

**Protecting Astronaut Health:  
A Grand Challenge for Prolonged Spaceflight  
and Inter-Planetary Exploration**

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**ASU Course LIA 194:  
Living In Space: Know Before You Go!  
21 April 2023**



- **proving humans can survive in space**
  - **Soviet cosmonaut, Yuri Gagarin**
  - **12 April 1961**



- **proving humans could land and return from an extra-terrestrial body**
  - **US astronauts Neal Armstrong and Buzz Aldrin**
  - **moon landing, 20 July 1969**

# Expansion of Human Space Travel



- **extended survival in low earth orbit (LEO)  
in orbiting space stations (1973-present)**



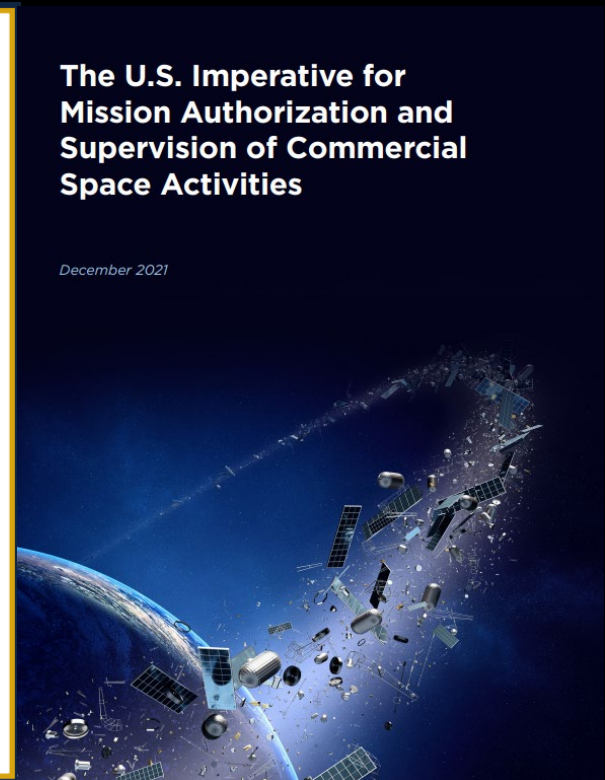
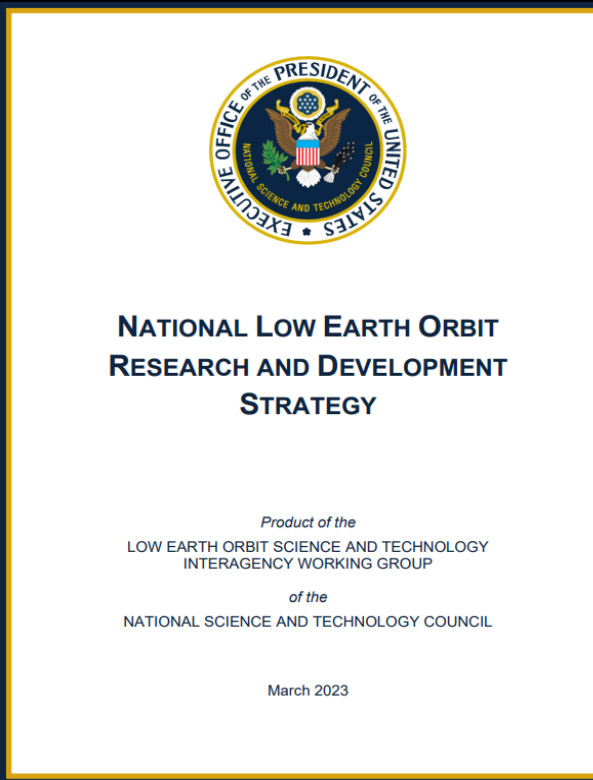
- **back to moon**
  - **Artemis III (2025?)**
  - **(cis)lunar gateway (?)**
  - **permanent moon base (?)**



- **and beyond (?)**

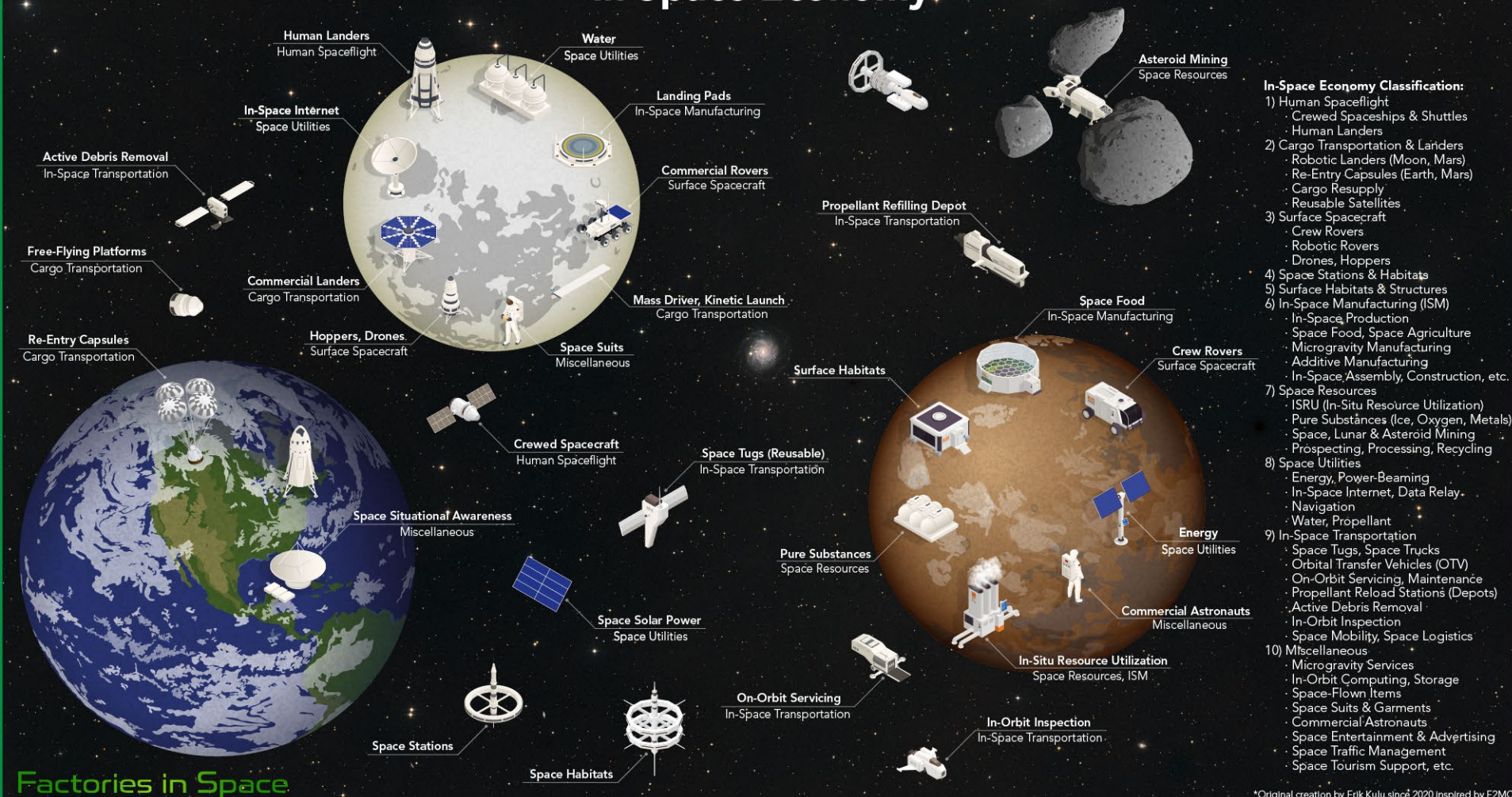
# Projected Major Expansion in Space Exploration and Space Commerce

- space-for-military superiority
- space-for-space economy
- space-for-earth economy





# In-Space Economy



\*Original creation by Erik Kulu since 2020 Inspired by E2MC

# The Rapid Rise of Private Sector Space Commerce and a New Civilian Space Workforce



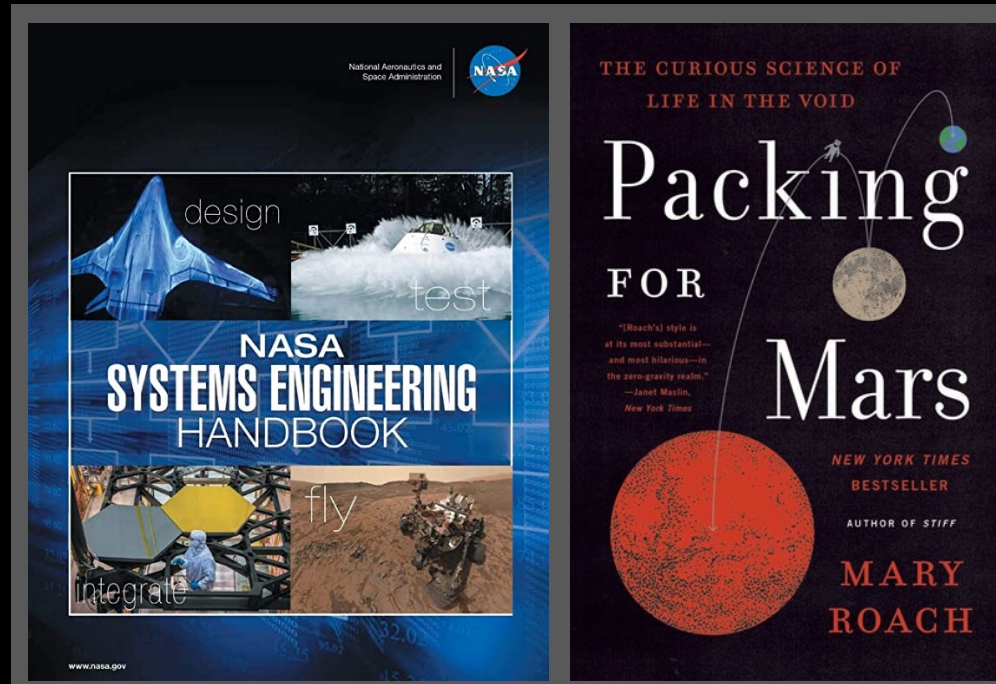
- “astropreneurs”
- “astronaut homesteaders”



# Humans in Space

- **how to thrive in high-risk non-physiological environments for extended periods?**
- **how to mitigate the short-and long-term adverse health risks from life off-earth?**
- **how to design and construct sustainable habitats on the moon and beyond?**

# Humans in Space

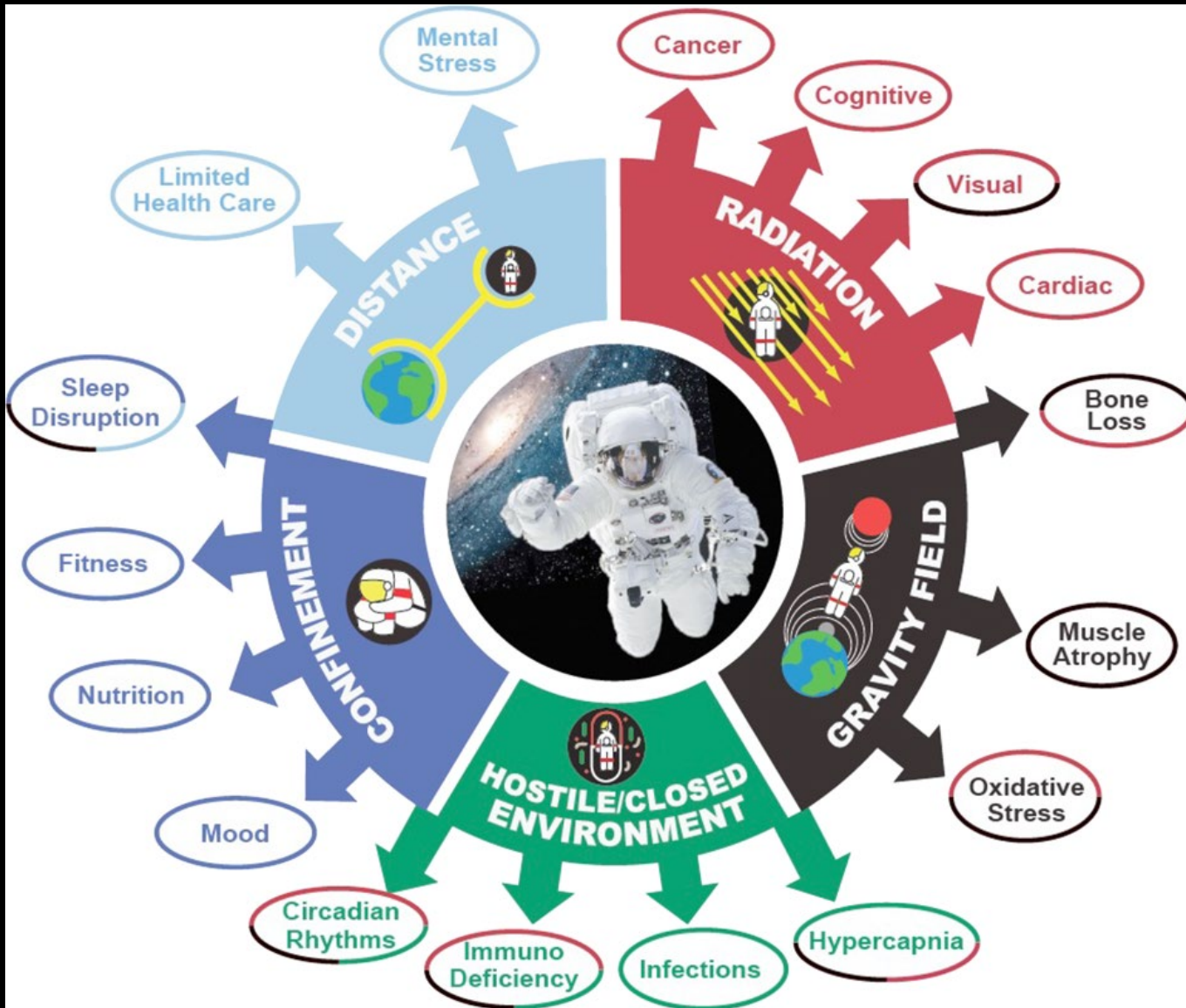


- to rocket scientists and engineers, humans are a problem
- humans are a complex, irritating component that comes with wide variation in physical and mental traits creating diverse and often unknown vulnerabilities that could threaten mission success
- everything we take for granted on earth has to be rethought, released, rehearsed

# Space-Induced Changes in Different Body Systems

- major knowledge gaps
- small 'N' problem: limited number of individuals in space to date
- LEO environments very different from deep space missions
- need for prolonged follow-up (longitudinal studies)
- reversible versus irreversible changes
- additional as yet unknown and unpredicted adverse risks
- eventual need for genetic modification for sustainable health augmentation (non-heritable), enhancement (heritable) in long duration missions and off-earth habitats?
- human reproduction in space

# Altered Health in LEO Environments



# Space Adaption Syndrome: Humpty Dumpty Head, Chicken Legs

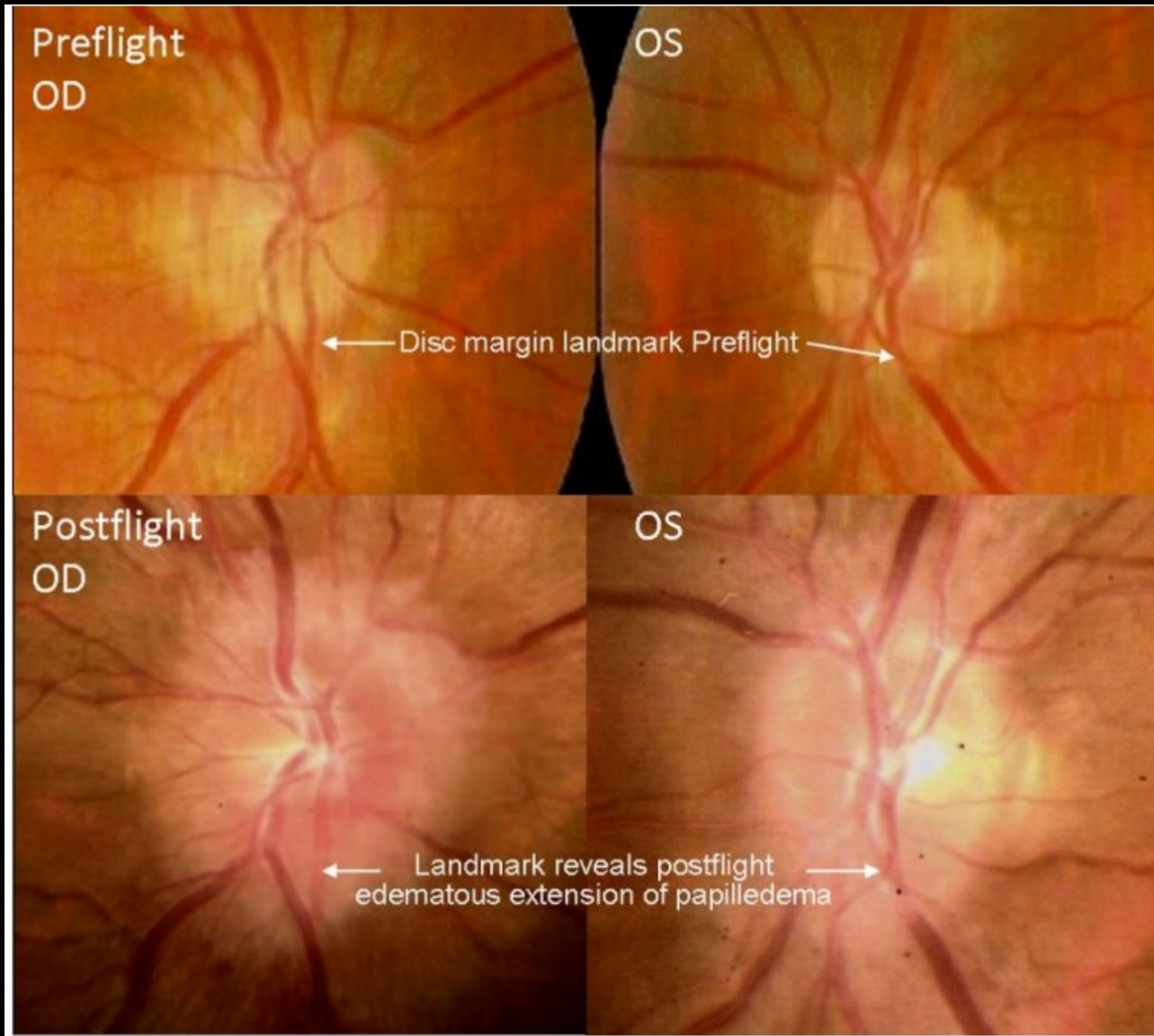


- **increased cranial pressure (ICP) due to body fluid redistribution in reduced gravity**
- **“The full-head sensation never completely goes away. It feels like standing on your head 24 hours a day.”**

**Scott Kelly**



# SANS: Spaceflight-Associated Neuro-Ocular Syndrome

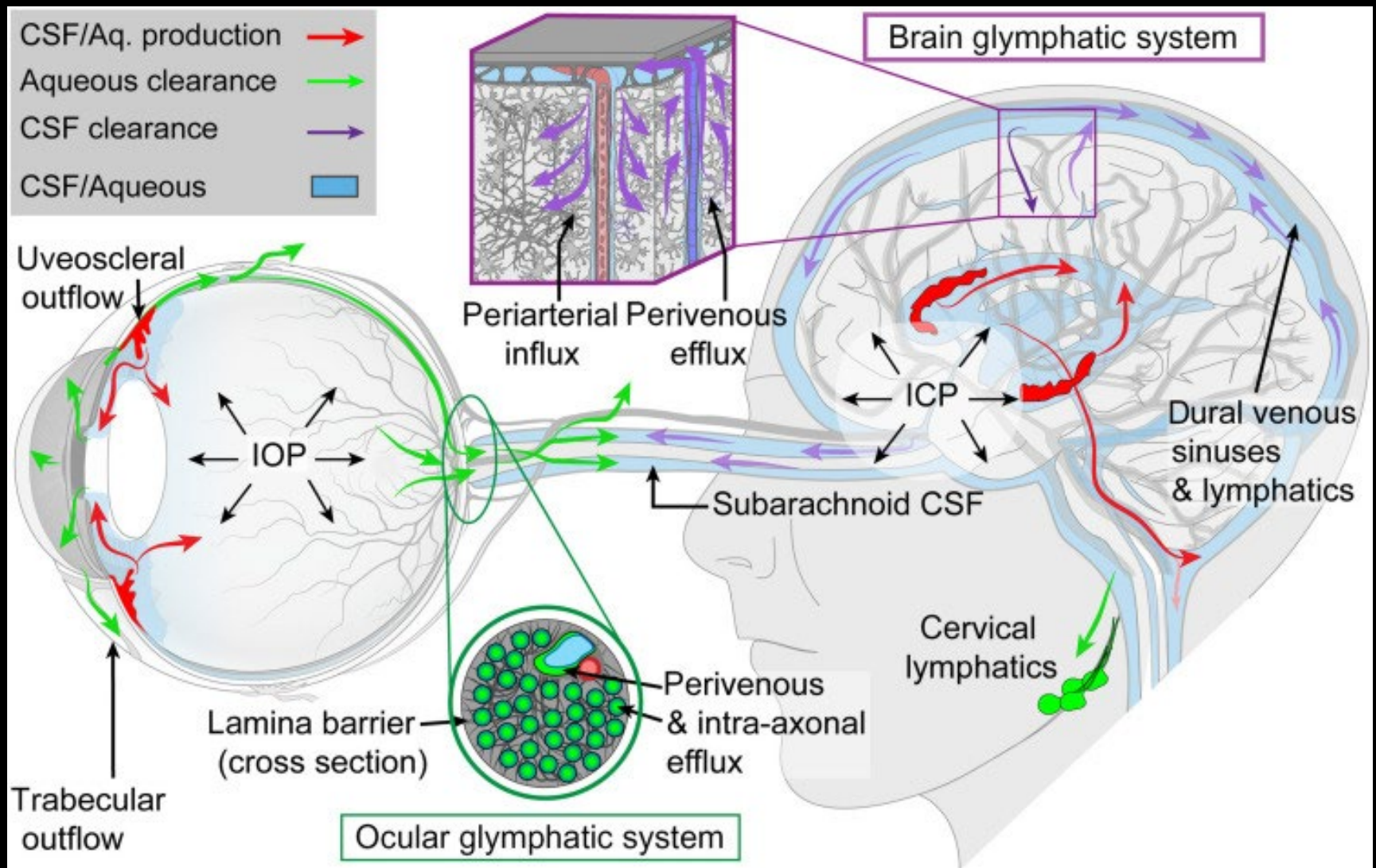


# In-Mission Ophthalmic Monitoring

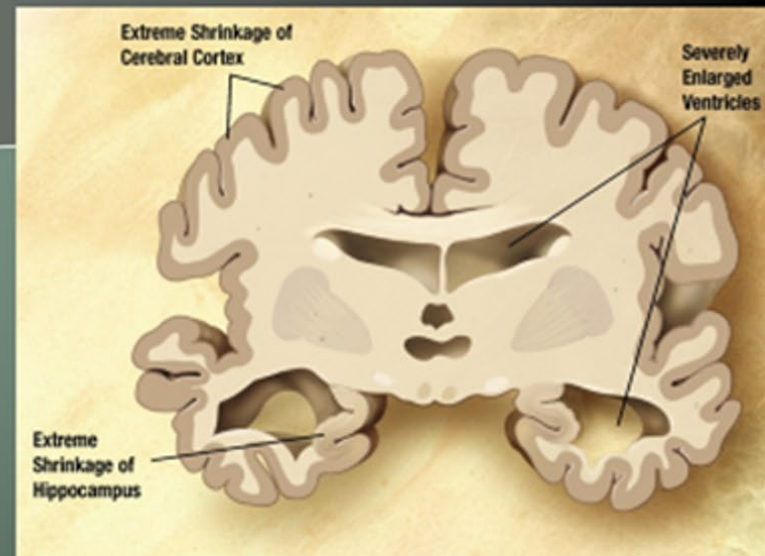
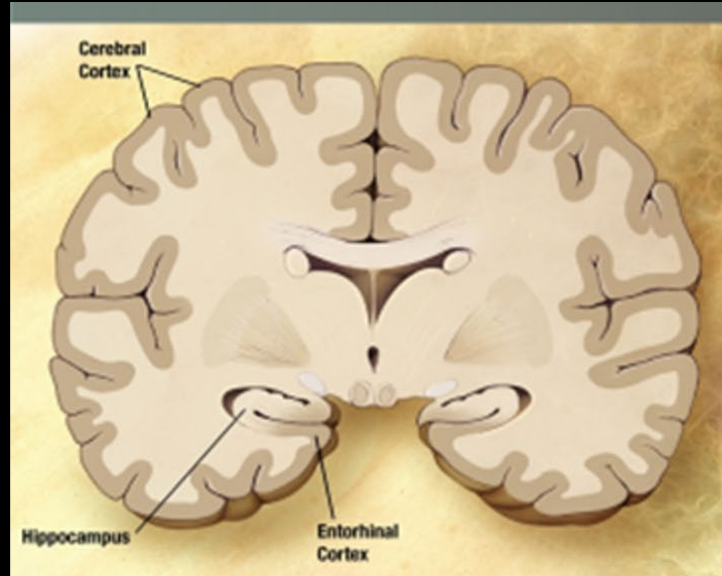




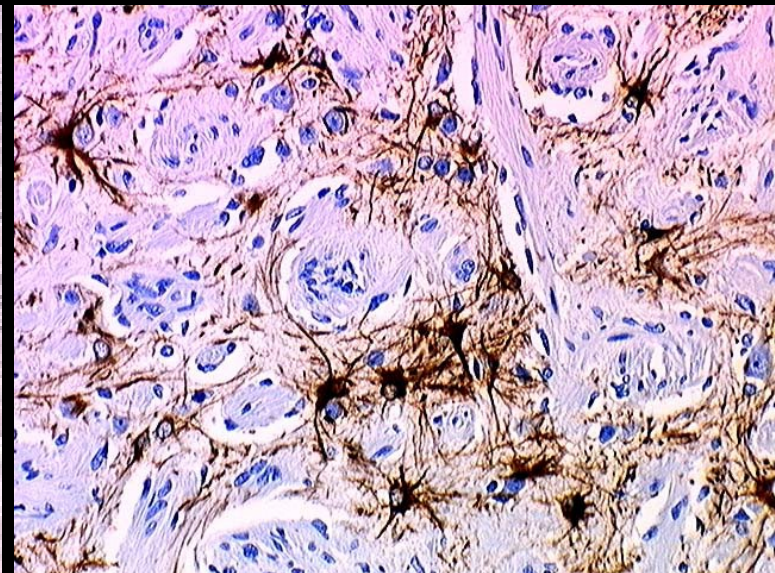
# The Glymphatic System (Ocular and CNS)



# Alzheimer's Disease and Neurodegeneration: Beta-Amyloid and TAU Neurotoxic Proteins



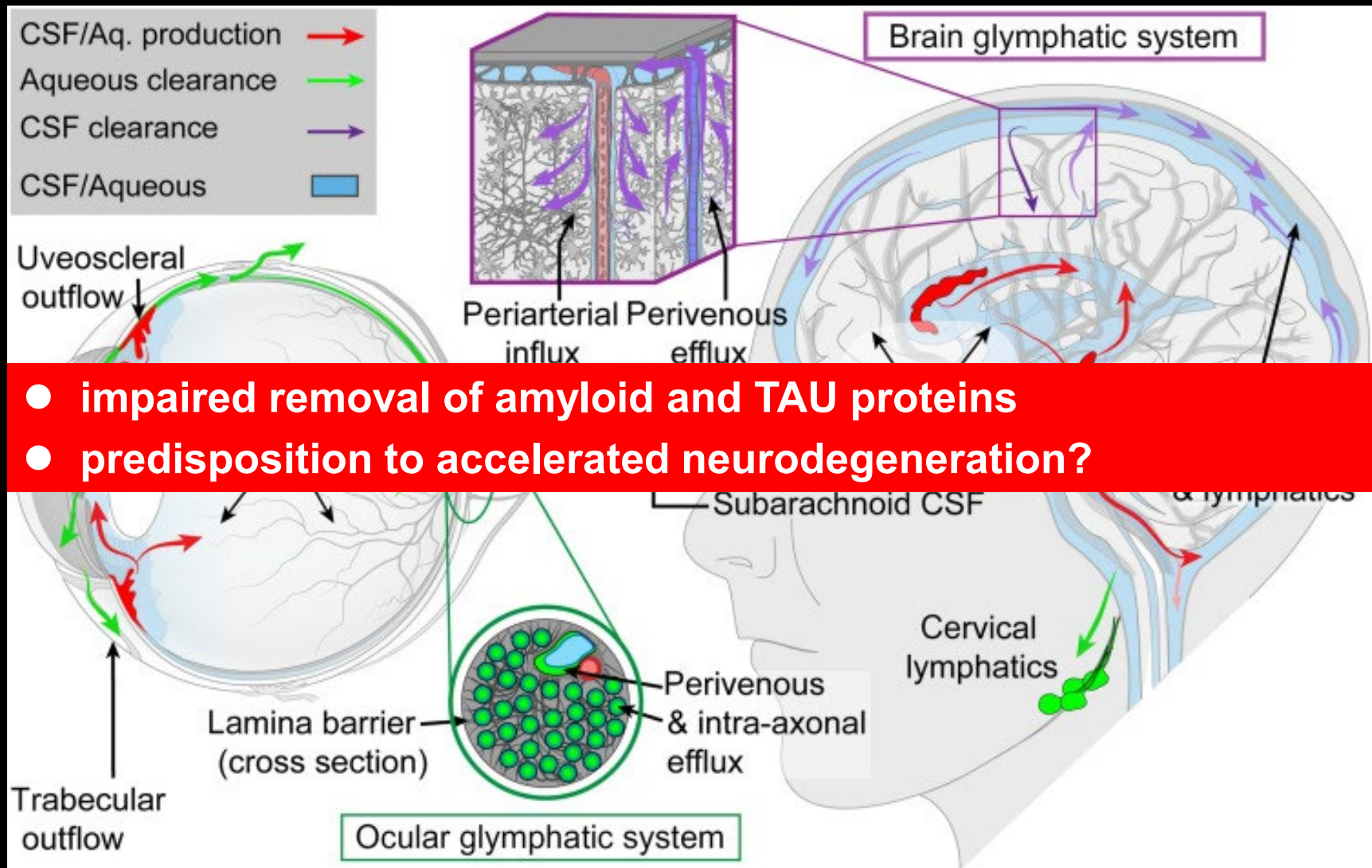
**Beta - Amyloid Plaques**



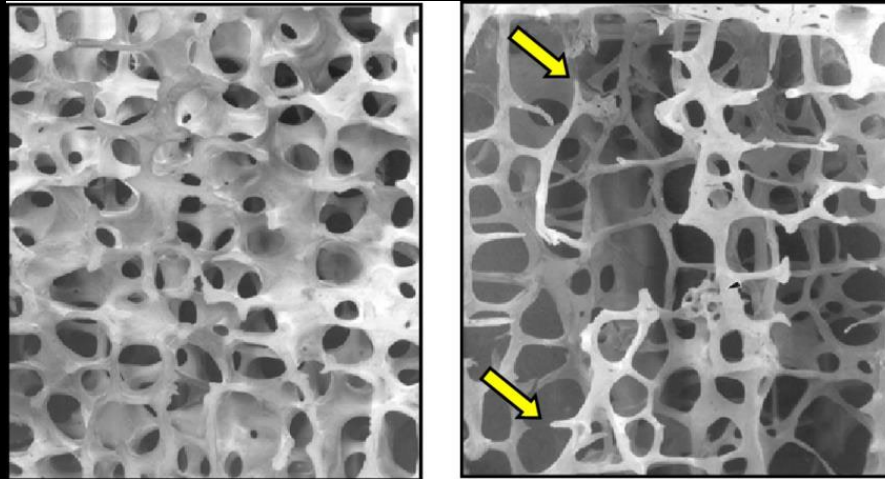
**TAU - Neurofibrillary Tangles**



# Glymphatic Drainage of Brain Metabolic Waste Products: Impaired Clearance with Increased IOP/ICP and Sleep Disturbance



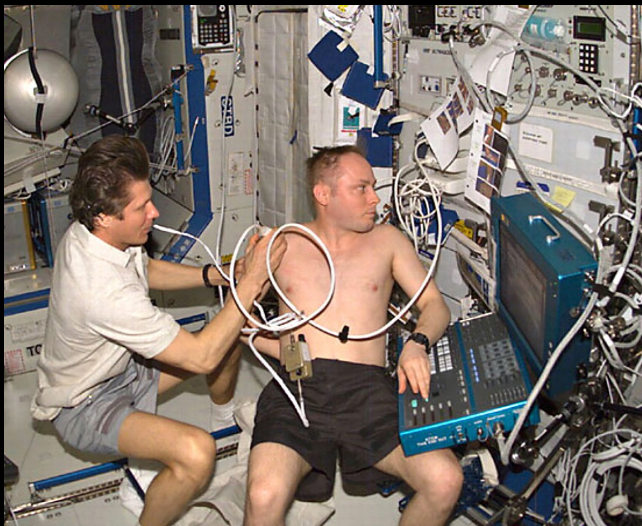
# Bone-Loss in Microgravity



- bones of legs, pelvis and lower back lose 20 times as much mass as upper body bones
- loss of bone mineral density/month
  - femur (1.6%), pelvis (1.4%), lower spine (1.1%)
  - whole body (0.35%)
- much higher demineralization than osteoporotic bone loss in post-menopausal women on earth
- urinary excretion of excess calcium (hypercalciuria)
  - predisposition to renal/bladder stones high levels of hydration



# On-Station Exercising to Mitigate Bone and Muscle Atrophy





# Disrupted Sleep in Reduced Gravity: Altered Circadian Rhythms



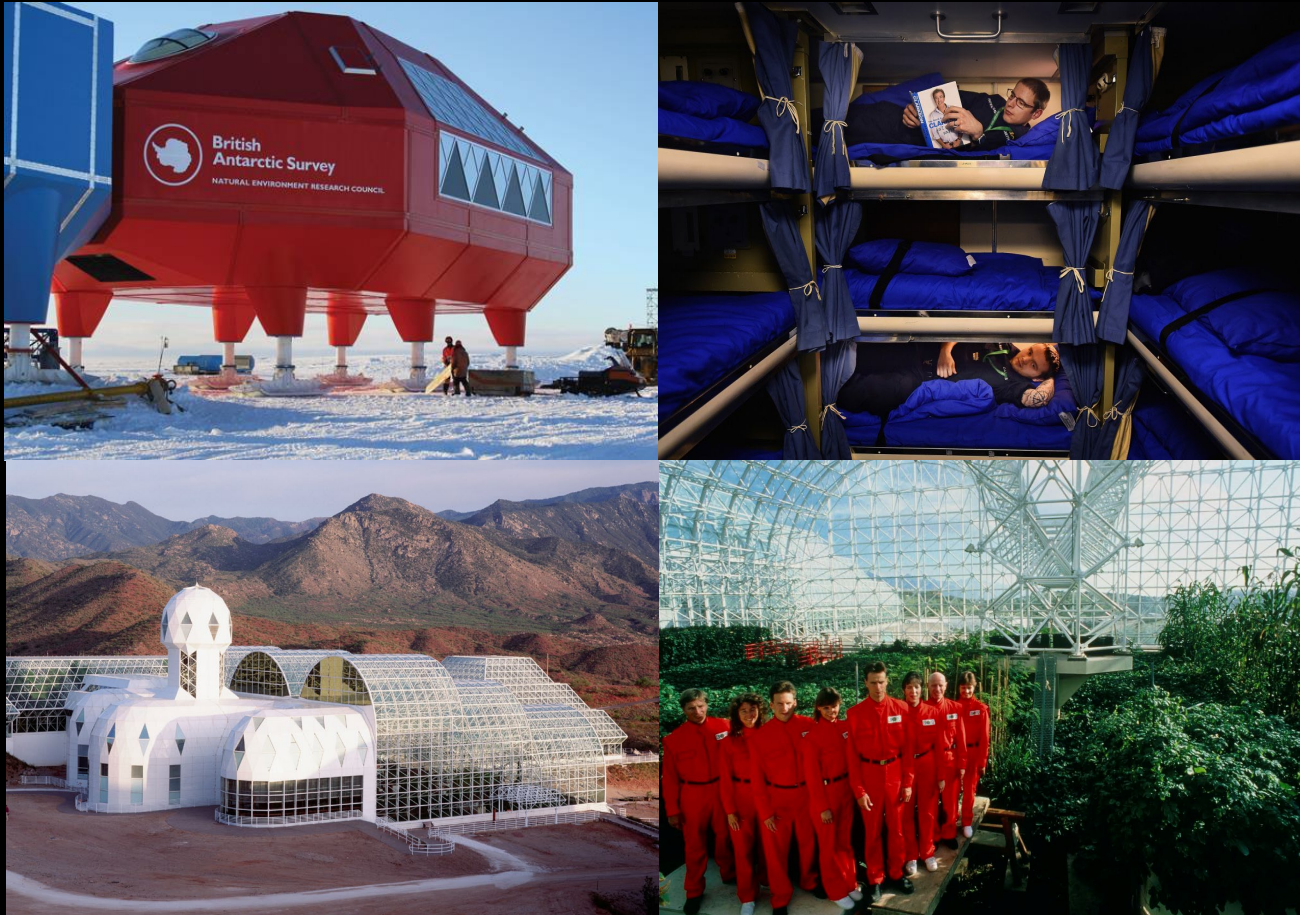
## **Sleep Disorders and Dreaming in LEO**

- **among most common perturbations**
- **dissatisfaction with depth and duration of sleep**
- **75% astronauts use sleeping pills**
- **disruption of five stages of sleep and cascading neurohormonal alterations**
  - **pineal gland, hypothalamus and pituitary functions**
  - **increased secretion of growth hormone**
- **adverse impact on cognitive and emotional behaviors**
  - **decision making, reasoning, irritability**
  - **complex spectrum of emotional responses, including overt clinical psychiatric conditions**



# Psychological Fragility Induced by Isolation and Confinement

- people don't anticipate how much they miss the natural world until they can't access it

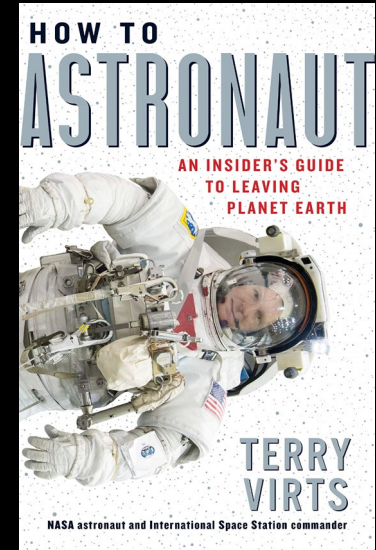


# **Mental Health Resiliency in Long Duration Missions in High Risk/High Stress Environments**

- **anxiety, despondency, depression, withdrawal and isolation**
- **impulsivity, mania, aggression, violence**
- **hallucinations**
- **resentment of workload and acceptance/conformity with critical SOPs needed for mission success**
- **conflict risk management**
- **cross-cultural clashes**
- **“irrational antagonism”: emerges after c.6 weeks**
  - **cumulative intolerance and annoyances at previously innocuous events**

# Learning to Tolerate Less Than Optimal Living Quarters

## personal hygiene



## ISS: smelly, noisy and awash in microbes and crumbs



- everything floats
- the benefits of anosmia

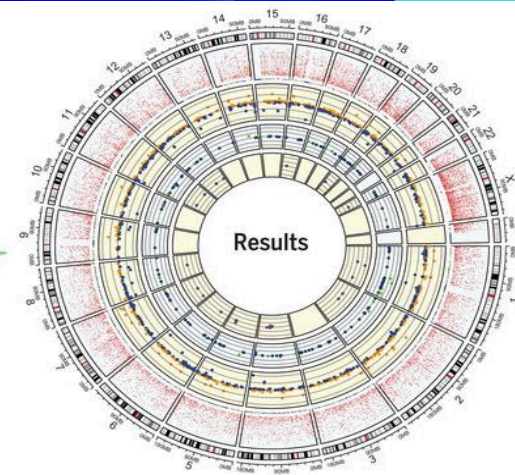
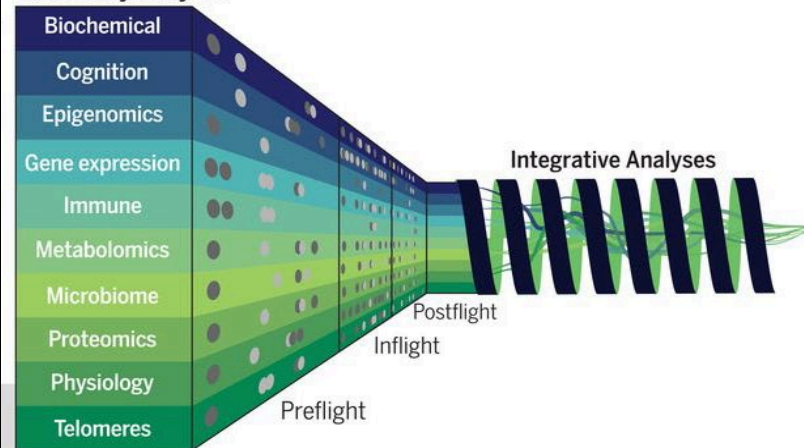




# The NASA Twins Study: Comprehensive MultiOmics Profiling of Extended Spaceflight Duration in LEO (One Year)



Twins Study Analyses

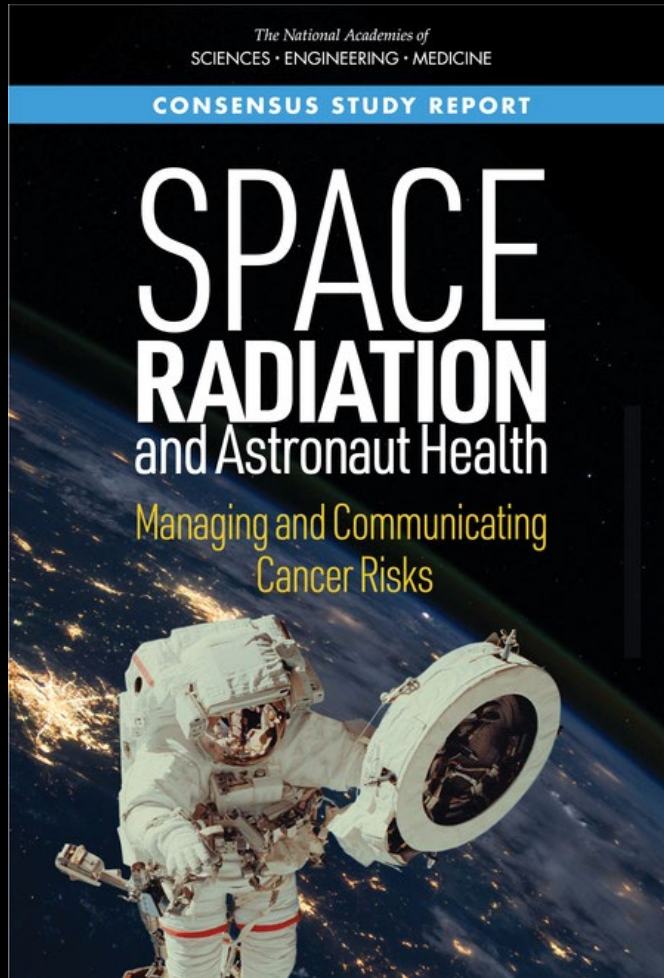


# Spaceflight and Human Health

- redistribution of body fluids and hemodynamic changes
- altered functions in multiple organ systems
- new (epi)genetic expression patterns in multiple cell types
- perturbed cell trafficking movements
- different gut absorption of nutrients and drugs
- immune dysregulation
- Reactivation of latent viral infections (herpes, GBV)
- microbiome dysbiosis (composition, virulence, antibiotic resistance)
- accelerated features similar to biological aging on earth



# Radiation: The Omnipresent Health Risk in Space Flight



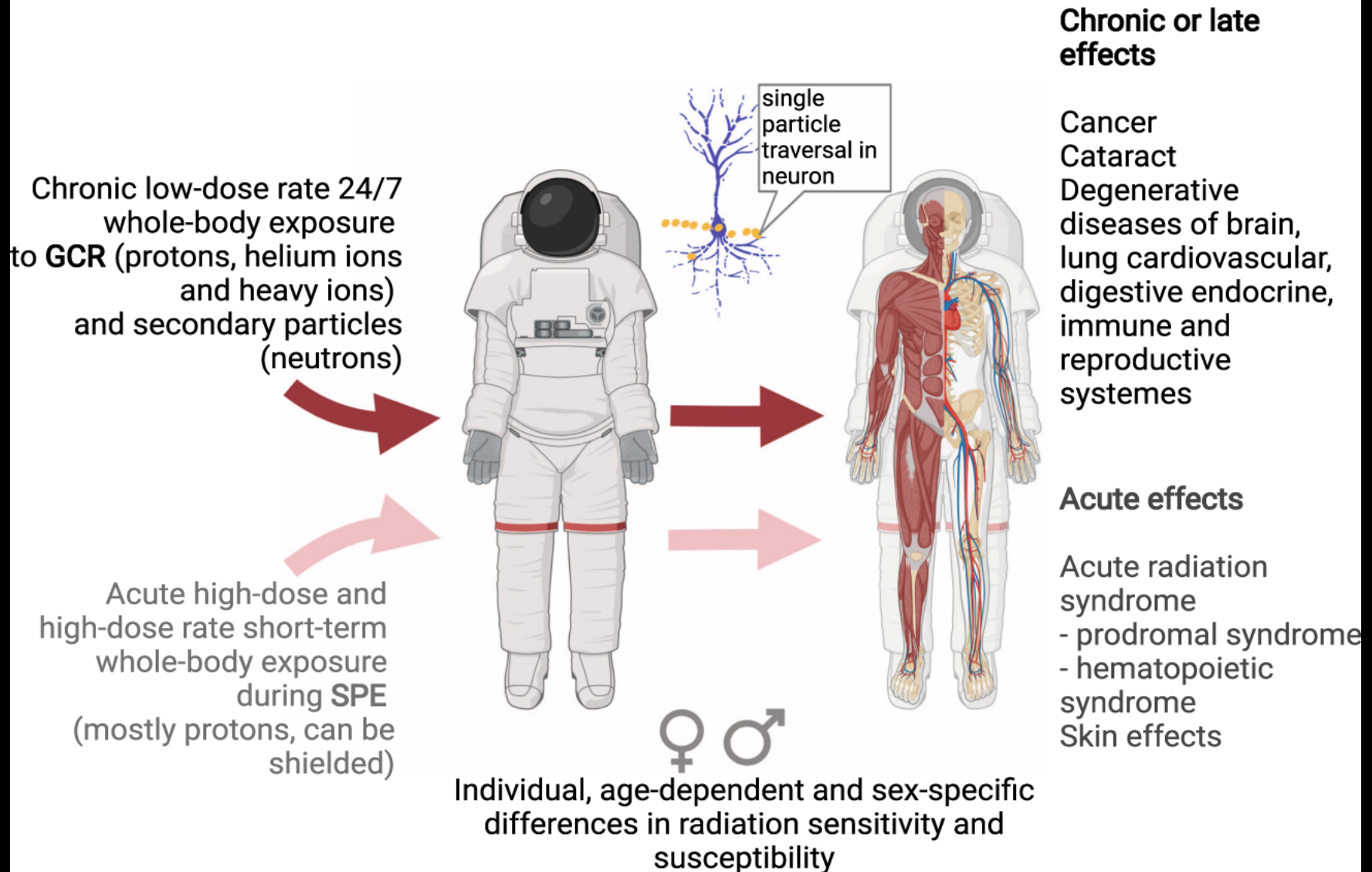
[doi.org/10.17226/26155](https://doi.org/10.17226/26155) (2021)



Commander Moonkin Campos:  
Artemis I return 1/10/2023

# Radiation Risk Exposure in Space:

**GCR = Gamma Cosmic Rays SPE = Solar Particle Events**



# Space-Acquired Radiation Mutation Damage to Gametes and Enhanced Risk of Fetal Abnormalities (Teratogenicity)



- **cryogenic storage of astronaut eggs/sperm harvested before mission for IVF use on return (or loss of life of donor on mission)**
- **analogous situation to use of IVF for donors facing high dose cancer chemotherapy**

# Medical Emergencies in Space

- **limited medical supplies, equipment and crew training**
- **limited on-board pharmacy**
- **limited storage for blood and blood derivatives (35 day shelf-life)**
- **faster deterioration of medicines and reduced shelf-life versus earth**
- **rapid evacuation from locations beyond LEO not currently feasible**

# Ranking of the Most Likely In-Mission Health Emergencies

- **cardiovascular**
  - clotting
  - myocardial infarction due to altered myocardial mass
- **infections**
- **trauma, hemorrhage, shock**
- **acute radiation sickness (Moon and beyond)**

individual or multiple cases

# Returning to Earth: Biological Readaptation

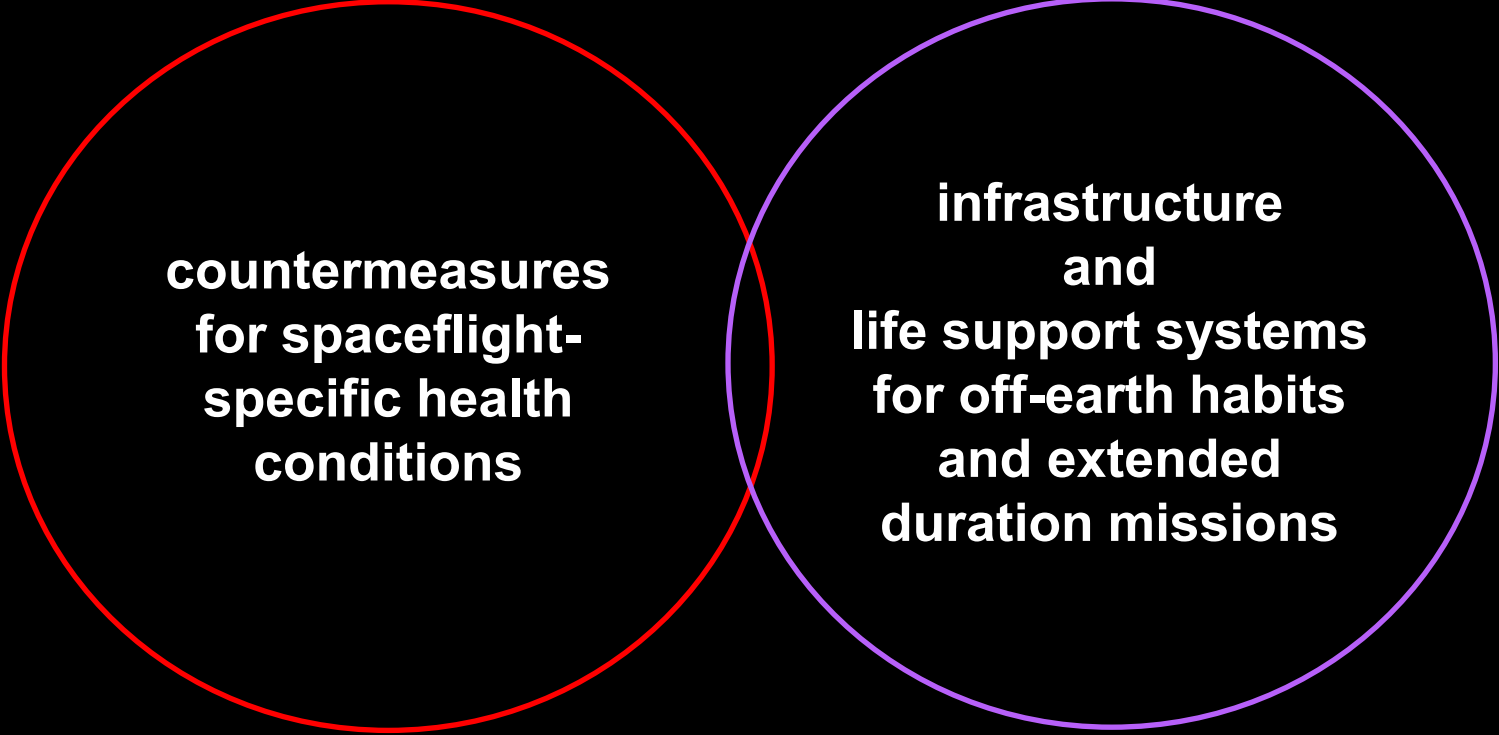
- **days**
  - impact of sudden postural shifts: fainting, vertigo, nystagmus
- **weeks**
  - variable persistent balance and walking problems
  - dysconjugate gaze (cross-eyed)
  - back/joint pain as spine/tendons recompress under Earth's gravitation
  - vision
- **month to years**
  - restoring muscle and bone mass
  - normal sleep patterns

## **Returning to Earth: Unknown Unknowns**

- **long-term health effects?**
- **influence of mission duration and location on risks?**
- **DNA mutation and cancer predisposition?**
- **chronic immune dysregulation and persistent subclinical inflammatory states?**
  - **autoimmunity, susceptibility to infection, cancer**
- **vision**
  - **SANS, accelerated cataracts?**
- **neurodegeneration?**
  - **impaired brain glymphatic drainage and accumulation of neurotoxic materials**



# Human Health and Performance in Space



**countermeasures  
for spaceflight-  
specific health  
conditions**

**infrastructure  
and  
life support systems  
for off-earth habits  
and extended  
duration missions**

**current dependency  
on terrestrial  
biomedical  
interventions**

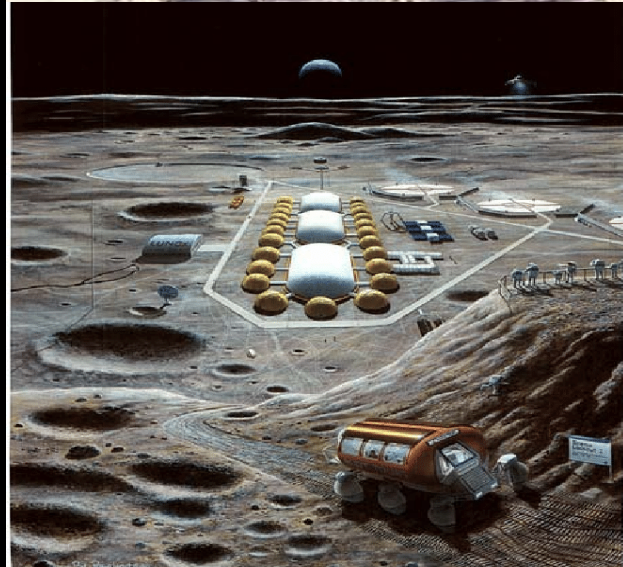
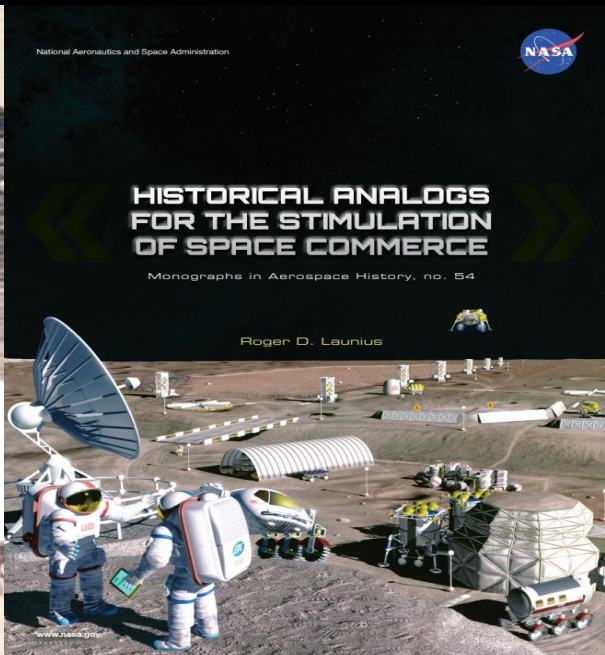
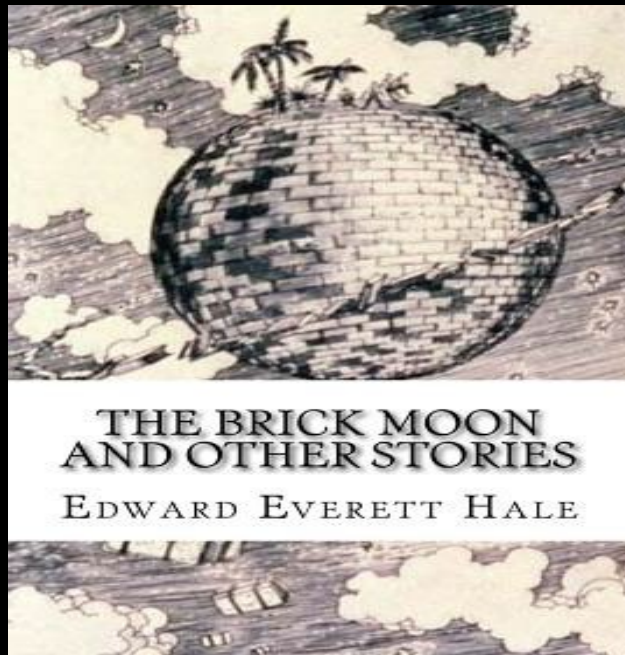
**no current  
demonstration of  
feasibility of large-scale  
construction beyond  
LEO**

# The Elephant in the Room: Unresolved Fundamental Issues in Space Exploration



Dr. Rowena Christiansen Australian Space Biology Symposium [rchr@unimelb.edu.au](mailto:rchr@unimelb.edu.au)

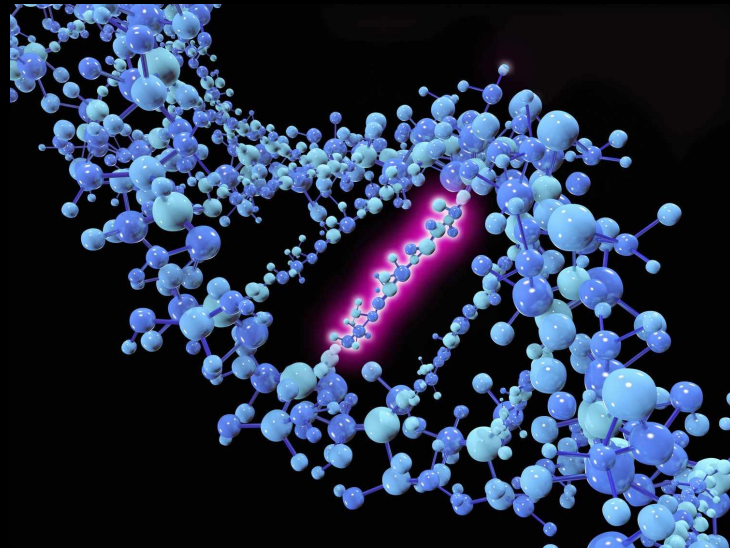
# Human Health in Off-Earth Locations: Moon Base





# **Future Issues in Space Exploration: Microbial Biocontamination, Biocontainment and Biosafety Risks**

- **two-way traffic: from the earth and back-to-earth**
- **microbial mutation and selection in off-earth locations**
  - **evolution of 'stress adaptation' phenotypes not present in terrestrial ancestors?**
  - **new microbial species?**
  - **need for new classes of antimicrobial drugs?**

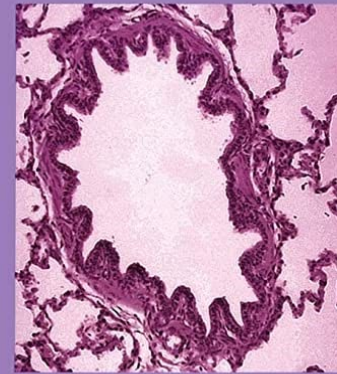




# Fundamental Issues in Space Exploration

- **feasibility of reproduction in reduced gravity environments?**

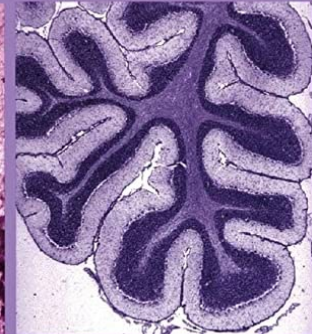
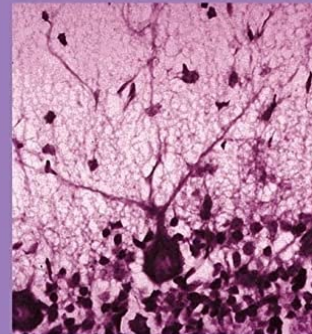
# The Critical Role of Mechanical Forces in Early Embryonic Development and Life-Long Maintenance of Complex 3D-Tissue and Organ Structures



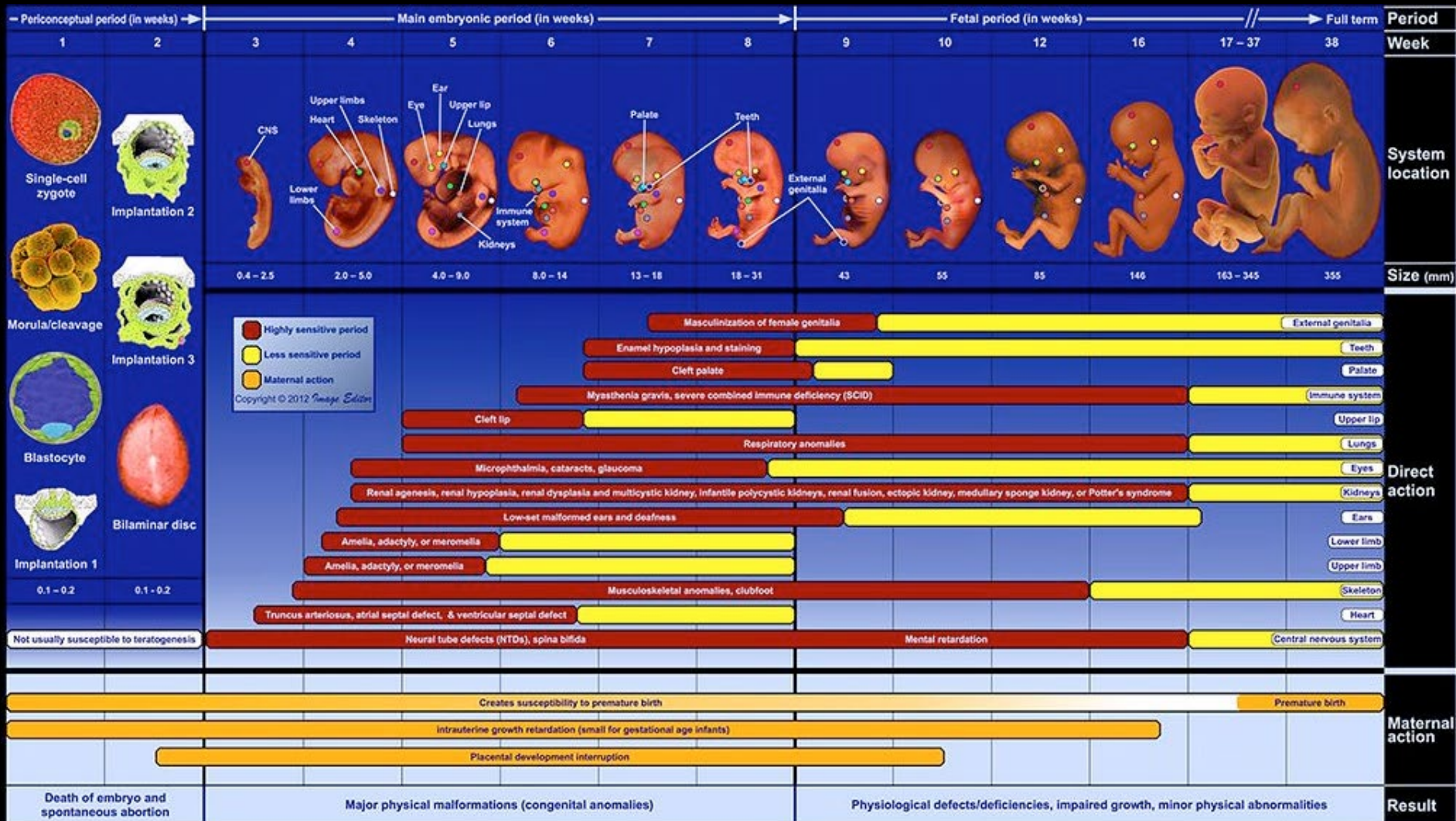
## FROM CELLS TO ORGANS

A Histology Textbook and Atlas

Alfons T.L. Van Lommel, Ph.D.



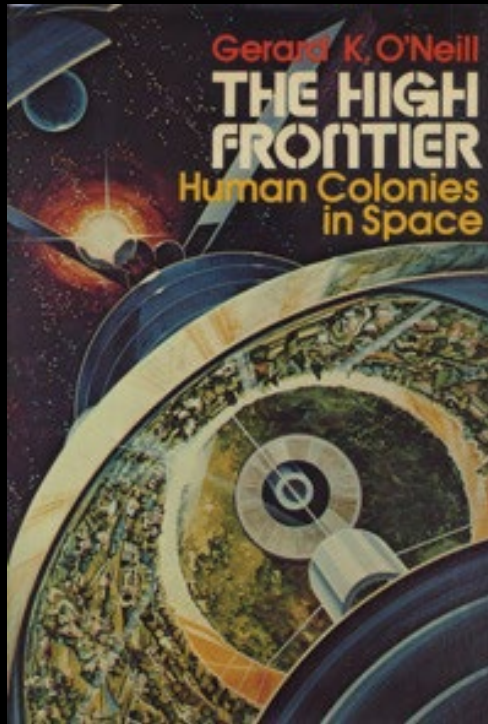
# Critical Stages in Human Prenatal Development and Risk of Fetal Abnormalities





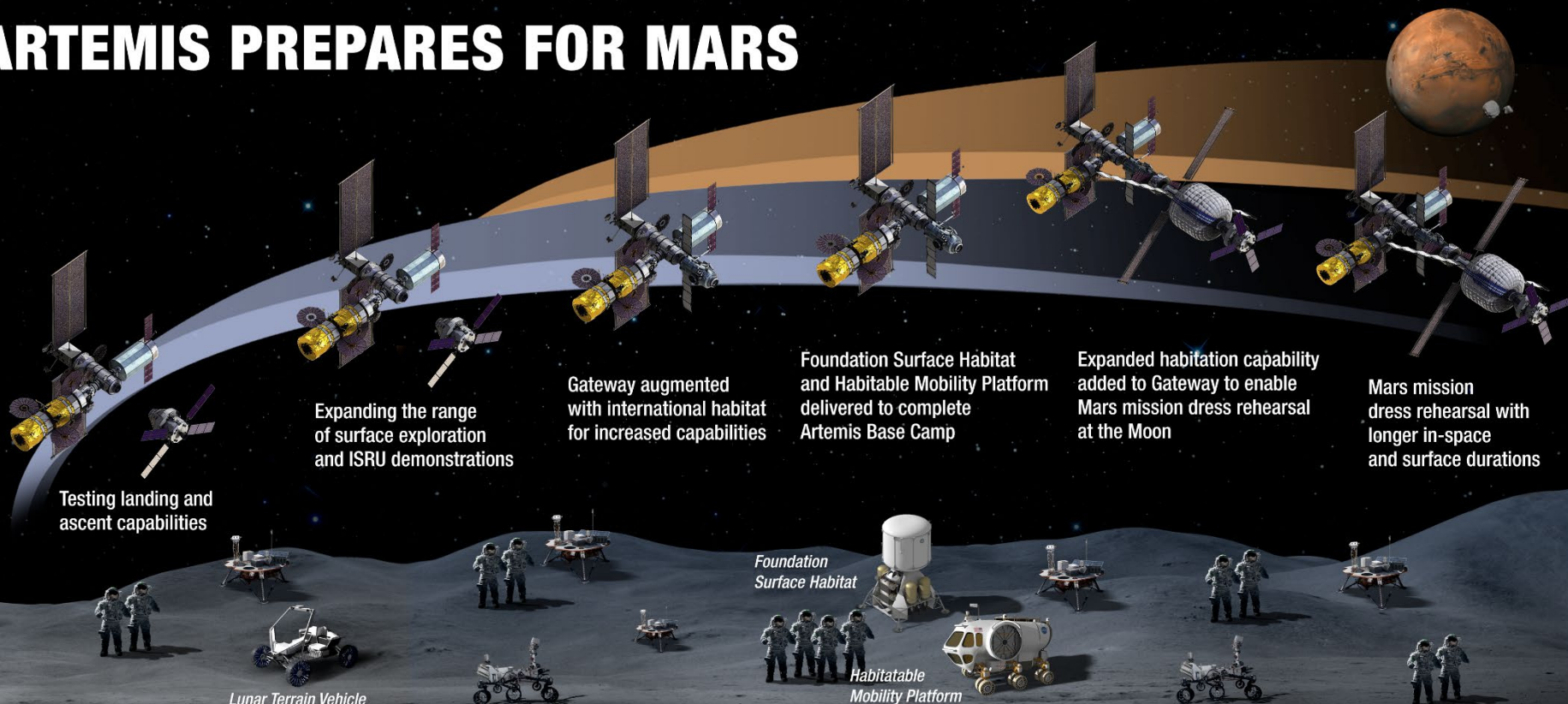
# Toroidal Colonies: Gerard O'Neill Princeton 1975

- giant space pods
- rotate to simulate earth's gravity
- position at Lagrange points to maintain a stable orbit





# ARTEMIS PREPARES FOR MARS

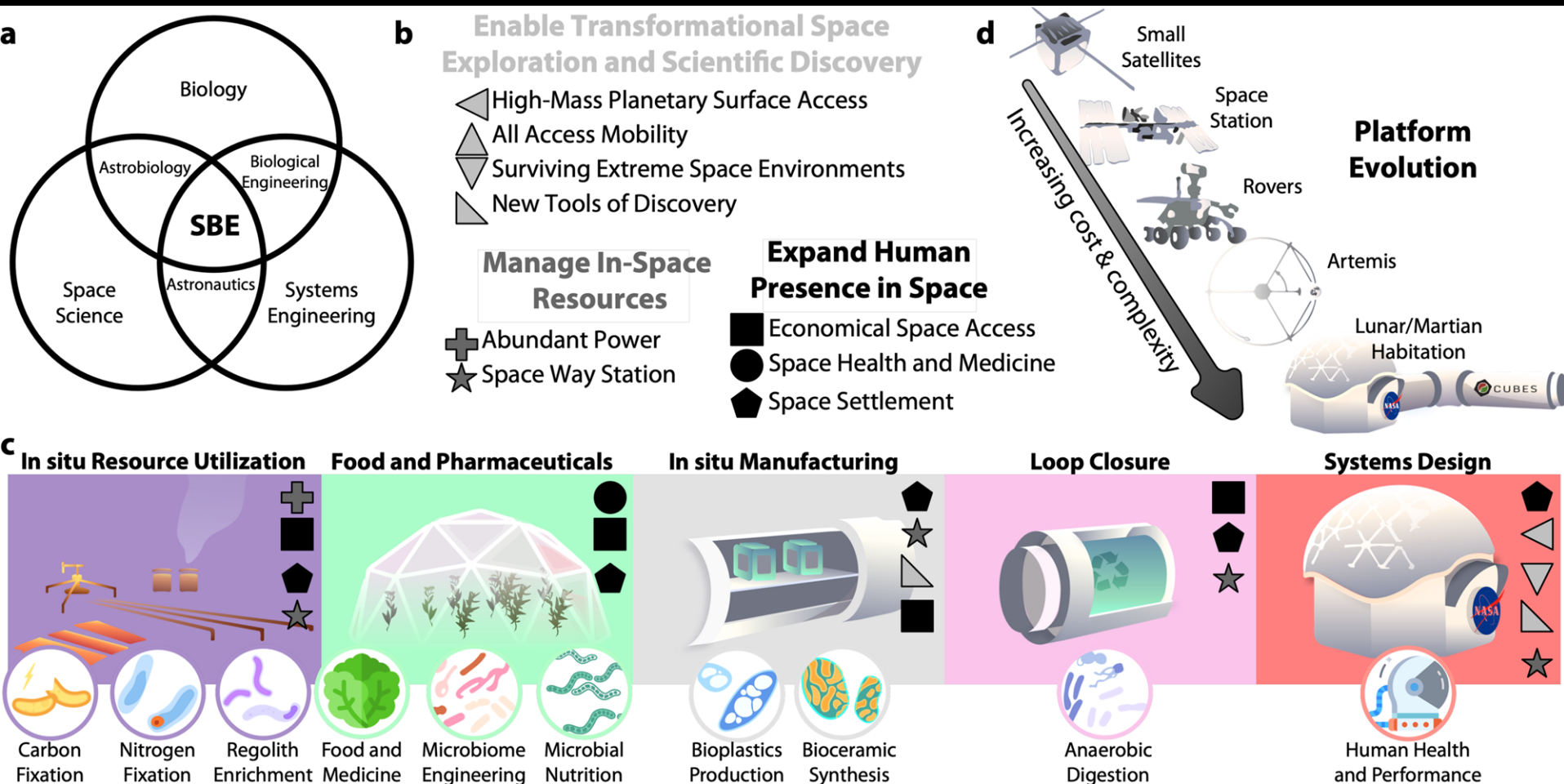


## SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

<https://www.orbital-velocity.com/news/nasa-details-how-artemis-missions-prepare-us-for-mars>

# Overview of Space Bioprocess Engineering Challenges: Technologies, Components, and Platforms

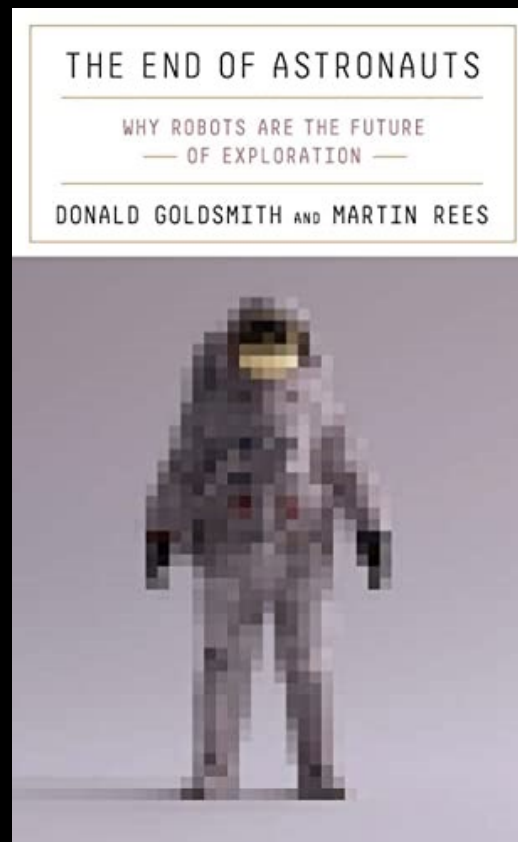


# **The Moon: The First Extraterrestrial Location for Human Planetary Exploration**

- **first or last?**
- **insurmountable barriers for onward travel?**
  - **sustainable habitats**
  - **health, reproduction, genetic modification**

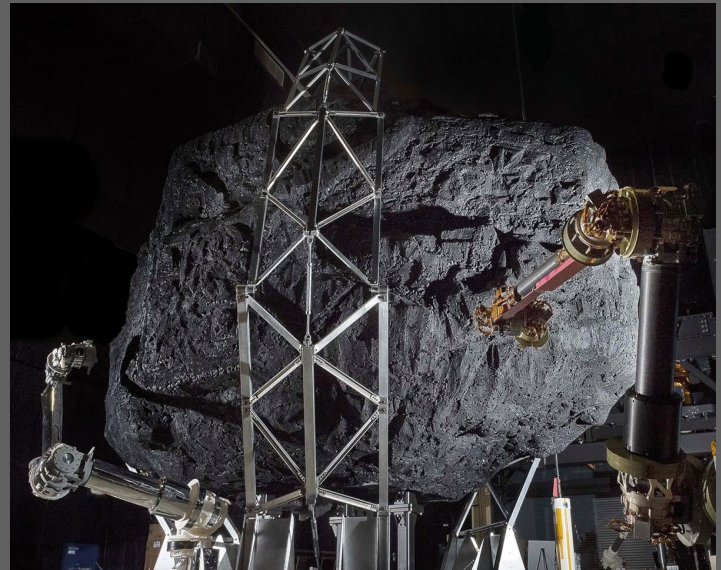
# Why Humans?

- **technology advances in robotics, autonomous systems and AI will outperform humans and dramatically expand the repertoire of machine-based capabilities to benefit humans on-earth**



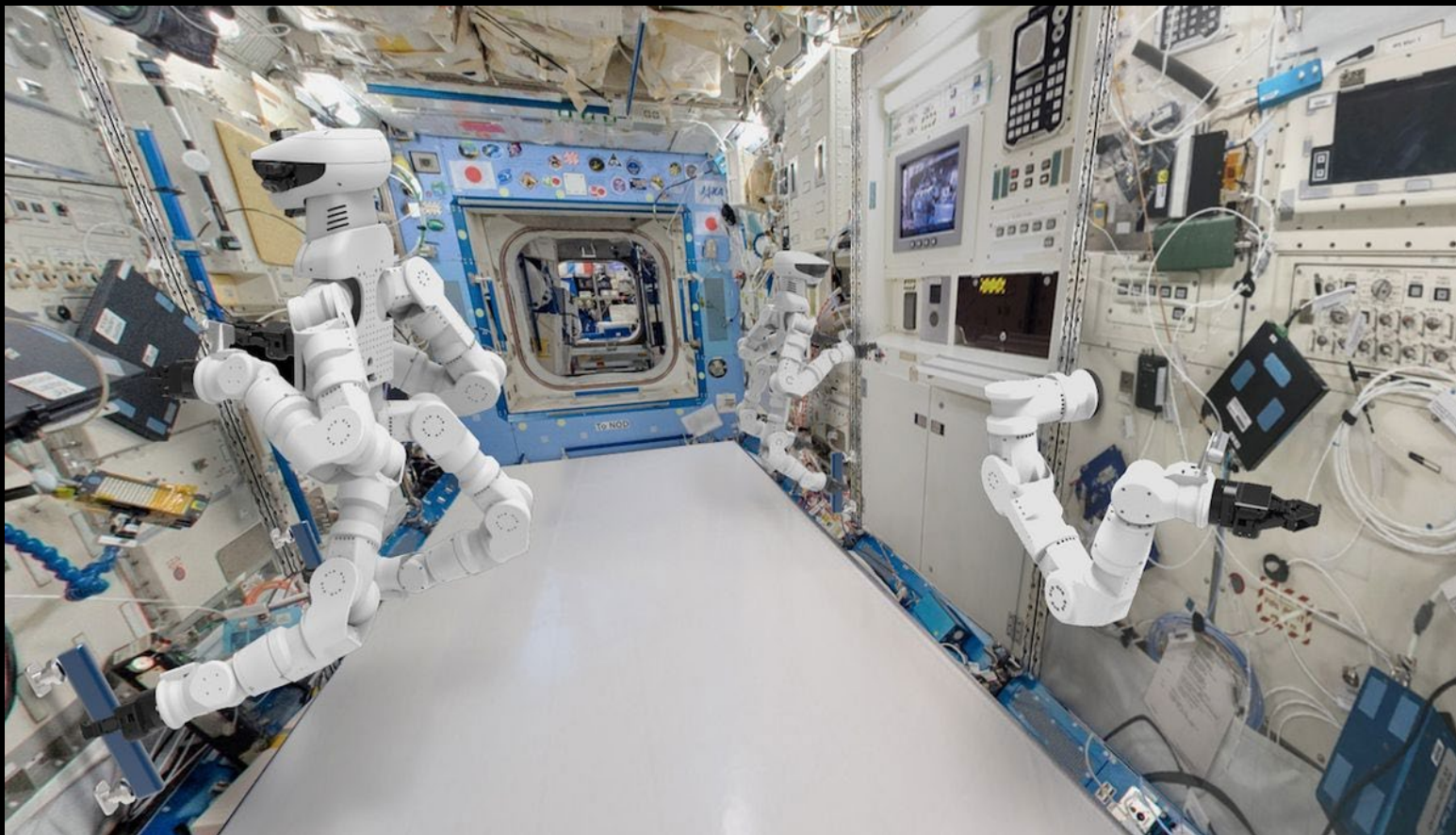


# Robots and Asteroid Mining





# Next Generation In-Craft Robots



## **Future Issues in Space Exploration: Construction of New Communities in Space**

- **technical feasibility of large-scale habitat engineering (time-lines)?**
- **affordability (cost-effectiveness and conflicting societal priorities on earth)?**
- **role of robotics, autonomous systems and AI versus humans?**
- **off-earth reproduction, citizenship and nationhood?**
- **heritable genetic modification for off-earth survival (Homo astrum, Homo ares, Homo astral)?**
- **hybrid humans: fusion of eugenic genetics and integrated physical devices (Homo cyborgensis)?**



Slides Available @  
<https://casi.asu.edu/presentations/>