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Personalized Products For the Space Economy: The Astronaut Genetic Persona Mapping

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Abstract: *The rapid commercialization of space exploration has transformed it into a trillion-dollar industry, driving scientific and technological innovation. Yet, space travel poses considerable physical and psychological challenges, such as microgravity, radiation exposure, and isolation, which demand innovative, science-based solutions. Human genetics offers a powerful approach to tackling these challenges by enabling personalized interventions to protect astronaut health. From mitigating muscle and bone loss to enhancing mental resilience, genetic insights are paving the way for tailored solutions that benefit not only space missions but also healthcare on Earth. This conceptual paper explores how genetic data can inform products and services for space exploration, emphasizing their potential to advance both astronaut well-being and consumer-focused innovation at the forefront of the commercialization of space activities and space tourism.*

1. INTRODUCTION

The rapid commercialization of space exploration has transformed it into a trillion-dollar industry, driving scientific and technological innovation. Yet, space travel poses considerable physical and psychological challenges, such as microgravity, radiation exposure, and isolation, which demand innovative, science-based solutions. Human genetics offers a powerful approach to tackling these challenges by enabling personalized interventions to protect astronaut health. From mitigating muscle and bone loss to enhancing mental resilience, genetic insights are paving the way for tailored solutions that benefit not only space missions but also healthcare on Earth. This conceptual paper explores how genetic data can inform products and services for space exploration, emphasizing their potential to advance both astronaut well-being and consumer-focused innovation at the forefront of the commercialization of space activities and space tourism.

2. COMMERCIALIZATION OF SPACE ACTIVITIES AND EMERGENCE OF SPACE ECONOMY

The space industry is experiencing unprecedented growth and diversification. In 2024, the global space industry achieved a record-breaking 263 orbital launches, surpassing previous years' totals (Klotz, 2025). The space economy is projected to grow significantly, with various estimates forecasting future values. There are different forecasts for the development of the sector by 2040, with projections ranging from $1.1 trillion to $2.7 trillion (OECD, 2019, p. 32). In 2023, the global space economy saw €106 billion in public funding (+11%), with Europe contributing €11.9 billion. Private investment declined to €6 billion globally, and space activity increased with 221 launches (+18%) and 2,940 satellites deployed (+17%) (ESA, 2024). In 2023, the global space economy reached a turnover of approximately 570 billion USD, up from 531 billion USD in 2022 (Figure 1). The commercial space products and services sector dominated, contributing nearly 60% of the total turnover (Statista, 2025), accounting for 78% ($427.6 billion), largely fueled by a 17% rise in demand for satellite broadband services (OECD, 2022).

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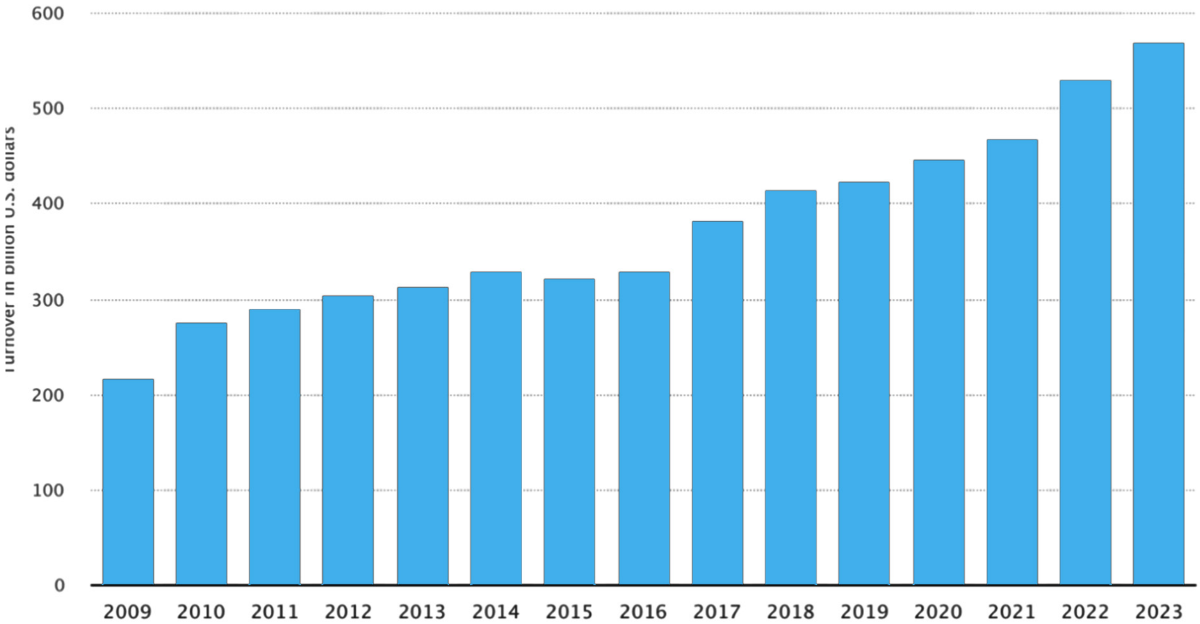

Figure 1. Global turnover of the space economy from 2009 to 2023 (in billion U.S. dollars)
Source: Statista (2025)

Governments also play a key role, with the U.S. alone contributing nearly 60% of global government space expenditures. The commercialization of space is reshaping the marketing of products for use in space. An increasing number of government actors, each with distinct objectives, are now engaged in space activities. Private companies (e.g, SpaceX, Blue Origin, Axiom Space) are shifting focus from government-funded missions to consumer-driven innovations, using marketing strategies that blend adventure with practical applications (CSG, 2023).

Space economy is defined as "the full range of activities and the use of resources that create value and benefits to human beings in the course of exploring, researching, understanding, managing, and utilizing space" (OECD, 2019, p. 30). As the space economy expands and private ventures accelerate innovation, the challenges faced by astronauts become increasingly critical to address.

3. CHALLENGES IN SPACE MISSIONS

Spaceflight poses significant challenges to human physiology due to exposure to extreme physical and environmental conditions such as microgravity, acceleration forces, radiation, confinement and isolation. Initial adaptation to microgravity can lead to various symptoms like space motion sickness, headaches, and back pain. Prolonged missions exacerbate these symptoms, potentially causing immune dysregulation, cardiovascular issues (Patel, 2020), muscle atrophy, and bone mass loss (Hodkinson et al., 2017; Krittanawong et al., 2022; Stepanek et al., 2019). The most common health problems fall into the following categories: visual (38%), cardiovascular (14%), and psychiatric and behavioral (9%) (Johnston et al., 2014). Microgravity profoundly affects the musculoskeletal and cardiovascular systems, leading to muscle atrophy and bone density loss of 1–2% per month despite exercise (Stepanek et al., 2019). Cardiovascular deconditioning, reduced blood volume, and orthostatic intolerance pose risks during re-entry, while fluid shifts can cause Spaceflight-Associated Neuro-Ocular Syndrome (SANS), affecting vision in 38% of astronauts (Johnston et al., 2014). Space travel also weakens the immune system, heightens infection risks, and exposes astronauts to radiation hazards, including DNA damage and cancer risks (Hodkinson et al., 2017). The NASA (n.d.) Twins Study observed unexpected telomere lengthening during missions, indicating adaptive responses (Tessier et al., 2022). To address radiation risks, NASA's "GCR Simulator" facilitates advanced research on radiobiological impacts and mitigation strategies (Simonsen et al., 2020).

Currently, personalized medicine for astronauts is limited. As longer missions beyond low Earth orbit become a reality, space agencies must adopt personalized strategies for each astronaut (Pavez Loriè et al., 2021; Schmidt et al., 2020), starting with preventive preclinical approaches and individualized countermeasures to minimize harmful physiological changes and target specific treatments for diseases. Astronaut health during space missions requires a personalized approach to account for significant inter-individual variability in physiological responses to the unique environmental stressors of space. Pavez Loriè et al. (2021) consider critical factors such as gender, physical status, immune response, tissue repair, pharmacokinetics/pharmacodynamics, nutrition, environmental conditions, mission duration, genetics/epigenetics, and age/aging. The distinction between biological age (BioAge) and chronological age (ChronAge) highlights how BioAge, based on epigenetic data, offers a more accurate prediction of consumer behavior, including volunteer work, spending on nondurables, and charitable contributions (Shaw et al., 2024).

Isolation, confinement, and limited social interaction contribute to psychological challenges, including stress, depression, and anxiety (Kanas & Manzey, 2008). Behavioral health issues have been documented in 9% of astronauts during missions, exacerbated by disrupted circadian rhythms due to irregular light-dark cycles onboard spacecraft (Johnston et al., 2014). Astronauts are also prone to experiencing so called "space fog", which refers to the general lack of focus, altered perception of time, and cognitive impairments experienced during spaceflight (Barger et al., 2014; Krittanawong et al., 2022). These effects can persist throughout the mission and are likely linked to chronic sleep deprivation, as astronauts often experience reduced sleep duration and quality, despite the frequent use of sleep medications. These psychological stressors can impair decision-making and mission performance and also trigger genetic behavioral conditions.

Given the severity of these health risks, space agencies are increasingly turning to cutting-edge technologies to better understand and mitigate them. One promising approach is the integration of omics, which uses genetic, proteomic, and metabolomic data to offer personalized countermeasures that can safeguard astronaut health during long-term missions.

4. UTILIZATION OF HUMAN GENETIC DATA FOR SPACE MISSIONS

As space missions extend further into deep space, astronauts will face unique risks, including radiation exposure, chronic stress, and hypoxia. Current reliance on rodent models for understanding human physiology and drug response is inadequate due to significant differences in genetic diversity, brain complexity, and metabolism between humans and rodents (Maletic-Savatic et al., 2023). Therefore, there is a proven necessity of integrating genetic data into the design of space travel products for astronauts (Berrios et al., 2021; Maletic-Savatic et al., 2023; Mason et al., 2024; Overbey et al., 2024), solidified by several large studies on integration of omics - the NASA Twin Study and the Japanese Aerospace Exploration Agency (JAXA) Cell-Free Epigenome (CFE) project (Garrett-Bakelman et al., 2019; Muratani, 2022). Moreover, advancements in human organoid models or the so-called "astronauts-on-a-chip" platforms are able to replicate human tissue interactions and responses to stressors in space, enabling personalized medicine (Maletic-Savatic et al., 2023). Overbey et al. (2024) published groundbreaking research on space omics, revealing the creation of the first-ever aerospace medicine biobank. A total of 2,911 samples were collected from astronauts, with 1,194 processed for sequencing, imaging, and biochemical analysis. Their study extends findings from the JAXA CFE and NASA Twins Studies and integrates the data into the NASA OSDR database, increasing human omics data by tenfold. The SOMA biobank serves as a platform for contributions from both commercial and non-commercial astronaut cohorts, revealing significant molecular changes and altered gene expression linked to immune activation, some of which persist for up to three months post-flight (Overbey et al., 2024).

Space omics have a fundamental importance for leveraging human genetic data in space conditions. Nutrition is another area subject to improvement for the astronaut's health, especially considering the recent debate on the actual benefits of the application of caloric restriction in space (Krittanawong et al., 2022). Studies have shown how nutrition can actually impact gene expression (Elsamanoudy et al., 2016). For example, the Bulgarian company Antarta produces the world's first patented space food, offering lyophilized meals designed to support astronaut health and performance. For example, astronaut Scott Kelly's microbiome from the NASA Twin Study was significantly altered during his time in space, likely due to the unique diet and environmental factors, but it returned to its preflight state after his return to Earth, demonstrating how space conditions can impact gut bacteria and the potential importance of nutrition in supporting microbiome balance during space missions (Space Center Houston, 2024). Future research is essential to validate the feasibility and efficacy of space food solutions, ensuring they meet the nutritional and physiological demands of astronauts in extreme environments.

5. ASTRONAUT GENETIC PERSONA MAPPING

As space exploration continues to evolve, designing solutions tailored to the unique physiological needs of astronauts becomes increasingly critical. Integrating human genetic data into product development can optimize astronaut health and performance during missions. Initially used for medical purposes, genetic data may, with advancing technology, serve as a foundation for hyper-personalized offerings across all sectors of the space economy, including private companies.

Understanding astronauts' behavioral and physiological responses through behavioral genetics is pivotal for creating these solutions. Behavioral genetics examines the interaction between genetic predispositions and environmental factors (Chabris et al., 2015; McGue & Gottesman, 2015). Turkheimer (2000) outlines three fundamental laws: (1) all human behavioral traits are heritable, (2) genetic influences outweigh family environment, and (3) much variation in behavior is unexplained by genes or family. Genetic influence ranges from 0% to 50%, depending on genetic variation and individual efforts, particularly in psychiatric disorders (Stoolmiller, 1999). A fourth law, proposed by Chabris et al. (2015), highlights that behavioral traits are influenced by numerous genetic variants, each with a small effect, often measured psychometrically or linked to psychiatric and social outcomes. Evidence from twin and adoption studies shows intelligence is highly heritable (Bouchard & McGue, 1981; Erlenmeyer-Kimling & Jarvik, 1963), with genetic influence on psychological traits increasing during adolescence and early adulthood (Bergen et al., 2007). While genetic factors play a significant role, environmental and epigenetic factors can also modify gene expression, complicating efforts to attribute specific behaviors to individual genes (Petronis, 2010).

Genetic factors can influence how astronauts cope with stress, isolation, and other challenges, making them more or less resilient to the psychological and physiological demands of space missions. Products addressing these needs might include personalized stress management tools, cognitive support systems, and behavioral health interventions tailored to an astronaut's genetic profile. For example, genes regulating dopamine production influence responses to stress and isolation, common in long-duration missions. Personalized nutrition plans, exercise regimens, and medications could also be crafted using genetic markers, mitigating the negative effects of extended space travel (Berrios et al., 2021; Maletic-Savatic et al., 2023). While full genome sequencing could offer significant insights into astronaut health, it remains unclear whether it is routinely performed as part of pre-flight testing, presenting an opportunity for advancing space medicine.

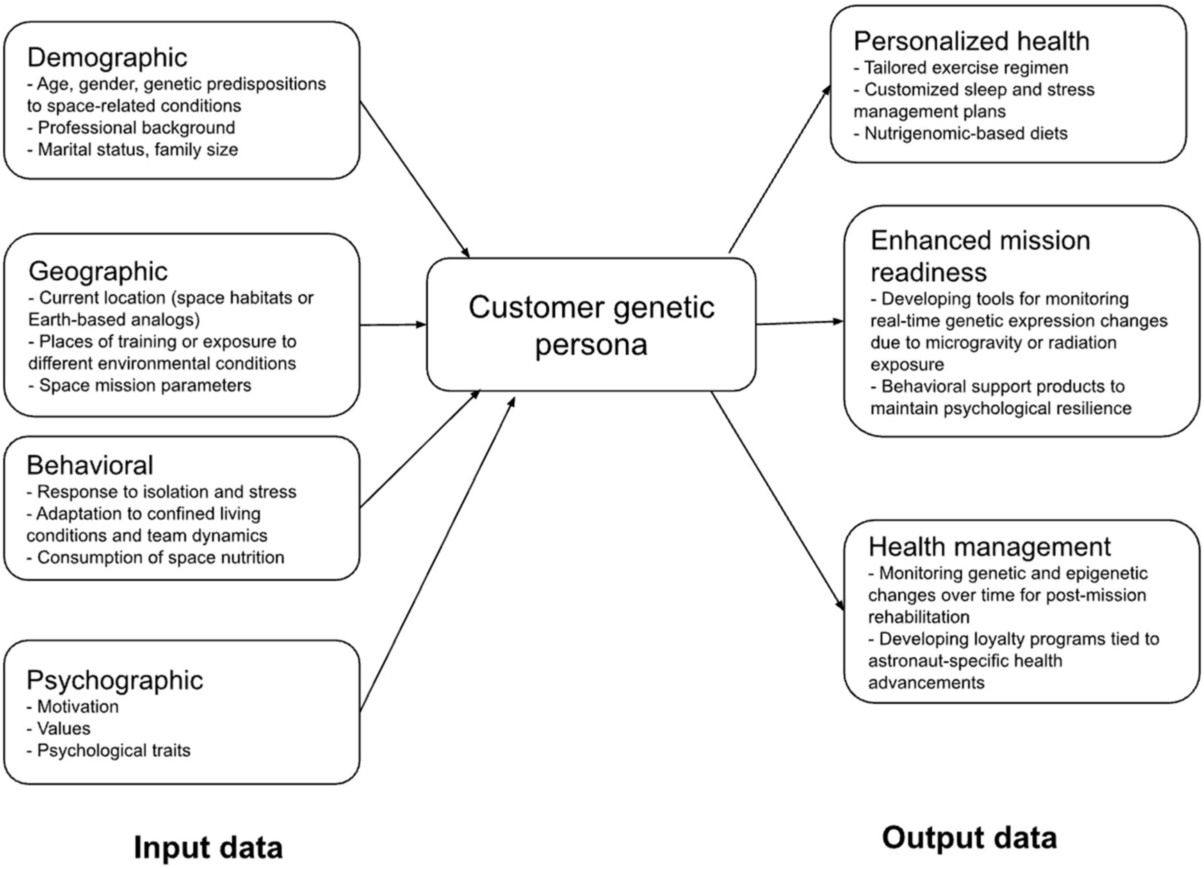

Figure 1. Astronaut genetic persona mapping
Source: Own processing

The Astronaut Genetic Persona Mapping diagram (Figure 1) is built upon Kotler et al.'s Segments-of-One Customer Profiling approach (Kotler et al., 2021, p. 136). It highlights the importance of customizing strategies to address the unique needs, preferences, and characteristics of individuals rather than relying on generalized group profiles. The proposed Astronaut Genetic Persona Mapping demonstrates how diverse input data—demographic, geographic, behavioral, and psychographic factors—converge to form a comprehensive "Customer Genetic Persona," which informs various output applications. Demographic data, such as age, gender, and genetic predispositions, establish a foundational understanding of astronaut needs, while geographic information captures environmental influences from training locations or space habitats. Behavioral insights address astronauts' responses to isolation, team dynamics, and nutrition, while psychographic traits reveal motivations, values, and psychological characteristics critical for space missions. These inputs collectively guide output strategies, including personalized health interventions like tailored exercise regimens and nutrigenomic diets, tools to enhance mission readiness through stress resilience, and ongoing health management through genetic monitoring. This integrated framework exemplifies the holistic approach required to optimize astronaut performance and well-being in extreme environments.

The proposed approach could enhance astronauts' well-being, resilience, and readiness for space exploration. Space agencies, researchers, and private spaceflight companies can use this mapping to optimize astronaut health and performance in extreme environments. Medical teams might develop tailored exercise regimens or diets to maintain astronauts' physical and mental fitness. Behavioral scientists could design stress management tools for isolated, confined spaces, while researchers monitor genetic and epigenetic changes to improve post-mission recovery techniques. Beyond space exploration, this framework could benefit healthcare providers and personalized medicine industries, offering insights for managing health in extreme or high-stress conditions on Earth.

Astronaut Genetic Persona Mapping exemplifies the potential for integrating genetic insights into space exploration, laying the groundwork for future advancements in both space and terrestrial applications.

6. FUTURE RESEARCH

The commercialization of space exploration presents opportunities for incorporating genetic data into astronaut health solutions. During the recent decade, direct-to-consumer companies, offering genetic testing at home, have accumulated immense quantities of consumer genetic data around the globe. Together with the national biobanks, they can contribute valuable datasets to space agencies for comparative analysis of human health in space conditions.

Genetic insights, including those related to dopamine and epigenetics (Daviet et al.), are potent to inform strategies for managing stress and improving psychological resilience during space missions. However, the exploration of astronaut durability requires a deeper analysis of biases in perceiving physical and psychological resilience. For example, younger, physically fit individuals may be more vulnerable to the psychological challenges of space than older individuals with a stronger sense of purpose and resilience shaped by life experience. Lessons from COVID-19 isolation demonstrate the profound impact of prolonged confinement on mental health, highlighting the importance of strategies to mitigate social and cultural deprivation.

Future research should also address the holistic well-being of astronauts by examining physical, psychological, and even spiritual resilience. The absence of art and cultural expression in long-term missions could have detrimental effects on the human psyche, leading to a form of "brain rotting" that undermines creativity and emotional stability across generations. Addressing these gaps will require designing interventions that integrate cultural and artistic elements alongside genetic insights to foster a well-rounded approach to astronaut health.

7. CONCLUSION

The integration of genetic data into the design of space products and services offers a transformative approach to astronaut health and performance optimization. As the space economy grows and missions extend into deep space, personalized interventions, derived from genetic insights, are essential for addressing the physiological and psychological challenges astronauts face. Space agencies can create tailored solutions for nutrition, exercise, stress management, and mental health, ensuring astronauts' well-being and performance in extreme environments. The concept of Astronaut Genetic Persona Mapping illustrates the potential of using genetic data not only to improve space missions but also to inform personalized medicine on Earth. Moving forward, ongoing research will be crucial in refining these personalized strategies, balancing technological advancements with ethical considerations, and ensuring the responsible application of genetic information for long-term space exploration and beyond.

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