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Materials' mission to reach strange new worlds

Advancements in materials science are central to space exploration, but equally important is addressing societal implications to ensure responsible and sustainable progress.

Space has long been a source of fascination, inspiring a wide range of artistic endeavours that reflect humanity's curiosity about the unknown. Particularly starting from the space race of the twentieth century, science fiction has not only drawn from scientific breakthroughs but has also contributed to the development of real-life innovations — a notable example is the modern cell phone inspired by the communicators in *Star Trek*[1]. As we continue to explore space, materials science has an increasingly important role in overcoming the unique challenges posed by this environment. In this Focus issue, we spotlight research that could shape the future of space exploration.

The harsh environment of space presents obstacles that current technology is only beginning to address. Exploring certain planets and celestial bodies, such as Venus, is currently difficult owing to intense heat, pressure or corrosive atmospheres that can quickly damage structural components and electronics. Among the contributions in this issue, Babak Anasori and colleagues discuss, in a Review, progress in ultra-high-temperature ceramics, and Deep Jariwala and colleagues highlight, in another Review, advances in high-temperature electronics. These developments could, among other applications, enable the creation of technologies to explore harsh, previously largely inacessible worlds.

To prepare for future human exploration, self-sufficiency will be essential to improving sustainability and cost-effectiveness. Innovations in materials manufacturing, like 3D printing, could enable the direct fabrication of items in space, reducing the need for costly resupply missions and minimizing the reliance on Earth. In a Comment, Siqing Wang and Ying Diao highlight how organic electronics that are 3D-printed in space can monitor plant health with minimal oversight, offering a promising solution for ensuring reliable food production. 3D printing can also be used to automate the manufacturing of building elements for large-scale structures, as explored by Zibo Zuo and colleagues in another Comment. Alongside other uses, large-scale 3D printing is particularly suited for the autonomous building of structures — such as space bases — in remote and challenging environments. Equally important for mission self-sufficiency are adaptable systems that can function independently in unpredictable environments. As a case in point, in a Perspective, Rebecca Kramer-Bottiglio and co-authors review the development of shape-morphing robots that can adjust to changing conditions. Maintaining crew health during extended missions is also crucial, with materials technologies providing a versatile toolbox to reduce the need for Earth-based intervention, as discussed in a Perspective by Alessandro Grattoni and colleagues.

Energy efficiency is another key area of innovation. Emerging photovoltaics could offer lightweight, efficient energy solutions for on-board space applications, as discussed in a Comment by Anita Ho-Baillie and co-authors. In another Comment, Paulo Lozano discusses materials innovations that are driving the development of ion propulsion systems, which could allow spacecrafts to travel long distances using minimal fuel.

The reality of space exploration is still full of challenges. Beyond the technical complexities, societal issues must also be addressed. For example, as we unlock new resources, there is a growing need for frameworks that ensure that the benefits of space exploration are shared equitably. Environmental responsibility is another critical factor — space activities not only generate orbital debris, but also risk contaminating native environments, compromising scientific research and introducing harmful biological materials that could impact both space environments and Earth. In a Viewpoint article, Martin Elvis, Moriba Jah, Erika Nesvold and Kazuto Suzuki discuss how international cooperation and thoughtful policies are essential to ensure that space exploration benefits all of humanity, while addressing the environmental and ethical considerations that arise from venturing beyond Earth.

As we strive to turn fiction into reality, it is important to approach both the technological and societal hurdles with a realistic understanding. Science fiction has long explored these very themes — sometimes envisioning advanced technologies that unite humanity and solve global challenges, and, at other times, cautioning us about the dangers of unchecked progress. These stories inspire innovation, but they also serve as reminders of the importance of addressing societal issues alongside technological advancements.

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References

1. Singer, P. W. in *Wired for War: The Robotics Revolution and Conflict in the 21st Century* Ch. 8 (Penguin, 2009).