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Editorial: Space resources and planetary sustainability—challenges and opportunities

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Editorial on the Research Topic
Space resources and planetary sustainability—challenges and opportunities

Earth's space environment is being used more and more intensively. Mega constellations are beginning to light up the night sky, offering essential services to the planet's inhabitants. However, they also pose challenges for ground-based astronomy and disrupt the natural rhythms of animal nightlife. Space debris is accumulating in the more heavily used Earth orbits, increasing the risk of a cascade effect which could render space-faring impossible. Meanwhile, several countries want to go or return to the Moon, and this time they plan to utilize its resources. Long-term plans even include spacemining asteroids or a *"multi-planetary society, where the resources of the solar system are available to the people of Earth"* (NASA). How are the issues of sustainable space use connected with the environmental challenges on Earth? This Research Topic combines the emergent topic of using space resources with the even more pressing issue of planetary sustainability, i.e., sustainability conscious of the fact that Earth is a planet with a space environment (Galli and Losch, 2019).

Space resources include both orbital space itself as well as water, ores, and other materials situated in space, on the Moon or other celestial bodies. The aim of the small collection is to initiate a discussion of the interrelation of the use of space resources with the pressing issue of planetary sustainability. In an exemplary fashion, the use of outer space as a research resource for studies of plant biology and the space environment's endangerment by the growing amount of space debris are discussed. Then, nothing less than a universal ("pancosmorio") theory of sustainable human migration and settlement in space is proposed, before finally the issue of "ground bias" as a driver for skepticism about space exploration is discussed. All these aspects present limitations for space exploration, which remains a necessary endeavour if the survival of humankind is to be prolonged beyond the inevitable end of Earth as a habitable planet in the near or far future (asteroid impacts, other mass extinction events, the end of the Sun's lifetime, *etc.*). "To some extent, a truly sustainable concept of sustainability therefore has to be an inter-planetary one" (Losch, 2018). Also, the importance of space for an understanding of processes relevant for life on Earth (e.g., the ozone layer, greenhouse gas effects on Mars and Venus, the atmosphere and magnetosphere as shields against energetic particles from the Sun or Cosmic Rays) should not be overlooked. Since all life (as so far known) has evolved under conditions of Earth's gravity, studies under altered gravity conditions allow insights into the fundamental role of Earth gravity, as well as into the response and adaptation of living systems to extraterrestrial environmental conditions. Omic studies provide valuable integrative insights into the functional architecture of living systems. This Research Topic's first article *Omics studies of plant biology in spaceflight*, authored by Hughes and Kiss, critically reviews recent experiments, including blue and red light and circadian rhythms. Some findings reviewed have linked microgravity and transcriptomic changes in genes relating to cell wall synthesis and modification, oxidative stress, abiotic stressors, phytohormones, sugar synthesis and metabolism, ribosomal biogenesis, and plant defence to other organisms. Although we have a better-established profile of the transcriptomic response of plants to reduced gravity, the developmental progression of the plant response to microgravity is a missing piece of the "omics-puzzle." The authors are optimistic that increased availability of commercial and suborbital spaceflights will help to overcome the current limitations of plant space experiments.

A threat to the sustainable use of our space environment is the growing space debris issue. *A new impact assessment model to integrate space debris within the life cycle assessment-based environmental footprint of space systems*, drafted by Maury-Micolier et al., attempts at evaluating the threat by analogy to conventional environmental impacts. The potential release of debris or generation of fragments can be considered as the emission of an environmental stressor damaging the orbital "natural" resource which supports space activities. Hence, it appears relevant to integrate systematically the impact of the emission of debris on the orbital resource within the life cycle impact assessment (LCIA) step to broaden the scope of life cycle assessment (LCA) for space systems.

While the increase of space debris is one limitation for space exploration and its sustainable use, there might be more constraints, as presented by the *Pancosmorio (world limit) theory of the sustainability of human migration and settlement in space*, formulated by Irons and Irons. Humans are a species connected to Earth through evolution. We are also connected to space; our bodies contain heavy elements generated by fusion in the cores of stars. What does this evolutionary connection of humans to a star and a planet mean for their ability to inhabit space? The argument combines research and scientific development of a theory of ecological thermodynamics with classical mechanics theory and analytical models of self-restoring heat engines to explain how the Sun and Earth have evolved into islands of order in the entropy of space. The science and evidence suggest that the ability to establish a human settlement in space without the self-restoring order, capacity, and organization of Earth will ultimately lead to settlement failure. The results of research are presented as a pancosmorio theory of human sustainability. Insights are provided regarding human endeavours on the Moon and Mars and regarding the Fermi paradox.

Another limitation for space-faring is *Ground bias: A driver for skepticisms about space exploration*, as analysed by Milligan. The bias in question involves a background underestimation of the importance of space for an understanding of terrestrial processes. Underestimation then operates as a driver for various kinds of skepticism about space exploration. Ground bias is also more widespread than skepticism about space exploration and does not, on its own, entail it. There may need to be some further factor before space skepticism is embraced. Nonetheless, ground bias can help to explain the stubborn persistence of skepticism about space exploration in the face of successive failed predictions about the negative impact of space programs upon humanity. The far-future fate of Earth provided, overcoming these limitations remains a challenge for the future survival of humankind. This collection attempts at contributing some important thoughts on this way. Also, the collection points out that space research does contribute to humankind's welfare here and now.

Author contributions

AL draft, AG revision, OU corrections, MJ review. All authors contributed to the article and approved the submitted version.

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