Giving Birth in Space

Q3 2021

SpaceTech Analytics

SPACEBORN UNITED

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SpaceTech Analytics and SpaceBorn United - Joint Report

SpaceBorn United is a BioTech company that researches and enables the conditions for human reproduction in space.

SpaceTech Analytics (STA) is a strategic analytics agency focused on markets in the Space Exploration, Spaceflight, Space Medicine, and Satellite Tech industries.

"If humanity wants to become a multi-planetary species, we also need to learn how to reproduce in space."

- Dr. Egbert Edelbroek - CEO of SpaceBorn United

This report is a joint initiative with Spaceborn United, a Netherlands-based BioTech company that researches and creates the conditions for human reproduction in space.

SpaceTech Analytics Contributors

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The first chapter covers the issue of **giving birth on Mars, with women at the center of attention**. The first part of the chapter describes the past experiences regarding female participation in space exploration and their adaptation to space. Predominantly, it is based on NASA's experience and observations. However, the USA has never had a serious policy to actually settle space. Consequently, very little research has been done on the ability of humans to procreate in altered-gravity environments.

The second part outlines current advances in the field of space settlement and birth on Mars. Starting with defining **the core risks related to space settlement and pregnancy**, it further provides a brief overview of **spaceflight, space medicine, and other technologies under development**. Likewise, the summary of birth-in-space animal experiments is included. Nevertheless, birth-in-space animal experiments results are too far from allowing us to make even approximate generalizations of human childbirth in space.

The third part provides an overview of the **future projections of the different space settlement plans**. It involves a discussion about hypothetical ethical and physiological issues related to birth on Mars. In particular, the Mars maternity hospital is discussed together with some notions of planet terraforming.

Our Approach

Database

Identification of relevant
- Companies;
- Investors;
- Universities & Research Centers;
- Government Ministries, Departments & Agencies; and
- Space Associations

that operate, interact with or are somehow involved in the question of human reproduction in space.

Applied Research & Analytics Methods

Descriptive Analysis	**Mixed Data Research**	**Exploratory Data Analysis**
Comparative Analysis	**Qualitative Data Collection**	**Data Filtering**

Data Sources*

Media Overview	Industrial Databases	Publicly Available Sources (Websites)	Industry Reports and Reviews	Interviews with Industry Leaders	Interviews with Industry Leaders

Relying on various research methods and analytics techniques, the report provides a comprehensive overview of human reproduction in space. This approach has certain limitations, especially when it comes to the leveraging of publicly available data sources and secondary research. SpaceTech Analytics is not responsible for the quality of the secondary data presented herein; however, we do our best to eliminate the said risks by using different analytical techniques and cross-checking data. Please note that we did not deliberately exclude certain companies from our analysis. In fact, the main reason for their non-inclusion was incomplete or missing information in the available sources. As for the investors in the main database, we include only institutional ones: those who've invested in SpaceTech companies or SpaceTech-related companies. The SpaceTech companies included in the database are those that belong directly to the SpaceTech Industry; that partially belong to it through working with clients from the SpaceTech Industry; or that include specific departments that work in this sector or cooperate with clients from it.

Reproduction in Space: Major Trends and Features

With the growing financial capabilities of the space industry, commercialization of space tourism is inevitable. But first, to prepare for long-term space flights, we have to get a better understanding of how the human body changes in conditions of weightlessness. Moreover, as long-term spaceflights are becoming closer to reality, we shall consider the possibility of gestation on other planets. In fact, **Space Medicine and Reproduction in Space is a required core competence for space exploration, development, and settlement.**

Numerous studies have shown that adaptation to the space environment differs between men and women. This difference appears in almost all organism systems: cardiovascular, immunological, sensorimotor, musculoskeletal, and behavioral alterations. Significant changes in **gene expression** responsible for tissue remodeling have been identified. Most of these genes are **pro-oncogenes** as well as genes that are involved in **bone metabolism** and the early stages of **muscle regeneration**.

The **Bioregenerative Life Support Systems (BLSS)** are considered the most advanced systems to provide space crew with oxygen, water, food, and air quality in a spacecraft.

Main Features of the Analytical Case Study

- Database of Key Market Players
- Past Experience Overview
- Women's Adaptation to Space
- Current Advances: Space Medicine, Birth-in-Space, Spaceflight
- Startups and Collaborations to Solve the Challenges
- Future Projections and Developments
- Key Takeaways

Overview of Past Experience

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Women's Access to Space

In some countries, women's access to space – not just as astronauts but as users and creators of space services like Earth observation and satellite telecommunications – is still far from equal. But there are initiatives helping to drive significant progress in it.
One is the **Space4Women** program run by the United Nations Office of Outer Space Affairs (**UNOOSA**), which aims to ensure that

> *"the benefits of space reach women and girls and that women and girls play an active and equal role in space science, technology, innovation, and exploration."*

This project facilitates access to the benefits of space exploration, science and technology, and science, technology, engineering, and mathematics (STEM) education, and **STEM careers** for women and girls around the world.

As UNOOSA director **Simonetta di Pippo** has noted, 40% of the targets of the UN's Sustainable Development Goals rely on the use of space science and technology.

Only 566 people have ever travelled to space.
Sixty-five of them, or about **11.5%, were women**.

NASA has proclaimed it will put the "first woman and next man" on the Moon by 2024. Despite nearly 60 years of human spaceflight, women are still in the territory of "firsts."

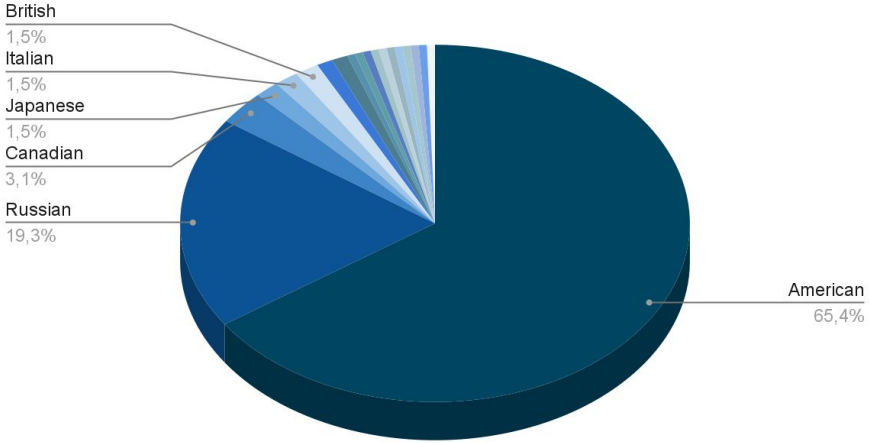
> *"A bird cannot fly with one wing only. Human space flight cannot develop any further without active participation of women.*

Valentina Tereshkova, First Woman in Space

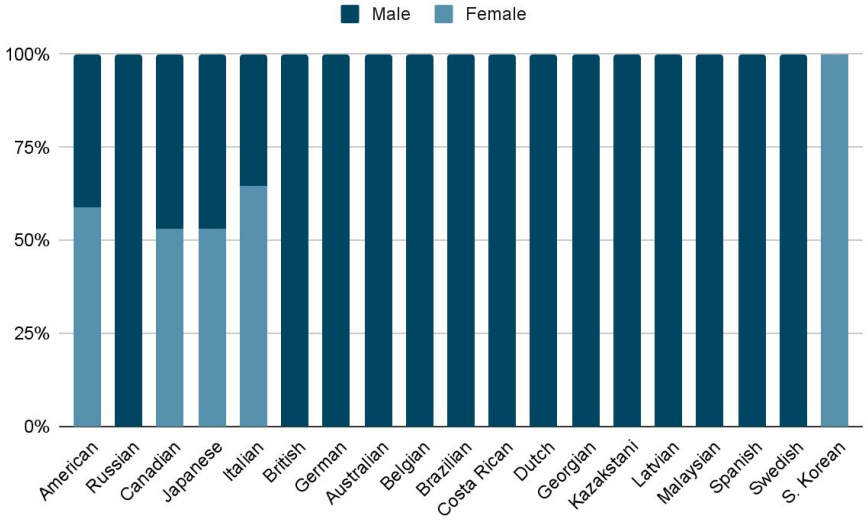
Source: Space4Women

Demographic Nationality and Gender Data for All Missions to the International Space Station

International Space Station astronauts by nationality



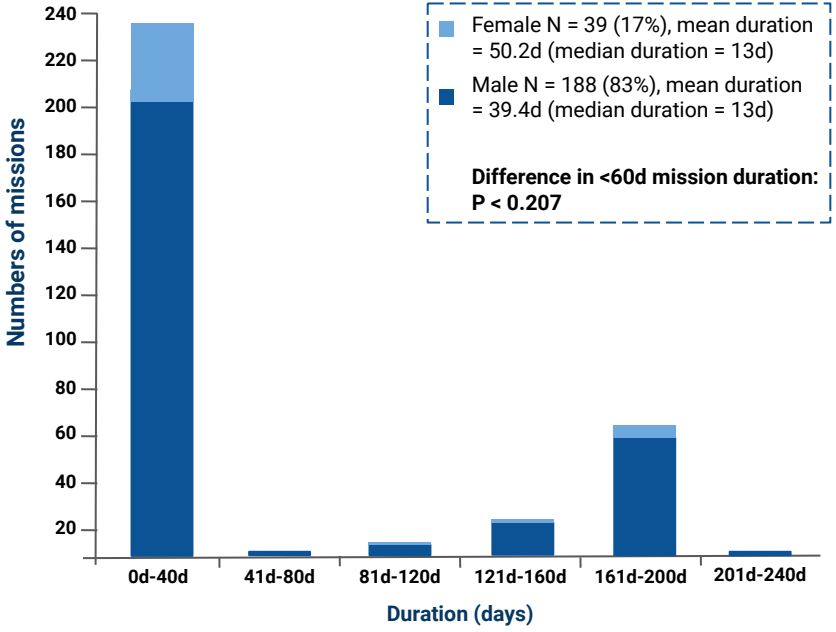
Percentage of male and female astronauts from each country on the International Space Station

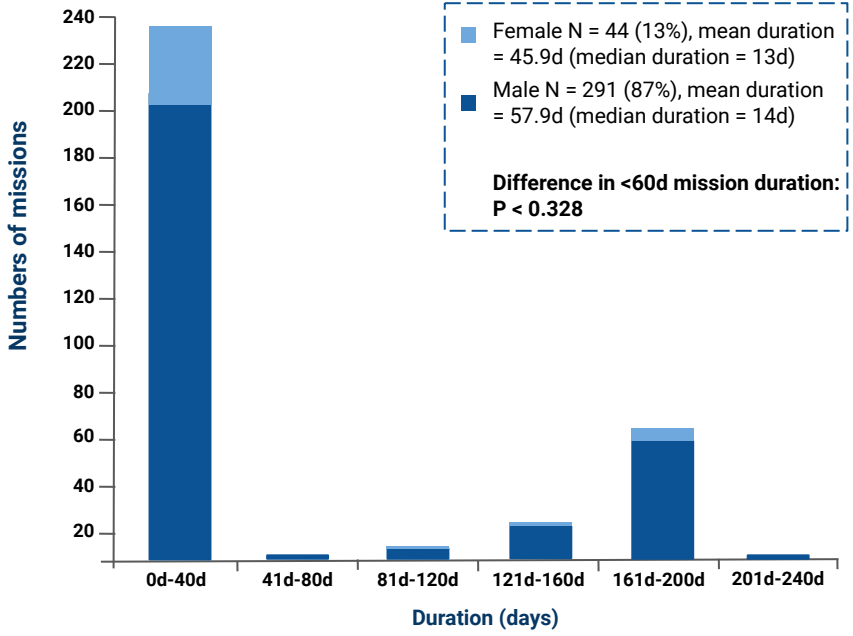


The term “International Space Station astronaut” refers to all astronauts who have traveled to, or stayed on board, the International Space Station (ISS) in the years 1998–2013. These include Space Transportation Shuttle (STS) mission astronauts, Russian cosmonauts, all crew members who traveled via Russian Soyuz, and all paid spaceflight participants. Analyses of demographic and mission information were obtained from publicly accessible government space agencies and military websites for female and male astronauts and cosmonauts from 1998–2013. The key observation is that women are still underrepresented among astronauts.

Source: NCBI

Space Mission Duration Distribution for Astronauts and Cosmonauts (All Nationalities) (1998–2013)





Analyses of demographic and mission information obtained from publicly accessible government space agency and military websites for female and male astronauts and cosmonauts from 1998–2013 (encompassing all missions to the ISS including short-duration construction missions) revealed there were a total of N=201 astronauts and cosmonauts across all nationalities who have traveled to the ISS: 30 females (15%) and 171 males (85%).

Source: NCBI

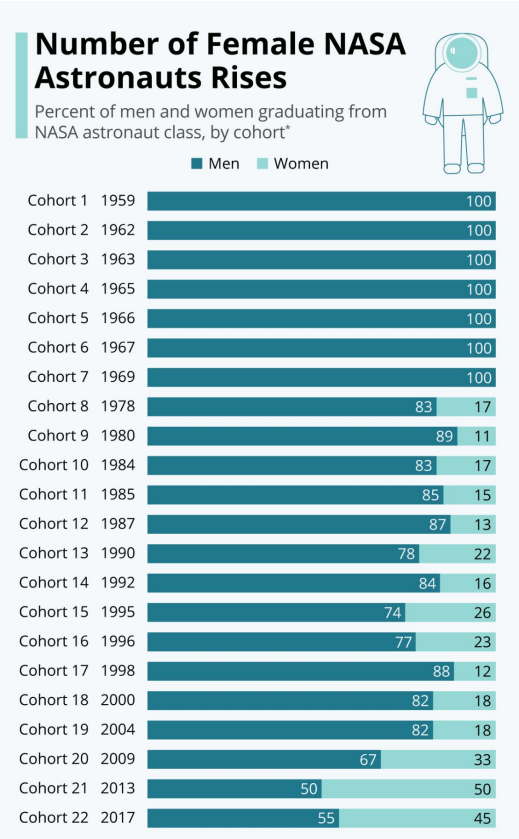
Number of Female NASA Astronauts Rises

New graduating cohort %

Women	45%	55%	Men

In its early days, NASA accepted only men as astronauts, through Apollo. That started to change in 1978. The first all-female spacewalk at the International Space Station was carried out in October 2019, and many other milestones have already been accomplished by female astronauts. Still, there is yet to be a first woman on the Moon (or on Mars), and since NASA is planning to return astronauts to the Moon soon, some female members of the newest cohort graduating last week might just be the ones to achieve that first.

According to NASA and Collect Space, the number of women admitted to the program has risen, in total and as a share of aspiring astronauts. Ride became the first American woman in space, after cosmonauts Valentina Tereshkova and Svetlana Savitskaya. Fisher became the first mother to fly in space. Resnik tragically died in the 1986 Challenger disaster. Funk, a member of the First Lady Astronaut Trainees program (“Mercury 13”), joined the flight of the New Shepard capsule and became the oldest person to go to space.



The first women to enter and graduate from the NASA astronaut class were Sally Ride, Anna Fisher, Judith Resnik, Kathryn Sullivan, Margaret Rhea and Shannon Lucid, who entered the program in 1978. Their portraits are below in the same order.


S. Ride


A. Fisher


J. Resnik


K. Sullivan


M. Rhea


S. Lucid

Source: Statista

Pregnancy After Space Flight

NASA conducted a survey involving a sample of 99 women. They are the final candidates selected during the five astronaut selection cycles between 1989 and 1997. Pregnancy after space flight was the main object of interest.

18/99	Number of female astronauts who have given birth (total number of children is 24)
40.5	The mean maternal age of the 15 postflight pregnancies in 9 astronauts that ended in spontaneous abortion
41.2	The average maternal age at the time of delivery for the first 15 children born to 13 US female astronauts after flight

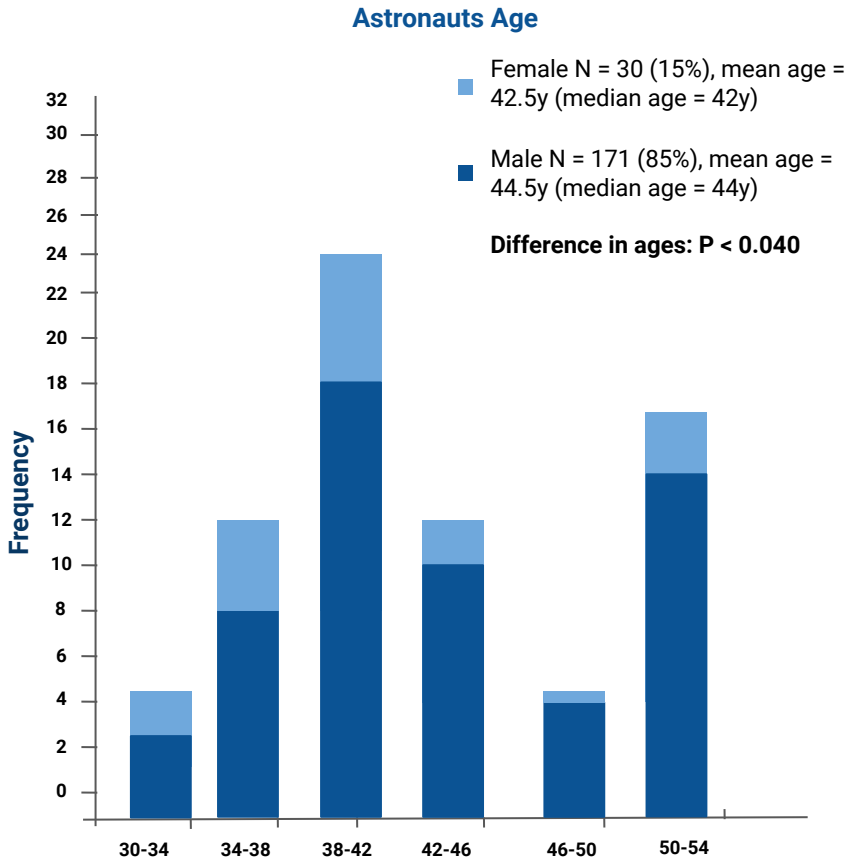
The poor fecundity is probably related to maternal age rather than space flight

Age has become one of the main reasons why many astronauts have not been able to have children. Moreover, because of their age, there was a considerable need for infertility services and assisted reproductive technology (ART). However, it is well-known that the success of ART, the rate of spontaneous abortion, and the rate of genetic defects in embryos depend directly on the age of the female gamete. The delay in childbearing is often the result of educational and career objectives that involve decisions that delay marriage and childbearing. Because of the constraints of pregnancy on training, many female astronauts prefer to delay their first pregnancy until after completing one or two space flights.

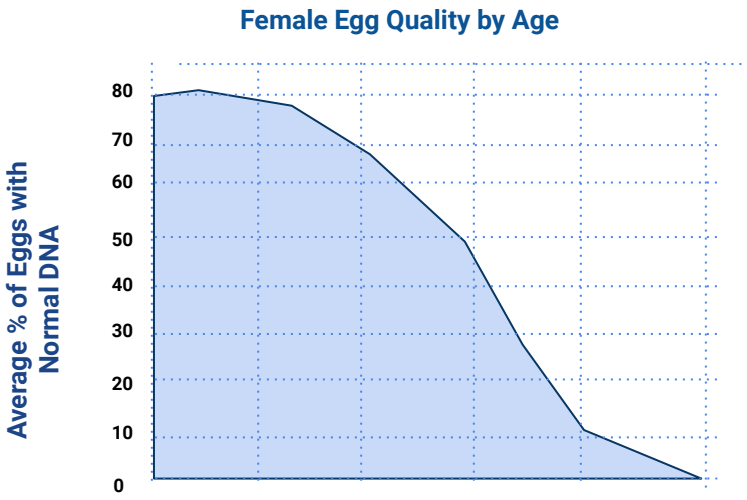
However space settlement is going to involve not astronauts, but settlers which have completely new goals. The new space trips require new approaches. In fact, when coming to Mars, women should be already well-prepared and well-trained. Nevertheless, the idea of space settlement implies the participation of young, strong and healthy adventurers. Thus, age shouldn't be an issue. The other hazards are of much greater concern.

Sources: Barratt, M. R., Baker, E. S., & Pool, S. L. (Eds.). (2019). Principles of Clinical Medicine for Space Flight.

Optimal Age For Giving Birth is 10 Years Less than the Average Age of Astronaut Women



Most women astronauts postpone getting pregnant. This decision, not surprisingly, has led to pregnancies at relatively advanced maternal ages. At the same time, the best age to get pregnant is between the late twenties and early thirties. This age range is associated with the best DNA quality of female reproductive cells and their number. One study pinpointed **the maximum level of health** predicted for mothers who had a first birth as being around **age 30.5**, which is **11.5 years earlier then the average year of women astronauts.**



Sources: Age distributions for astronauts

Legal Policies

Birth legislation. NASA astronauts are not allowed to be pregnant during training and missions. However, humanity has to develop solutions to legal issues, such as citizenship of children born off-planet or in settlements on the Moon or Mars.

NASA's Policy

After astronauts Jan Davis and Mark Lee's secret marriage the year prior to their mission in 1992, NASA prohibited any unprofessional relationship in space, due to the **astronaut code**. The official policy **forbids pregnancy** as well. Female astronauts are tested regularly in the ten days prior to launch. However, there is currently no law against pregnancy in space for private space travelers.

ESA's Policy

The European Space Agency does not allow pregnant women to apply to space missions but is highly supportive of astronauts during pregnancy and maternity.

"In the case that an applicant cannot be awarded the required medical certificate due to pregnancy at the time of application, ESA will accept a letter from the aeromedical examiner stating that the examinations have been done, provided satisfactory results and the person is ***temporarily unfit due to pregnancy only****."*

Children citizenship

According to Article VIII of the **Outer Space Treaty**: *"A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body."* This means children born in outer space or in the constructed objects (e.g. space settlement) on a celestial body will not be stateless but will **have citizenship of the nation that controls the object**.

Sources: www.unoosa.org, www.esa.int

Women’s Adaptation to Space

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Women's Health Indicators in Spaceflight are Different than Men's

G TOLERANCE

Several studies on female G tolerance compared to men are unequivocal. It has been demonstrated that women have less tolerance to gravitational stress. It may be possible that hormones play a role in cardiac and vascular response under gravitational force conditions.

BONE & MUSCLE PHYSIOLOGY

It has been demonstrated that women have more slow-twitch muscle fibers, which are important for endurance; while men have more fast-twitch fibers, important for rapid bursts of energy.

CARDIAC PHYSIOLOGY

Terrestrially, women and men respond to cardiovascular stress with increased heart rates and increased peripheral vascular resistance. In space, it has been shown that women tend to have a reduced ability to maintain venous cardiac output, with the underlying mechanism potentially being hormonal.

CIRCADIAN DYSSYNCHRONY

The spaceflight environment may lead to poor sleep quality, thus resulting in increased chances of errors and mishaps, as well as a reduction in performance and an inability to cope with adversity and other challenges. There is no evident between males and females in these effects..

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IMMUNOLOGY

Solar and cosmic radiation increases the risk of cancer among men and women because of a lack of protection from radiation, considering immune dysregulation in the context of the hostile environment of space.

NEUROVESTIBULAR ISSUES

Neurovestibular changes in spaceflight are the principle factors that affect posture control, locomotion, gaze stabilization, spatial orientation, and space motion sickness (SMS). Individuals' capacity to function while experiencing SMS symptoms is highly variable in men and women.

UROGYNECOLOGICAL & REPRODUCTIVE ISSUES

Long-duration missions pose a great risk for renal calculi. Concerning gynecological health, it was initially feared that female astronauts may be more predisposed to endometriosis because the lack of gravity may cause retrograde menstrual flow.

BEHAVIORAL CHANGES

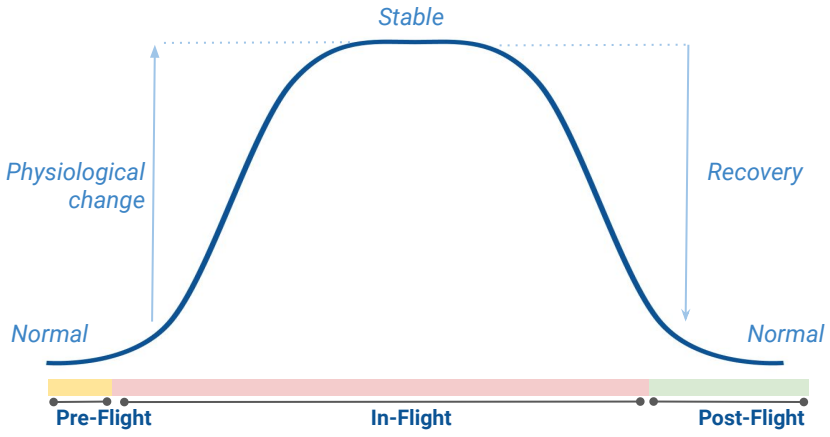
On Earth, anxiety and major depressive disorders are about twice as common in women as in men. There is no evidence that female astronauts experience the same risk for depressive and anxiety disorders as their counterparts in the general population.

Source: "Women's Health in Spaceflight" by Laura Drudi and S. Marlene Grenon

The Physiological Changes in Astronauts

Astronauts enter orbit in perfect health, but during spaceflight, their bodies undergo physiological changes. These changes stabilize during their stay in space, but a transformation occurs again when they return to Earth. The astronauts then need to undergo rehabilitation before recovering to their initial, stable condition. Space-medical researchers can observe and examine this entire process over short periods of time.

Changes in Biomarker Level during Spaceflight



Even with the rehabilitation process, some post-flight health conditions are still observed.

Sensorimotor deficits reported during and after spaceflight

Loin and paraspinal muscle volume is 5% less after spaceflight

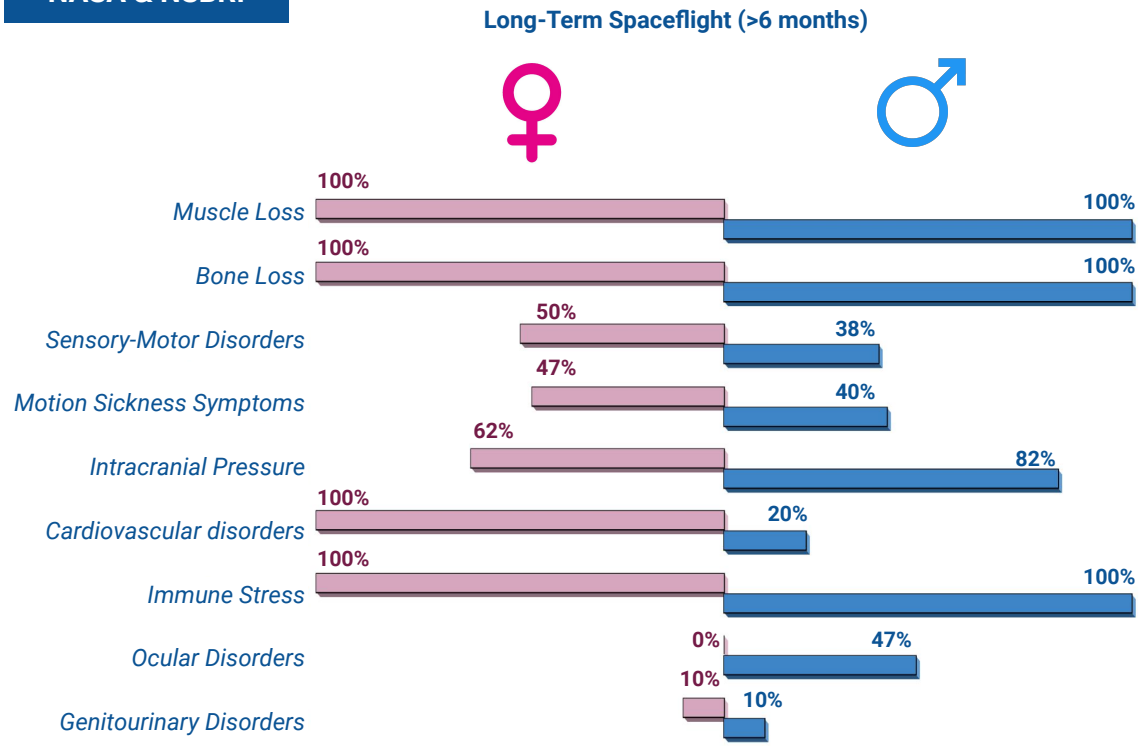
Astronauts' rate of lower limb bone loss is 0.8%.

Changes in microbiome taxa richness and antimicrobial resistance markers

Source: JAXA

Study Investigates How Men and Women Adapt Differently to Spaceflight

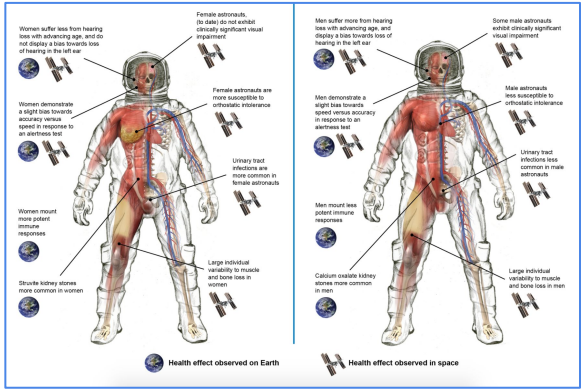
NASA & NSBRI



This diagram shows key **differences between men's and women's** physiological **adaptation to the spaceflight** environment.

This includes:

- **Cardiovascular** Health
- **Immunological** Health
- **Sensorimotor** Health
- **Musculoskeletal** Health
- **Behavioral** alterations



Source: NASA

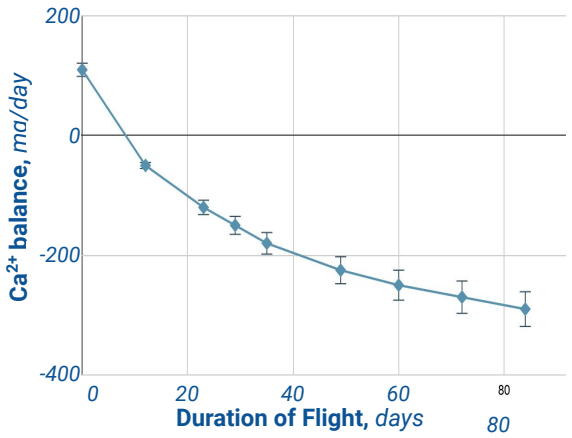
Weightlessness Effects are Deleterious for Both Men and Women

The human body evolved within the constant pull of the **Earth's gravity.** In the weightless environment aboard the orbiting International Space Station, astronauts experience **physiological and biochemical changes** during their stay in space.

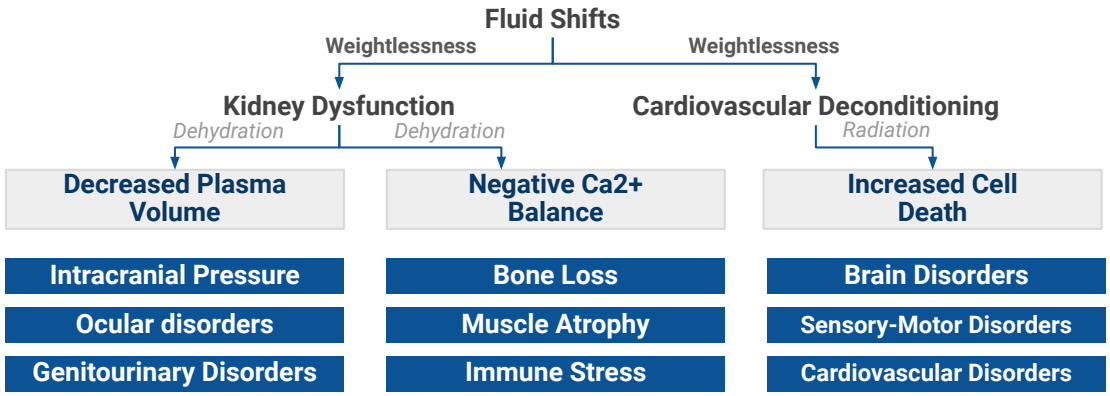
Russian Valeri Polyakov spent 437 consecutive days on a single space mission, and American Christina Koch spent 328 days. Both of them set the records for the single longest space mission (in the male and female categories respectively). Based on their experience, and the experiences of other astronauts, researchers have discovered a number of deleterious effects weightlessness has on the human body. However, some long-term effects probably remain unknown, and we can only hypothesize.

Generally, bones in the lower body atrophy, while the upper body skeletal parts grow in density. If the long-term effects of weightlessness don't ruin the body but it instead adapts, a new type of human might appear, but we currently lack the data to predict such an outcome.

Ca2+ Balance in Astronauts during Spaceflight



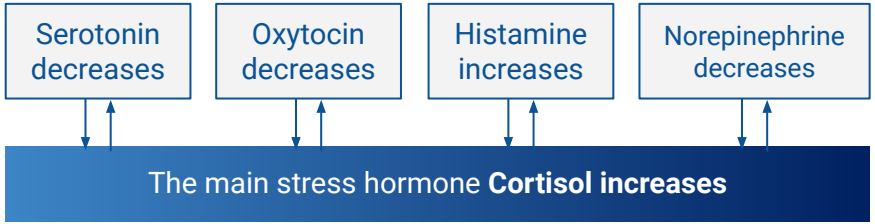
Biochemical and Physiological Changes in Astronauts



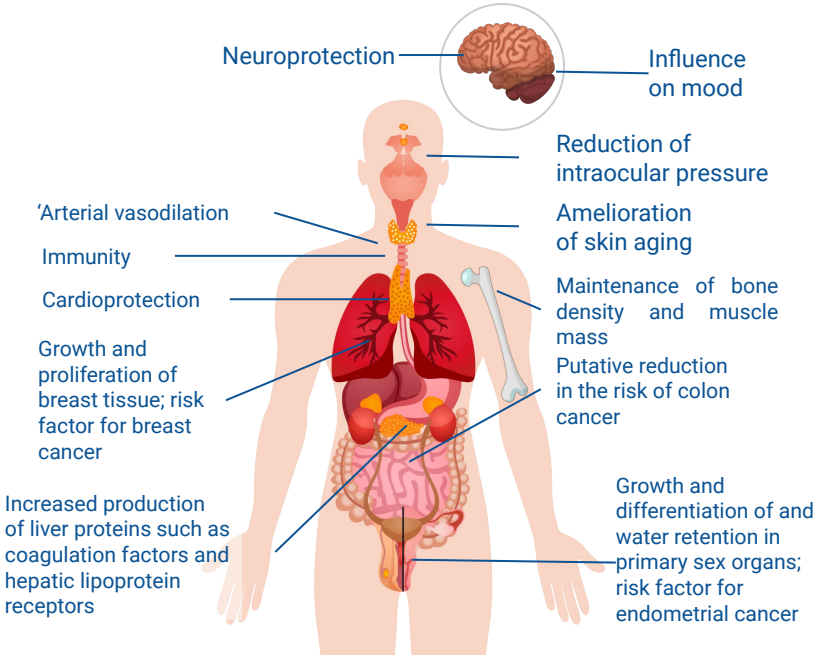
Source: NASA

Spaceflight Adversely Affects Hormonal Activity

Hormones. An astronaut's endocrine system is usually altered during spaceflight. Hormones, which recover only by returning to Earth, may have a strong impact on healthy aging and on the reproductive system.



Oral contraceptives that female astronauts use on pre-mission training and during spaceflight **strongly affect the reproductive system,** with impacts on a number of related hormones such as testosterone, dehydroepiandrosterone, corticosteroid-binding globulin, prolactin, and sex hormone-binding globin.



Studies have shown age-related changes in estrogen-receptor signaling to many vital organ systems, shown in the figure above. Some of these systems showed similar alterations in experiments on animals during spaceflight. **Dropping estrogen levels** as a result of hypo-gravitational and weightless environments **may lead to a reduction in gonadal function** in both men and women. Nevertheless, estrogen levels recover in the Earth's gravity.

Source: Effects of Sex and Gender on Adaptations to Space: Reproductive Health by April E. Ronca, PhD and others

Menstruation in Space Should Not Be an Issue

This physiological aspect of women's bodies may be a matter of particular importance when sending women into space. However, it should be noted that years of observation indicates that menstruating in space is little different from menstruating on Earth.

Menstrual difficulties in space:

- Waste disposal systems were not designed to handle menstrual blood.
- Limited shower facilities and water supplies.
- Zero-gravity environment limits mobility.

SOLUTINS

Suspend menstruation:

- Combined oral contraceptive pill (the most common with a good track record in space).
- contraceptive implants.
- Intrauterine device.
- Contraceptive injection.

Duration of safe use

Oral Progesterone Pill	-
IUD	5 years
Contraceptive implants	3 years
Contraceptive Injection	3 years

"It's completely safe to suppress the menstrual cycle"
Varsha Jain (a gynecologist and visiting professor at King's College London)

3 years — The estimated duration of travel to Mars and back. Even in the case of a one-way trip, it could take 1-3 years to sort out a safe and viable settlement.

1100 pills — The approximate number of contraceptive pills one woman can use for 3 years. Every pill has some weight; it should be stored and the waste utilized afterward.

The IUD is considered to be the most suitable contraceptive for long-duration space travel. It does not take up much space, does not add excess weight, and does not create problems with waste disposal. The main advantage is that the allowed duration of its use is sufficient for a mission on Mars. Contraceptive implants could be used as well but with reservations, due to the shorter duration of safe use.

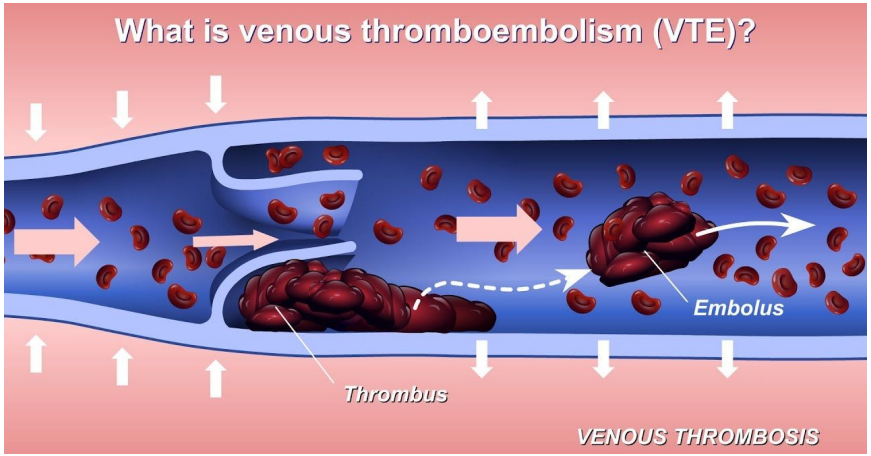
Sources: Nature.com

New Study Examines Women's Health During Spaceflight

ISU's Human Performance in Space Resident Faculty Dr. Virginia Wotring, along with women's health physician Dr. Varsha Jain and **NASA biomedical statisticians,** published a new study on the potential risks of developing a blood clot (venous thromboembolism) in space in the May issue of Aerospace Medicine and Human Performance. The study builds on previous work by Wotring and Jain and examined data from a large cohort of female astronauts from 2000 to 2014, in fact, more than half of the women who have ever flown to space.

> "We see a need for continuing studies with female astronauts. Much of the previous biomedical research in space was conducted on male astronauts, simply because most of the astronauts were male. That has changed, and now we need a better understanding of how the spaceflight environment effects female astronauts" said Dr. Wotring.

The data show that spaceflight and combined oral **contraceptive pill (COCP)** use does not increase the risk of **venous thromboembolism (VTE),** despite the fact that COCP use on Earth is known to double the risk.



Whether the unique environment of space affects risk of venous thromboembolism (VTE) in astronauts is not known. On Earth, it is known that use of combined oral contraceptives (COCs) doubles the risk of VTE. Since some female astronauts choose to use COCs, this retrospective study examined known risk factors associated with VTE risk to determine whether the available data suggested elevated VTE risk in female astronauts. **The first case of VTE** on a space mission was reported in **January 2020**.

Source: Ingenta Connect

Physical Effects of Space on Women

Female astronauts are subject to the same general physical effects of space travel as men. These include physiological changes **due to weightlessness** such as loss of bone and muscle mass, health threats from cosmic rays, dangers due to vacuum and temperature, and psychological stress. **NASA reports** initially argued that menstruation could pose serious **health risks** or have a negative effect.

> Astronaut clothing for men has been based on technology used to make bras, and since women have been sent to space, the previously male-focused clothing has been reconsidered to address the issues and needs for clothing like space suits for extravehicular activity (EVA) and bras, e.g. for exercise in weightlessness environments. The low number of smaller-sized space suits has been hindering women astronauts in doing EVAs due to a lack of fitting suits.

Furthermore, **space toilet designs did not have women in mind** until October 2020 when the first toilet with a better design for women (as well as men) was delivered to the ISS.

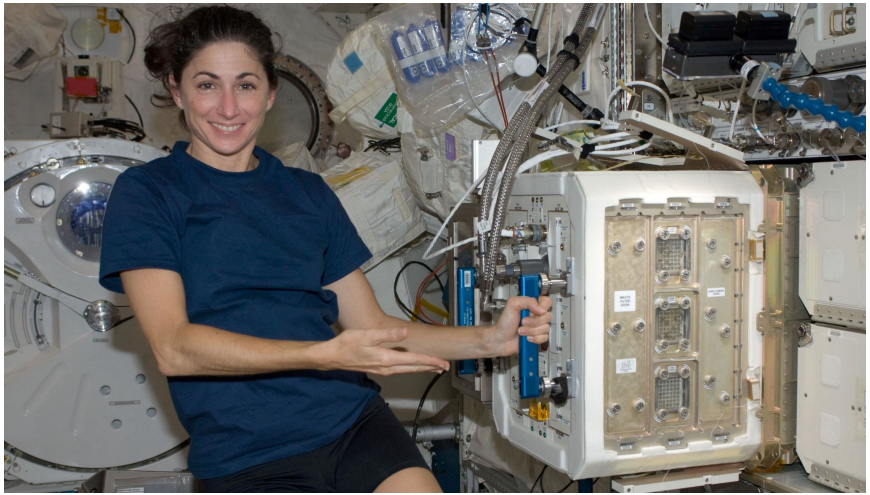
Colonel Liu Yang is a military pilot and astronaut who served as a crew member on the space mission Shenzhou. On June 16, 2012, Liu became the first Chinese woman in space.

Kathryn D. Sullivan poses for a picture before donning her space suit and extravehicular mobility unit in the airlock onboard the April 25, 1990 shuttle mission, deployed the Hubble Space Telescope.

Physical Effects of Space on Women: Radiation, Uterine and Breast Cancer

Men and women are both affected by radiation. Massive particles are a concern for astronauts outside the earth's magnetic field who receive solar particles from solar proton events (SPE) and galactic cosmic rays from cosmic sources. These high-energy charged nuclei are blocked by Earth's magnetic field but pose a major health concern for astronauts traveling to the moon and to any distant location beyond low earth orbit. Evidence indicates past solar-particle-event (SPE) radiation levels that would have been lethal for unprotected astronauts.

However, due to the currently used risk models for endometrial, ovarian and breast cancer, women at NASA can currently only spend half as much time on missions as men, which limits their career options relative to men. German standards for pregnant woman set a limit of **50 mSv/year** for the ovaries and uterus, and 150 mSv/year for the breasts.
Astronauts on Apollo and Skylab missions received on average **1.2 mSv/day** and **1.4 mSv/day** respectively. Exposures on the ISS average 0.4 mSv per day (150 mSv per year), although frequent crew rotations minimize risk to individuals.



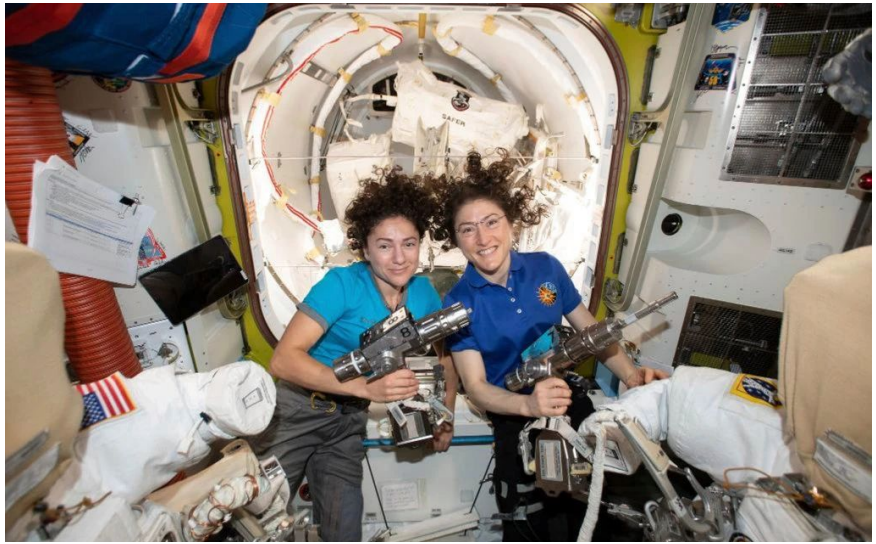
NASA astronaut Nicole Stott, Expedition 20/21 flight engineer, is pictured near the Mice Drawer System (MDS) in the Kibo laboratory of the ISS

A trip to Mars with current technology might be related to measurements by the Mars Science Laboratory which for a 180-day journey estimated an exposure approximately 300 mSv. That would be equivalent of 24 CAT scans or "15 times an annual radiation limit for a worker at a nuclear power plant".

Physical Effects of Space on Women: Fertility and Pregnancy

A study published in 2005 in the International Journal of Impotence Research reported that short-duration missions (no longer than nine days) did not affect "the ability of astronauts to conceive and bear **healthy children to term**." In another experiment, the frog Xenopus laevis successfully ovulated in space. NASA has not permitted pregnant astronauts to fly in space, and there have been **no pregnant women in space**. However, various science experiments have dealt with some aspects of pregnancy. For air travel, the United States' Federal Aviation Administration recommends a limit of 1 mSv total for a pregnancy, and no more than **0.5 mSv per month**.

> For a fetus, radiation increases the risk of childhood cancers. Beyond that, children of female astronauts could be sterile if the astronaut were exposed to too much ionizing radiation during the **later stages of a pregnancy**. Ionizing radiation may destroy the egg cells of a female fetus inside a pregnant woman, rendering the offspring infertile even whilst grown. While no human had gestated in space as of 2003, scientists have conducted experiments on non-human mammalian gestation.



The astronauts Jessica Meir, left, and Christina Koch, aboard the International Space Station

A Soviet **experiment** in 1983 showed that a rat that orbited while pregnant and later gave birth to healthy pups; the pups were "thinner and weaker than their Earth-based counterparts and lagged behind a bit in their **mental development**," although the developing pups eventually caught up.

We Lack Data about Effects of Spaceflight on Women

The groups observed that the disparity of spaceflight data available for men and women who have flown in space – **477 men vs. 57 women as of June 2013** – makes it difficult to derive concrete conclusions based on sex and gender alone. In the latest crew selection, NASA selected eight astronauts, comprising four women and four men.

The Sex & Gender work groups released five recommendations:

- Encourage and facilitate the participation of more female and male subjects in both ground and flight research studies.
- Focus on the responses of individual astronauts to spaceflight and return to Earth.
- Include sex and gender factors in the design of the experiments.
- Incorporate sex and gender and other individual risk factors into NASA-funded research programs

The 2013 astronaut candidate class, shown here in front of a Orion crew capsule mockup, comprises four women and four men

"This is the first major integrated examination of the issues of sex and gender in relationship to space exploration," said Dr. Mark Shelhamer, Chief Scientist for NASA's Human Research Program at Johnson Space Center.

Source: NASA

Current Advances: Space Medicine, Birth-in-Space, Spaceflight

September 2021

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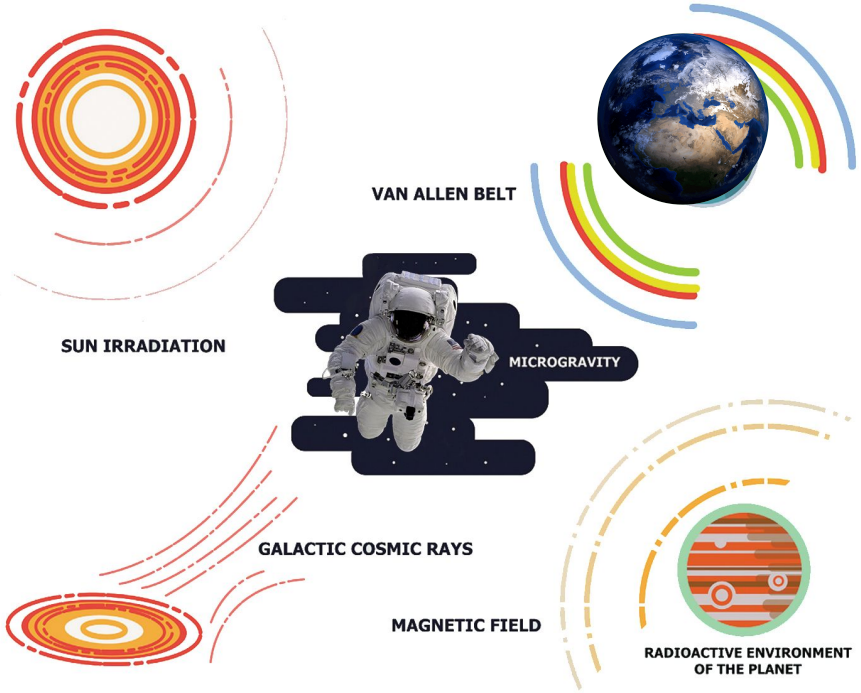
Space Travel Will Require Longer Healthspan

Advances in longevity are crucial to the future of the space economy. People should be able to not only live and work effectively in space for weeks, months, years, and, eventually, decades. In **ideal conditions** on Earth, the human body typically lives to **90 years** or more until aging-associated diseases lead to its decay and death. Surviving the harsh conditions of space travel, especially multi-month or multi-year missions, will lead to enormous physical losses for astronauts.

With current technology, it would take a crewed mission roughly **six months** to reach Mars, **eighteen months** to the Asteroid Belt, and up to **several years** to the outer planets. Given the current state of medical technologies, a multi-year journey to the nearest star system (let alone a multi-decade one) would probably **not be survivable**, even if we had propulsion technology to travel at large fractions of the speed of light.

The interplanetary environment presents immensely difficult challenges: zero gravity weakens and wreaks havoc on all bodily systems; cosmic radiation damages cellular DNA; traveling any appreciable distance will result in decades of artificial aging.



Space Medicine Framework

SELECTING FITTEST INDIVIDUALS

Conducting genetic, biochemical, physiological psychological, and physical tests to select the fittest individuals capable of surviving extreme space flight conditions.

HIBERNATION

Lowering the body's temperature with the help of chemicals or neural stimulations to reduce the need for food in humans.

GENE THERAPY

Biotechnologically enhancing radioresistance, weightlessness tolerance and DNA repairing mechanisms of the human body.

PROTECTION DRUGS

Researching and producing drugs capable of reducing damage caused by radiation, weightlessness and general stress (e.g. radioprotectors, geroprotectors and redox scavengers).

P4 MEDICINE

P4 (Precision Preventive Personalized Participatory) diagnostic, prognostic and therapeutic technologies to maintain an optimal state of astronauts' health for as long as possible.

CELL THERAPY

Cell therapies, bioengineered organs, tissue engineering and xenotransplantation targeting damage caused by space flight conditions.

BIOMARKERS

Discovering and developing biomarkers of damage and resistance, as well as the core infrastructure required for testing the safety and efficacy of therapies and effectiveness of interventions

LONGEVITY NEUROTECH

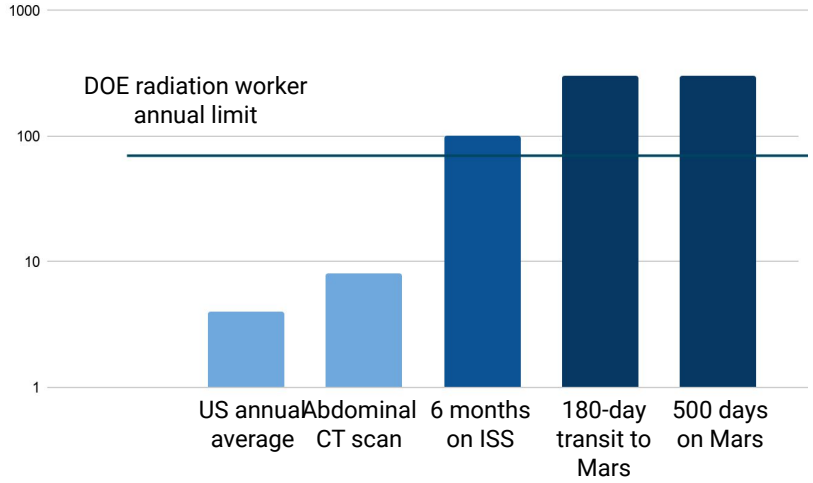
NeuroTechnologies to improve and maintain cognitive abilities, neurological plasticity, sleep quality (SleepTech) and psychological well-being of astronauts

Radioprotectors

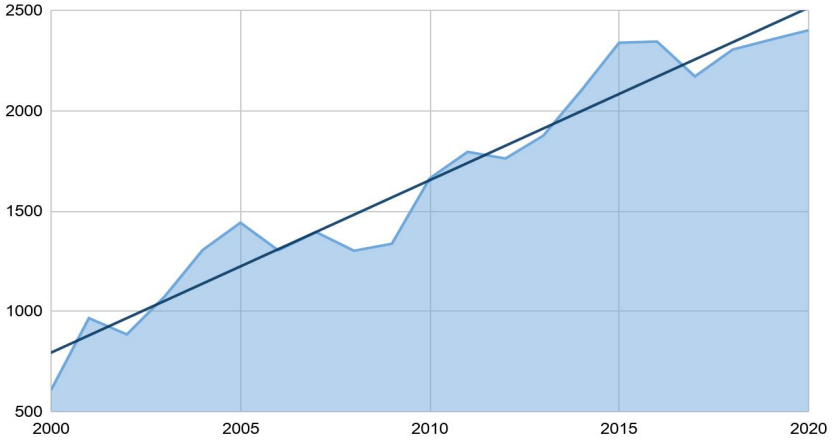
Outside the safe cocoon of Earth's atmosphere and magnetic field, subatomic particles zip around at close to the speed of light. **Space radiation** can penetrate habitats, spacecraft, equipment, spacesuits, and even astronauts themselves. The **interaction of ionizing radiation** with living organisms can lead to harmful health consequences, such as tissue damage, cancer, and cataracts, in space and on Earth. The underlying cause of many of these effects is damage to deoxyribonucleic acid (DNA).

Drugs called **Radioprotectors** are capable of reducing damage caused by space radiation and increasing astronauts' resistance to radiation exposure. Having a formidable potential, they are extremely important in the era of space exploration, development, and settlement.

Radiation Dose (Milliseverts)

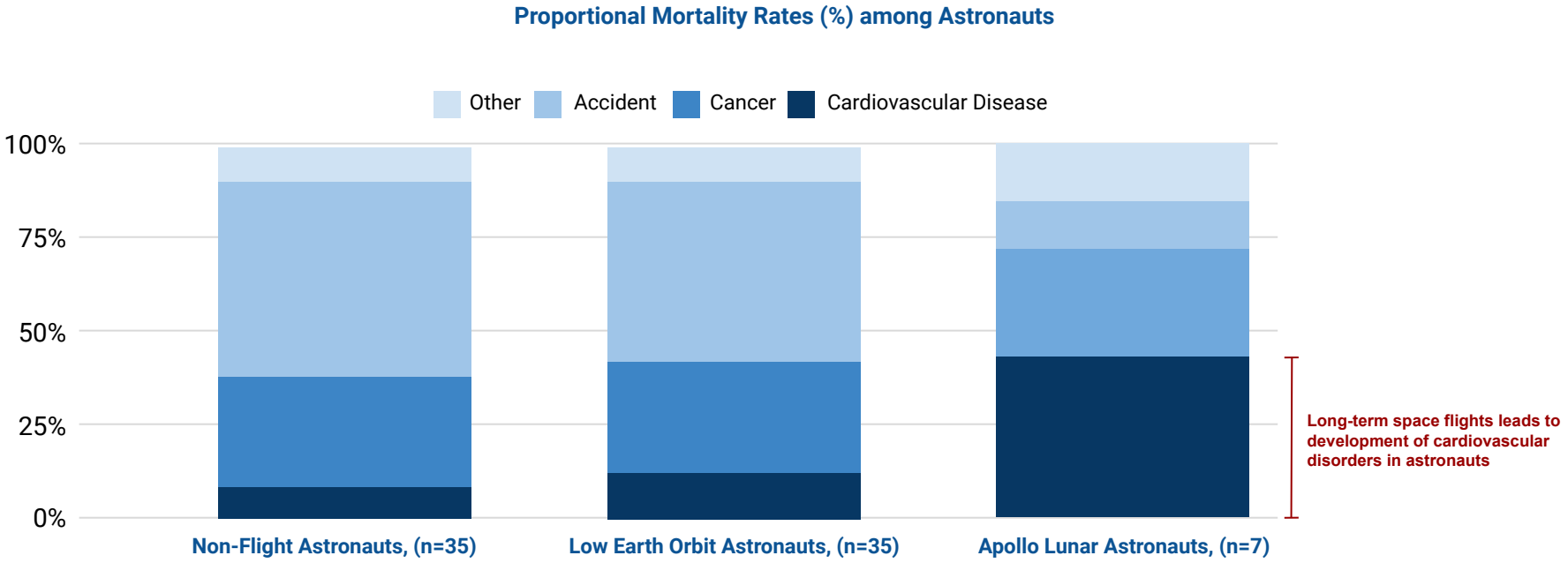


There is an Upward Trend in Research Into Radioprotectors:



Source: PubMed

Health Risks for Astronauts

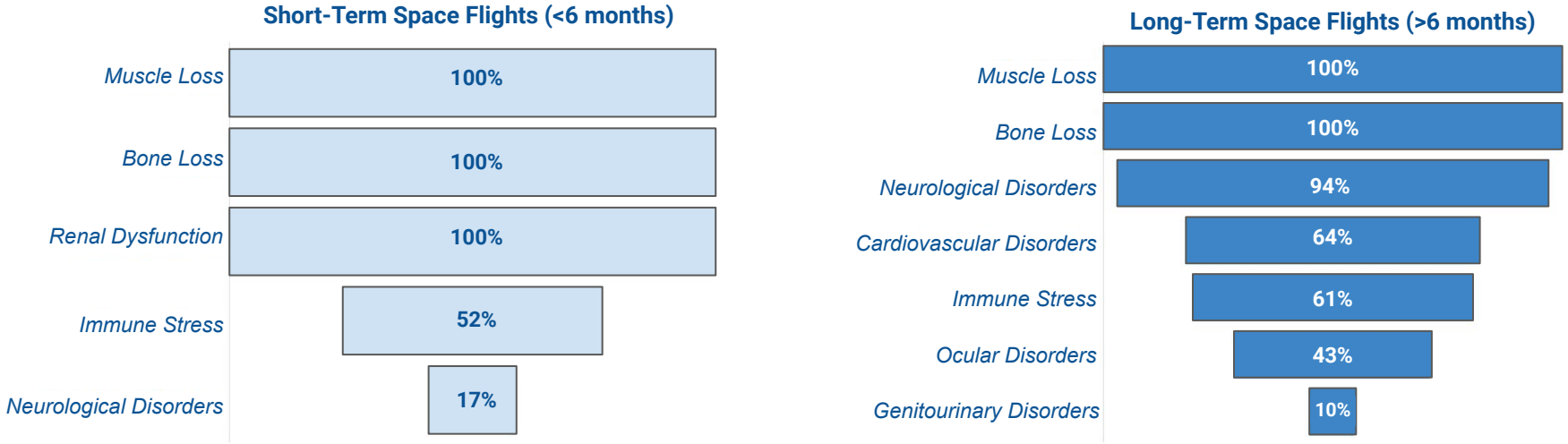


As multiple spacefaring nations contemplate extended human trips to Mars and the Moon, health risks could be elevated as travel goes far beyond the Earth's protective magnetosphere into the more intense deep space radiation environment. There no differences in CVD mortality rates between non-flight (9%) and LEO (11%) astronauts. However, the CVD mortality rates among Apollo lunar astronauts (43%) was 4–5 times higher than in non-flight and LEO astronauts.

Source: M. Delp at al. (2016) Scientific Reports, 6, Article number: 29901

Health Risks for Astronauts: Long-Term vs Short-Term Spaceflight

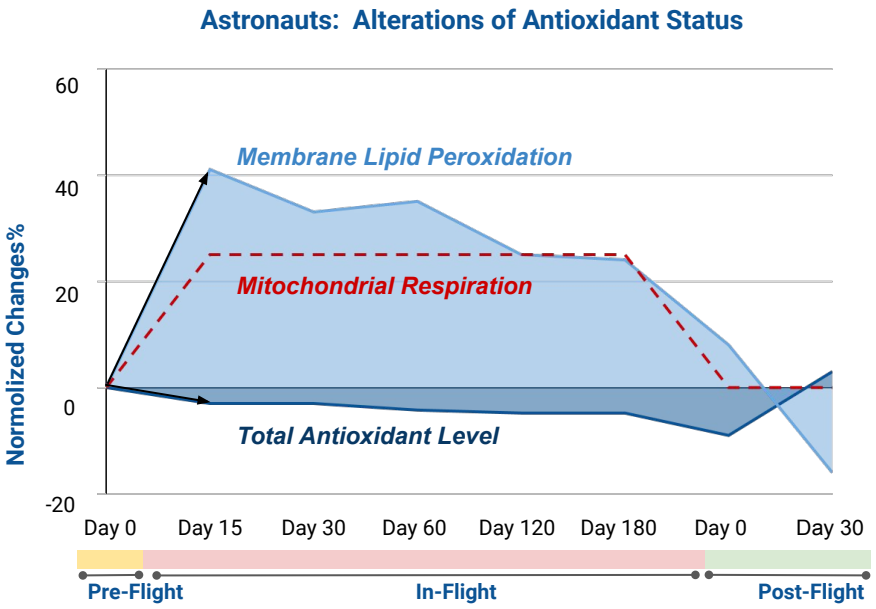
Disorder Rates (% of cases) of Organ Systems among Astronauts

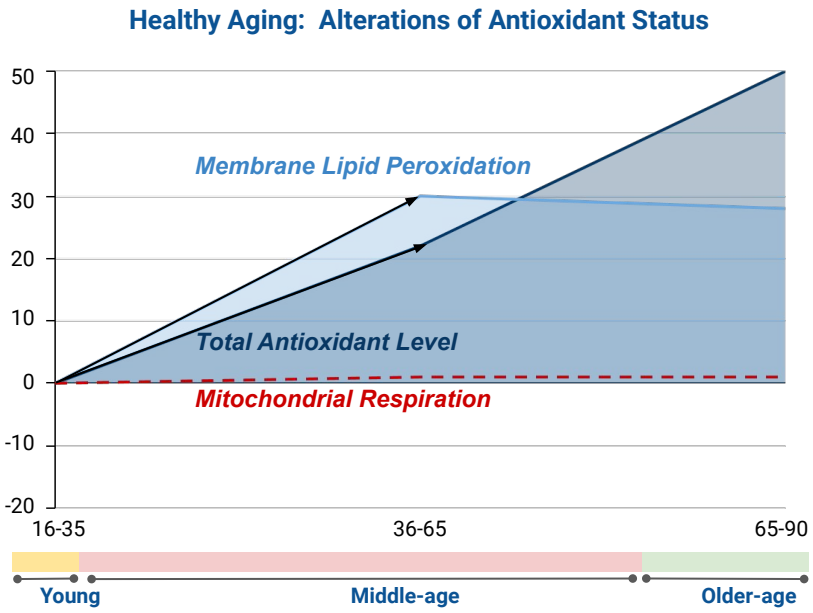


Astronauts are people with normal physiology who live in an abnormal environment. Often in response to weightlessness, many complex physiologic changes can be identified. During spaceflight, blood and other fluids move from the lower limbs to torso and head, so “puffy face, bird leg” syndrome will be observed. **Redistribution of body fluids is responsible for some of the early symptoms of space-motion sickness. Muscle and bone loss are constant.** An upward shift of the brain, increased intracranial pressure, narrowing of the central sulcus, and narrowing of CSF spaces at the vertex are present in both long-term and short-term spaceflight. Additionally, **cell-mediated immunity** and reactivation of latent herpes viruses are associated with spaceflight. **Genitourinary disorders and renal dysfunction are present with 10% in long-term spaceflight and 100% in short-term spaceflight,** respectively.

Source: NCBI

Mitochondrial Respiration and Redox Status in Astronauts vs. Aging

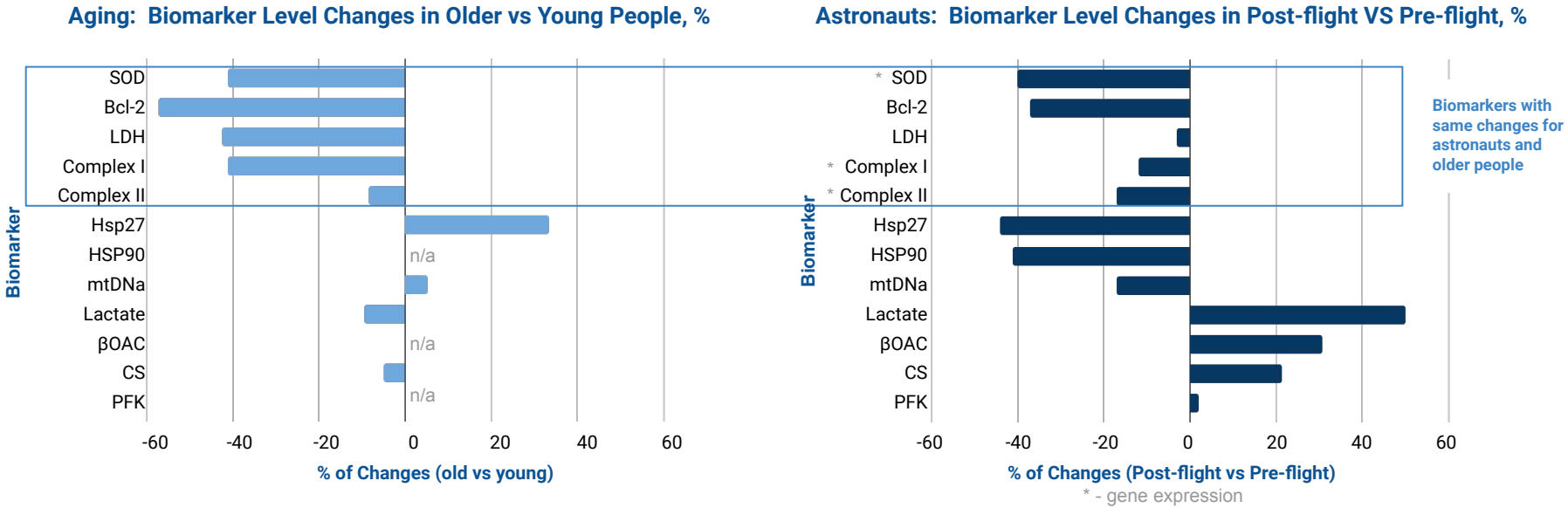




Long spaceflight leads to **~25% activation of mitochondrial respiration** and **~30% growth of membrane lipid peroxidation** in comparison with peroxidation level before flight. The **antioxidant level in astronauts is 4-10% lower** in space flight than antioxidant levels before flight. Oxidative membrane damage was evaluated through the assessment of lipid peroxidation also observed in oldery people vs young, but they had increased level of antioxidants and there were no any changes in mitochondrial respiration.

Source: Science Magazine, da Silveira et al., 2020, Cell 183, 1185–1201

Mitochondrial Biomarkers Changes: Space Flights vs. Aging



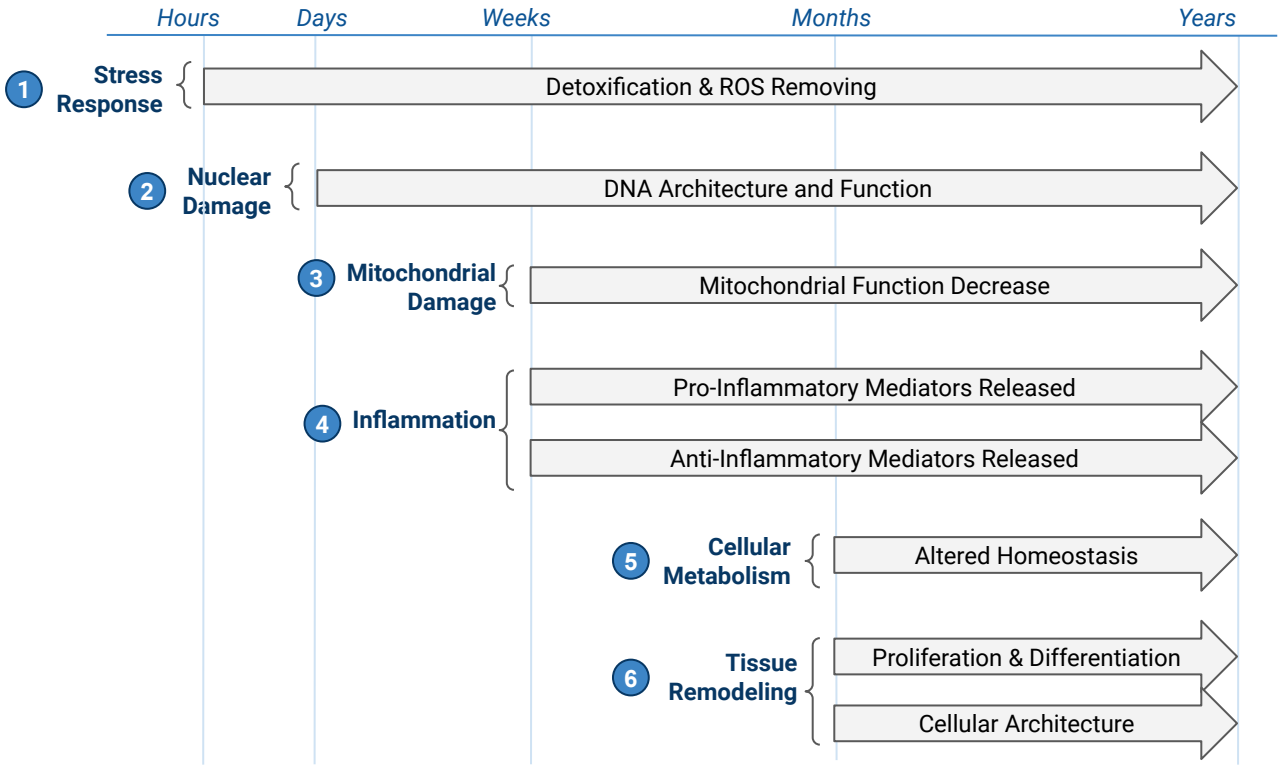
The NASA Twin Study provided excellent insight, looking at the same variables in an astronaut on a year-long mission with a control on the ground. A number of mitochondria-related changes at the genomic and functional levels related to the one-year mission have been identified.

Unfortunately, studies of space-related stress in the whole organism of astronauts are different than in isolated cells. **Only five mitochondrial biomarkers, as SOD, Bcl-2, LDH, Complex I and Complex II have the same changes** in astronauts after space flights (>6 months) and aging.

Source: Mitochondria in Longevity and Space Medicine

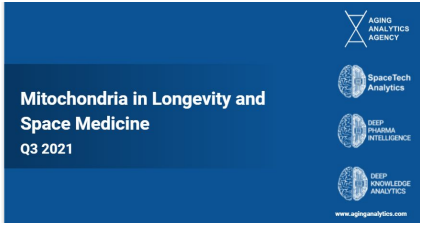
Genomic Biomarkers are Warning Signs for Health in Space

Expression of Age-related Biomarkers during Spaceflight



Several studies have been conducted for biomarker screening in astronauts during spaceflight. One is sponsored by the **JAXA-ISS Space Medicine Program**. The results of the combined data from Pre-flight, In-flight and Post-flight stages show significant changes in key gene expressions that are related to mitochondrial function and aging. Space factors in flight result in the DNA and mitochondrial damage that is apparent post-flight, promoting cellular aging.

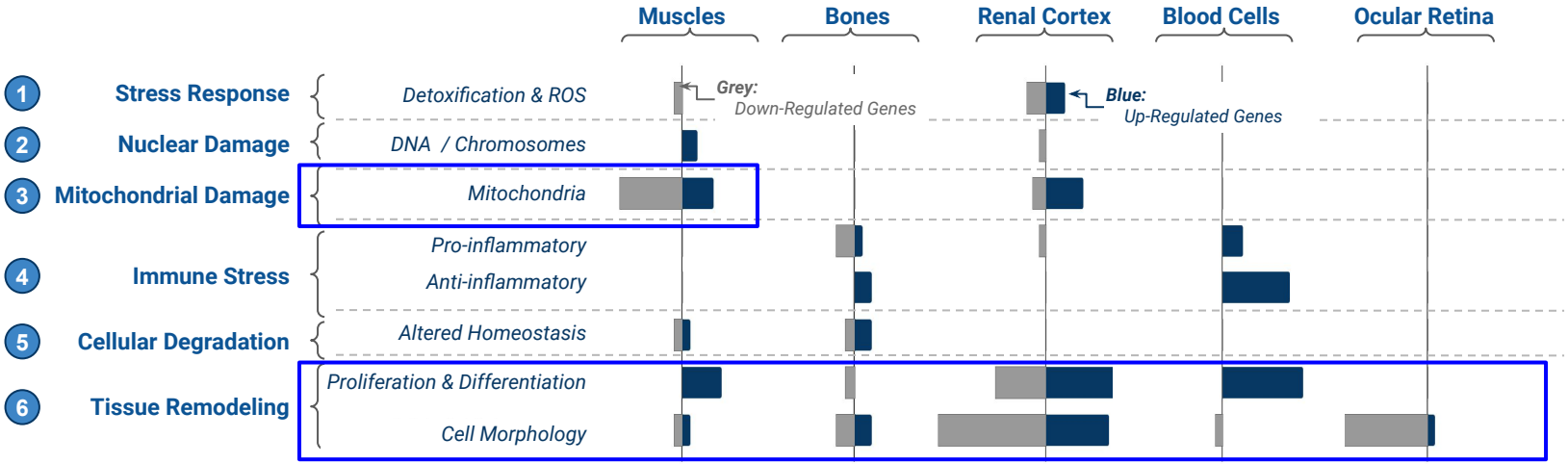
The data is partly taken from the "Mitochondria in Longevity and Space Medicine"report by AAA.



Source: Science Magazine

Single-Cell Gene Expression in Weightlessness (Human Cells)

Effect of Weightlessness on Gene Expression in Human Cells



Analysis of the results of different studies identified significant changes in gene expression responsible for **tissue remodeling** for all types of cells. Most of this genes are **pro-oncogenes: p53, c-Syn, Zip, WT33, Unph** etc. On the other hand, five markers: **IL-6, CRP, IL-10, CCL2/MCP 1, and IL-1Ra**, were elevated during space flight. These included tumor **TNF-α, IL-1α, and IL-1β**, which are normally associated with **immune dysregulation** but are also involved in **bone metabolism and early stages of muscle regeneration**. Annotation of genes upregulated in post-flight compared with the ground indicated that mitochondrial pathways were still enriched, demonstrating that a return to normal gravity does not completely restore normal mitochondrial gene expression. In muscles, expression of genes from the mitochondrial electron chain were decreased more significantly than in other tissues: down-regulation of **complex I & II, LDH, SOD** led to altered mitochondrial respiration.

Source: PubMed

Deep Space is not the Best Place to Raise Kids

Lack of food

Pregnancy during a long term space flights such as Mars One is dangerous as it could put the entire crew in danger. Resources such as air, food, and medical supplies will be limited and carefully gauged to keep the crew members alive.

The health of mother and crew

Pregnancy on the mission would also pose a greater risk to the mother. Although one or two of the astronauts will receive comprehensive medical training and medical equipment to treat anticipated illnesses or injuries will be available, the crew will likely not be prepared to assist with birth complications or provide care for a newborn.

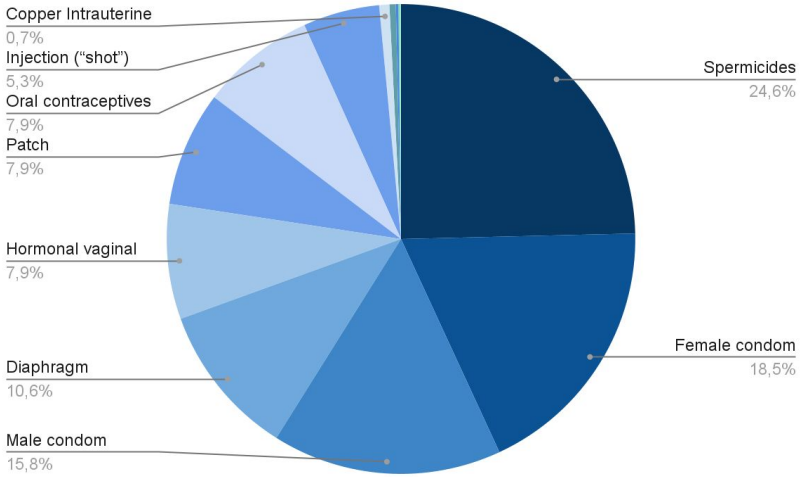
Sex in space

Human sex drive has been found to persist when humans are isolated in a small group for an extended time. At this time, NASA's policy forbids sex in space, and there have been no confirmed instances of it happening, but the lengthy trip to Mars and starting a settlement would almost unavoidably result in sex.

Contraception in space

There is a possibility that it could be easier to become pregnant in weightlessness. Radiation exposure will likely reduce sperm count, but there is evidence that suggests sperm cells swim faster in weightlessness. One study found that sperm is affected by small changes in gravity and found that fertilization in hypergravity was slowed down.

Failure rate of various forms of contraception in space



Source: Mars ain't the kind of place to raise your kid: ethical implications of pregnancy on missions to colonize other planets

Animals Born in Space or in Zero Gravity

Jellyfish

Jellyfish have gravity receptors similar to humans

After returning to Earth, their spatial orientation functions worked worse than those of jellyfish born on Earth. Accordingly, they moved with greater difficulty.

There could be some gravity receptors calibration tissues or distortions in their connection to the jelly's nervous system.

Snail

Snails also have similar gravitoceptors to humans

Space-born snails develop larger gravity recptors than the Earth-born ones but still have difficulties with their proper use.

- Unable to distinguish up from down
- Able to turn themselves right side up faster
- Turn was not always in the right direction

Rat, mice and hamster

Newborn rats spent the last week of gestation in space

- unable to distinguish up from down
- unable to flip themselves right side in the water
- over time, they recovered the normal sense of gravity

Other experiments showed worse results

1. *Fertilization of frog eggs on a Sounding Rocket in space*
2. *Fertilization of sea urchin eggs and sperm motility under low hyper-gravitational forces*
3. *Fish mating and eggs laying in space*

Therefore, the full development of an embryo may require normal gravity. The development of bones, muscles, heart, and neurology is at risk.

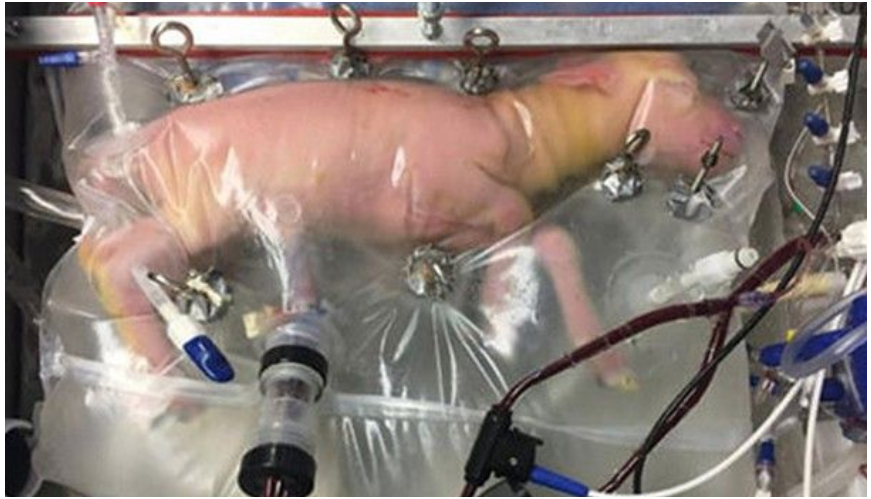
Sources: Business Insider, Wired, PlosOne

The Coming Revolution in Postnatal Care

Since the Mars environment and spaceflight are fraught with infertility, recent advancements in postnatal care technologies can come to the rescue. These technologies are intended to solve fertility and birth issues on Earth but might be adapted to challenges of settling Mars.

Artificial wombs are designed to save prematurely born babies , particularly to support preemies born as early as 21 weeks. The artificial-womb technology is moving to the point of development at which it will be possible to accept a fertilized egg and sustain it for an entire pregnancy.

A **"bio bag"** can mimic prenatal fluid to help give babies (born too early) extra weeks for their lungs to develop. It has been tested on fetal lambs. The next step in the development of artificial wombs is to provide the lambs with life support that doesn't require gas exchange through their lungs.



"We want to take the lung out of the equation."

All these steps are on their way to total ectogenesis, but it is still at least decades away.

Sources: Neo.Life 1, Neo.Life 2

Countermeasure Protocols and Post-Flight Rehabilitation

Exercises

Active fitness is required to prevent the body from losing bone and muscle.

Exercise increases the amount of plasma in the body.

It also increases blood volume and circulation and prevents fainting.

"No other activity except eating and sleeping is given that much priority. Two and a half hours each day are devoted to fitness."

Don Hagan, director of exercise physiology at Johnson Space Center

1. **The Cycle Ergometer** is similar to a bicycle, so pedaling is the main activity. It also measures heart rate and amount of work performed.
2. **The Treadmill** involves a regular walk or jog. Since this is not possible in space due to the lack of gravity, there are special harnesses that hold astronauts on the walking surface.
3. **The Resistance Exercise Device (RED)** is a comprehensive exerciser that allows one to train almost all parts of the body. Astronauts pull and twist stretchy cords attached to pulleys using their legs or arms.

These three exercises are common countermeasures to weightlessness outcomes. However, to take care of women's reproductive health, the protocol should be expanded with special exercises for the pelvic floor and other internal muscles of the abdomen, because they will play a major role in childbirth. Moreover, note that countermeasures remain an incomplete solution and bone loss will still occur. The existing effective countermeasure devices are too large to be delivered and incorporated.

Rehabilitation. Since post-flight injuries have sometimes occurred, NASA has created a rehabilitation program for astronauts returning from long-duration space flights. The program accelerates the recovery of functional capabilities to return crewmembers to baseline. For female astronauts, most of the risk is expected to be mitigated with oral contraceptives, hormone replacement therapy, doing impact exercise, and resistive exercise. All these approaches should be improved and adapted to Mars or Moon conditions.

Sources: Space.com

Medical Equipment Developed for Space is Implemented on Earth

Extraterrestrial Organs for Terrestrial Needs

Bioprinting of organs is another exciting technology. The weightless environment in the station is appropriate for 3D-printing tissues as it minimises the risk of collapsing under gravity.

Drug Development

The weightless environment on the ISS allows liquids that would not usually mix on Earth to combine and spontaneously form tiny spherical liquid-filled bubbles surrounded by a semipermeable outer membrane. Studying the samples upon return to Earth can help scientists to understand how to create the same microcapsules on Earth.

Next-generation Wearables

Astronauts need to monitor their physiological data. It usually means using several medical devices, which is bulky. The Bio-Monitor created a single “smart shirt” that measures pulse and electrical activity of the heart, breathing rate and volume, skin temperature, blood-oxygen saturation, etc.

However, this device can also be helpful for people with limited access to medical support or workers in dangerous environments such as mines, industrial sites, or factories.

Diagnosing the Remotest Patients

Astronauts live with limited access to medical facilities. VisualDX created a machine-learning algorithm that helps non-medical professionals to diagnose some conditions. This platform uses a picture and answers for particular questions. On Earth, this tool can be used for emergencies and low-resource areas.

Downsizing Labs

Standard laboratory tools are unavailable in space. 1Drop Diagnostics created a portable device that measures a range of biomarkers to determine cardiovascular function and kidney and liver function from a small blood sample. On Earth, this tool can also be widely used because it detects the condition anywhere.

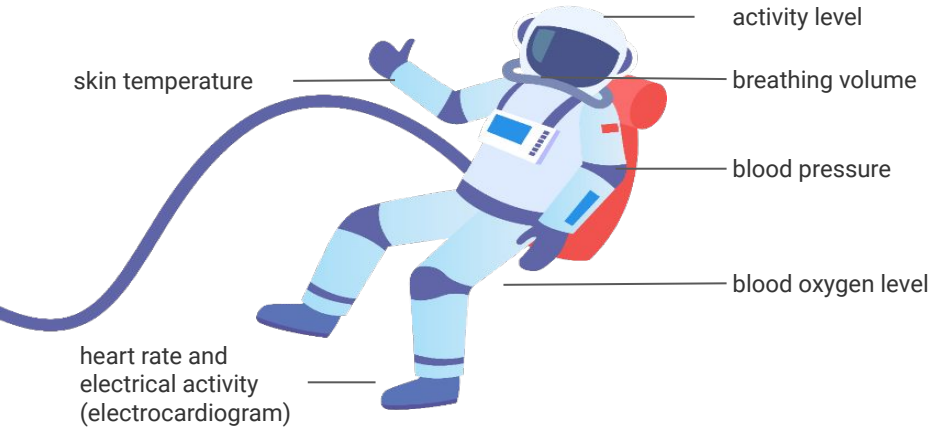
Sources: The Medical Futurist, Government of Canada, the Pharmaceutical Journal

Implementation of AI in Space Health - Non-Invasive Techniques

Wearable technologies for non-invasive health-monitoring systems has been in use for a long time. Today, it incorporates Artificial Intelligence (AI) for real-time tracking of astronaut health.

Wearable technologies

Bio-Monitor - technology developed by Canadian Space Agency aiming to carry out comprehensive analysis of astronaut conditions, including:



Electronic skin, motion sensors, smart shirt, etc.

Source: Nora M. Haney et al., 2020

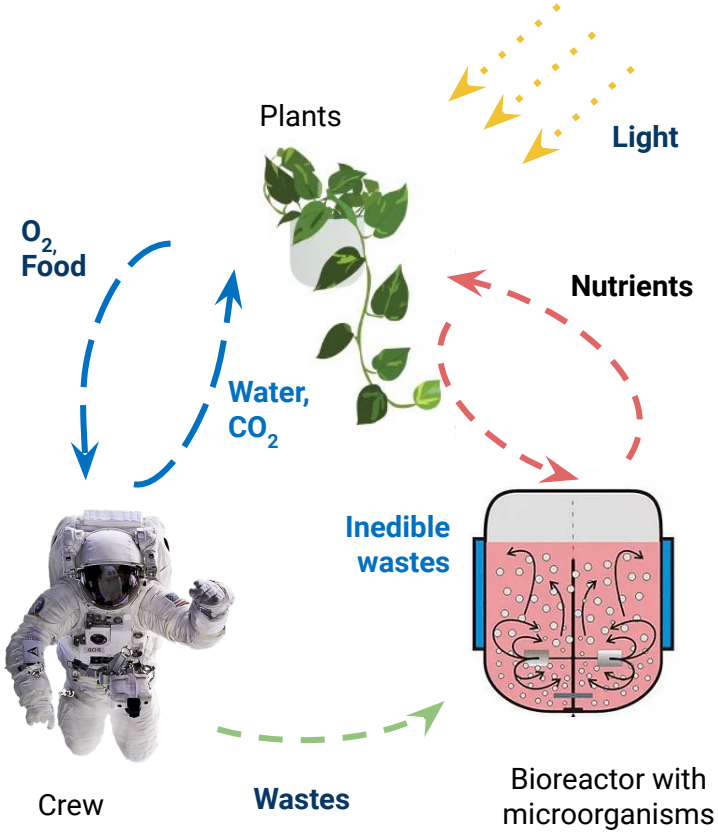
Bioregenerative Life Support Systems are an Advance Over Traditional Mechanical Life Support

Bioregenerative Life Support Systems (BLSS) are considered as the most advanced systems to provide space crew with oxygen, water, and food, and to clean up the air in a spacecraft.

This is achieved by sticking to the main principles of closed ecological systems, where waste products such as carbon dioxide, feces and urine must eventually be converted into oxygen, food, and water. To achieve maximum reusability, physico-chemical systems are often used, along with autotrophs such as algae, mushrooms, plants and microorganisms.

Previous BLSS were created exclusively as Earth-based experiments. The last attempt was carried out in China in 2017.

Yuegong-1 or "Lunar Palace" 2017



Source: Ecotechnics

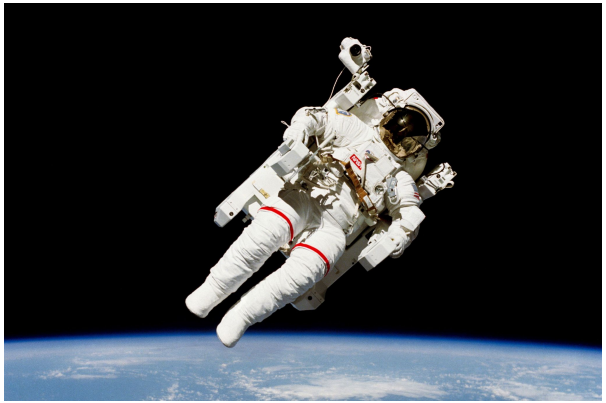
Tackling Weightlessness and Radiation Outcomes

Muscles and Bones

Researchers at the Jackson Laboratory for Genomic Medicine found that using pharmaceuticals to block certain signaling proteins in mice not only prevented the loss of bone and muscle mass that usually takes place in weightlessness but actually increased their density. This might become an effective solution to zero-gravity and weightlessness problems. Perhaps some in-utero treatment based on a cocktail of such proteins could help a space fetus grow bones and muscles in weightlessness, although much more research is needed before this could be determined.

The other more common alternative is to use bisphosphonate. It is a therapeutic agent that has been used to treat osteoporosis patients with a proven efficacy to increase bone mass and decrease the occurrence of bone fracture. Some research on Earth confirmed that this agent has a preventive effect on the loss of bone mass. Moreover, JAXA and NASA have collaborated to research this in more depth. Their crew members are participating in this study by taking this agent once a week while in space. The early results suggest that astronauts can significantly reduce the risk of bone loss and renal stones with the combination of resistive exercise and an antiresorptive such as a bisphosphonate.

However, the common physical exercises that were discussed previously are still required for astronauts and settlers to be fit.



Source: NASA, The Jackson Lab

Academic Institutions Studying Space Medicine all across the Globe

Biomarkers

- University of Alabama at Birmingham (USA)
- University of Michigan (USA)
- University of Washington (USA)
- Max Planck Institute for Biology of Ageing (Germany)
- University of Vienna (Austria)
- UCL (UK)
- Leiden University Medical Center (The Netherlands)
- Tsinghua University (People's Republic of China)
- University of Auckland (New Zealand)
  Institute of Nuclear Medicine & Allied Sciences (India)

Radioprotector

- University of Notre Dame (Australia)
- University of Sydney (Australia)
- Université de Lyon (France)
- Harwell (England)
- Philipps-University Marburg (Germany)
- Mittelhessen University of Applied Sciences (Germany)
- Belgian Nuclear Research Centre (Belgium)
- National Council on Radiation Protection and Measurements (USA)
- Southern Illinois University Carbondale (USA)
- University of New Mexico School of Medicine (USA)
- Memorial Sloan Kettering Cancer Center (USA)

Hibernation

- University of Tsukuba (Japan)
- RIKEN Center for Biosystems Dynamics Research (Japan)
- Niigata University (Japan)
- University of Bologna (Italy)
- Gifu University (Japan)
- Oregon State University (USA)
- University of British Columbia (Canada)
- Trento Institute for Fundamental Physics and Applications (Italy)
- National Institute of Nuclear Physics (Italy)
- University of New England (USA)

Gene Therapy

- University of London (England)
- GSK (England)
- Herlev Hospital (Denmark)
- University of Copenhagen (Denmark)
- The Icahn School of Medicine at Mount Sinai (USA)
- Universite Sorbonne Paris Cite (France)
- University of Pennsylvania (USA)
- The University of Tasmania (Australia)
- Baylor College of Medicine (USA)
- the University of Massachusetts Medical School (USA)

Source: PubMed

* Selected and categorized by the subject of their recent researches

Startups and Collaborations to Solve the Challenges of Space

September 2021

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Startups to Tackle Core Martian Settlement Issues

Carbon Utilization

Cemvita Factory is working on carbon utilization solutions, developing technology to capture carbon from the atmosphere. It would allow production of carbon-based products including food, pharmaceuticals, and construction materials. The technology could also be used for terraforming on Mars.

Oxides Utilization

Helios develops technologies to extract oxygen and various metals from oxides in Martian and lunar surfaces. It has designed a reactor that is able to turn the metal into infrastructure components. Also, this technology can be used to provide people and homes with oxygen, and to also convert oxygen into propellants.

Carbon Utilization

UP Catalyst also develops technologies to extract oxygen and valuable carbon nanomaterials from carbon dioxide on the Martian surface. The short list of possible applications: battery and ultracapacitor technologies, conductive and strengthening coatings, polymer formulations, water filters, etc.

Mars' atmosphere is 95% carbon dioxide compared to 0.04% on Earth

Each extra kilogram significantly increases transportation costs. In order to successfully establish a settlement, provide it with all the necessary resources and maintain a settlement on the Moon or Mars, it is extremely important to obtain resources and materials in situ.

Startups to Tackle Core Martian Settlement Issues

Quantum Telecommunication

TCT Aerospace develops quantum telecommunication and space hardware technologies based on quantum entanglement principles that would provide instantaneous, unbreakable point-to-point communication over vast distances. Probably, Earth to Mars communication may become extremely fast and with infinite data transfer capabilities.

Quantum telecommunication can revolutionize space industry due to plenty of opportunities it would open

Onboard Autonomy

Mission Control develops robotics-based solutions. Its AI-enabled technology is able to assess soil automatically. Particularly, it classifies the terrain, detects novel features, and aggregates data. Moreover, the startup provides solutions to improve the navigation autonomy of rovers in extraterrestrial terrain.

Robots will become the main and indispensable workhorses for space missions.

Human Milk

On July 1, 2021 startup BIOMILQ announced they produced cell-cultured human milk (outside of the animal). This technology might ease the issue of infant feeding away from Earth. However, this solution is not specifically focused on extraterrestrial application.

Childcare in the first year of life on Mars or the Moon, is a completely unexplored field. Such solutions may or may not be useful.

Sources:StartUps, EU startups

Startups to Tackle Core Martian Settlement Issues

Women oriented telemedicine

TCT Aerospace develops quantum telecommunication and space hardware technologies based on quantum entanglement principles that would provide instantaneous, unbreakable point-to-point communication over vast distances. Probably, Earth to Mars communication may become extremely fast and with infinite data transfer capabilities.

Space suits to protect astronauts health

ILC Dover is now the lead manufacturer of space suits, mostly because they have been supplying NASA with them for every Apollo mission. However, there is a startup founded in 2018 called Final Frontier Design that is already selling all types of spacesuits (except for Mars exploration suits) and are planning to reduce their prices vastly.

Artificial Wombs

Nextnation Network along with Maxima Medical Centre has developed the novel design of artificial womb. And received €2.9 million grant to develop a working prototype of their concept. Not to mention the work of Prof. Gied Oey, who is transferring existing artificial wombs from animal model to humans in a sophisticated fluid environment.

Top Space Food Initiatives for Space Settlers

Aleph Farms - the Israel-based company that is developing the technology of growing steak directly from non-GMO animal cells. The company launched its 'Aleph Zero' program focused on cultivating meat for space exploration. Aleph Farms partnered with technology companies and space agencies to leverage its knowledge in cell biology, tissue engineering, and food science to establish BioFarms in extraterrestrial environments. In 2019, the company conducted a successful experiment of producing meat on the International Space Station, in collaboration with 3D Bioprinting Solutions.

Finland biotechnology company **Solar Foods** synthesize proteins right from the air. The process takes a single microbe, and grows it by fermenting it, which is also called a bioprocess. They feed the microbe like we feed a plant, but instead of watering and fertilising it, company use air and electricity. They use the same process to yeast fermentation but instead of sugar and yeast, they milk water from the air for the microorganisms to live in and feed them CO2, as well as nutrients like nitrogen, calcium, phosphorus and potassium.

Italian **Argotec**, the company chosen by European Space Agency to develop -in the SpaceFood Lab- the food supply program for European astronauts in the ISS (International Space Station). This kind of special food (called "bonus-food") is specifically studied for each astronaut, and also has the purpose to support him/her psychologically during the permanence in space. For italian astronauts Argotec made, for example, tiramisù and lasagne.

Advances in Food Technology will be Crucial for Space Exploration and Settlement

The Vegetable Production System is a deployable plant-growth unit capable of producing salad-type crops in space. This technology will provide future space explorers with a sustainable food supplement during their long-duration missions, and ultimately allow space settlement.

Developed by NASA's Center of Excellence for Collaborative Innovation, ISS Fit app is designed for use aboard the International Space Station. It provides astronauts with an option to track their food intake by making audio recordings, shooting videos, taking photos or scanning barcodes.

Being a health technology company, Mission: Space Food brings together a team of Michelin star chefs, aerospace engineers, doctors, astronauts and cognitive nutritionists. They are working together to define the future of space nutrition.

A company that develops space food which can also be used for mass consumption on Earth.

The Space Foods Company Ltd. has the knowledge and ingredients to provide its services to the modern space traveller.

Source: NASA

Top Companies Advancing Reproduction in Space and Astronauts Protection

United States

Cemvita Factory Inc.
Houston, TX,
United States

Angiex
Cambridge, Massachusetts,
United States

Zopherus
Arkansas,
United States

Marsha AI
New York,
United States

Blue Origin
Kent, Washington,
United States

ILC Dover
Newark, DE,
United States

Final Frontier Design
New York City, New York,
United States

BIOMILQ
Durham, North Carolina,
United States

Open Lunar
San Francisco, California,
United States

SpaceX
Hawthorne, California,
United States

Israel

Helios
Thousand Oaks, California,
United States

Scotland

TCT Aerospace
Edinburgh,
Scotland

Finland

Solar Foods
Helsinki,
Finland

Estonia

UP Catalyst
Tallinn,
Estonia

Canada

Mission Control Inc.
Ottawa, Ontario,
Canada

Netherlands

Maxima
Eindhoven,
The Netherlands

Next Nature Network
Amsterdam, North Holland,
The Netherlands

SpaceBorn United
Eindhoven,
The Netherlands

Switzerland

Aleph Zero
Zug, CH, Switzerland

42% of companies shown have their headquarters in the **U.S.**, with the **Netherlands** in second place (**16%** of all private companies). Other companies are distributed equally among **Israel, Scotland, Finland, Estonia** and **Canada**.

NASA Partnerships to Advance Moon and Mars Technology

Advanced Communication, Navigation and Avionics	• Advanced Space of Boulder, Colorado, will partner with NASA's Goddard Space Flight Center in Greenbelt, Maryland, to advance lunar navigation technologies. The collaboration will help mature a navigation system between Earth and the Moon that could supplement NASA's Deep Space Network and support future exploration missions. • Vulcan Wireless of Carlsbad, California, also will partner with Goddard to test a CubeSat radio transponder and its compatibility with NASA's Space Network.
Advanced Materials	• Aerogel Technologies of Boston will work with NASA's Glenn Research Center in Cleveland to improve properties of flexible aerogels for rocket fairings and other aerospace applications. The material can result in 25% weight savings over soundproofing materials currently used in rocket fairings. • Lockheed Martin of Littleton, Colorado, will work with NASA's Langley Research Center in Hampton, Virginia, to test materials made from metal powders using solid-state processing to improve the design of spacecraft that operate in high-temperature environments. • Spirit AeroSystem Inc. of Wichita, Kansas, will partner with NASA's Marshall Space Flight Center in Huntsville, Alabama, to improve the durability of low-cost reusable rockets manufactured using friction stir welding.
In-Space Manufacturing and Assembly	• Maxar Technologies of Palo Alto, California, will work with Langley to build a breadboard – a base for prototyping electronics – for a deployable, semi-rigid radio antenna. In-orbit assembly of large structures like antennae will enhance the performance of assets in space. Such capabilities could enable entirely new exploration missions that are currently size-constrained and reduce launch costs due to improved packaging.
Power	• Blue Origin will partner with Glenn and Johnson to mature a fuel cell power system for the company's Blue Moon lander. The system could provide uninterrupted power during the lunar night, which lasts for about two weeks in most locations. • Maxar will test lightweight solar cells for flexible solar panels using facilities at Glenn and Marshall that mimic the environment of space. The technology could be used by future spacecraft to provide more power with a lower mass system.

Sources: NASA

NASA Partnerships to Advance Moon and Mars Technology

Entry, Descent and Landing	• Anasphere of Bozeman, Montana, will partner with Marshall to test a compact hydrogen generator for inflating heat shields, which could help deliver larger payloads to Mars. • Bally Ribbon Mills of Bally, Pennsylvania, will perform thermal testing in the Arc Jet Complex at NASA's Ames Research Center in California's Silicon Valley. The facility will be used to test a new seamless weave for a mechanically deployable carbon fabric heat shield. • Blue Origin of Kent, Washington, will collaborate with NASA's Johnson Space Center in Houston and Goddard to mature a navigation and guidance system for safe and precise landing at a range of locations on the Moon. • Sierra Nevada Corporation of Sparks, Nevada, will work with NASA on two entry, descent and landing projects. The company will partner with Langley to capture infrared images of their Dream Chaser spacecraft as it re-enters Earth's atmosphere traveling faster than the speed of sound. • SpaceX of Hawthorne, California, will work with NASA's Kennedy Space Center in Florida to advance their technology to vertically land large rockets on the Moon. This includes advancing models to assess engine plume interaction with lunar regolith.
Propulsion	• Aerojet Rocketdyne of Canoga Park, California, and Marshall will design and manufacture a lightweight rocket engine combustion chamber using innovative processes and materials. The goal of the project is to reduce manufacturing costs and make the chamber scalable for different missions. • Blue Origin, Marshall and Langley will evaluate and mature high-temperature materials for liquid rocket engine nozzles that could be used on lunar landers. • Colorado Power Electronics Inc. of Fort Collins, Colorado, will partner with Glenn to mature power processing unit technology that extends the operating range of Hall thrusters, which are primarily used on Earth-orbiting satellites and can also be used for deep space missions. By integrating their technology with NASA and commercial Hall thrusters, the company expects to provide a propulsion system that can significantly increase mission payload or extend mission durations. • SpaceX will work with Glenn and Marshall to advance technology needed to transfer propellant in orbit, an important step in the development of the company's Starship space vehicle.
Other Exploration Technologies	• Lockheed Martin will partner with Kennedy to test technologies and operations for autonomous in-space plant growth systems. Integrating robotics with plant systems could help NASA harvest plants on future platforms in deep space.

Sources: NASA

Future Projections & Developments: Living on the Moon and Mars

September 2021

www.spacetech.global

SPACEBORN UNITED

SpaceTech Analytics

Giving Birth on Mars

There are numerous challenges to giving birth on Mars. The following ones are the most salient:

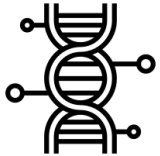
radiation	weightlessness	stress

Considering all of the aspects above, plenty of companies and nations are developing **Mars/Moon settlement programs**. Private initiatives are characterized by greater ambitions. However, different nations are appearing to put much more effort and resources into space settlement projects than they used to do decades before.

Nevertheless, that were private initiatives that revived the big idea of space settlements, and they are remaining the main driving force of that process. Notwithstanding that some of the private initiatives have already announced project collapse due to bankruptcy or other causes, the overall commitment to the idea is growing. In turn, people's willingness to engage in this project is growing too.

Under harsh Mars conditions, the successful survival of a fetus and consequent childbirth is extremely difficult to achieve.

Genetic engineering may assist in the treatment or cure of a set of single-gene related diseases for which the cure was already developed. However, we have no idea how genetic engineering could assist beyond this. It brings a set of new challenges. First of all the long-term effects are undiscovered yet. Besides, plenty of ethical issues will arise.



The Mars settlement will bring **a completely different socioeconomic culture**. It might make parenting nearly impossible as parents will have plenty of other responsibilities. In a settlement of about 5000 people, everyone will be needed to provide some contribution and work in a space settlement.

Some technological solutions can also help to resolve the issue of radiation and weightlessness. The stress factor is even less clear on how to predict and prevent.

Sources ESPI :

Initiatives to Go Beyond the Earth

Asgardia - The Space Nation. Asgardia is the first space nation, a unique international community of forward-looking people, a digital state with its own transparent economy focused on scientific progress on Earth and in space. Asgardia aims to ensure peaceful space exploration, protect our home planet from cosmic threats and lead the development of new Space Law to eliminate militarization of space.

The key scientific goal is facilitating the first human childbirth in space — a crucial step on the path to immortality as a species.

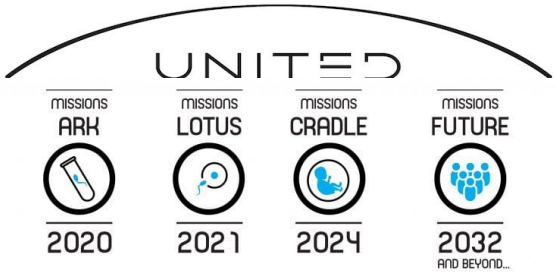
The Asgardian website says: "Let's be very clear: every penny, every cent spent on Asgardia up to date and still for quite some months to come is the investment by Dr Ashurbeyli."

Asgardia-1 is a 1U CubeSat that stores a 512 gigabyte of private information of Asgardians (mainly photoes). It was developed by NanoRacks and boosted to space and then deployed by US companies on a NASA-funded mission so the satellite falls under US jurisdiction

At the moment, anyone can become a citizen of Asgardia. But Dr Ashurbeyli has said he wants to attract the world's most creative minds, and may eventually bring in a mandatory IQ test for potential Asgardians. **Dr Ashurbeyli wants to recruit a total population of about 150 million within the next 10 years.**

Source: Asgardia.space.en

Initiatives Attempts to Go Beyond the Earth



SpaceBorn United based in the Netherlands, wants to send a pregnant woman, accompanied by a “trained, world-class medical team,” in a capsule to the space above Earth. The mission would last **24 to 36 hours**. Once the woman delivered the child, the capsule would return to the ground. “A carefully prepared and monitored process will reduce all possible risks, similar to Western standards as they exist on Earth for both mother and child,” SpaceBorn United website states.

The company has set the year 2024 as the target date for the trip.

Mars One was a private project led by Bas Lansdorp that envisioned a flight to Mars with the subsequent establishment of a **settlement on its surface and broadcasting everything that happened on television**. Organizationally, the project consisted of two legally independent organizations: the non-profit Mars One Foundation, responsible for the implementation of the project, and the commercial Mars One Ventures AG, to which all rights to television broadcasts and Mars One symbols were transferred, and whose proceeds were to finance the project.

On January 15, 2019, Mars One Ventures AG was declared bankrupt and liquidated in court.

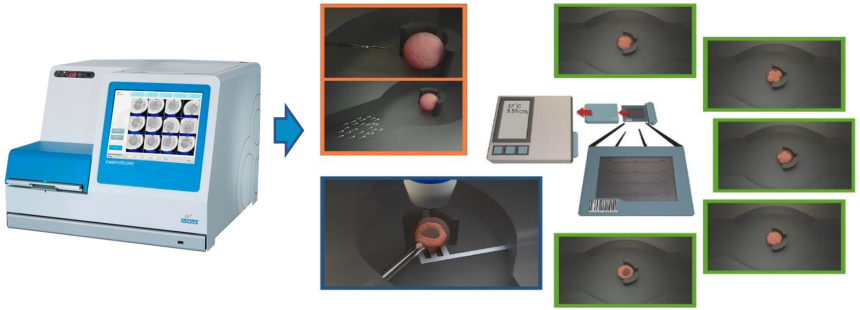
Source: SpaceLife Origin, Mars-One

Biotech/ research company plans for conception in LEO

SpaceBorn United (SBU), a Dutch biotech/ research company researches the conditions for each stage of human reproduction in space. SBU translates the research outcomes into a missions program with execution partners and they develop the biomedical devices required for these missions.

Their first step is to enable conception and early embryo development in LEO. A recoverable biosatellite, provides artificial gravity (1G), during a 6 day mission. Follow up missions aim to study embryo development in partial gravity environments (e.g. Mars level).

> "SBU is currently focused at developing ARTIS: assisted reproductive technology in space, by re-engineering existing IVF technology. We optimise and extend functionalities of existing embryo incubators to function as a life support system in space. We therefore apply microfluidic- and cryogenic technology and add adjustable artificial gravity" explained CEO Dr. Edelbroek.



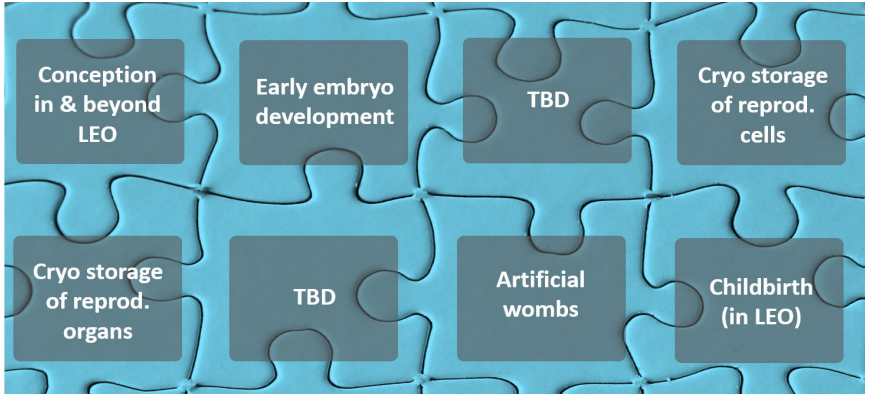
Studying conception and embryo development in partial gravity is essential in order to understand the gravity requirements for this stage of reproduction. It fills crucial data gaps in existing research roadmaps enabling deep space exploration and becoming a multi-planetary species.

Biotech/ research company plans for conception in LEO

SPACEBORN UNITED

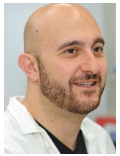
Meanwhile SBU closely follows technological developments like artificial wombs and works on mission architectures that enable subsequent reproduction stages in space.

Reproduction stages and research areas in different gravity environments



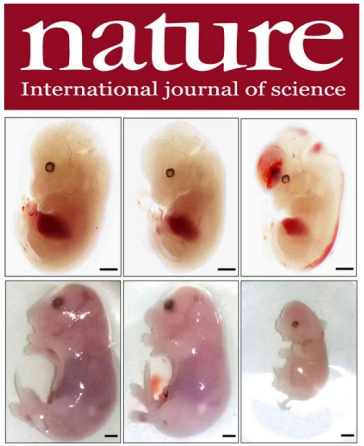
Regarding artificial wombs, SBU follows two developments; Prof. Oei. received a large grant to transform the artificial womb for mammals (sheep) into a human version (in this stage applied to premature babies). Future versions are expected to increase options for human space exploration.

Dr. Hanna and his team succeeded in removing (1000+) embryos from the uteruses of mice at five days of gestation and growing them for six more days in artificial wombs, resulting in healthy pups.



Dr. Jacob Hanna
Weizmann Institute of Science (Israel)

Prof. Gied Oei
Eindhoven University of Technology (NL)



Mouse embryo development inside an artificial womb

SBU's long term research roadmap includes long term mission concepts (childbirth in microgravity), astro-sociology, advanced concepts (Next Nature Network), partial gravity compensation beyond Earth (e.g. rotating Mars habitats) and radiation resistance enhancement (supported by her research and industry partners).

Living on the Moon and Mars

On March 9, 2021 the heads of the Chinese and Russian space agencies signed an agreement to work together to build a research base on the Moon.

China has previously disclosed its ambitions to build an international lunar station at the **South Pole of the Moon**, beginning with robotic missions and followed by short-term human missions in the early 2030s. The country plans to establish a long-term human presence at the South Pole—which is believed to contain vast reserves of water ice—during the period of **2036 to 2045**. These plans were initially discussed at a meeting of the UN Subcommittee of the Committee on the Peaceful Uses of Outer Space last year.

NASA plans to go to the Moon in 2024 and establish a permanent settlement called the **Artemis Base Camp** within another decade. As part of the Artemis mission, NASA is also planning to launch a cislunar space station in **2024** called Gateway. NASA is cooperating with SpaceX for this and future lunar projects, and some claim that the lunar station will make it easier for SpaceX to resupply the future lunar settlement.

After the Moon comes Mars, and the collaboration between **SpaceX** and **NASA** is accelerating the timeline for getting there. NASA's plans are purposeful, but the organization hasn't provided a timeline. **Elon Musk**, on the other hand, has proclaimed that he intends to have a self-sufficient settlement on **Mars by 2050.**

Source: TheAtlantic

Planned crewed lunar missions, 2021–2036

Asia

Japan has plans to land astronauts **on the moon by 2030** — with a little help from the United States. The Japanese space agency JAXA said it envisions human missions to the moon, potentially to study and make use of water ice deposits at the **lunar poles**.

China wants to put astronauts on the moon by 2036, a senior space official said, the latest goal in China's ambitious lunar exploration program. Advancing China's space program is a priority for Beijing, with **President Xi Jinping** calling for the country to establish itself as a space power.

US

US billionaire **Jeff Bezos** has outlined his plans for a lunar base in the 2020s

Independently, **SpaceX** plans to send Starship to the Moon to establish a base.

In March 2019 NASA unveiled the **Artemis program's mission** to send a crewed mission to the **Moon by 2024**, in response to a directive by President Trump, along with plans to establish an outpost in 2028. Despite funding issues, NASA plans have remained to return to the moon by 2024.

Global organizations

In August 2019, the **Open Lunar Foundation** came out of stealth with an explicit plan to develop a collaborative and global open group to allow denizens of all nations to participate in building a peaceful and cooperative lunar settlement. The effort got underway in early 2018 when a group of Silicon Valley entrepreneurs came together after realizing that significantly-reduced launch costs of private companies could make possible a lunar settlement that might be instantiated with an investment of "single-digit billions", perhaps **$2–3B**. Founders include Steve Jurvetson, Will Marshall, Chelsea Robinson, Jessy Kate Schingler, Chris Hadfield, and Pete Worden. Initial funding for Open Lunar was $5M.

European Space Agency Initiative to Found a Moon Village

European Space Agency
Paris, France

Skidmore, Owings & Merrill (SOM)
Chicago, IL, USA

MIT Department of Aeronautics and Astronautics
Cambridge, MA, USA

Moon Village is a Moon exploration strategy proposed by the European Space Agency (ESA) and aimed at establishing lunar habitation systems. It is less a solid plan than a vision, which encourages participation of private and national partners. However, the project is still in the early stages of development. **In 2021 Moon Village was presented at Venice Biennale with a "Life Beyond Earth" installation.**

MIT Media Lab
Cambridge, MA, USA

Source: ESA, MIT Media Lab

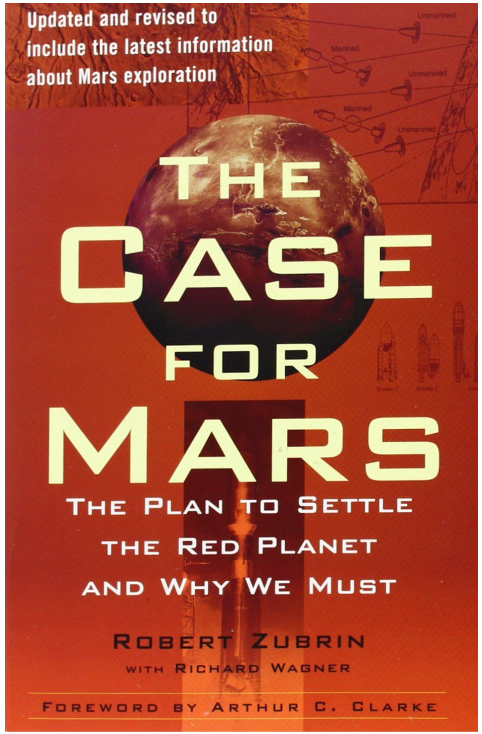
The Mars Society

The Mars Society is an American worldwide volunteer-driven space-advocacy non-profit organization dedicated to **promoting the human exploration** and settlement of the planet Mars. **The goal is to educate** the public, the media and government on the benefits of exploring Mars, the importance of planning for a humans-to-Mars mission in the coming decades and the need to create a permanent human presence on the Red Planet. Annually, Mars Society carries out training and experiments to prepare potential settlers for trips to Mars.

The Mars Society has chapters in the U.S. and around the world, including: *Canada, Austria, France, Germany, Netherlands, Poland, Switzerland, United Kingdom, South Asia, India, Australia and New Zealand.*

Mars Direct is a sustained humans-to-Mars plan developed by Dr. Robert Zubrin that advocates a minimalist, live-off-the-land approach to exploring the planet Mars, allowing for maximum results with minimum investment.

Published in **1990** and elaborated in detail in 1996 in the book **The Case for Mars**, Mars Direct was a radical break with previous NASA thinking on how human Mars missions might be accomplished.



> The Society's goals are not purely theoretical. The goal is to show that Mars is an achievable goal through the implementation of a number of practical, technical and other projects.

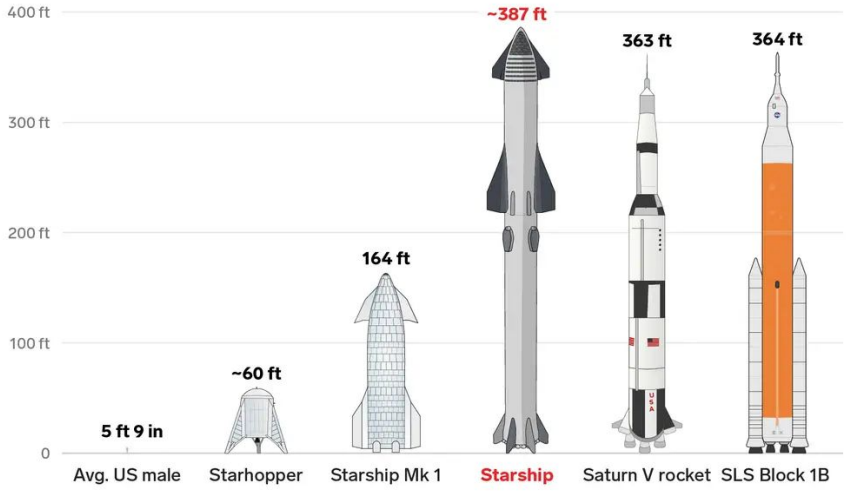
Starship/Superheavy May Make Humans Multiplanetary

Elon Musk: A Million Humans Could Live on Mars By the 2050s

Elon Musk thinks it's possible to begin shuttling thousands of people between Earth and our smaller, redder neighbor sometime within the next decade or so. And not too long after that—perhaps in a few decades, Mars could be home to a **self-sustaining settlement** of a million people.

> "This is not about everyone moving to Mars, this is about becoming multiplanetary," he said.

It starts with a really big rocket, at least **200 feet tall** when fully assembled. In a simulation of what SpaceX calls its Interplanetary Transport System, a spacecraft loaded with settlers will launch on top of a **39-foot-wide booster** that produces a whopping **28 million pounds of thrust**. Using 42 Raptor engines, the booster will accelerate the assemblage to **5,374 miles an hour**. Overall, the whole thing is **3.5 times more powerful than NASA's Saturn V**, the biggest rocket built to date, which carried the Apollo missions to the moon.



A to-scale comparison of SpaceX's planned Starship and Super Heavy rocket with other launch systems

The rocket would deliver the crew capsule to orbit around Earth, then the booster would steer itself toward a soft landing back at the launch pad, a feat that SpaceX rocket boosters have been doing for years now. Next, the booster would pick up a fuel tanker and carry that into orbit, where it would refuel the spaceship for its journey to Mars.

Source: Spaceflight Insider

To Reach Mars, the Human Body May Need Some Updates

Human bodies are exquisitely adapted to life on Earth, and aren't likely to hold up well during the long journeys required to settle on Mars. One day soon, however, advances in genetics and medicine — such as the **CRISPR gene-editing technology**, or **CAR T-cell therapies**, in which immune cells are re-engineered to fight cancer — might be used to help astronauts better withstand the rigors of spaceflight.

Hazards for Human Health

- **Change in Gravity** → Changes in bones, muscles and genes structure
- **Radiation** → Long-term risk of cardiovascular disease and cancer

In this 2015 photo (by NASA), astronauts Terry Virts, bottom, and Scott Kelly perform eye exams at the ISS as part of ongoing studies on vision health in weightlessness. Kelly sees the mission as a "stepping stone" to Mars.

Scientists are studying durable organisms like tardigrades and certain forms of yeast, looking for genes that protect their cells from radiation or help repair damage to their DNA after it's occurred.

- Scientists at the University of Wisconsin Madison are **blasting bacteria with high doses of ionizing radiation to watch them evolve radiation resistance in real time and study which genes are involved.**
- Geneticists like George Church, cofounder of Harvard Medical School's Consortium for Space Genetics, have suggested **dozens of genes that might benefit space-faring humans.**

Source: Bloomberg

To Reach Mars, the Human Body May Need Some Updates

Radiation is the most hazardous danger in space. Gene modification could become the most sophisticated solution to the problem. Thus, the scientists are discovering genes in the human genome and other genomes, that could be used to regulate the health. **The eventual goal is to assure that human can survive a long space flight to another planet and survive on it.**

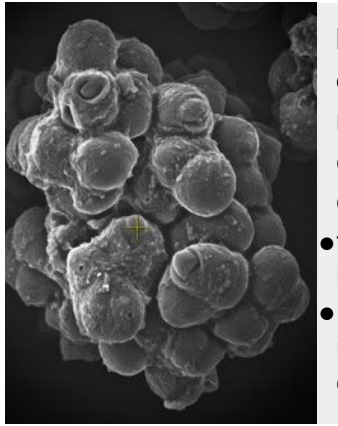
Some scientists envision "**a future in which the human genome can be bioengineered to adapt to almost any environment, augmented with genes from other species that allow humans to explore and settle the farthest corners of the Universe.**"

One of the most interesting objects of research is tardigrade. This creature is extraordinary resistant to radiation exposure. Perhaps scientists will find a way to modify human cells with tardigrades' properties. Particularly, a recent **study** used human cultured cells and identified tardigrade-unique DNA-associating protein that improves radio-tolerance. It suppresses X-ray-induced DNA damage by ~40%. Also it can protect chromatin DNA from hydroxyl radicals

One of the alternative ways concerns radiation-repair mechanisms. It is known that cells are able to accommodate moderate DNA damage through different repair processes. However, space conditions may adversely affect the DNA repair process leading to the accumulation of DNA injuries. Thus, **an artificial boost of radiation-repair mechanisms might help the cells to recover faster than DNA injures are accumulated.** It can be possibly achieved through pharmaceutical means. On the other hand, **blocking DNA repair mechanisms could improve radiation therapy to treat cancer more effectively**. This treatment uses the same approach (concerning radiation-repair mechanisms) but in the opposite way.

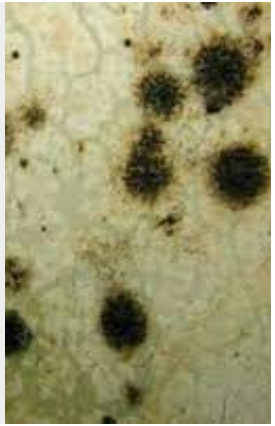
To Reach Mars, Modified Microorganisms May Be Needed

Microorganisms could be significantly beneficial in solving space challenges. **Scientists** talk about microbial cells that would be engineered to produce products and resources or to provide **a live radiation shield**. They intend to develop a genetic tool kit that will let settlers counteract the ill effects of long-term space travel, and produce the things they need like food and fuel. Consequently, the more genomes we have in our kit, the more tools we can make.



Extremophile fungus (Cladosporium sphaerospermum) **can grow in radioactive environments (including Chernobyl nuclear plant)**. "C. sphaerospermum is a melanized, radiotrophic fungus—an organism capable of converting radioactive energy into chemical energy, which it does use melanin pigments inside its cell walls". The experiments conducted affirmed the assumption:

- fungi were capable of adapting to the weightlessness environment of low Earth orbit and live off the incoming radiation.
- 1.7-millimeter-thick layer of a *fungal lawn* as the researchers described it, blocked incoming radiation somewhere between 1.82% to 5.04% compared to the negative control.



Synthetic biology **has the potential** to generate organisms for space settlement needs. Photosynthetic microbes may be ideal for supplying human nutritional needs in space. They are more efficient than green plants at conversion of light to chemical energy, biomass and nutritional molecules. The microbes are easier and faster to genetically engineer, facilitating not only design and terrestrial manufacture of organisms optimized for growth and nutrient production in the artificial conditions of space, but superior ability in space to develop organisms suited to newly discovered environments. The rapid ability to adapt and create new microbes to suit new circumstances when in space offers significant potential for risk reduction.

Space Settlement Entails Ethical Issues

5816 Estimate of the minimum viable population according to ecological studies on Earth, to ensure long-term survival of an isolated Mars settlement. The success of settlements on Mars would be inherently linked to contact with other settlements or Earth, but such a number may allow for self-preservation of the community in case of isolation.

Ethical and biological challenges

1. Reproduction in a population of 5816 people may eventually increase the chance of recessive genetic disorders.
2. Pregnancy termination should be acceptable in cases where pregnancy poses a high risk to the mother and when the fetuses display severe conditions unsuitable for life, in utero.
3. Parent selection based on genetic screening should be used to avoid high-risk conceptions. Monitoring of the mother and fetus health and development across all stages of the pregnancy should take place as usual.
4. The settlers may have to make difficult decisions about who should have offspring and who should not based on resources available to the community.
5. The community might install policies such as euthanasia, as preservation of community may surpass the preservation of individuals in extreme situations.
6. Pregnancy on Mars would require extra care and resources than on Earth, and is likely to be more risky.

Sources: Onlinelibrary.wiley.com | Space.com | Sciencedirect.com

Women May Be the Best Suited for Spaceflight

There are some suggesting that women may perform better than men in space in some respects, including:

Women are lighter

Sending too much weight to space requires fuel, costing a lot of money. Having more women on the crew could help **reduce the cost of space travel**.
Women eat **fewer calories** and use fewer resources: When one plan to send humans to Mars, it may be a good idea to have more women on the crew because they require **15 to 25% fewer energy** calories than men.

Space traveling affects men and women differently

Due to the effects of partial gravity and radiation, space-traveling can have several implications on astronaut's health. It seems that men are less **affected by space motion sickness than women**, but men are quicker to experience diminished hearing. Men also have a higher risk of vision problems, while women tend to have more urinary tract infections.

Women can give birth

One idea for the long-term **settlement of space** is to send an all-women crew to Mars or other locations. This would reduce travel costs, as an all-women crew to reproduce over time through artificial means. More significantly, men tend to have problems with deteriorating vision, which **women don't experience as often or as severely.**

Thus, it is likely that a community in Mars may be **unbalanced in gender**, tending to have **more women**, leading to changes in social structure in comparison to Earth and unexpected psychological, ethical, and social issues.

Birth on Mars Challenges

Possible partial gravity effects on embryo and child

Stage: prenatal environment disturbances

1. Intrauterine growth retardation (IUGR)
2. Low birth weight
3. Hypertension

Stage: postnatal maternal deprivation

1. Growth retardation
2. Delayed neural development
3. Impaired cognitive function and emotional disorders

Partial gravity can cause a number of childbirth problems

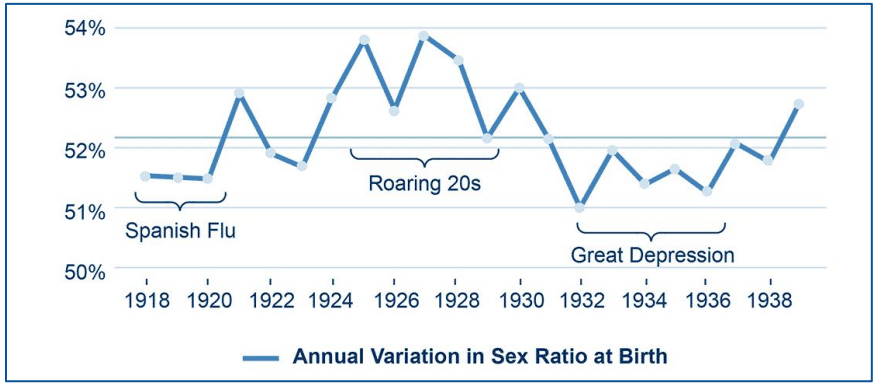
- Gravity's downward tug is unavailable and may influence a woman ability to push a child out
- The pregnant woman must be in a fixed bed to avoid harm to both woman and child
- Bodily fluids would clump into blobs and glide through the capsule
- Decreasing bone density could increase the risk of pelvis fracture in the birth process
- C-section process and further recovery may be harmful to the mother who will be immunosuppressed by effects of partial gravity.

Sources: Space.com, Mammalian Development in Space April E. Ronca* Life Sciences Division, NASA Ames Research Center, Moffett Field,

There May Be Newborn Sex Biases off Planet

The space environment poses extreme challenges for humans. For example, **changes in the sleep cycle** can be counterproductive for astronauts, whose tasks range from a tight work schedule with hard cognitive tasks, to conducting experiments, or repairing satellites. This creates **additional pressure on an astronaut's mental health**. Settlers's lives will be difficult as well. Previous studies have shown that there are sex biases in environmentally challenging times.

For example, it is known, that **during such time periods** – the Spanish Flu (1918–20) and the Great Depression (1932–36) – relatively **fewer boys were born** relative to time periods of rapid economic and population growth and relative abundance of resources – such as the Roaring '20 s (1925–29). A similar situation might occur with the newborn sex ratio on Mars.



The likelihood of an **IVF** (in-vitro fertilization) birth resulting in a boy was between 53% and 56%, depending on how soon the fertilised egg was put back into the womb. In average, in every hundred births, **56 would be baby boys** and 44 would be girls. This compares with **49 boys** in every hundred births for **Intracytoplasmic sperm injection** and **51 boys** in every hundred births with **natural conception.** Due to the fact that Y chromosome-carrying sperm are lighter than X-carrying. This is an advantage for an *in-vitro* experiments, but not in the body.

Source:Nature Magazine

Radiation is the Most Hazardous Factor In Giving Birth on Mars

Radiation. Astronauts should avoid getting pregnant on a route to Mars due to enormous radiation hazards. Mars will soak up some dose of radiation. However, it is still not enough to protect a pregnant woman.

5 mSv	The max total radiation dose to which pregnant women can be exposed
0.72 mSv	The level of radiation dosage per day that sometimes appear on the Mars surface
> 100 mSv	This level of radiation may be associated with microcephaly and mental retardation

Besides, the 3-years long travel to Mars implies significant radiation exposure that may prevent conception and birth of children. In males, sperm can be restored if stem cells are alive, but females have a fixed number of eggs from birth.

The decision to get pregnant after reaching the Moon or Mars

1. The DNA that guides development of a fertilized embryo and the functioning of all the cells in the body is extremely vulnerable to space radiation
2. According to studies in nonhuman primates even relatively low doses of ionizing radiation are sufficient to kill most of the immature oocytes, or egg cells, in a female fetus. Thus a girl conceived in interplanetary space might well be born sterile because of damage to her eggs.
3. Although the effects of chronic space radiation are unclear, low doses of radiation can kill or damage sperm, which might render a man infertile or lead to birth defects.

Consider risks to the mother, the child, the ability to provide and care for the child and how welcoming is the community to a newborn at the moment.

Sources: Barratt, M. R., Baker, E. S., & Pool, S. L. (Eds.). (2019). Principles of Clinical Medicine for Space Flight.

Other Challenges to Giving Birth on Mars

Different types of radiation, partial gravity, cold, stress, temporary vision loss, dehydration, changes in the nervous system, accelerated muscle and bone deterioration, and some other hazards are related to space travel. Most of them were discussed on other slides above. Still, there are some additional diversified challenges and issues settlers might encounter.

Immunosuppression

Any pregnant woman experiences significant immunosuppression. Immunosuppression is also frequently developed by astronauts. Scientists **suppose** that "Such a state may aggravate the risks of infection-induced abortions and facilitate the dissemination of diseases among pregnant and non-pregnant individuals".

Recovering

Mostly astronauts recover for months. However, the life-supporting environment of a Martian settlement won't facilitate astronaut recovery to a necessary healthy status.

Diet

A healthy pregnancy requires constant monitoring and the modification/supplementation of a mother's diet, to ensure key nutrients are sufficient. It will be an issue of great importance as diet remains one of a few controllable and fully discovered factors.

Society and Biology

Speciation is unlikely to take place in the near future of space exploration. On the other hand, culture and moral values are expected to change dramatically.

Psychological and well-being

New ethical changes (more liberal pregnancy termination and euthanasia policy) imply new ethical policies. Basically, it is reflected in the value of a group over an individual. That causes distinct psychological challenges. Thus, it implies the need for profound psychological preparations of all settlers.

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Space Foodsphere Association

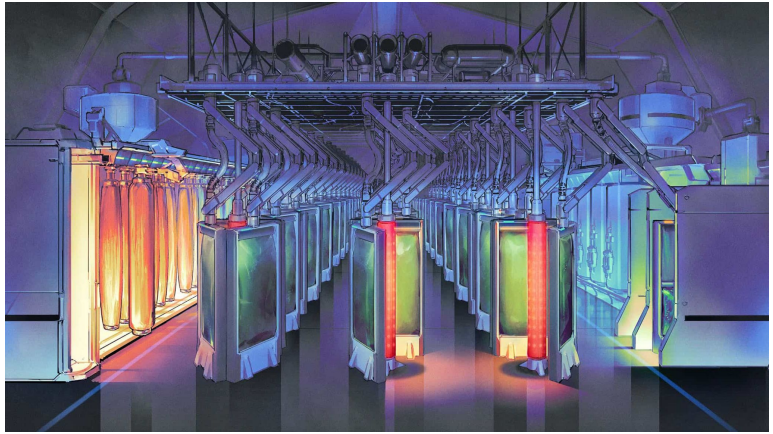
Space Foodsphere is a **Japanese association to promote collaboration between industry, academia and governmental institutes to envision a space food market.** The aim is to elaborate a strategy of food supply system that is fully recyclable and highly efficient capable to provide settlers with all needed nutrients and feelings of happiness.

The global aim is to contribute to the realization of a long-term stay of 1,000 people on the moon in 2040, and to achieve planetary migration and dramatic recovery of the global environment in the long term. Basically, alt the settlers will encounter a number of **challenges** such as food, resource, labor, and nutrition shortages, space constraints, power shortages, transportation weight constraints, mental and physical health issues, plus community issues.

The solutions include:

- Enclosed plant factories
- Full automation
- Menu plans
- Genome editing crops
- Terrestrial Ecosystems
- Microbial protein
- Marine ecosystems
- Environmental monitoring
- Cultured meat
- Automated robots
- 3D food printers
- Full resource recycling

Space Food Automated Farms - concept



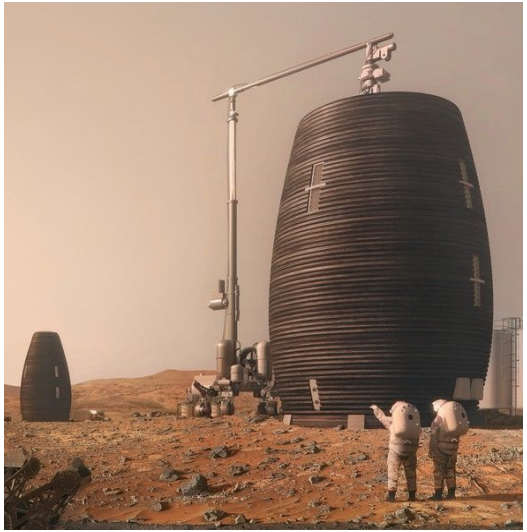
Sources: SpaceFood Sphere

Startups to Tackle Core Martian Settlement Issues

3D printing of Mars habitats

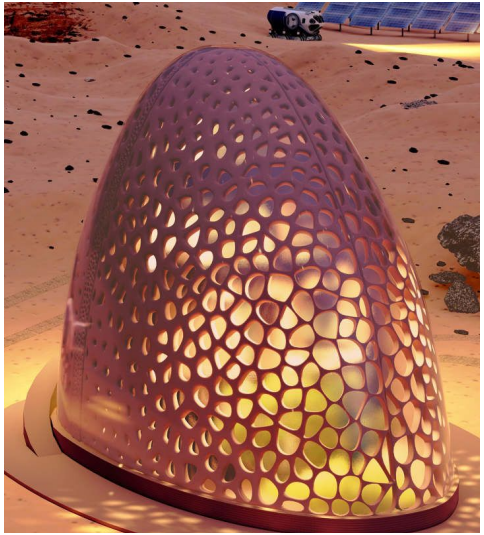
Current advances in 3d printing technologies have allowed NASA to complete the multi-phase "**3D Printed Habitat Challenge**" for deep space exploration, including the agency's journey to the Moon, Mars or beyond. This challenge has been carried out from 2015 to 2019 and centered on a sustainable housing solutions for Earth and beyond. **The competition awarded a total of $2,061,023.**

1st place
Marsha AI Spacefactory's



2nd place
Zopherus

3nd place
Kahn-Yates



Source:NASA

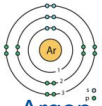
Terraforming Mars: Artificial Magnetosphere

The atmosphere of Mars is the layer of gases surrounding Mars. It is primarily **composed of carbon dioxide (95%), molecular nitrogen (3%) and argon (1.6%)**. It also contains trace levels of water vapor, oxygen, carbon monoxide, hydrogen and noble gases. The atmosphere of Mars is **much thinner than Earth's**. The average surface **pressure** is only about 610 pascals (0.088 psi) which **is less than 1% of the Earth's value.**

Principal components of the Martian atmosphere

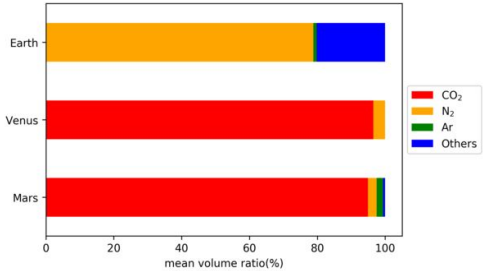
Carbon dioxide
95%

Molecular nitrogen
2.8%

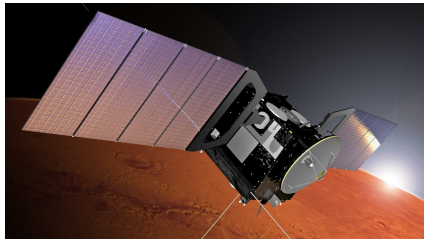


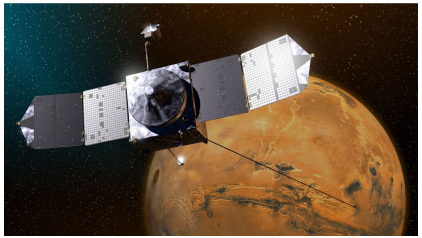
Argon
2%

This leads to key challenges for crewed space trips connected to high radiation levels, extra-fine dust on Mars, and a lack of oxygen to breathe. The current thin Martian atmosphere prohibits the existence of liquid water at the surface of planet. However, 4.2 billion years ago Mars had a magnetic field that protected its atmosphere (like Earth does). The atmosphere protected an ocean. Also magnetosphere stopped cosmic rays.



Comparison of the abundance of carbon dioxide, nitrogen and argon in the atmospheres of (from top to bottom) Earth, Venus and Mars.





Supposedly, it was quite a warm, wet and life-suitable planet. Nevertheless, the field suddenly disappeared and during the following 500 million years the atmosphere disappeared too (mainly, because of solar wind). Thus, Mars became a cold, uninhabitable place.

This theory was confirmed by data from ESA's Mars Express and NASA's Mars Atmosphere and Volatile EvolutioN Mission (**MAVEN**). They have been studying the Martian atmosphere since 2004 and 2014.

Terraforming Mars: Artificial Magnetosphere

MARS

In order to be successful, human reproduction should start on the Mars. The planet's atmosphere, and Mars, itself would soak up or slow down much of the radiation

Lost of magnetic field ▶ Lost of atmosphere ▶ Uninhabitability

Solution

Magnetic dipole shield at the Mars L1 Lagrange Point

Wrapping a superconducting wire around Mars

Mars maternity hospital to solve radiation problem

Some have proposed to use Phobos (the largest satellite of Mars) as a maternity hospital. It has a huge Stickney crater on its surface. That crater is probably a safe place for a maternity hospital due to its high walls. Along with Mars itself, it might obstruct up to 90% of cosmic rays.

Core Benefits: allow larger landed mass of equipment to the surface, extend the ability for oxygen extraction, provide "open air" greenhouses to exist for plant production, stabilize the dusty weather and shield the planet against solar wind and radiation.

Shielding with regolith

The other variant is to build habitats using regolith for radiation shielding. It might be even a better solution than going to a Martian moon. Additionally, Mars transports might use water or wastes for shielding.

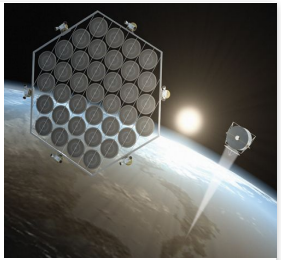
The next step to replenish the Martian atmosphere require enhanced outgassing. Otherwise it would take million of years for Martian atmosphere to become equivalent to Earth's.

Terraforming Mars and Other Solutions

Orbital mirror

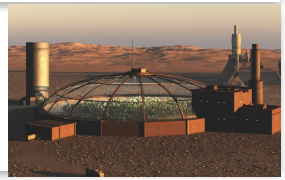
According to NASA-funded **study**, orbital mirrors could appear to be helpful in terraforming Mars. The mirrors will provide extra sunlight that would provide warmth and solar power for settlers at least on a small patch of the planet's surface.

More ambitious **concepts** propose to apply orbital mirrors with 100-125 km radius to vaporize the CO2 in the south polar cap. Such mirrors could drive vast amounts of water out of the permafrost that will definitely benefit the nascent Martian ecosystem. The largest obstacle is that such mirrors might be hard to deploy.



Greenhousing

The manufacture of halocarbon gases on the Mars's surface may well be the most practical option to Greenhousing Mars. Total surface power requirements to drive planetary warming using this method is estimated at 1000 MWe that also implies the period of 50 years for climate and atmosphere modification.

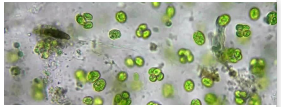


Domed cities

Domed cities and local greenhouses could be built in craters on Mars to provide settler with safe environment. Such cities could have the right temperature for liquid water with a 2-3 centimeter dome of silica aerogel. The dome enables heating up under by 50 degrees kelvin without any heaters.

Ecopoiesis

Sealed biodomes that would employ settlements of oxygen-producing cyanobacteria and algae for the production of molecular oxygen (O2) on Martian soil. It might synergize with the Domed cities concept.



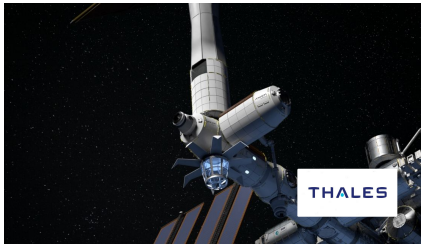
Ammonia

Bombarding Mars with large icy asteroids with ammonia to generate tons of greenhouse gases and water on the red planet might be another solution. However, it also would take hundreds of years to continue safe settlement.

Sources: NASA

The Coming Era of Private Habitable Space Stations

NASA **awarded Axiom** the right to attach one of its own crew modules to a docking port on the ISS—and a **$140 million contract** to make it happen. The company's plan is to launch its first module to the space station by 2024 and expand from there. In addition to the crew-habitation module, CEO Suffredini says Axiom is planning for at least two others: One will be a laboratory and manufacturing facility, and the other will be a panoramic observatory similar to the ISS cupola.



Thales Alenia Space, a Joint Venture between **Thales** (67%) and **Leonardo** (33%), and **Axiom Space** of Houston, Texas (USA), have signed the final contract for the development of **two key pressurized elements of Axiom Space Station**. Scheduled for launch in **2024 and 2025** respectively, the two elements will originally be docked to the International Space Station (ISS), marking the birth of the new Axiom Station segment. The value of the contract is **110 Million euro**. Thales Alenia Space and the Italian Air Force have ratified a Memorandum of Collaboration, aiming to promote access to low earth orbit in favor of institutions, the scientific community, industry, and commercial operators.

The Large Integrated Flexible Environment (LIFE) habitat is under development by engineers for the **Sierra Nevada Corporation**, and a ground prototype is being used to evaluate how crew members could perform mission tasks in outer space. **The LIFE habitat** is meant to travel into space furled inside commercial launch vehicles and will then inflate on-orbit to its full size to house **four astronauts and their equipment. The three stories of space includes science labs, robotics work stations, medical and sick bays, sleep and hygiene quarters, exercise equipment, a plant growth system, and more.**

Sources: Axiom Space, Thales Group, Bigelow Aerospace

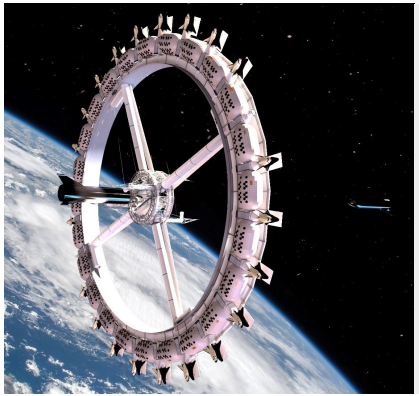
The Upcoming Space Hotels will be Equipped with Artificial Gravity Systems

Artificial gravity can be created using a centripetal force.

A centripetal force directed towards the center of the turn is required for any object to move in a circular path. In the context of a rotating space station it is the normal force provided by the spacecraft's hull that acts as centripetal force.
Thus, the "gravity" force felt by an object is the centrifugal force perceived in the rotating frame of reference as pointing "downwards" towards the hull. In accordance with Newton's Third Law **the value of little g** (the perceived "downward" acceleration) **is equal in magnitude and opposite in direction to the centripetal acceleration.**

It is still unknown **what level of artificial gravity** should be implemented to mitigate the negative impact of weightlessness on human body.

The previous attempts to implement artificial gravity resulted in very small amounts of G. For Example, the **Gemini 11 mission** attempted to produce artificial gravity by rotating the capsule around the **Agena Target Vehicle** to which it was attached by a 36-meter tether. They were able to generate a small amount of artificial gravity, about 0.00015 g, by firing their side thrusters to slowly rotate the combined craft



Orbital Assembly Corporation, a new construction company run by former pilot John Blincow, is planning to open a luxury space hotel by 2027. Voyager Station, as it's being called, would accommodate 280 guests and 112 crew members while aiming to be the first commercial space hotel, upon completion.

Voyager Station would have artificial gravity from its rotation to maintain Lunar gravity - approximately 1/6th of Earth's gravity.

Sources: Architectural Digest

Conclusions

September 2021

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Key Takeaways

The report covered past experiences, current advancements, and future projections regarding giving birth in space. It appeared to be an extremely complicated topic requiring comprehensive analysis. The data gathered by NASA and other agencies for decades is not appropriate to make strong assumptions about the human ability to give birth on Mars.There are plenty of risks quite distinct from those professional astronauts are used to. Therefore, it requires completely new approaches to reach the goal of giving birth on Mars.

Nowadays, a lot of private companies and state space agencies worldwide are working on space settlement programs and cover a wide range of technologies from extracting oxygen and various metals in Martian and lunar surfaces to quantum telecommunication, artificial wombs, or new generation rockets. It reflects the paradigm turn from space exploration to space settlement. However, it is just the beginning with private companies ahead of the process.

Space radiation, weightlessness, Mars environment are hazardous factors for childbirth. Giving birth on Mars will become possible when all these factors are fully researched and resolved. Nevertheless, unexpected physiological, psychological, ethical challenges concerning birth on Mars will arise.Women are becoming more represented in the space industry (e.g. NASA space programs) and more data are collected on women health in space.

Mars settlement brings plenty of risks (radiation and weightlessness are the most serious among them) that can hazard women health, fertility, and embryo. Although experiments on animals show that birth beyond Earth is possible, pregnancy during spaceflight is fraught with harmful consequences.

The today's era of commercial space flights and habitable Low-Earth Orbit predisposes is accelerating the pace and necessity of experiments and related data concerning living and procreating in gravity environments. To reach Mars, the human body may need new and extra care: gene therapy, reproductive assistance, radioprotectors, advanced biomedical technologies and treatments, to increase chances of successful births and lives on Mars. Terraforming Mars may be required to create a safe child-friendly environment (e.g. artificial magnetosphere to provide an atmosphere providing radiation protection and oxygen).

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