https://doi.org/10.1038/s41893-024-01318-6

Building a sustainable place in space

As our reach extends outside our planet into Earth's orbital space and beyond, the need for proactive research and equitable governance of human activity in outer space is more urgent than ever.

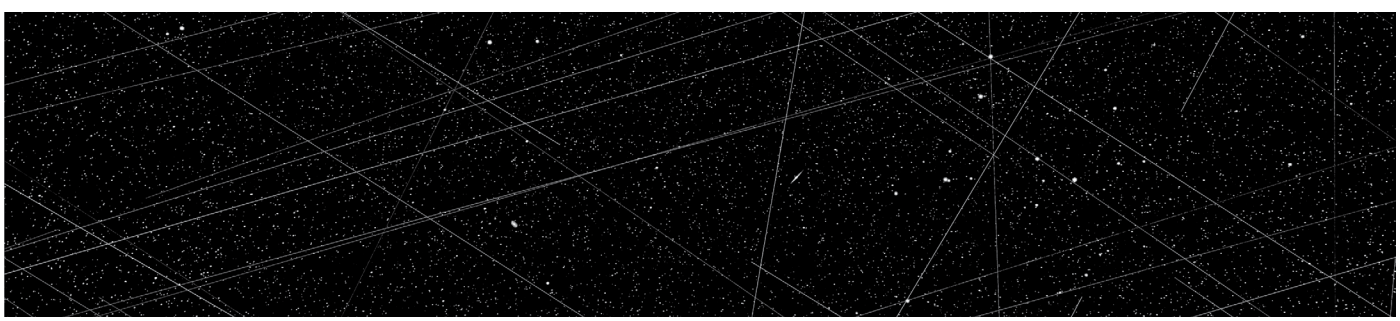
When we imagine building a sustainable future, we imagine how to balance humans' needs with a healthy environment here on Earth. However, for more than half a century, our anthropogenic impact has reached beyond our planet's boundaries into Earth's near orbital space and beyond. Our lives are increasingly dependent on a myriad of satellites, public and commercial, that do everything from orienting everyday navigation technology, to providing internet access to remote and beleaguered populations, to fostering an unprecedented blossoming in scientific Earth observation. But our orbital space is getting crowded; currently, there are thousands of satellites orbiting our planet and, if current plans for satellite mega-constellations are carried out, this number could approach 100,000 within the next decade, as Williams et al. mention in their Comment article in this issue. Operational satellites aren't alone; debris from rocket launches, defunct satellites and other space debris pose a threat not only to space infrastructure like the International Space Station and other satellites but to life on Earth, as this debris leaves orbit and re-enters Earth's atmosphere (J. D. Shutler et al., *Nat. Geosci.* **15**, 598–600; 2022). Rocket launches, now largely privatized, similarly generate debris and have been suspected to dump fuel within Earth's atmosphere. Despite the current boom in development in our orbital space, we lack robust regulation on how this development should continue, and our consciousness of the environmental impacts our expansion into space may cause is still in its nascent stages. In our Focus on 'Sustainable Space', *Nature Sustainability* sheds lights on the potential and pitfalls of the sustainable use and exploration of space.

The privatization of the space sector, seemingly into the passion project of a few high-profile billionaires, has made many cynical of its objectives, while others question the massive public investment required to run space programmes. However, for the past half-century, human exploration of space has been seen as a utopian exercise, pushing the boundaries of science, technology and knowledge for the common good. In a Perspective in this issue, Vengerova et al. lay out a framework for how space engineering can and should be designed simultaneously for supporting humans' exploration into space and humans' needs on Earth. By engineering bioprocesses that can sustain human habitation in space, scientists and engineers in the space sector can deliver solutions for greener and more circular water sanitation, crop fertilization, and biological and biodegradable materials, among other solutions. This could ensure that public money invested into the space sector will have equitable returns throughout society.

Environmental, climate and sustainability research has also been greatly bolstered by the unprecedented advances in space-borne Earth observation. Satellite missions like NASA's Landsat and Copernicus' Sentinel programmes provide detailed information about the Earth's surface, allowing scientists to monitor vegetation and ecosystem health, land-use changes, climate, water and cryosphere resources, and more. However, as Anderson et al. draw attention to in a Comment article in this issue, the storage and processing of mushrooming satellite Earth observation data has widespread and detrimental environmental impacts. As data and data processing move onto the cloud via services like Google Earth Engine, access is democratized but resource consumption and environmental impacts also increase. The collection, storage and use of Earth observation data must therefore be carefully considered to counterbalance against the detrimental impacts of data centres and big data processing. The Earth, environmental and climate scientists who regularly use Earth observation data are well positioned to lead the way in calling attention to this often-overlooked problem.

The time has come to think critically and proactively about protecting Earth's orbital space as an extension of our planetary habitat. Robust scientific research on sustainable pathways for development in space is needed alongside strong international and equitable regulation of the use of space and space technology. As Williams et al. remind us, we have a precedent for these actions when we look at environmental movements over the past century. Adaptive, flexible and equitable governance frameworks, such as those used to tackle chlorofluorocarbons, are needed to ensure responsible anthropogenic expansion into space. The astronomy community, whose view into the cosmos is threatened by the loosely regulated proliferation of orbital objects, has already begun to raise the alarm with policymakers at the national and international level (A. Lawrence et al., *Nat. Astron.* **6**, 428–435; 2022). Sustainability and environmental scientists and practitioners should join their call to ensure a sustainable future for humans on earth and in space.

Published online: 22 March 2024



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