National Aeronautics and Space Administration

Planning for Mars: An Exploration Medicine Overview

UTMB USRA Grand Rounds

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Conflicts of Interest Disclosure

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I have financial interests in the above entities.

The opinions shared here are my own and not necessarily reflective of the above institutions.

Outline

- **Defining the challenge**
- **History of Spaceflight Medical Systems**
- **Mars is different**
- **Principles of Approach**
- **Scoping a Medical System**
- **Where are we now?**

What is the challenge?

- When we say “Mission to Mars" what do we really mean?
- What implications does that have for how you provide medical care?
- Is this really so different from what we do on the ISS or when we went to the moon?

ExMC Responsibilities

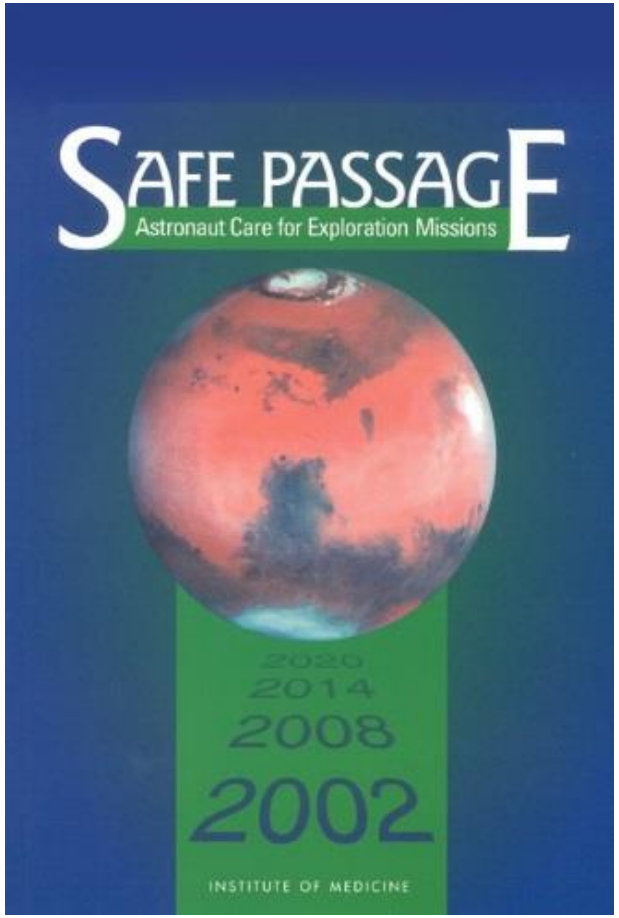
Risk Title: Risk of Adverse Health Outcomes & Decrements in Performance due to Inflight Medical Conditions

Description: Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes and decrements in performance during these missions and for long term health.

Our Mission

To minimize mission medical risk through medical system design and integration into the overall mission and vehicle design.

SOME HISTORY



2001, Conclusion 6:

NASA, because of its mission and history, has tended to be an insular organization dominated by traditional engineering. Because of the engineering problems associated with early space endeavors, the historical approach to solving problems has been that of engineering. Long duration space travel will require a different approach, one requiring wider participation of those with expertise in divergent, emerging, and evolving fields. NASA has only recently begun to recognize this insufficiency and to reach out to communities, both domestic and international, to gain expertise on how to remedy it.

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)

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

Gemini and Apollo

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

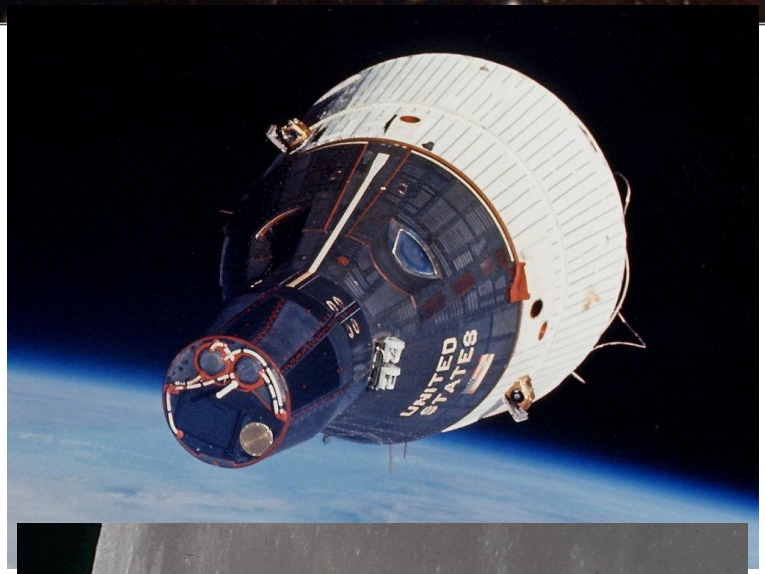
Medication	Indication	Dose	Amount
D-Amphetamine sulfate	Stimulant	5-mg tablets	8
Aspirin-phenacetin-caffeine	Pain	Tablets	16
Cyclizine HCl	Motion sickness	50-mg tablets	8
Diphenoxylate HCl	Diarrhea	2.5-mg tablets	16
Meperidine HCl	Pain	100-mg tablets	4
Methyl cellulose solution	Eye lubricant	15-ml bottle	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
Triprolidine HCl	Decongestant	2.5-mg tablets	16

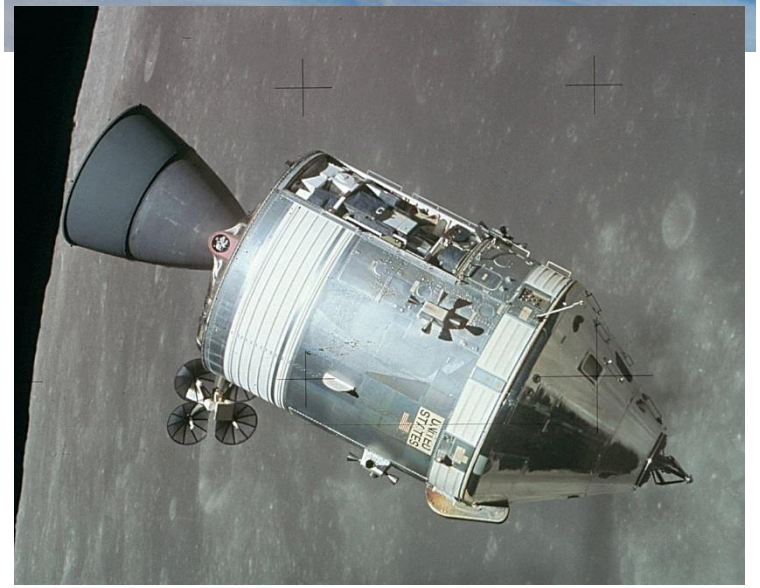
FIGURE 4.3. Apollo medical kit containing items such as skin cream, antibiotic ointment, nasal spray, band-aids, and stimulants (Photo courtesy of NASA)

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

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

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





Principles of Clinical Medicine for Spaceflight
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Space Shuttle

Table 4.2. Contents of the Apollo Command-Module medical kit [12].

Items	Indication	Formulation	Amount[a]
Actifed (triprolidine/pseudoephedrine)	Decongestant	Tablets	60
Afrin (oxymetazoline)	Decongestant	Nose drops	3
Ampicillin	Antibiotic	Tablets	60
Aspirin	Analgesic	Tablets	72
Atropine[b]	Cardiac arrhythmias	Injectable solution	12
Bacitracin	Antibiotic	Eye ointment	1
Benadryl (diphenhydramine)[c]	Antihistamine	Tablets	8
Darvon (propoxyphene)	Analgesic	Tablets	18
Demerol (meperidine)[b]	Analgesic	Injectable solution	6
Dexedrine (d-amphetamine)	Stimulant	Tablets	12
Lidocaine[b]	Cardiac arrhythmias	Injectable solution	12
Lomotil (diphenoxylate)	Diarrhea	Tablets	24
Marezine (cyclizine)	Antihistamine	Injectable solution	3
Marezine (cyclizine)[d]	Antihistamine	Tablets	24
Methylcellulose	Laxative	Capsules	2
Multivitamins		Tablets	20
Mylanta (simethicone)	Antiflatulent	Tablets	40
Nasal emolient			1
Neosporin (polymixin B)	Antibiotic	Ointment	1 or 2
Ophthaine (proparacaine preparation)	Topical anesthetic	Eye drops	1
Pronestyl (procainamide)[b]	Cardiac arrhythmias	Tablets	80
Scopolamine-dexedrine	Motion sickness	Tablets	12
Seconal (secobarbital)	Sleeping aid	Tablets (100 mg)	21
Seconal (secobarbital)[e]	Sleeping aid	Tablets (50 mg)	12
Skin cream			1
Tetracycline	Antibiotic	Tablets	Varied
Tetrahydrozoline HCl[a]		Eye drops	1
Tylenol (acetaminophen)[e]	Analgesic	Tablets	14
Band-aids			12
Compress bandages			2

[a]Not all medications were carried in the amounts noted on all flights.
[b]Carried on Apollo-16 and -17 only.
[c]Carried on Apollo-8 only.
[d]Carried on the first 4 missions only.
[e]Carried on Apollo-17 only.

Table 4.3. Contents of the Apollo Lunar Module medical kit [12].

Items	Indication	Formulation	Amount[a]
Actifed (triprolidine/pseudoephedrine)	Decongestant	Tablets	8
Afrin (oxymetazoline)	Decongestant	Nose drops	1
Aspirin	Analgesic	Tablets	12
Atropine	Cardiac arrhythmias	Injectable solution	4
Darvon (propoxyphene)	Analgesic	Tablets	4
Demerol (meperidine)	Analgesic	Injectable solution	2
Dexedrine (d-amphetamine)	Stimulant	Tablets	4
Lidocaine	Cardiac arrhythmias	Injectable solution	8
Lomotil (diphenoxylate)	Diarrhea	Tablets	12
Methylcellulose		Eye drops	1
Neosporin (polymixin B)	Antibiotic	Ointment	1
Pronestyl (procainamide)	Cardiac arrhythmias	Tablets	12
Seconal (secobarbital)	Sleeping aid	Tablets	6
Band-aids			6
Compress bandages			2
Urine collection and transfer devices			6

[a]Not all medications were carried in the amounts noted on all flights.

Table 4.4. Contents of the Skylab In-Flight Medical Support System [13].

Equipment	Kit	Usage requirement
Accumulator assembly	Microbiology	No restriction
Adhesive tape, Dermicel	Bandage	No restriction
Adhesive tape, Micropore	Bandage	No restriction
Air sampler	Bandage	Not applicable
Airway, pharyngeal	Therapeutic	No restriction
Aneroid sphygmomanometer	Diagnostic	No restriction
Applicator, dental	Bandage	No restriction
Applicators, silver nitrate (12)	Bandage	No restriction
Antibiotic lubricant	Catheterization	No restriction
Band-Aids (100)	Bandage	No restriction
Barrier, sterile field (2)	Minor Surgery	Physician use/approval required
Batteries (8 AAA), (8 AA), (8 C)	Diagnostic	No restriction
Betadine squares (4)	Minor Surgery	No restriction
Bili-Labstix/Urobilistix	Hematology/Urinalysis	No restriction
Binocular loupe	Diagnostic	No restriction
Blood lancets (75)	Hematology/Urinalysis	No restriction
Calcium alginate balls (50)	Hematology/Urinalysis	No restriction
Can opener	Not applicable	Not applicable
Cannula	Therapeutic	Physician use/approval required
Capillary pipettes (50)	Hematology/Urinalysis	No restriction
Catheter, urinary	Catheterization	Physician use/approval required
Coagulase plasma	Command Module Resupply	No restriction
CO_2 accumulator assembly	Microbiology	No restriction
CO_2 generators (24)	Microbiology	No restriction
Collection bag (3)	Catheterization	No restriction
Container, injectables	Therapeutic	Physician use/approval required
Demerol injectors (5)	Therapeutic	No restriction
Dermicel surgical tape	Hematology/Urinalysis	No restriction
Digital hand counter	Hematology/Urinalysis	No restriction
Disinfectant pads (60)	Not applicable	No restriction
Disposable bags (20)	Microbiology	No restriction
Dressing boot (Unna's)	Bandage	No restriction
Dressing, abdominal (6)	Bandage	No restriction
Drug modules (2)	Drug Supply Module	Not applicable
Elastic wraps (3)	Bandage	No restriction
Elevator	Dental	No restriction
Endotracheal tube	Therapeutic	Physician use/approval required
Eye patch, cotton (8)	Bandage	No restriction
Eye patch, plastic (2)	Bandage	No restriction
File	Dental	No restriction
Filter strips (10)	Microbiology	No restriction
Fluorescein strips (12)	Bandage	No restriction
Forceps, 6-in (3)	Microbiology	No restriction
Forceps, mandibular anterior	Dental	No restriction
Forceps, mandibular posterior	Dental	No restriction
Forceps, maxillary anterior	Dental	No restriction
Forceps, maxillary posterior	Dental	No restriction
Forceps, mosquito	Minor Surgery	Physician use/approval required
Forceps, splinter	Bandage	No restriction
Forceps, tissue	Minor Surgery	Physician use/approval required
Gauze, dental	Dental	No restriction
Gauze, roller (6)	Bandage	No restriction
Gauze squares		No restriction
4 in. × 4 in. (24)	Bandage	
2 in. × 2 in. (12)	Bandage	
2 in. × 2 in. (20)	Minor Surgery	
Gauze squares, Betadine	Bandage	No restriction
	Minor Surgery	Physician use/approval required
Gauze, Vaseline (6)	Bandage	No restriction
Glass marking pencil (2)	Microbiology	No restriction
Gloves, examination (2 pair)	Hematology/Urinalysis	No restriction
Gloves, surgical (2 pair)	Catheterization	No restriction

(continued)

Table 4.4. (continued)

Equipment	Kit	Usage requirement
Glucose (2)	Therapeutic	Physician use/approval required
Heat sink	Command Module Resupply	No restriction
Hemacheck assembly	Hematology/Urinalysis	No restriction
Hemoglobin meter	Hematology/Urinalysis	No restriction
Hemolysis applicators (50)	Hematology/Urinalysis	No restriction
Hemostat	Catheterization	No restriction
Hemostat, Crile, curved	Minor Surgery	Physician use/approval required
Hemostat, Crile, straight	Minor Surgery	Physician use/approval required
Hemostat, Kocher	Minor Surgery	Physician use/approval required
Hemostat	Therapeutic	No restriction
Hydrogen peroxide	Command Module Resupply	No restriction
Immersion oil bottles (3)	Microscope	No restriction
Incubator	Not applicable	Not applicable
Injectables container	Therapeutic	No restriction
Lancets (75)	Hematology/Urinalysis	No restriction
Laryngoscope	Therapeutic	Physician use/approval required
Lens (100×)	Drug Supply Module	No restriction
Lens tissue	Microscope	No restriction
Light bulbs (14)	Diagnostic	No restriction
Loop holders (2)	Microbiology	No restriction
Light source, head-mounted	Diagnostic	No restriction
Microscope	Microscope	No restriction
Microscope stage	Drug Supply Module	No restriction
Mirror/light	Dental	No restriction
Myringotomy knife	Diagnostic	Physician use/approval required
Nasogastric tube	Catheterization	No restriction
Needle holder	Minor Surgery	Physician use/approval required
Needles, hypodermic		
16-Gauge (2)	Therapeutic	No restriction
18-Gauge (2)	Therapeutic	No restriction
20-Gauge, 4 in. (1)	Command Module Medical Kit	Physician use/approval required
20-Gauge (2)	Therapeutic	No restriction
25-Gauge (4)	Therapeutic	No restriction
27-Gauge, 13/16 (3)	Dental	No restriction
Neurologic exam instruments	Diagnostic	Physician use/approval required
Nozzle	Catheterization	Physician use/approval required
Ophthalmoscope	Diagnostic	No restriction
Otoscope	Diagnostic	No restriction
Otoscope specula (33)	Diagnostic	No restriction
Oxidase strips (25)	Command Module Resupply	No restriction
Petri dish, large (20)	Command Module Resupply	No restriction
Petri dish, small (20)	Command Module Resupply	No restriction
Pressure infusor assembly	Not applicable	Physician use/approval required
Probe	Minor Surgery	Physician use/approval required
Resupply container (2)	Command Module Resupply	No restriction
Retractors, skin/muscle (ALMS)	Minor Surgery	Physician use/approval required
Scalers, curette	Dental	No restriction
Scalpel, #10 (2)	Minor Surgery	Physician use/approval required
Scalpel, #11 (2)	Minor Surgery	Physician use/approval required
Scissors	Bandage	No restriction
Scissors, sharp/sharp	Minor Surgery	Physician use/approval required
Sedative restorative material (8)	Dental	No restriction
Sensitivity discs	Command Module Resupply	No restriction
Ampicillin (50)		
Cephalothin (50)		
Erythromycin (50)		
Sulfasoxazole (Gantrisin) (50)		
Penicillin G (50)		
Tetracycline (50)		
Sensitivity disc dispenser (3)	Microbiology	No restriction
Silver nitrate applicators (12)	Bandage	No restriction

(continued)

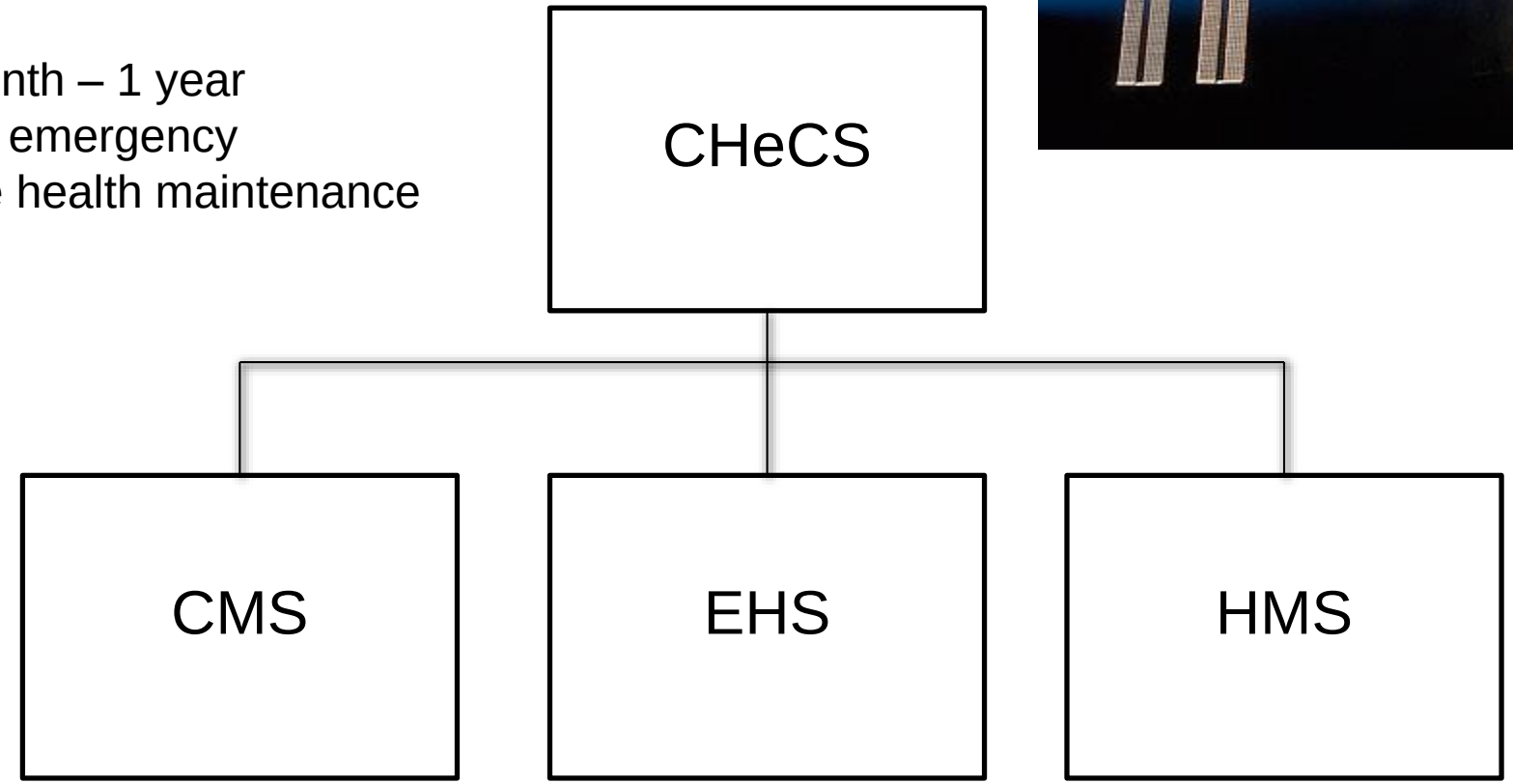
And more, but it is still a kit.

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

International Space Station

Start of a medical-vehicle system

6 month – 1 year
Less emergency
More health maintenance



HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

U.S. companies provide access to low-Earth orbit

Mastering fundamentals aboard the International Space Station

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

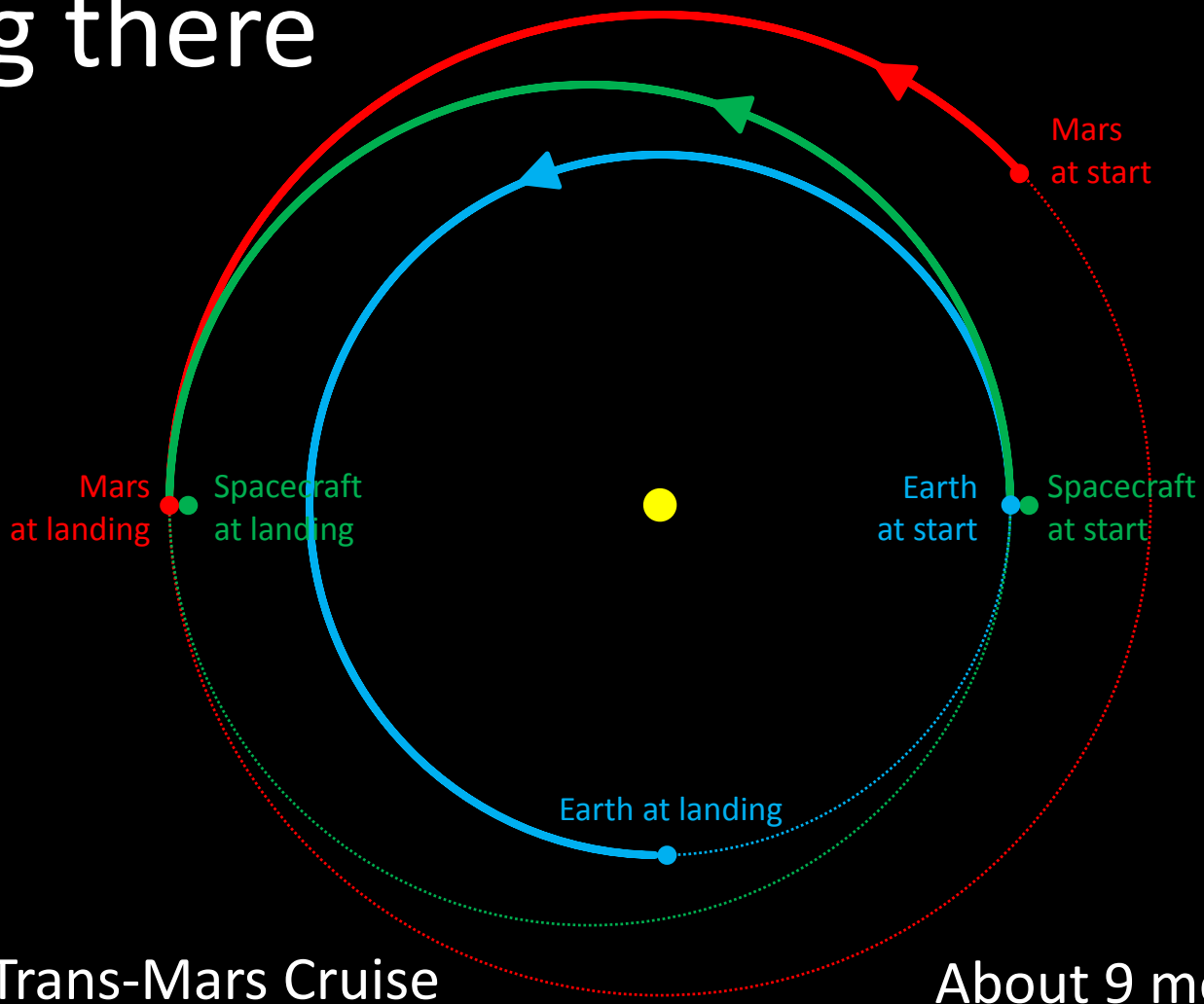
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov


What about Mars?

Going there

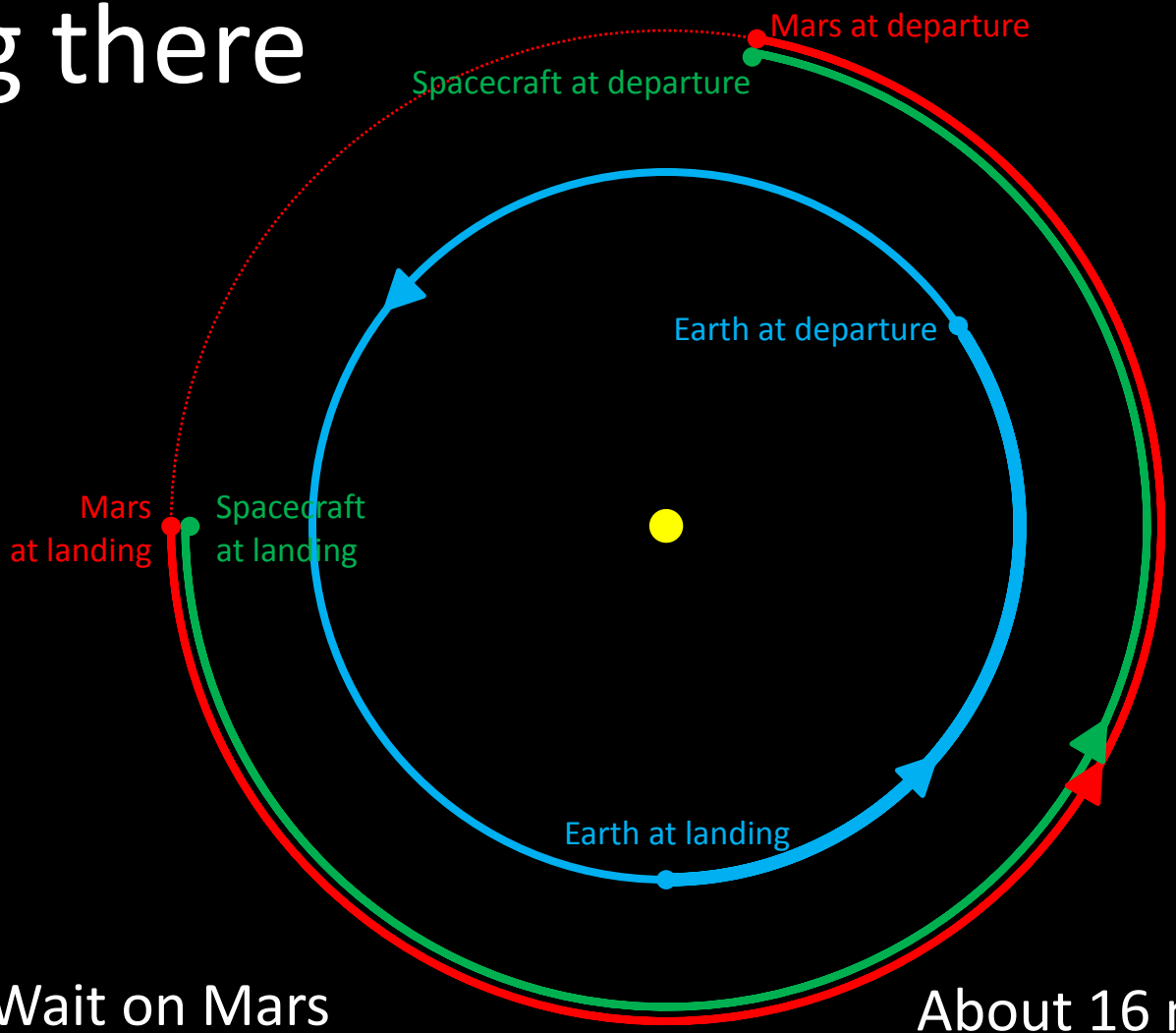


Trans-Mars Cruise

About 9 months

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

Being there

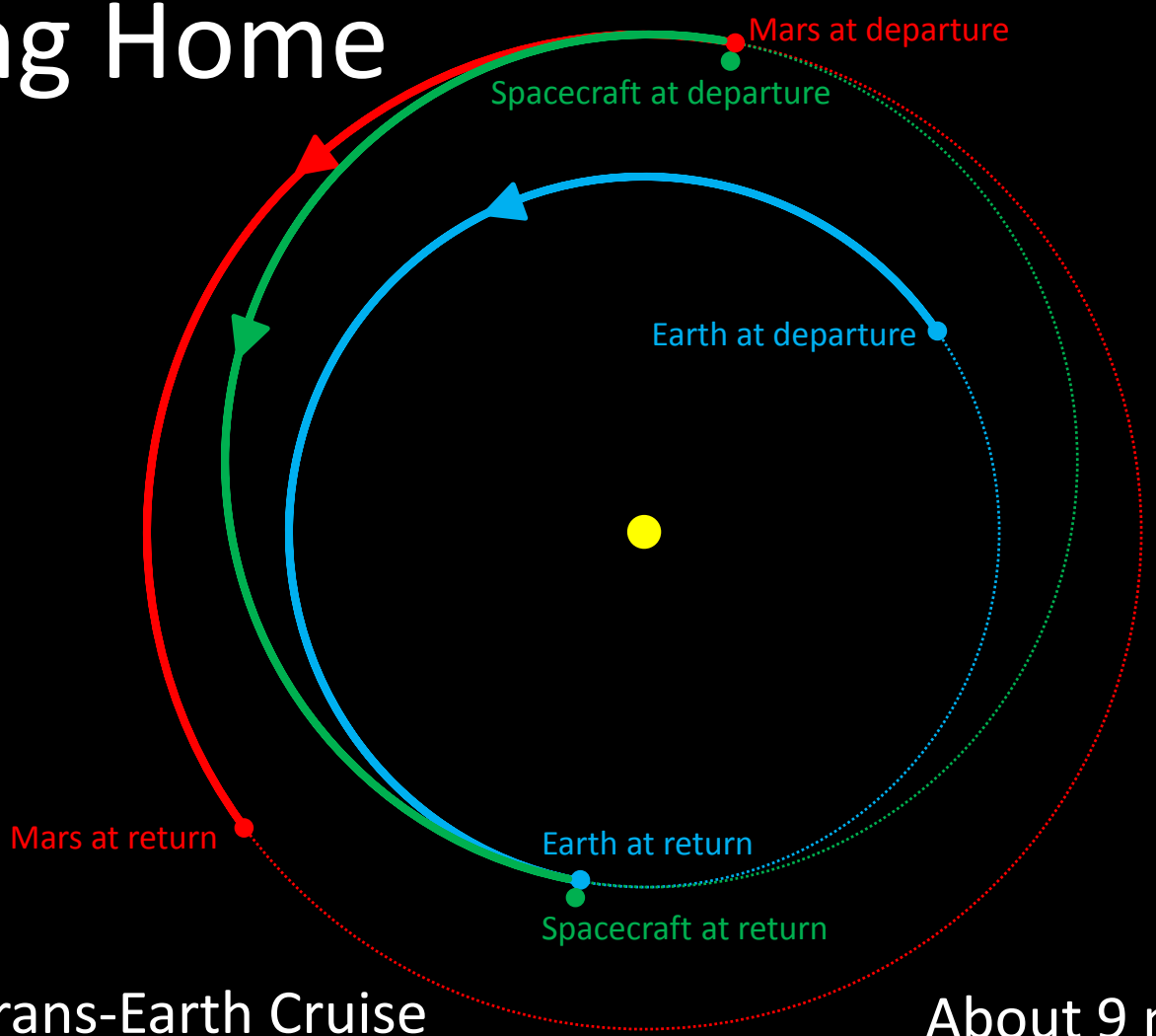


Wait on Mars

About 16 months

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

Coming Home



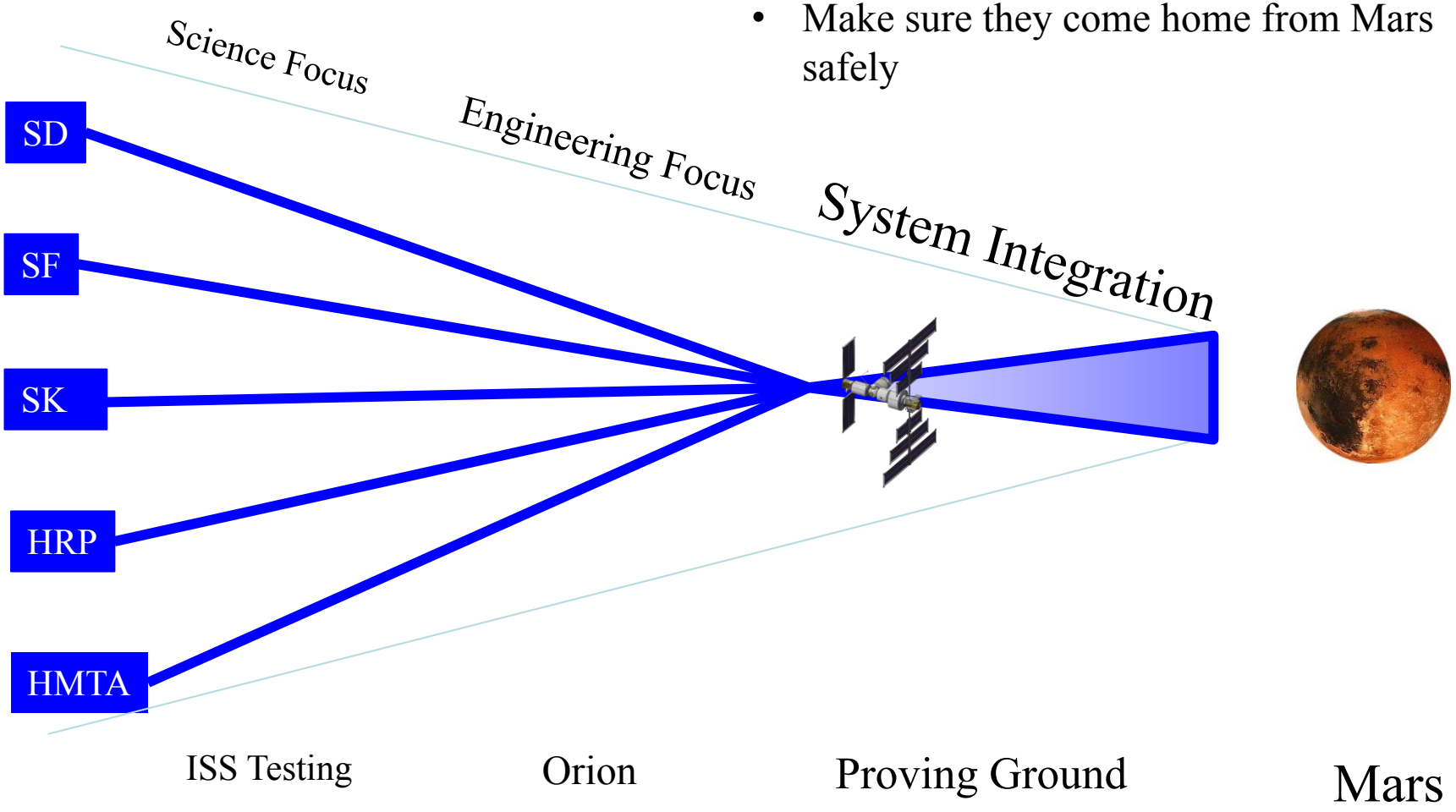
Trans-Earth Cruise

About 9 months

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

Health and Human Performance System

- Keep the crew safe
- Making sure they can get to Mars safely
- Make sure they come home from Mars safely



All is well until the methods legitimated by the paradigm cannot cope with a cluster of anomalies; crisis results and persists until a new achievement redirects research and serves as a new paradigm.

- Thomas S. Kuhn 1962

What are the anomalies?

- **NO real-time communications**
  - What does it mean to have a medically autonomous crew?
  - Cannot provide real time guidance
  - How do we train for medical needs?
  - How do we keep skills fresh?
  - What is the role of the flight surgeon?
  - Do we transition from real time guidance to a store-and-forward consult model?
  - What does it mean to provide situation awareness to earth-based support?

More Anomalies

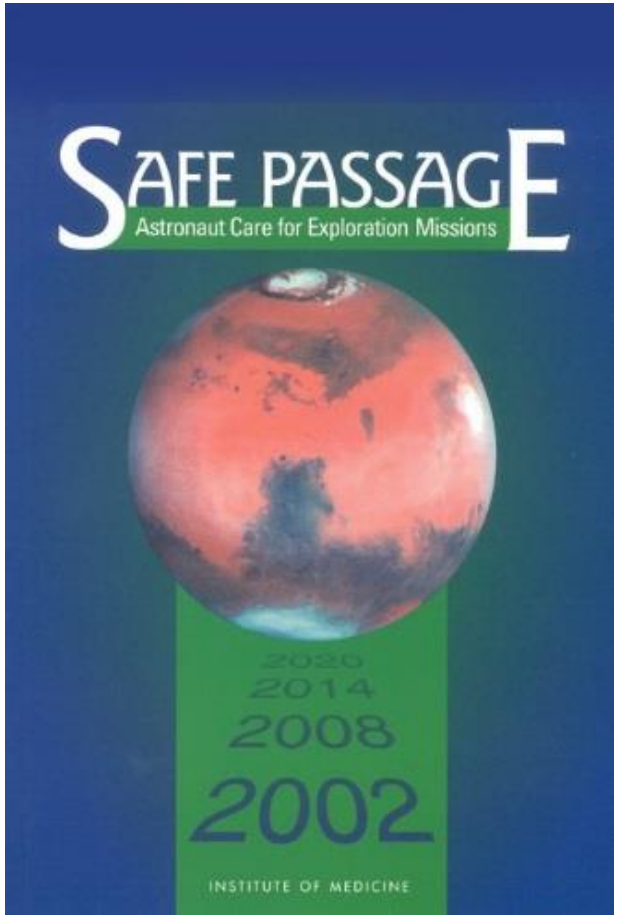
- **NO regular resupply of materials**
  - How do we provide a safe and effective pharmacy when medications will expire?
  - How do we plan to limit medical consumable usage when a crew is autonomous?
  - How do we track that usage so the crew understands their risk posture throughout a mission?

Does ISS prepare us?

- **NO potential for evacuation if serious medical concerns arise.**
  - How do we plan for serious illness and injury?
  - How long do we treat severe injury or illness?
  - How do we decide what consumables to expend on an injured crew member such that we don't increase the risk to the rest of the crew?
  - How do we make ethical decisions in our plans for supplying a crew and recommendations to an autonomous crew on how to implement medical care?

PRINCIPLES OF APPROACH

Safe Passage

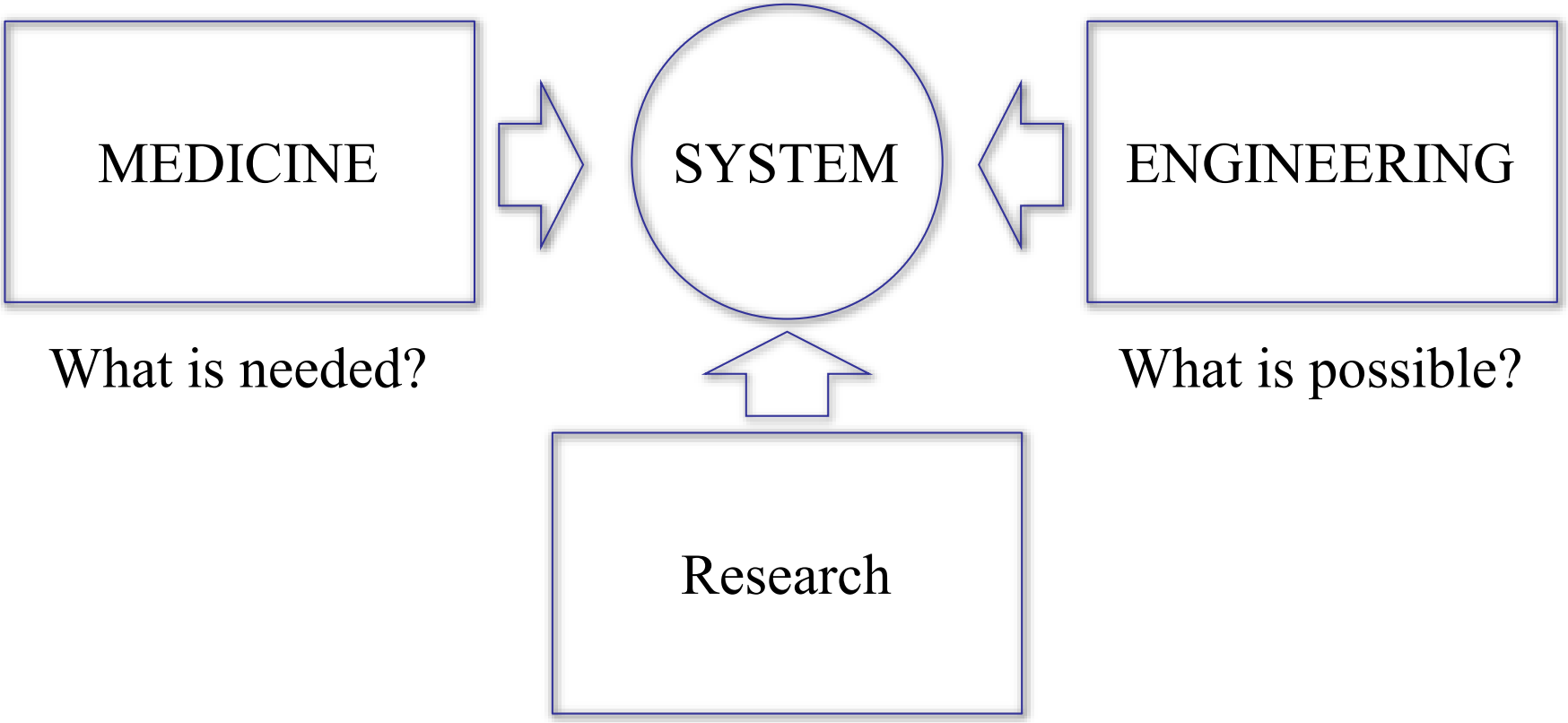


- *From Conclusion 2:*
- *"Currently, there is no comprehensive and inclusive strategy to provide optimum health care for astronauts in support of long-duration missions beyond low Earth orbit, nor is there sufficient coordination of health care needs with the engineering aspects of such missions."*
- *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.

The Medical Engineering Challenge

What you end up with.



How can you get more of what is needed?

Fundamental Content Drivers

- **Concept of Operations – The user's experience of the system?**
- **Risk Assessment and Trade Capability – How do we value and prioritize medical capabilities?**
- **System Design**
  - Medical Data Architecture
  - Medical Appliances
  - Vehicle Integration
- **Programmatics – What drives successful execution?**
- **Ethics – What level of care do we provide?**

Concept of Operations

Planned medical events

- Private Medical Conferences
- Self exams
- Private psychiatric conferences
- Scheduled Exercise
- Etc.

Unplanned medical events

- Exploration Medical Condition List
- Three categories:
  - Self Care
  - CMO Directed Care
  - Emergency Care

Concept of Operations

Planned medical events

- Private Medical Conferences
- Self exams
- Private psychiatric conferences
- Scheduled Exercise
- Etc.

Unplanned medical events

- Exploration Medical Condition List
- Three categories:
  - Self Care
  - CMO Directed Care
  - Emergency Care

What is needed

Getting to Possible

- Medical care includes:
  - Prevention/Screening
  - Diagnostic capability
  - Treatment capability
  - Rehabilitation capability
  - Prognosis

- Characterize the likely medical risks
- Identify medical needs to address those risks
- Create a medical system to optimize crew response to those risks
- Engage in a testing pathway to validate and improve that system
- Work with vehicle engineers and flight surgeons to ensure useful implementation of that system

QUANTIFYING MEDICAL RISK

Well, what are you trying to treat?

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

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

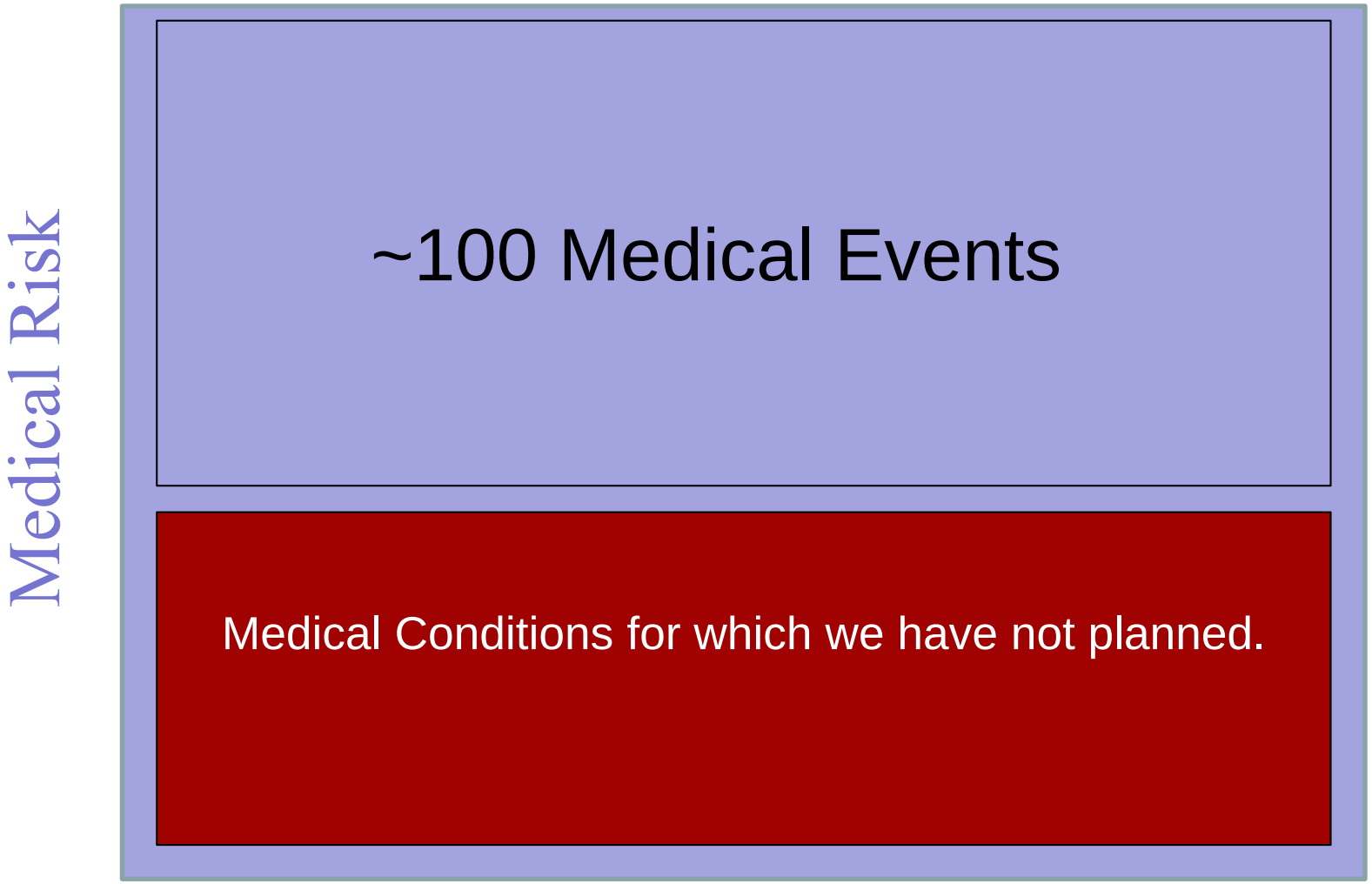
GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

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_2)

Spaceflight Medical Risk



Tools

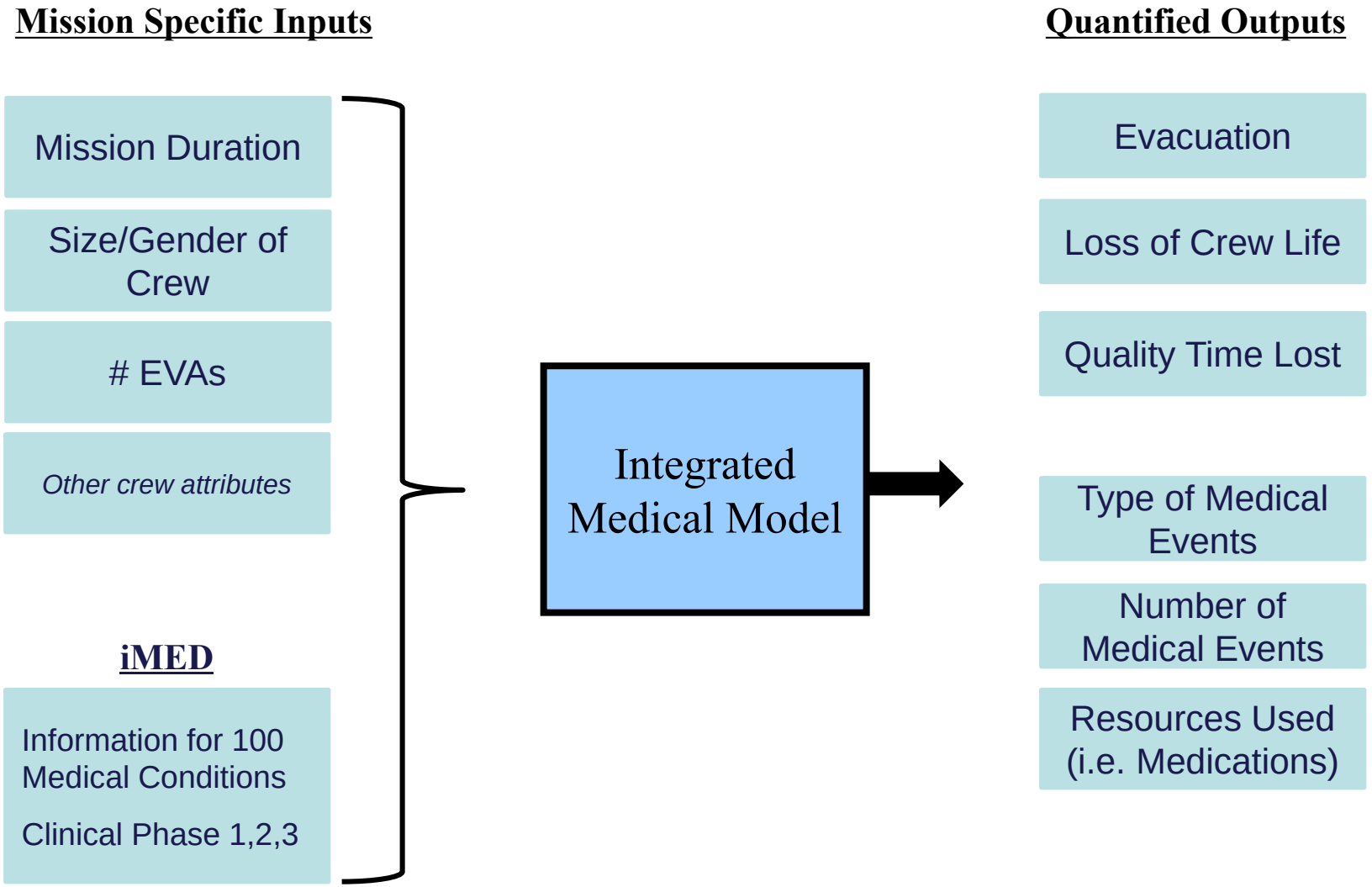
Three tools are highlighted which currently describe the medical trade space:

1. **The Exploration Medical Condition List (EMCL)** - Identifies ~100 conditions of interest for medical system development

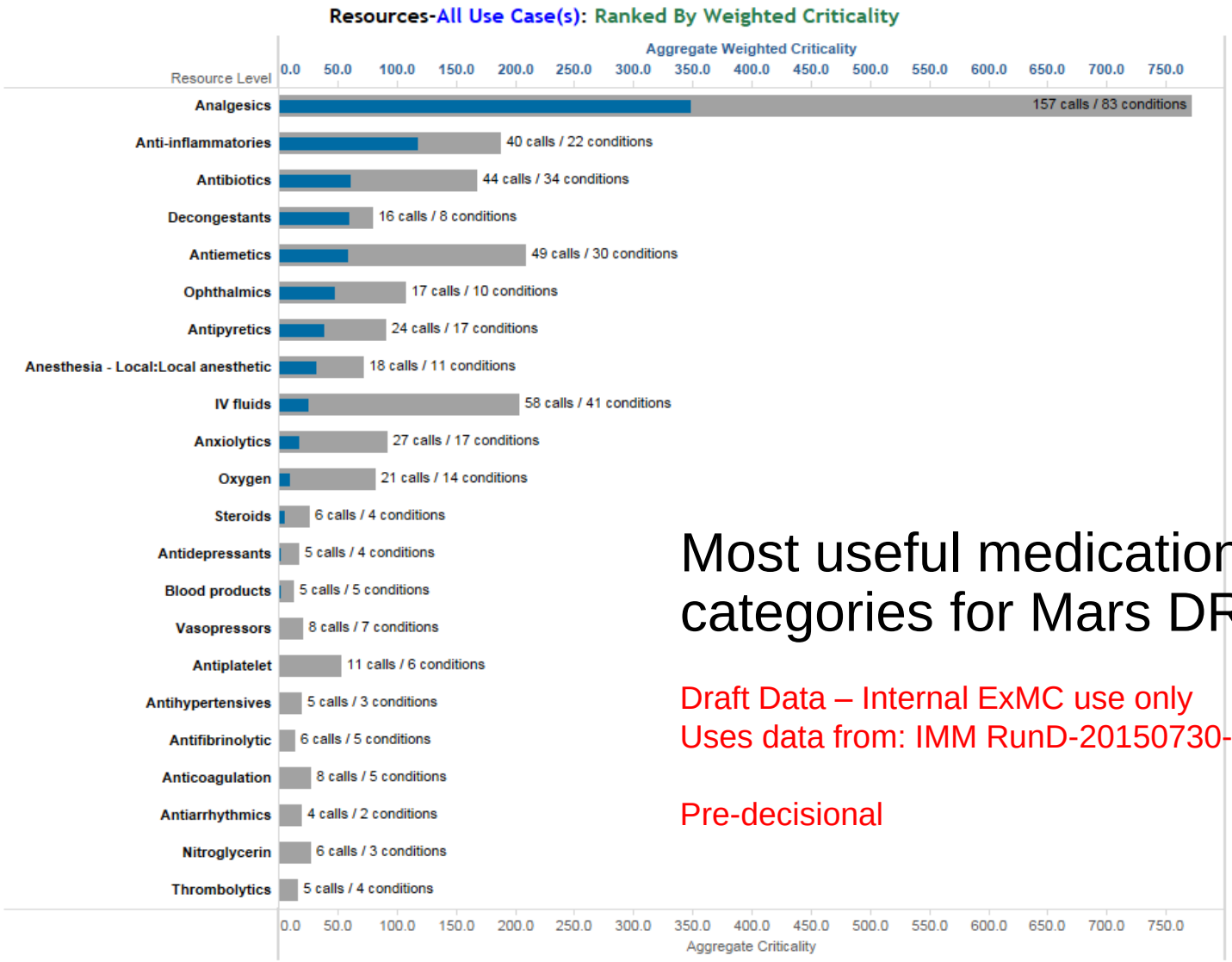
2. **The Integrated Medical Model (IMM)**

3. **The Medical Optimization Network for Space Telemedicine Resources (MONSTR)**

Quantitative Risk - Integrated Medical Model



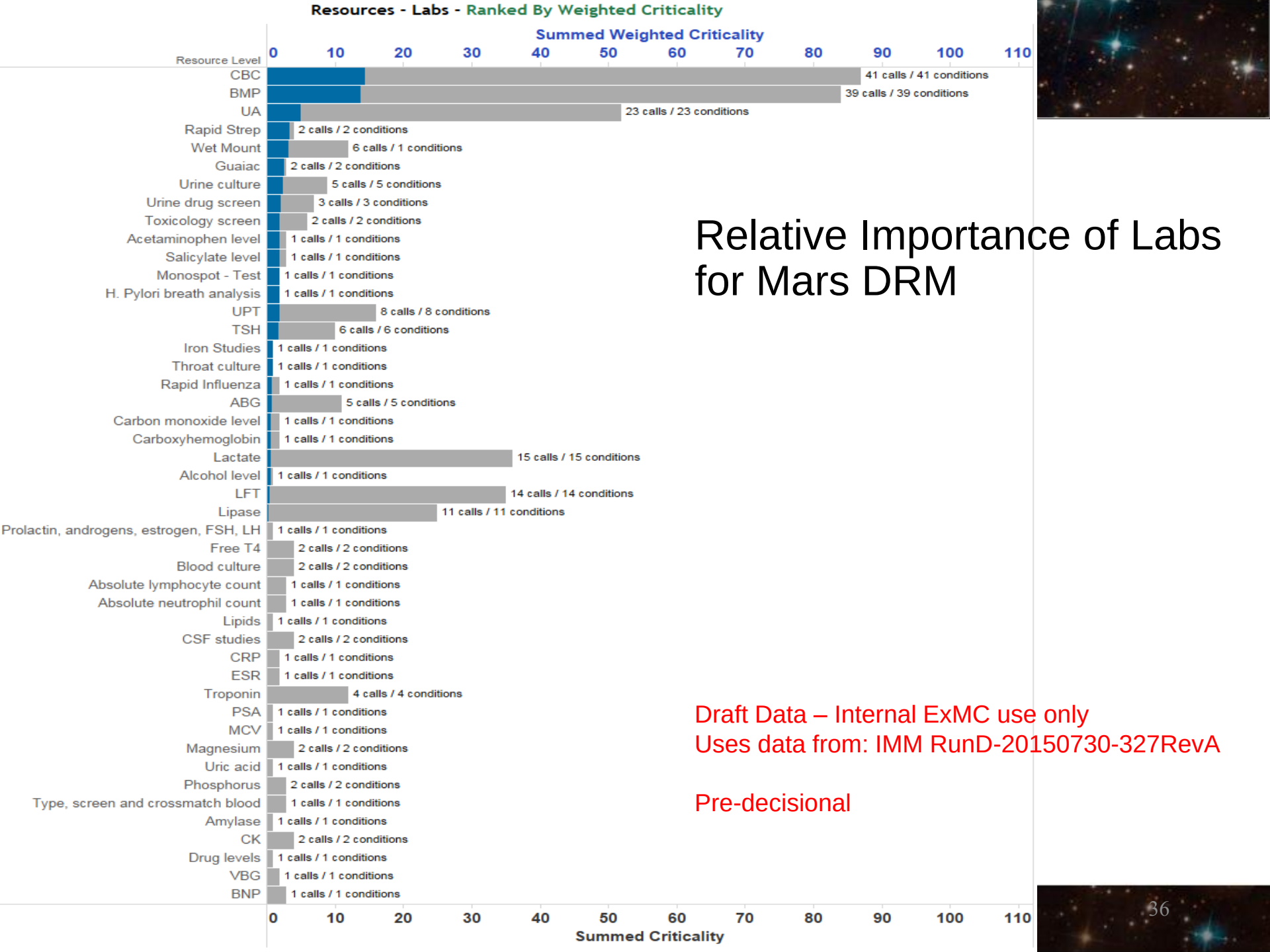
Quantitative Risk - MONSTR



Most useful medication categories for Mars DRM

Draft Data – Internal ExMC use only
Uses data from: IMM RunD-20150730-327RevA

Pre-decisional



Relative Importance of Labs for Mars DRM

Draft Data – Internal ExMC use only
Uses data from: IMM RunD-20150730-327RevA

Pre-decisional

What does it take to scope a medical system?

- **How do we envision doing medicine?**
  - Planned medical operations
  - Unplanned medical operations
  - Performance
  - Research

ConOps

- **How do we value and prioritize medical capability?**
  - What is likely to happen and how often?
  - What would a physician want to have with them if it happened?
  - A repeatable way of prioritizing medical capability to invest research $$ in.

Risk

- **How do we enable system operations that support crew autonomy?**
  - Information handling from lots of sources
  - Command and control of devices (ultrasound, lab analysis, etc.)
  - Proving System-Vehicle and Ground-Vehicle Interfacing

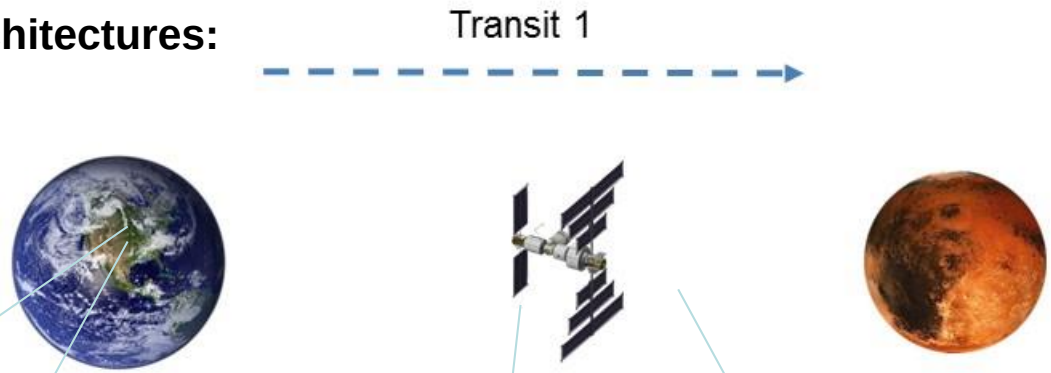
SCOPING A MEDICAL SYSTEM

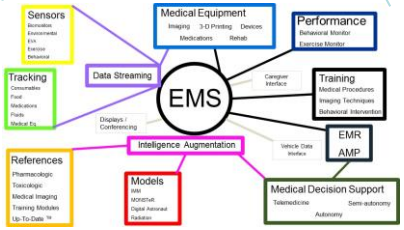
A medical system is judged by its ability to provide a crew fit for duty when called

Medical System Augments Crew Autonomy

Ground Based and Vehicle Data Architectures:

- **Clinical Care**
- **Operational Needs**
- **Occupational Surveillance**
- **Research**





Vehicle Exploration Medical System

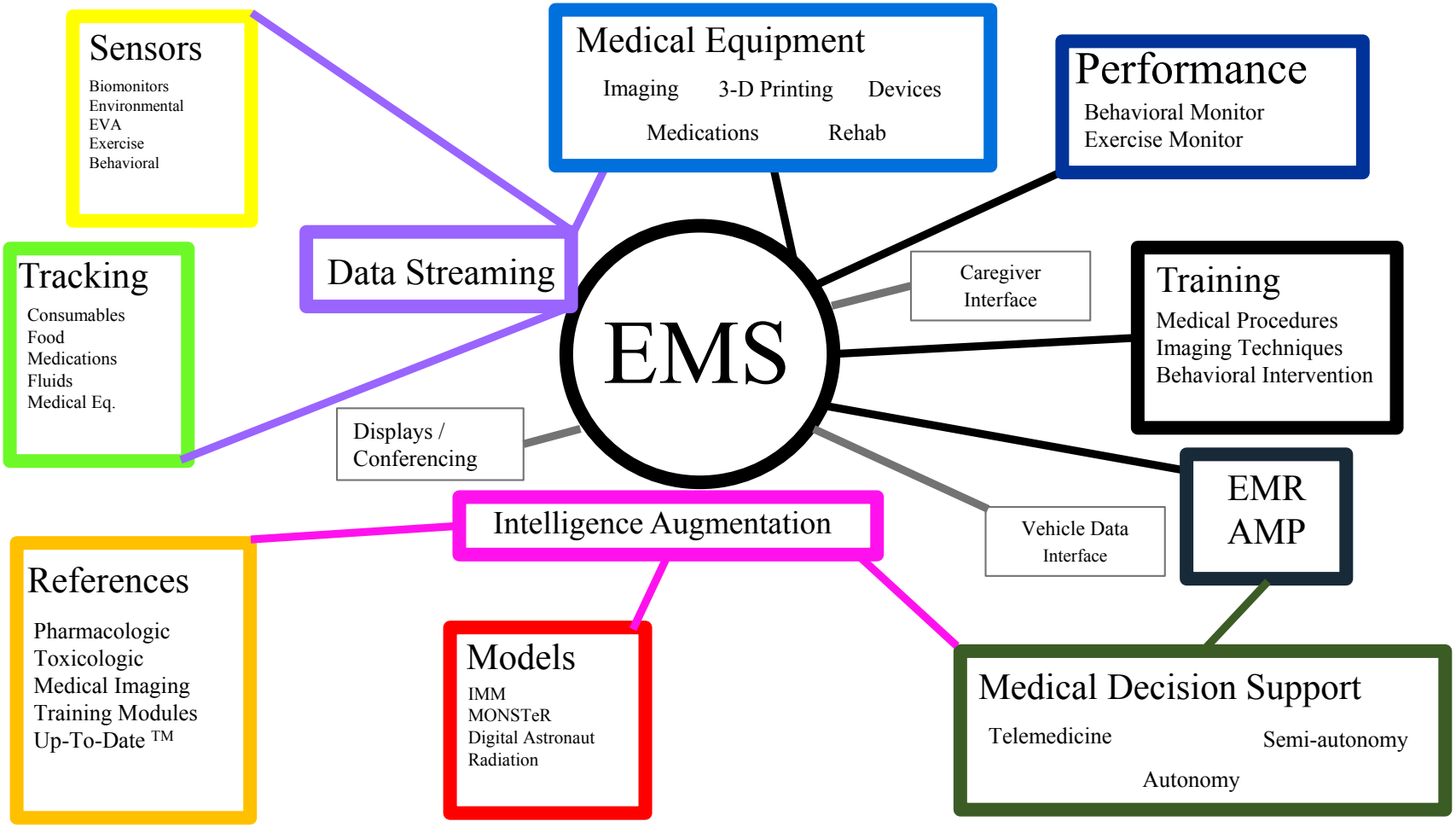
- Flight Surgeon/BME
- External Consults

Occupational Health and Mission Support

- Crew Medical Officer
- Crew Medical Support

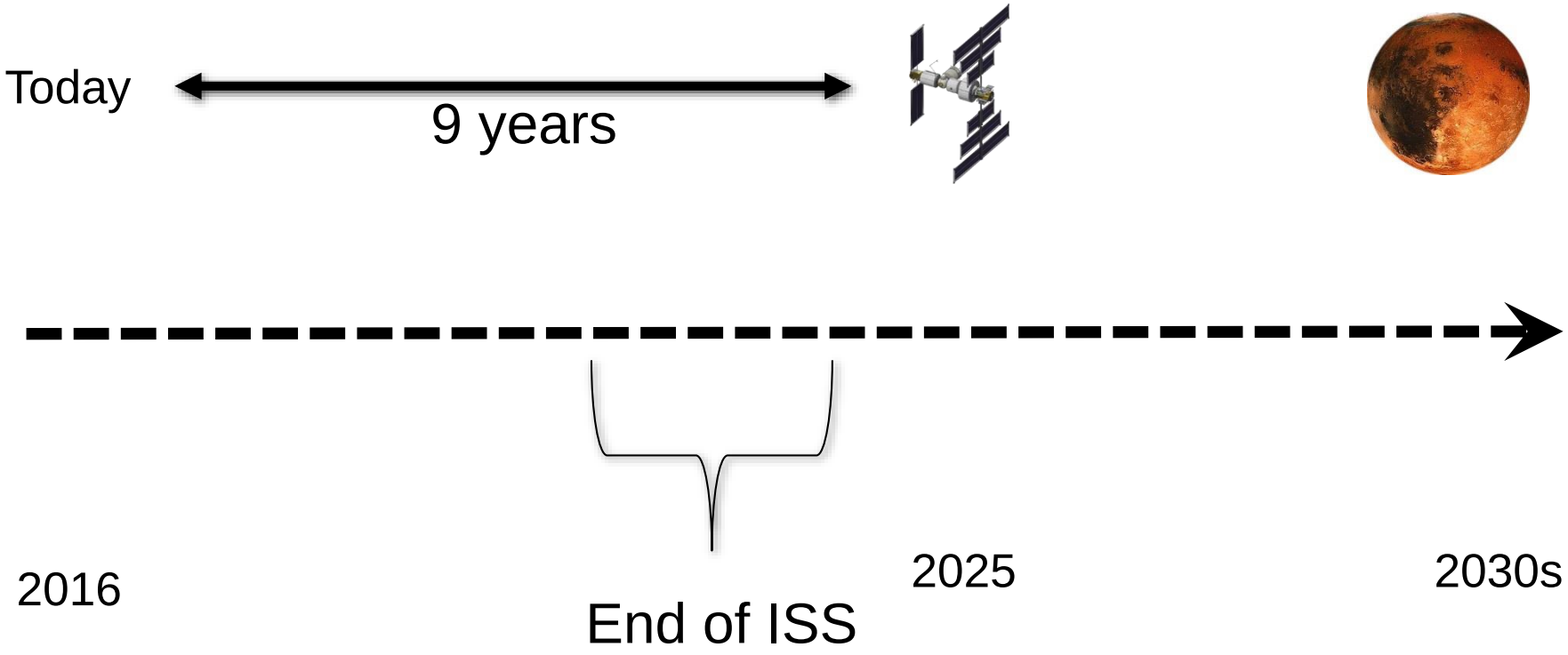
Real-Time Data Processing for Crew

Medical System Capture Diagram



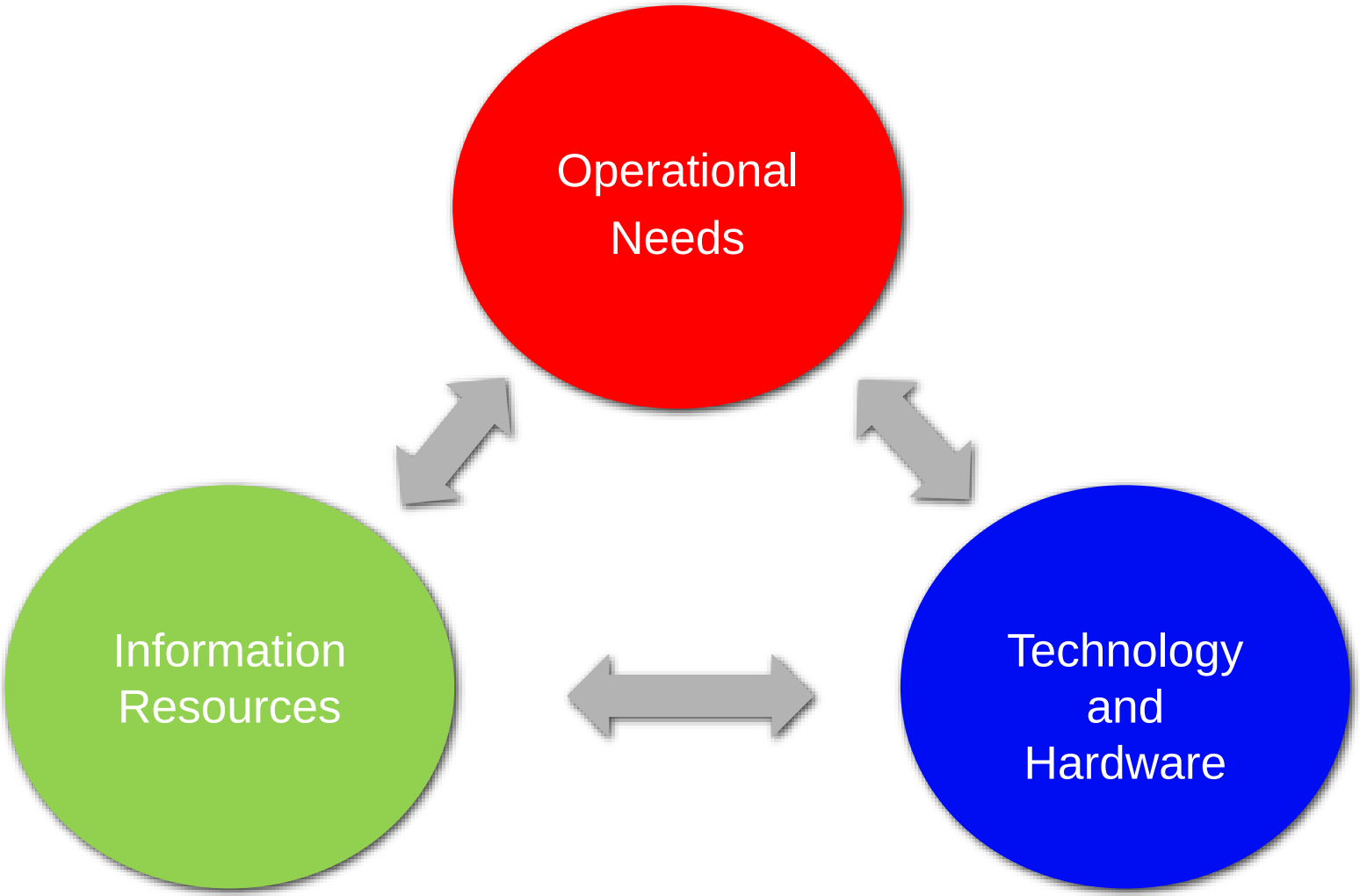
Programmatics and Ethics

- Must have a target to design towards
- Must have a way to make hard decisions
- This is not “sometime” in the distant future



WHERE ARE WE NOW?

ExMC Work Decomposition



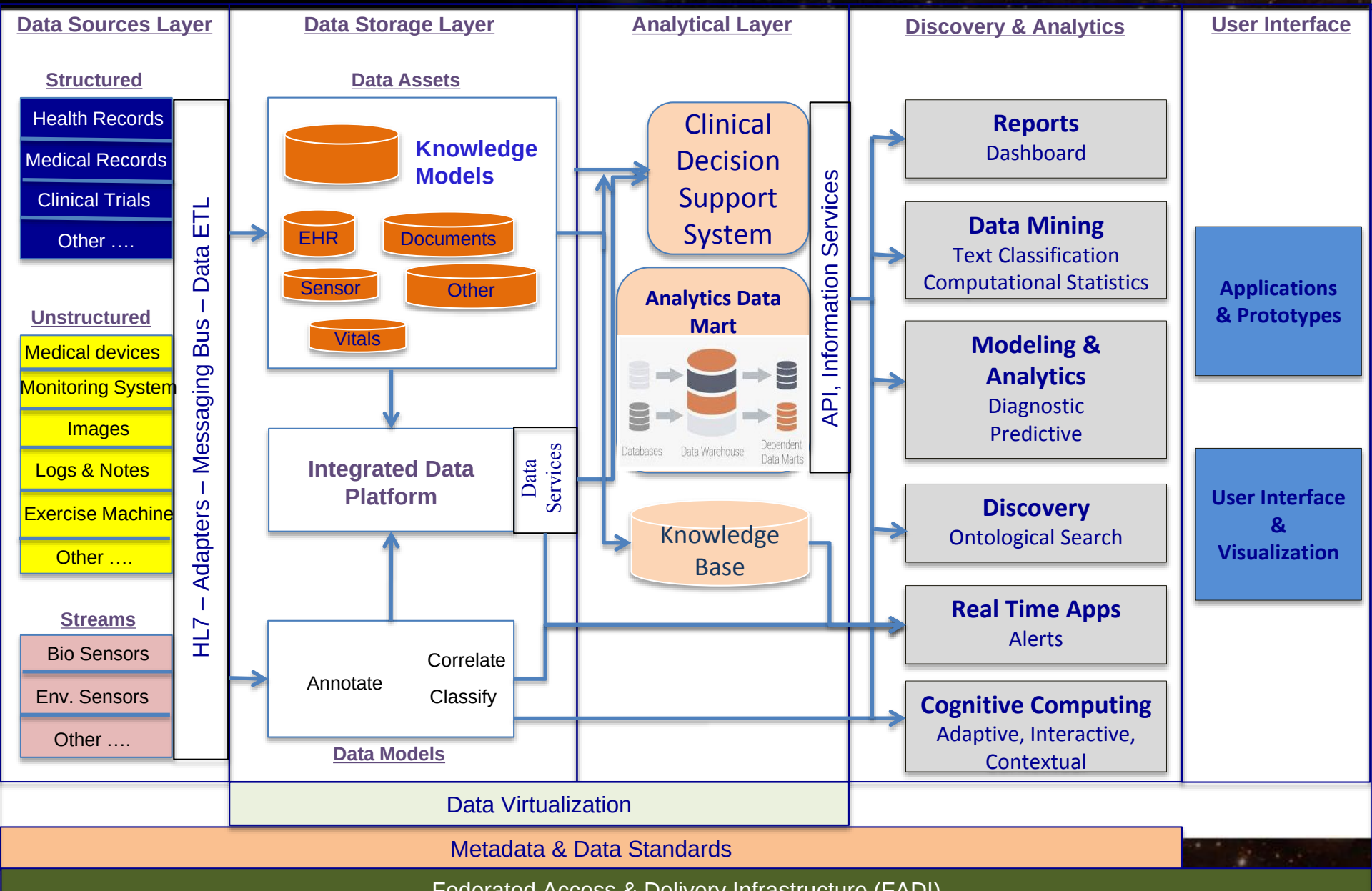
Research Gaps

Med01	**We do not have a concept of operations for medical care during exploration missions.**
Med02	**We do not have the capability to provide a safe and effective pharmacy for exploration missions.**
Med03	**We do not know how we are going to apply personalized medicine to reduce health risk for a selected crew.**
Med04	**We do not have a defined rehabilitation capability for injured or de-conditioned crew members during exploration missions.**
Med05	**We do not know how to train crew for medical decision making or to perform diagnostic and therapeutic medical procedures to enable extended mission or autonomous operations.**
Med06	**We do not know how to define medical planning or operational needs for ethical issues that may arise during exploration missions.**
Med07	**We do not have the capability to comprehensively process medically-relevant information to support medical operations during exploration missions.**
Med08	**We do not have quantified knowledge bases and modeling to estimate medical risk incurred on exploration missions.**
Med09	**We do not have the capability to predict estimated medical risk posture during exploration missions based on current crew health and resources.**
Med10	**We do not have the capability to provide computed medical decision support during exploration missions.**
Med11	**We do not have the capability to minimize medical system resource utilization during exploration missions.**
Med12	**We do not have the capability to mitigate select medical conditions**
Med13	**We do not have the capability to implement medical resources that enhance operational innovation for medical needs**

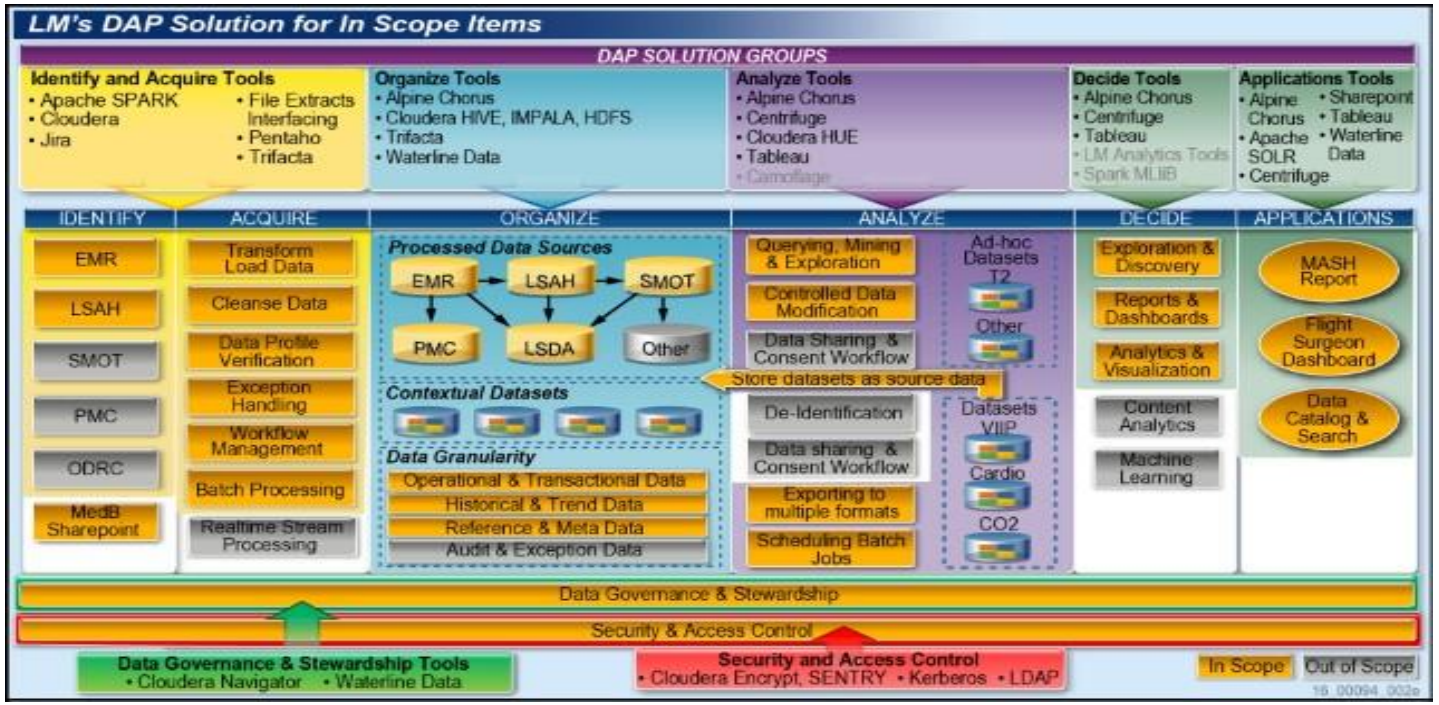
ExMC Current Status

- **ExMC Research Pathway Changed 2015**
- **IMM external review finishing**
- **MONSTR phase 2 completed for evaluation**
- **Concept of Operations started, delivery of Mars transit ConOps expected February**
- **Pharmacy research plan expected in November**
- **Medical Data Architecture underway**
- **Medical Device Projects Continue**
- **Clinician's Working Group created**
- **Systems Engineering and Operations Group created**

ExMC Data Architecture (ARC)



Ground Data Architecture and IMPALA



- CHS already investing
- Creating a governance model
- Data Reservoir
- Analytics Platform
- Phase 1 integrates **LSAH**, MMR, EMR

POCs: Andy Carnell
Ram Pisipati

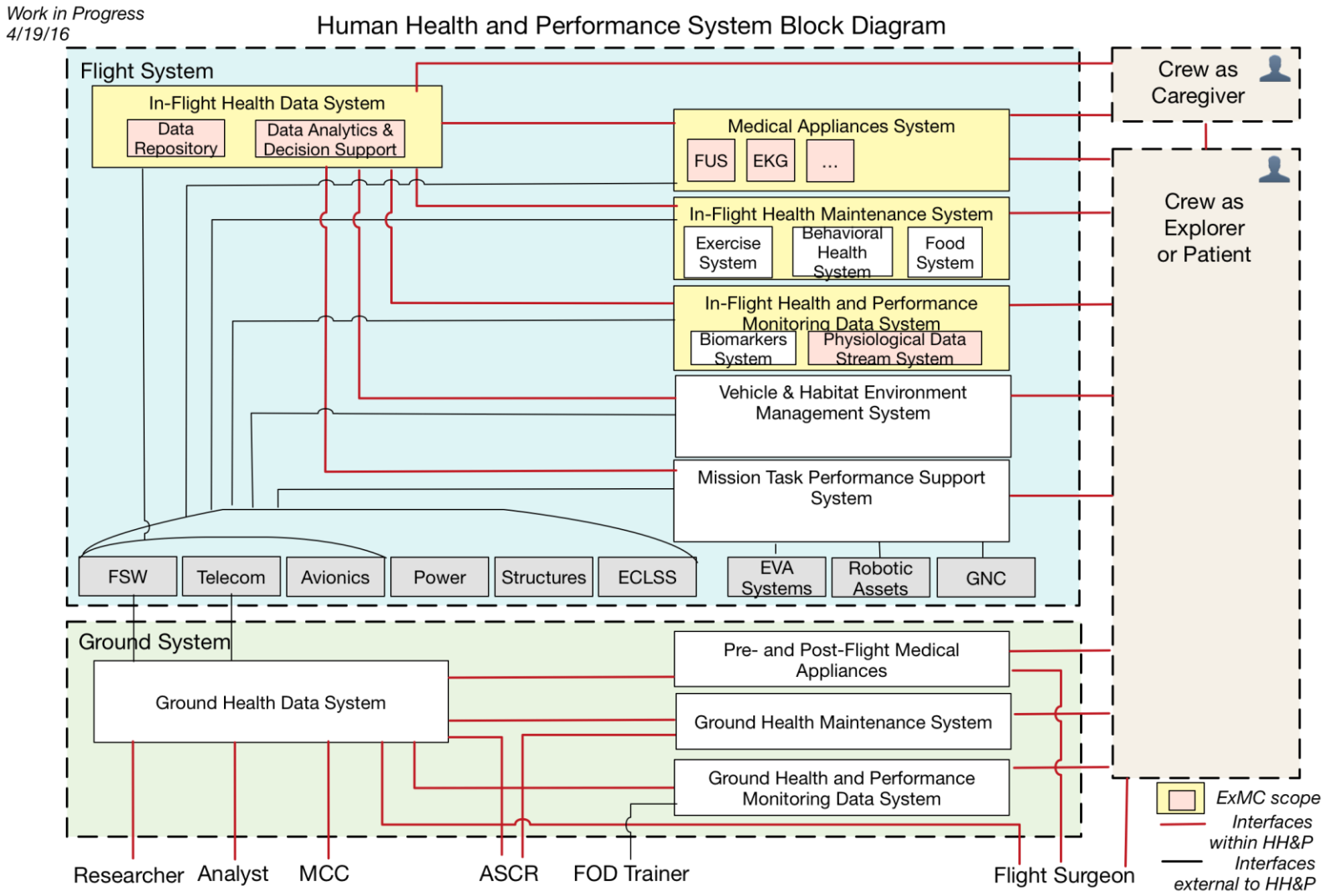
Appliance Examples

- **FUS – Flexible Ultrasound**
  - Kidney stone diagnostics and therapies
  - Bone healing
- **RTA – Measure the degradation of pharmaceuticals non-invasively**
- **Dose Tracker – Track pharmaceutical usage, efficacy, and side effects**
- **Medical Consumables Tracker – RFID tagging to track pharmaceuticals usage**
- **EKG Cardiax device delivered to Space Station**
- **Laboratory Analysis devices in development and evaluation**

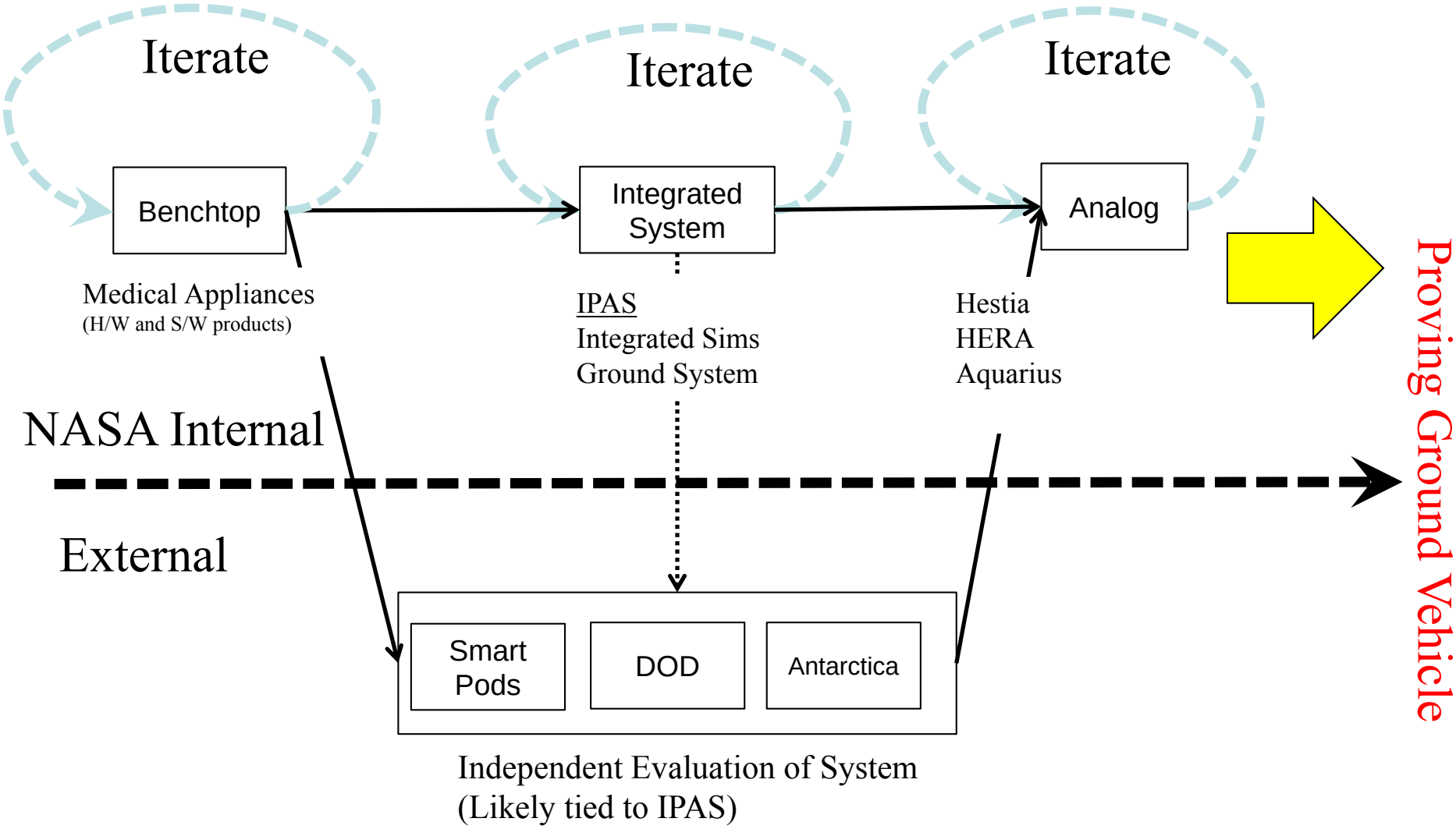
Test Bed Roadmap

Phase	Test Bed 1	Test Bed 2	Test Bed 3	Test Bed 4
Capability	• MDA System Definition • Biomedical Device Integration Definition • Image Analysis • Data Mining • Basic UI	• MDA System Enhancements • Biomedical Device Provisioning • Knowledge Base • Improved UI • Interface Engine	• Multi-agent Data Mining • Computed Problem Solving • Semantic Relations Network • Optimized UI • Ground System Int.	• Computed Clinical Diagnosis • Augmented Intelligence • Remote Data Asset Synchronization • FDIR • Analog Test Prep
Medical Resources	• Astroskin • EKG • Dose Tracker	• Medical Consumables Tracking • Flexible Ultrasound • ELA • Raman Analyzer	• BHP appliances, apps and data • HHC appliance apps and data • Ground System Data Analytics Platform	• Vehicle Resources Oxygen, Medical Suction • Vehicle subsystem integration (ECLSS, Avionics, Power, Thermal)

Notional System Block Diagram



Integrated System Testing



Summary

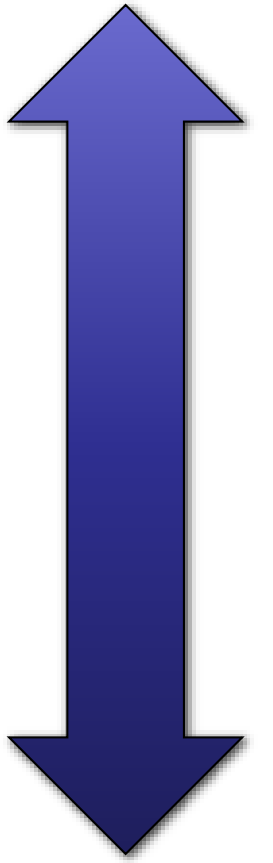
Forward Plan

Risk Mitigation Strategy

- Planning: Concept of Operations Development

Medical System Development

- Characterization of Risk
- Active Risk Reduction (system to support crews)
- Engineering Testing Pathway
- Integration of Medical with Vehicle Designers and ECLSS SMTs



QUESTIONS?

HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

U.S. companies provide access to low-Earth orbit

Mastering fundamentals aboard the International Space Station

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov

BACKUP SLIDES

Background

In 2001 *Safe Passage: Astronaut Care for Exploration Missions* prompted National Aeronautics and Space Administration (NASA) to improve the integration of the vehicle and human systems through a very intentional and evidence based design of medical systems to support human spaceflight for exploration missions

The Human Research Program was established in 2005 to focus NASA's research on the highest risks to human health and performance during exploration missions.

- Perform research necessary to understand and reduce spaceflight human health and performance risks in support of exploration
- Develop technologies to reduce medical risks
- Develop NASA spaceflight human system standards

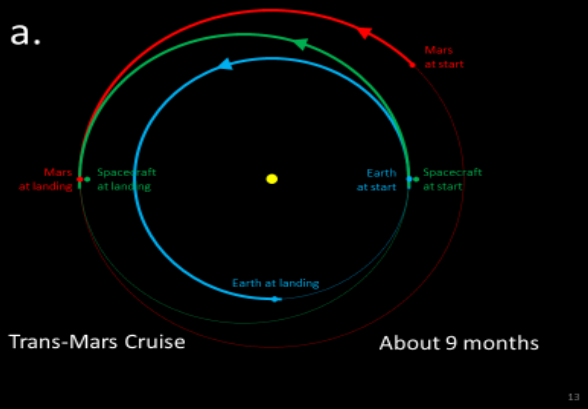
Providing health care capabilities for exploration class missions will necessitate the definition of new medical requirements and development of technologies to ensure the safety and success of exploration missions.

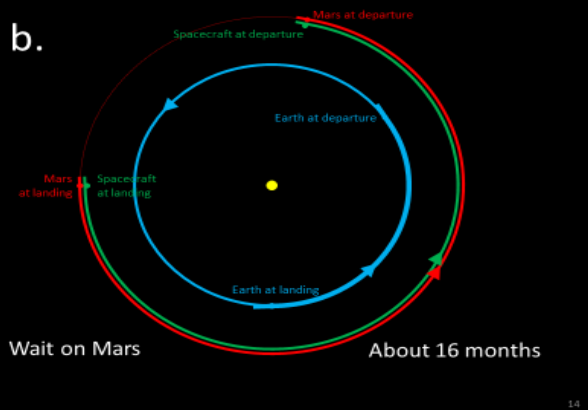
A Medical System should maximize flexibility to enable a care provider to address conditions that were not considered in the initial design.

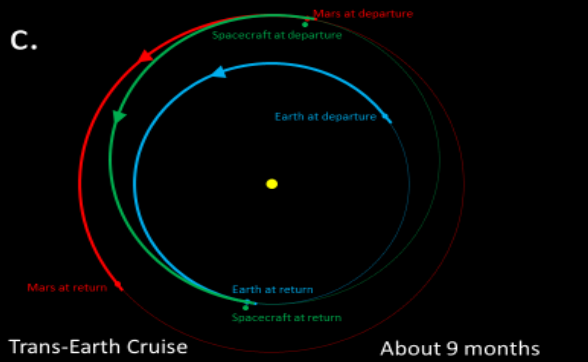
Mars Design Context

- **Current architectures for exploration call for long duration missions of 1-3 years**
- **Mars will not have a capability for medical evacuation.**
- **Mars missions cannot expect resupply although some prepositioning of resources may be available.**
- **There will be periods of limited communications and extended transit times.**
  - Comm rates: kilobits per second, like dial-up internet.
  - The one-way flight time for radio signals can be more than 20 minutes.
  - Comm will not be continuous.
- **Mars Mission will require multiple launches**
  - Launch one or more durable unpiloted ships with non-perishable supplies and equipment to Mars 78 or 52 or 26 months before the crew departs.
  - Construct the crew transit ship in high Earth or Moon orbit with several SLS payloads launched
  - Crew launch.

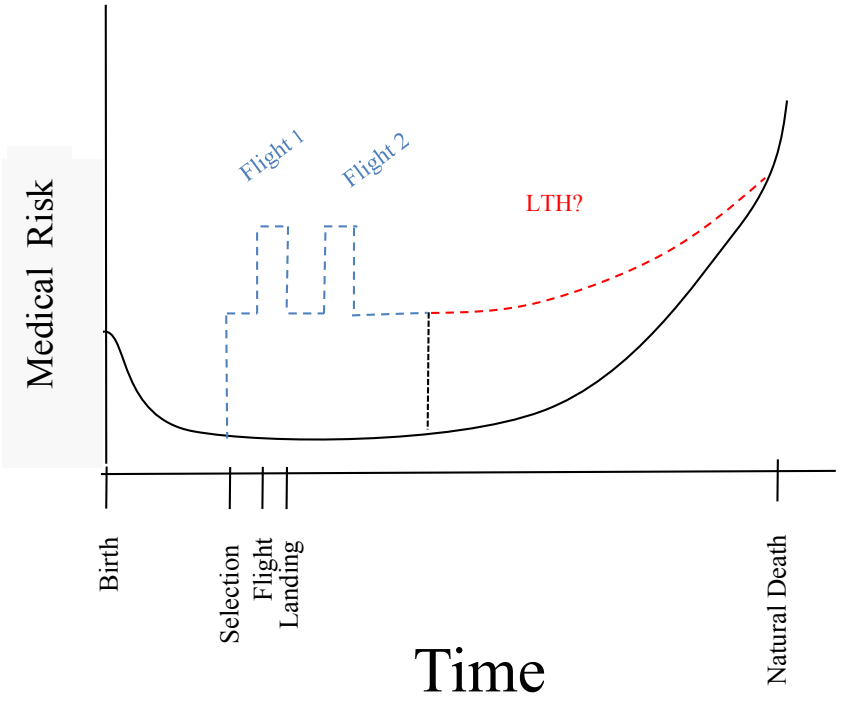
With low margins available on these missions, we can expect increasing scrutiny and competition for resources across mission systems.







tronaut Long Term Health



- Understanding Long Term Health effects is challenging
- Occupational Surveillance to follow lifetime challenges
- Human Research Program to identify emerging issues

2013 Mortality Multiple Cause Micro-data Files
http://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm

Concept of Operations

The ConOps captures the planned operational use of the exploration medical system.

- Provides guidance on medical capabilities required for prevention, diagnosis, treatment, and rehabilitation as envisioned for a Mars Mission to enable crew medical autonomy.
- Individuals will need to be sufficiently trained as medical officers
- The exploration medical system must be operable at the skill level of those selected to serve as medical officers.
- ConOps envisions and documents both planned and unplanned medical activities so that capabilities required to enable those activities can be identified.

Risk Characterization

But what if it happens?

- Secondary Prevention
- Diagnosis
- Treatment
- Chronic Management
- Rehabilitation

Medical Capability

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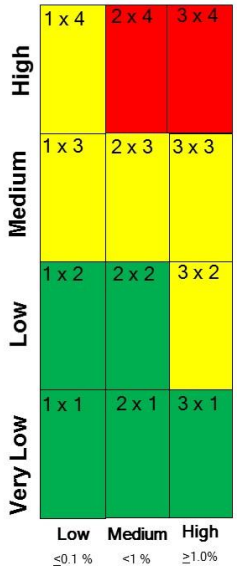

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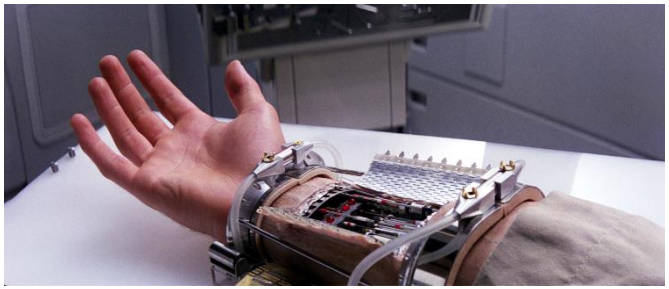
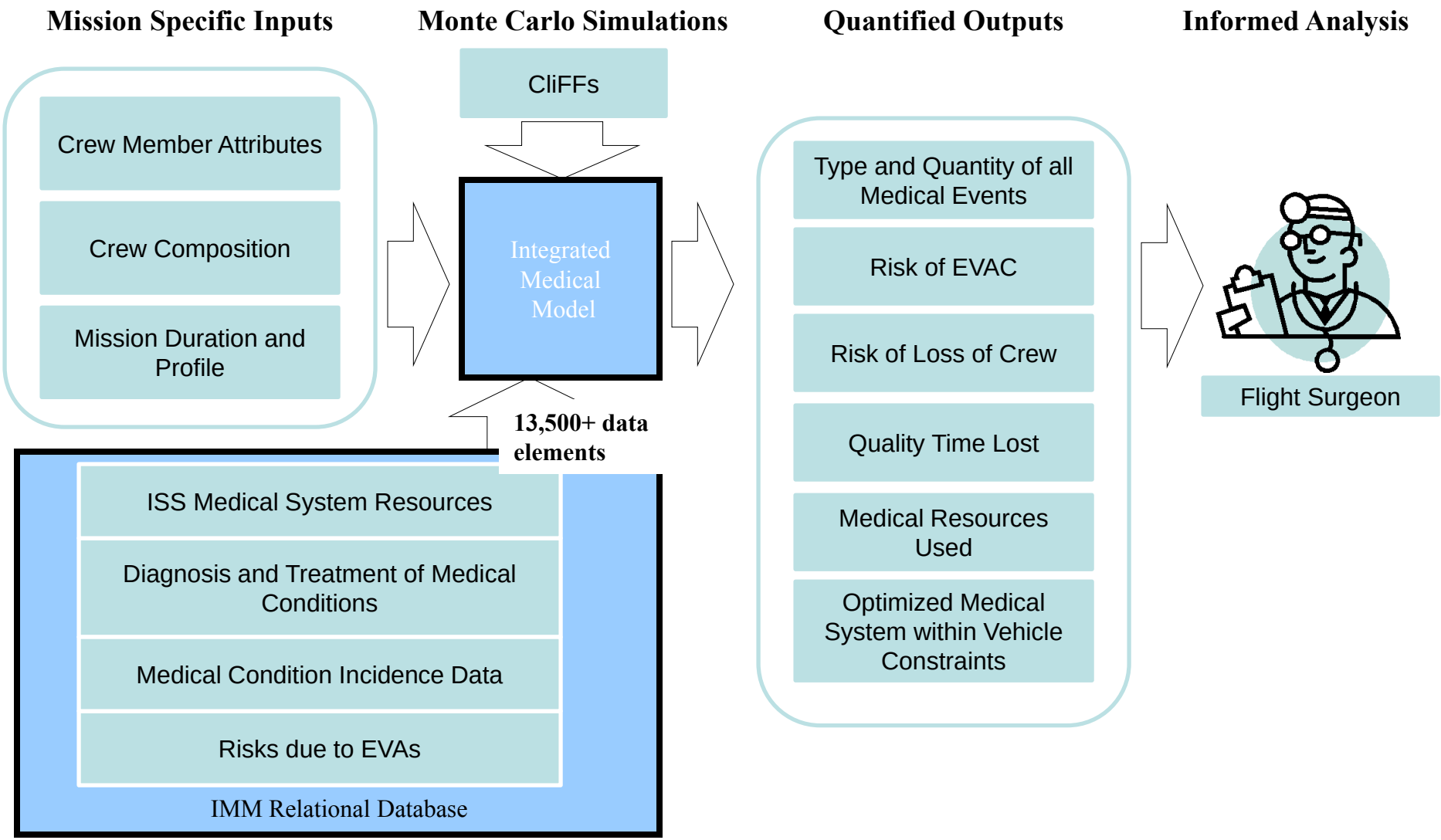
For known risks:
How do we decrease this?



Keep it from happening?

- Selection
- Screening
- Primary Prevention
- Vehicle Design Standards
- Mission Architecture

2. IMM cont. - informs decision making

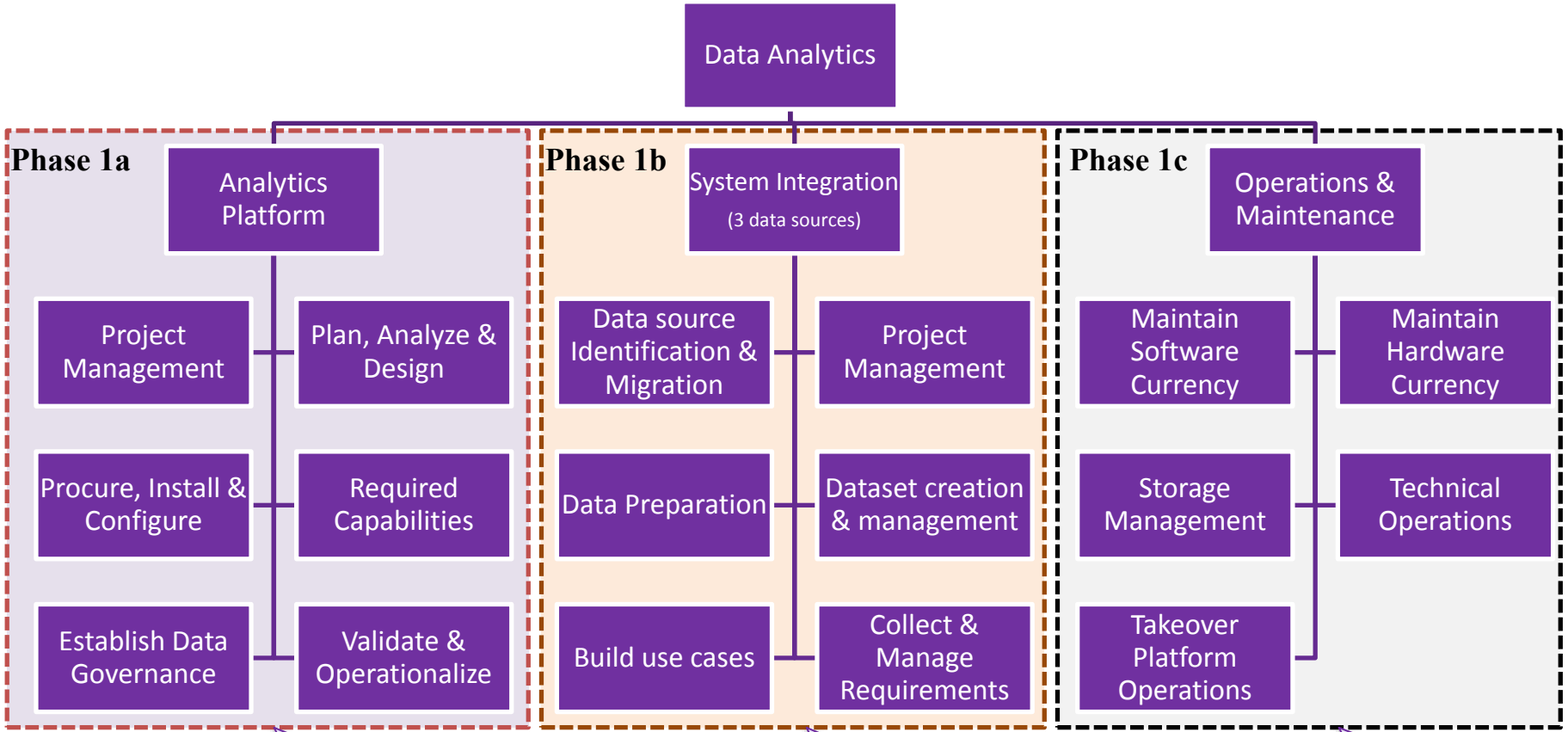


Forward Plan

- Risk Mitigation Strategy
  - Planning
    - Concept of Operations Development (Ops Risk Reduction)
    - Long Term Health Planning
  - Characterization of Risk
    - Models – Integrated Medical Model (IMM), MONSTR prototype
    - Active Data Gathering – Medical Consumables Tracker (MCT), Biosensors, Flexible Ultrasound
    - Medical Support – Exploration Medical System Demonstrator, Data Architecture
    - Long Term Health data collection
  - Active Risk Reduction
    - Technology Development – Oxygen Concentrator Module, Medical Suction, IVGen…
    - Training
    - Decision Support
    - Long Term Health interventions
    - Integration of Medical with Vehicle Designers and ECLSS SMTs

Medical System Development

IMPALA Phasing



- Awarded to Lockheed Martin
- Delivery date Sep 30, 2016

- Planned delivery date – Dec 2016

- Platform Sustainment and O&M

Condition	Use Case	Resource Type	Resource	Criticality
Abdominal Injury	Diagnosis	Procedure	Vital Signs	3
			Physical Exam - Abdominal	3
			Physical Exam - Trauma Survey	2
		Imaging	Ultrasound - AC	2
			CT - Torso	3
		Lab	BMP	2
			CBC	3
			LFT	2
			Lactate	3
			Lipase	1
			UA	3
	Treatment (Best Case)	Procedure	IV Access - Minor	2
			IV Fluids	1
			Monitoring - Standard	2
		Medication	Analgesics	3
	Treatment (Worst Case)	Lab	IV Access - Minor	3
			IV Access - Major	3
			IV Fluids	2
			Blood Products	3
			Monitoring - ICU	3
			Advanced Airway	3
			Palliative Care	1
		Surgery	Surgery - Trauma	3
		Medication	Antibiotics	1
			Analgesics	3
			Antifibrinolytics	2