National Aeronautics and Space Administration

Human System Risk in Spaceflight

July 26, 2019

Erik Antonsen MD, PhD, FAAEM, FACEP
Assistant Director, Human Health and Performance
Human System Risk Management
NASA Johnson Space Center

Conflicts of Interest Disclosure

1. Assistant Professor of Emergency Medicine, Baylor College of Medicine
2. Assistant Professor of Space Medicine, Center for Space Medicine
3. Attending Physician, Ben Taub General Hospital

4. Assistant Director, Human Health and Performance, NASA Johnson Space Center

I have financial interests in the above entities.

Today I am speaking in my capacity as an Assistant Director for NASA

19

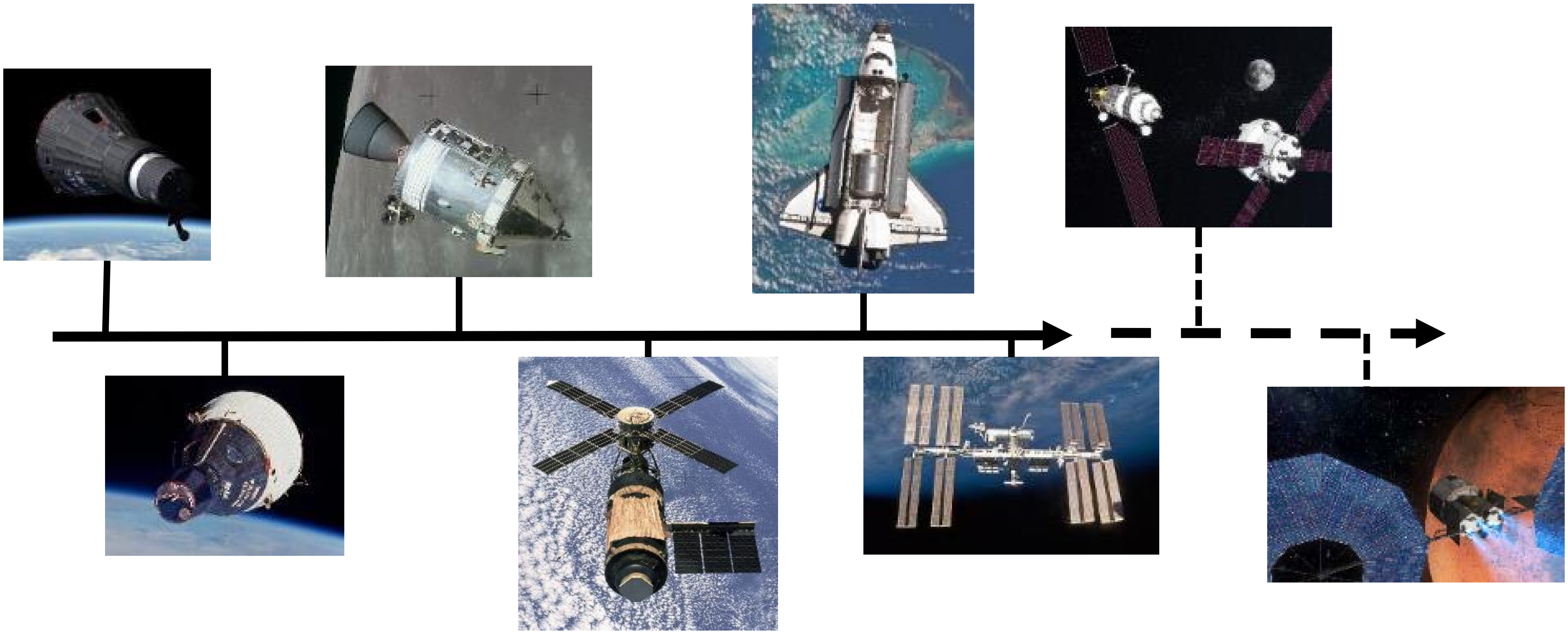
~560

1,000,000,000

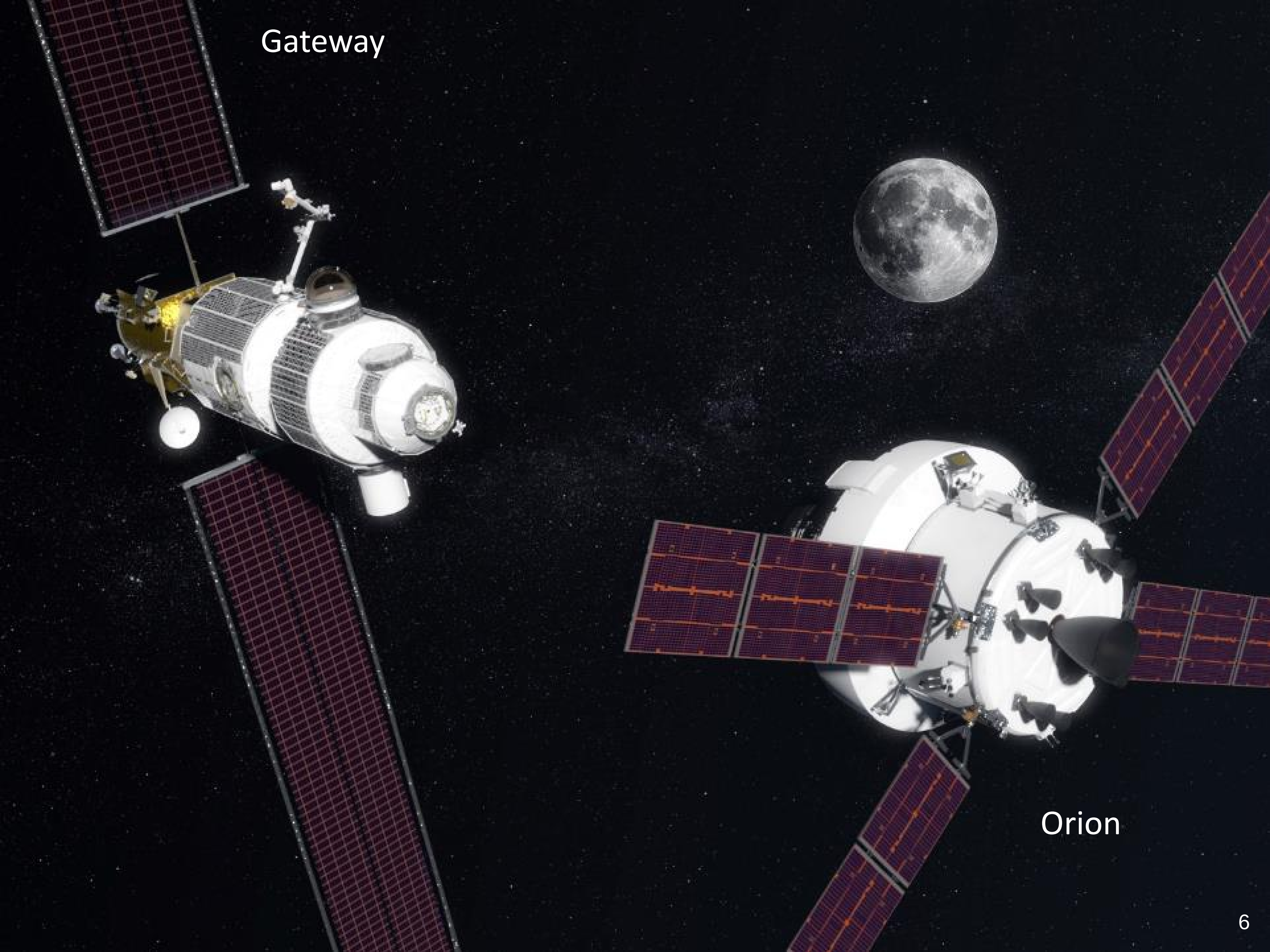
Outline

- Historical Spaceflight Medical Systems
- Upcoming Missions and Medical Challenges
- Medical Risk and Spaceflight Events
- Medical System and Technology Integration

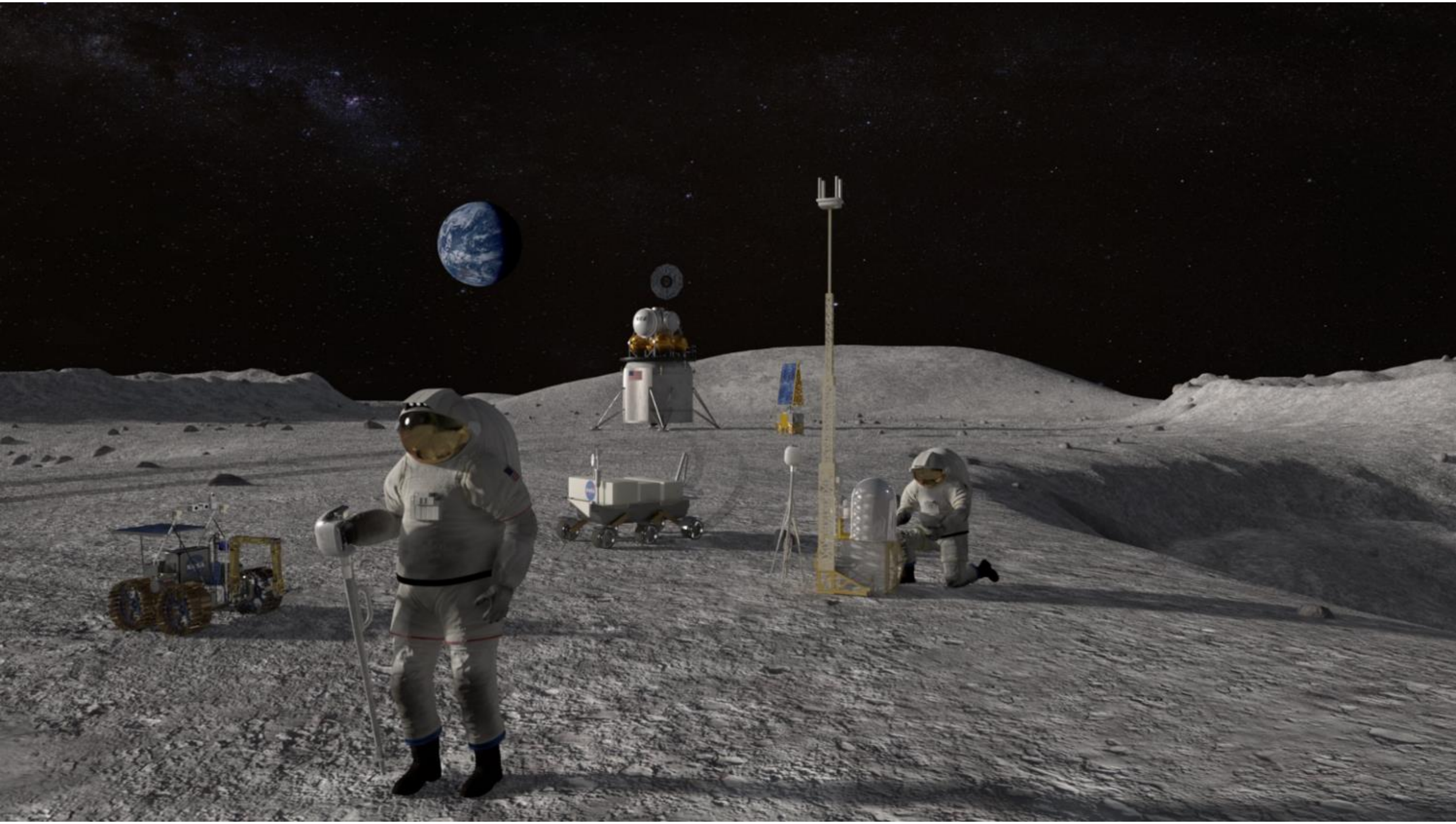
Space Medicine History

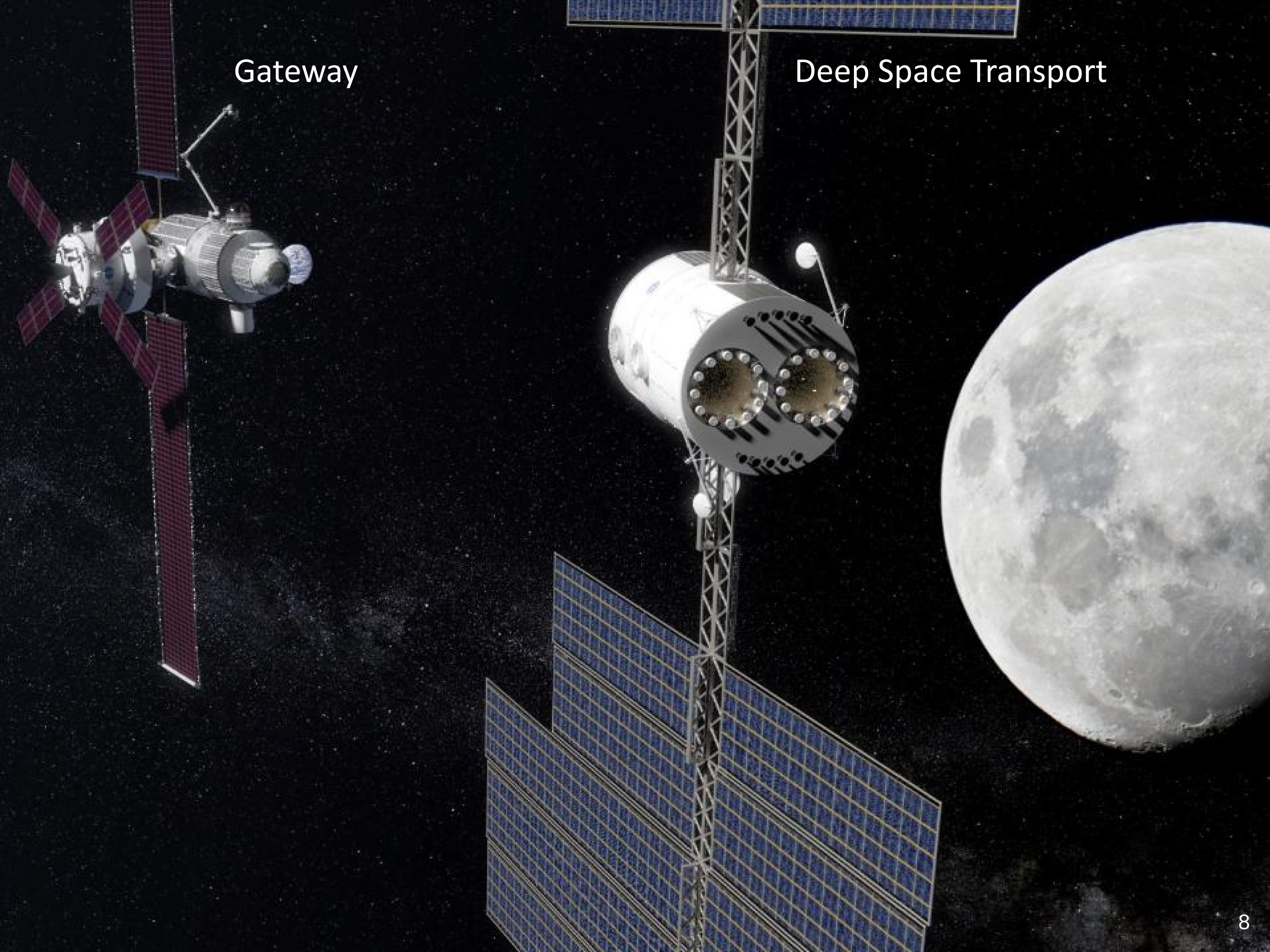


1961 2019

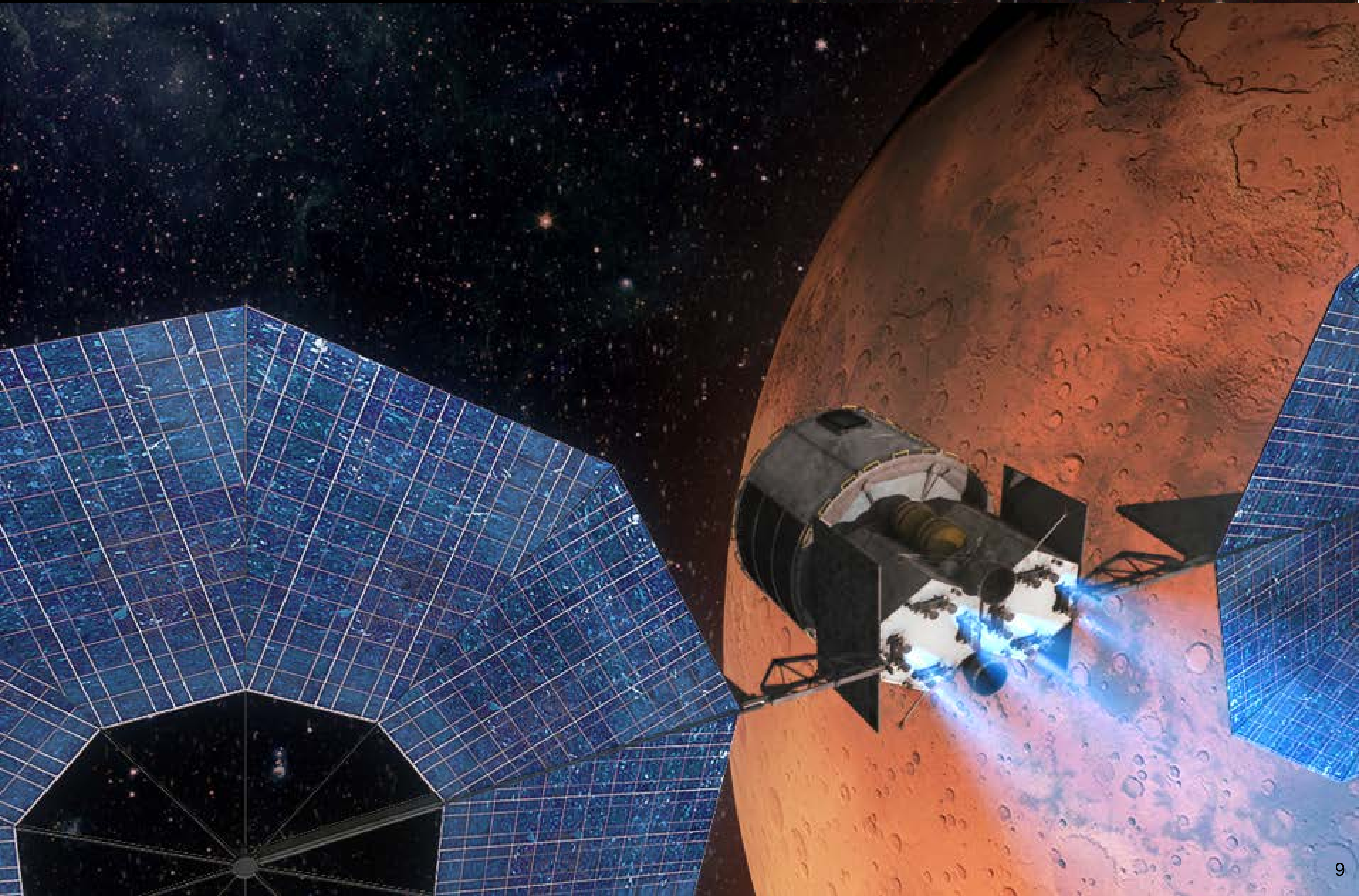

Gateway
Orion

Artemis

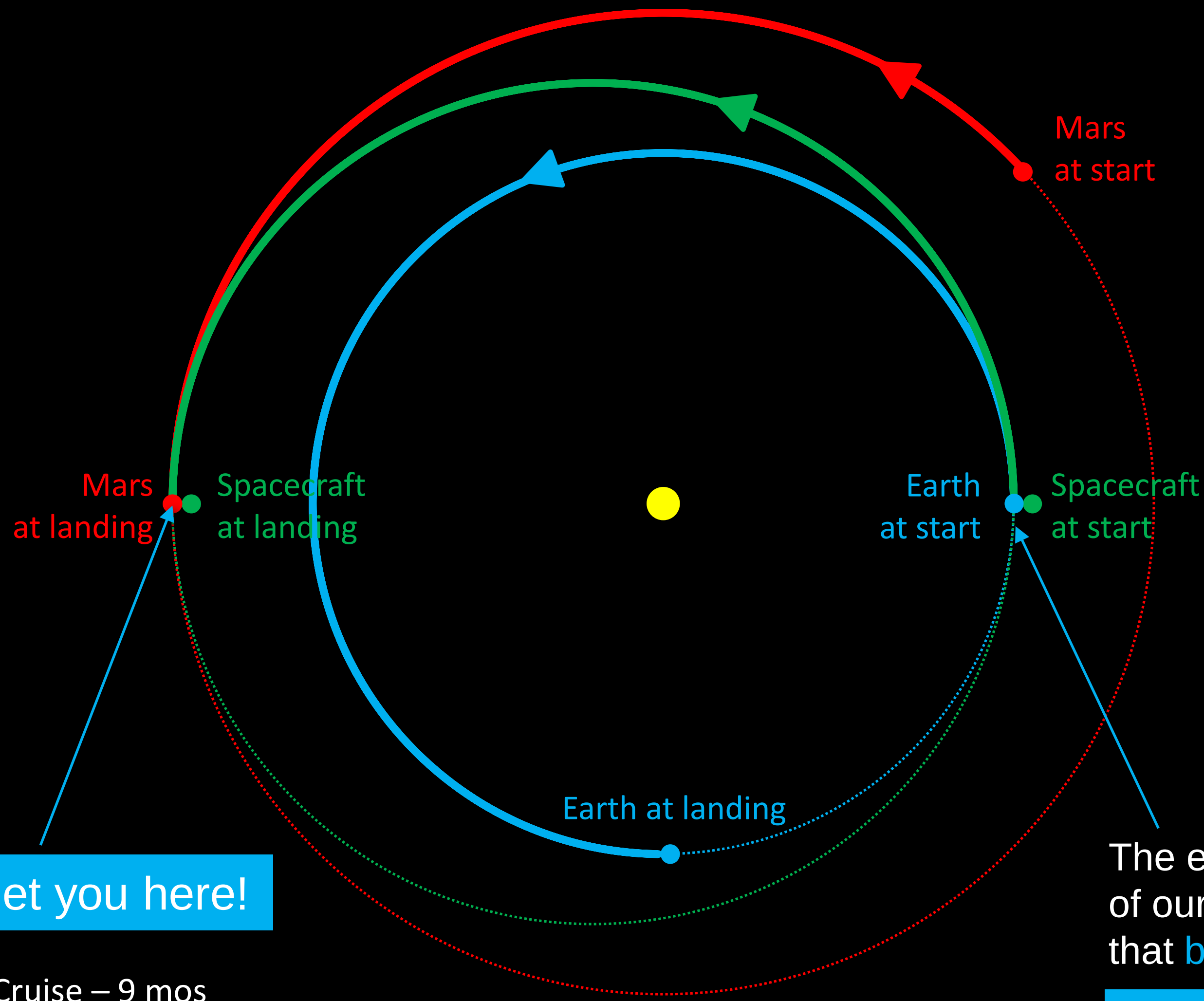



Gateway
Deep Space Transport

What about Mars?



No comparable human experience for Mars



Will not get you here!

Trans-Mars Cruise – 9 mos
Full Mission - ~34 mos

The entire experience of our species fits into that blue dot.

What got you here…

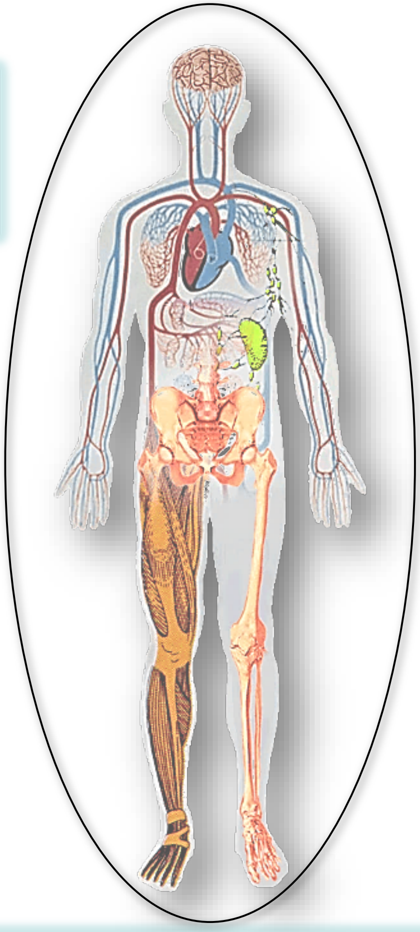
Adapted from S. Love, E. Nelson, Mars Mission Concept of Operations, Aug 2016

Hazards of Spaceflight

Hazards Drive Human Spaceflight Risks

Altered Gravity - Physiological Changes

Distance from earth



Hostile/ Closed Environment

Space Radiation

Isolation & Confinement

Why does performance matter?

Humans in Extreme Environments

Mitigating Impacts on Human Health & Performance

Exposure Sources
•Carbon dioxide
•Celestial dust
•Toxic
•Sunlight
•Radiation

Isolation
•Cognitive, behavioral, psychiatric disorders
•Cooperation, coordination, psychosocial adaptation

Work
•Sleep loss
•Circadian desynchronization
• Work overload

Altered body function
•Immune response
•Hypobaric hypoxia
•Decompression
•Renal stone
•Bone fracture
•Host-microorganism interactions
•Urinary retention
•Orthostatic intolerance
•Cardiac rhythm
•Back pain

Preparedness
•Food and nutrition
•Inflight medical conditions
•Medication

Injury sources
•Dynamic loads
•EVA
•Electrical shock

Reduced capacities
•Hearing loss
•Intracranial hypertension/vision alteration
•Vestibular/sensorimotor alteration
•Muscle mass, strength, endurance
•Aerobic capacity

How Crew Is ***Impacted*** by Mission

Enabling Unique Human Capabilities for Earth-Independent Ops

Anomaly Response

Causal Diagnostics

Next Worst Outcome Analysis

Knowledge Integration

Contingency Planning

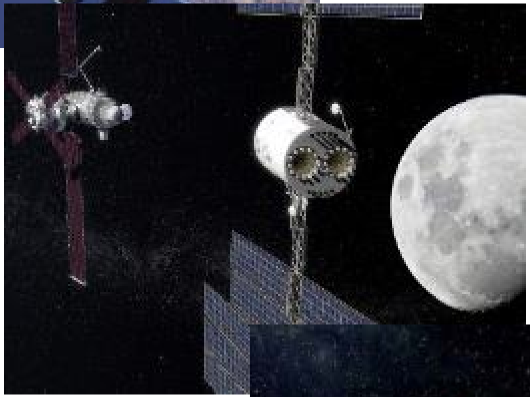
Complex Procedure Execution

Risk Assessment / Time to Criticality

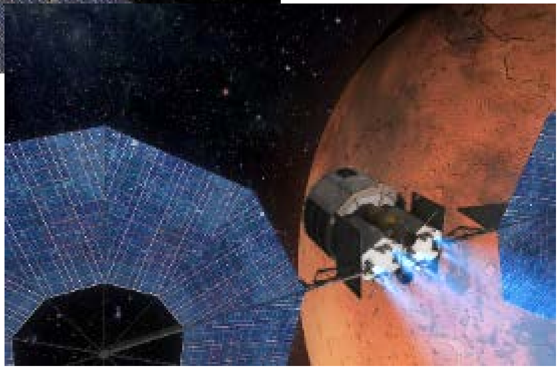
How Crew Is ***Impacting*** Mission

Progressive Earth Independence

- Real Time Communications
- Evacuation Capability (1.5 – 36 hrs)
- Strong Consumables Resupply



- Near Real Time Communications
- Evacuation Capability (**72 – 144 hrs**)
- **Limited** Consumables Resupply



- **No** Real Time Communications
- **No** Evacuation Capability
- **No** Consumables Resupply

Increasing exposure to Hazards

Crew Health and Performance Goal

Provide a crew that is fit for duty when the mission calls.

Do we need medicine in Spaceflight?

Table 2. Number of occurrences of medical conditions that have affected NASA astronauts during previous space missions (NASA 2017b). Data are obtained from LSAH records for medical conditions that occurred among US astronauts during the Space Shuttle Program, Mir, and ISS (through Expedition 13 in 2006) missions. EVA: extravehicular activity

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		

Antonsen E, Bayuse T, Blue RS, Daniels V, Hailey M, Hussey S, et al. The Risk of Adverse Health Outcomes and Decrements in Performance due to In-Flight Medical Conditions. National Aeronautics and Space Administration 2017; TR: NASA/TR-2017-0004604

What about between flights?

- Kidney stone x 14
- Clostridium deficile infection
- Gastroenteritis/ colitis
- Inguinal hernia x 4
- Olecranon bursitis r/o septic joint
- Hand bacterial tenosynovitis
- Pneumonia x 2
- Corneal ulcer
- Severe epistaxis
- Right ovarian cyst
- Dysmenorrhea
- Sudden hearing loss x 2
- V-tach, exercise induced
- Angina
- Allergic reaction - severe
- Retinal detachment x 2
- Appendicitis x 2
- Diverticulitis

- Prostate Cancer x 5
- Stroke with Patent Foramen Ovale
- TIA from A. Fib
- Bladder Outlet Obstruction
- Ulcerative Colitis
- Flexor Digitorum Synovitis
- Bowel Resection
- Fatty Liver Disease
- Bulging Disc with Radiculopathy x 44 (Cervical 18 and Lumbar 26)
- Hypercholesterolemia
- Hypertension (essential)
- Atrial Fibrillation with ablation x 5
- Brain (Pituitary) Tumor x 2
- Choledocholithiasis x 4
- Pancreatitis x 2
- Hemorrhagic cyst
- Lower GI bleeding
- Duodenal ulcer with upper GI bleeding
- Malignant Melanoma
- Total Knee replacement x 2
- Total Hip Replacement X 2
- Shoulder surgical repair x 22
- Coronary Disease (Asymptomatic x 12)
- SANS

How is medical care provided in mission?

- **Live remote guidance**




- **Live monitoring**

- **Store and forward**

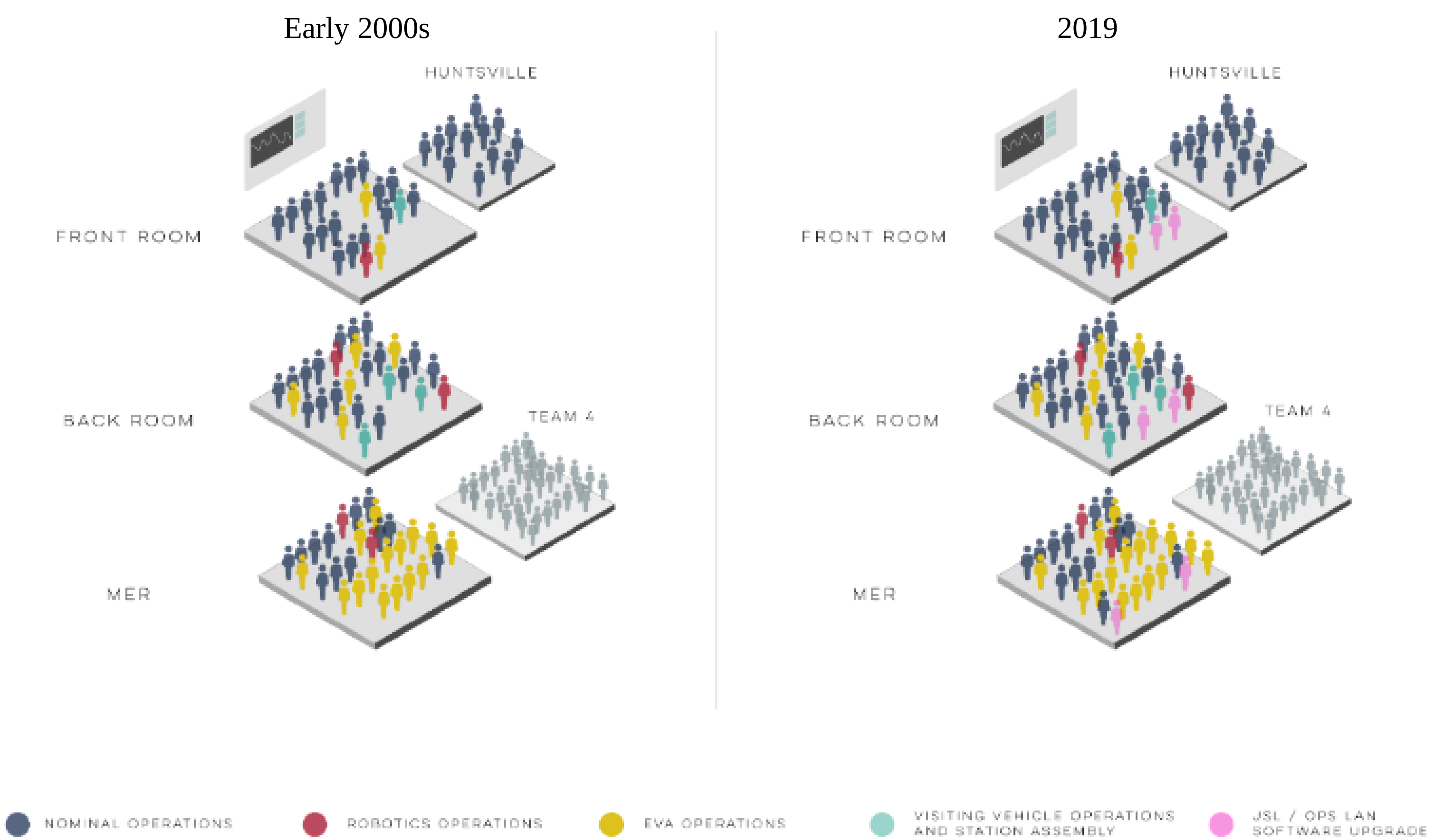



- **Autonomous**

What does autonomous mean?

Can be up to 150 people working the first 1 hour of a critical situation

MCC Staffing



MEDICAL RISK

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

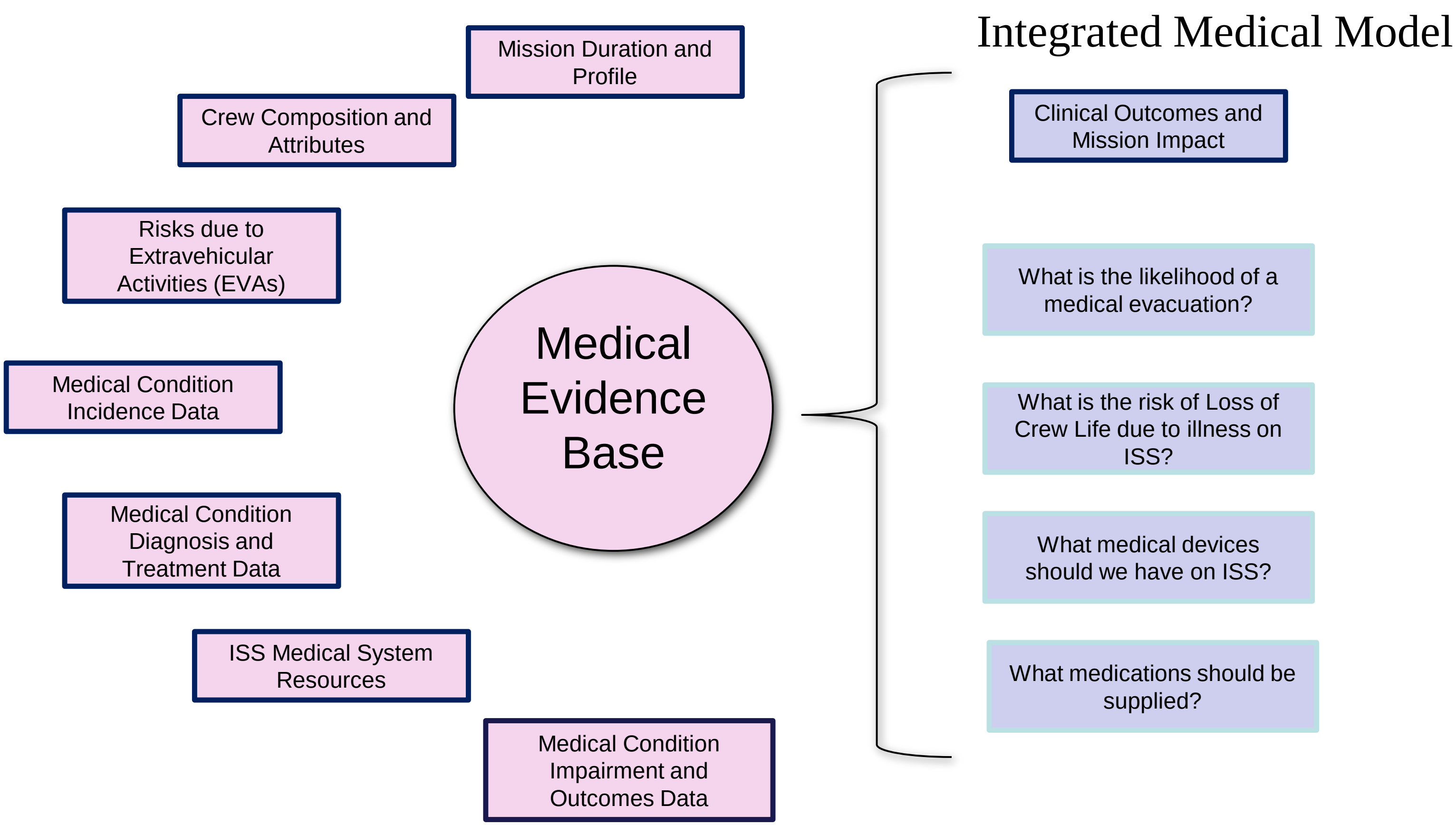
GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

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

IMMUNE
- Allergic Reaction
- Anaphylaxis
- Skin Rash
- Medication Reaction

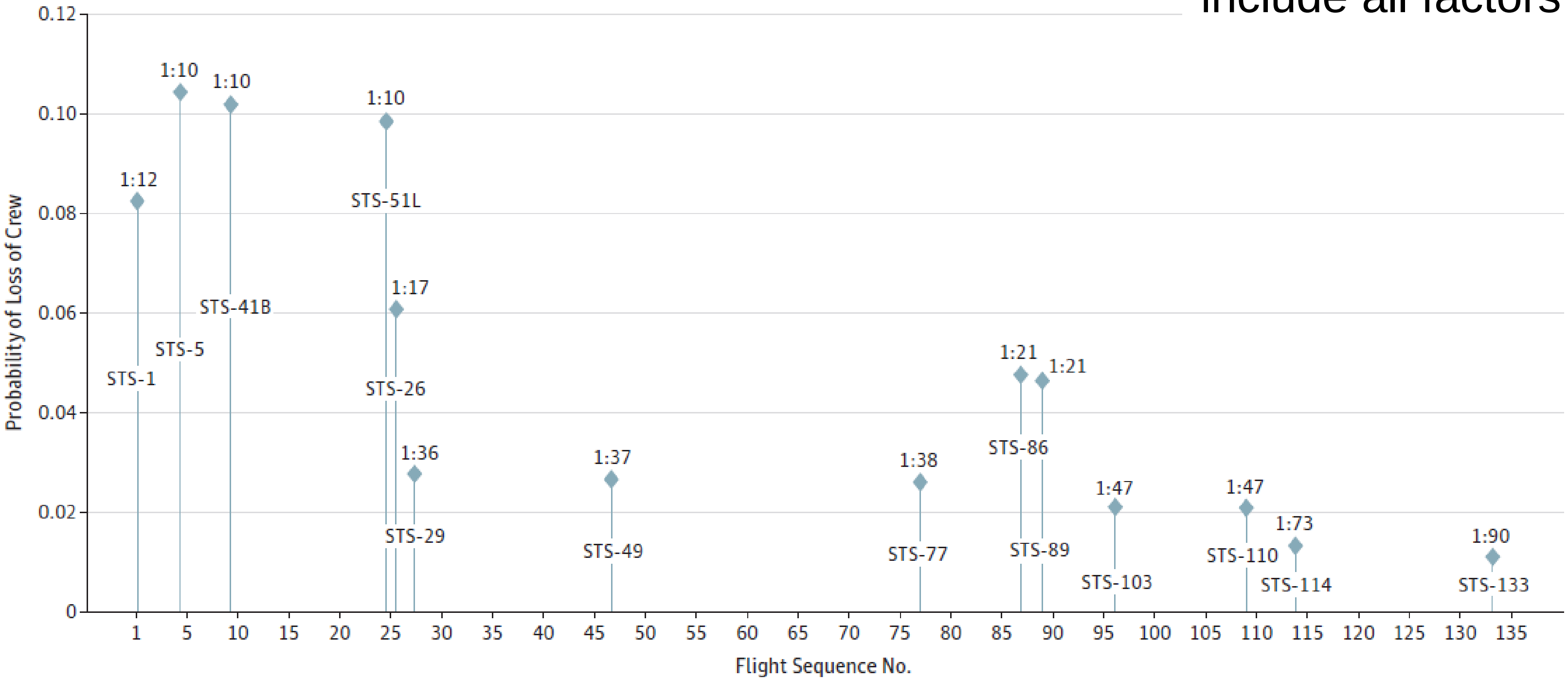
ENVIRONMENT
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness (EVA)
- Headache (CO_2)

What need does it fill?



Accepting Risk

Figure. Results on Retrospective Analysis on Shuttle Risk



These results include all factors

STS-1 estimate includes crew escape with ejection seats (risk is 1:9 ratio without ejection seats). STS-1 risk may have been higher because of unquantified risks.

The vertical lines indicate individual flights. Adapted from the National Aeronautics and Space Administration Aerospace Safety Advisory Panel.[4]

Bagian, JAMA Neurology January, 2019

Evacuation

EVAC is baselined to ISS

EVAC if any criteria are met:

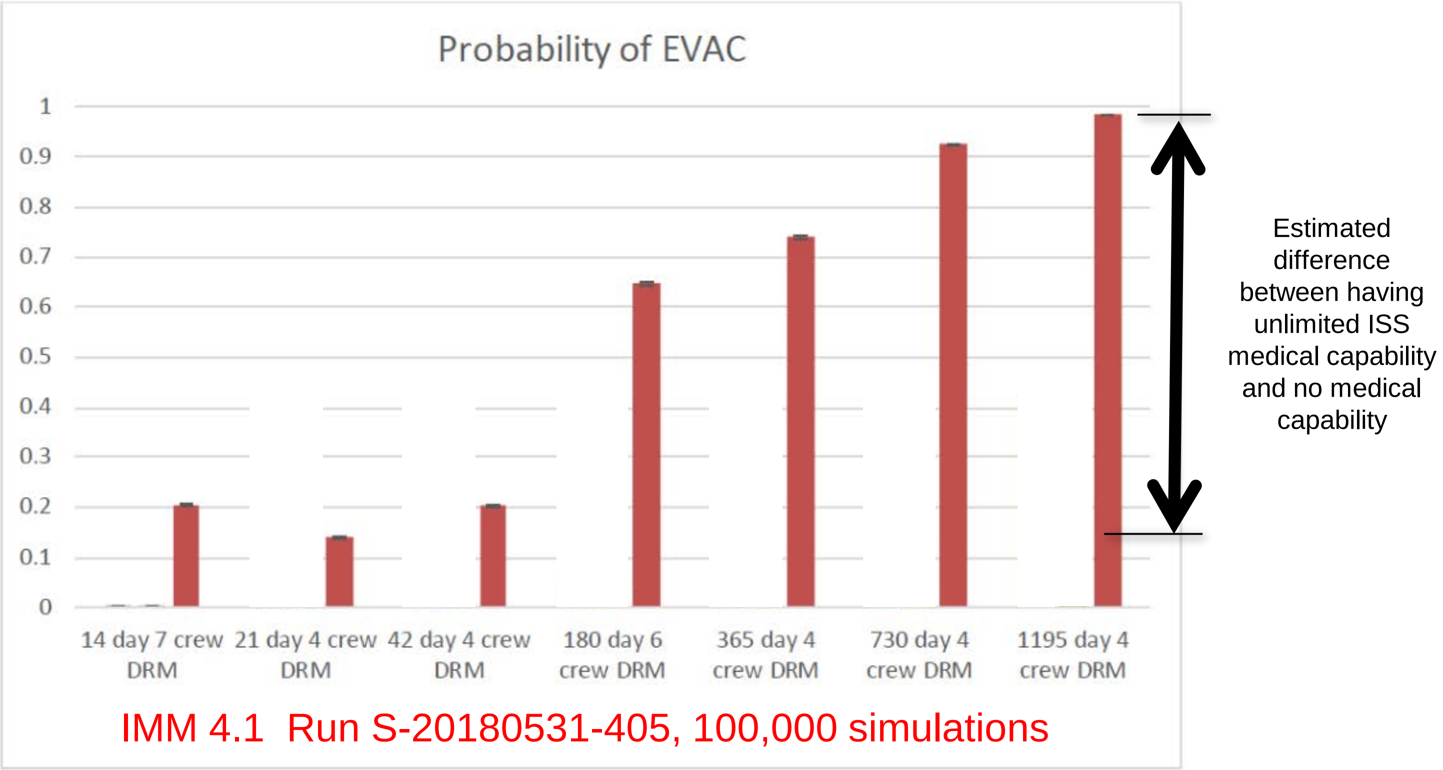
- potential LOCL
- potential significant permanent impairment
- potential intractable pain
- No other assumptions are made

What happens when evacuation takes longer? Or there is no evacuation option?

No Medical Capability

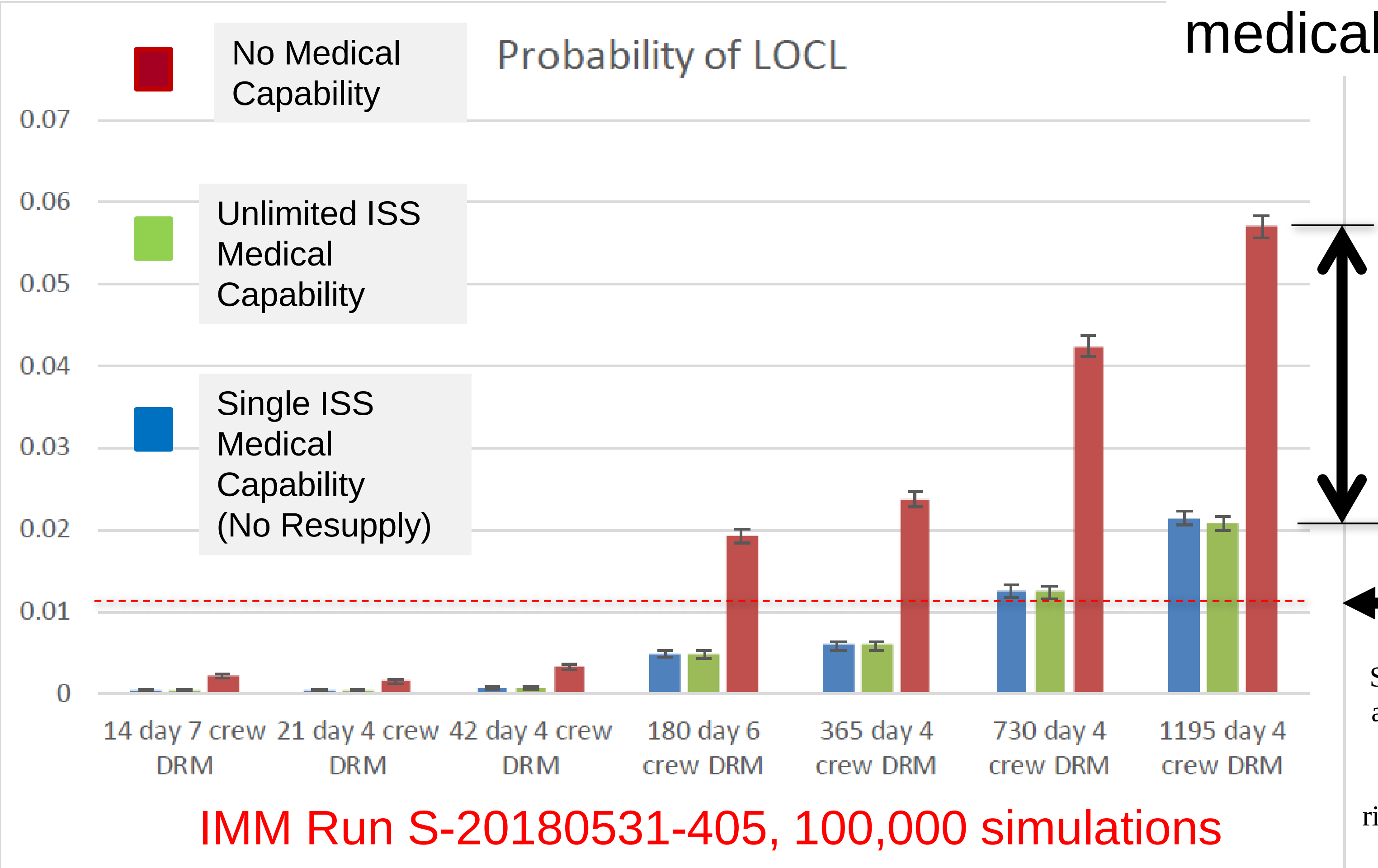
Unlimited ISS Medical Capability

Single ISS Medical Capability (No Resupply)



Loss of Crew Life

These results are medical event only



Estimated difference between having unlimited ISS medical capability and no medical capability

1/90 is where the Space Shuttle total LOC risk fell at the end of the program.

Remember we flew with risk as high as 1/10 in early shuttle.

Quantifying Performance Deficits

Small differences between treated and untreated reflect the benefits of selecting very healthy individuals

CHI Definition: Proportion of mission time *not* lost to medical events

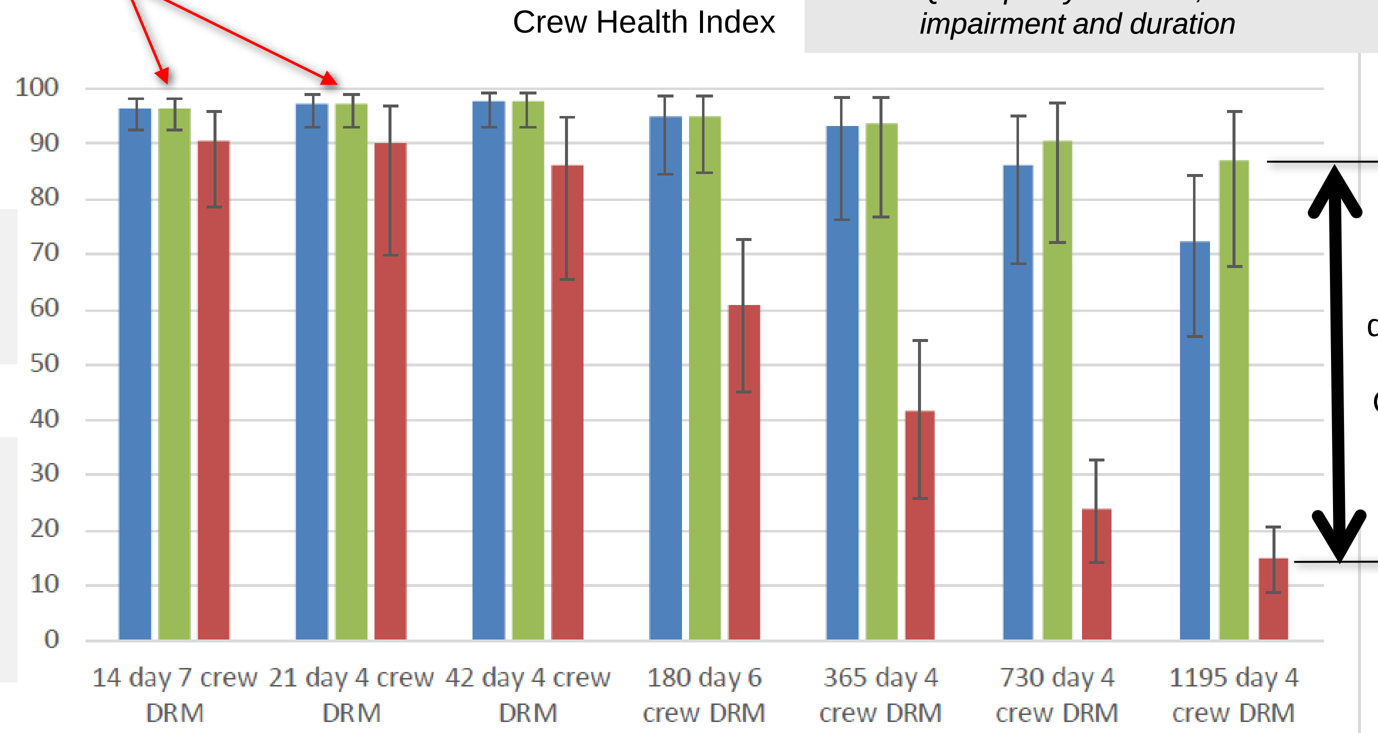
$$1 - \frac{\sum QTL}{L * n} = CHI$$

N= # crew,
L = mission length,
QTL=quality time lost; is a function of functional impairment and duration

No Medical Capability

Unlimited ISS Medical Capability

Single ISS Medical Capability (No Resupply)



Expected Performance deficit between Unlimited ISS Capability and No Medical Capability.

IMM Run S-20180531-405, 100,000 simulations

Spaceflight Medical Risk

Medical Risk

~100 Medical Conditions

Medical Conditions for which we have not planned.

How do models compare to real life?

<u>IMM Simulation Data</u>

- Medical Illness
  - VIIP/SANS
  - Dental Abscess
  - Kidney Stone
  - Sepsis
  - Stroke
  - Angina/ MI
  - Afib/Aflutter
- Environmental
  - Smoke/Toxic Exposure
- Injury/Trauma
  - Hypovolemic Shock
  - Wrist Fracture
  - Back Injury

<u>Actual Russian Flight Data</u>*

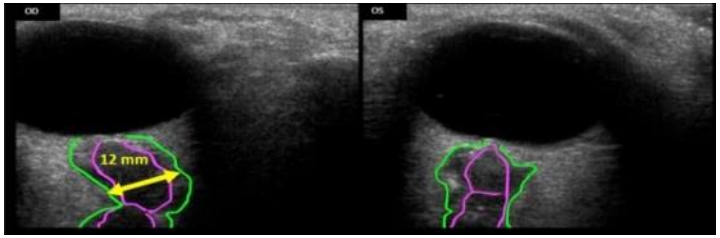
- EVAC
  - Urosepsis
  - Cardiac Arrhythmia
  - Smoke Inhalation
- Close Call EVAC
  - Kidney Stone
  - Dental Abscess
  - Toxic Exposure

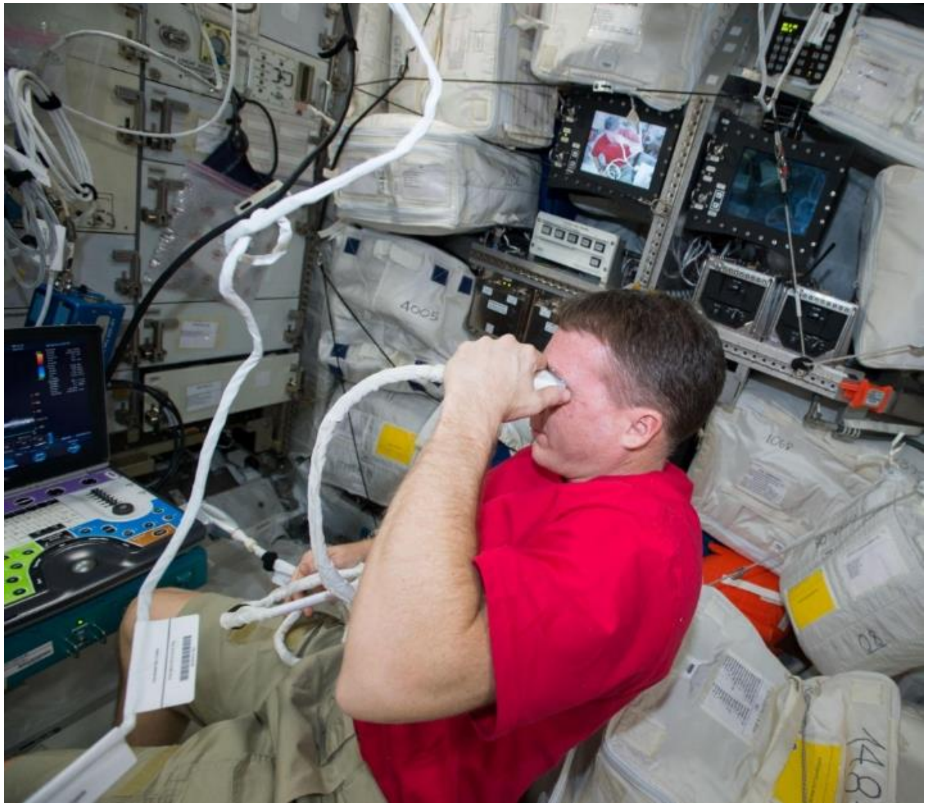
* Russian medical data not used in IMM

Fire and Toxic Exposure

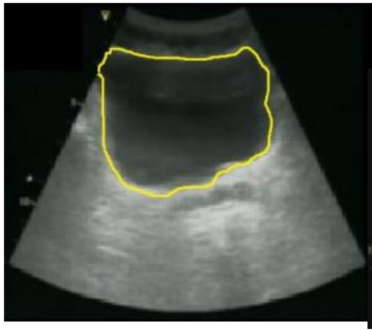
Near Drowning in EVA

SANS – adaptation or pathology?

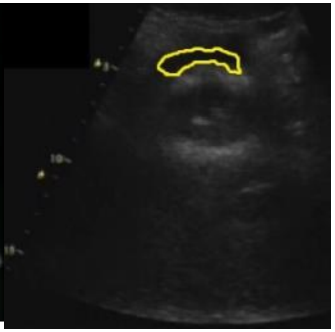




Urinary Tract Infections and Sepsis



In-flight Post-void Ultrasound

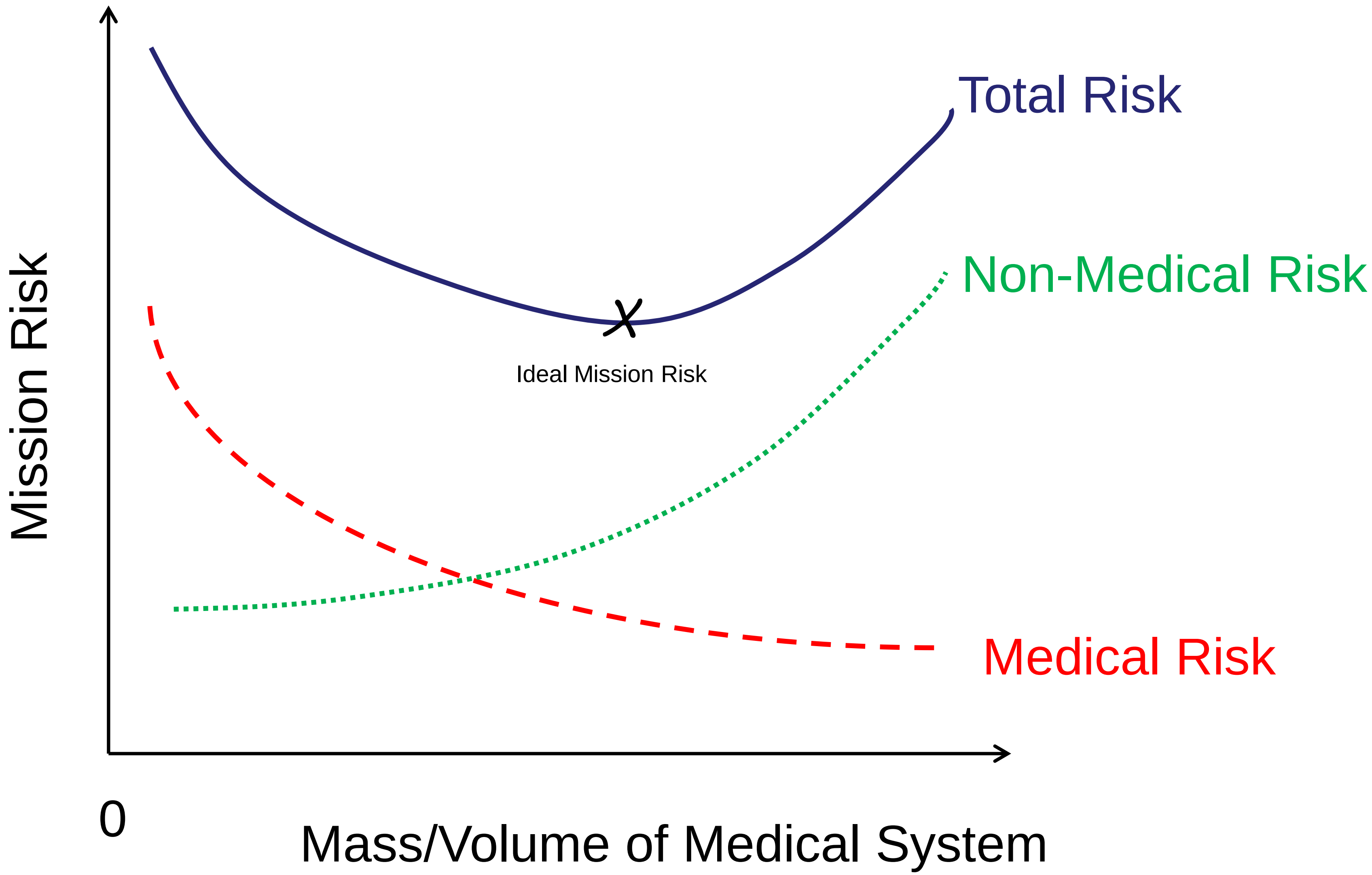


Ground Post-void Ultrasound

Return to Earth gravity

Capsule Egress

Medical and Non-medical Risk

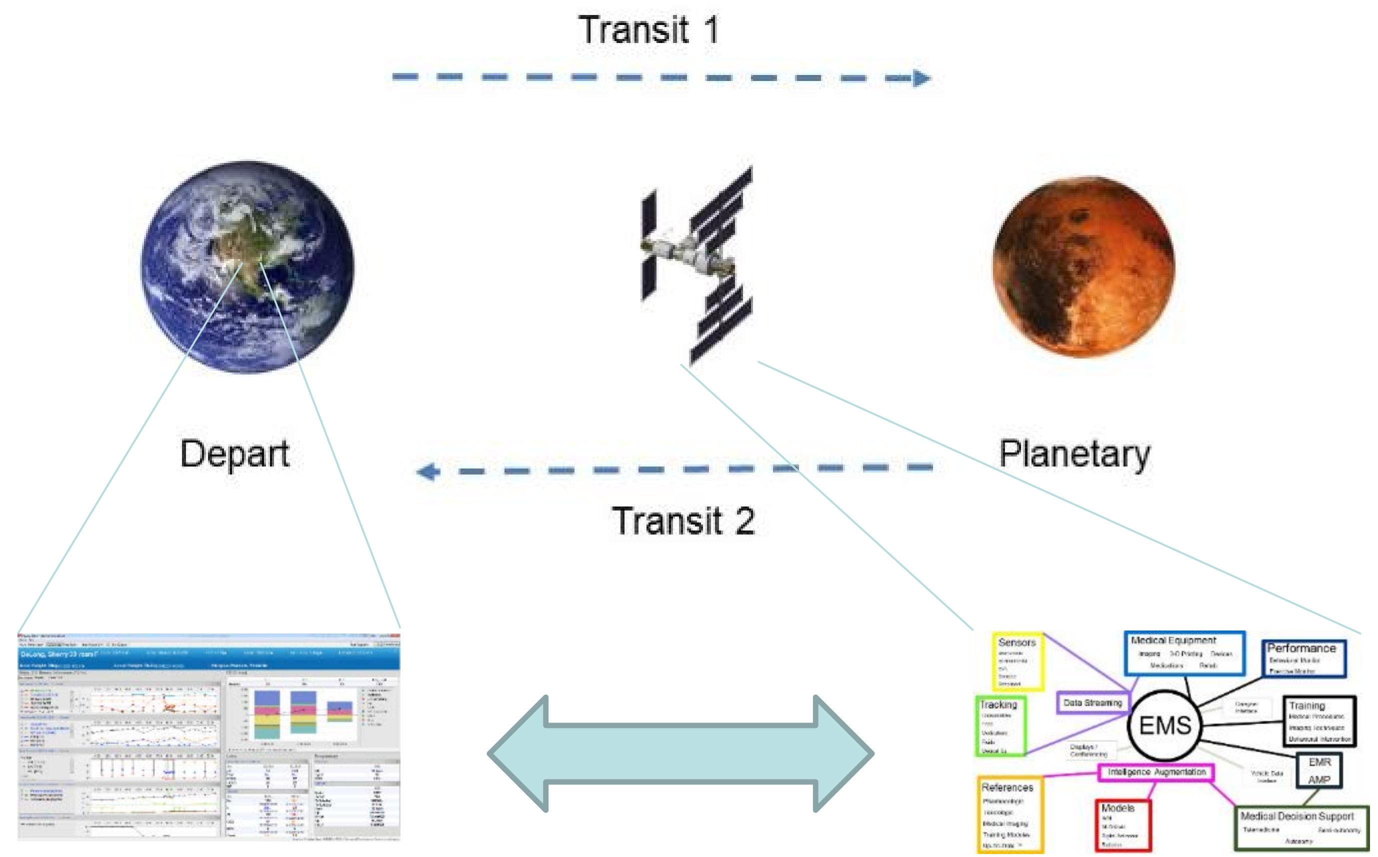


Notional

There are more risks than medical

Human Spaceflight Risks	In Mission Risk - Operations						Post Mission Risk - Long Term Health					
	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation
	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years
Renal Stone Formation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Inflight Medical Conditions	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation
Vision Alterations	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Cardiac Rhythm Problems	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring
Cognitive or Behavioral Conditions	Accepted with Monitoring	Requires Mitigation	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation
Space Radiation Exposure	Accepted	Accepted	Accepted	Accepted	Requires Mitigation / Data	Requires Mitigation / Data	Accepted with PELs	Accepted with PELs	Accepted with PELs	Requires Mitigation	Requires Mitigation	Requires Mitigation
Inadequate Food and Nutrition	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted / Optimize	Requires Mitigation
EVA Operations	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation
Psychosocial Adaptation within a Team	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted with Monitoring
Inadequate Human-System Interaction Design	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Standard Refinement, May Require Mitigation	Standard Refinement, May Require Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted

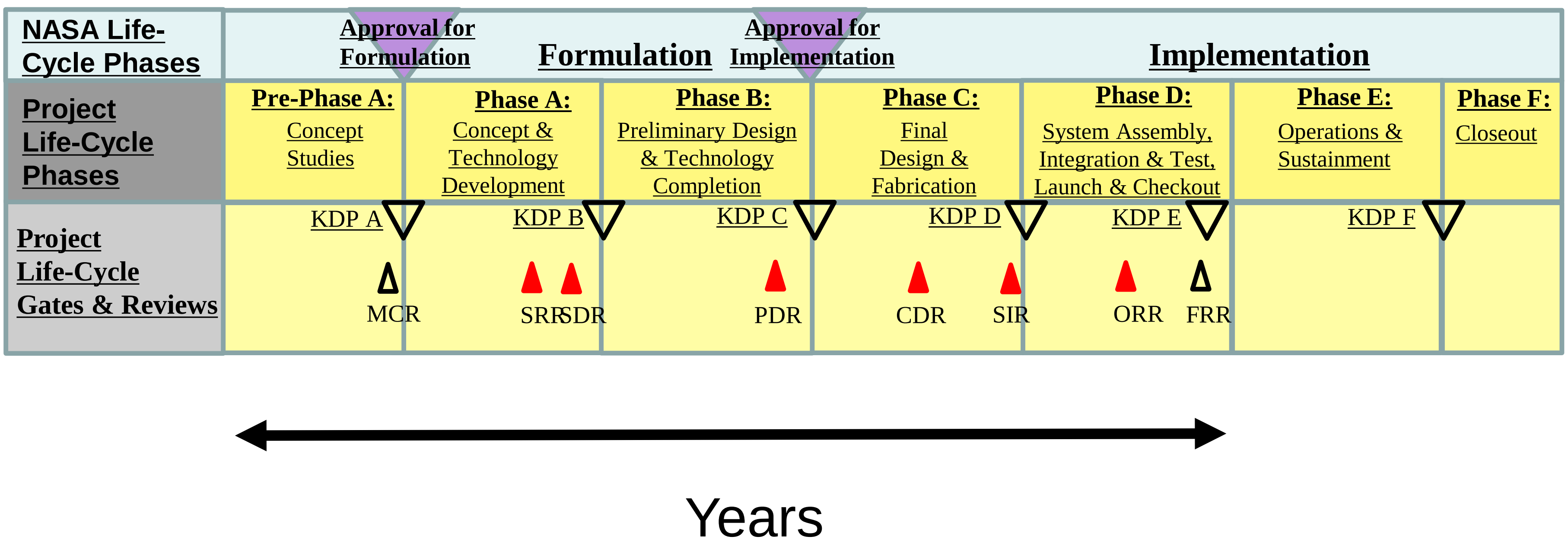
Implementation requires a Health and Performance System



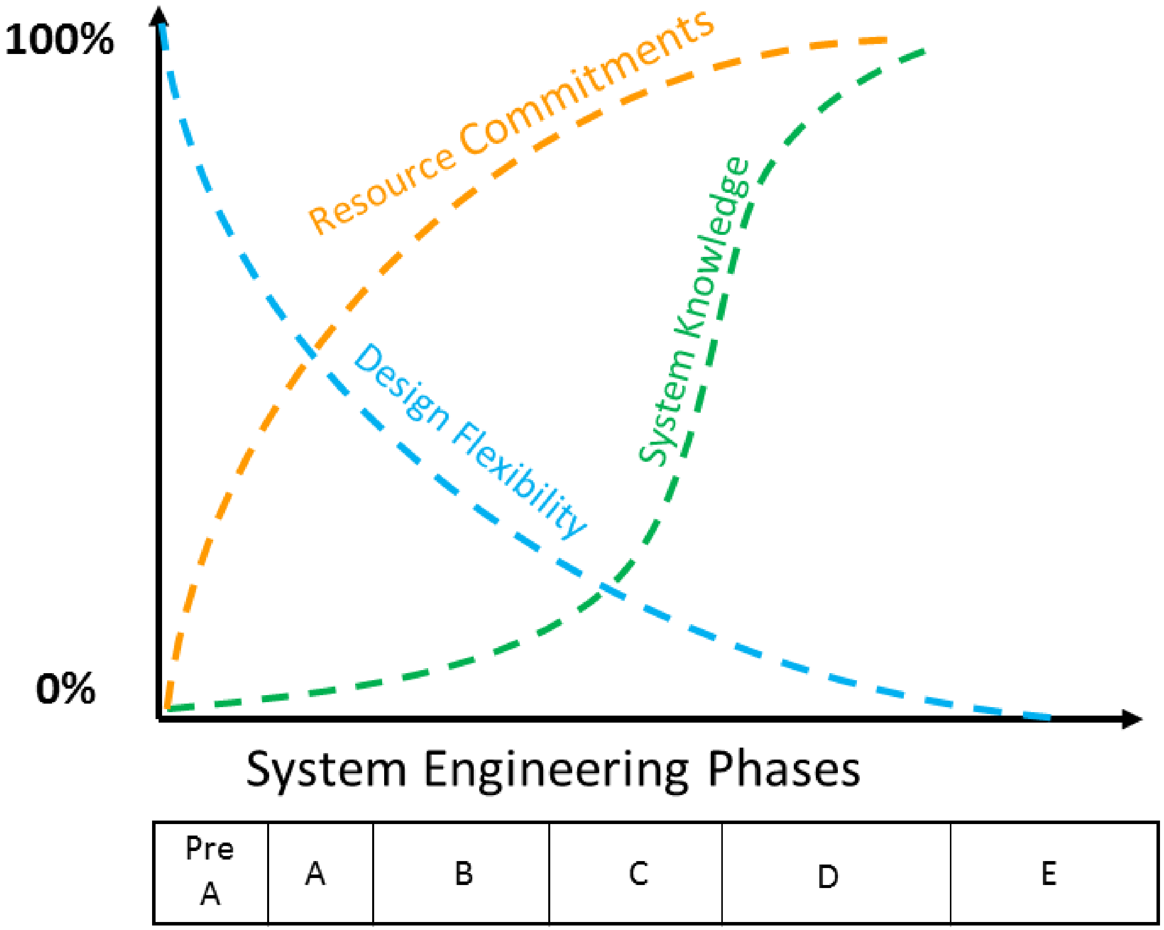
Ground Support

Crew Autonomy

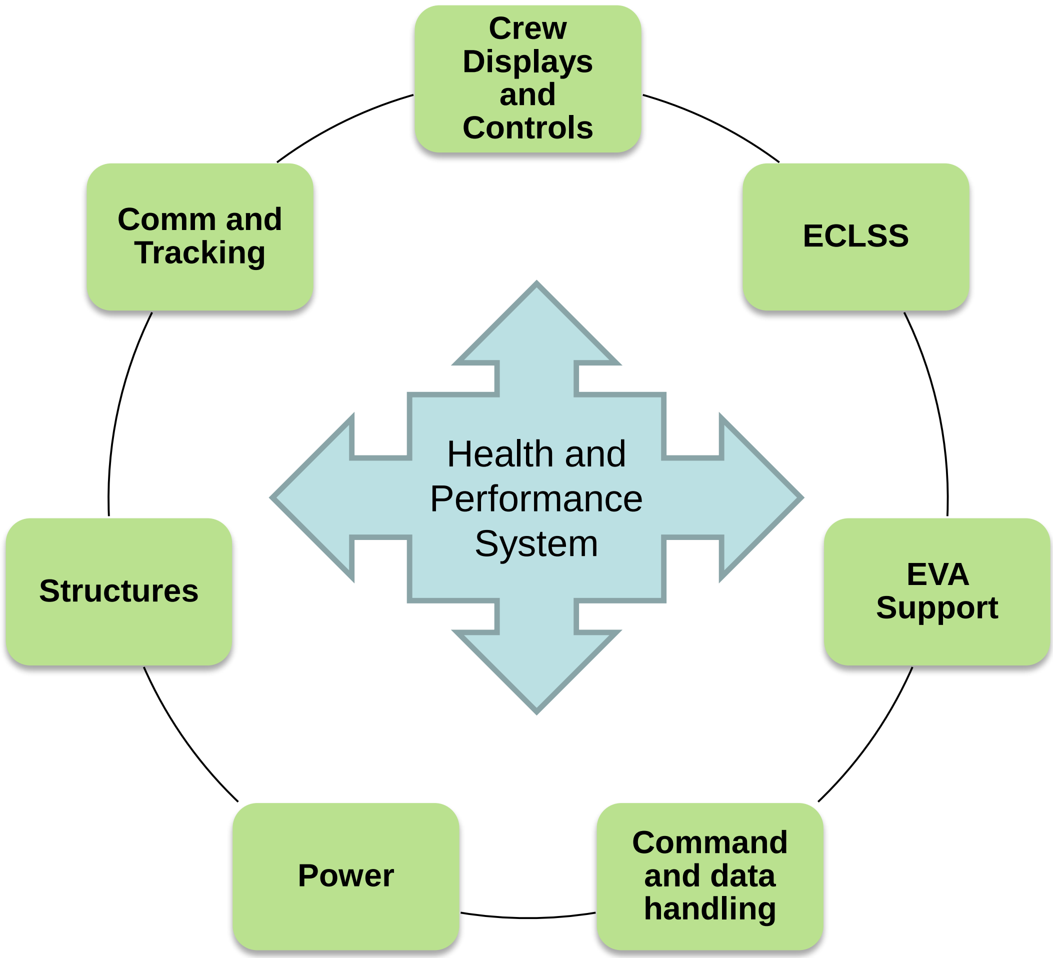
NASA Engineering Life Cycle



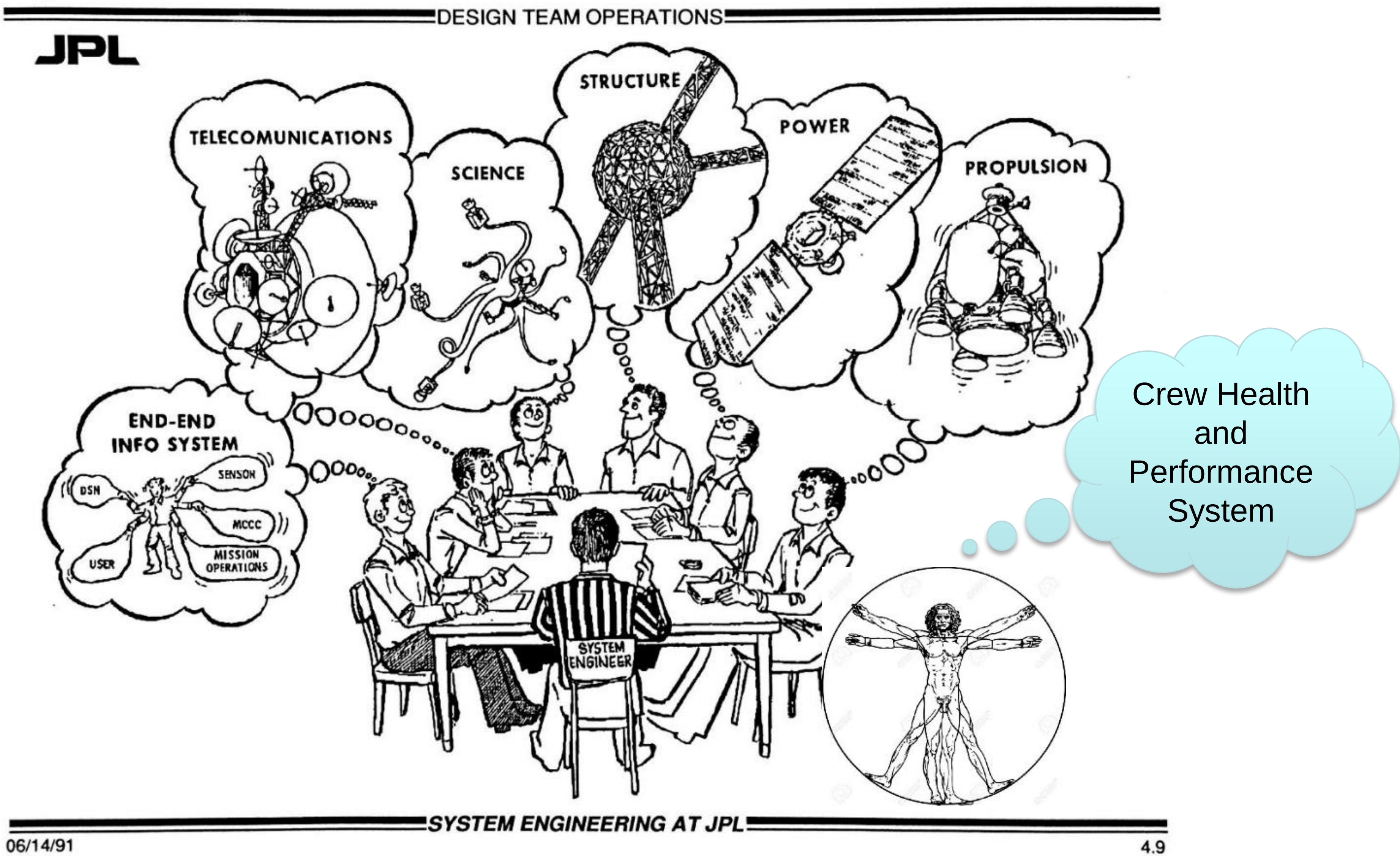
Human Systems Integration



System Interfaces with the Flight System



Medical Systems Engineering



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

Crew Health and Performance System Must…

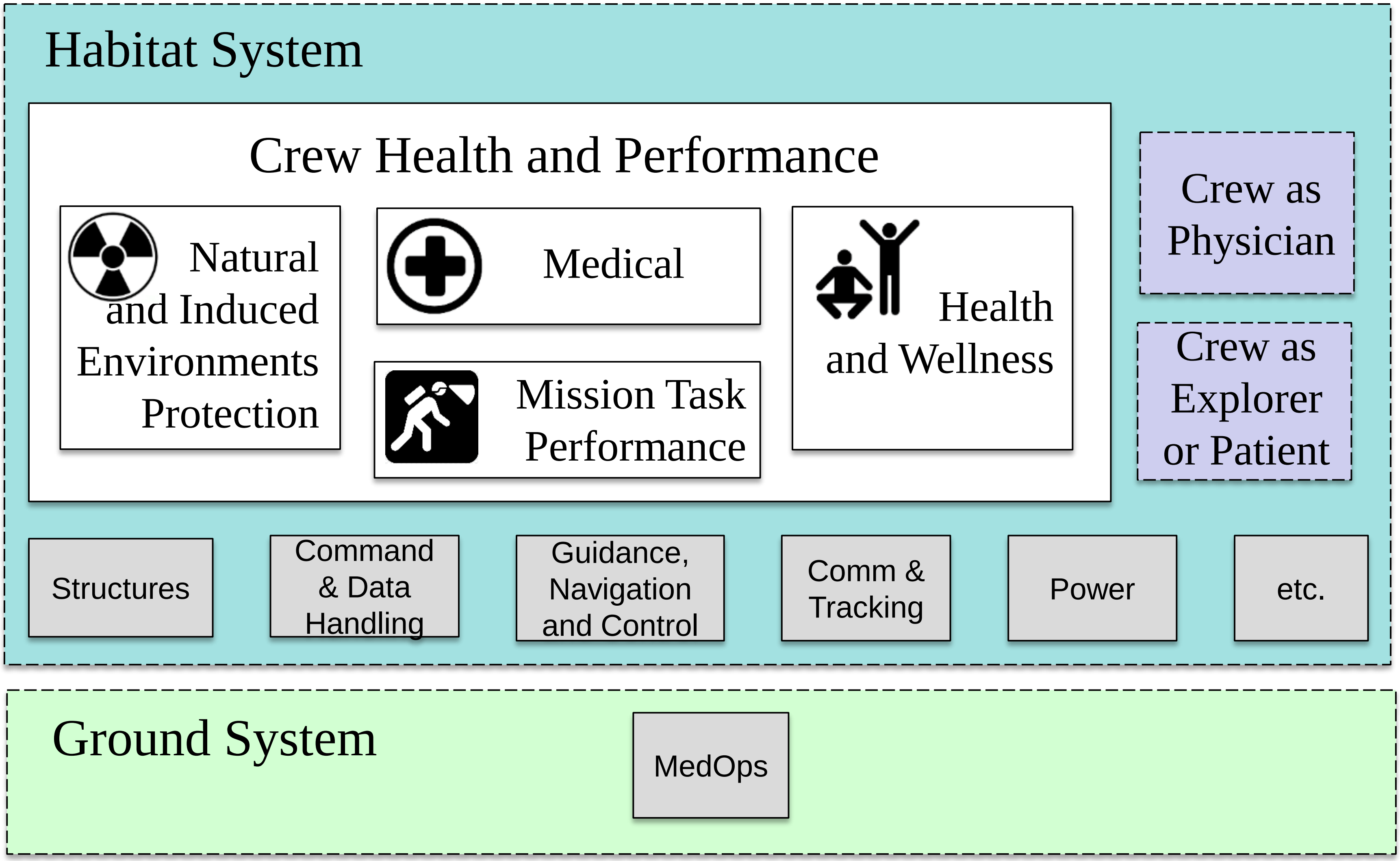
- **Protect from environmental hazards**
  - Radiation protection
  - Noise, vibration, CO_2, etc.

- **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

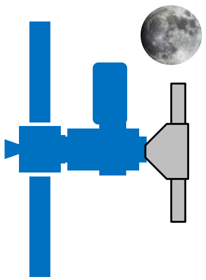
- **Support crew to accomplish mission tasks**
  - Procedures
  - Training
  - User interfaces

Vehicle/Mission Architecture Integration

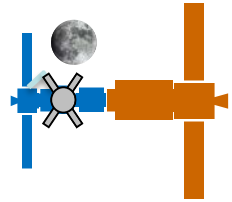


Stepwise Progression

Gateway-Artemis
2024

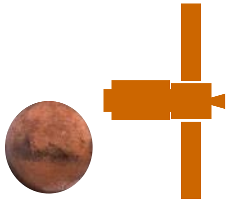


Deep Space Transport
2027



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

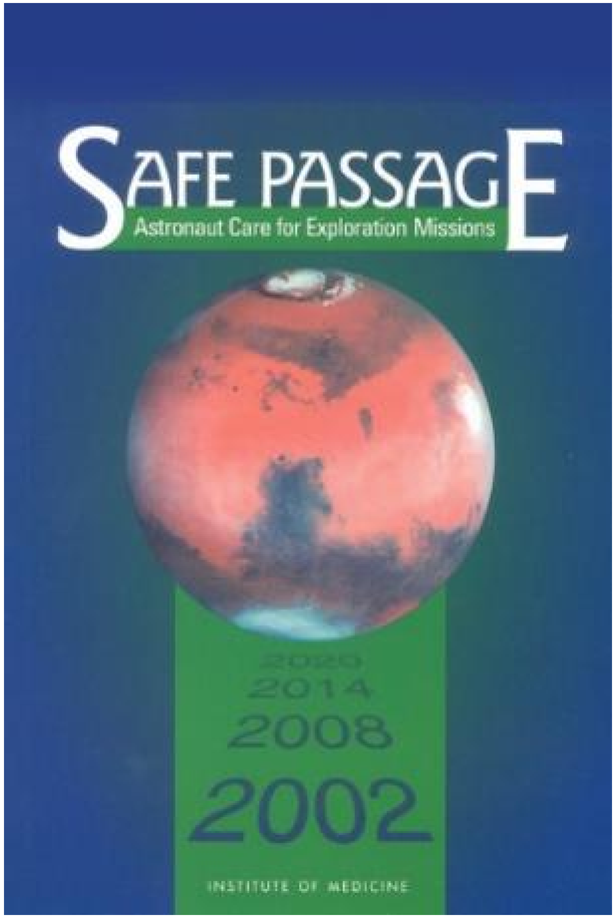
Redefined Ground Operations Paradigm

Ground System Requirements

Perspective

- **Less than 600 people - The entire human experience in space**
- **19 years – we’ve had a constant human presence in low earth orbit**
- **Every day we fly we learn more, but each step farther out requires re-examining our assumptions and reassessing the current state of technology.**
- **Medicine and Engineering are intimately tied together in reducing the risks humans face in spaceflight.**

Our work continues…



- *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.

Backup

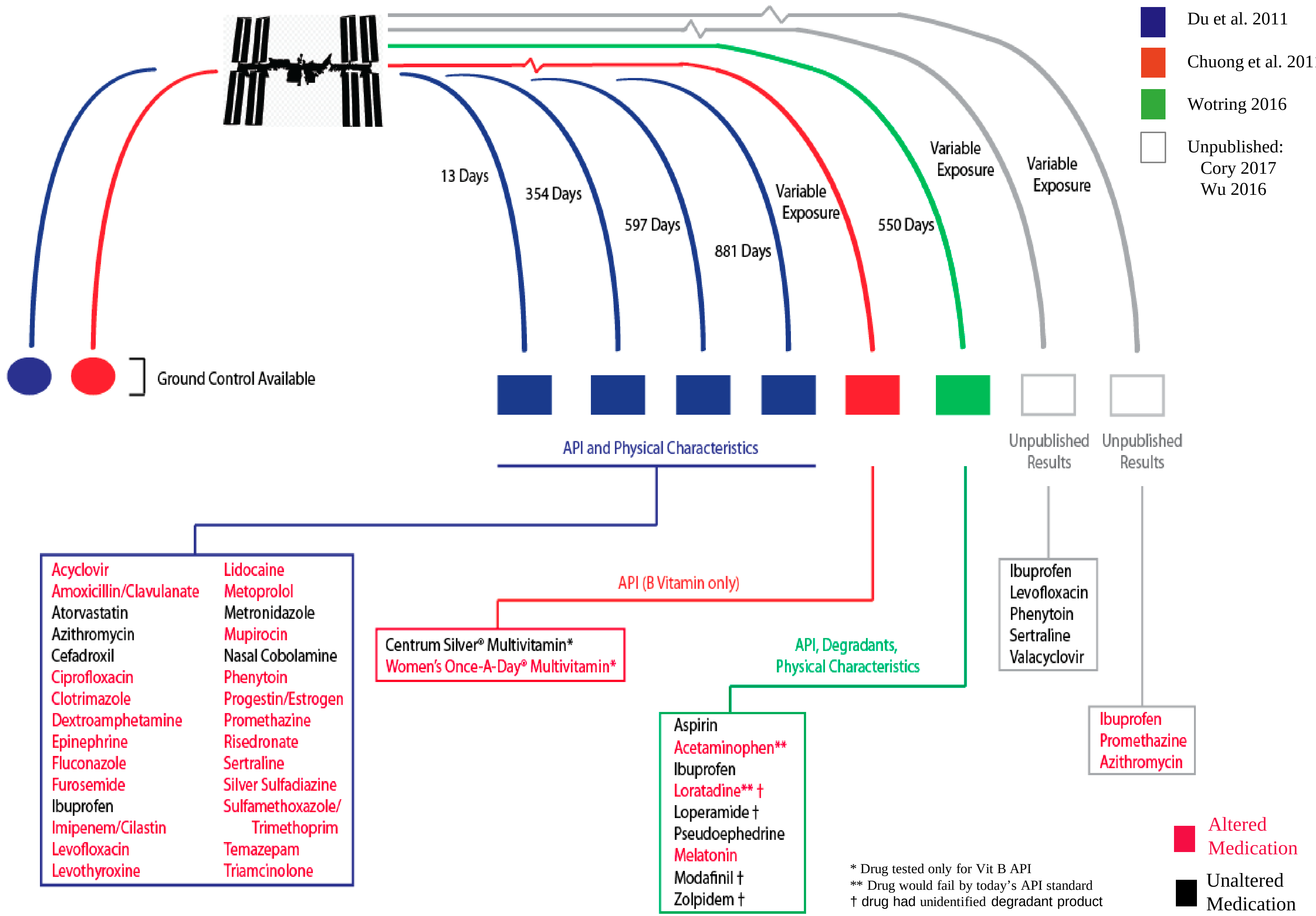
Consumables Resupply

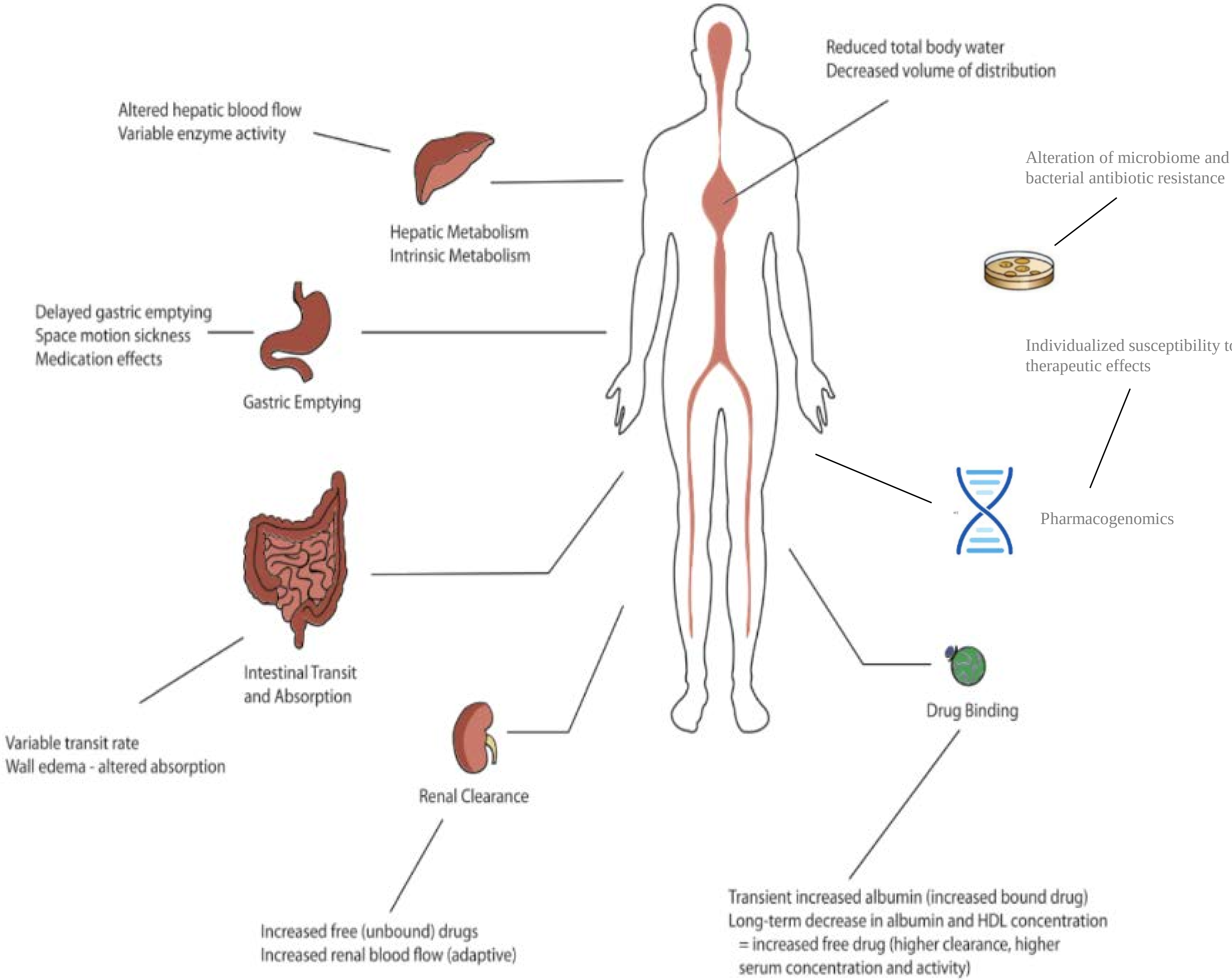
Gateway 2024	Deep Space Transport 2027	Precursor 2029	Mars 2033

26-41 days	190-221 days	1 year	2 years	3 years
100%	100%	100%?	80%?	16%?

Current Operational Models Sufficient For Pharmacy Provision

Current Operational Models Inadequate For Pharmacy Provision


Du et al. 2011
Chuong et al. 2011
Wotring 2016
Unpublished: Cory 2017 Wu 2016
13 Days
354 Days
597 Days
881 Days
Variable Exposure
550 Days
Variable Exposure
Variable Exposure
Ground Control Available
API and Physical Characteristics
Unpublished Results
Unpublished Results
Acyclovir
Amoxicillin/Clavulanate
Atorvastatin
Azithromycin
Cefadroxil
Ciprofloxacin
Clotrimazole
Dextroamphetamine
Epinephrine
Fluconazole
Furosemide
Ibuprofen
Imipenem/Cilastin
Levofloxacin
Levothyroxine
Lidocaine
Metoprolol
Metronidazole
Mupirocin
Nasal Cobolamine
Phenytoin
Progestin/Estrogen
Promethazine
Risedronate
Sertraline
Silver Sulfadiazine
Sulfamethoxazole/ Trimethoprim
Temazepam
Triamcinolone
API (B Vitamin only)
Centrum Silver® Multivitamin*
Women's Once-A-Day® Multivitamin*
API, Degradants, Physical Characteristics
Aspirin
Acetaminophen**
Ibuprofen
Loratadine** †
Loperamide †
Pseudoephedrine
Melatonin
Modafinil †
Zolpidem †
Ibuprofen
Levofloxacin
Phenytoin
Sertraline
Valacyclovir
Ibuprofen
Promethazine
Azithromycin
* Drug tested only for Vit B API
** Drug would fail by today's API standard
† drug had unidentified degradant product
Altered Medication
Unaltered Medication

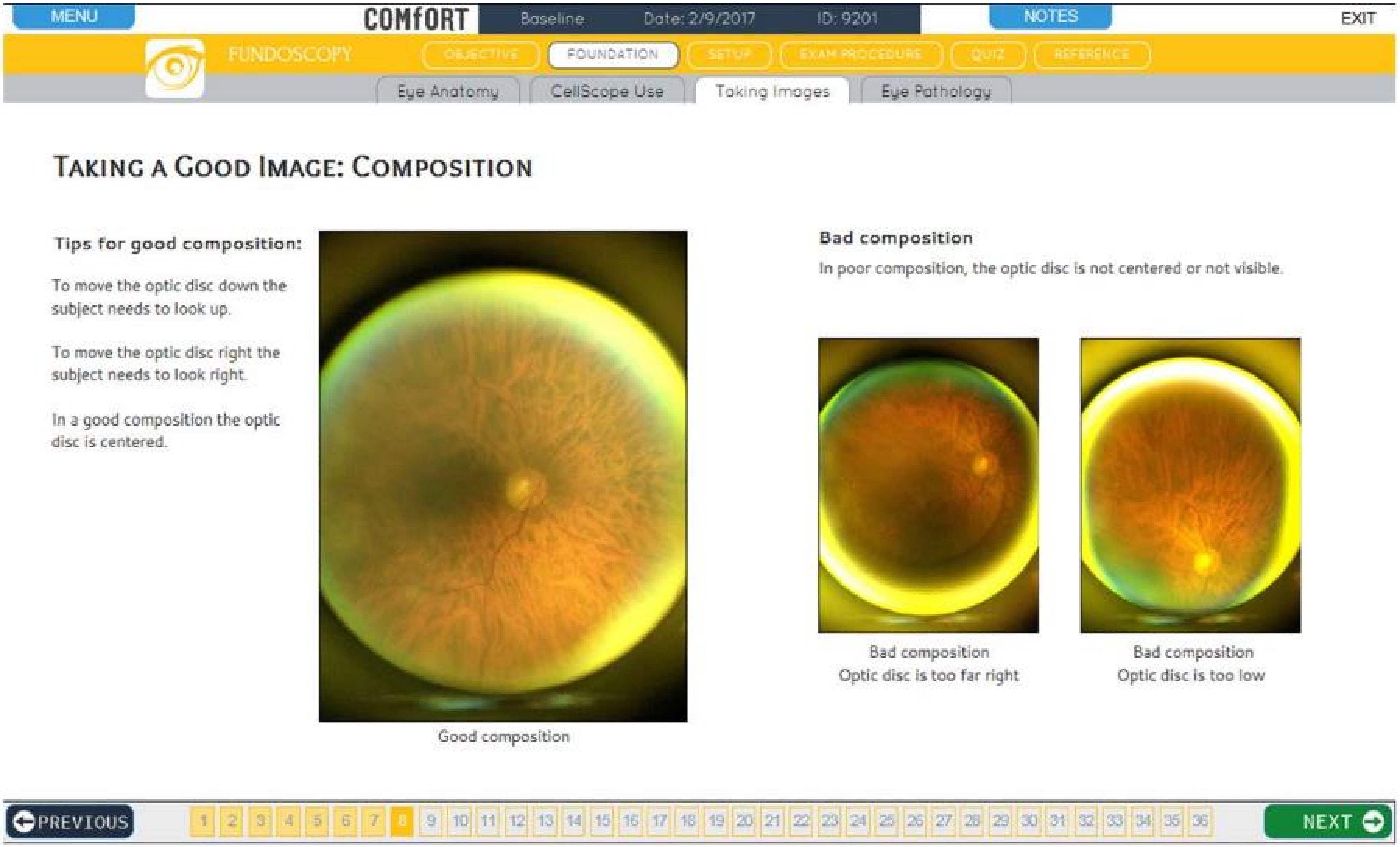

Reduced total body water
Decreased volume of distribution
Altered hepatic blood flow
Variable enzyme activity
Alteration of microbiome and
bacterial antibiotic resistance
Hepatic Metabolism
Intrinsic Metabolism
Delayed gastric emptying
Space motion sickness
Medication effects
Gastric Emptying
Individualized susceptibility to
therapeutic effects
Pharmacogenomics
Intestinal Transit
and Absorption
Drug Binding
Variable transit rate
Wall edema - altered absorption
Renal Clearance
Transient increased albumin (increased bound drug)
Long-term decrease in albumin and HDL concentration
= increased free drug (higher clearance, higher
serum concentration and activity)
Increased free (unbound) drugs
Increased renal blood flow (adaptive)

Increasing Crew Self-Reliance

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.

Provision of Training and Crew Support

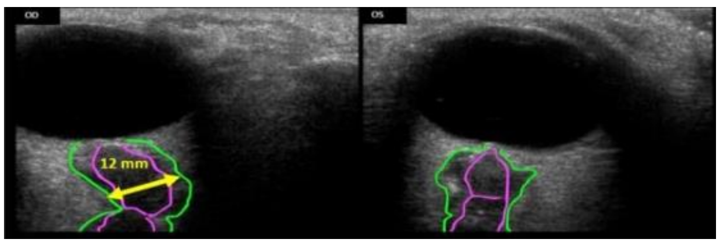


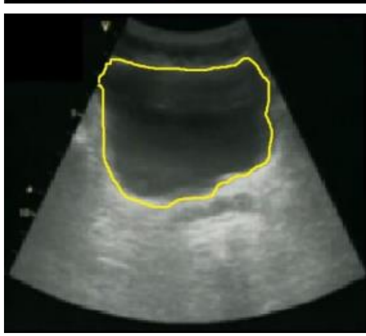
but I think it would help us be more efficient.

Remote -> Autonomy

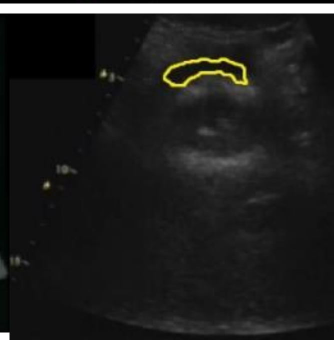
Augmented Reality Training
Tietronix

Sensor Technology



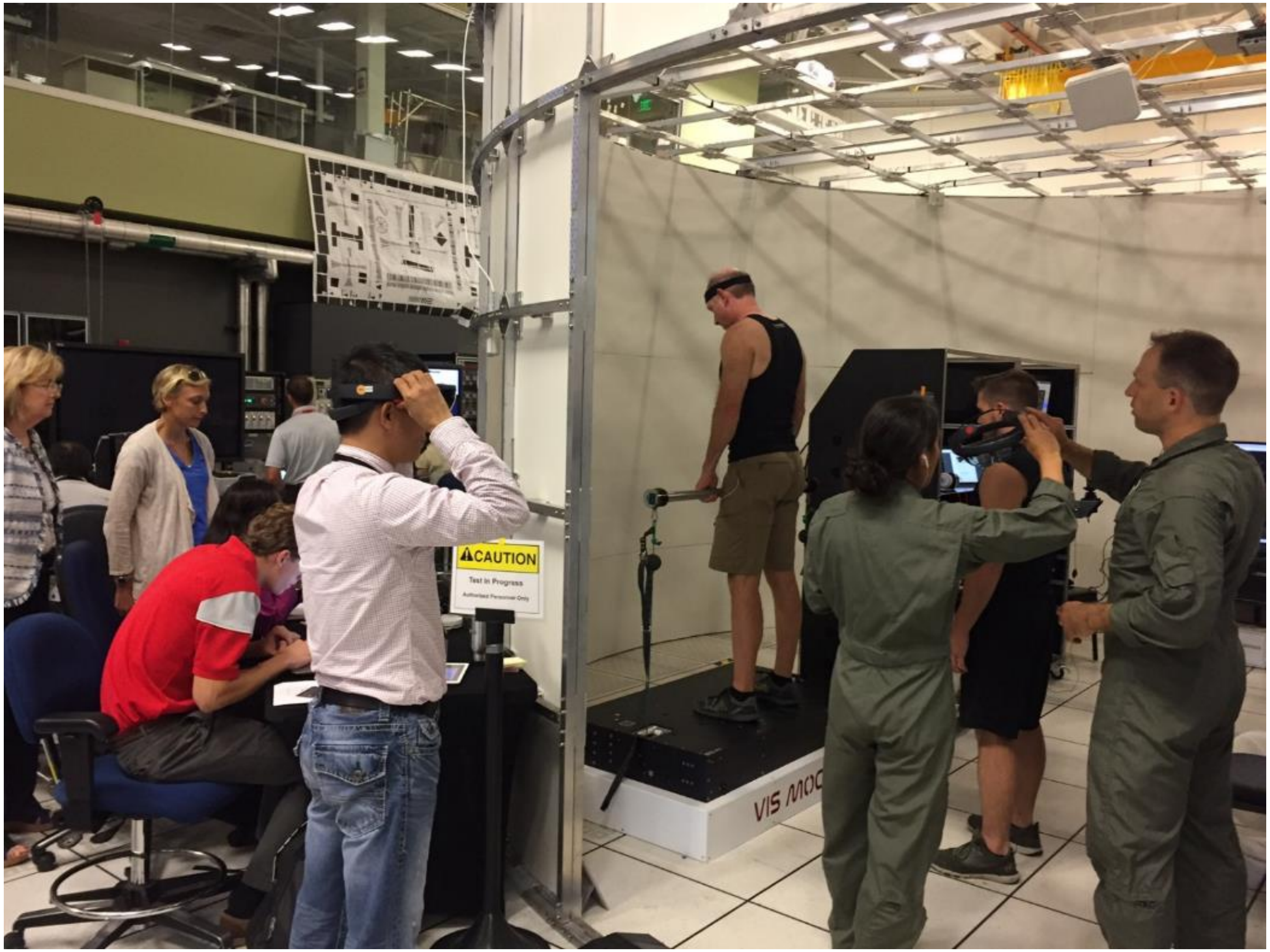


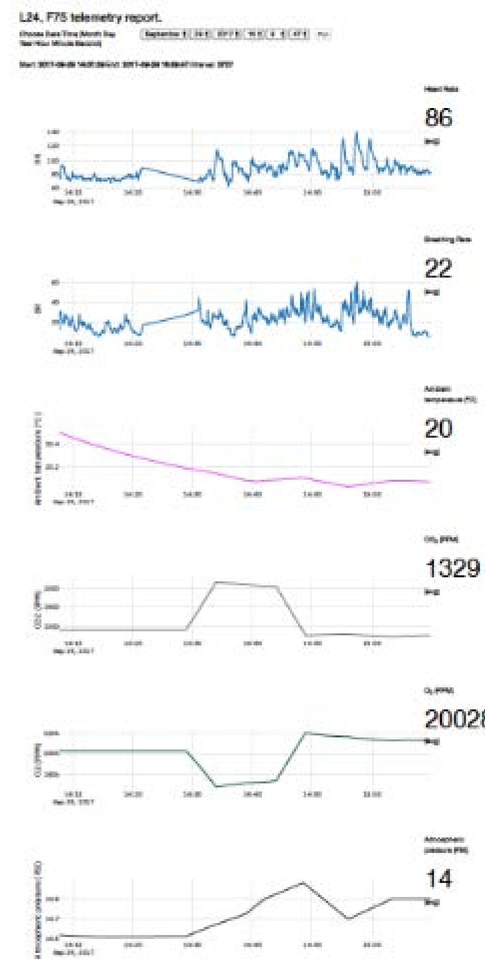
In-flight Post-void Ultrasound



Ground Post-void Ultrasound

Where are we today?





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

Mars Telecommunication - Three Main Challenges

- Three major challenges face all communication with deep space (CLA):
  - **Capacity**: The link data rate or average daily volume
  - **Latency**: Speed of light delay between the planets
  - **Availability**: The percentage of time (over a day/Sol, week, month or year) that an asset has access to a link
- Deep Space Network CLA needs to be considered for the case of crew support needs
- What data rates are acceptable for Store-and-Forward type crew support? Emergency medical support? Behavioral health support?
- What if emergencies occur during planned daily link outages (due to Mars occultation)?

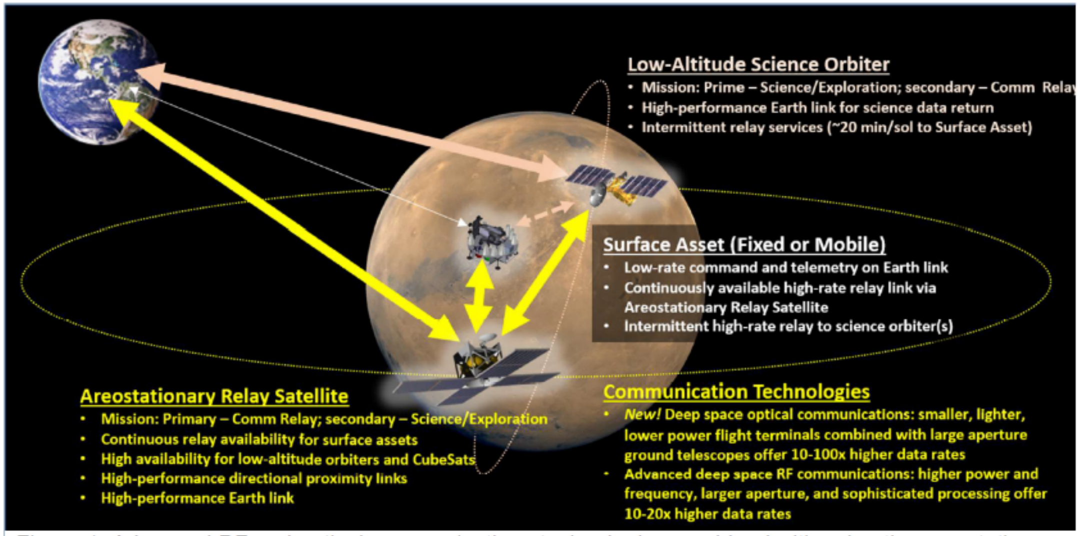


Figure 1. Advanced RF and optical communications technologies combined with using the areostationary orbit offer 100-1000x greater data return from Mars and nearly continuous availability.

	Frequency Band	Maturity	S/C Aperture	S/C Tx Power	Ground Rx / Tx	Data Rate @2AU (Megabits/sec)
LEO: ISS	Ku-band	TRL 10 / Operational	2 m	>2 W	TDRSS Relay	Return: 90-110 (1/19: 517)*
				N/A		Forward: 25 (1/19: 50)*
MARS Current State-of-the-art (MRO SDST)	X band	TRL 10 / Operational	3 m	100 W	1x34 m DSN Station	Return: 1-2
		TRL 10 / Operational		N/A	1x34 m DSN Station	Forward: 0.5
	Ka-band	TRL 10 / Operational		35 W	1x34 m DSN Station	Return: 6
		TRL 4	None	N/A	N/A	Forward: 0
Next Generation Mars Trunks (Future human missions)	Ka-band / DSRC	TRL 3-4	5 m	1kW	1x34 m DSN Station	Return: EST 250
					1x34 m DSN Station	Forward: EST 125
	Optical / Lasercomm / DSOC	TRL 6	22 cm	4 W	5 m ground telescope	Return: >5.2
				N/A		Forward: >0.1
		TRL 3	50 cm	40 W	12+ m ground telescope	Return: >600
				N/A		Forward: >25

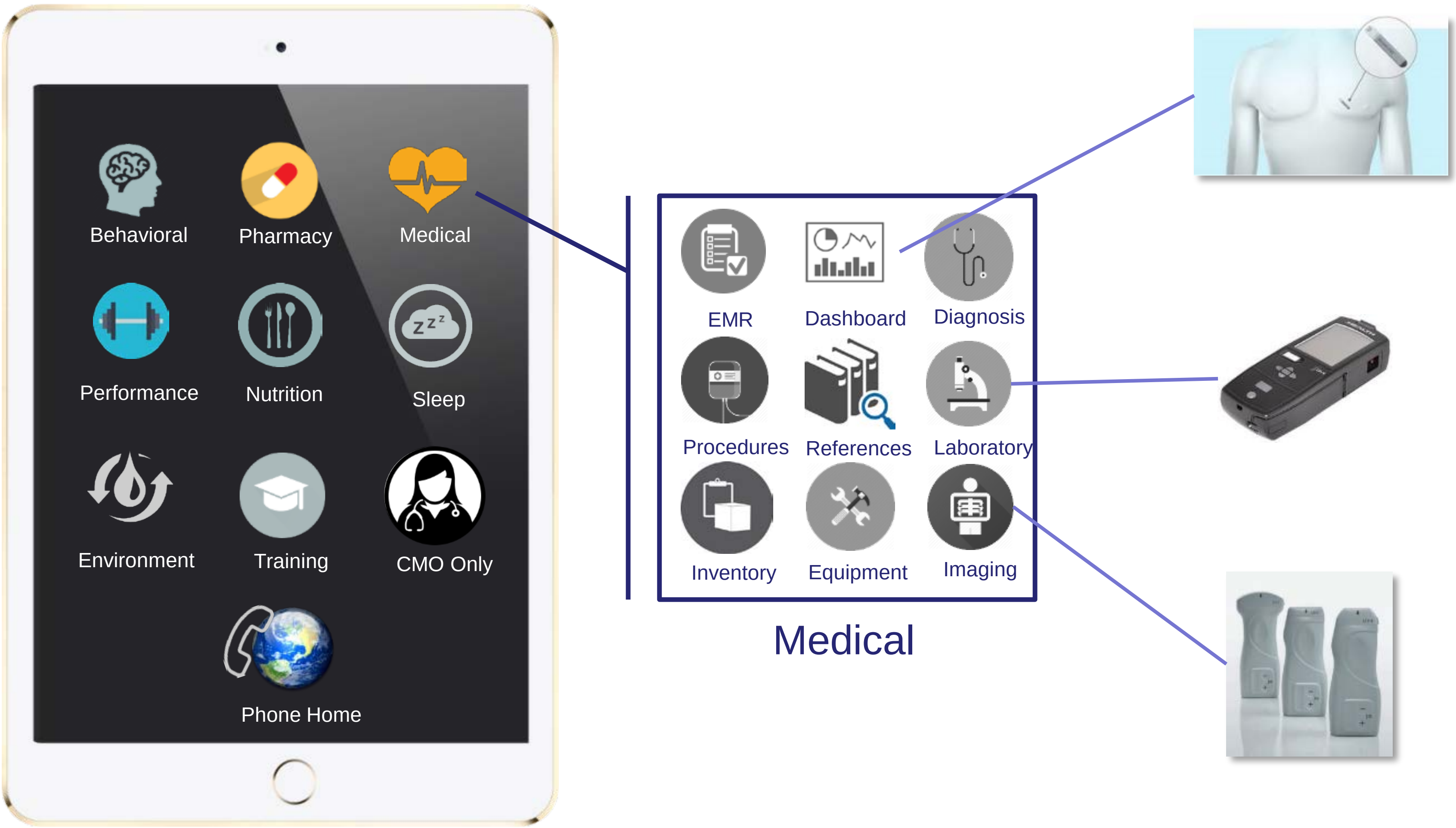
* - Expected performance after Jan 2019 upgrade

Source: SCaN Team (M.Seibert, J.Schier, D.Abraham, D.Cornwell, G.Fujikawa)

We’re not bringing an Intensive Care Unit

Crew Health and Performance System

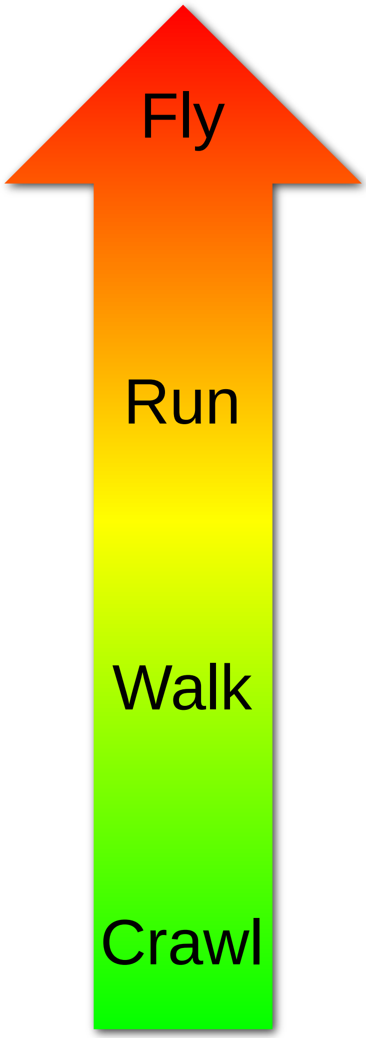
These technologies exist today



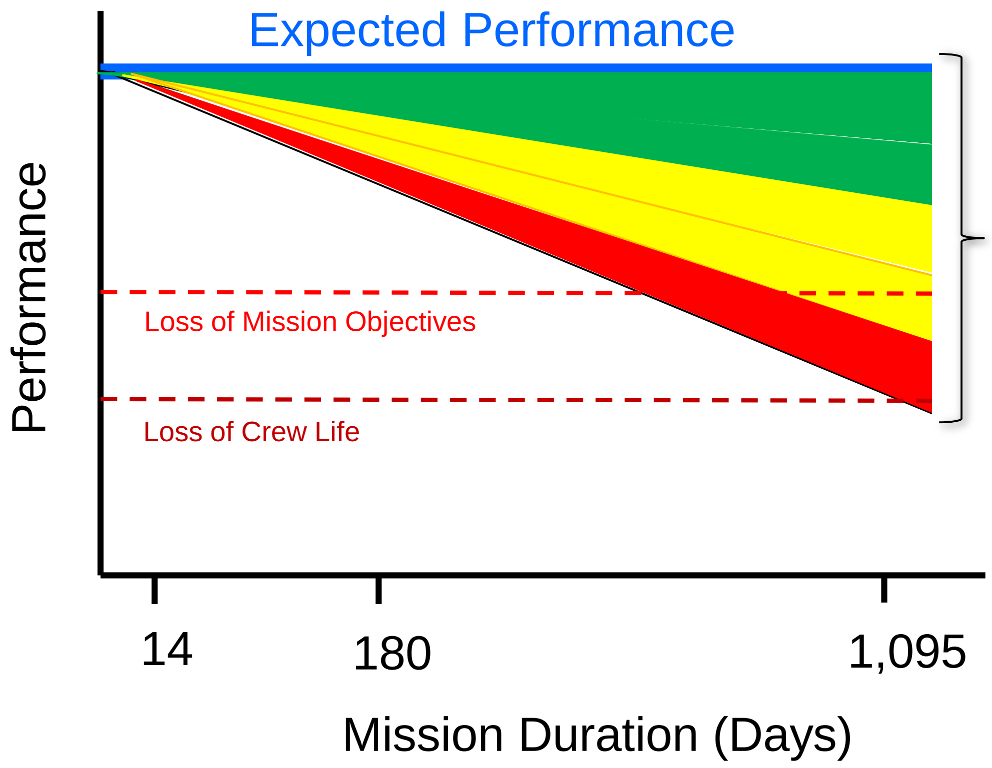
Notional

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**



Risks to Health & Human Performance won't occur in isolation

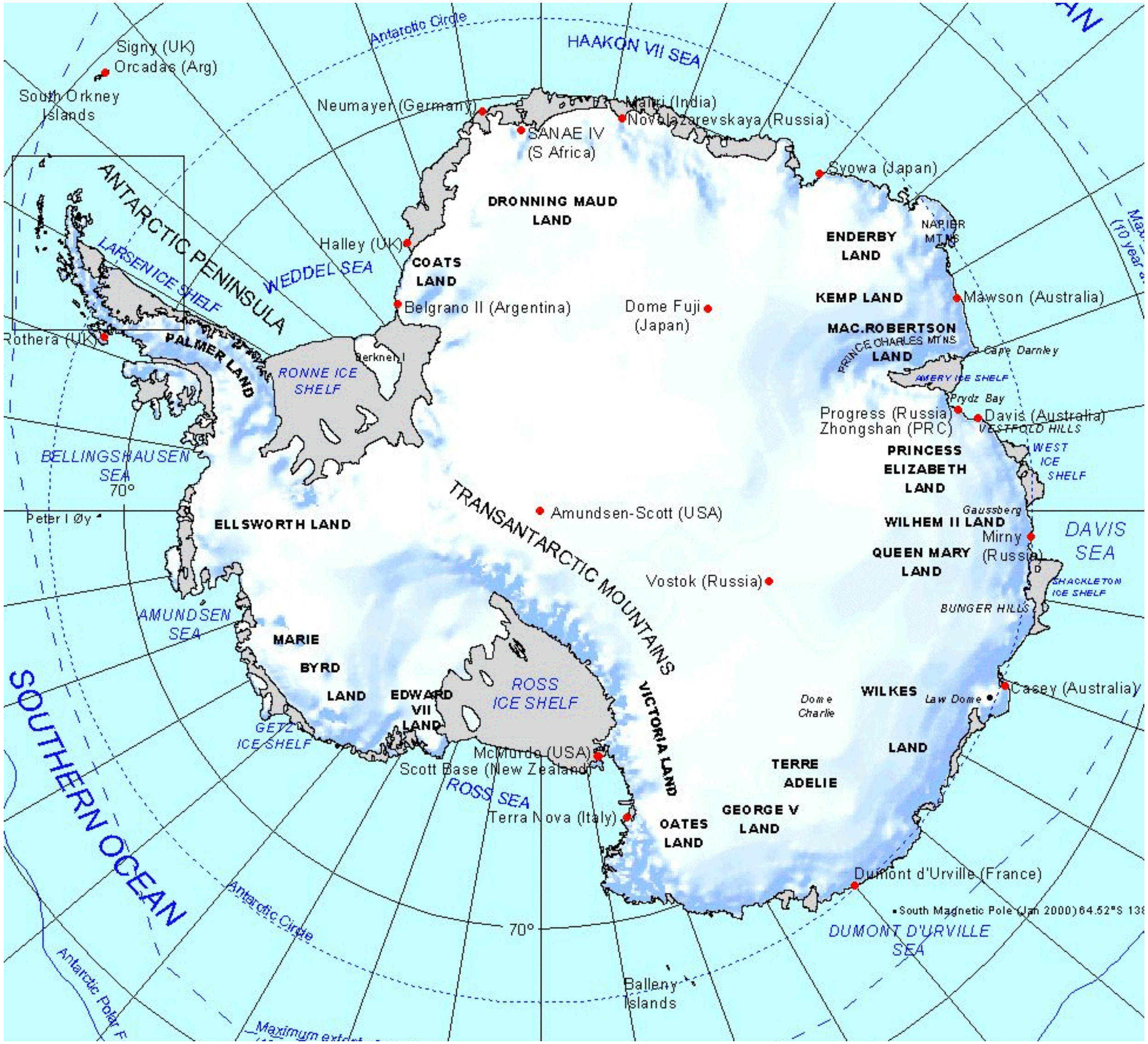


Example Factors Affecting Performance

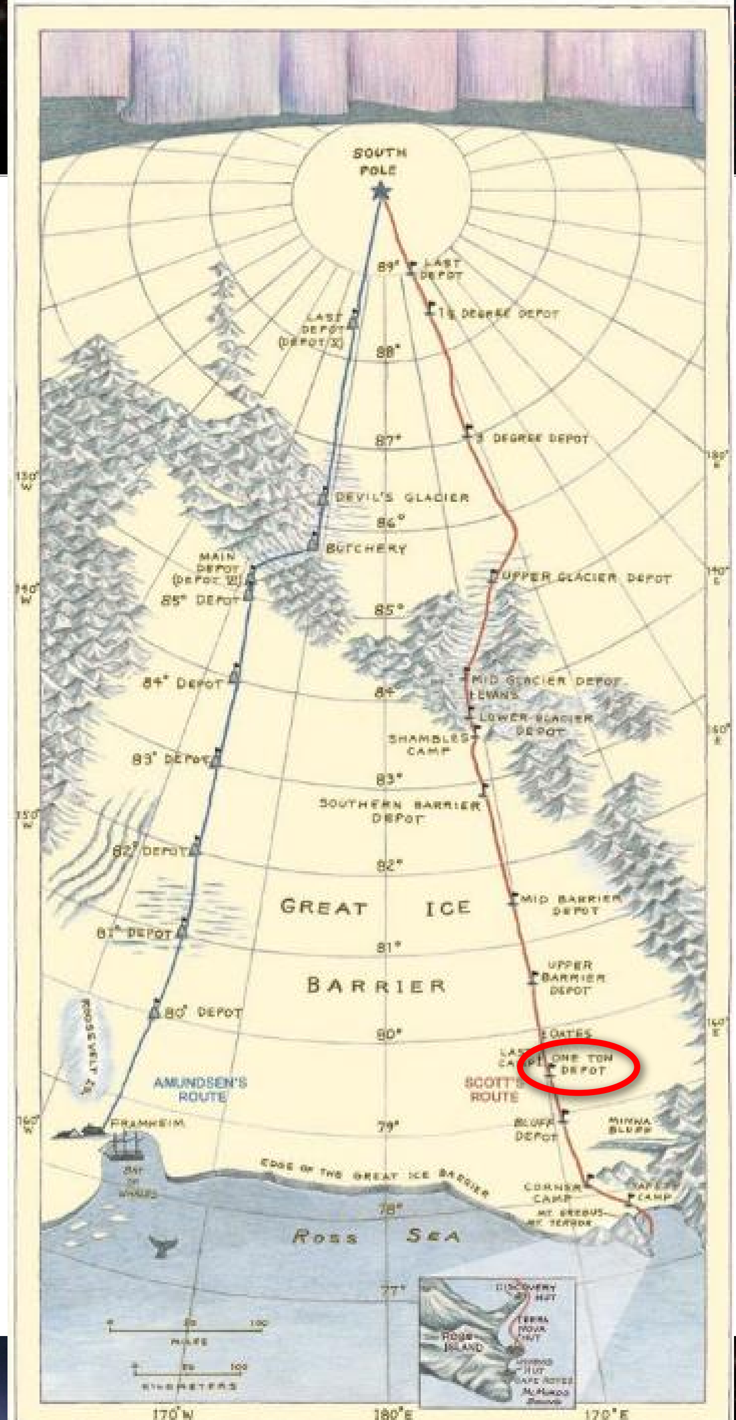
- Physical Deconditioning
- Chronic Radiation Effects
- Depression/Team Dynamics
- Loss of Real Time support
- Insufficient Medical Capability

Where are the red lines and when will we hit them?

Observation Hill


Antarctic Circle
HAAKON VII SEA
Signy (UK)
Orcadas (Arg)
South Orkney Islands
Neumayer (Germany)
Maitri (India)
Novolazarevskaya (Russia)
SANAE IV (S Africa)
Syowa (Japan)
DRONNING MAUD LAND
ANTARCTIC PENINSULA
LARSEN ICE SHELF
WEDDEL SEA
Halley (UK)
COATS LAND
ENDERBY LAND
NAPIER MTNS
KEMP LAND
Mawson (Australia)
Belgrano II (Argentina)
Dome Fuji (Japan)
MAC.ROBERTSON LAND
PRINCE CHARLES MTNS
Cape Darnley
AMERY ICE SHELF
Rothera (UK)
PALMER LAND
Berkner I
RONNE ICE SHELF
Prydz Bay
Progress (Russia)
Zhongshan (PRC)
Davis (Australia)
VESTFOLD HILLS
PRINCESS ELIZABETH LAND
WEST ICE SHELF
BELLINGSHAUSEN SEA
70°
TRANSANTARCTIC MOUNTAINS
Amundsen-Scott (USA)
Gaussberg
Peter I Øy
ELLSWORTH LAND
WILHEM II LAND
Mirny (Russia)
DAVIS SEA
QUEEN MARY LAND
Vostok (Russia)
SHACKLETON ICE SHELF
BUNGER HILLS
AMUNDSEN SEA
MARIE BYRD LAND
ROSS ICE SHELF
VICTORIA LAND
EDWARD VII LAND
WILKES LAND
Dome Charlie
Law Dome
Casey (Australia)
SOUTHERN OCEAN
GETZ ICE SHELF
McMurdo (USA)
Scott Base (New Zealand)
ROSS SEA
TERRE ADELIE
Terra Nova (Italy)
OATES LAND
GEORGE V LAND
Dumont d'Urville (France)
South Magnetic Pole (Jan 2000) 64.52°S 138
Antarctic Circle
70°
DUMONT D'URVILLE SEA
Balleny Islands
Antarctic Polar F
Maximum extent

1911 - 1912


SOUTH POLE
LAST DEPOT
1½ DEGREE DEPOT
LAST DEPOT (DEPOT X)
88°
87°
3 DEGREE DEPOT
DEVIL'S GLACIER
86°
BUTCHERY
MAIN DEPOT (DEPOT IX)
85° DEPOT
UPPER GLACIER DEPOT
85°
84° DEPOT
MID GLACIER DEPOT
84°
EVANS
LOWER GLACIER DEPOT
SHAMBLES CAMP
83° DEPOT
83°
SOUTHERN BARRIER DEPOT
82° DEPOT
82°
GREAT ICE BARRIER
MID BARRIER DEPOT
81° DEPOT
81°
UPPER BARRIER DEPOT
80° DEPOT
80°
OATES
ONE TON DEPOT
AMUNDSEN'S ROUTE
SCOTT'S ROUTE
ROOSEVELT IS.
FRAMHEIM
79°
BLUFF DEPOT
MINNA BLUFF
EDGE OF THE GREAT ICE BARRIER
CORNER CAMP
SAFETY CAMP
78°
MT. EREBUS
MT. TERROR
ROSS SEA
77°
DISCOVERY HUT
TERRA NOVA HUT
ROSS ISLAND
MILES
KILOMETERS
170° W
180° E
170° E

Amundsen and Scott Pole Race

Differences between Scott and Amundsen expeditions

Scott

- Overtechnologization (16 men, 23 dogs, 10 ponies, 13 sledges, 2 motor sledges)
- Followed what was tried before “because it worked”
- Thin margin of error
- Last minute decisions
- Died 12 miles short of his last food depot

Amundsen

- Focused preparation (5 men, 20 dogs)
- Made a new path
- Significant margin of error
- Lots and lots of preparation and field testing
- Got to Pole first and lived




There are evidence-based ways to systematically identify and match what is needed from a health perspective with what gets fielded in a mission