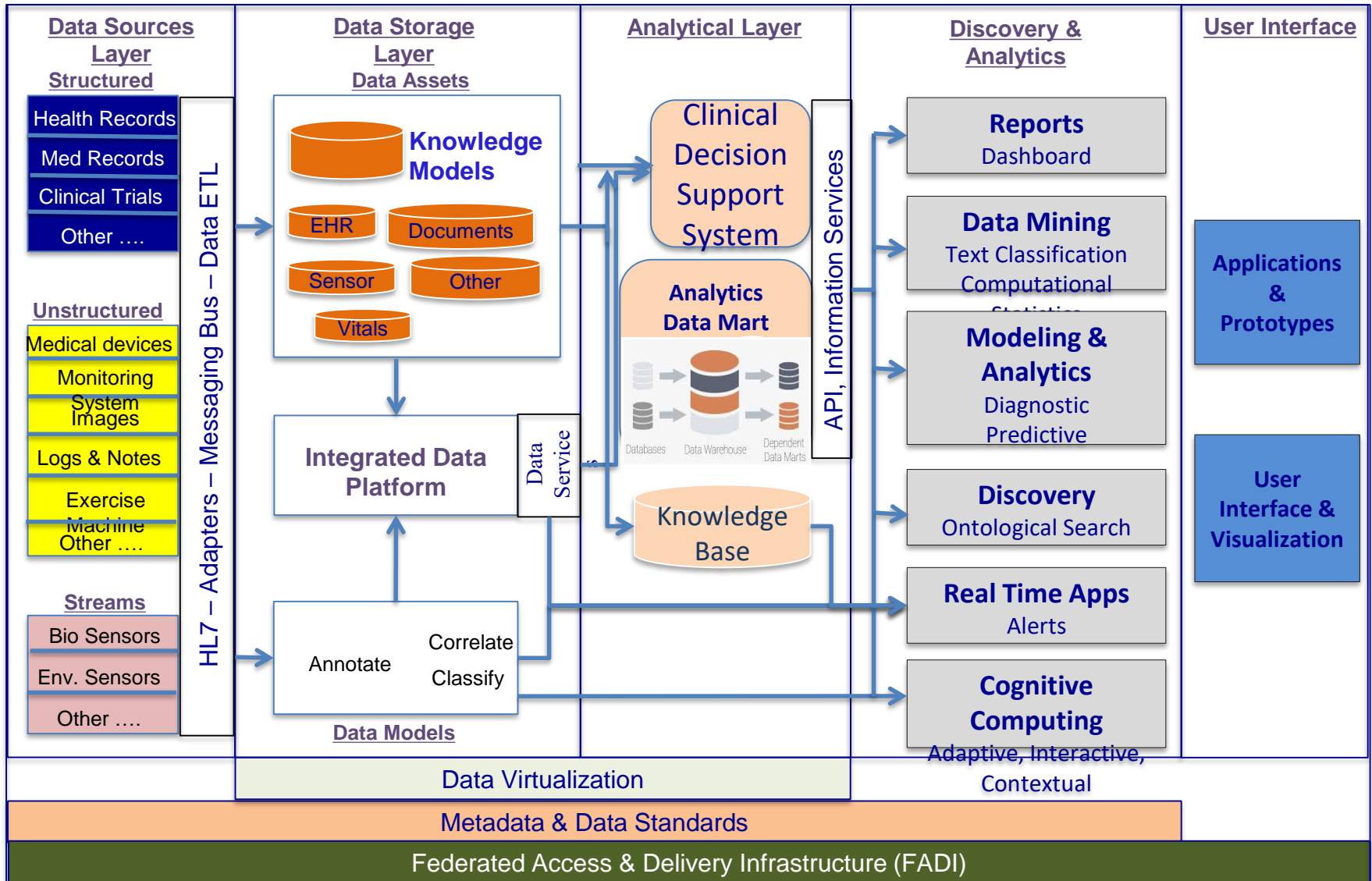
These technologies exist today



Medical



# Where are we today? MDA



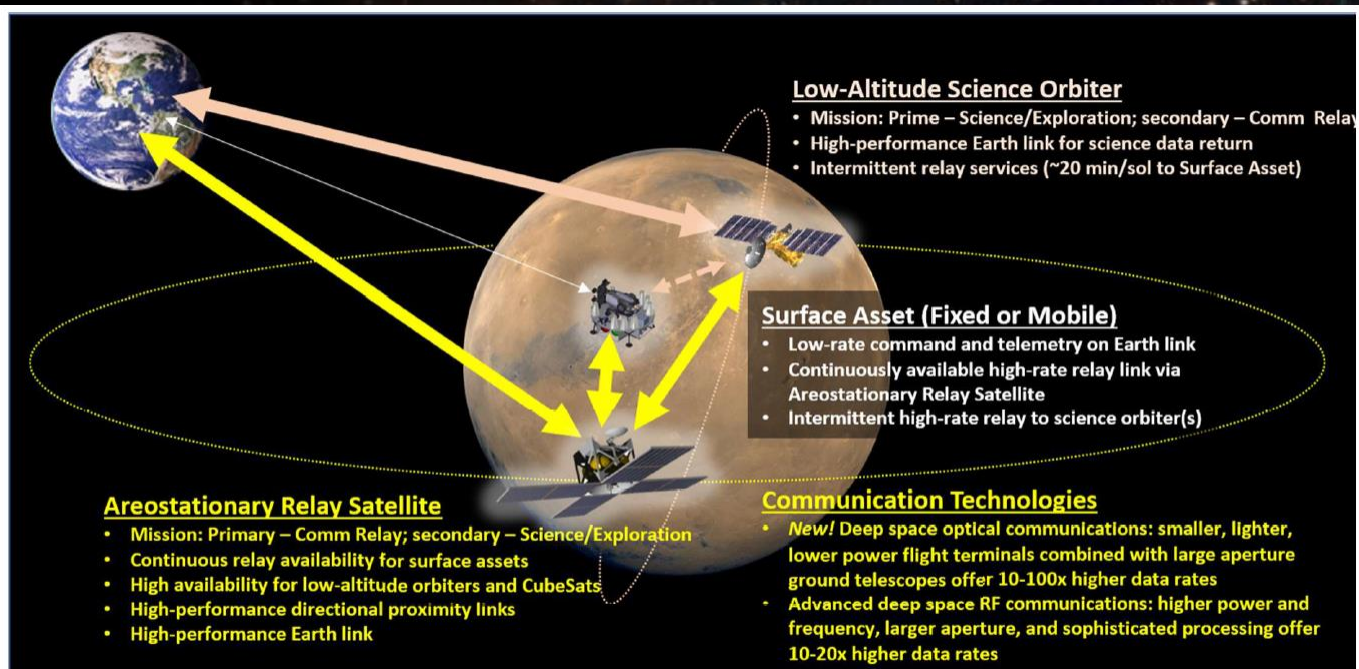


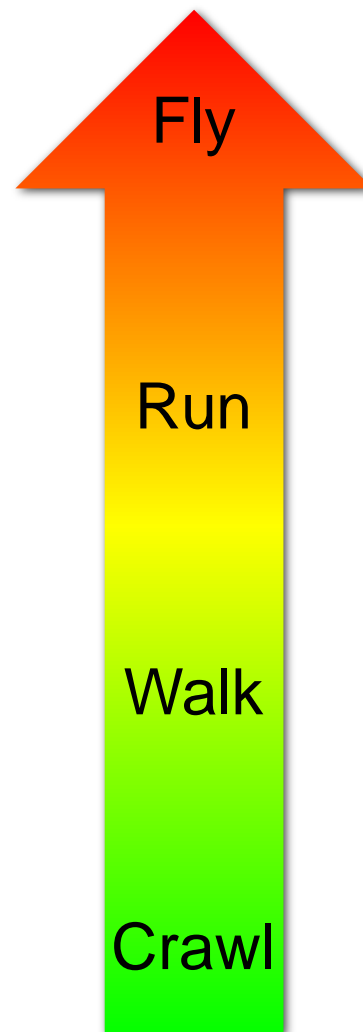
Figure 1. Advanced RF and optical communications technologies combined with using the areostationary orbit offer 100-1000x greater data return from Mars and nearly continuous availability.

Table 1. High-Performance Mars-Earth Trunk Line Capability

	Frequency Band	Maturity	S/C Aperture	S/C Txmt Power	Ground Receiver	Data Rate (@ 2 AU)
<b>Current State-of-the-Art (MRO)</b>	X-band	Operational	3 m	100 W	34 m DSN BWG antenna	<b>1 Mb/s</b>
<b>Next-Generation Trunk Line Options</b>	Ka-band	TRL 6	3 m	200 W	34 m DSN BWG antenna	<b>5 Mb/s</b>
		TRL 3-4	5 m	1 kW	34 m DSN BWG antenna	<b>70 Mb/s</b>
	Optical (1550 nm)	TRL 6 (DSOC; to fly on 2023 Psyche Discovery Mission)	22 cm	4 W	5 m ground telescope	<b>1 Mb/s</b>
		TRL 3	50 cm	50 W	12 m ground telescope	<b>100 Mb/s</b>

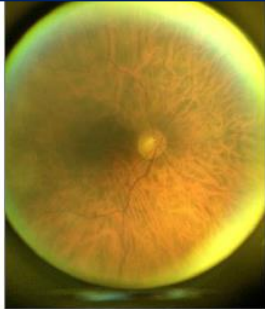
# Can we replace the doctor?

- Full Artificial Intelligence
- Integrative Health and Performance Prediction
- Condition Specific Guidance
- Differential Diagnosis Generation
- Automated Image/Data Analysis
- Knowledge Support/Known Algorithm Provision
- Preventive Care Strategies



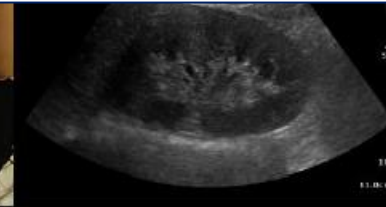
# Autonomy - COMfORT

## Fundoscopy – Retinal Imaging

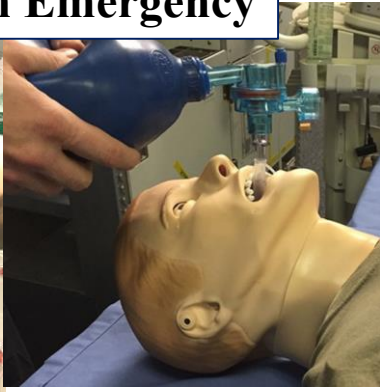
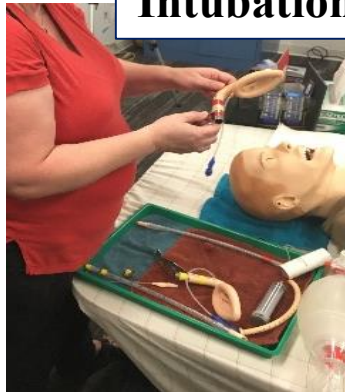


Good composition

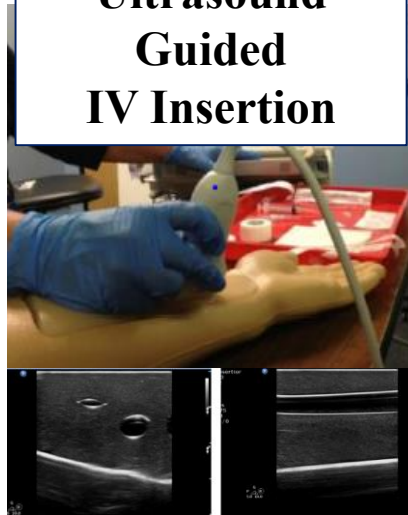
## Urinary Tract – Kidney and Bladder Ultrasound Imaging



## Intubation Emergency



## Ultrasound Guided IV Insertion



## Diagnosis and Treatment Exercise

**PATIENT DATA**

Click a body area on the right to view the patient's symptoms in that area.

Head  
Eyes  
Ears  
Nose  
Neck  
Pharynx  
Chest/Lungs  
Heart  
Abdomen  
Rectum  
Urogenital (pelvic)  
Extremities  
Back  
Neuro  
Skin  
Lymph Nodes

**Abdomen**  
Bowel sounds absent, severe diffuse tenderness to palpation, distended, guarding.

**DIFFERENTIAL DIAGNOSIS**

Perform physical exam, and collect vitals.

**Vitals**

Blood Pressure: 140/95 mmHg  
Heart Rate: 120 bpm  
Temperature: 38.3 °C  
Respiratory Rate: 20 bpm  
Oxygen Saturation: 100 %

**Heart**

regular rhythm  
 irregular rhythm  
 abnormal sounds

**Lungs**

rapid shallow breathing  
 wheeze  
 other abnormal sound

**Back exam**

back not quite non-tender  
 cervicovertebral angle tenderness - right  
 cervicovertebral angle tenderness - left

**Pelvic exam**

normal  
 cervical motion tenderness  
 adnexal pain - right  
 adnexal pain - left  
 not performed

**Bowel sounds**

normal  
 increased  
 decreased  
 absent

**Tenderness to palpation (abdomen)**

none  
 minimal  
 moderate  
 severe

**Location of tenderness to palpation (abdomen)**

right upper  
 right lower  
 left upper  
 left lower  
 none  
 suprapubic  
 suprapubic  
 diffuse

**Other**

none  
 distended or firm abdomen  
 palpable mass/organs/enlargement  
 abnormal tenderness  
 guarding

PREVIOUS    NEXT

# Fundoscopy Module

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

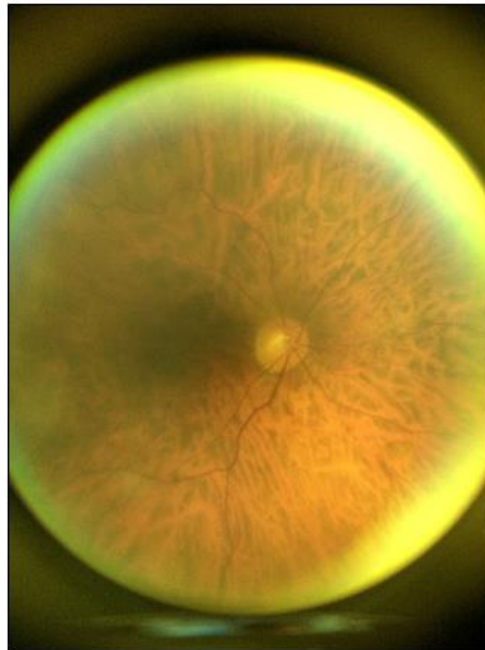
## TAKING A GOOD IMAGE: COMPOSITION

### 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.

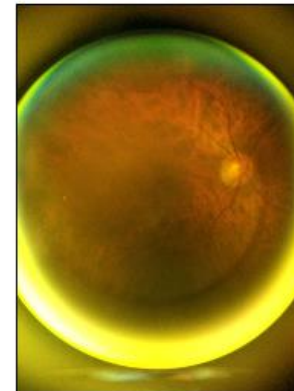
In a good composition the optic disc is centered.



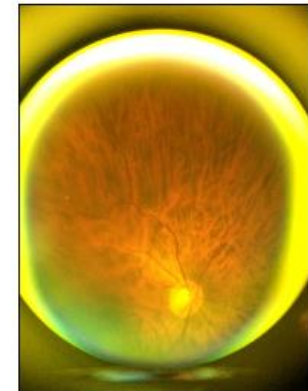
Good composition

### 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

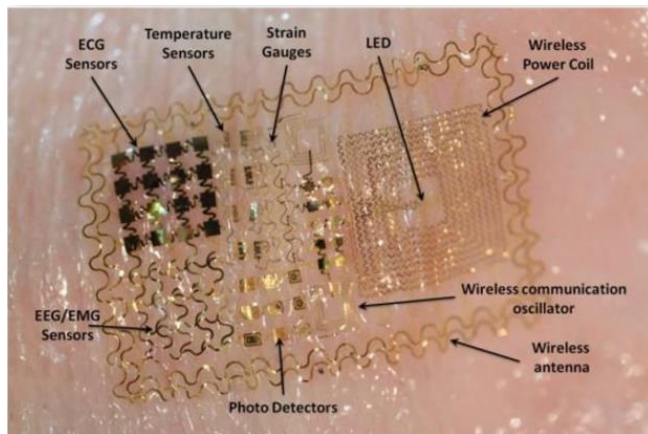
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

NEXT

# Medical Technology Development



**FUS moving stone in ER patient**

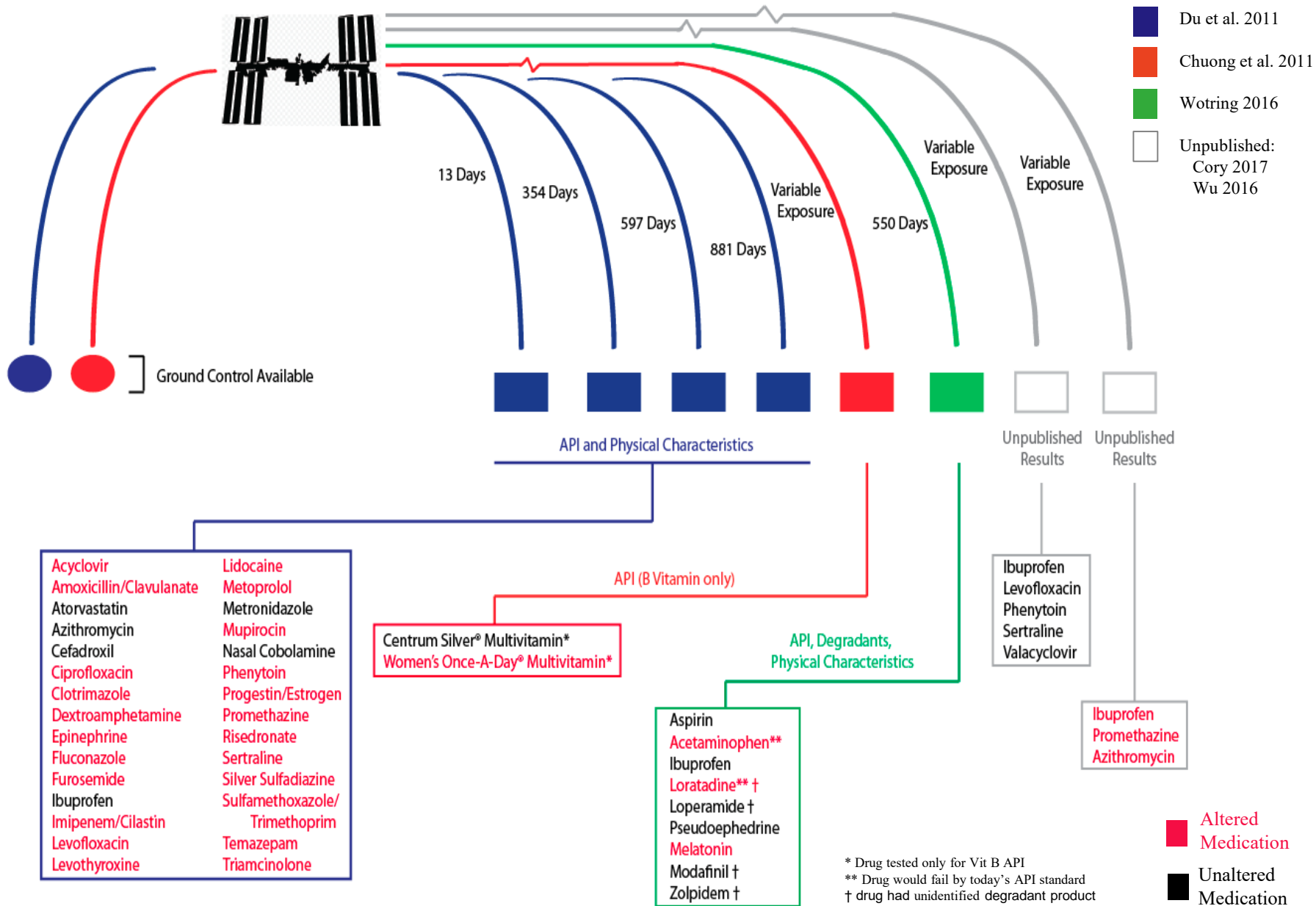


**SEEQ Mobile Cardiac Telemetry System: Medtronic**



# PHARMACY

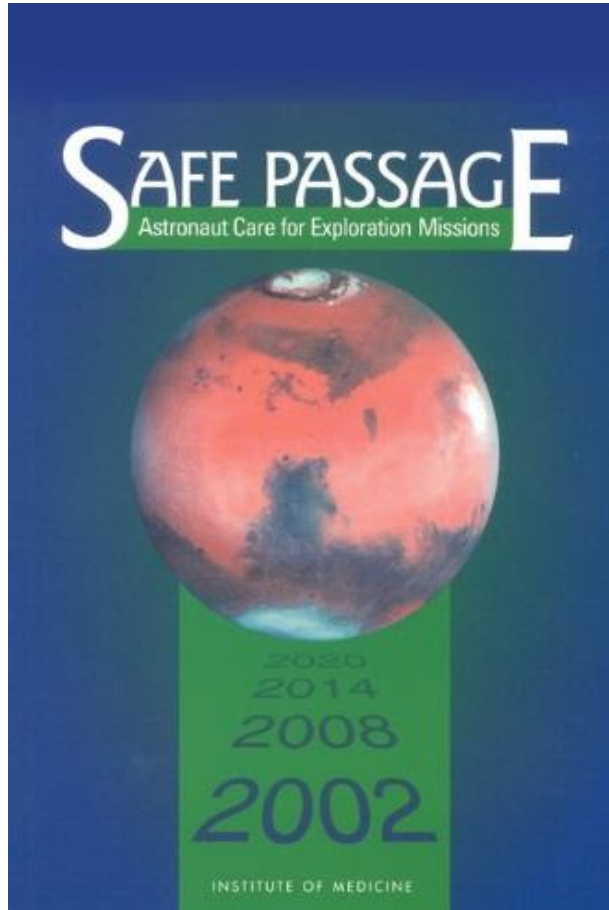




# Other Topics within In-Flight Medical Conditions

- **Imaging**
- **Rehabilitation**
- **Lab Analysis**
- **Biomonitoring and Wearables**
- **Personalized Medicine**
- **Renal Stones**

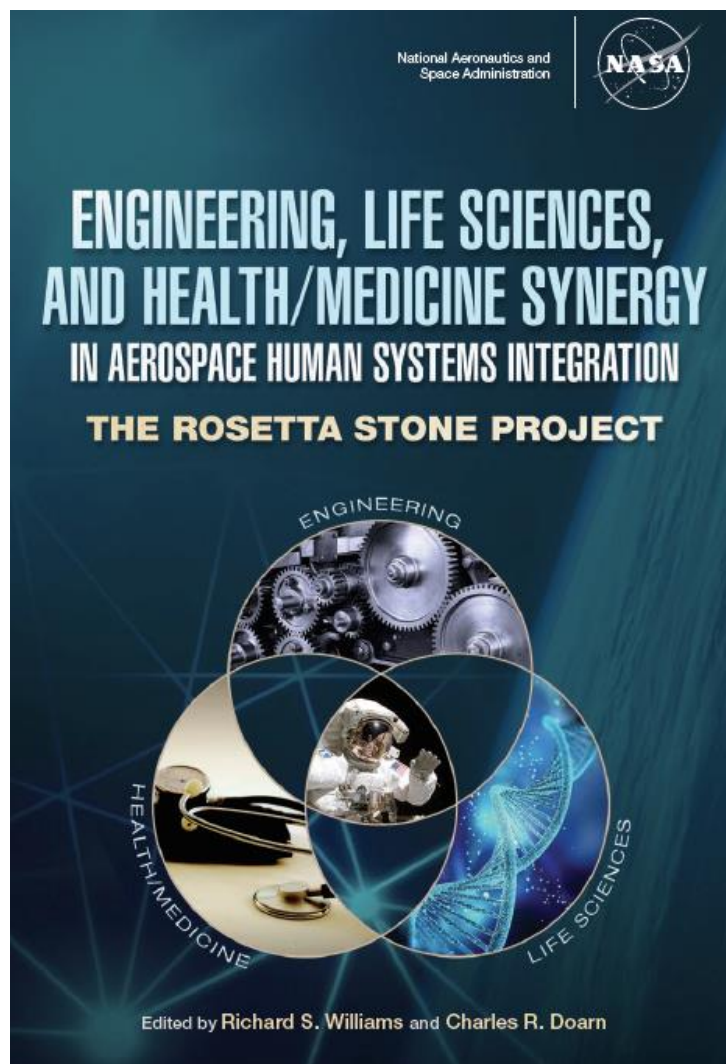
# Safe Passage



- *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.

# Rosetta Stone



# Questions?



[benjamin.easter@nasa.gov](mailto:benjamin.easter@nasa.gov)