Humans Back on the Moon

Research, Technology Development, and Validation for Bioastronautics

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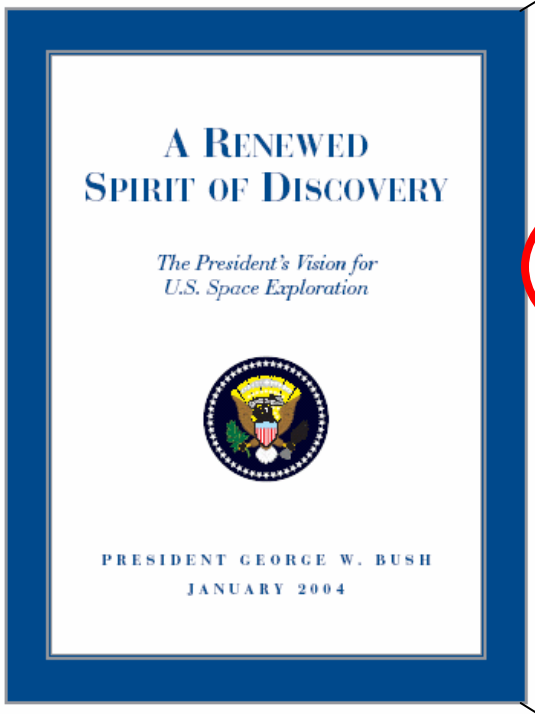
National Vision for Space Exploration

THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM



Implement a sustained and affordable human and robotic program to explore the solar system and beyond

Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

VSE & ESAS lunar mission progression

1. Sortie Missions (2016+)
   - 4 crewmembers
   - 4-14 days on Moon

2. Establish and Occupy a Base (2020+)
   - 4-8 crewmembers
   - Up to 6 months

3. Mars and beyond
   - Moon as stage for solar system exploration (2030+)

Risk Mitigation and Performance Optimization

- Pre-2004: NASA planned that all needed Bioastronautics research for Mars missions would be done on ISS or on Earth
- 2004: Announcement of the Vision for Space Exploration, with shift of emphasis to goals beyond Earth orbit
  - ISS & ground-based research to re-focus specifically to support exploration, rather than a broader science program
  - Opportunities for research on ISS (crew & hardware availability) inadequate to retire large number of risks
    - Unlikely to fully quantify and retire medical risks
  - Additional risk reduction *via* lunar mission research

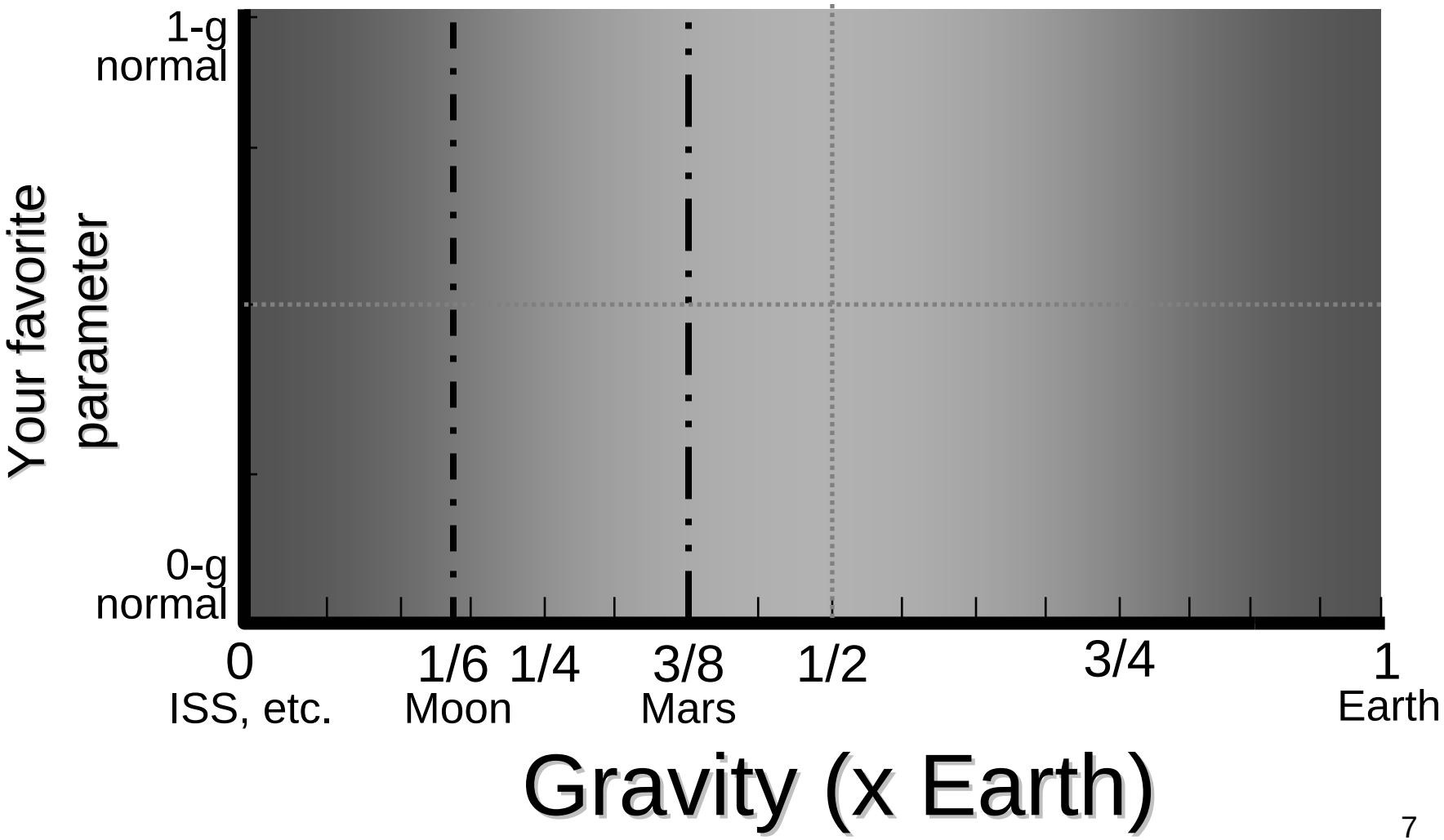
Bioastronautics preparation for VSE

- SEI/FLO (1989)
- Bioastronautics Roadmap (BR) (1998-2005)
- ESAS support (2005)
- Continuing data mining and generalization during STS and ISS eras

Some bioastronautically-relevant lunar environmental factors

- Earth
  - 1 g
  - 1 atm.
  - Temperature
  - 24 hr. solar day at equator
- Moon
  - 1/6 g
  - 0 atm. (byo)
  - +120C / -150C (byo)
  - 708 hr. solar day at equator
    - Circadian rhythms
    - Mission activity planning
  - Dust (abrasive, possibly biologically reactive)
  - Intense ionizing radiation (byo)

How does human physiological capacity vary with gravity?



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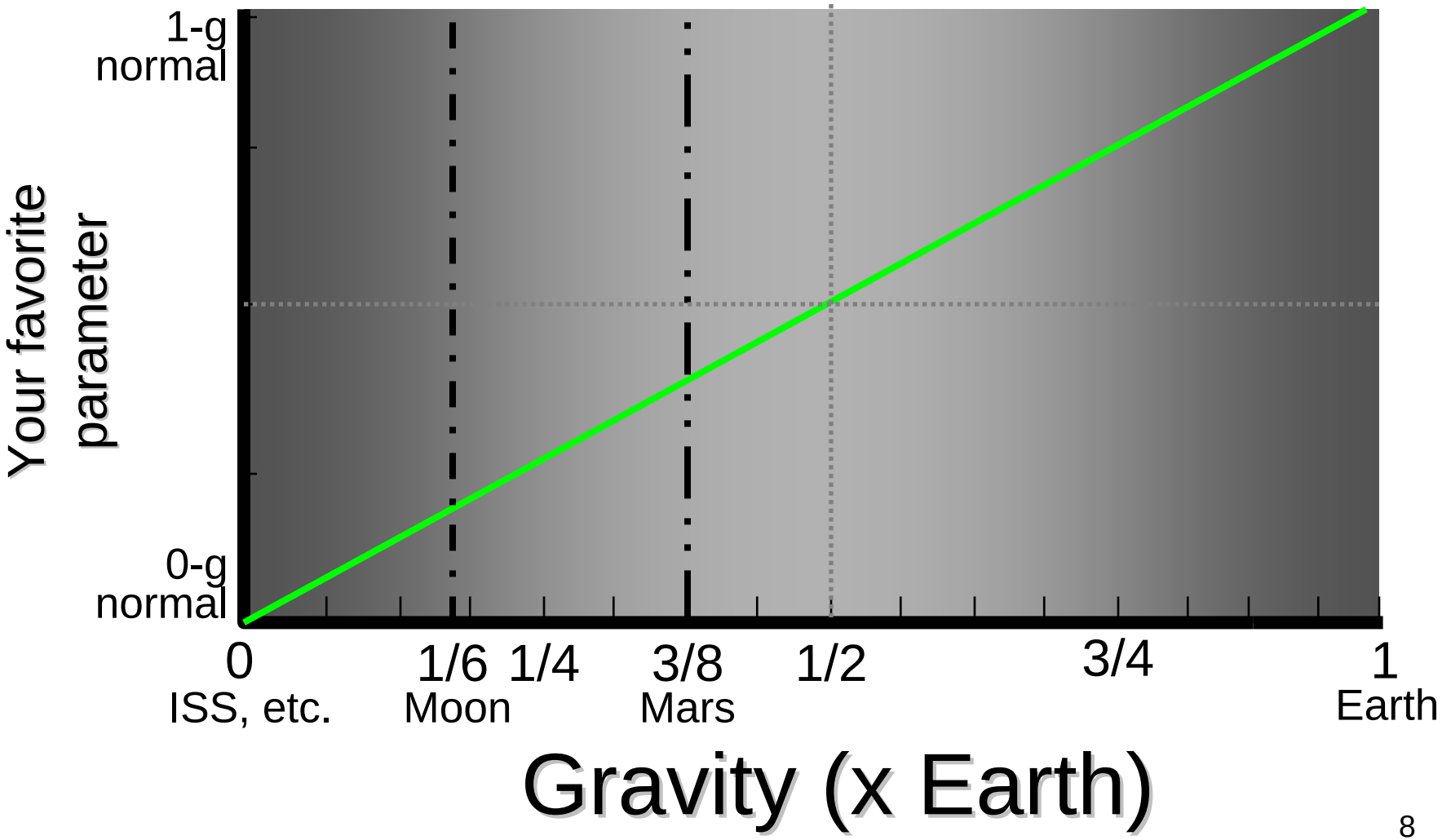

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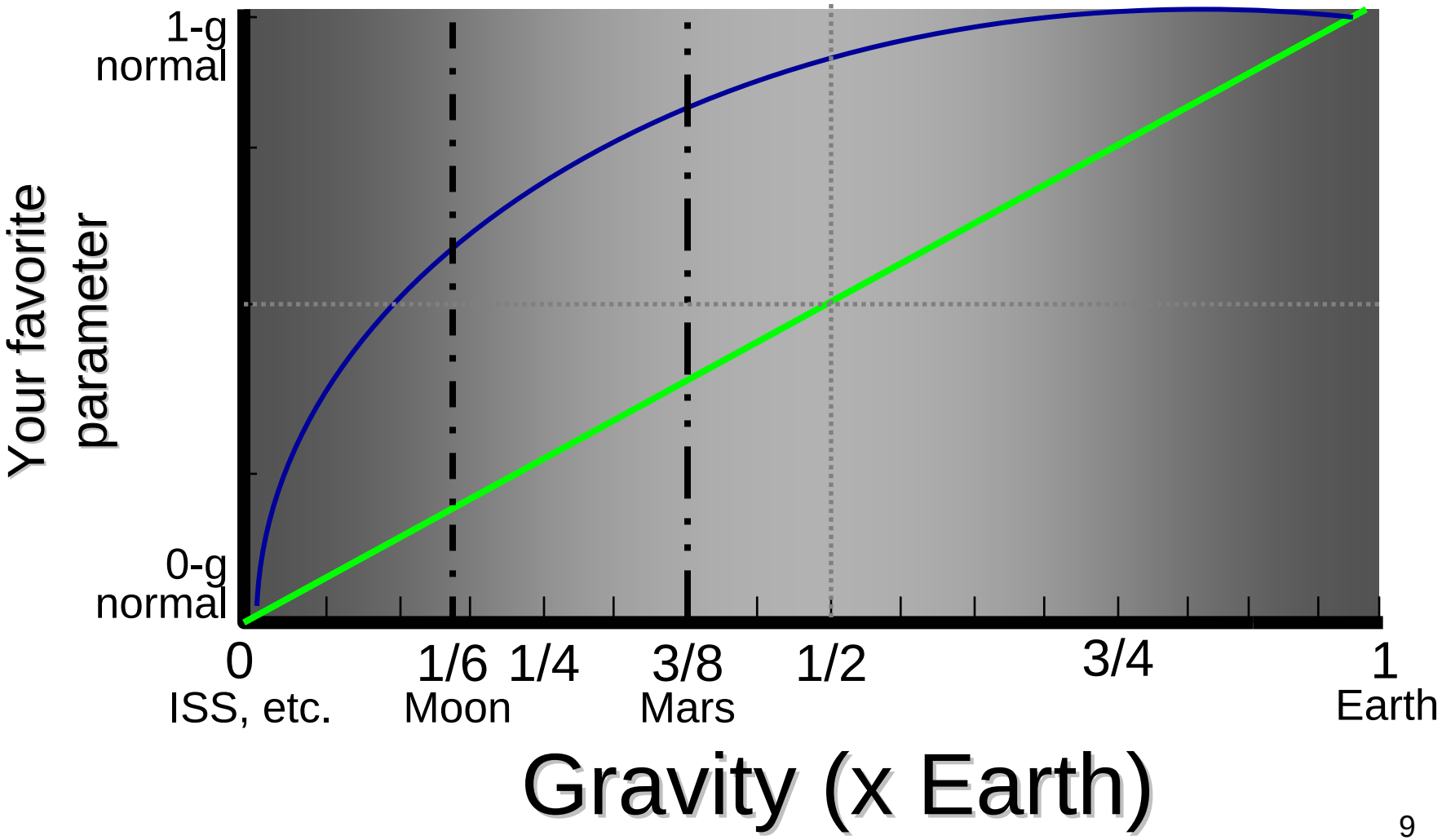

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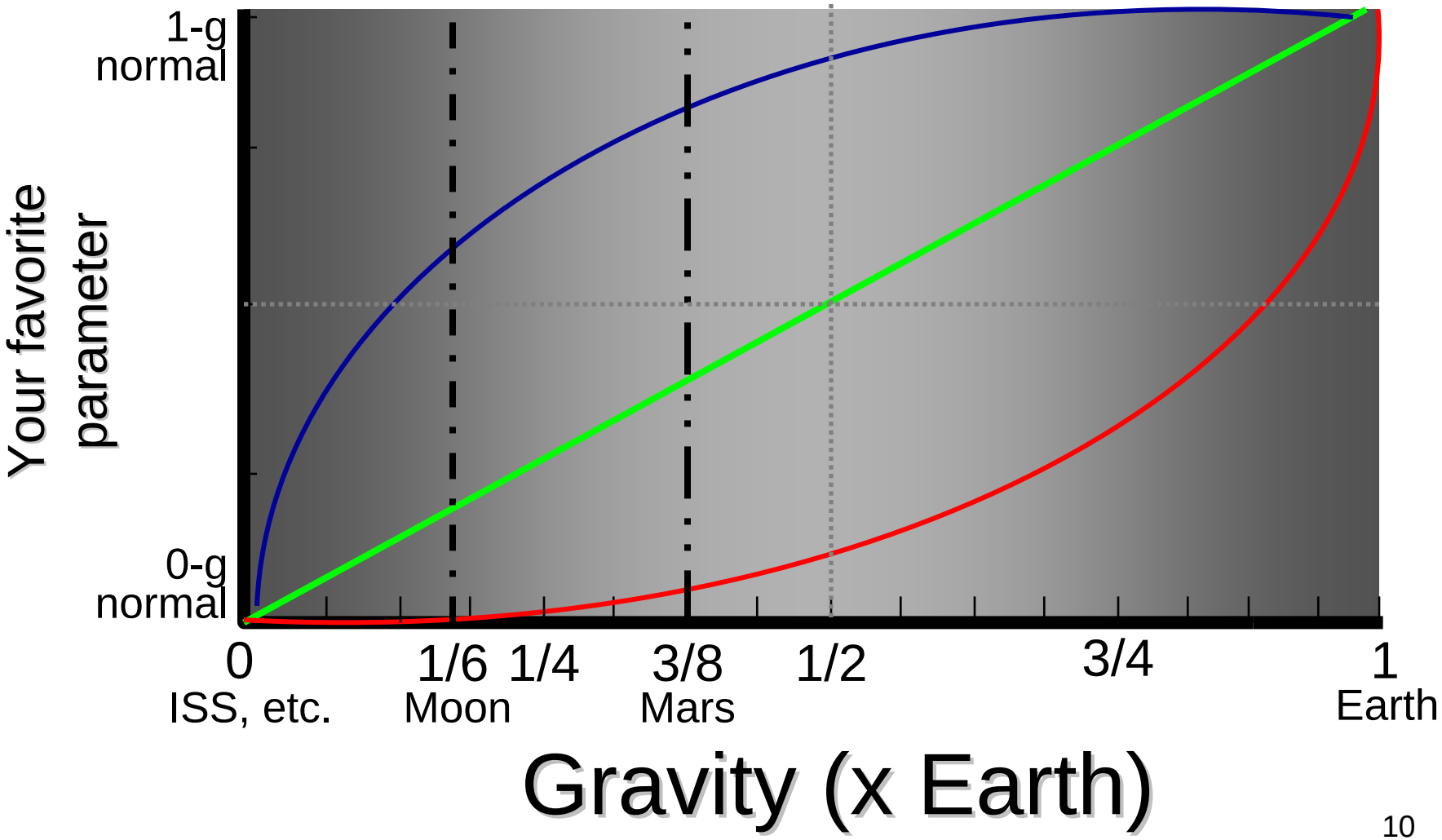

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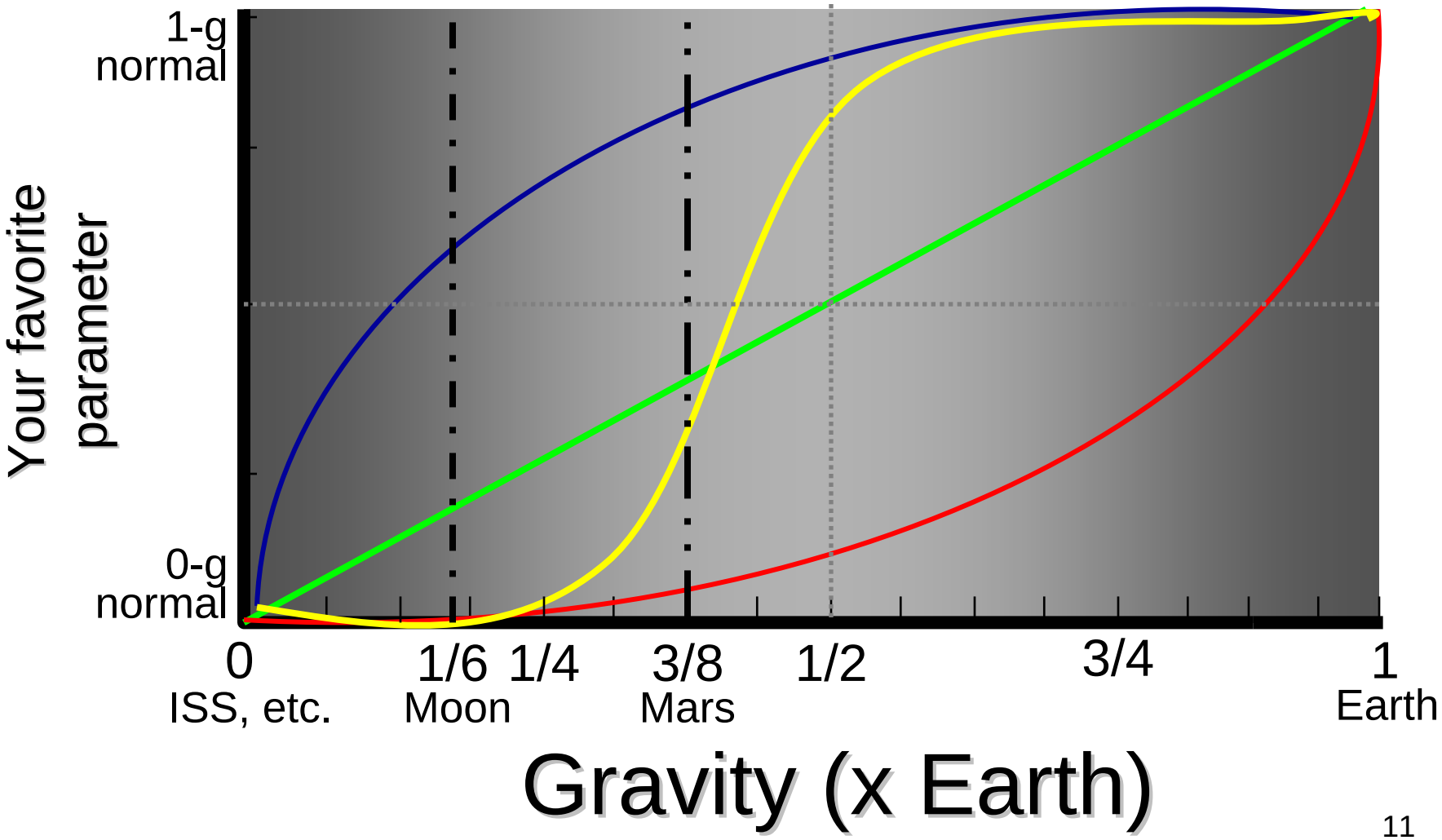

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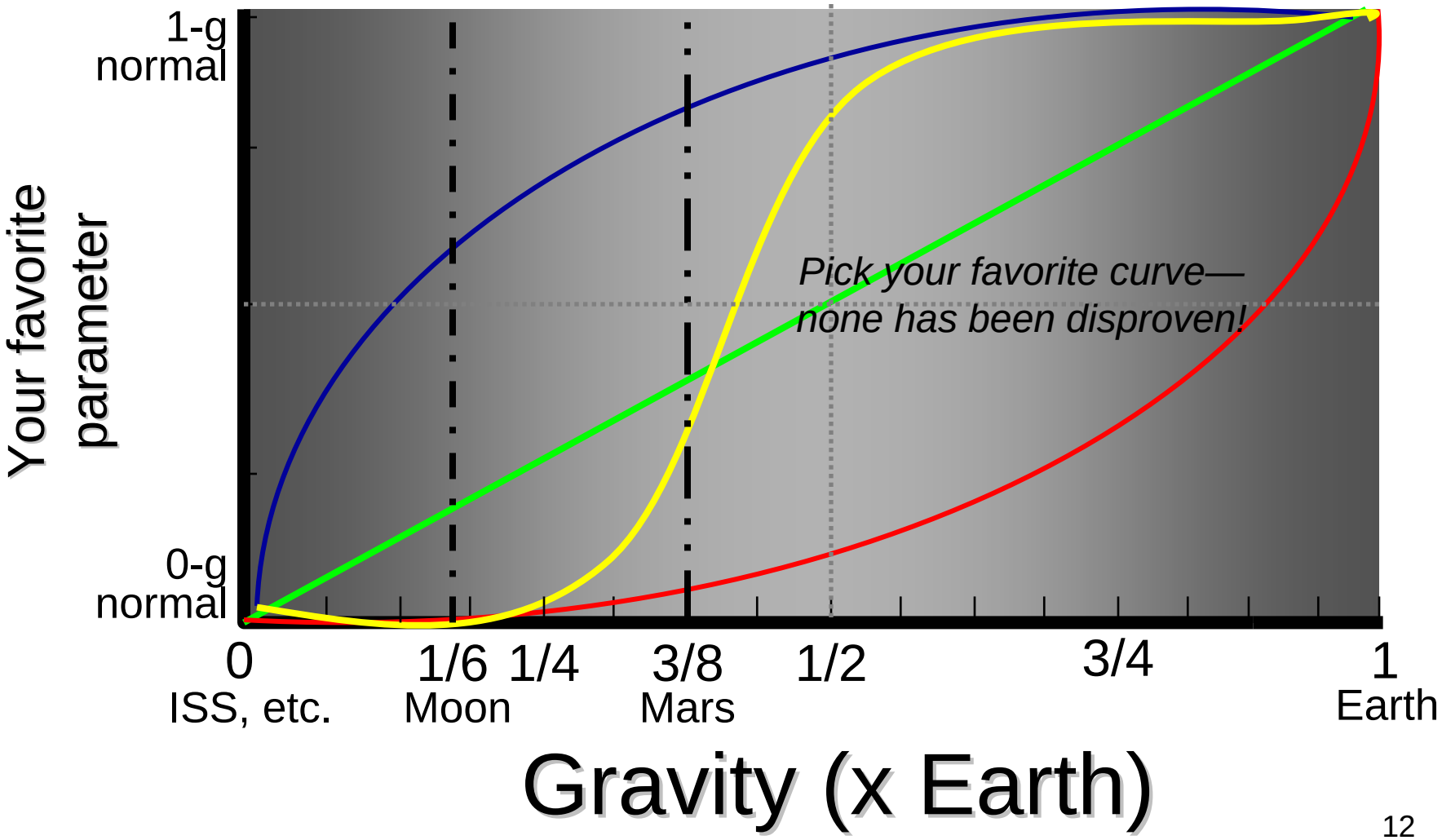


Protective effect of lunar gravity?

- If lunar gravity is adequate countermeasure for adaptation, then expected benefit from Mars gravity is greater
  - Generally considered unlikely (esp., lunar)
- If lunar g levels not adequate, additional countermeasures will be necessary
- Note: Even at 1 g, we use daily countermeasures

Environmental characteristics of DRMs analyzed by BR

	1-year ISS	Lunar	Mars DRM
Launch Date	~2005 - 2016	2015 - 2020	NET 2025 - 2030 Oct.2024; Nov.2026; Jan.2029; Feb.2031
Mission Duration	1 year	10-44 days	30 months
Outbound Transit & Return Transit (each)	2 days	3-7 days	4-6 months
On-site Duration	1 year	4 - 30 days	18 months
One-way Comm. Lag	0+	1.3 seconds+	3 - 20 minutes
“G” Transitions (assume no artificial gravity)	2	4	4
Hypogravity	0 g	1/6 g on Moon	1/3 g on Mars
Spacecraft Internal Environment	14.7 p.s.i 21% O_2	TBD (maybe 10.2 p.s.i, 30% O_2)	TBD
Equivalent Deep Space Radiation Exposure	33% per year plus trapped electrons (SAA)	100% while in transit plus 50% while on or near Moon (due to solid angle shielding)	100% while in transit plus 40% while on Mars (due to solid angle & atmosphere shielding) plus TBD neutron backscatter

Operational characteristics of DRMs analyzed by BR

	1-year ISS	Lunar	Mars DRM
Crew Size	2+	4-6	6
EVA opportunities	0 - 4 per LDM	2 - 3 per week ~ 4 - 15 EVAs per person	2 - 3 per week ~ 180 EVAs per person
Destination Planet Landing Responsibilities	N/A	Piloting (or monitoring autoland) aboard LSAM	Monitor autoland aboard MSAM
Destination Planet Landing Posture	N/A	Upright	Recumbent (atmosphere entry); upright (landing)
Earth Landing Responsibilities	Passenger aboard STS; supervisory autoland aboard Soyuz, CEV	Monitoring autoland aboard CEV	Monitoring autoland aboard CEV
Earth Landing Posture	Recumbent	Recumbent	Recumbent

BR risks for “Moon 30”

- Human health risks
  - Priority 1
    - Major illness & trauma
    - Carcinogenesis from radiation exposure
  - Priority 2
    - Injury to joints and intervertebral structures; serious cardiac dysrhythmias; diminished cardiac and vascular function; Impaired sensory motor capability during piloting and post-landing
    - Clinical monitoring and prevention; pharmacology; informatics; skill maintenance
    - Psychosocial and neurobehavioral problems; cognitive task mismatch
    - Acute and chronic effects of radiation on CNS and tissue degeneration
    - Define acceptable limits for air and water contaminants

BR risks for “Moon 30”

- System performance/efficiency risks
  - Priority 1
    - Air quality; water quality; internal surfaces, food and soil; external environment
  - Priority 2
    - Integrated autonomous control of LSS
    - Space suits and PLSS
    - Acceptable atmosphere; acceptable thermal balance; waste management; provide and recover potable water; bioregenerative LSS
    - Mismatch between crew physical capabilities and task demands; poorly integrated ground, crew and automation functions

New capabilities needed for human exploration of Moon and Mars

- Moon
  - Improved radiation event detection and protection
  - Efficient and effective medical monitoring and medical care
  - Efficient and effective environmental monitoring
  - Efficient trash management (e.g., food packaging)
  - Means of stabilizing pharmaceuticals for long durations
  - Efficient and effective exercise countermeasures (hardware and protocols)
  - Enhanced human performance monitoring and prediction for physical and mental performance
  - Understanding of lunar dust toxicity
- Mars
  - Physiological, psychological, and pharmacological countermeasures, including exercise, nutrition, performance training, and skill maintenance
  - Efficient and effective remote medical care systems, including some level of autonomous health care
  - Enhanced capability for preserving nutritional value of food during long duration missions
  - Behavioral health tools and training
  - Efficient and effective radiation shielding capabilities

New technologies needed for human exploration of Moon and Mars

- Improved exercise countermeasure hardware
- Improved food packaging
- Improved autonomous health care systems, including detection, diagnosis, and treatment
- Improved pharmaceutical preservation techniques
- Improved personal radiation dosimetry

ISS research/activities to enable development of needed technologies

- Verification of integrated physiological countermeasures in an operational environment
- Human system monitoring using Clinical Status Evaluation approach (e.g., Holter monitoring to obtain comprehensive database on human physiology during six month long missions)
- Evaluation of prototype autonomous medical systems
- Environmental monitoring evaluation and validation
- Confirmation of biological effects of space flight radiation environment

Bioastronautics research for, about and on the Moon

		Venue for research			
		Earth	ISS	Lunar sortie	Lunar Base
Beneficiary	Lunar sortie	X	x	X	
	Lunar Base	X	X	X	X
	Mars	X	X	x	X

Medical strategies for lunar missions

- Human is most complex, most adaptable system in human space operations.
  - Failure catastrophic, to individual and to mission.
- Cannot prevent <u>all</u> medical contingencies
  - Pre-flight screening and attention to safety to minimize frequency, severity of injury or illness
  - Majority of medical events likely to be minor
    - Headaches, minor cuts, short-lived viral infection, etc.
  - Analogs, experience foretell more serious events
  - Crew must handle wide range of medical procedures
- Routine monitoring of astronaut health
  - Document continued fitness for duty
  - Document adaptation to lunar environment for Mars program (closest thing to “research” on Moon)

Medical strategy for lunar sorties

- Build upon STS/CEV/ISS model
- Preventive medicine as prime risk mitigation
- Low-overhead exercise capability in CEV during transit to/from Moon
  - May not have exercise capability in LSAM
- Two crew medical officers
  - Not necessarily MD
  - MD astronauts likely to be multi-qualified (e.g., also engineers, pilots, geologists, etc.)
- Immediate life-saving measures available
  - critical care after serious event will be limited by consumables, training, and LSAM constraints
- Stabilization of ill or injured crew, transport to Earth are TBD

Medical strategy for lunar outpost

- Build upon ISS/Sortie model
- Preventive medicine as prime risk mitigation
- Low-overhead exercise capability
  - CEV during transit to/from Moon
  - Habitat during surface
- Increased exposure risk on lunar surface plus increased Earth return time requires advanced and ambulatory care at outpost
  - Crew medical officers should include EMT or MD
  - Immediate life-saving measures to be available
    - greater amount of equipment in habitat
    - critical care needed after serious event still limited by consumables, training, and habitat constraints
- Stabilization of ill or injured crew, transport to Earth are TBD

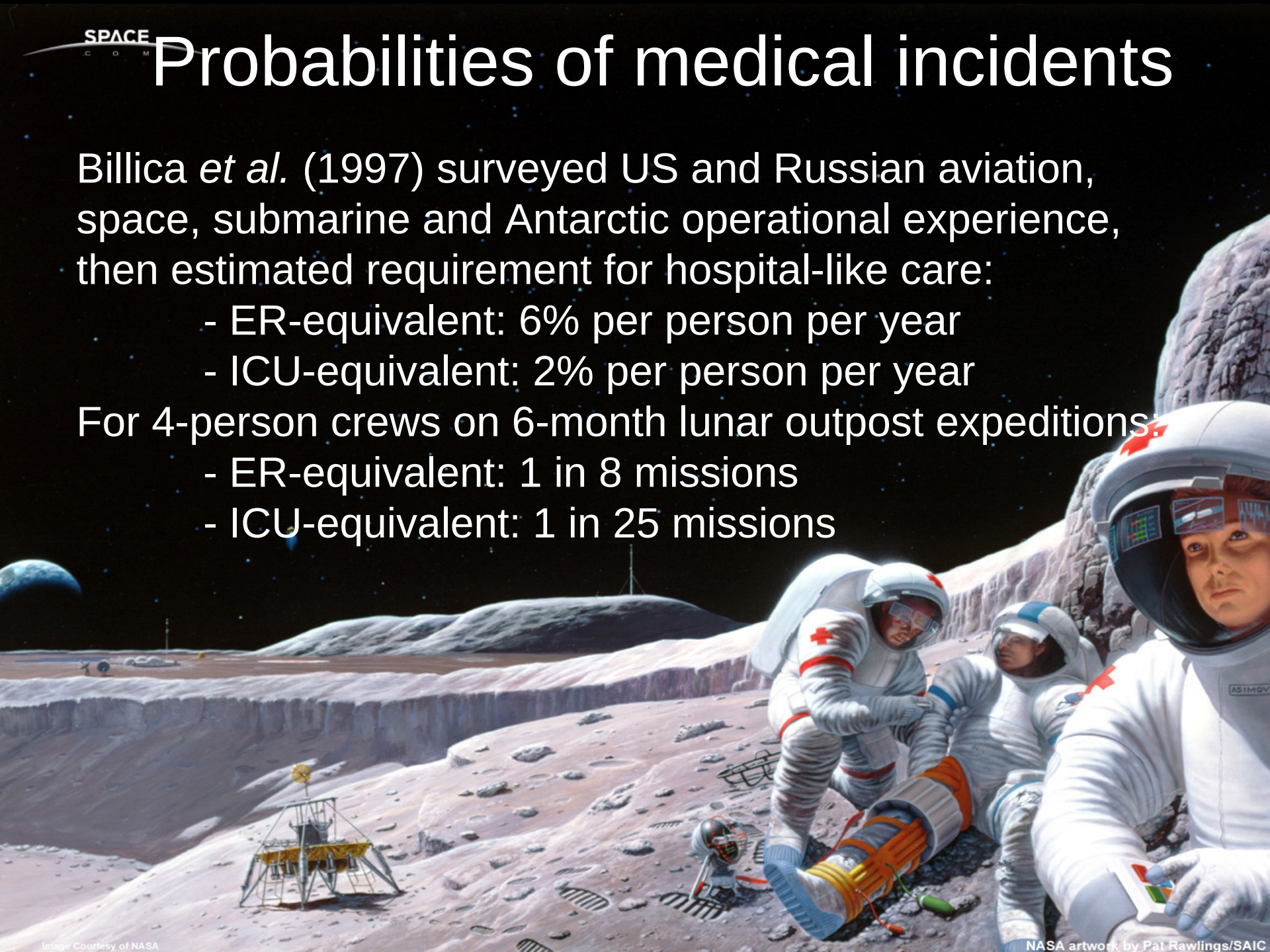
Probabilities of medical incidents

Billica *et al.* (1997) surveyed US and Russian aviation, space, submarine and Antarctic operational experience, then estimated requirement for hospital-like care:

- ER-equivalent: 6% per person per year
- ICU-equivalent: 2% per person per year

For 4-person crews on 6-month lunar outpost expeditions:

- ER-equivalent: 1 in 8 missions
- ICU-equivalent: 1 in 25 missions



Behavioral health strategy for lunar outpost

- Behavioral health strategies and equipment to be important
  - As on Mir and ISS
  - Allow for adequate rest, communication with loved ones, adequate recreation, and a workload that is interesting, challenging, not excessive

Fitness strategy for lunar outpost

- Reasons for exercise in lunar habitat
  1. Daily exercise, as on ISS, on non-EVA days
     - Reduce risk of injury due to weakening bones and muscles
  2. Quantitative health monitoring purposes
     - Requires calibrated and well characterized equipment.
  3. Rehabilitation after injury
- Include aerobic and resistance exercise
- Creative approaches for multipurpose equipment to reduce overall mass delivered to the lunar surface
- Vibration-dampening as appropriate to limit structural stress on habitat

Hardware strategy for lunar outpost

- All medical care and countermeasure equipment
  - Testing and demonstration in advance of Mars missions
  - First and foremost for crew health support at the outpost
- Hardware must be certified for primary mission, recertified for each subsequent crew
- Long-term goal for countermeasure and crew health equipment is verification of hardware capability
  - Beyond requirements for six month Moon mission
  - Fulfill additional or more rigorous requirements of Mars mission
- Design goal should be equivalent to long-term stay on Mars: at least 18 months
- Repairs and replacement are feasible, even if undesirable
  - Develop the spares and repair strategy for Mars

Countermeasures strategy for lunar outpost

- ISS countermeasures initially used in lunar habitat
  - Transition to program to evaluate the effects of partial gravity and determine countermeasure requirements under lunar conditions
- Probably conservative requirements (mass, power, crew time)
- With Moon experience, revised requirements might significantly reduce overhead to support a human mission on Mars
  - Conservative approach to obtaining data on Moon will be paid back during Mars missions

Return to the Moon…

…Enabled by Bioastronautics