H2MM: Technological & Societal Issues

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Societal Issues

- **Psychological impact of long-duration missions**
- Familial relationships of astronauts
- Public perception

Long-duration Missions: Psychological Impact

- Antarctic research bases are one of the best analogs we currently have to study the effects of long-term missions in deep space

- By examining how over-winter personnel adapt to the antarctic environment, we can infer how best to design semi-permanent missions to the Moon and Mars

Table 1 Characteristics of crew members of Antarctic research stations and long-duration spaceflights

Factors	Antarctic research stations	Long-duration spaceflights
Selection of personnel	Volunteers Medical and psychological screening Occupational requirements and skills	Volunteers Medical and psychological screening Occupational requirements and skills
Nature of work	Science Exploration Support Administration Construction Maintenance Logistics Communication Medical	Science Exploration Support Administration Construction Maintenance Logistics Communication Medical
Crew composition	Men and women Military and civilian personnel Different nationalities	Men and women Military and civilian personnel Different nationalities
Crew size		
5–10	Field camps	Exploratory missions
11–20	Small stations	Initial planetary bases
21 and more	Large stations	Advanced planetary bases
Organizational structure		
Agency	NSF/U.S. Antarctic Program	NASA
Division of labor	Science and support	Science and support
Chain of command	Officer in charge Station manager Station science leader	Mission commander Science leader
Duty rotations	4–13 month tours	3–36 month tours

Long-Duration Missions in Extreme Environments

Physical Impacts	Psychological Impacts
- Shortness of Breath - Headaches - Hypoxia - Suppressed Immune System - Circadian Rhythm Disorders - Rheumatism	- Insomnia & Fatigue - Depression - Irritability & Aggression - Decline in motivation and alertness - Anxiety - Increased alcohol consumption - Impaired memory

Lessons from Antarctica

1. Personnel screening
    a. Cheerful, trusting and cautious individuals consistently perform better in Antarctica
    b. Introverted people outperform extroverts
2. Group Dynamics
    a. Individual interaction -> clique formation -> group cohesion
    b. Conflict resolution training can help the group transition peacefully from stage 2 to stage 3
3. Group Composition
    a. Heterogeneous crews tend to develop a group cultural identity to help with cohesion
4. Support Infrastructure
    a. Consistent and clear contact is needed to prevent conflict between the crew and mission control from escalating

Biosphere 2

- Finished in 1991 as an analog for a self-sustaining Mars habitat
  - Goals: test self-sufficiency of 8 “biospherians” and test technologies for the creation of a self-sustaining biosphere
- Upon starting the initial, 2-year test:
  - The biosphere collapsed: many of the plant and animal species died out, and pests flourished
  - Oxygen levels dropped to 14%, and carbon dioxide rose up to 4000 ppm
  - The group split into two opposed factions and could not reconcile

Societal Issues

- Psychological impact of long-duration missions
- **Familial relationships of astronauts**
- Public perception

Familial relationships of astronauts

Astronauts provide a fairly small sampling size

But...

Similarities between astronauts and deployed military members:

- High risk environments
- Long-term family separation

Familial relationships of astronauts

Studies on deployed military and their families:

- Spouses experience increased rates of depression, anxiety, sleep disorders, and acute stress / adjustment problems
- Young children can experience sleep disturbances
- Older children can experience increased stress and difficulties at school

NASA has an Astronaut Family Support Office

- Primary Goal: Assure no loss of mission goals due to deterioration in family functioning

Societal Issues

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Public Perception - Mission Cost and Risk

Using Apollo and Space Shuttle as case studies

Apollo

- Originally had 10 planned landings, 3 canceled
- Apollo seemed risky following Apollo 1 and 13 failures
- Public interest waned
- Final 3 missions canceled due to cost, risk, loss of public interest
- Funds allocated to Skylab, and shuttle program.

Public Perception - Mission Cost and Risk

Space Shuttle

- Results of Challenger disaster
  - Shuttle program suspended for almost 3 years
  - Reduced scope as a satellite launch vehicle
  - Less aggressive launch schedule
- Results of Columbia disaster
  - Shuttle program suspended for 2 years
  - Afterwards the Shuttle only went to the ISS (with one mission to Hubble as an exception)
  - Further Shuttle missions primarily focused on completing the ISS

Public Perception - Who to Send?

- Children more inspired by seeing people like themself doing science
  - Miller et al. 2018 is a meta-analysis of 78 Draw-A-Scientist studies
  - By age 16 75% of girls and 98% of boys draw men when asked to draw a scientist (Miller et al. 2018)
  - Representation Matters!
- Women Astronauts
  - 1967 Valentina Tereshkova (USSR)
  - 1983 Sally Ride (USA)
  - Only about 12% of all astronauts
- African American Astronauts
  - 1983 Guion Bluford (USA)
  - 4.1% of American astronauts (compared to 13.4% of US pop.)

Tech Issues

- **Health concerns**
- Space hazards
- Power
- Artificial gravity

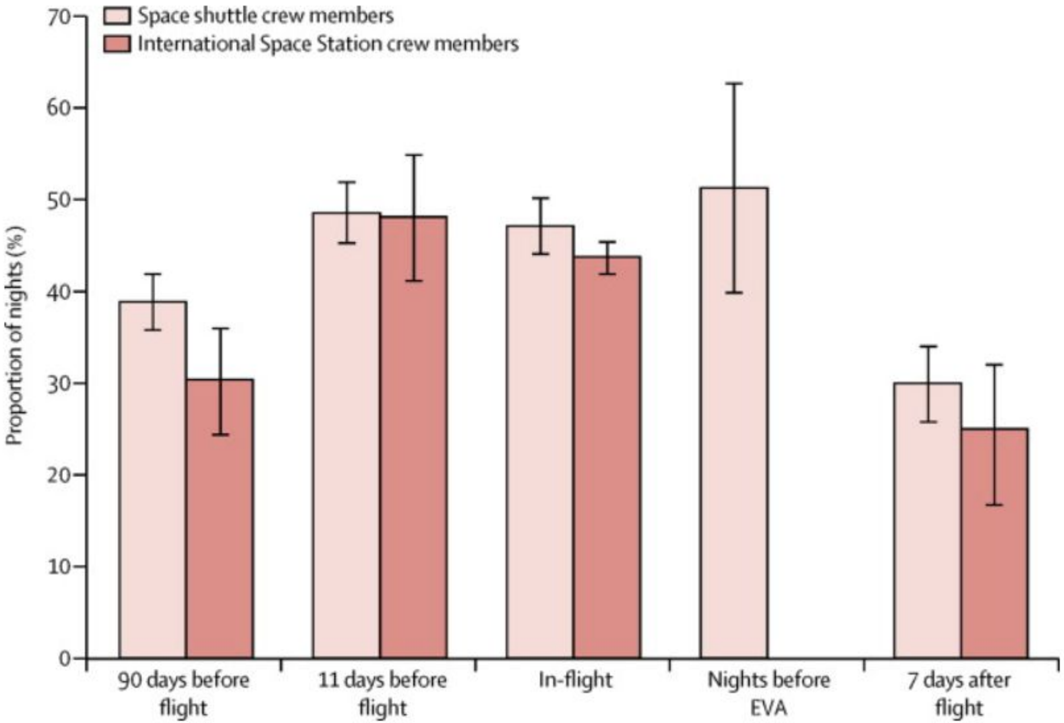
Health Risks to Solve:

Table 1: Timeline of physiologic acclimation and acclimatization experienced by astronauts from launch to after return to earth

		Duration of flight					Postflight period		
Physiologic effects	Launch	24 h	48 h	2 wk	> 1 mo	Landing	24–48 h	1–2 mo	> 1 yr
Fluid redistribution	• Redistribution of fluid to the torso and head • 10% decreased fluid volume in the legs	• 17% reduction in plasma volume	• Gradual decrease in erythropoietin secretion, leading to a 10% decrease in total blood volume			• Orthostatic hypotension from pooling of fluids in the legs	• Return of normal fluid distribution		
Neurovestibular effects	• Space motion sickness					• Space motion sickness			
Muscle changes		• Gradual decrease in muscle mass by 20%			• Gradual decrease in muscle mass by 30%	• Muscle soreness and tightness		• Full recovery of muscle mass and strength	
		• Gradual decrease in muscle strength (up to 50% loss observed)							
Bone demineralization		• 60%–70% increase in calcium loss (urinary, fecal). Reduced parathyroid hormone and vitamin D production.							• Complete or almost complete restoration of bone density
		• Gradual loss of bone density (1%–2% per month)							
Psychosocial effects	• Fatigue, sleep debt, isolation, emotional effects, stress to the astronaut's family, multicultural crew environment								
Immune dysregulation		• Possible reactivation of latent herpes viruses and impairment of cell-mediated immunity				• Numerous cellular and other changes leading to impaired immunity		• Gradual improvement in immunity (days to weeks)	

“Space Insomnia”

- 85 astronauts, 93 missions
- significantly less sleep per night pre-launch and during flight
- sudden change of schedule in 13% of 2043 days aboard the ISS
- absence of circadian cues like light cycles disrupt biorhythms
- Antarctica analogue: sleep occurred at same “clock time” but was poorer in quality



Percentage of night with <6 hrs of sleep

“Space Insomnia” Countermeasures

- Improve sleep environment
- Reasonable work-rest schedules
- Light treatment
- Pharmacologic intervention

Effects of Sleep Loss & Fatigue

Psychological	Physiological
• Depression • Anxiety • Personality Changes	• Cardiovascular deconditioning • Muscle atrophy • Decreased immune response • Decrease or lag in body temperature & cortisol levels

“Space Insomnia” Countermeasures

- Improve sleep environment
- Reasonable work-rest schedules
- Light treatment
- Pharmacologic intervention
  - sleep-promoting drug use already pervasive during flight (70%)
- Psychological support

Effects of Sleep Loss & Fatigue

Psychological	Physiological
• Depression • Anxiety • Personality Changes	• Cardiovascular deconditioning • Muscle atrophy • Decreased immune response • Decrease or lag in body temperature & cortisol levels

Muscle Atrophy

- After a 2-week space flight, muscle mass is diminished by up to 20%.
- On longer missions (3–6 months), up to 30% loss
- Up to 20% loss of calf muscle volume, strength decrease of 50% after 6 months

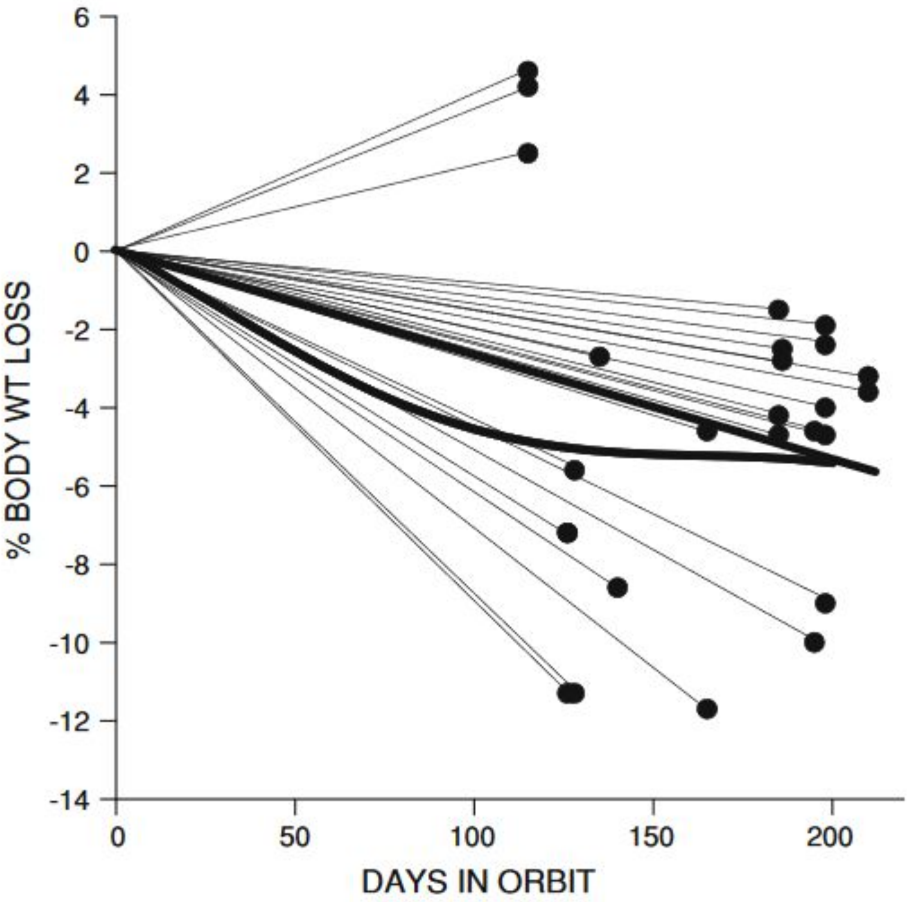


Fig. 2 Variability of weight loss on the ISS (Matsumoto et al. 2011; Smith et al. 2005)

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“There have been no life-threatening events.”

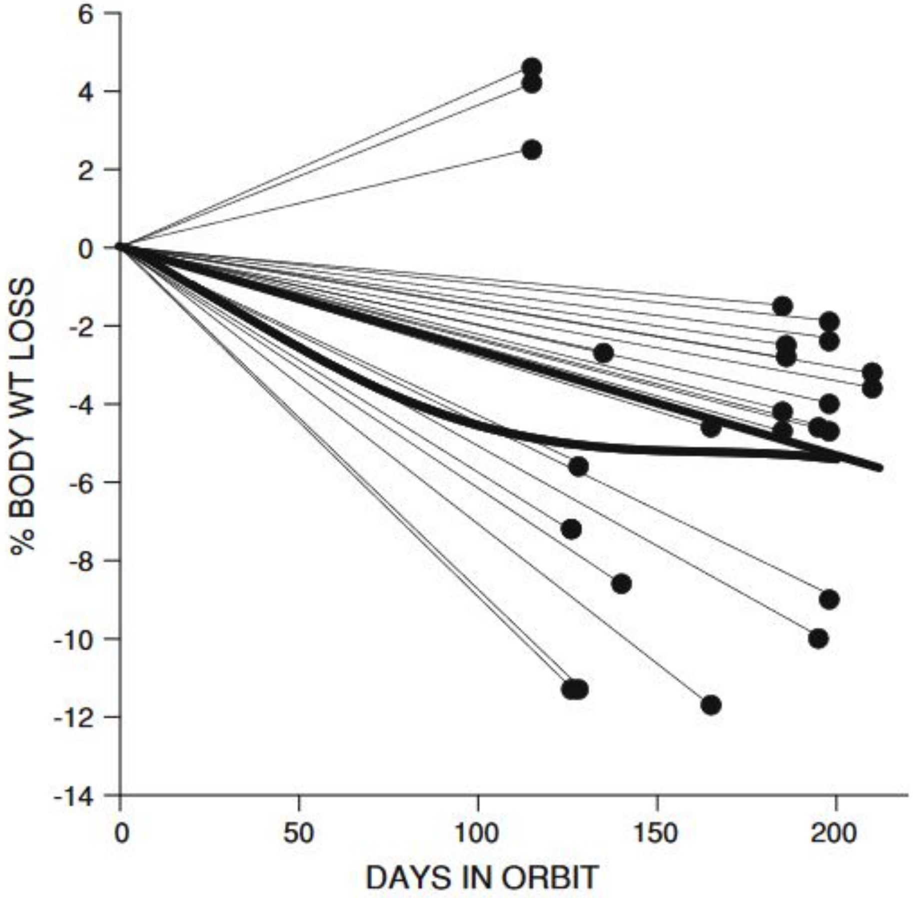
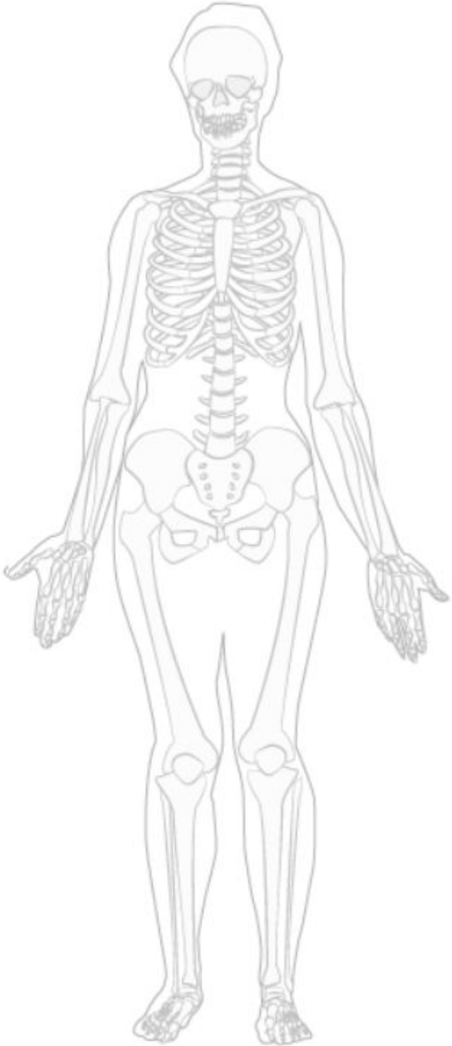


Fig. 2 Variability of weight loss on the ISS (Matsumoto et al. 2011; Smith et al. 2005)

Bone Loss

- Begins immediately
- 60%–70% increase in calcium excretion
- Lose 1%-2% per month in weight-bearing bones
  - Lumbar vertebrae, pelvis, femoral neck, trochanter, tibia, calcaneus
- 8%-12% total after 6-months
- 2.5 year trip to Mars ➔ bone may deteriorate to osteoporotic levels
- The loss of trabecular bone could be so great that osteoblasts would be unable to rebuild post-flight



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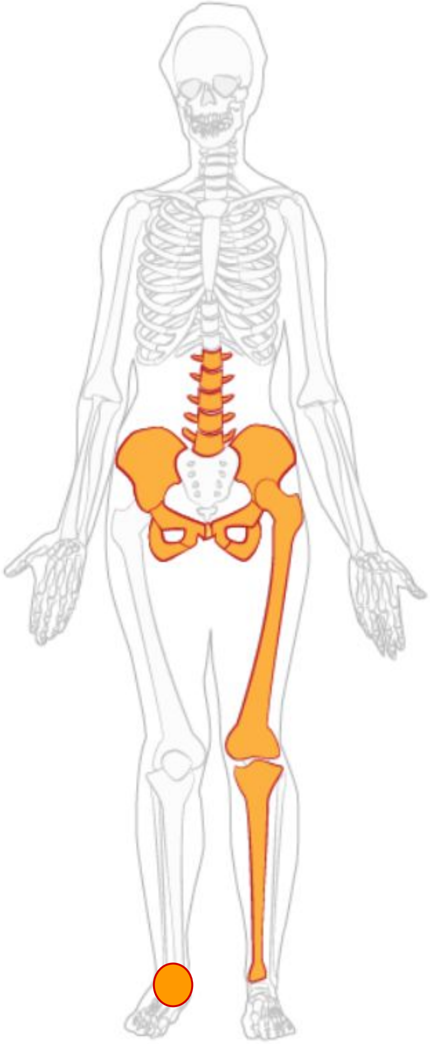

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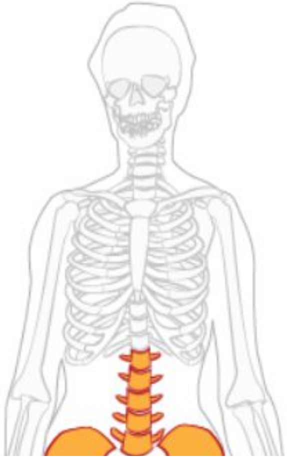
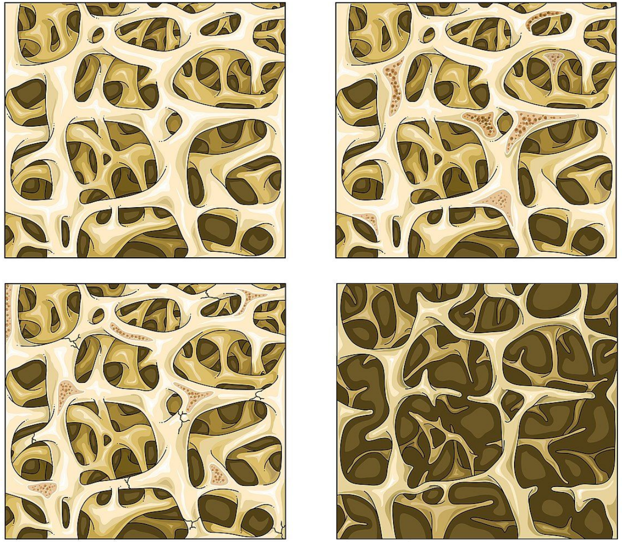
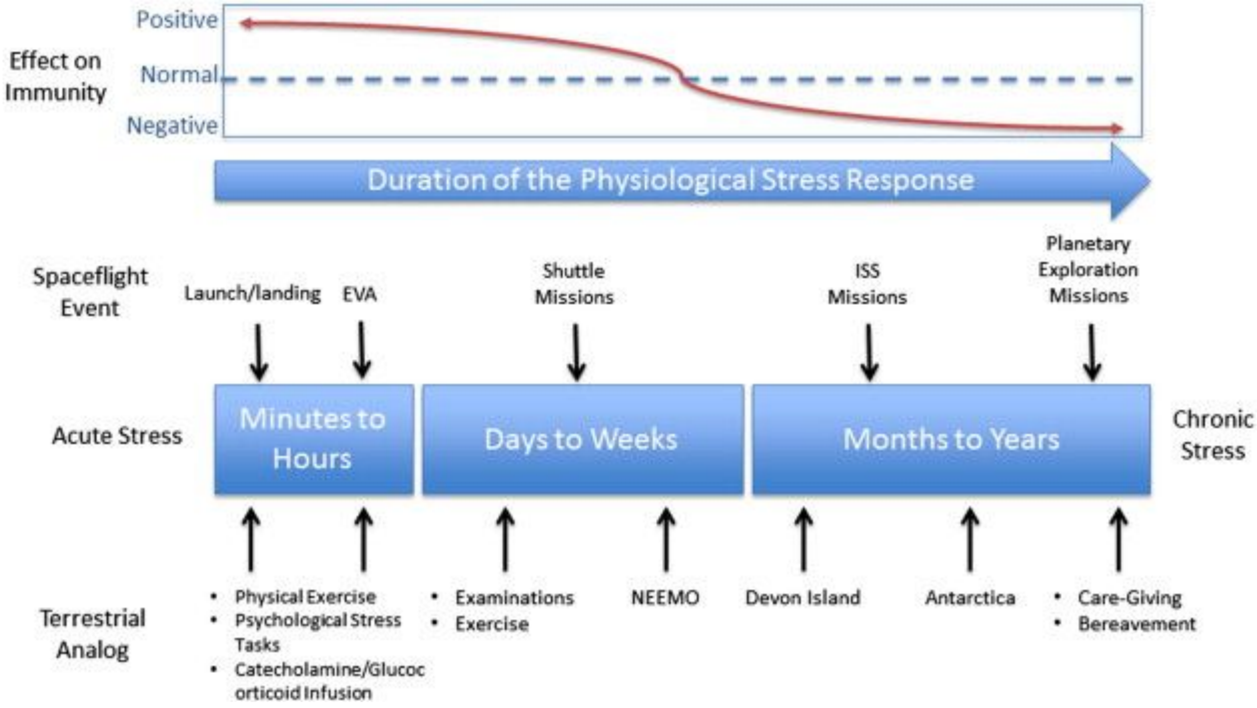
- 8%-12% total after 6-months
- 2.5 year trip to Mars ➔ bone may deteriorate to osteoporotic levels
- May take about 2–3 years to regain lost bone density or **loss may be permanent**





Immune System Dysregulation

- Autoimmunity
- Hypersensitivities
- Infectious diseases
- Latent viral reactivation
- Malignant diseases



Adverse Health Effects, Long & Short Term

Altered distribution of circulating leukocytes, autoimmunity, altered production of cytokines, decreased activity of natural killer cells, decreased function of granulocytes, decreased activation of T cells, altered levels of immunoglobulins, latent viral reactivation, altered virus-specific immunity, altered neuroendocrine responses, allergies, infectious diseases, latent viral reactivation, microbial shifts, alterations in gene regulation, decrease in plasma and blood volume, left ventricular mass increase, loss of muscle mass and strength, negative calcium balance, increased calcium excretion, renal stones, changes in telomere length, gene regulation, gut microbiome composition, body weight, carotid artery dimensions, malignant diseases, subfoveal choroidal thickness and peripapillary total retinal thickness, serum metabolites, decrease of volume in the lower limbs, shift in body fluids, facial pallor, cold sweating, stomach awareness, nausea, hypersensitivities, vomiting, headache, lethargy, bone loss, transient benign intracranial hypertension, neurovestibular effects, puffy face-bird leg syndrome

Adverse Health Effects, Long & Short Term

Going to space is bad for you

Altered distribution of circulating leukocytes, autoimmunity, altered production of cytokines, decreased activity of natural killer cells, decreased function of granulocytes, decreased activation of T cells, altered levels of immunoglobulins, latent viral reactivation, altered virus-specific immunity, altered neuroendocrine responses, allergies, infectious diseases, latent viral reactivation, microbial shifts, alterations in gene regulation, decrease in plasma and blood volume, left ventricular mass increase, loss of muscle mass and strength, negative calcium balance, increased calcium excretion, renal stones, changes in telomere length, gene regulation, gut microbiome composition, body weight, carotid artery dimensions, malignant diseases, subfoveal choroidal thickness and peripapillary total retinal thickness, serum metabolites, decrease of volume in the lower limbs, shift in body fluids, facial pallor, cold sweating, stomach awareness, nausea, hypersensitivities, vomiting, headache, lethargy, bone loss, transient benign intracranial hypertension, neurovestibular effects, puffy face-bird leg syndrome

Tech Issues

- Health concerns
- **Space hazards**
- Power
- Artificial gravity

Health Effects of Radiation

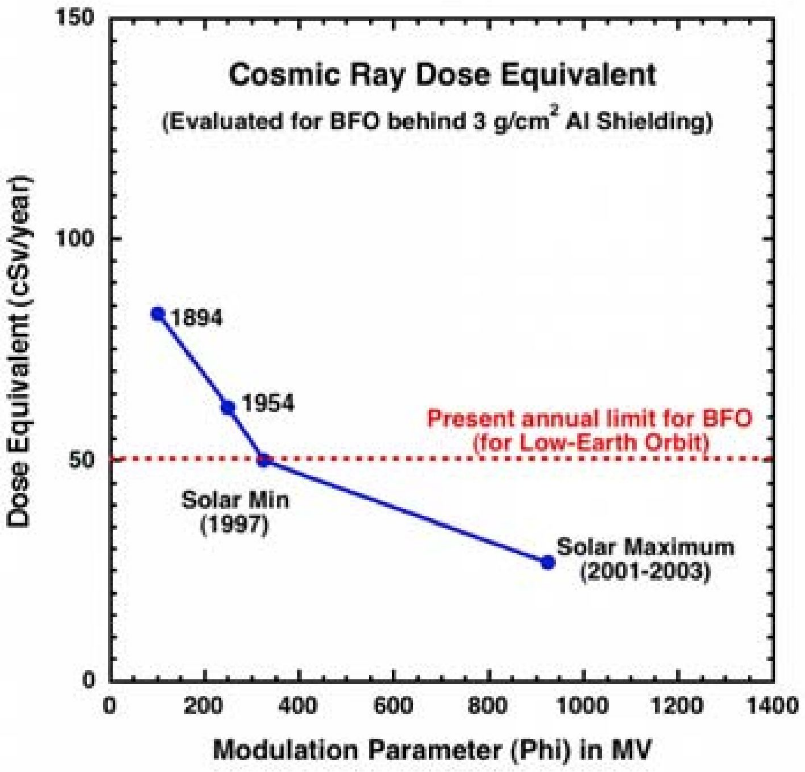
- Increased exposure to background radiation is linked to cancer (especially in the skin and blood forming organs) and other chronic health problems (e.g. cataract formation)
    - A dose of above 0.7 Gy can cause Acute Radiation Syndrome, which consists of nausea, vomiting, and fatigue
        - A dose of as little 0.1 Gy can lead to ARS in high dose-rate conditions
    - A dose of 3.25 Gy causes death in 50% of people, usually from infection and internal bleeding
- In addition to total dosage, a dose rate of greater than 0.05 Gy/h has been found to amplify the biological effects of radiation

Radiation Hazards

- Travel to the Moon and Mars requires passing outside of Earth’s magnetosphere, exposing astronauts to enhanced levels of background radiation
  - Solar Radiation
  - Solar Wind (SW)
  - Galactic Cosmic Radiation (GCR)

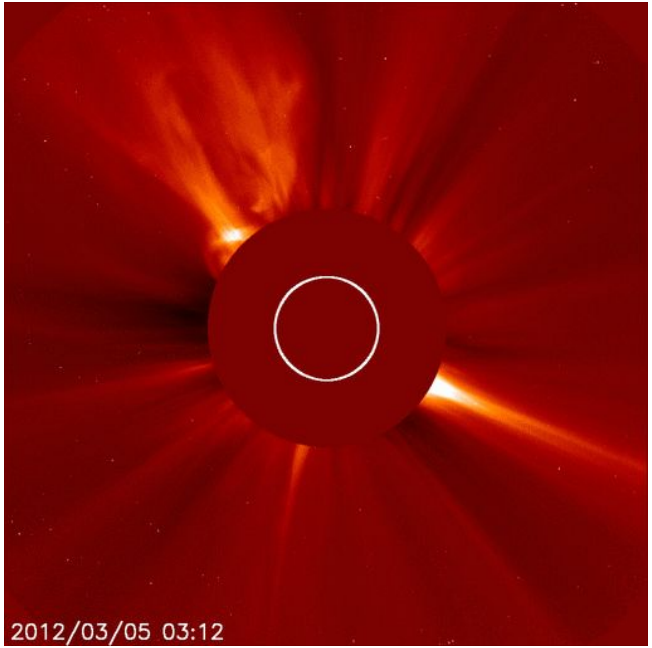
Radiation Hazards

- No additional shielding is needed against SW plasma or UV radiation
- The GCR is difficult to block efficiently, but ~3 g/cm^2 of Aluminum shielding reduces it to below NASA's yearly limit for LEO
  - Estimates of a 2 ½ year crewed Mars Mission (two 6-month transfers and an 18 month stay on the surface) give a total of 114 cSv at solar minimum and 46 cSv at solar maximum



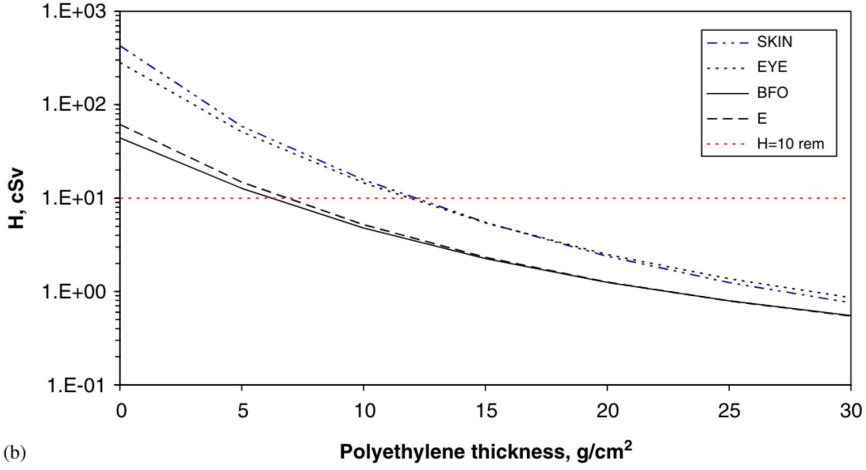
Solar Particle Events

- Sometimes, the Sun explosively ejects plasma, resulting in a Coronal Mass Ejection and (usually) an associated acceleration of protons and ions to GeV energies (SEP)
- Since we rely on seeing the magnetic features on the Sun's surface to predict CME's, we can't predict when one will happen unless it's facing Earth
  - In order to predict SPE's at Mars, we either need to improve space-weather forecasting (and far-side solar modelling), or develop space-weather monitoring infrastructure at Mars



Solar Particle Events

- Unshielded crew members hit with an SPE could be exposed to more than the LEO career limit in one SPE event
  - ~12 g/cm^2 polyethylene shielding (combined with 5 g/cm^2 of Al) can reduce exposure to below the 30-day limit for most SPE's...



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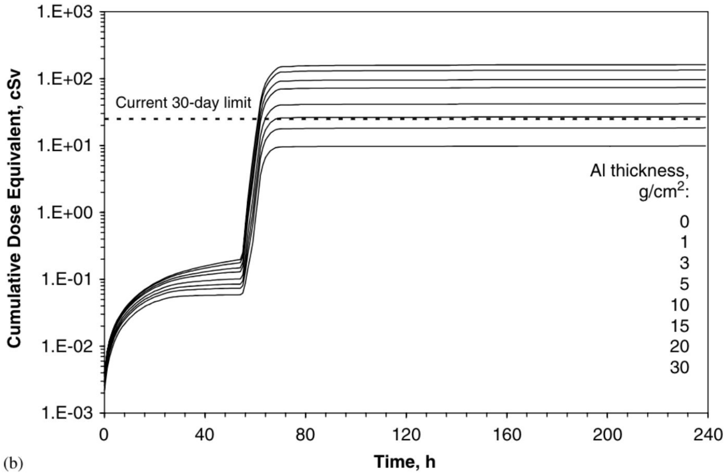
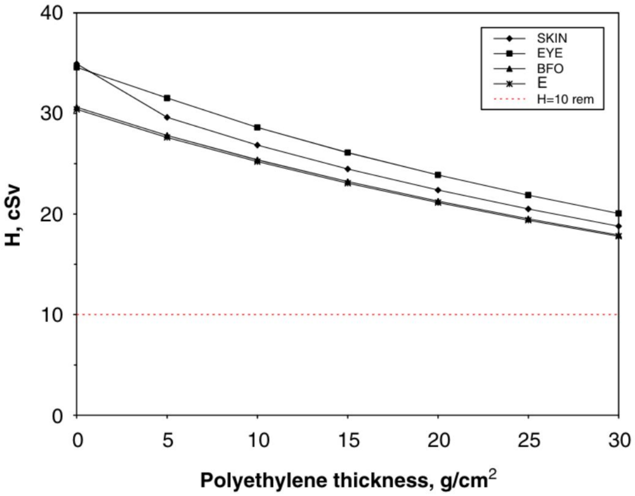
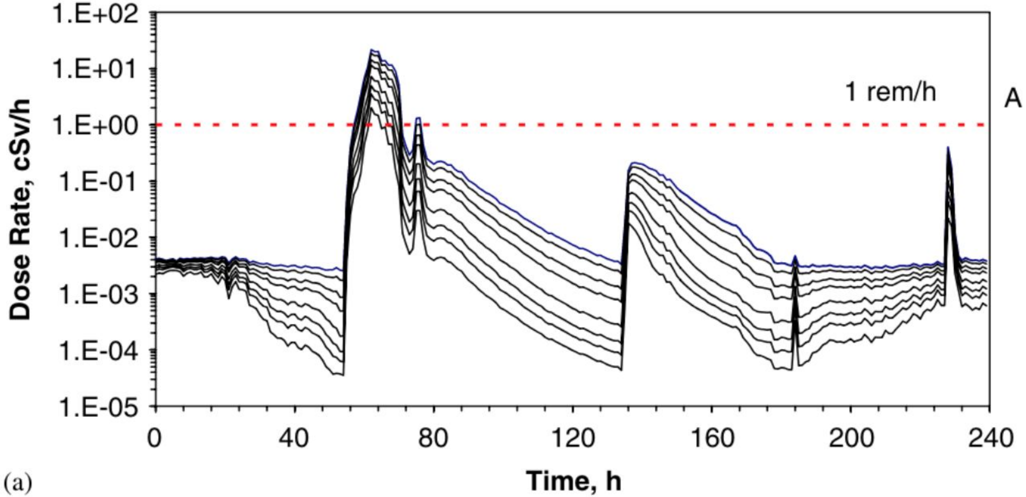


(b)

Solar Particle Events

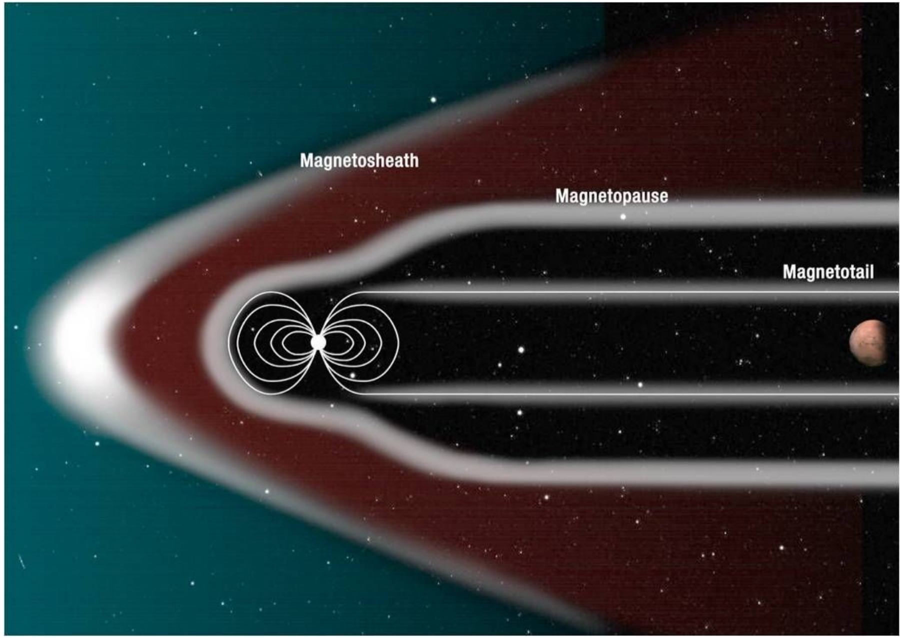
- … but not all





Future Technologies

- Better radiation shields?
  - Right now, the highest efficiency shields are polyethylene and water, due to their high hydrogen content
  - Hypothetically, the most mass-efficient shield is liquid hydrogen
- Mars Magnetosphere?
  - Mars doesn’t have a magnetosphere to protect it from SPE’s, but a 1-2 T magnet at L1 could shield it in its magnetotail



https://phys.org/news/2017-03-nasa-magnetic-shield-mars-atmosphere.html

Tech Issues

- Health concerns
- Space hazards
- **Power**
- Artificial gravity

Power - Mars Mission

Challenges

- Solar flux at mars orbit is 44% of the flux at earth orbit
- Mars has a 25 hour day -- need to have batteries
- Dust

Alternatives

- Radioisotope Thermoelectric Generator (RTG)
  - Proven, but fairly low power (~100 W), safety concerns
- Nuclear Power
  - Safety concerns, weight,

Power - Fuel Production at Mars

Power requirements for producing propellent

- MOXIE (on Mars 2020) plans to produce 10-22 g/hr of O_2 from CO_2 in the air using 300 Watts
  - Would need to be 100x larger to be useful for a human mission
- InSight uses solar panels which produce 600-700 Watts when clean, on a clear day
- Over an 18 month mission, MOXIE would produce only about 260 kg of O_2 if running constantly
- To scale up MOXIE to the desired level would require about 200 m^2 of solar panels

Tech Issues

- Health concerns
- Space hazards
- Power
- **Artificial gravity**

Artificial Gravity

Long-term exposure to microgravity has negative physiological effects

- Vision alterations, sensorimotor alterations, bone fracture, impaired performance, reduced aerobic capacity, urinary retention, back pain, cardiac rhythm problems, intervertebral disk damage, etc…

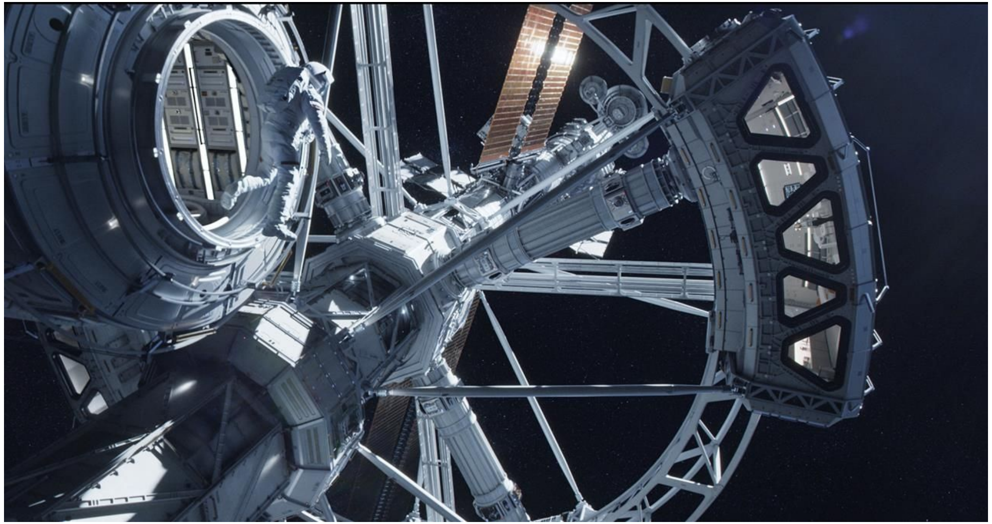
ISS counteracts these effects by:

- Fluid loading
- Exercise

Artificial Gravity - on the way to Mars

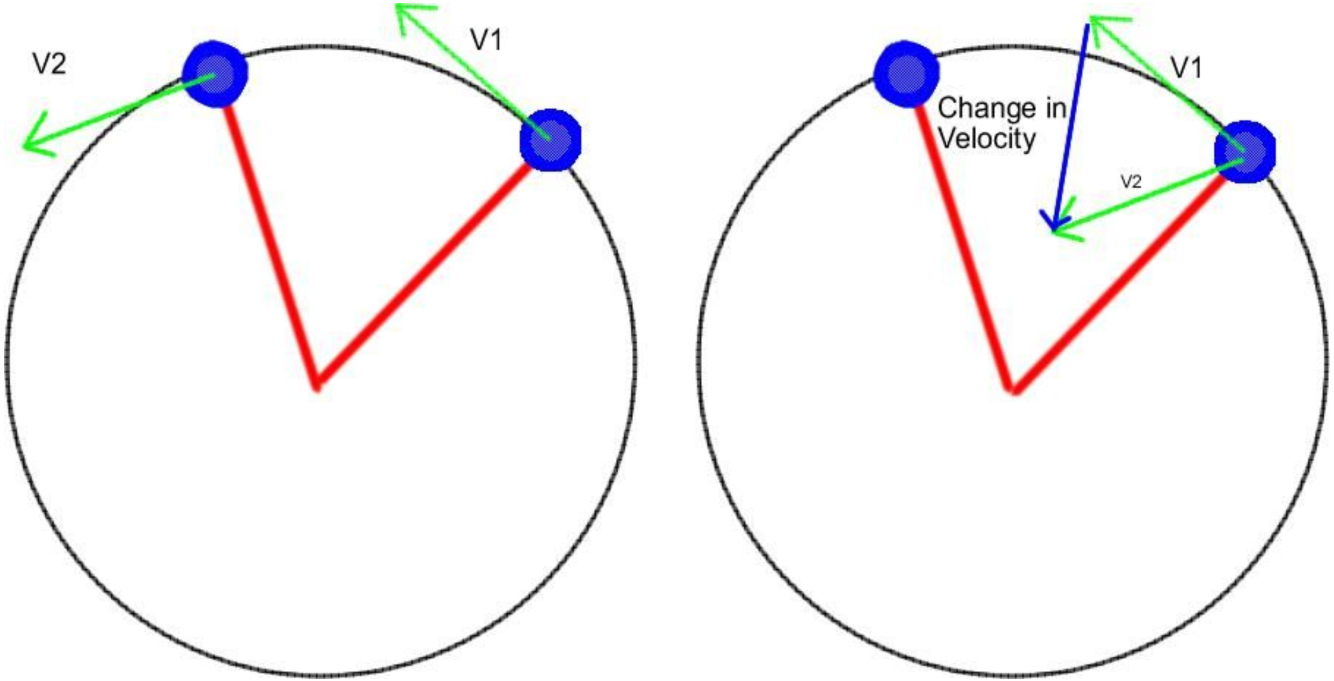
3 ways to produce artificial gravity on a spacecraft

- Entire spacecraft rotates
- Part of spacecraft rotates
- Crew members intermittently use onboard short-radius centrifuge



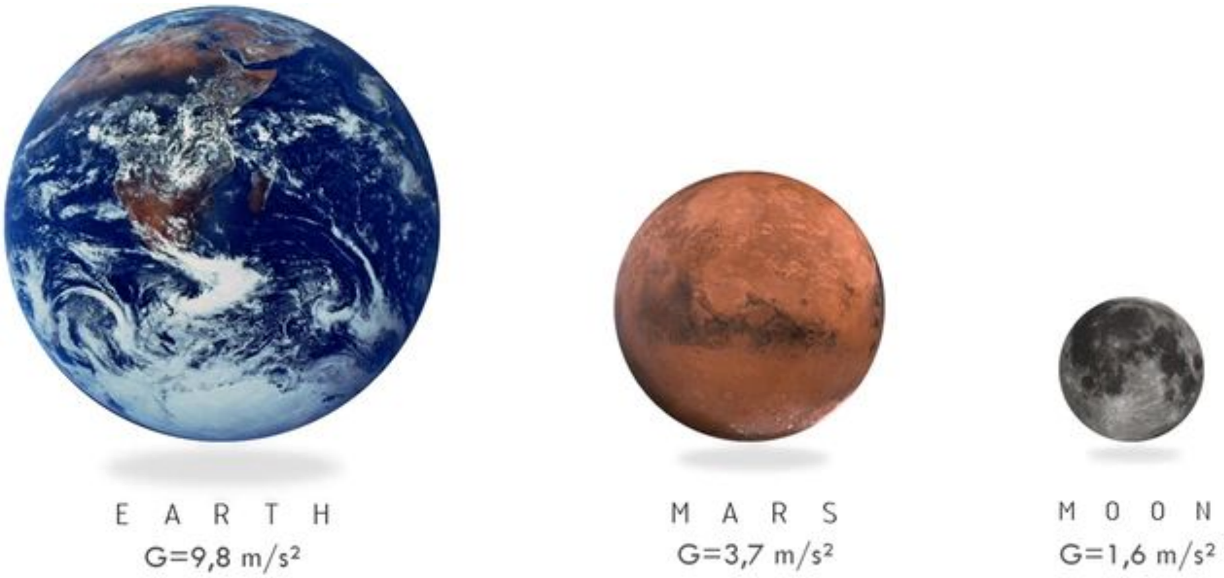
Artificial Gravity - why rotate?

$$a = \frac{v^2}{r}$$



Artificial Gravity - on the surface of Moon/Mars

Long-term habitation on the surface of the Moon or Mars could benefit from artificial gravity



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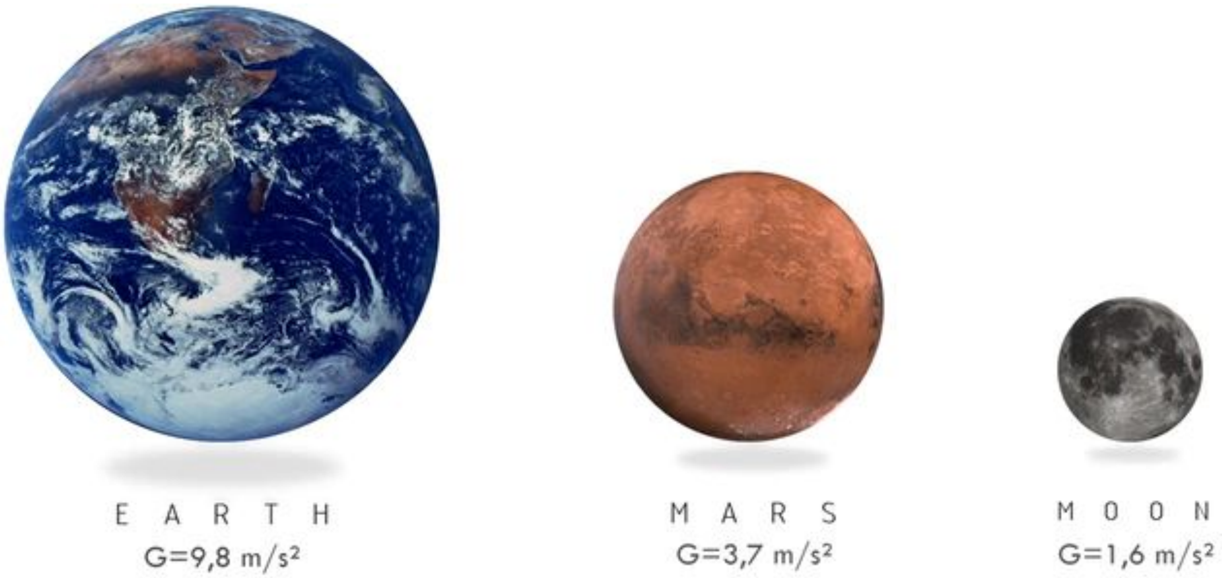
How can we do this?



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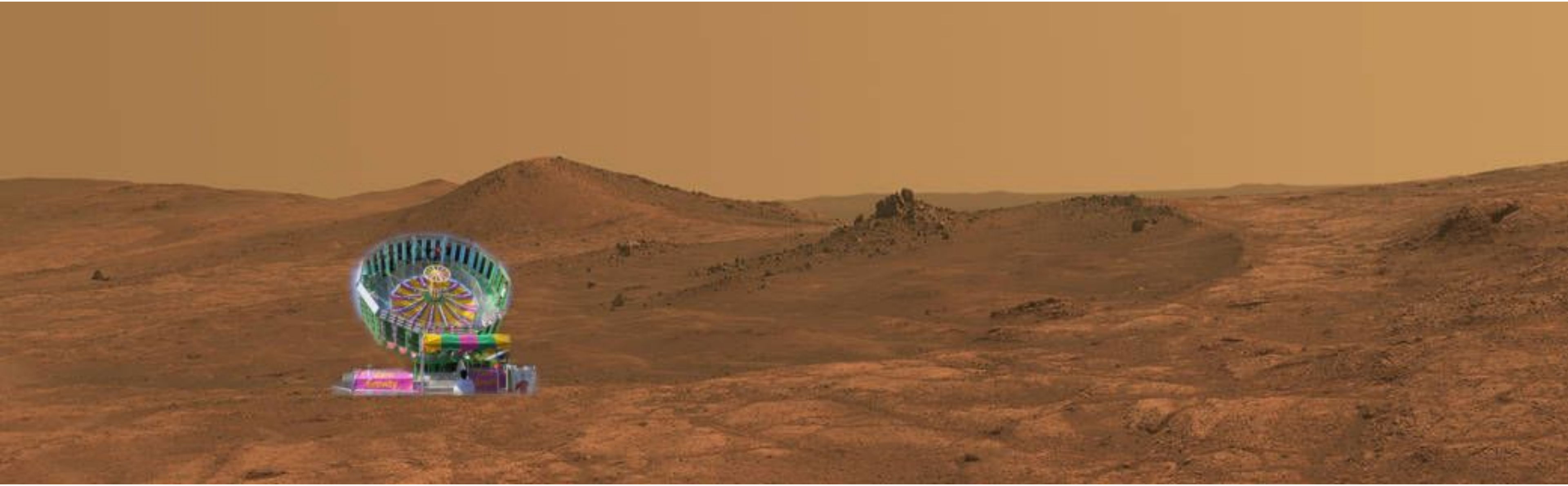


Artificial Gravity

2015 NASA Technology Roadmaps TA 7:
Human Exploration Destination Systems

7.4.4 Artificial Gravity	Objectives:	Reduce crew health degradation on long-duration spaceflight missions.
	Challenges:	Spacecraft complexity, course correction, and maneuvering.
	Benefits:	Reduces the detrimental effects of long-duration zero-gravity on human physiology and increases crew productivity and well-being while reducing long-term human health and performance risks. Allows for reconsidering the size and deployment sequence of several elements in the mission, which can result in a more flexible and compact packaging strategy on the launch vehicle.

Table 20. TA 7.4.4 Technology Candidates – not in priority order

TA	Technology Name	Description
7.4.4.1	Off-Center of Gravity Thrust Technology	Provides steering, control, and course correction of artificial gravity rotating and spinning spacecraft.
7.4.4.2	Controlled Energy Release Mechanisms	Controlled energy release mechanisms for deployable and retracting mechanism.

Artificial Gravity - should we do it?

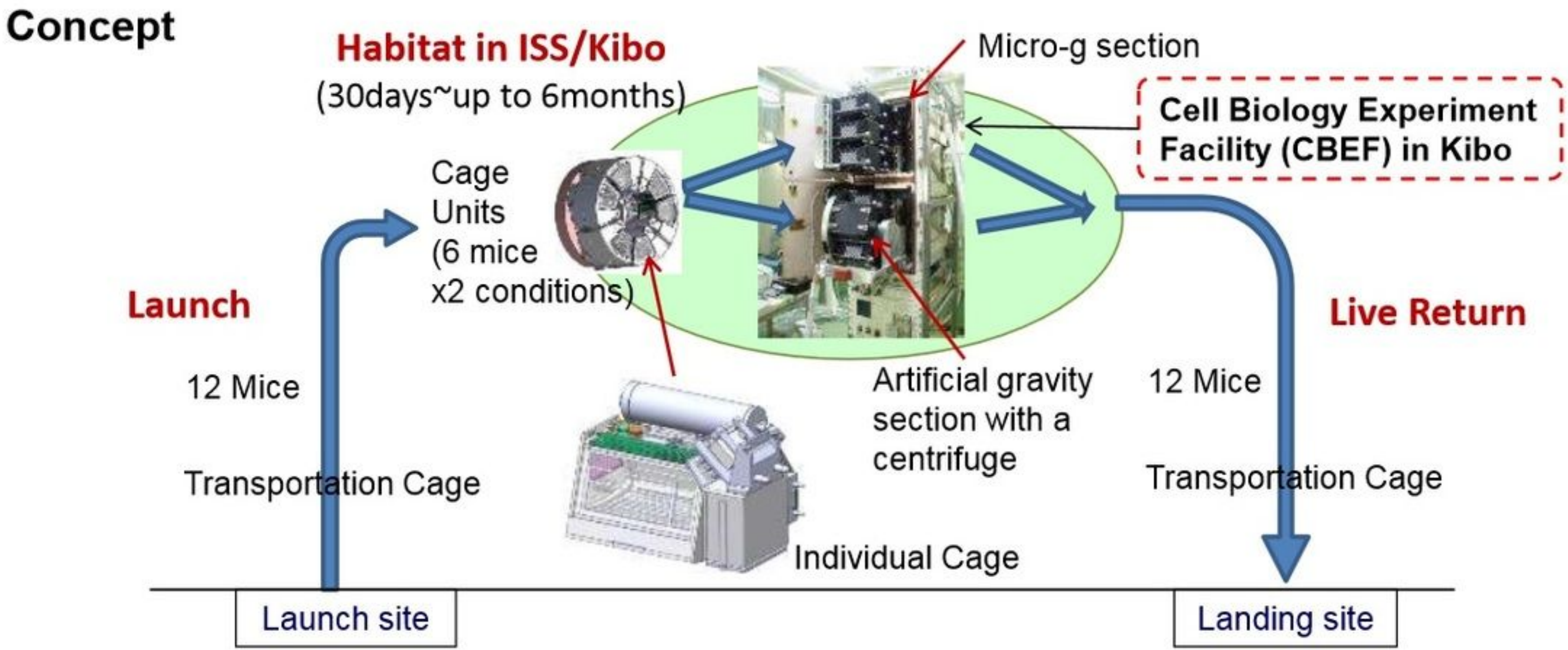
NASA organized an international workshop in Feb. 2016 to create an artificial gravity roadmap. Research is main goal at this point.

- Gap 1 - what are the physiological effects of microgravity on humans?
- Gap 2 - what are the effects of Mars gravity on humans?
- Gap 3 - can humans adapt to rotation, how fast can we spin them, and how frequently can we spin them?
- Gap 4 - what are the health effects of artificial gravity on humans?
- Gap 5 - testing in space vs. on Earth

Artificial Gravity - should we do it?

Gap 1 - what are the physiological effects of microgravity on humans?

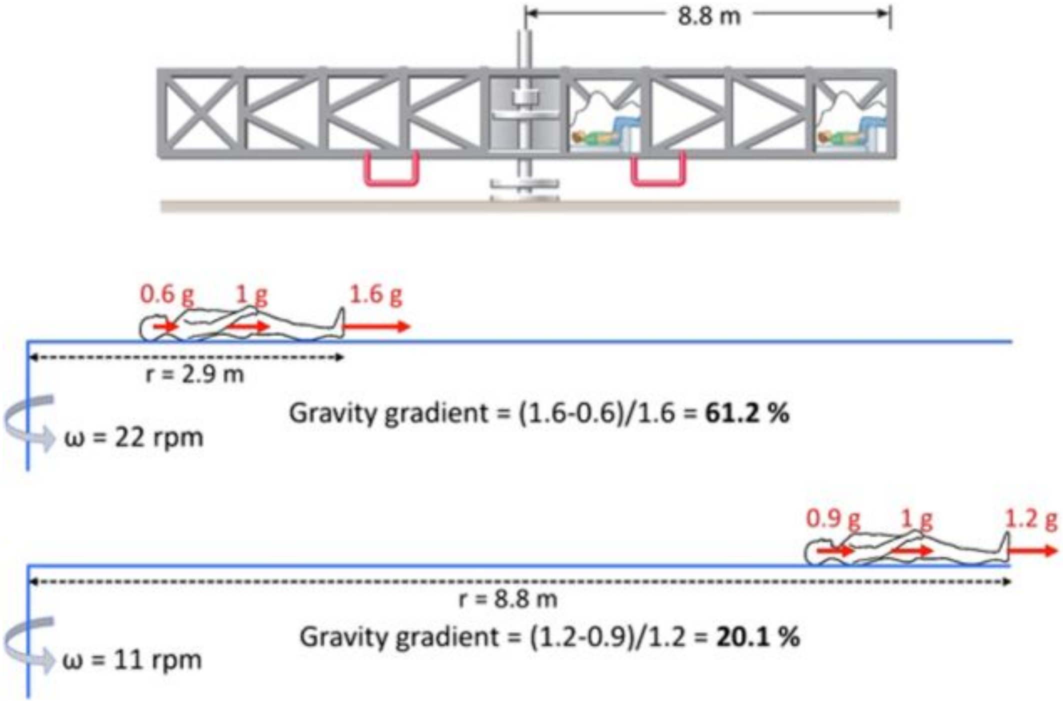
- JAXA Mouse Habitat Unit on ISS



Artificial Gravity - is rotating humans a good idea?

Gap 4 - what are the health effects of artificial gravity on humans?

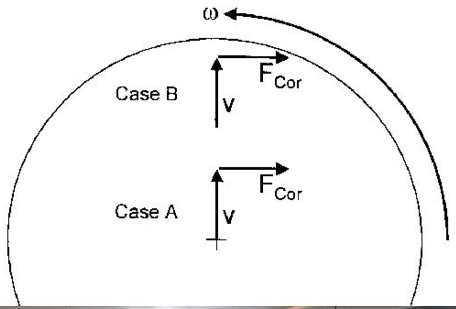
- Short- and long-radius centrifugation
  - Counteracts headward fluid shift, reduces vascular and lymphatic congestion, allows outflow of cerebral spinal fluid
  - Experiment will study physiological responses and ability to handle objects with increased radius



Artificial Gravity - is rotating humans a good idea?

Gap 4 - what are the health effects of artificial gravity on humans?

- Slowly rotating rooms
    - Causes disorientation due to Coriolis force and cross-coupled accelerations during movement.
    - Experiments in Pensacola in the 60s showed that most people hadn't completely adjusted to rotation after 12 days at 10 rpm.
    - Progressively increasing rotation rate helps people adapt.



Artificial Gravity

2020 NASA Technology Taxonomy TX06:

Human Health, Life Support, & Habitation systems

TX06.3.7 System Transformative Health and Performance Concepts

This area covers technologies to fundamentally transform the manner in which human health and performance occur in space.

Example Technologies

- Autonomous clinical care
- Artificial gravity
- Bioengineering

GROUP DISCUSSION

Based on these societal and technological issues:
Who should go and what should we bring on a mission to Mars?

Resources - Tech Issues

Artificial Gravity

https://www.nasa.gov/offices/oct/taxonomy/index.html
https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_7_human_exploration_destination_final.pdf
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5701204/
https://www.nasa.gov/audience/foreducators/teachingfromspace/dayinthelife/exercise-adil-index.html
http://iss.jaxa.jp/en/kiboexp/pm/mhu/
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150009516.pdf

Health Concerns

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3142679/
https://www.mdpi.com/2072-6643/4/12/2047/htm
https://www.faseb.org/Portals/2/PDFs/LSRO_Legacy_Reports/1985_Bone%20Demineralization%20During%20Space%20Flight.pdf?pdf=1985_Bone%20Demineralization%20During%20Space%20Flight
https://www.cmaj.ca/content/cmaj/180/13/1317.full.pdf
https://link.springer.com/article/10.1007/s00421-012-2548-9
https://link.springer.com/content/pdf/10.1007%2Fs00421-012-2548-9.pdf
https://www.fasebj.org/doi/abs/10.1096/fasebj.7.5.8462780
https://www.sciencedirect.com/science/article/pii/S0889159114000129
https://science.sciencemag.org/content/sci/364/6436/eaau8650.full.pdf
https://mmrjournal.biomedcentral.com/articles/10.1186/s40779-018-0165-6
https://www.nature.com/articles/npjmgrav201519
https://arc.aiaa.org/doi/pdf/10.2514/6.1992-1370

Resources - Tech Issues, cont’d

Power
https://mars.nasa.gov/mars2020/mission/instruments/moxie/
https://mars.nasa.gov/news/8393/insight-is-catching-rays-on-mars/?site=insight

Radiation Hazards
https://humanresearchroadmap.nasa.gov/Evidence/reports/EvidenceBook.pdf
https://www.sciencedirect.com/science/article/pii/S1350448706001399
http://www.srl.caltech.edu/ACE/ASC/DATA/bibliography/ICRC2005/usa-mewaldt-RA-abs1-sh35-oral.pdf

Resources - Societal Issues

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Supplemental Slides

Health Effects: Countermeasures Chart

Table 2: Countermeasures to minimize risks to astronauts before, during and after spaceflight

Physiologic effects; duration of flight	Before flight	During flight	After flight
Shift in body fluids (cardiovascular effects)			
Long and short duration	• None	• Exercise • Negative pressure suits for the lower body (to mechanically induce an earth-equivalent body fluid distribution while in space) • On re-entry: isotonic fluid taken orally,[2] use of a pressurized anti-gravity suit to minimize fluid pooling in the legs, use of a liquid cooling garment, recumbent position for astronauts on long-duration missions[3]	• The use of midodrine (to counter postflight orthostatic intolerance) is being considered
Space motion sickness (neurovestibular effects)			
Long and short duration	• Neurovestibular conditioning (virtual reality, parabolic or aerobatic flights) • Antinauseant medications	• Antinauseant medications[4] (promethazine, scopolamine[5]) often given with dextroamphetamine to counter sedation	• Intravenous antinauseant and fluid administration for severe postlanding syndrome
Muscle atrophy			
Long and short duration	• Resistance exercise program • Aerobic exercise program	• Exercise (aerobic and strength) monitored and modified by on-ground medical support team[6,7,8] • Others measures under consideration: electrical muscle stimulation, dietary supplementation with amino acids, artificial gravity (e.g., rotating spaceship)[6,7,8,9]	• Muscle conditioning and rehabilitation program, including a combination of adapted exercises, massages, icing and nonsteroidal anti-inflammatory agents
Bone demineralization			
Long and short duration	• 3 DXA scans per year		
Long duration	• 2 DXA scans within 6 months after flight	• Resistance exercises[10,11,12] • Diet supplemented with calcium and vitamins D and K[10,13] • Others measures under consideration: bisphosphonates; potassium citrate; parathyroid hormone; low magnitude, high frequency vibrations[10,11,14]	• 4 DXA scans over 3 years • Temporary restriction of some activities (e.g., flying high-performance jets)[14,15]
Psychosocial effects			
Long and short duration	• Specific criteria for recruitment[16,17] and specific behavioural competencies for assignment to missions • Didactic training, including teamwork in multicultural settings, and field-based training in leadership and followership skills	• Individualized work schedules monitored by ground support crew, with 8 hours rest per day • Short-acting hypnotics (to prevent sleep loss and cumulative sleep deficit) and modafanil (to enhance performance after periods of reduced sleep)	
Long duration			• Psychological debriefing sessions
Immune dysregulation			
Long and short duration	• Quarantine program • Restricted contact with general public for 1 week before flight	• Daily exposure to artificial gravity[18] and nutritional supplementation with nucleotides[19] are being considered	• Collection of biological samples to assess immune function