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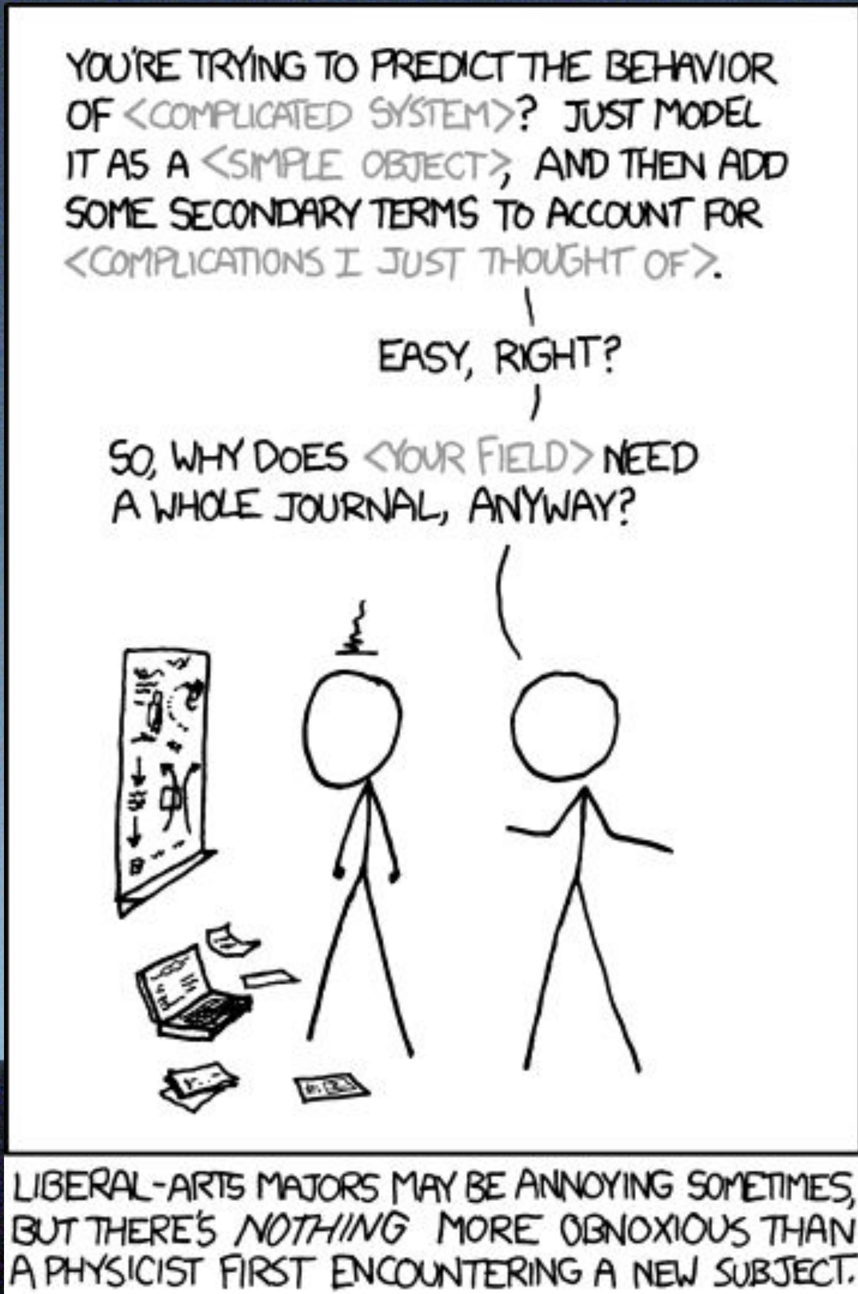
Human Factors and Challenges of a Venus Flyby en route to or from Mars

Mark Shelhamer, Sc.D.
Johns Hopkins University School of Medicine
Chief Scientist, NASA Human Research Program (2013-2016)

Venus Science Enabled by Human Proximity Symposium
Keck Institute for Space Studies
21 July 2022



Imagine how hard physics would be if electrons could think.

– Murray Gell-Mann

“It’s just one damn thing after another.”

Humans to Mars

Why Do I Care About Mars?

- Focuses the mind, acute issues
- Not designing a spacecraft, but the crew's world
- There will be things we can't predict (otherwise why go)
- Laboratory for dealing with complexity

- It includes everything, yet we can't think of everything.

Things go wrong with people in space, and the longer they’re there the worse things get.

SMS

- Mercury, Gemini: confined, little movement, few problems reported
- Apollo: more spacious, SMS more prevalent (11 of 33 astronauts)
- Shuttle (first 36 missions):
    - 38% moderate or severe SMS on first flight
    - 16% moderate or severe SMS on subsequent flights
    - Onset usually within first hour
    - Resolves within 3-6 days
- Terrestrial motion sickness not a predictor (even parabolic flight)
- Head movements, disorienting visual cues are contributors

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Central Neurovestibular Role

- Altered mood in patients with vestibular disorders
  - Bigelow et al. (2015) *J Neurol Neurosurg Psych*, jnnp-2015.
- Contributions to spatial orientation, memory, motor reflexes
  - Palla & Lenggenhager (2014) *Front Integr Neurosci* 8: 40.
  - Smith & Zheng (2013) *Front Integr Neurosci* 7: 84.
- Vestibular cognition
  - Smith PF (2017) *Current Opinion in Neurology* 30:84-9.
  - Poor visuospatial ability, spatial memory deficits, hippocampal atrophy. increased cortisol levels, risk factor for dementia.
- Body self-perception
  - Lopez (2013) *Front Integr Neurosci* 7: 91.
- Altered sense of self-and-other can impact relationships
    - Deroualle & Lopez (2014) *Front Integr Neurosci* 8: 16.
- Vestibulo-autonomic interactions, orthostatic intolerance
  - Yates et al. (2014) *Compr Physiol* 4: 851-887.
- Vestibular lesions in rats produce loss in the weight-bearing bones
  - Vignaux et al. (2013) *J Bone Mineral Res* 28: 2136-2144.
- Mental number-pair bisection task
  - Arshad et al. (2016) *Eur J Neurosci* 44:2369-74.

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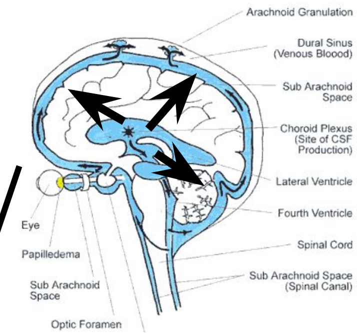
SANS

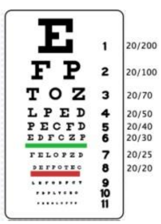
Spaceflight-Associated Neuro-Ocular Syndrome

1. Headward fluid shift

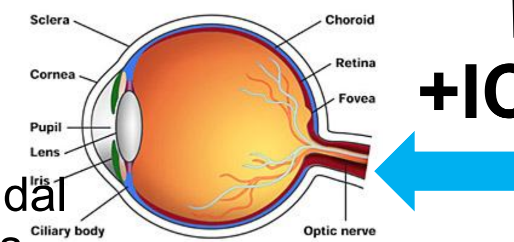
2. Increased ICP



3. Elevated ICP transmitted to eye and optic nerve

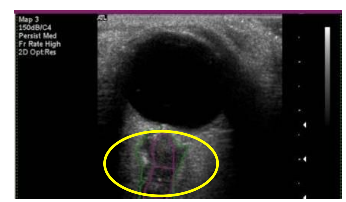


Hyperopic Shifts



+ICP

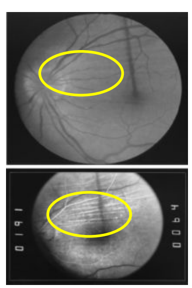
Increased Optic Nerve Sheath Diameter



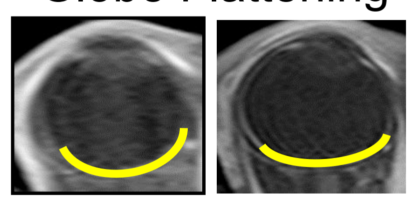
Altered Blood Flow

Scotoma

Choroidal Folds



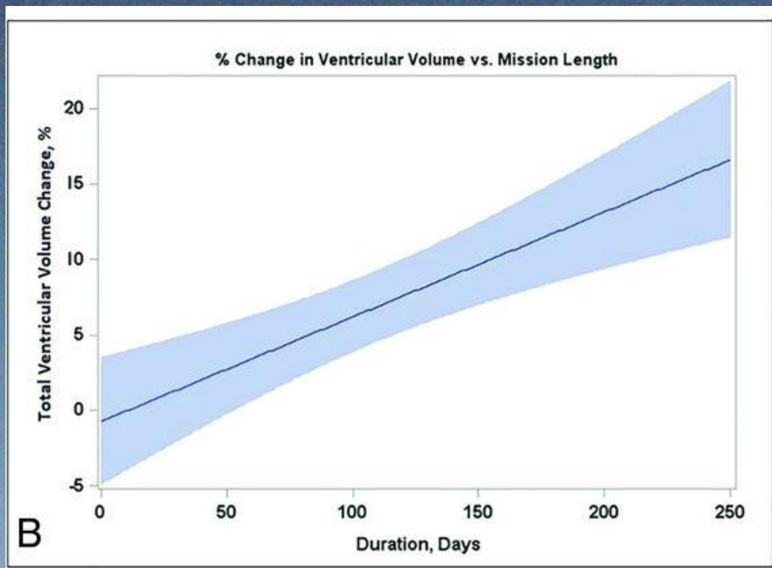
Globe Flattening



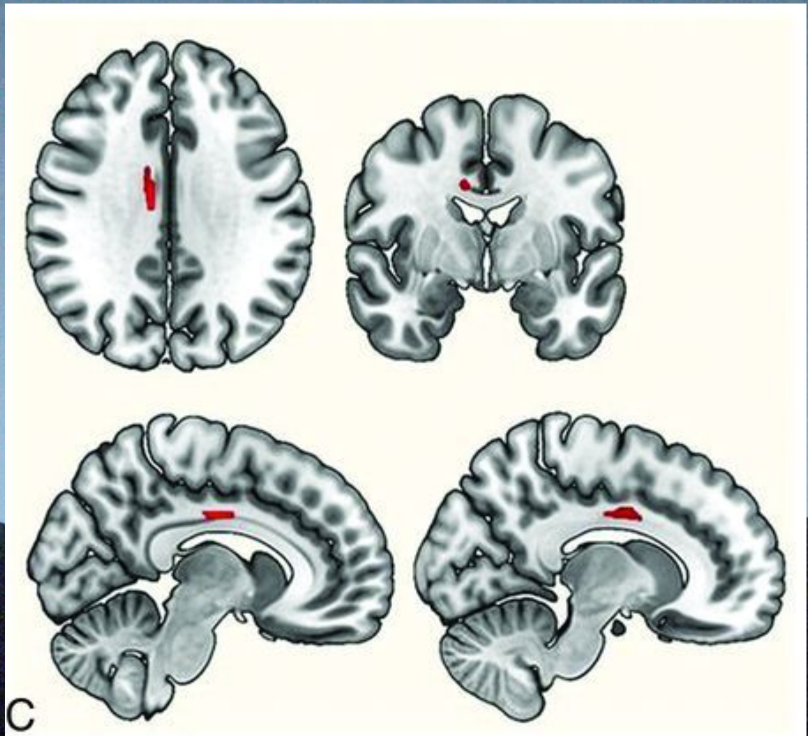
Optic Disc Edema

Courtesy Dr. Christian Otto

Roberts et al. (2019) Prolonged Microgravity Affects Human Brain Structure and Function
American Journal of Neuroradiology 40:1878-1885



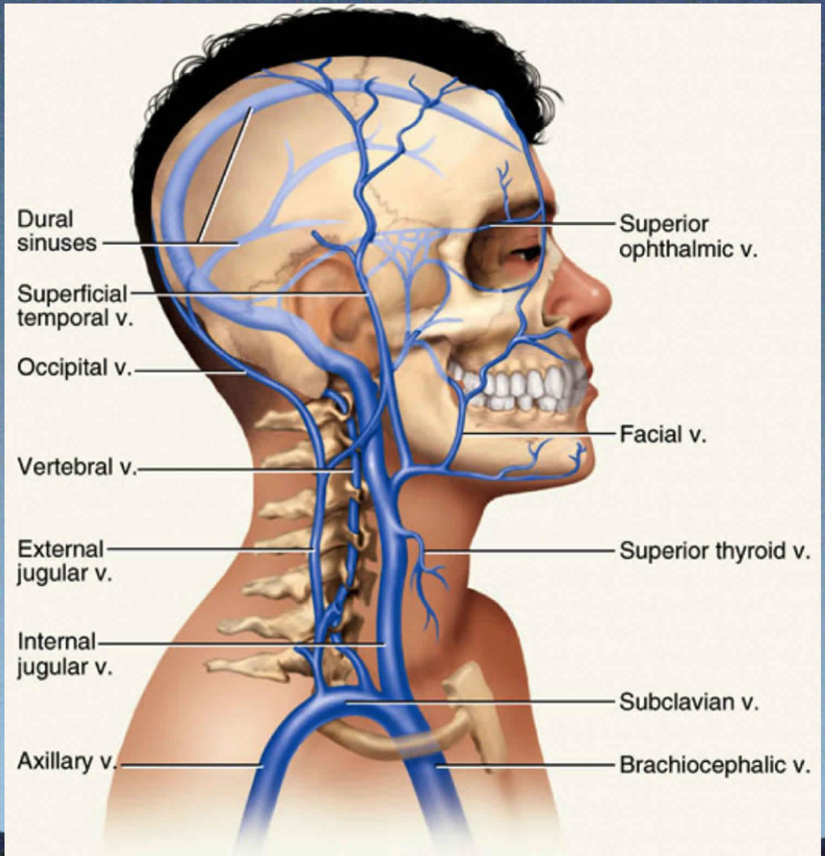
Post-flight ventricular enlargement.
Not correlated with SANS.



Regional deformation of brain parenchyma that significantly predicted performance on the Seated Egress and Walk Test (*P* < .05): local structural change of the right lower extremity primary motor area/midcingulate.

Deep Vein Thrombosis

- Found on ultrasound during research study
- Treat aggressively or sparingly?
- Risks of clot blocking a vessel
- Unknown risks of anticoagulation therapy in space
- ISS: 20 vials of injectable enoxaparin, no anticoagulation-reversal drugs
- Limited syringes, complications of dealing with fluids



Veins of the head and neck

https://healthjade.net/jugular-vein/

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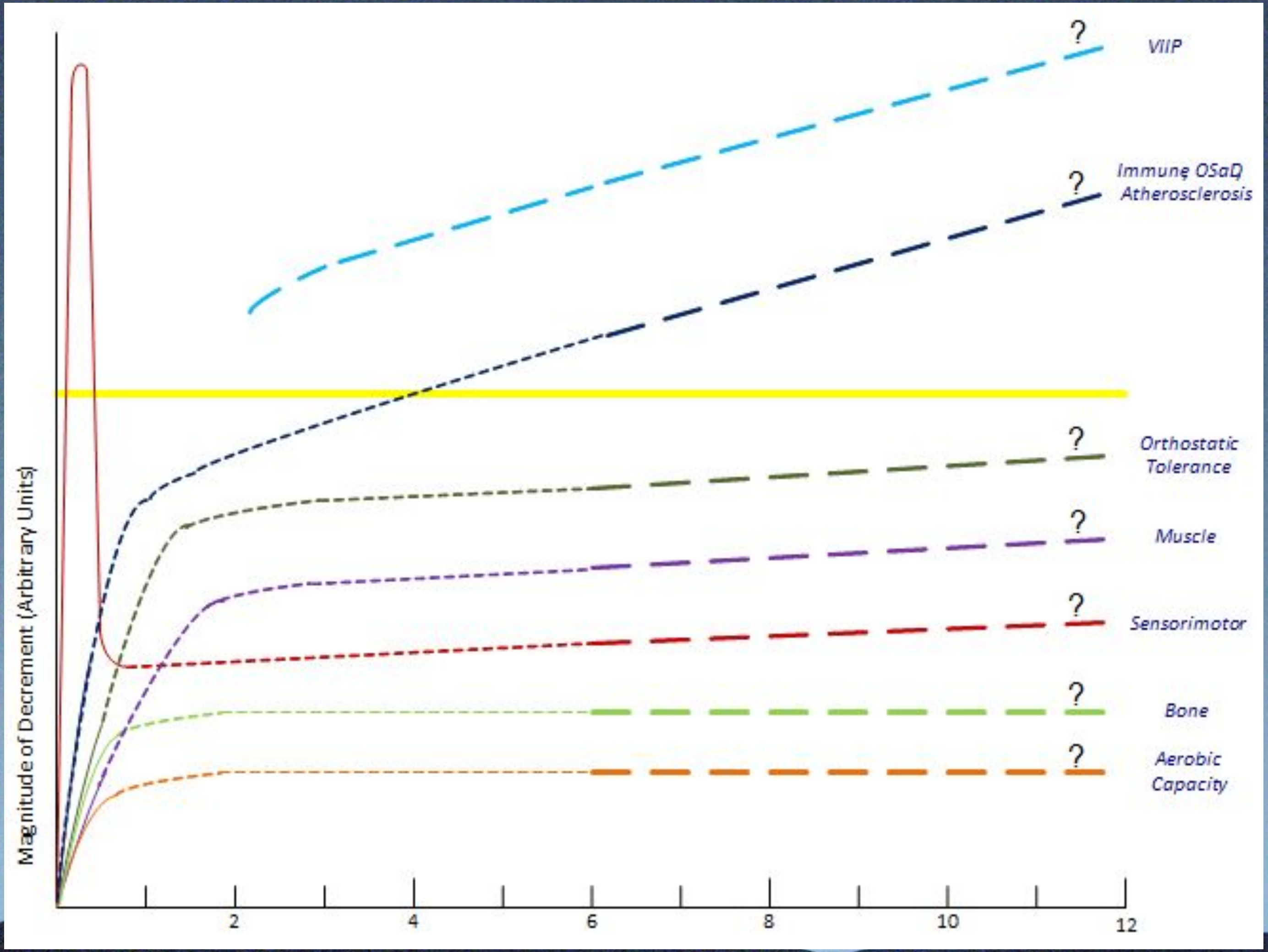

Courtesy J Mindock, NASA Human Research Program

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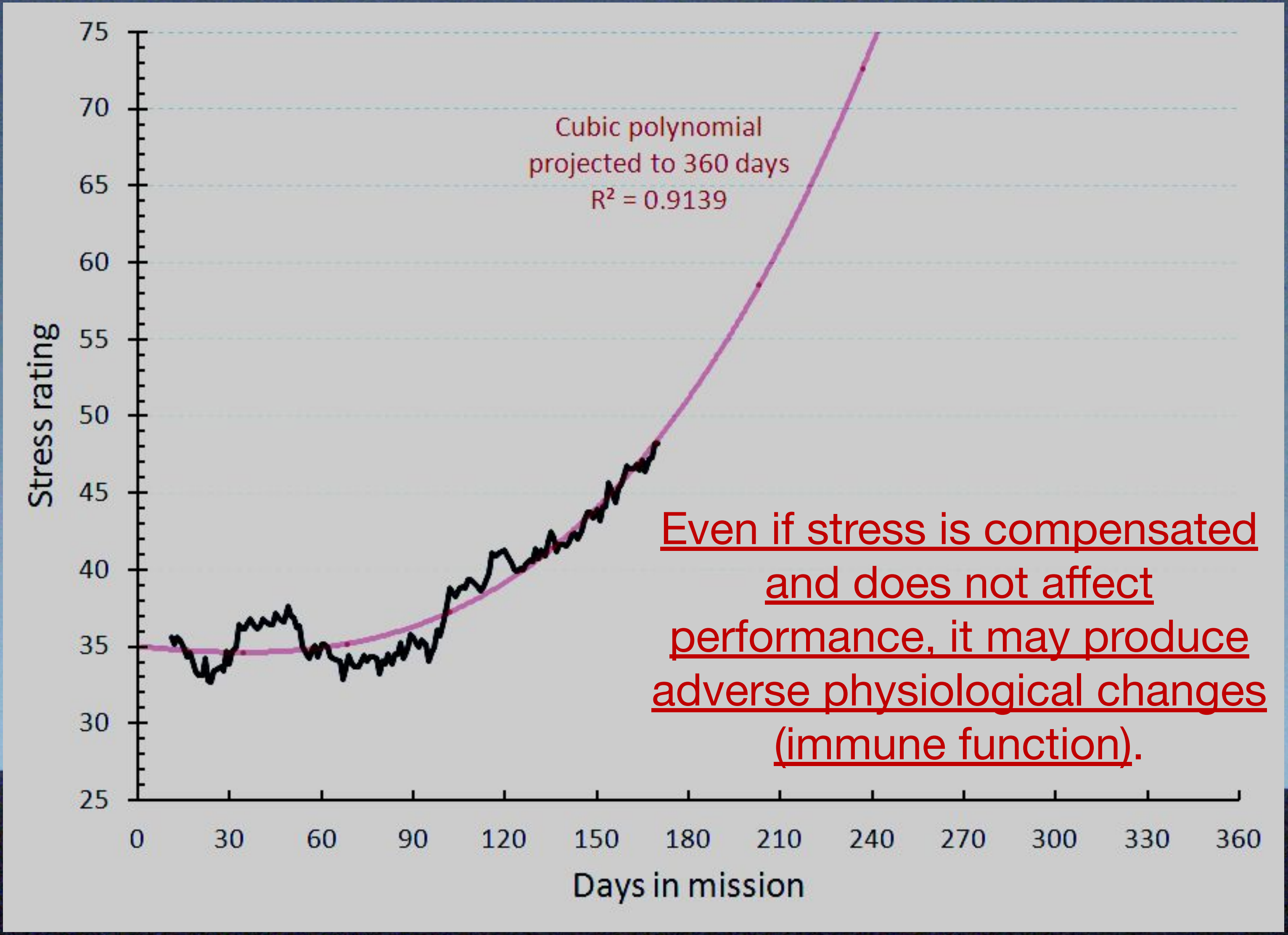
VAS Stress Rating



Even if stress is compensated and does not affect performance, it may produce adverse physiological changes (immune function).

Courtesy David Dinges, Univ of PA.

"All the necessary conditions to perpetrate a murder are met by locking two men in a cabin of 18 by 20 feet . . . for two months."

- Valery Ryumin, 1980

Soviet Soyuz 21 mission (1976): Entire crew evacuated due to complaints of an odor in the cabin. Cause was never found, may have been imagined.

Payload Specialist on STS-51B/Spacelab-3 (1985). Severe depression due to failed experiment leads to some subsequent commanders putting a lock on the egress hatch.

"Funny thing happened on the way to the moon: not much – should have brought some crossword puzzles."

- Gene Cernan, *The Last Man on the Moon*

Meaningful Work for Long Duration Exploration Missions (RR) (Completed)

Last Published: 04/20/22 11:43:24 AM (Central)

Task Book: Entry Unavailable
Principal Investigator: Britt, Thomas

Short Title: Meaningful Work (RR)

Responsible HRP Element: Behavioral Health and Performance

Collaborating Org(s):

Funding Status: Completed - Task completed and produced a deliverable
Procurement Mechanism(s): Solicited

Aims:
This task is a research requirements task consisting of a literature review and operational assessment to identify the aspects of meaningful work that are most relevant cognitive and behavioral health for long duration missions. This task will inform further research into the feasibility and effectiveness of using meaningful work to promote cognitive and behavioral health for long duration missions

Meaningful Work

- Planetary:
  - Geology
  - Observations
  - Remote teleoperation of surface rovers
- Human Health and Performance
  - Detailed monitoring
  - Testing of personalized countermeasures
  - Development of systems models

Just a Few of the Issues

- Food & Nutrition – for 3 years
- Pharmaceuticals – for 3 years
- Bone mineral loss – fracture risk
- Renal stones – Ca metabolism
- Human-System Interaction
- Immune function
  - Change in T-cell function and cytokine profile
  - Latent herpesvirus reactivation
- Microbiome alterations
- Sleep
- Radiation

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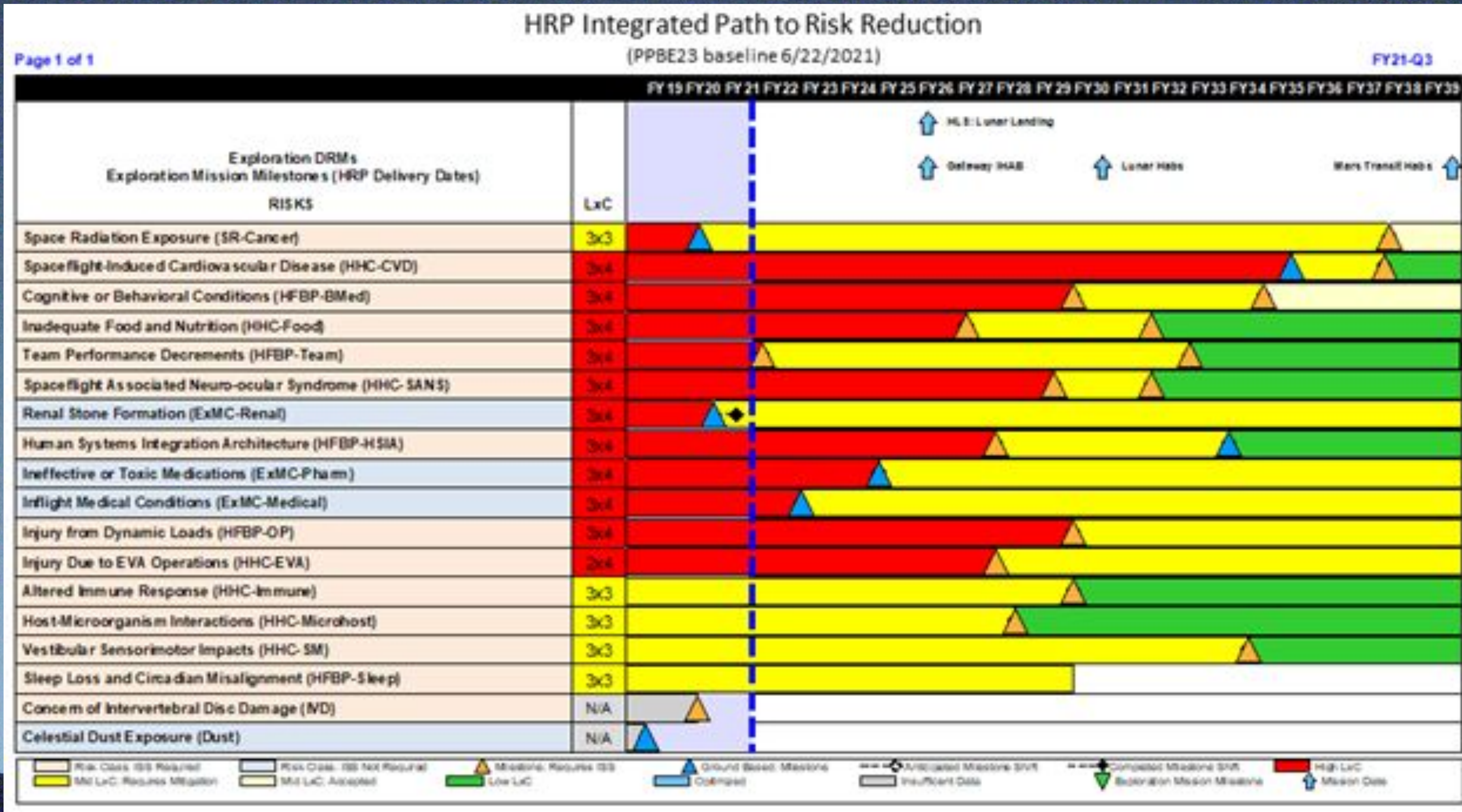


Premise

- Discipline-specific silos are not sufficient.
  - We need to understand interactions.
  - Includes physiology, psychology, engineering, operations.
  - But we can never understand it all in detail.

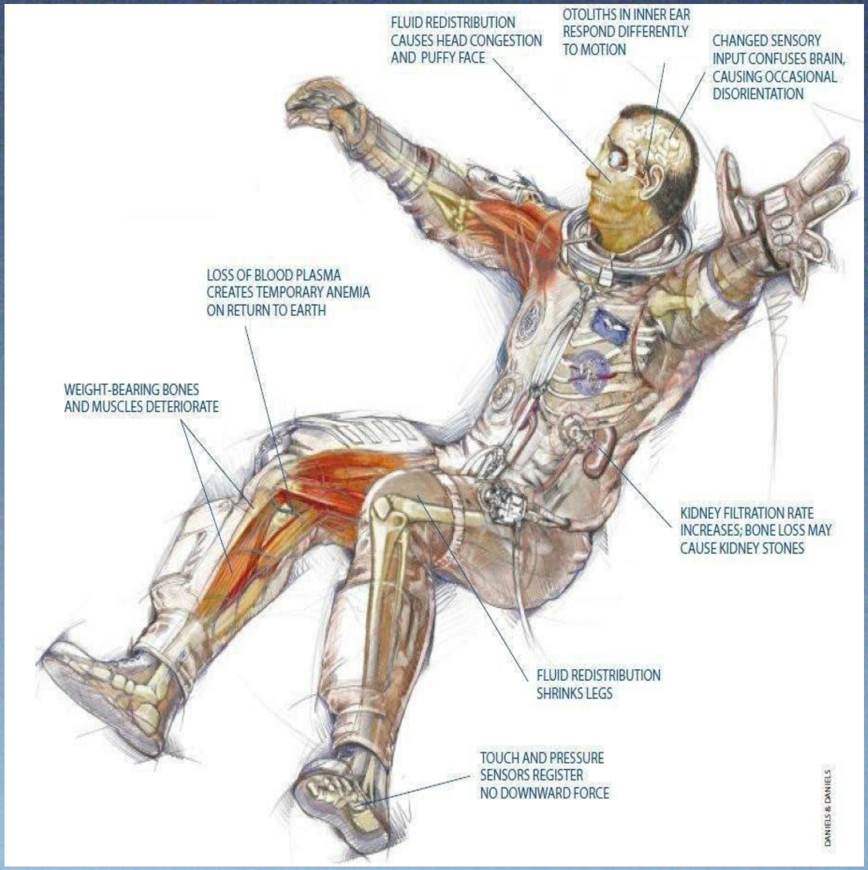
- Do not have the luxury of terrestrial resources, including time.
- Do not need to "understand" all aspects in classic scientific sense.
  - It just needs to work.
  - Understand enough to not inhibit resilience.
  - Let the crew/system work it out.

 Provide the *tools* for resilience

Need an Integrated Approach

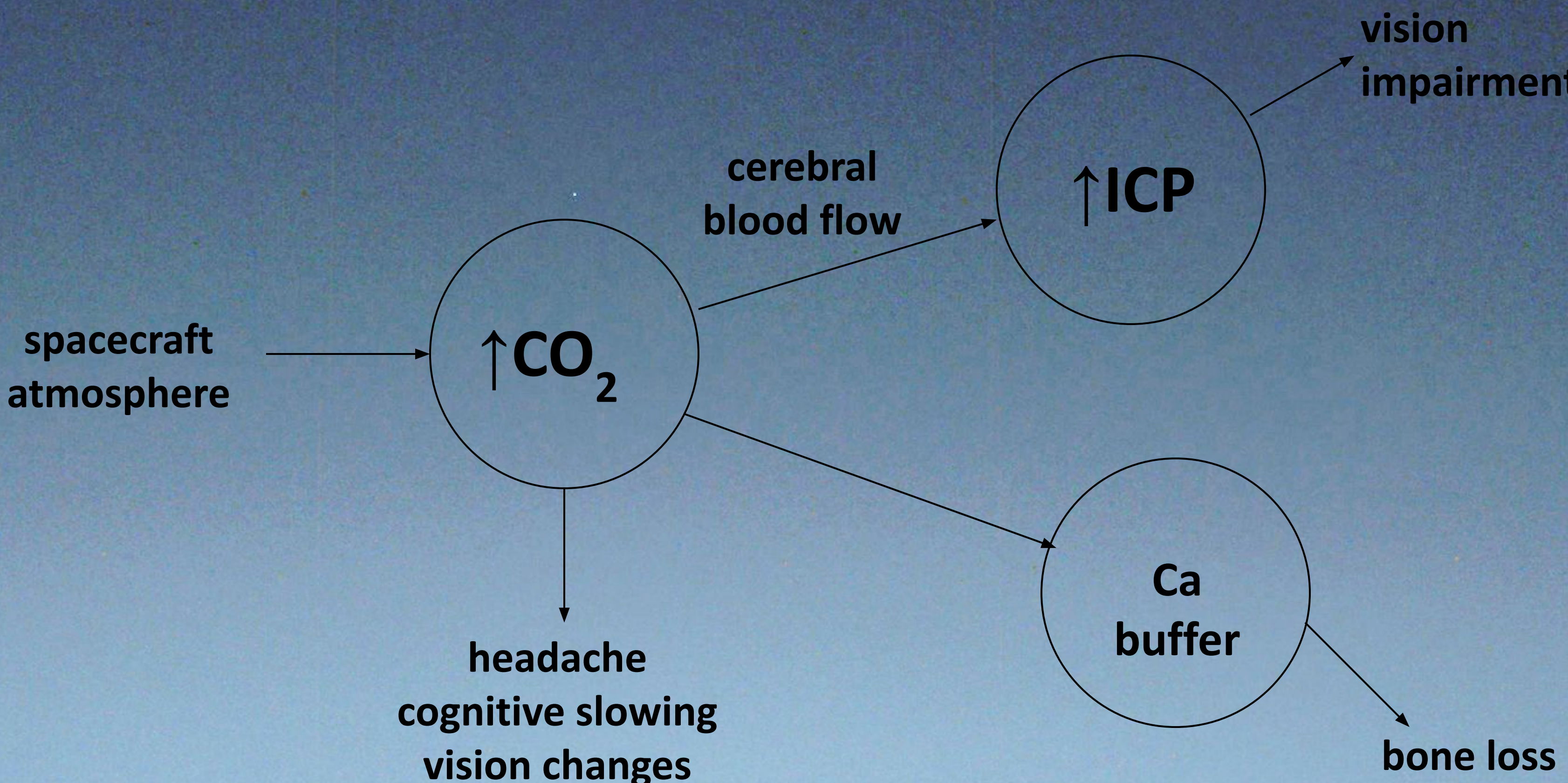
Meeting the health-related challenges of human space exploration requires that one abandon any model of the human body that has the muscles, bones, heart and brain acting independently. Body parts will not travel on exploration missions. Instead, the individual space traveler's body must be viewed realistically, with <u>all parts connected and fully interacting</u>.

White & Averner (2001) Humans in space. *Nature* 409:1115-1118.



Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. – WHO Constitution

CO_2


spacecraft atmosphere
↑CO_2
cerebral blood flow
↑ICP
vision impairment
Ca buffer
bone loss
headache
cognitive slowing
vision changes

Network Approach to Resilience

- Explicit recognition of interconnectedness
  - Lacking in biomedical research
  - Need to span domains
  - Need to capture feedback loops
- Can draw on results from network theory and complexity
- Networks have **emergent properties**
  - Hopelessness of understanding details
  - Common features regardless of details

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LETTER

doi:10.1038/nature16948

Universal resilience patterns in complex networks

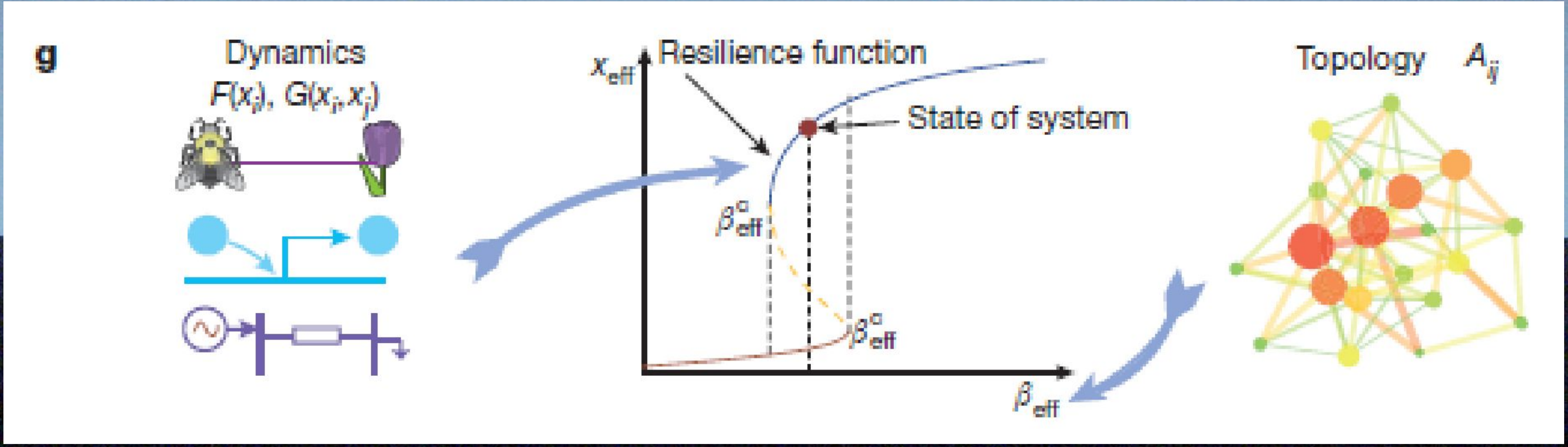
Jianxi Gao[1]*, Baruch Barzel[2]* & Albert-László Barabási[1,3,4,5]

Consider a system consisting of N components (nodes) whose activities $\mathbf{x} = (x_1, \ldots, x_N)^\top$ follow the coupled nonlinear equations[12,13]

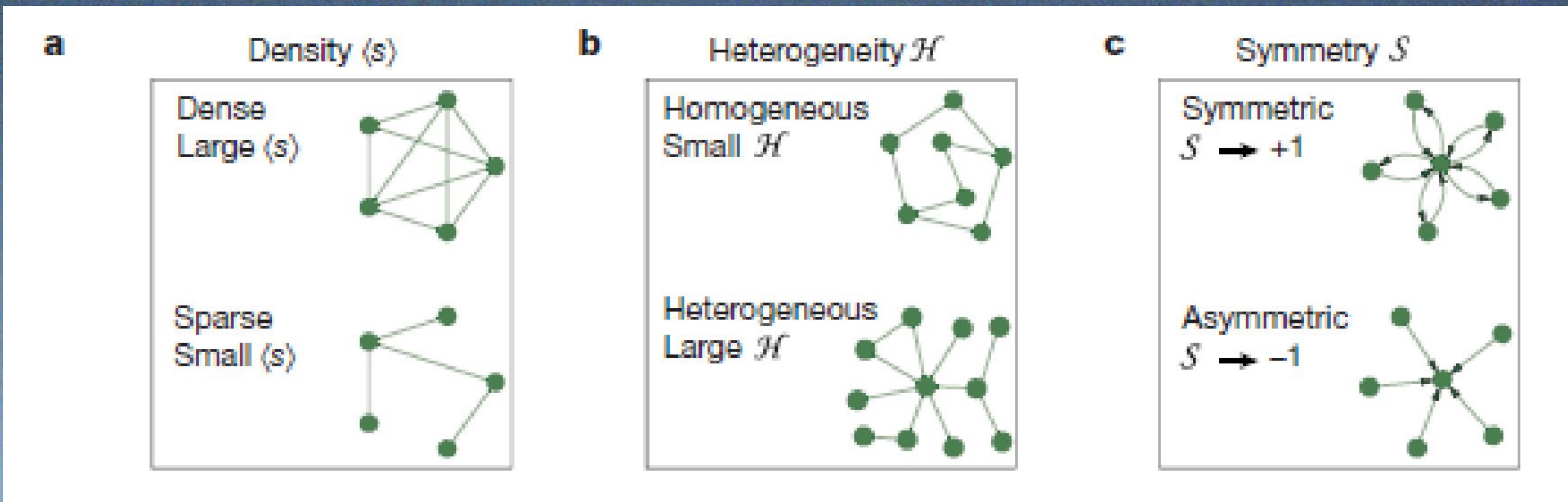
$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = F(x_i) + \sum_{j=1}^{N} A_{ij} G(x_i, x_j) \tag{4}$$

In a network environment, the state of each node is affected by the state of its immediate neighbours. Therefore, we characterize the effective state of the system using the average nearest-neighbour activity.

$$x_{\mathrm{eff}} = \frac{\mathbf{1}^\top A \mathbf{x}}{\mathbf{1}^\top A \mathbf{1}} = \frac{\langle s^{\mathrm{out}} x \rangle}{\langle s \rangle}$$



$$\beta_{\text{eff}} = \langle s \rangle + \mathcal{S}\mathcal{H}$$



Connectivity (topology) determines resilience

Density
Heterogeneity
Symmetry

Early-warning signals for critical transitions

Marten Scheffer[1], Jordi Bascompte[2], William A. Brock[3], Victor Brovkin[5], Stephen R. Carpenter[4], Vasilis Dakos[1], Hermann Held[6], Egbert H. van Nes[1], Max Rietkerk[7] & George Sugihara[8]

Complex dynamical systems, ranging from ecosystems to financial markets and the climate, can have tipping points at which a sudden shift to a contrasting dynamical regime may occur. Although predicting such critical points before they are reached is extremely difficult, work in different scientific fields is now suggesting the existence of generic early-warning signals that may indicate for a wide class of systems if a critical threshold is approaching.

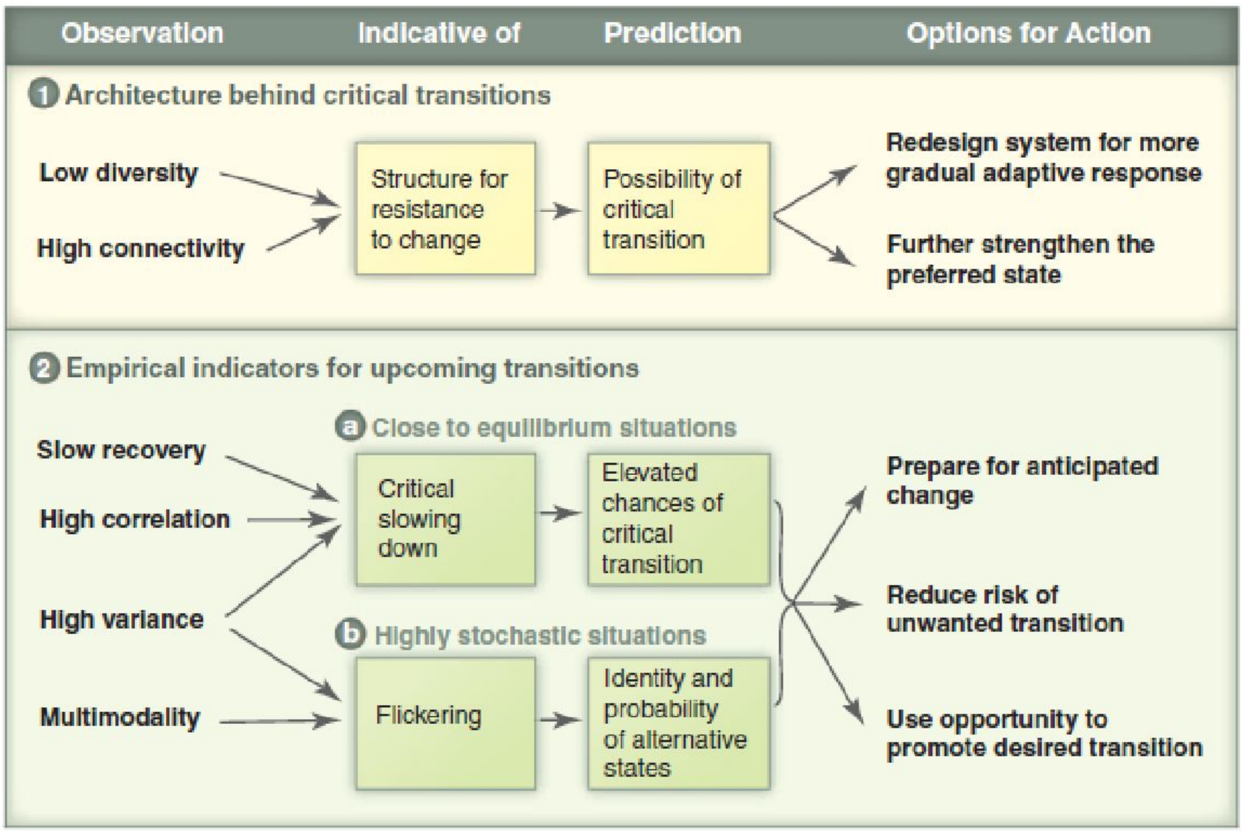


Fig. 4. Different classes of generic observations that can be used to indicate the potential for critical transitions in a complex system.

Early Warning Indicators

- Dynamics and imminent breakdown
  - Latent indicators of impending failure
- Critical slowing near transition
  - slower recovery from perturbation
- Increased correlations
  - slowed dynamics, increased memory
- Increased variance
- Use perturbations (natural and artificial) as probes
  - monitor recovery time

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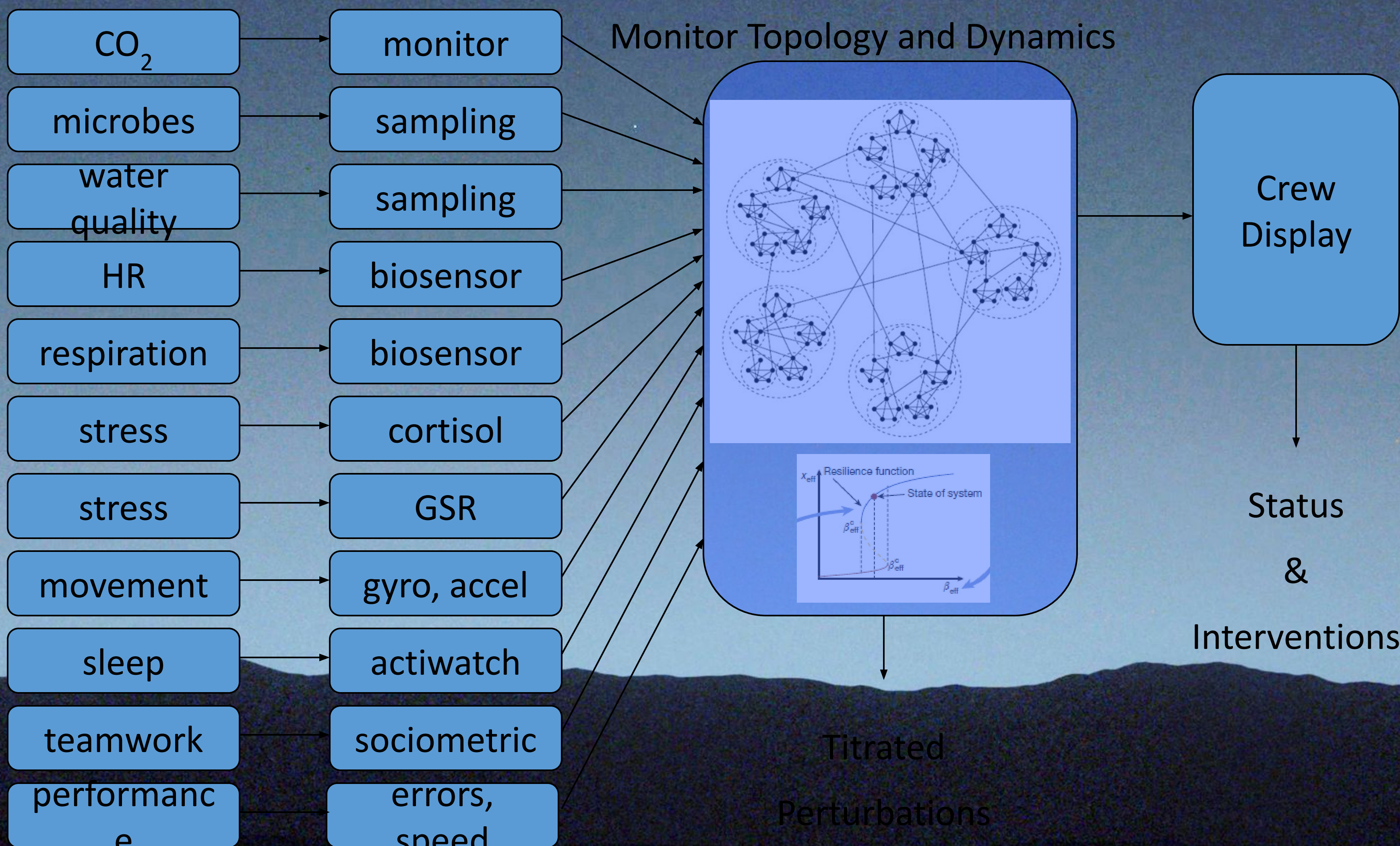


Problem Areas

- Stress as a central hub in the network
- Stressors:
  - Physiological changes, Cognitive changes
  - Isolation, confinement, human-system interfaces, automation
  - Inter-personal relations

Problem Areas ?

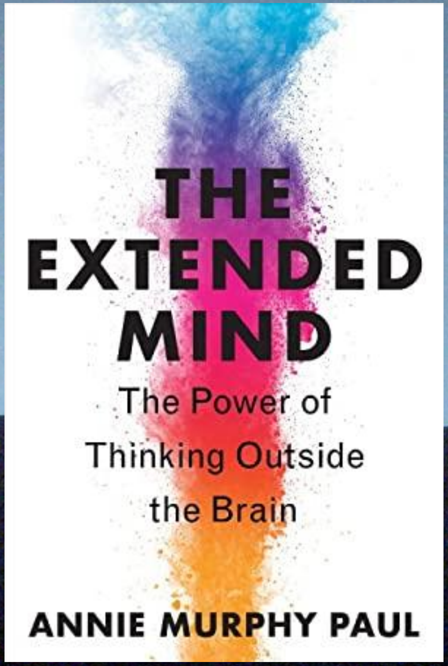
- Stressors:
  - Physiological changes, Cognitive changes
  - Isolation, confinement, human-system interfaces, automation
  - Inter-personal relations
- Just as these “external” factors can influence individual health and performance, these same factors can help in their solution.

What Tools can We Provide

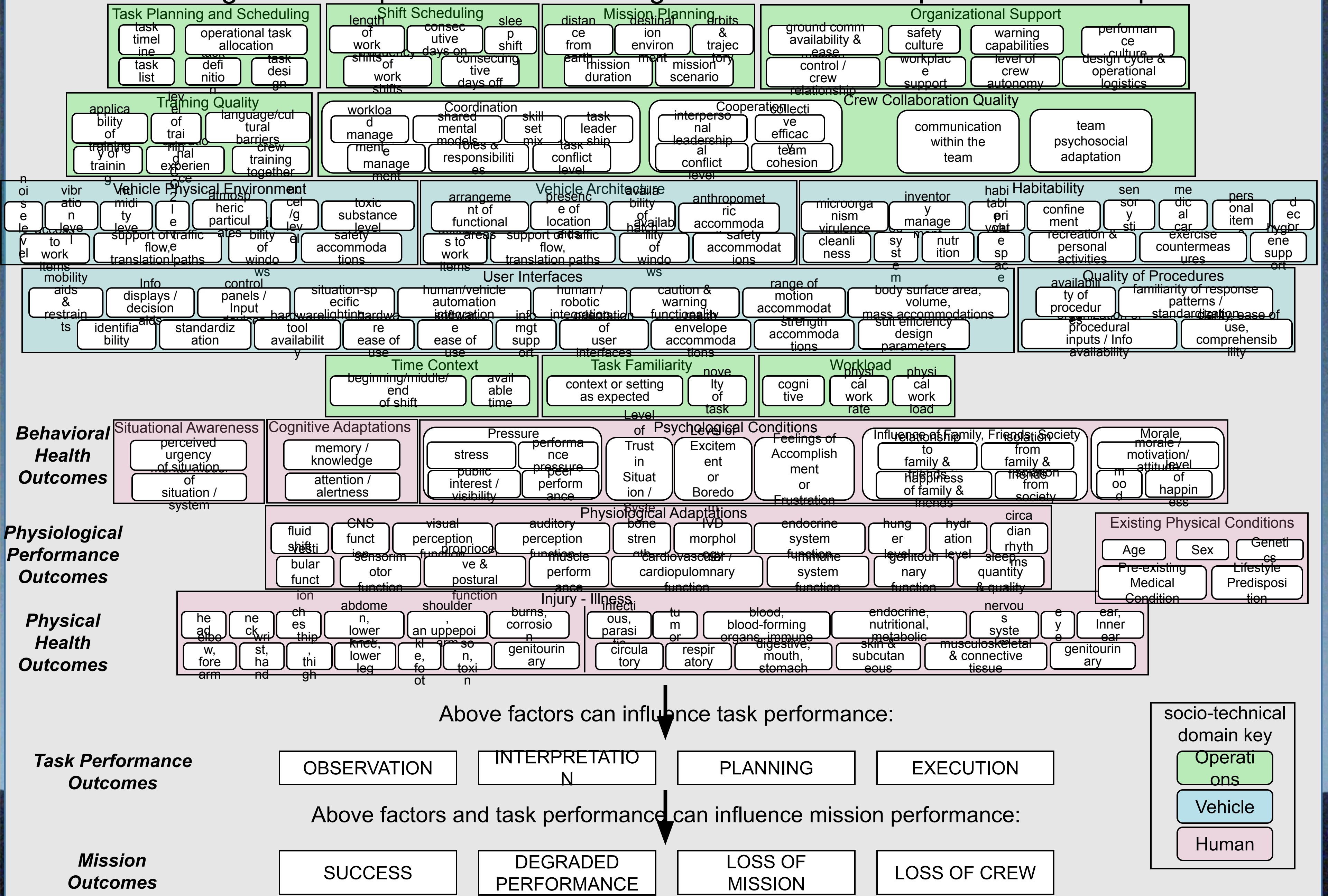
for the crew to maintain resilience

The Extended Mind

- Clark A, Chalmers D (1998) The extended mind. *Analysis* 58:7-19.
- Where does the mind stop and the rest of the world begin?
- Embodied
- Situated
- Distributed



Contributing Factor Map – factors influencing human health and performance in space



Adapted from: J Mindock, *Development and Application of Spaceflight Performance Shaping Factors for Human Reliability Analysis.* University of Colorado, Boulder, 2012.

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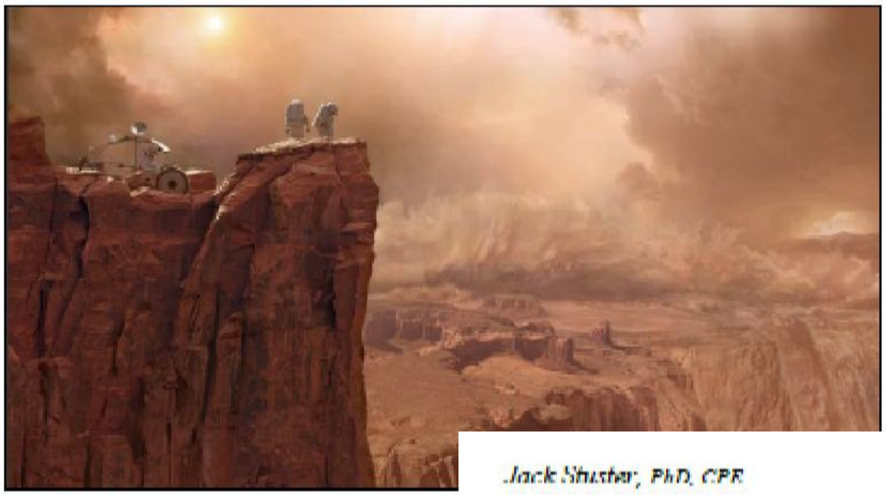
NASA/CR-2018-220445

Generalizable Skills and Knowledge for Exploration Missions



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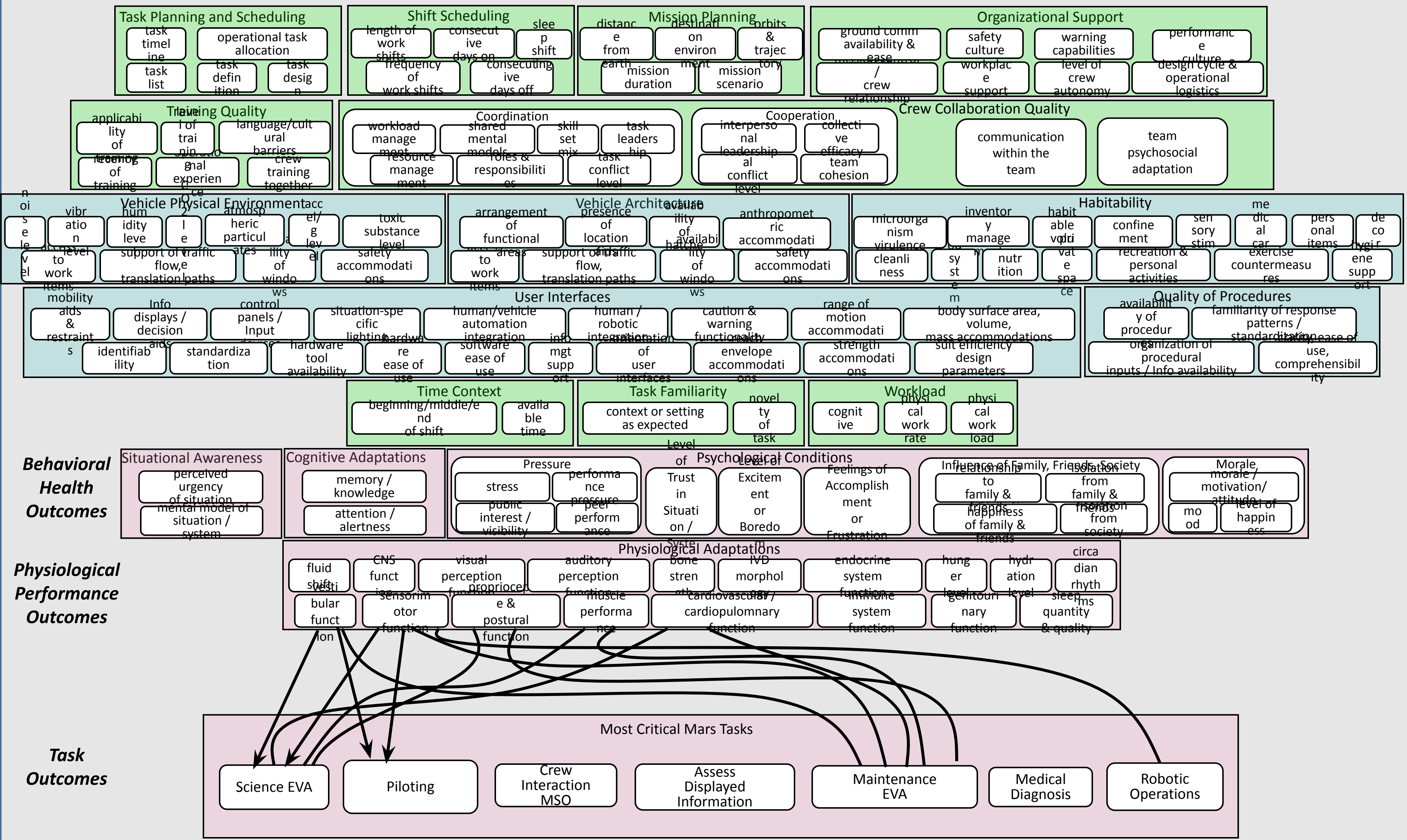
KBRwyle
Johnson Space Center
Houston, Texas

National Aeronautics and Space Administration
Johnson Space Center Houston, Texas 77058

Most Critical Mars Tasks

- Science-related EVA
- Piloting
  - Mars descent & ascent
  - Mars orbit injection & ops
  - Earth descent
- Interact with crew during MSO
- Assess displayed information
- EVA for maintenance en route
- Perform medical diagnoses
- Perform robotic operations



Task Planning and Scheduling
task timeline
operational task allocation
task list
task definition
task design
Shift Scheduling
length of work shifts
consecutive days on
sleep shift
frequency of work shifts
consecutive days off
Mission Planning
distance from earth
destination environment
orbits & trajectory
mission duration
mission scenario
Organizational Support
ground comm availability & ease
safety culture
warning capabilities
performance culture
crew relationship
workplace support
level of crew autonomy
design cycle & operational logistics
Training Quality
applicability of training
level of training
language/cultural barriers
recency of training
operational experience
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Crew Collaboration Quality
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vibration level
humidity level
atmospheric particulates
accel/g level
toxic substance level
access to work items
support of traffic flow, translation paths
safety accommodations
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arrangement of functional areas
presence of location aids
availability of hatches
anthropometric accommodation
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support of traffic flow, translation paths
availability of windows
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Habitability
microorganism virulence
inventory management
habitable volume
confinement
sensory stim
medical care
personal items
decor
cleanliness
nutrition
privacy space
recreation & personal activities
exercise countermeasures
hygiene support
User Interfaces
mobility aids & restraints
Info displays / decision aids
control panels / Input devices
situation-specific lighting
human/vehicle automation integration
human / robotic integration
caution & warning functionality
range of motion accommodation
body surface area, volume, mass accommodations
identifiability
standardization
hardware tool availability
hardware ease of use
software ease of use
info mgt support
standardization of user interfaces
reach envelope accommodations
strength accommodations
suit efficiency design parameters
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availability of procedures
familiarity of response patterns / standardization
organization of procedural inputs / Info availability
usability, ease of use, comprehensibility
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beginning/middle/end of shift
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Workload
cognitive
physical work rate
physical work load
Behavioral Health Outcomes
Situational Awareness
perceived urgency of situation
mental model of situation / system
Cognitive Adaptations
memory / knowledge
attention / alertness
Psychological Conditions
Pressure
stress
performance pressure
public interest / visibility
peer performance
Level of Trust in Situation / System
Level of Excitement or Boredom
Feelings of Accomplishment or Frustration
Influence of Family, Friends, Society
relationship to family & friends
isolation from family & friends
happiness of family & friends
recognition from society
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morale / motivation/ attitude
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level of happiness
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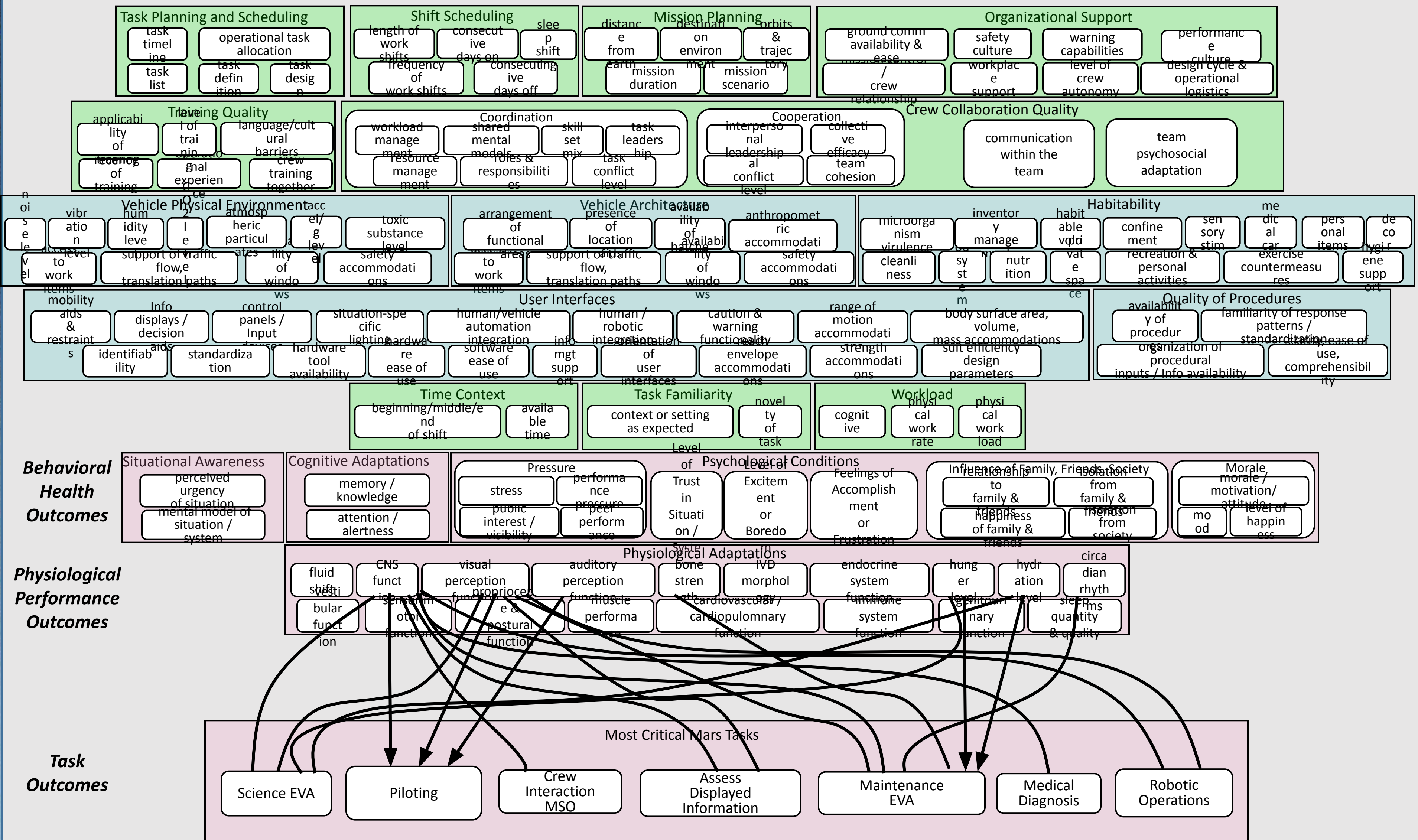
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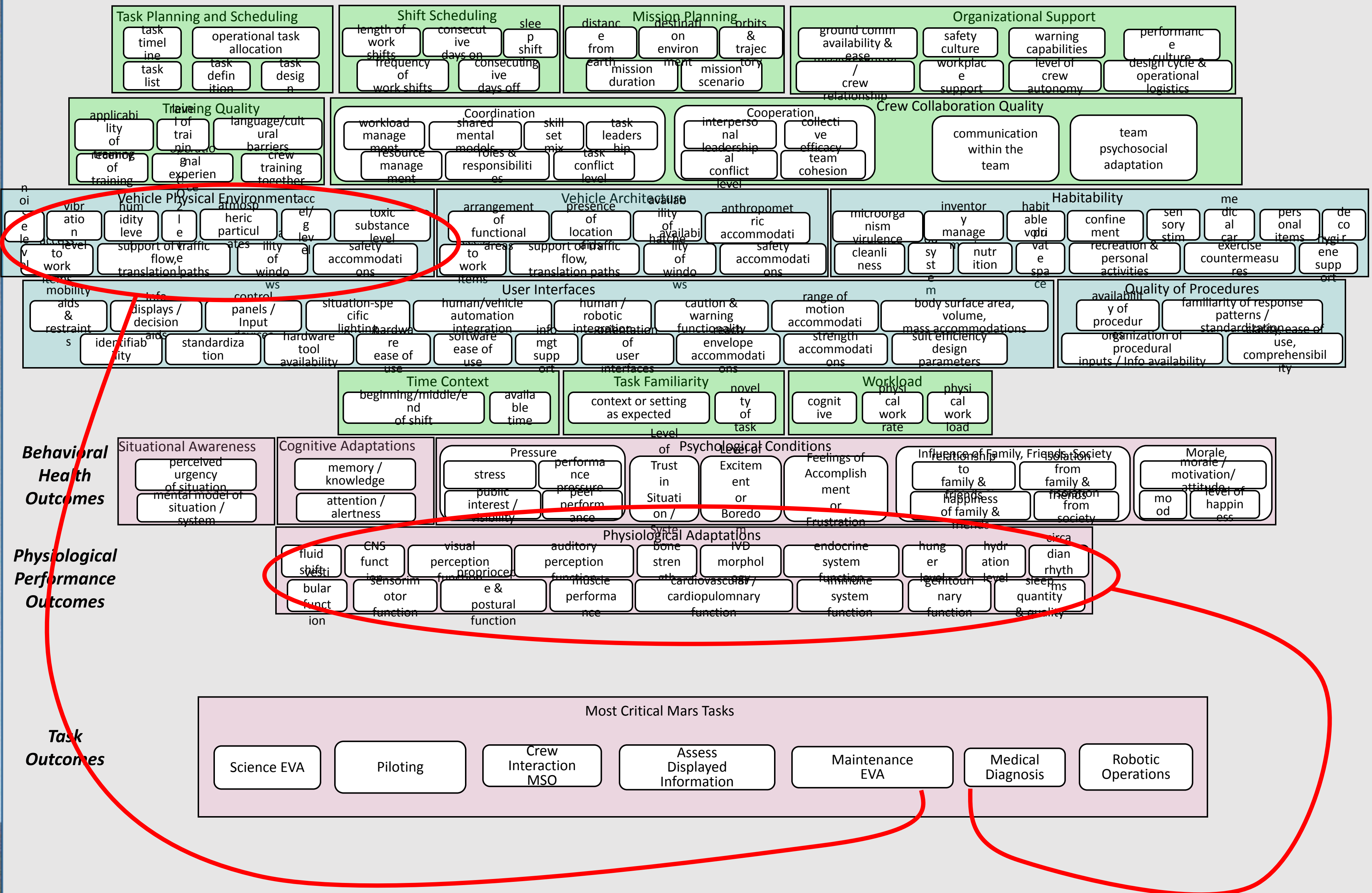

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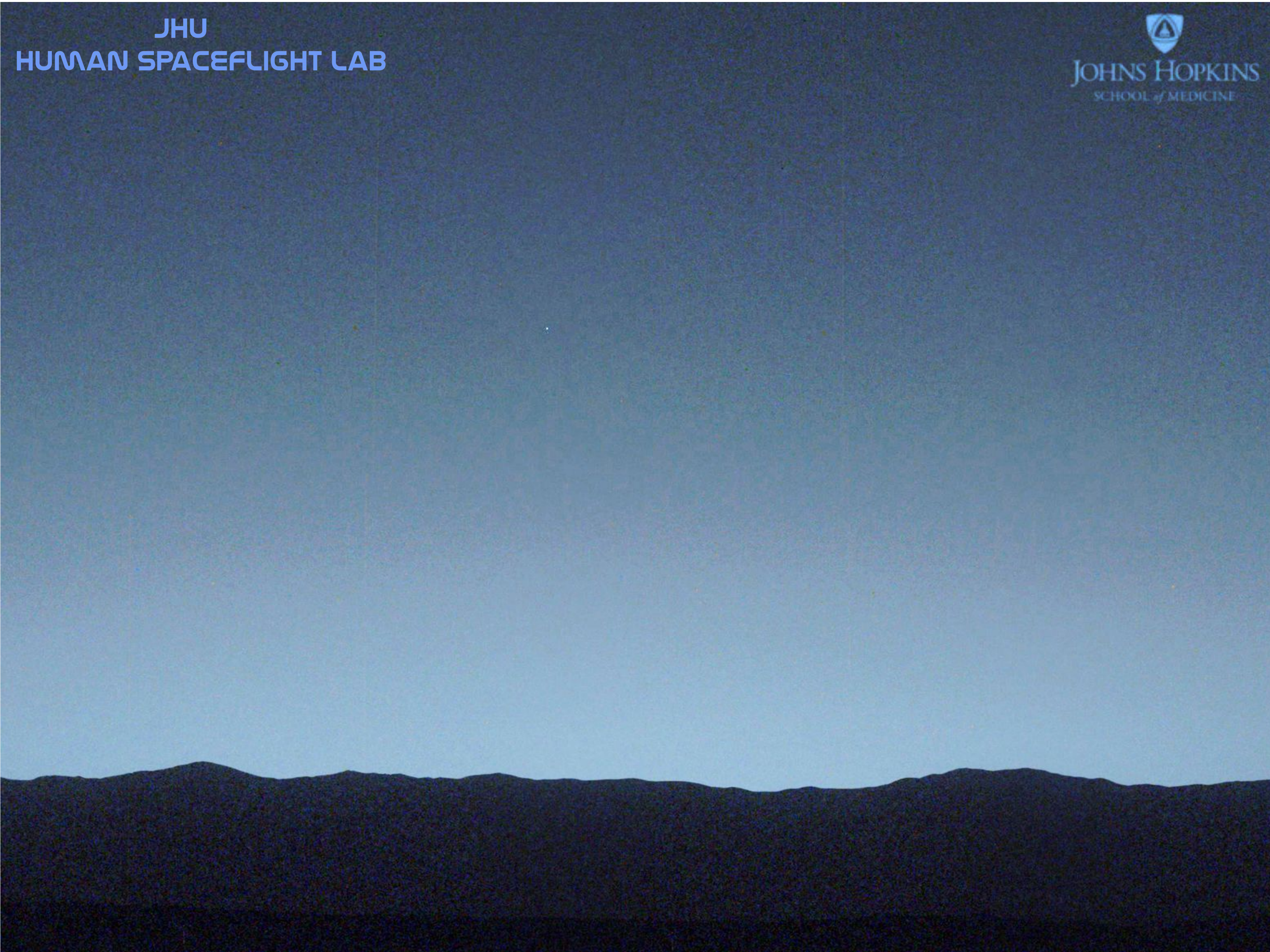
IVD morphology
endocrine system function
hunger level
hydration level
circadian rhythms
vestibular function
sensorimotor function
proprioception & postural function
muscle performance
cardiovascular / cardiopulmonary function
immune system function
genitourinary function
sleep quantity & quality
Task Outcomes
Most Critical Mars Tasks
Science EVA
Piloting
Crew Interaction MSO
Assess Displayed Information
Maintenance EVA
Medical Diagnosis
Robotic Operations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Why?

- It's not just science
  - Expands the human experience
- Science on ISS has been programmed not exploratory
  - Should be applauded for doing any science and as well as it has been given the constraints
- Would you want a robot in your lab?
  - Capitalize on serendipitous observations
- Synergy of human and robot
- Sending a world not a vehicle
  - Must understand resilience under uncertainty

Why?

- Ultimately – we explore to better understand our place in the universe
    - Just like astronomers
- Maintain health and performance In order to enable exploration
    - Telescopes
    - EVAs
- But also, if astronomy makes a claim to helping us understand our place in the universe, so does human spaceflight, by helping us understand how humans are adapted to Earth, and adaptable (or not) to being in space

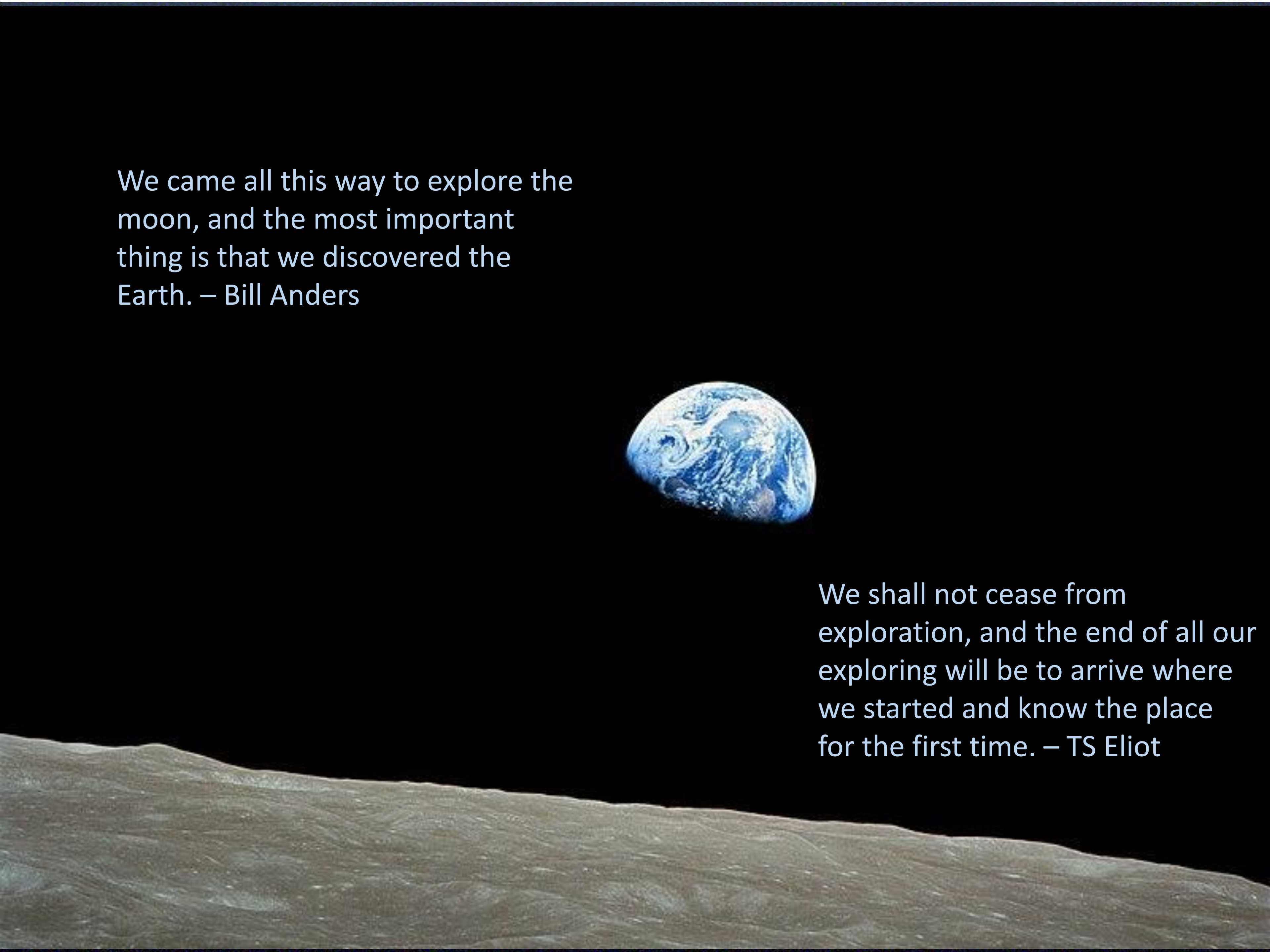
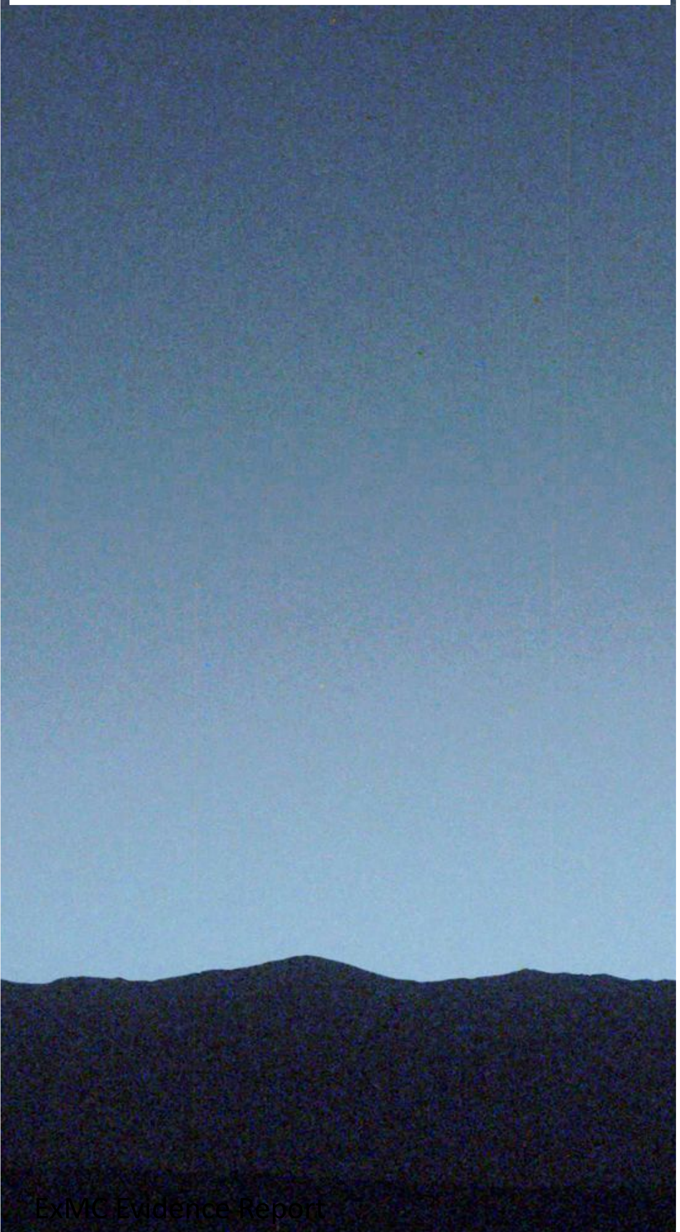

We came all this way to explore the moon, and the most important thing is that we discovered the Earth. – Bill Anders
We shall not cease from exploration, and the end of all our exploring will be to arrive where we started and know the place for the first time. – TS Eliot

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 (CO_2 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		



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EXPLORATION MEDICAL CONDITION LIST

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Abdominal Injury	Dental – Filling Replacement	Indigestion	Seizure
Abdominal Wall Hernia	Dental - Crown Replacement	Insomnia (Early/Late)	Sepsis
Acute Arthritis	Dental - Exposed Pulp/Pulpitis	Intra-Abdominal Infection (Diverticulitis, Appendicitis, Other)	Shoulder Dislocation
Allergic Reaction (Mild to Moderate)	Dental - Abscess	Lumbar Spine Fracture	Sinusitis
Altitude Sickness	Dental – Avulsion / Tooth Loss	Malignancy	Skin Abrasion
Anaphylaxis	Depression	Medication Overdose/Adverse Reaction	Skin Laceration
Anxiety	Diarrhea	Mouth Ulcer (aphthous ulcer; Herpes Simplex Virus – cold sore)	Skin Rash
Back Injury	Dysfunctional Uterine Bleeding	Nasal Congestion (Space Adaptation)	Small Bowel Obstruction
Back Pain (Space Adaptation)	Elbow Dislocation	Nausea/Vomiting	Smoke Inhalation
Barotrauma (Ear/Sinus Block)	Eye Abrasion (Foreign Body)	Neck Injury	Space Motion Sickness (Space Adaptation)
Behavioral Emergency	Eye Chemical Burn	Nephrolithiasis	Extremity Sprains/Strains
Burns	Eye Corneal Ulcer	Neurogenic Shock	Stroke
Cardiogenic Shock	Eye Infection	Nosebleed (Space Adaptation)	Sudden Cardiac Arrest
Cellulitis	Eye Penetration (Foreign Body)	Osteoporosis	Surgical Treatment
Chest Injury/Pneumothorax	Finger Dislocation	Otitis Externa	Toxic Exposure
Chest Pain/Angina	Fingernail Delamination (EVA)	Otitis Media	Upper Extremity Fracture
Choking/Obstructed Airway	Glaucoma – Acute	Palliative Treatment	Urinary Incontinence (Space Adaptation)

- Function depends on dynamics not topology
- Location along the resilience function depends on topology
- Some networks are more resilient than others
  - depends on Density, Heterogeneity, Symmetry
- Resilience function
  - effective state as function of effective topology
- Can have critical points and bifurcations to undesired states
- Establish resilience – stay away from a bad critical point
- But how to define desired and undesired effective states?

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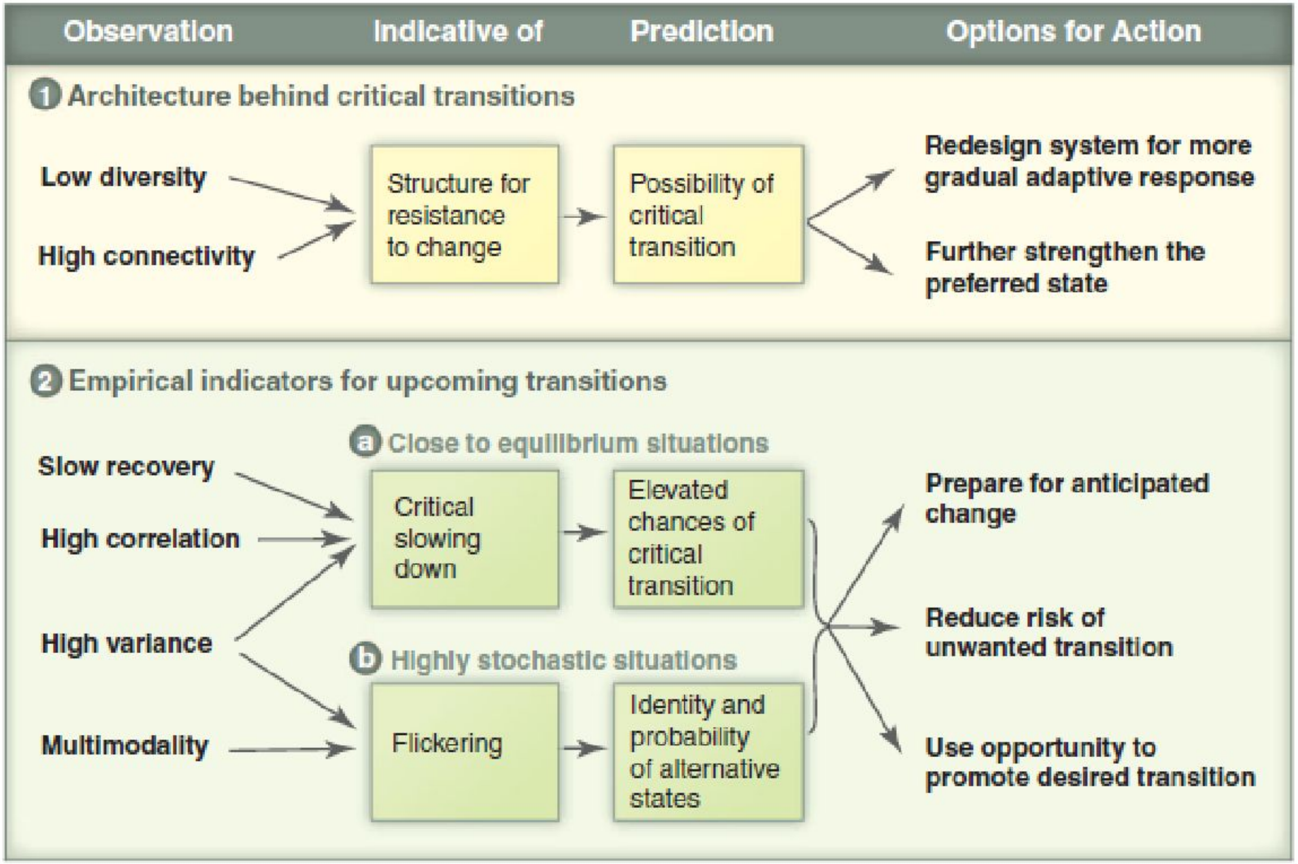


Fig. 4. Different classes of generic observations that can be used to indicate the potential for critical transitions in a complex system.

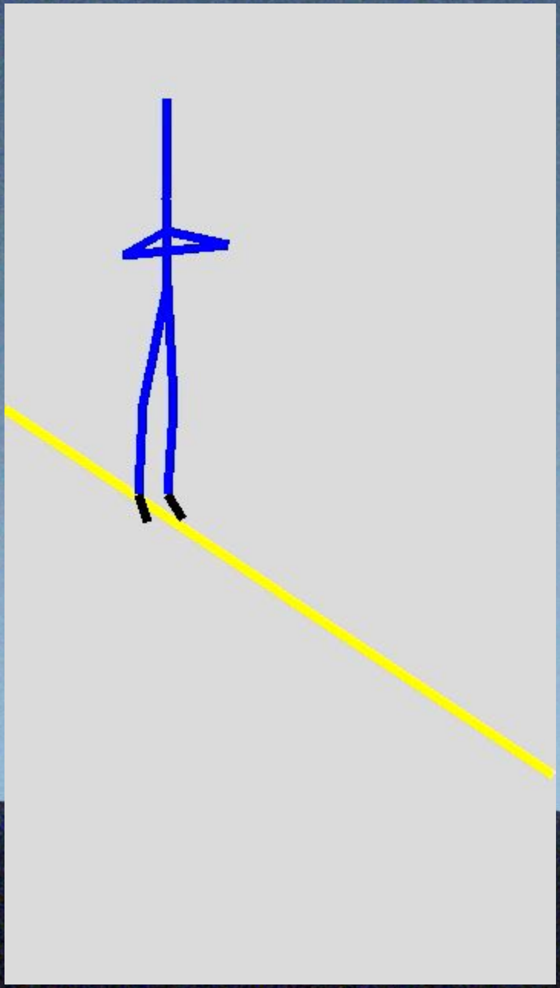
- Dynamics and imminent breakdown
  - Latent indicators of impending failure
- Critical slowing near transition
  - slower recovery from perturbation
- Increased correlations
  - slowed dynamics, increased memory
- Increased variance
- Use perturbations (natural and artificial) as probes
  - monitor recovery time

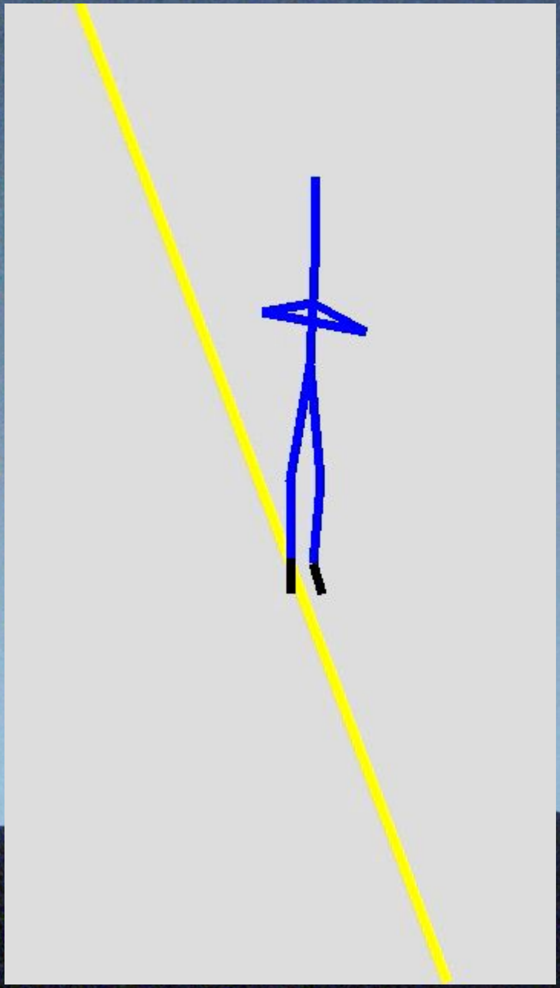
Top 32 Summary Task Statements Ranked by Criticality

	Summary Task Statement	Frequency	Difficulty	Importance	Criticality	Function
1	**Perform science-related EVA functions during Mars Surface Operations (MSO).**	3.679	4.036	4.286	**12.000**	Science EVA
2	Monitor systems/perform piloting functions during Mars Surface Ascent.	2.912	4.158	4.807	11.877	Piloting
3	Perform piloting functions during Mars Surface Descent.	2.589	4.375	4.821	11.786	Piloting
4	**Interact/communicate with crew members directly during MSO.**	**4.638**	2.298	4.672	11.609	Comms
5	Perform piloting functions during Earth Descent.	2.545	4.268	4.750	11.563	Piloting
6	Perform piloting functions during Mars Orbit Injection.	2.386	4.246	4.860	11.491	Piloting
7	Perform piloting functions during Mars Orbit operations.	2.556	4.241	4.691	11.487	Piloting
8	Enter control inputs, manually/visually with gloved hand, to pilot Earth Ascent Vehicle (EAV) during launch and cruise to LEO/CLO.	2.772	4.000	4.702	11.474	Piloting
9	Monitor systems/perform piloting functions during Trans Earth Injection.	2.800	3.893	4.732	11.425	Piloting
10	Perform piloting functions during Earth Approach.	2.518	4.107	4.786	11.411	Piloting
11	Assess displayed information, cognitively, to determine readiness to launch to LEO/CLO.	3.123	3.632	4.579	11.333	Piloting
12	Conduct Extra-Vehicular Activity (EVA) to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Mars.	2.246	4.491	4.596	11.333	EVA
13	Monitor displays/verify configurations before/during launch to LEO/CLO	3.554	3.333	4.439	11.326	Monitoring
14	Monitor systems during Earth Descent.	3.481	3.382	4.436	11.300	Monitoring
15	Perform monitoring functions in surface habitat or modules to ensure crew and system health during Mars Surface Operations.	3.897	3.000	4.386	11.283	Monitoring
16	Enter/exit surface habitat, manually while wearing pressure suit and helmet, during Mars Surface Operations.	3.544	3.246	4.474	11.263	EVA

17	Perform medical diagnoses and evaluations, cognitively, during MSO.	2.690	4.053	4.517	11.260	Medical
18	Perform robot operations-related functions during MSO.	3.527	3.750	3.982	11.259	Robotics
19	Perform geology-related science functions in surface habitat or modules during Mars Surface Operations.	3.491	3.754	4.000	11.245	Science
20	Assess displayed information, cognitively, to determine readiness for TMI.	3.018	3.571	4.643	11.232	Piloting
21	Monitor crew behavioral health/respond to behavioral health issues during Mars Surface Operations.	3.133	3.559	4.517	11.209	Medical
22	Monitor systems to ensure proper functioning during Cruise to Mars.	3.897	2.983	4.328	11.207	Monitoring
23	Perform medical diagnoses/evaluations, cognitively, during Cruise to Mars.	2.649	4.055	4.491	11.195	Medical
24	**Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Mars.**	1.948	4.509	4.724	11.181	Medical
25	Perform surface rover piloting/driving functions during MSO.	3.464	3.411	4.304	11.179	Piloting
26	Respond to medical emergencies, following procedures and with equipment provided, during Mars Surface Operations.	2.069	4.263	4.825	11.157	Medical
27	Perform surface EVA physical functions on foot during MSO.	3.298	3.482	4.368	11.149	EVA
28	Adjust system controls, manually during buffeted descent, in response to displayed information.	2.673	3.870	4.585	11.128	Piloting
29	**Respond to technical emergencies, following procedures and with equipment provided, during Cruise to Mars.**	2.140	4.053	4.930	11.123	Technical
30	Monitor systems during Mars Surface Descent.	3.148	3.444	4.509	11.102	Piloting
31	Perform tests and examinations, physically, to support medical diagnoses during Mars Surface Operations.	2.741	3.860	4.483	11.084	Medical
32	Perform biology-related science functions in surface habitat or modules during Mars Surface Operations.	3.474	3.579	4.018	11.070	Science

ISS Locomotion Pre/Post





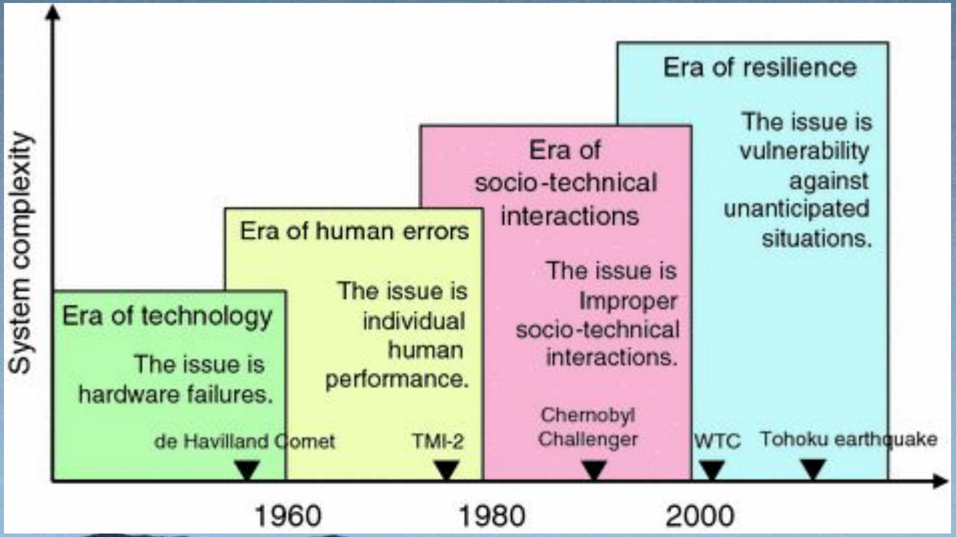
- Just provide breathing room for self-organization
- The people on site know the situation best (personal)
- *Any problem can be solved using the materials in the room Edwin Land* (if you don't die first). There will be things we can't think of, at least don't rule out possible solutions. Keep things viable until crew finds solution. Doctr's job is to comfort patient until body heals itself.

Stress as a central hub, control node
Intervention does not have to address the exact cause, Frankl

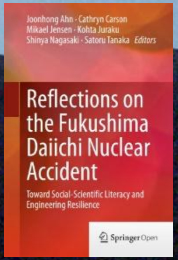
- Systems approach
- Extended Mind
- Personal Ecology
- How to capture it?
- Martin Short?
- Couplings – implicit and explicit

Resilience Engineering

- Promote positive outcomes, don't just mitigate negative outcomes
- Health is more than just the absence of disease



K Furuta (2014) Resilience Engineering. *Reflections on the Fukushima Daiichi Nuclear Accident*, 435-454.



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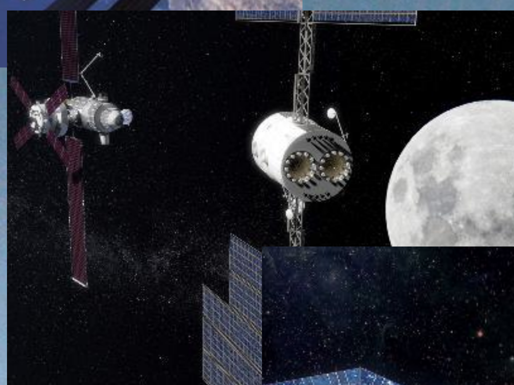
Progressive Earth Independence

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



- Near Real Time Communications
- Evacuation Capability (**3 – 11 days**)
- **Limited** Consumables Resupply

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

→ **Increasing Exposure to Hazards**

Courtesy of Erik Antonsen, NASA

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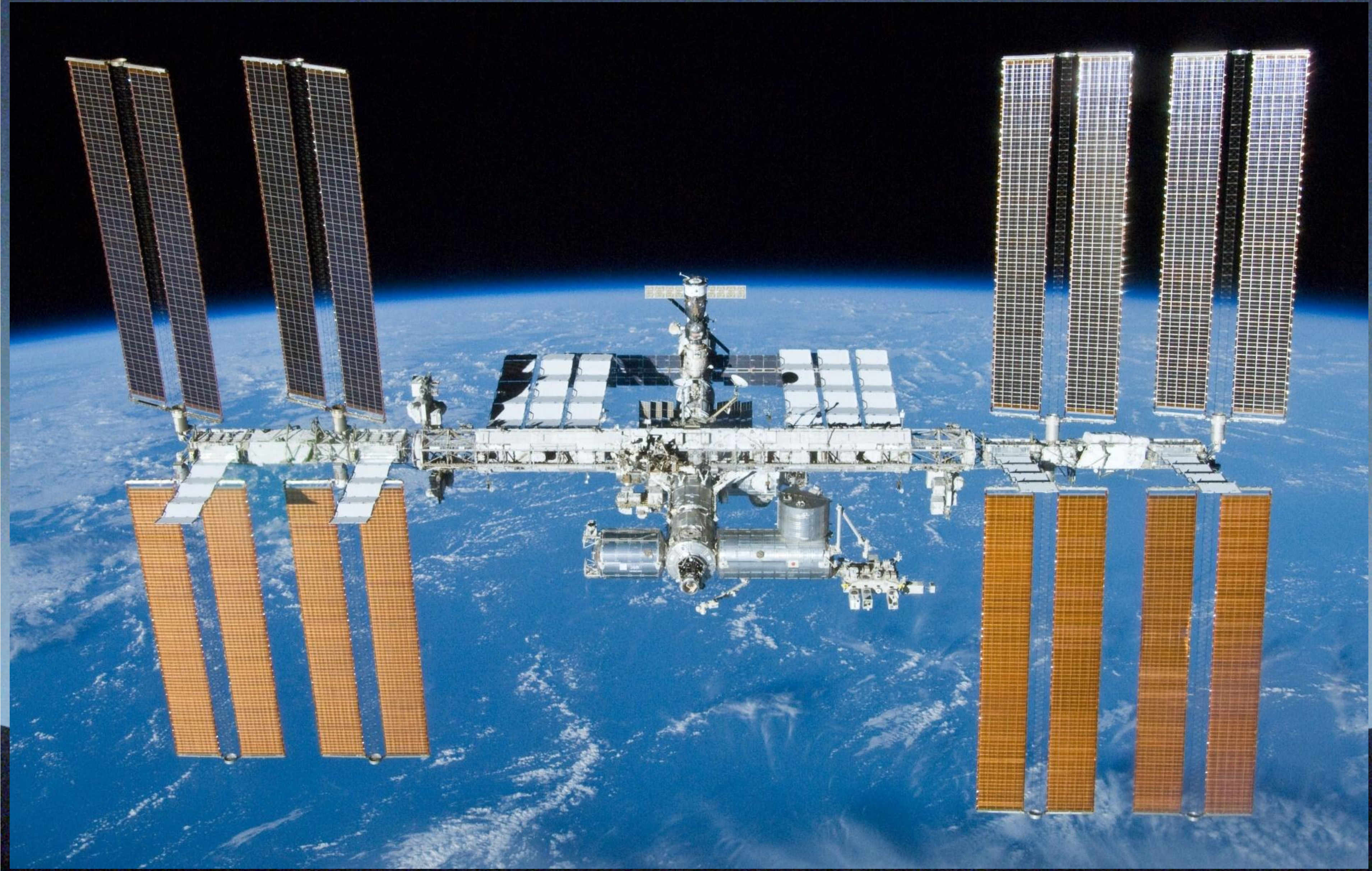

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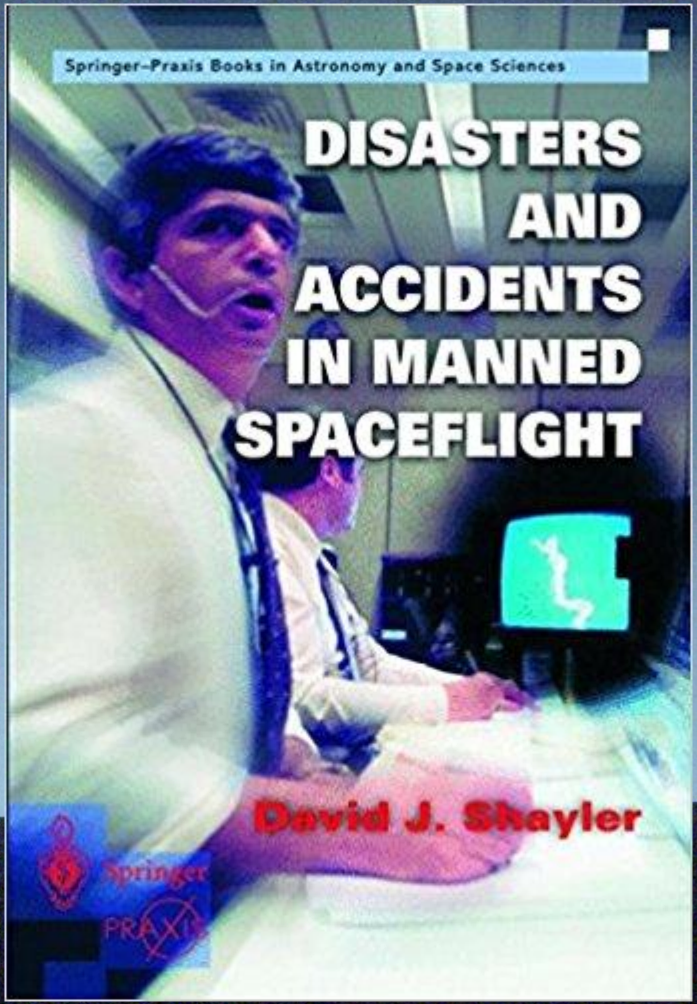
Case Study

- David J. Shayler
- *Disasters and accidents in manned spaceflight*
- Springer Science & Business Media
- pp 309-342



MIR/Progress Collision

MIR/Progress Collision - Contributing Factors I

Precipitating events

- Previous onboard fire
  - flight engineer blamed, initially
  - pre-existing stress from fire
- Later re-use of oxygen candles due to failure of oxygen separator
  - CO_2 scrubber failure and backup use
  - problems with availability and reliability of spares for separator
  - incompatible connectors for gas fittings
- Failure of attitude sensor
  - gravity-gradient mode
  - power reduction
  - increase in temperature
  - reduction in exercise and use of LBNP
- Coolant leak into the module
  - flight engineer allergic eye reaction
- Toilet failure and repair
- Passageways cluttered with equipment
- Earlier failed re-docking of Progress M-33

MIR/Progress Collision - Contributing Factors II

Hardware/software issues

- Restricted views from observation windows
- Commander had video image of Mir from Progress POV
- Poor Progress thruster performance

Human factors

- High Cosmonaut workload
  - falling behind in maintenance
  - no free weekend in three months
- Crew cohesion and shared workload
  - Foale offered to do some work
    - Russian reticence to accept assistance
  - Russians shared little with American astronauts

MIR/Progress Collision - Contributing Factors III

Implementation issues

- Commander showing signs of stress before docking
- Unclear instructions on what to expect from the docking initiation
- Bad visual reference and lighting on video image
- Had not practiced docking for 130 days
- Poor ground communication impaired real-time assistance

Overarching issues

- Poor information flow
  - crew-ground, crew-crew
- Crew health status
  - fatigue, pressure, workload
- Performance pressure

MIR/Progress Collision - Contributing Factors

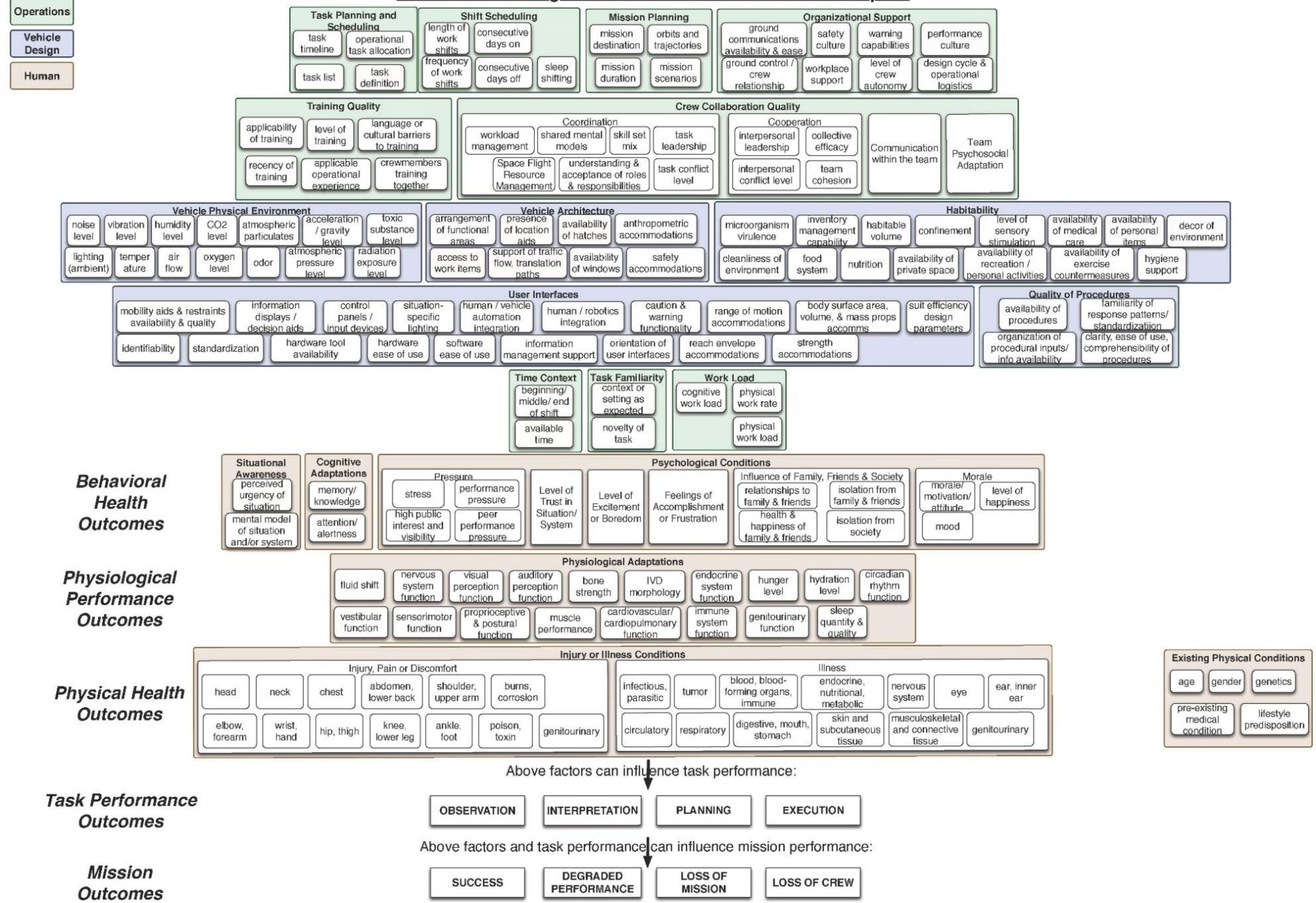
Trend of increasing problems

"It was not the fault of one person or element, but a combination of several actions of a variety of people and by different hardware and software." – Shayler p 339

Contributing Factor Map

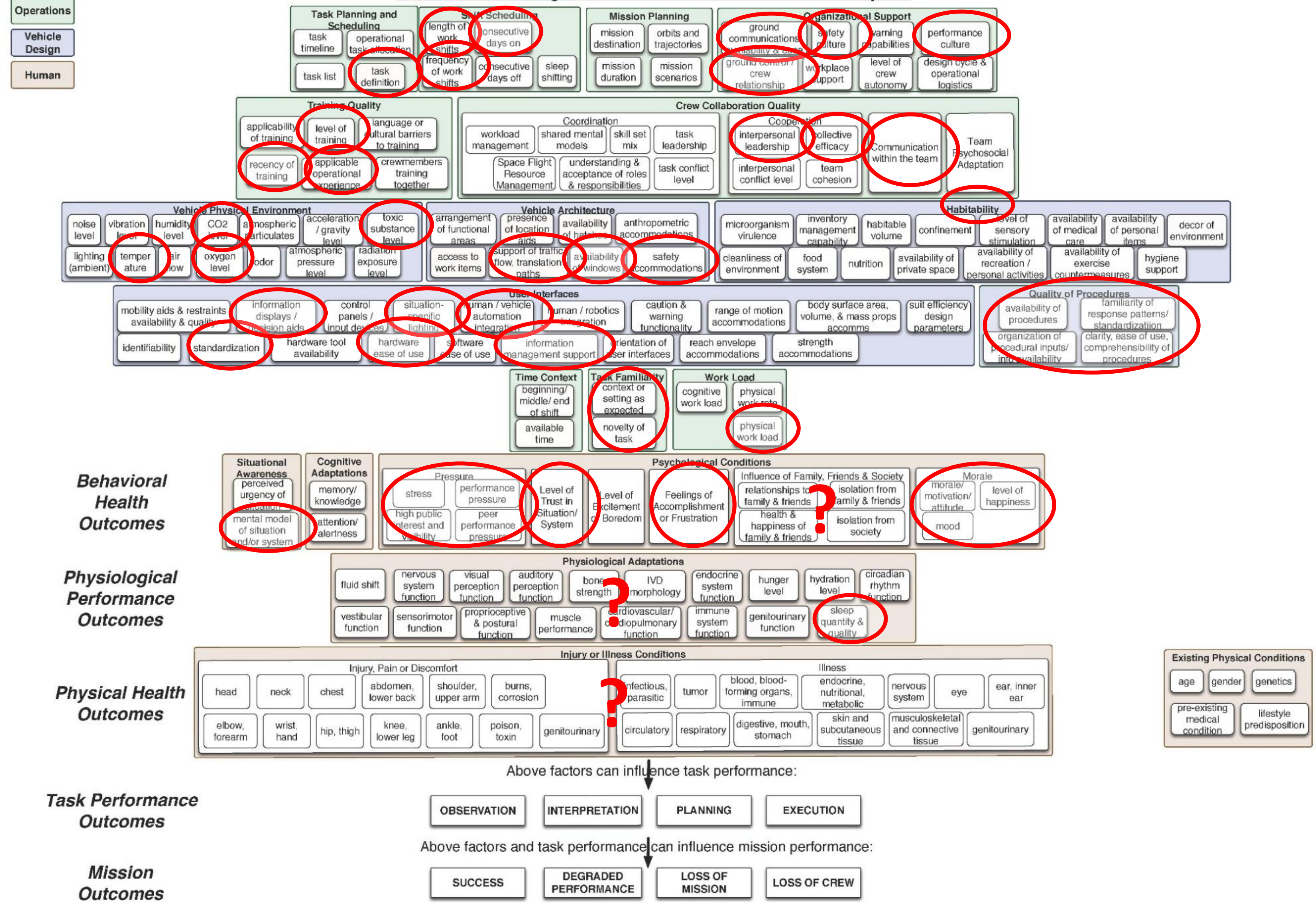
Factors Influencing Human Health and Performance in Space

9/5/13



Adapted from Mindock, J., *Development and Application of Spaceflight Performance Shaping Factors for Human Reliability Analysis.* University of Colorado, Boulder, CO, 2012.

Contributing Factor Map
Factors Influencing Human Health and Performance in Space



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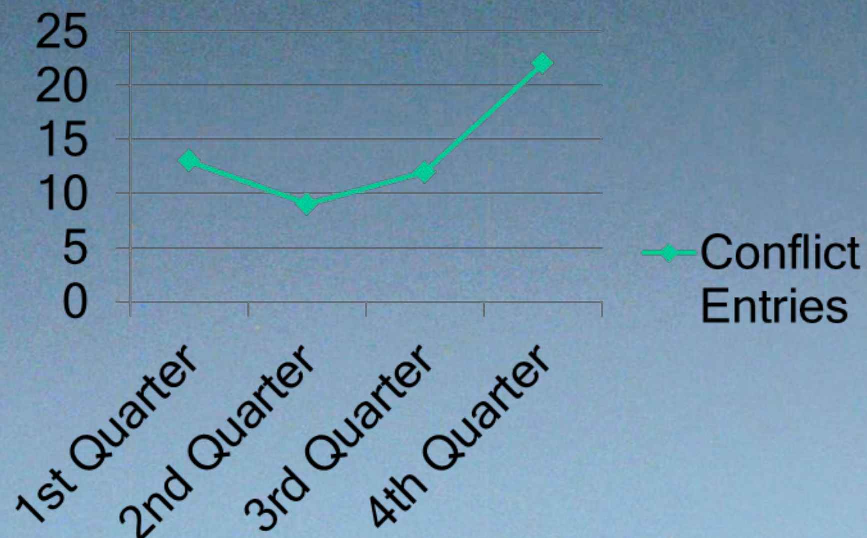
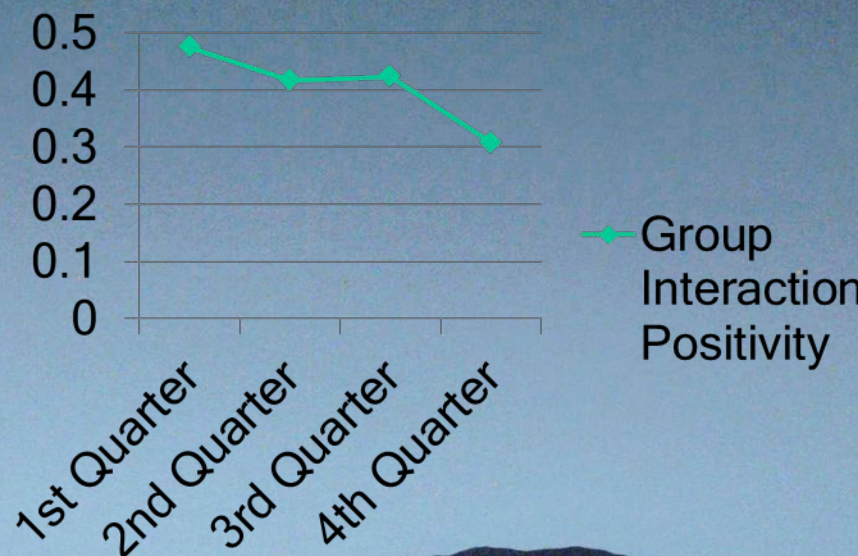
Interpersonal Conflicts

ISS Journal entries on conflict by quarter



ISS Group Interaction Positivity Ratings by mission quarter



Stuster (2014) Behavioral Issues Associated With Long Duration Space Expeditions: Review and Analysis of Astronaut Journals Experiment 01-E104 (Journals). Phase 2 Final Report. NASA/TM-2016-218603.

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