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Brief Communication

Addressing disaster and health risks for sustainable outer space

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EDITOR'S NOTE:

This article is one of three companion papers addressing sustainability considerations for the future of space exploration, exploitation, and tourism. The articles document and advance the current and future state of the practice concerning the potential impacts of the New Space industry. Specific topics discussed include sustainability improvements for space missions, disaster and health risks for sustainable space, and future sustainability aspects of tourism in the New Space industry.

Abstract

Any future outer space exploration and exploitation should more fully consider disaster and health risks as part of aiming for sustainability. The advent of the so-called "New Space" race, age, or era characterized by democratization, commercialization, militarization, and overlapping outer space activities such as tourism presents challenges for disaster-related and health-related risks in and for outer space. Such challenges have been extensively researched for earth, but less so for space. This article presents an overview of key aspects for addressing disaster and health risks in outer space within a wider sustainability framing. After an introduction providing background and scope, this article's next section considers some key health and disaster risks within sustainable outer space and offers insights from earth. The following two sections apply this knowledge by focusing on how analogue missions and international legal and voluntary regimes can each be used to reduce risks and potentially make outer space healthier and safer. The findings advocate that there is a wealth of knowledge and experience about mitigating risks to health and disaster risk reduction on earth that can inform spaceflight and exploration. The examples explored include the physical, legal, and regulatory aspects of the "New Space" industry, which highlights the relevance of equating examples on earth. The article concludes that expectations must be managed regarding scenarios for which response, rescue, and recovery are precluded, prompting a necessary focus on prevention and risk reduction. In doing so, earth-based scenarios and aspects of the so-called "Old Space" offer useful insights and should be examined further for "New Space." *Integr Environ Assess Manag* 2022;00:1–8. © 2022 The Authors. *Integrated Environmental Assessment and Management* published by Wiley Periodicals LLC on behalf of Society of Environmental Toxicology & Chemistry (SETAC).

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INTRODUCTION

Many state that humanity is at the dawn of a "New Space" race, age, or era (Hampson, 2017; İnce, 2020; Pekkanen, 2019). İnce (2020) describes this realm as a shift from "from big to small, from primarily government to extensively private sector and from a few players to profusely many" (p. 235). Fourteen national space agencies are currently working together, in collaboration with private space companies, such as SpaceX and Blue Origin, to expand humankind's presence around our solar system (Laurini et al., 2018). A human mission to the surface of Mars is a major goal, to be achieved alongside further lunar missions. In comparison to the space race of the 1960s termed "Old Space," this so-called "New Space" age is said to emphasize international cooperation and the inclusion of entities beyond governments due to the suggestion that deep space exploration (and exploitation) will be possible only if humankind works together (Dawson, 2021; Shan & Wang, 2004). Others decry the apparent attempts to introduce colonialism and post-colonialism into outer space by replicating the inequity mistakes from earth (Sutch & Roberts, 2019). Collaboration and the private sector catalyze some abilities to research,

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design, and build the infrastructures and systems needed to explore space, yet commercialization, marketization, overexploitation, lawlessness, and competition are ever-present (Crowell, 2020).

Consequently, alongside the excitement of the New Space discourse, the realization emerges that outer space activities—especially resource exploitation—are not without risk, controversy, or difficulties (Cermack, 2006; Romero & Francisco, 2020; Sutch & Roberts, 2019; Zannoni, 2019). Greater access and increased activities entail changing challenges to human health, safety, and overall sustainability, ranging from orbital clutter (Blount, 2019) to biosecurity (Ricciardi et al., 2022). SpaceX, Blue Origin, Virgin Galactic, and others aim to open up suborbital space travel to reduce travel times around the world, and in doing so, launch the space tourism industry. Introducing tourists to space reveals many health and safety risks (Cole, 2015; Zhang & Wang, 2022).

Whereas astronauts are typically healthy people who have undergone substantial pre-spaceflight training and medical checks, space tourists will not likely be expected to have the same levels of training, health, and experience. Whether or not tourists or other casual travelers should have some mandated level of space-related training, health, and experience before boarding is an open question. Exploring it requires examination of the health and disaster risks as well as the costs, benefits, and morals of different risk prevention, reduction, and mitigation measures. Examining these topics contributes to the wider field of outer space health as well as outer space disaster risk reduction and response (DRR/R), including lunar and Martian space exploration and beyond (Chang, 2020; Knutson, 2007; Romero & Francisco, 2020). Emergency planning, sustainability planning, and legal planning have been extensively researched for earth, but significant gaps remain across these areas for outer space (Crowell, 2020; Martinez, 2021; Sokiran, 2019; Trur, 2021).

To advance existing knowledge and to provide recommendations for action, this article presents an overview of key aspects for addressing disaster and health risks in outer space, through three overlapping topics:

1. Understanding some disaster and health risk challenges of "New Space."
2. Using analogue space missions on earth to simulate impacts on and responses of people in space (tourists and nontourists) to different disaster and health risk scenarios.
3. Integrating with existing international legal and voluntary regimes to deal with outer space disasters and health risks, such as space weather and near-earth objects (NEOs)—which, here, would be referred to as near to spaceport/spaceship objects.

This article draws on the wealth of knowledge and experience in DRR/R that exists on earth, revealing the diversity of its settings and the continued relevance of its lessons. The conclusions offered are cautious given the potential consequences of outer space activities on humanity's pursuit of sustainable life on earth and, hence, with implications for sustainable outer space.

HEALTH AND DISASTER RISKS OF NEW SPACE

Risks relating to disasters and health, including pandemics and war, and how to deal with them, have been extensively explored for earth, but less so for outer space. The advent of the so-called "New Space" race, age, or era presents significant challenges and increases the need for investigating and addressing disaster-related risks in and for outer space. This section presents some obstacles to implementing safe and sustainable space activities, sharing some examples from earth that may hold promise for the future of addressing disaster and health risks for sustainable outer space.

International activities and technological advances and applications for outer space are typically thought to have spin-off applications for dealing with health and disaster risks on earth (Bhatt et al., 2010; Dutta et al., 2019; Kaku, 2019; Richards, 1982). An example is "satellites for communication, Earth observation, navigation, and telecommunication" (Valdes & Purcell, 2013), thus enabling meteorological data to inform warning systems that potentially save lives through early action with appropriate preparation and training (Glantz, 2009). Though the actual and consistent level of applicability and effectiveness is questionable, some countries use this spin-off potential to justify initiating domestic space programs (Vongsantivanich et al., 2018). Domestic and international law norms for outer space are also being examined in the context of earthbound spaces with parallels, such as Antarctica and the deep sea (Collis, 2017; Crowell, 2020; von der Dunk, 2015), including the long-standing yet debated notion of space activities as *legibus solutae*—a legal vacuum—until specific norms and provisions are created (Zannoni, 2019).

Nonetheless, the prominence of health risk and DRR/R considerations for outer space remains unclear, particularly for New Space. Many health and disaster risks that space travel presents for direct participants, and for people on the ground including staff and the public, are well known and are redressed to a large extent. For instance, provisions dealing with risks during training, preparation, launches, flights, and returns to earth are well developed and applied (Pelton et al., 2020). Risks of increasing space debris, from operators creating and failing to remove it, are recognized, albeit DRR/R measures are less developed or forthcoming (Lewis & Marsh, 2021; Madi & Sokolova, 2021) and are "likely insufficient to ensure safe scientific and commercial activity in space" (Bullock & Johanson, 2021, p. 8).

Research on preventing and responding to disasters in space that goes beyond technical and policy-based risk management for space mission safety is scarce, particularly with regard to the implications of commercial travel and potential settlements in space. The same is the case for reducing specific disaster risks, that is, how could DRR/R efforts in space—sometimes referred to as a vast, unregulated, and contested international commons (Goehring, 2020) that may be affected by conflict (Dawson, 2018)—be encouraged before disasters occur, and how could these same principles be applied to health risk reduction?

Technically speaking, planning for these scenarios is a similar exercise to considering similar risks faced on earth. With examples given earlier, many risks relating to outer space are known and dealt with to prevent disasters and reduce health impacts. At this arguably early stage of New Space exploration and exploitation, unknowns and uncertainties abound regarding the potential risks that may emerge. For instance, with respect to NASA's Mars Design Reference Mission, Mendell (2005, pp. 679–680) outlines uncertainties relating to (1) assuring the health and performance of the direct space travel participants, (2) "lack of experience with mission operations of the scale and scope of a human expedition [for instance] to Mars" such as in the context of, (3) reliability and maintainability of the hardware and software systems, and (4) political viability and volatility, notably in the context of the international cooperation expected and likely required for a successful mission. Political challenges have been illustrated previously by (1) a Soviet cosmonaut aboard the Mir space station during the USSR's collapse in 1991 being uncertain when he could return to earth and (2) likely unwarranted concerns that an American astronaut could not return from the International Space Station on a Russian spacecraft due to Russia's invasion of Ukraine in February 2022.

Uncertainties also include the New Space activities' possible consequences for earth. Such uncertainties can undermine the abilities to respond to manifesting health and disaster risks, and preferably preventing, reducing, or mitigating them and their impacts. This situation is not dissimilar from remote field care for health, which, while relatively established for helping people over short amounts of time, is not well explored or developed for prolonged periods of time (Kelman & Harris, 2020). On earth, the gap in knowledge and action by formal entities can be met by informal disaster governance, that is, the efforts of people, who are not officially tasked with DRR/R activities, to reduce disaster risks and/or respond to disasters (Duda et al., 2020). Such informal action, including rapid communication to acquire information, for reducing risks of and responding to disasters and health situations is less likely to succeed in outer space due to the isolation, vast distances, and poorly established networks. Similarly, telemedicine can be used for real-time consultations, diagnoses, and even operations on earth, but ends up with major limitations in space (Barratt et al., 2019; Cermack, 2006).

In such cases, should plans for rescue be developed? Or just let people accept that if rescue is needed, then they probably will not make it through the situation alive? Is this an acceptable standard of safety, including for explorers, scientists, other staff, and tourists?

Efforts to ensure effective DRR/R and health risk management in space are complicated by the growing number and diversity of actors and approaches that are said to characterize New Space (Pekkanen, 2019). With them comes the potential for diverging opinions and actions on safety, health, risk reduction, and sustainability—which could endanger each other if some parties adhere to health and safety protocols more than others. For example, private actors are demanding and accepting an increasingly leading role in this realm, whether in partnership with governments or not, sometimes under the presumption that the private sector is more competent than the government (Tinoco, 2018). How will they be held accountable for the DRR/R, health, and sustainability practices, which they do and do not follow?

This challenge is suggested as continuing to increase with the space industry forecast to reach trillions of US dollars by the 2040s (Bockel, 2018; Hampson, 2017). As Pelton et al. (2020, p. 265) warn, "without improved space safety practices and standards, billions of dollars (US) of space assets, many astronaut lives, and even people here on Earth could all be increasingly in peril." With space exploration and exploitation still being a relatively recent human development, there is a rapidly closing window of opportunity to institutionalize a health and DRR/R-centered approach. Doing so could support full implementation by the many entities and individuals engaged in space activities, rather than reacting after it is too late to avert problems. As examined in depth by Decadi (2018), the space industry could benefit from analyzing the process that the aviation industry went through to develop what is today "the most severe, mature [safety] standard accepted worldwide" (p. 147). The space industry adopting now a "health and safety first" strategy could mean that adverse impacts emerging from health and disaster risks could be minimized.

In contrast to the aviation industry, which remains physically tied to earth and governance through national and supranational institutions, the space industry seeks to operate predominantly in a vast realm in space and time that is often viewed as a global commons (Goehring, 2020; Pekkannen, 2019). Recent debates over digital platform regulation (van Dijck, 2020), as epitomized by the Digital Platforms Inquiry launched by the Australian Competition and Consumer Commission (Flew & Wilding, 2021), may be indicative of the challenges that could exist in a legal "gray zone" such as space, if the current "permissive" regulatory structure persists amidst rapidly increasing commercialization, marketization, and competition (Crowell, 2020; Hampson, 2017). As noted by Bullock and Johanson (2021), efforts to regulate outer space could benefit from the lessons of existing strategies for managing, for instance, large forests and fisheries. The case of Antarctica and its critiqued but enduring treaty offers additional insights that may be relevant for sustainable space (Lord, 2020).

ANALOGUE SPACE MISSIONS ON EARTH

The health and safety of people who will participate in spaceflight, including space tourists, is central to health and DRR/R policy and strategy (Patel et al., 2020). Regardless of the differences and similarities between Old Space and New

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Space, expectations must be managed in terms of scenarios for which response, rescue, and recovery could be precluded. These scenarios have parallels to many remote environments on earth, from high elevations to the deep sea, permitting the development and use of earthbound analogues and training.

Analogue space missions take place on earth and simulate space missions (Sánchez-García et al., 2020). There are many forms of analogues, each simulating specific characteristics of space. The location of analogue missions depends on the simulations needed, the scenarios explored, and the level of human and robotic involvement. For example, analogue missions can take place in remote environments (e.g., deserts or the polar regions), below sea level, or in confined land masses such as small islands and caves (Groemer et al., 2020; Sandal et al., 2017; Trembanis et al., 2012). In this section, a variety of analogues and their impacts on people in space and on earth are described. The focus is on analogue missions that involve humans, including human–robot combinations, rather than nonhuman-only missions (Ng & Lum, 2022), as the value of human spaceflight is well established, meaning that humans will continue traveling into space (Shelhamer, 2017).

Parabolic flights are analogue missions that involve an aircraft flying downwards at a speed which results in the simulation of zero- or low-gravity (Shelhamer, 2016). Parabolic flights are used to research the effects of zero- or low-gravity on human physiology, providing insights into how human physiology changes during deep-space missions and how the body reacts, with key examples being space sickness and disorientation (Karmali & Shelhamer, 2008). Such biomedical research is integral to planning for healthcare during the long-duration spaceflights of the future (Hettrich et al., 2015). Without parabolic flight analogue missions, the risks to astronaut health would be much harder to quantify, analyze, and address (Seibert et al., 2019). In contrast to low- or zero-gravity, centrifuge analogues enable research into high-gravity space exploration (Vessey et al., 2020). Future exploration of deep space, within and further afield than our solar system, is likely to involve travel to planetary bodies with greater (as well as lesser) gravity than earth (Goswami et al., 2021). While the impact of this research on terrestrial life is, at present, minimal, some pilots are an example of people experiencing high levels of G-force regularly. Centrifuge analogue missions provide opportunities to investigate the health of people involved in such activities (Kowalczuk et al., 2018; Vessey et al., 2020).

Another major health consideration is that deep space activities require prolonged periods of isolation with a small number of crew reliant on each another to complete mission objectives and, in effect, to survive (Landon et al., 2018). Isolation from family, friends, and the earth has the potential to have negative impacts on physiological and psychological health (Kolodziejczyk et al., 2021; Pagel & Choukèr, 2016; Riva et al., 2022). Thus, analogue missions that simulate isolation reveal its effects and the importance of coping strategies (Choukér & Stahn, 2020). The impacts on mental health and wellbeing of the COVID-19 pandemic that began in 2020 have revealed the relevance of such analogue research, in that prolonged periods of isolation can negatively impact cognitive function, so investigating this topic through analogue research contributes to wider health outcomes (Ingram et al., 2021).

Outer space brings many other risks requiring robust investigation in order to address them. Exploring other planetary bodies and living in space stations, such as the International Space Station (ISS), require extravehicular activities (EVAs), namely, spacewalks. Planetary EVAs expose astronauts to extreme risks to health, including high doses of solar radiation, limitations on fluid and nutritional intake, and reliance on life-support systems (Chappell et al., 2017). Analogue missions enable the testing of spacesuits and the rehearsal of space mission designs and protocols to mitigate risks to astronaut health during EVAs (Belobrajdic et al., 2021). Such research makes valuable contributions to health risk reduction for astronauts, including those traveling to Mars (Payler et al., 2019). Analogue missions further provide the opportunity to trial human–robotic space research, including developing safety procedures and standards for this hybrid model of working (Wedler et al., 2021; Wormnes et al., 2022). All this work, in turn, contributes to DRR/R by adopting the ethos of prevention, preparedness, and planning for risks (Chan & Shaw, 2020).

Meanwhile, the number of space tourists is expected to continue to increase during the next few decades (Zhang & Wang, 2022). A current area of research is the amount of training required for safe spaceflight, with analogue missions being a much safer process than spaceflight to provide the testing, training, and public education needed to reduce health and disaster risks (Florom-Smith et al., 2021). Certainly, people accept different levels of risk meaning that different space tourism operators might choose to have different health requirements, training levels, and safety standards. Overall, the level of acceptable risk and how to address risks are management decisions for all space exploration and exploitation, requiring thorough investigation in order to determine the level of regulation, monitoring, and enforcement for space tourism and other space travel (Isnardi, 2020; Spector, 2020).

With more people, less experienced people, and less healthy people engaged in spaceflight, space tourism opportunities could continue to grow, at least while it is perceived to be safe, which will also open up more research opportunities. Currently, research in outer space (i.e., not using analogue missions) is extremely expensive and time-consuming, including the preparation phase. With a thriving space tourism industry, much more data would be available for quicker processing and analyses, even being viable for a three-year doctoral dissertation due to the number of spaceflight opportunities and the number of people involved (Webber, 2013). Nonetheless, spaceflight brings health and disaster risks that need to be addressed and balanced with people's interests in space and with any gains from the interests and actions.

INTERNATIONAL LEGAL AND VOLUNTARY REGIMES

This article's previous sections summarized some complexities of institutionalizing legal and regulatory frameworks in space for addressing health and disaster risks, with an emphasis on the challenges presented by New Space. International legal and voluntary regimes for understanding and addressing outer space disasters and health risks began with the advent of space travel and hence were key components of Old Space endeavors (Bloomfield, 1965). The importance of, interest in, and work regarding these regimes has not diminished with New Space, instead opening up different international pathways through the private sector including small consortia alongside multinational corporations with wealth exceeding that of many countries. Existing mechanisms thus produce a patchwork, with little coherence. Consequently, developing a generic framework or seeking consistent comparative analysis across the international regimes would be difficult and might not be accepted by everyone involved (Isnardi, 2020). Instead, illustrative examples are provided here to indicate the possibilities for further approaches, without neglecting what is already available.

In particular, this section highlights more common space-related disasters and health risks, which have been dealt with to some extent through international regimes, rather than those that are speculative, or which have no international regime or mechanism. An example of speculative risks would be extraterrestrial beings, perhaps microorganisms that reach earth after having drifted through the solar system for millennia, or perhaps intelligent creatures trying to make contact. Aside from the usual tropes of invasion and war found in fiction (Lucanio, 1987), a significant disaster and health risk is a disease outbreak, covering bio-contamination on earth from alien organisms and vice versa (Pugel et al., 2020; Ricciardi et al., 2022). An example of a known disaster and health risk lacking international mechanisms would be limited warning for planet-wide destruction from stars, namely through a supernova (Fields & Ellis, 1999) or gamma-ray bursts (Palmer et al., 2005). The mass extinction risks are well documented (Fields & Ellis, 1999; Palmer et al., 2005) with limited work completed for prevention or mitigation, principally because there is not much that could be done for reducing vulnerabilities from these planet-wide hazards.

Two ongoing risks with existing international legal and voluntary regimes are examined here for spaceports and spaceships: first, space weather damaging power and communications equipment, and second, collisions with space objects.

For space weather, the International Space Weather Initiative was started in 2009 by the United Nations (UN) Committee on the Peaceful Uses of Outer Space within the UN Office for Outer Space Affairs (UNOOSA). It connects parties interested in space weather and its impacts on science as well as science communication. For warnings and recommendations on responding to warnings, national agencies typically take charge, even when cooperating across international borders. Supranational organizations also contribute. The European Space Agency runs a Space Weather Service Network, which provides publicly available real-time forecasts and conditions for space weather. Registered users can view specific information for sectors, such as aviation, aurora tourism, pipelines, and power grids. Some of these domains cover human spaceflight and satellite operations, showing that it could easily be expanded to apply further to humans in space, tailoring further warnings and responses to reduce health and disaster risks to spaceports and spaceships.

Space objects are frequently referred to as NEOs, which, in the context of this article, would be modified to become near-spaceport objects or near-spaceship objects. As the definitions of "meteor" and "meteorite" refer to the earth, the appropriate terms for space objects in reference to spaceports and spaceships would be mainly dust, meteoroids, asteroids, and comets.

For space objects approaching the earth, some international coordination and action since 2014 have followed UN recommendations for the Space Mission Planning Advisory Group (SMPAG) and the International Asteroid Warning Network (IAWN). Neither of these groups has formal UN status. The collective term has been "planetary defense" (see also Kofler et al., 2019)—with long-standing initiatives at the national level, such as for the United States (Morrison, 1992)—which would extend to "spaceport defense" and "spaceship defense." The IAWN disseminates information and connects those interested in detecting, tracking, and monitoring objects compared to SMPAG, which plans and prepares for various forms of international response, such as deflecting or destroying a threatening object. These actions apply to spaceports and spaceships as much as to the earth (and to the moon and other off-earth settlements). One major difference is that spaceports and spaceships might have the option of moving out of the way of a space object, even though this is not often easy or desirable since the spacecraft might be on a trajectory, which is costly, difficult, and dangerous to deviate from.

Other international legal and voluntary regimes deal with both space weather and space objects in tandem. Primarily connected to Old Space, the UN (e.g., Jasentuliyana, 1999), including its space agency UNOOSA, supports science, monitoring, cooperation, and response for outer space phenomena, nominally focused on the earth, but easily extended beyond the earth. One recent example is the UN (2022) aiming for a UN resolution on space and global health. Other UN organizations are involved in specific ways. The UN Office for Disarmament Affairs (UNODA) seeks outer space to be used for peaceful purposes, which, if desired and supported by member states, could theoretically apply to assessing and responding to risks to spaceports and spaceships from space weather and space objects—in addition to negotiating with extraterrestrials. Similarly, the UN Office for Disaster Risk Reduction (UNDRR) classifies outer space hazards (UNDRR, 2020) and thus could

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pursue more activities regarding outer space DRR/R, such as vulnerability mapping for spaceports and spaceships, monitoring hazards and running hazard scenarios, and promoting measures to reduce risks and avert disasters.

Also, arguably still mainly within Old Space, the International Astronomical Union (IAU) is an international scientific organization for astronomy-related cooperation. Through public education and research exchange, the IAU has the scope to incorporate aspects of health and disaster risks within its expertise—and to contribute even more to New Space than it does already. Firmly within New Space, many private initiatives exist, offering products and services to any earth-based client around the world who might need, for instance, a warning of an incoming solar storm to shut down a satellite or a water treatment plant. Space-based operations, public or private, could subcontract monitoring of and responses to space weather and space objects to the private sector or to nonprofits. Markets could develop—as has occurred for earth—for detailed databases and projections of space object trajectories, in the case of outer space for avoiding collisions or for a rendezvous for mining, science, or tourism.

In fact, New Space has already produced international start-ups and ventures worth hundreds of millions of dollars (Frischauf et al., 2018; İnce, 2020). They supply regularly updated high-resolution images of earth from satellite constellations. The concept has straightforward analogies for the moon and other planets/moons as well as scanning for space objects or space weather threatening spaceports and spaceships. Other applications for small or multinational ventures include providing fast Internet to outer space (compare with SpaceX's Starlink)—thereby also entailing outer space cybersecurity (Manulis et al., 2021)—and supply chains for spaceports and spaceships (compare with the International Space Station's needs; Hannan, 2018). Many of the New Space groups have been created and advanced through crowdfunding (Pomeroy et al., 2019) which, in theory, is international even if a small, geographically focused cohort often provides most of the funds.

Science diplomacy is another major area of international regimes, older and newer. Countries have individual agencies, such as the Japan Aerospace Exploration Agency, and other scientific offices dealing with outer space disasters and health risks, such as the United Kingdom's Met Office being responsible for space weather monitoring and warnings. These agencies collaborate extensively, sharing data, conducting joint research (e.g., Ueno et al., 2020), funding projects, and exchanging experiences. Science diplomacy endeavors easily extend to outer space, supporting international cooperation for space activities in a manner reducing health and disaster risks from earth observations to space travel (Goel, 2021).

CONCLUSION

This article presents an overview of key aspects for addressing disaster and health risks in outer space, with a focus on what is being dubbed the "New Space" race, age, or era. At this arguably early stage of so-called "New Space" exploration and exploitation, many of the potential risks remain unknown or uncertain, limiting the ability to plan for and manage them. The task of making space healthy/ier and safe(r) is further complicated by the currently scattered legal and regulatory regimes and the growing number and diversity of actors and approaches that are said to characterize New Space. To address these challenges, instead of "looking to the stars" and "reinventing the wheel," more should be done to draw on the wealth of knowledge and experience that exists on earth for addressing health risks and DRR/R. This article offers examples, touching upon the physical, legal, and regulatory aspects of the space industry and the environment in which it operates, revealing the rich diversity of earth's settings and the continued relevance of its lessons. With space activities arguably still in their infancy, there is a rapidly closing window of opportunity to leverage this knowledge and institutionalize a risk reduction-centered standard for disasters and health.

Similarly, this article urges the space industry to consider the wider sustainability of its operations (see also Paladini et al., 2021). As the space industry grows, there is a danger that pursuing the opportunities of outer space may have catastrophic rather than supportive implications for earth and humanity's recent efforts to transition to more sustainable living. No longer limited by earth's finite resources, many might assume that we could and should continue a model of boundless economic growth based on resource extraction, consumption, and waste. The principles (although not the practices) for improving are well established on earth, from the circular economy (Lacy et al., 2019) to the steady-state economy (Washington & Twomey, 2016). They should be designed into outer space activities from the beginning—especially as, by definition, they reduce health and disaster risks. By learning from humanity's past and by embracing a sustainability and risk reduction approach, humanity can create a healthier and safer future, on earth and in outer space—achieving sustainable earth as well as sustainable space.

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