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Opinion/Position paper

Advances in planetary sustainability

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ABSTRACT

In the 21st century, existing human societies and biodiversity on the Earth are under threat because human resource consumption is exceeding or projected to exceed some of the physical and chemical boundaries of our planet (Rockström et al., 2009). Space research and space exploration are an integral part of a sustainable development that mitigates these threats: Space science and exploration allow us to monitor environmental threats and they open up access to global communication and participation for all human societies. In addition, space exploration also promises to expand the existing limitations and planetary boundaries imposed on human development. On the other hand space exploration can also cause additional environmental problems. The best known example for the latter is the anthropogenic space debris orbiting Earth, but similar problems are likely to occur in other places, for instance on the Moon, due to scientific and commercial space exploration in the near future.

Planetary sustainability is a helpful concept to address the promises and challenges posed by space exploration with respect to sustainability. This concept can be understood as a sustainable development that considers the Earth as a planet in its space environment and considers the space environment as an integral part of sustainable development, with scientific, ethical, economic, and legal ramifications.

In this article we review the recent advancements in planetary sustainability. This includes the proposal that the space environment of Earth should be added as an independent goal to the existing 17 Sustainable Development Goals defined by the United Nations, considerations of the planned return of humans to the Moon in 2024, and the implications of the increase of commercial satellite networks in low Earth orbit.

1. Introduction

Planetary sustainability is an approach to sustainability which takes into account that Earth is a planet with a space environment. The term was first coined by the NASA initiative for "Planetary Sustainability" (NASA, 2014) and developed further by researchers at the University Bern and beyond (Galli and Losch, 2019; Losch, 2019b): "As space researchers, we need a framework to help us guide research and exploration of outer space [...] in a wider scope than the very specific planetary protection guidelines. Planetary sustainability is a useful general concept but its implications on space research and exploration must be elaborated." (Galli and Losch, 2019).

Over the last few years, we have been advancing the concept and studying its implications and implementations by means of a project (www.planetarysustainability.info) and interdisciplinary workshops, combining viewpoints from physics, history, space law, space policy, religion, and economy (for a general overview of interdisciplinary topics related to space exploration see Landfester et al., 2011). The initial exploratory workshops in 2018 were followed by two online events, the Planetary Sustainability 2021 (PLASUS21) workshop (Losch, 2021) and the SDG18.SPACE workshop in 2022 (Losch et al., 2022b). The executive summary for the PLASUS21 workshop report states: "A systemic approach to sustainability is needed, including advancements in international practices and rules regarding space.(...) The most pressing problem are the emerging megaconstellations, but one may not underestimate the potential of space resources to transform human civilization and life on Earth. The question how to share the benefits remains. There is conceptual convergence regarding the need of something like an SDG18 Space environment(...) Also it could be helpful, if the concept of planetary boundaries would include something like 'orbital boundaries' in the near future." (Losch, 2021).

Recent studies by other researchers have elaborated on related topics: Yap and Truffer (2022), e.g., assess the implications of "earth-space sustainability" in the context of increasing satellite traffic, Miraux et al. (2022) argue for including "environmental considerations in

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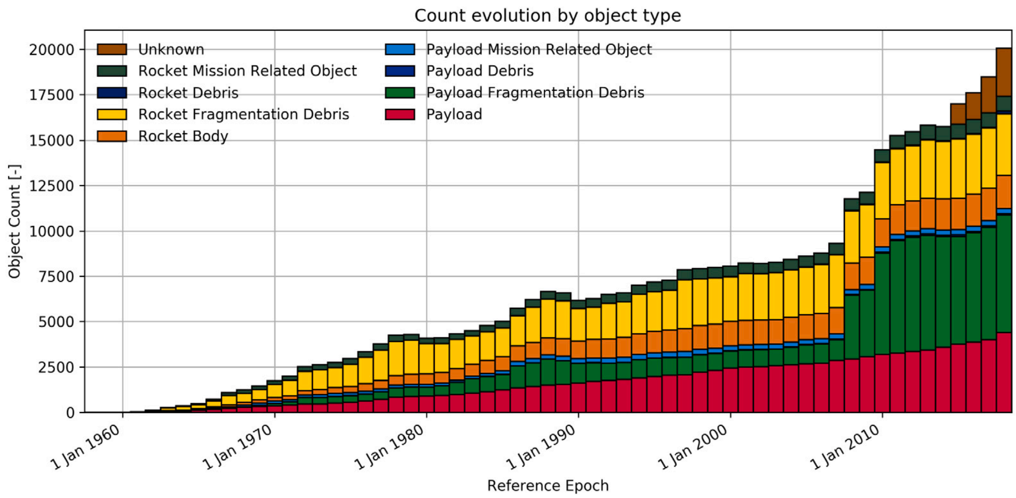

Fig. 1. Number of known active payload (red) and types of space debris (other colours) in Earth orbits year-by-year until 2018. The 25% increase of observable space debris objects in 2007 was caused by the intentional destruction of the FengYun-1C satellite.
Source: Figure taken from ESA (2023).

addition to technical and economic analyses in space projects definition and space systems design", and Worms (2022b) puts forth four basic ethical laws of space exploration in analogy to Isaac Asimov's Three Laws of Robotics.

The present article summarizes the recent advances in planetary sustainability in the following way: It discusses the implications of planetary sustainability for three areas of immediate concern (Galli and Losch, 2019), i.e., Earth orbit space (Section 2), the Moon (Section 3), usage of space resources (Section 4), the prospects of space as an independent sustainable development goal (Section 5), and it gives an overview of recent developments in the Committee on Space Research (COSPAR) to address similar questions around planetary sustainability (Section 6).

2. Near Earth space

Near Earth space is a critical area for the discussion of planetary sustainability both because of its relevance for Earth monitoring and enabling communication but also because of the user conflicts and rising risks.

A central challenge to the sustainable use of near Earth space is space debris or orbital debris. This includes all human-made objects in Earth orbit that are no longer of use (derelict satellites, fragments of rockets, particles from rocket motor firings, etc.). Since the dawn of the space age, the number of space debris has steadily increased. This evolution until 2022 is summarized in Fig. 1.

In recent years, the growth of active satellites and thus the prospect of future space debris has grown more rapidly than ever before. This increase of satellite traffic in low Earth orbit is dominated by commercial satellite networks (see Fig. 2). Considering the foreseeable detrimental effects on Earth-based astronomy, the International Astronomical Union launched the IAU centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference on 3 June 2022 (International Astronomical Union, 2022).

Before any countermeasures can be implemented, the situation of space debris must be carefully monitored. Progress on this account has been reported recently by Steindorfer et al. (2020), Yao and Changyin (2021), Mironov and Murtazov (2021), including measurement methods viable for daylight observations. The most critical altitudes for space debris seem to be low Earth orbits between 500 to 1500 km altitudes, as below 400 km most debris is lost swiftly to the atmosphere and also because "Overall, orbital debris dominates the impact risk between altitudes of 600 and 1300 km, while meteoroids dominate below 270 km and above 4800 km." (Moorhead and Matney, 2021).

Maury-Micolier et al. (2022) calculated the potential economic damage related to the emission of one debris for a specific orbit as the product of collision likelihood, residence time, and economic effect factor; they found the largest impact numbers for altitudes between 550 and 2000 km, but the orbit inclination also played a role. This economic cost factor is exacerbated by the fact that de-orbiting large space debris from low Earth orbits will be much more expensive compared with e.g. geostationary orbits (Baranov et al., 2021). Another recent contribution from an economic point of view (Barry, 2022) stated that space debris removal is currently economically, legally, and technically infeasible, describing it as a tragedy of the commons example. The author then presented exemplary case studies from other areas where government and private actors have worked to successfully address other "large public negative externalities profitably without major disruption to business practices".

Four specific groups of actors (in addition to the wider public) can be identified that can influence space debris and are also affected by space debris: Space scientists, NGOs (e.g. NSS, 2022), commercial actors, and state actors (in particular space agencies like NASA and ESA, but also military branches like the U.S. Space Force, 2022.) At space conferences and workshops where the various stakeholders met we have never encountered any participant who disagreed that an overabundance of space debris in Earth orbits is bad for all actors. There is consensus that open access to space must be safeguarded for all humanity. The method how best to address this issue may be more contentious. This pertains, for example, to the question if reduction of space debris is to be achieved mostly via regulations or if self-regulatory approaches (the Space Safety Coalition, 2023 and the American Institute of Aeronautics and Astronautics, 2022 compiled best practices for sustainable and safe space operations by commercial actors) and incentives like those provided by the recent launch of the Space Sustainability Rating (ESA, 2021) should be used as main policy tools. Migaud (2020), Haroun et al. (2021) recently presented overviews on the policy challenges related to space debris. Haroun et al. (2021) favour legal remedies including the definition of space debris under international law (see Mejía-Kaiser, 2020 for a synopsis on current international space law relevant for space debris) and the adaptation of environmental law principles while Migaud (2020) generally advocated advances in policy and technology to monitor and remove debris from Earth's orbital environment.

To formulate any policy approach the status of space debris situation and the intended goal must be well defined. From a physics point of view, any positive growth rate of space debris per time period is unsustainable in the long term, as this implies exponential growth of

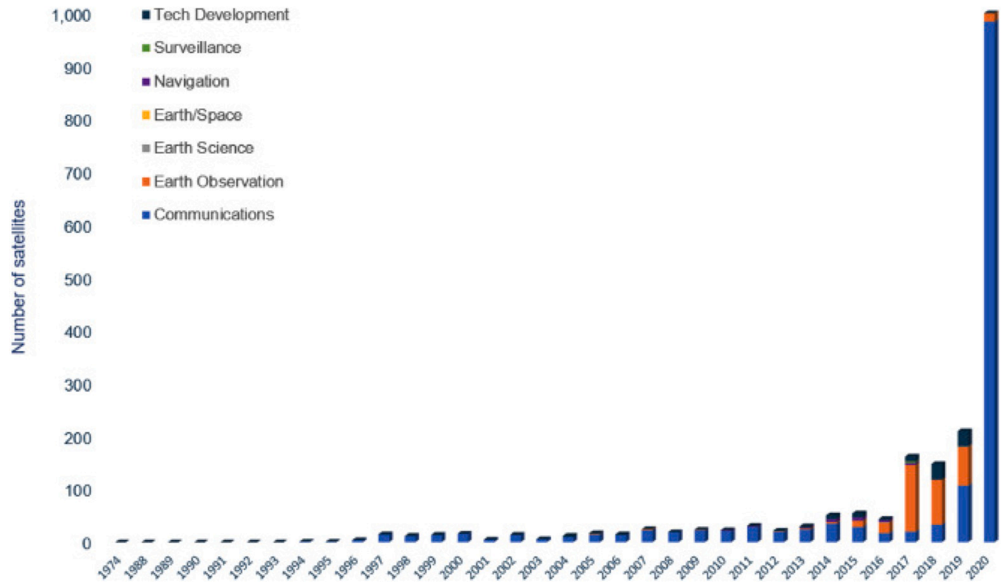

Fig. 2. Number of commercially launched satellites by segment,1974–2020.
Source: Figure taken from Yap and Truffer (2022).

space debris in orbit for that given time period. This agrees with ESA's "zero debris policy" (ESA, 2023) to be achieved by 2030 (statements by ESA Director General Josef Aschbacher at the Clean Space Webinar on June 23, 2022, and by Tim Flohrer at the Astronomical Institute of the University of Bern on November 25, 2022). The seemingly trivial mathematical statement has far reaching implications on pre- and post-launch mitigation strategies. Unless the launch rate of spacecraft to Earth orbits decreases (unlikely in the foreseeable future) this means that mitigation strategies to prevent satellites from turning into space debris are important (as a case in point, the Federal Communications Commission recently adopted the rule that satellites must be de-orbited within 5 years after the end of their mission (FCC, 2022), but they are not sufficient to achieve a net zero or negative space debris growth rate. That will also require active cleaning up of space debris (de-orbiting large derelict satellites and/or collecting smaller pieces of space debris). Recent advances on technical adaptation and solutions to remove space debris from LEO were proposed by e.g. Aslanov and Ledkov (2022), Baranov et al. (2021), Cai et al. (2022), Peltoniemi et al. (2021). By 2026, the Clearspace-1 mission, mandated by ESA, is to be launched (Clearspace, 2022) and the Cleaning Outer Space Mission through Innovative Capture is to remove two defunct British satellites (Astroscale, 2023).

Precise numbers for growth versus removal rates are hard to find. From simulations and empirical data (see Fig. 1 and NASA, 2022), the amount of debris to be removed from LEO to prevent space debris growth is usually estimated as 5–10 large pieces or derelict satellites per year (pers. comm. by Thomas Schildknecht at the workshop in 2018). In sum, the growth rate of space debris (at a given spacecraft launch rate) must be kept at net zero, in analogy to the intended net zero CO2 emissions to stay within the 1.5° C limit to global warming communicated by the Shukla et al. (2022). This target of zero or negative growth after all is easier to define and more serviceable for near Earth space than defining "orbital boundaries" in analogy to planetary boundaries (Rockström et al., 2009), as PLASUS21 concluded.

One obvious way to raise awareness and provide information to interested public and policy makers is to maintain a public database with easy to understand graphs on space debris. This database should illustrate the current status, including timelines, model predictions, growth rates, and the assessment of past and pledged policy impacts. A useful port of call in that regard is NASA (2022) with their quarterly news, but the public profile of these resources should be enhanced. Along these efforts the stakeholders affected by space debris (scientists, space agencies, companies and civil society) should consider organizing themselves in an "Intergovernmental Panel on Space Debris" that keeps track of the status, evolving threats, and countermeasures. In comparison to the existing Inter-Agency Space Debris Coordination Committee (2023) for space agencies, such an Intergovernmental Panel on Space Debris would also include non-governmental stakeholders and would, beside monitoring the progress of space debris mitigation, also raise public awareness and develop recommendations for space policy relevant for all actors. The analogy to the Intergovernmental Panel on Climate Change is suggested by the type of problem (global challenge and an environmental problem that can be understood as a tragedy of the commons) and even by the terms used to discuss policy, like "adaptation" and "mitigation strategies". The secrecy of military deployments might provide an obstacle for this cause, although military actors have a huge interest in "Space Sustainability" as well (U.S. Space Force, 2022). Here, intergovernmental and scientific bodies such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and COSPAR should use their influence to convince all states to agree on a complete ban on the use of weapons in space. This pertains in particular to a ban on direct ascent anti-satellite because these have contributed to a sizable part of the orbital debris (see the effect of the destruction of FengYun-1C in Fig. 1). The model followed in Antarctica by all operating nations may provide a useful analogue for these negotiations.

3. Rising interest in the Moon

By the end of 2022, the return of humans to the Moon (within the ARTEMIS program led by NASA (NASA, 2019)) is imminent. The current schedule foresees several unmanned missions and the Lunar Gateway followed by the first astronaut crew landing near the lunar South pole in 2025 at the earliest (Lloyd et al., 2022). In addition, there also is a plethora of unmanned lunar missions planned for this decade. Many national space agencies are working on missions, such as the Indian Chandrayaan-3 lander (ISRO, 2022), the Chinese Chang'E 6 and 7 to the Aitken basin in the South pole region (Xu et al., 2018), and the US VIPER Rover (Colaprete, 2021) to prospect for water ice in the south pole region to name but a few. In contrast to the earlier phase of human exploration of the Moon from the 1960s–1990s, now also private companies lead space missions (such as Blue Origin (Blue Origin, 2023), Firefly Aerospace (Firefly Aerospace, 2023), and the

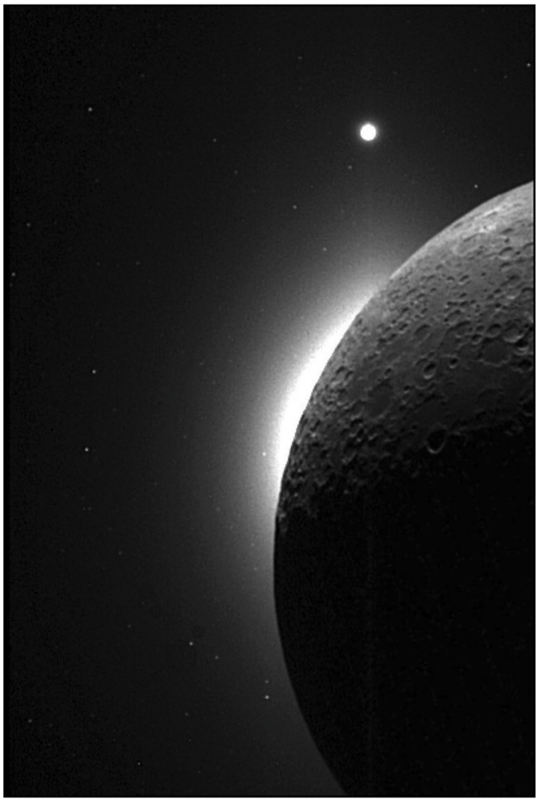

Fig. 3. Lunar horizon glow caused by dust particles, observed by the Clementine spacecraft in 1994.
Source: Image credit: NASA.

companies participating in the Commercial Lunar Payload Services program (NASA, 2023)).

The return of humans to the Moon and the increase in robotics missions will be relevant to planetary sustainability for several reasons:

First, as more nations and companies engage in lunar exploration, awareness of the value of near Earth space and the moon will rise. This raised awareness might both help or hinder the development of universally accepted guidelines on space activities in accordance with planetary sustainability. The value ascribed to the Moon will differ between different stakeholders: Scientifically, the Moon is uniquely interesting because it "presents a record of geologic processes of early planetary evolution in the purest form." (National Research Council, 2007). The Moon allows researchers a look at the initial stages of planetary evolution and of our entire solar system as the lunar interior was never modified by plate tectonics or planetary-wide volcanism and its surface sees hardly any erosion due to the absence of a dense atmosphere. Moreover, the Moon also provides a unique location for research in astronomy in the absence of an atmosphere or ionosphere (National Research Council, 2007). In terms of space resources, the economic value of water ice, rare earths, and ^{3}He-rich ore for nuclear fusion reactors is being discussed (David, 2015; Nature Astronomy (editorial), 2019). Because of its proximity to Earth, the Moon is by far the most accessible celestial body outside Earth, which makes it the ideal staging and test ground for space exploration in general. Finally, the Moon also harbours cultural heritage sites (Rummel et al., 2012; Froehlich, 2020) and has a potential for space tourism. Collins (2006), e.g., discussed possible economic, political, and cultural benefits of lunar tourism versus its detrimental effects for lunar science related to the alteration of the pristine atmosphere and the loss of far-side radio silence.

Second, the continued presence of humans on the Moon will change the lunar environment in an irreversible way to some extent. To minimize this extent, the frequency of landings, duration of stays, and astronaut crew size could be minimized. As a case in point, an intense lunar horizon glow due to dust particles was observed in the 1970s (Zook and McCoy, 1991), but the dust densities inferred or measured by LADEE in 2014 (Horányi et al., 2015; O'Brien and Hollick, 2015) or other missions in the 1990s and the 2010s (Glenar et al., 2014; Feldman et al., 2014) (see Fig. 3) were orders of magnitude lower. The intense lunar horizon glow observed in the 1970s thus may have been a transient phenomenon caused by rocket thruster firings related to the Apollo and Surveyor missions. As an additional measure, the international community could agree on no-go areas in regions of great cultural or scientific interest (Cockell and Horneck, 2006; Rummel et al., 2012). Regarding cultural heritage (e.g. the landing sites of first human missions to the Moon) identifying and listing the sites is the first step, but the current legal framework is insufficient for protection (Farsaris, 2020). Regions of special scientific interest could include e.g. the permanently shadowed craters in the polar regions where the reservoirs of ices and other volatiles will react very sensitively to any disturbance (in particular drilling, heavy machinery and waste heat of human tools and infrastructure). Permanently shadowed regions were also discussed within the COSPAR Panel on Planetary Protection, which led to the definition of a separate Planetary Protection category for lander missions accessing "Permanently Shadowed Regions and the lunar poles, in particular latitudes south of 79°S and north of 86°N" (COSPAR Panel on Planetary Protection, 2021). Access restrictions related to these regions create an obvious conflict with the planned landing sites of several lunar missions mentioned earlier (e.g. ARTEMIS and Chang'E 6).

Finally, several exploration missions to the Moon are pitched as enabling or at least be relevant for mining of lunar resources in the near future (e.g. "Understanding this vertical distribution of water will reduce uncertainty in water resource maps, as well as ensuring the water ice is characterized to a depth where the amount of ground material removal may be acceptable to economic mining models." Colaprete, 2021). Therefore, universally agreed guidelines about the acceptable use of space resources are a pressing issue, and the legal debate about the meaning of the "use" of space according to the Outer Space Treaty should be settled as soon as possible. Prolonged robotic and/or human presence on the Moon or in lunar orbit on their own will increase the demand of space resources (water in particular) from the Moon itself and from near-Earth asteroids (Sercel, 2018; Hein et al., 2020).

4. Space resources

In a narrow sense, the term "space resources" describes the materials available in space for in situ use or for consumption on Earth. In a broader sense, space resources also include the use of the Earth's space environment for satellite orbits (which is limited, see Section 2) or experiments to study the effect of micro-gravity on plants and tissues (Vandenbrink and Kiss, 2016; Hughes and Kiss, 2022). In such a broad sense, a recent collection of studies discusses various aspects of space resources (Losch et al., 2022a).

Sources of conflict are foreseen in particular for the usage of space resources in the narrow sense. Different space actors may have conflicting needs and the space resources themselves (such as near-surface water ice deposits on the Moon) are finite. After initial more visionary ideas about the potential of mining precious asteroids, following the 2015 US Space Act (U.S. Congress, 2015). Luxembourg started with its own concrete plannings to make this vision a reality, providing a legal structure first (LSA, 2018; Cookson, 2017; Losch, 2019a). The harvesting of precious asteroids remains a long term goal, but the resources on the moon (water and regolith) are firstly targeted at for an in situ use (LSA, 2018; Sercel, 2018), and of course not only by Luxembourg. An open question remains if space resources can indeed, as originally envisioned by NASA's planetary sustainability vision (NASA, 2014), facilitate sustainable development of "the people of the Earth". Which planetary protection measures would need to be preserved and how would the addition wealth from space resources affect the distribution of wealth and resources on the Earth?

5. The planetary plan: space as an additional 18th sustainable development goal?

Attendees polled at the COSPAR Assembly 2018 were in favour of considering space an autonomous goal for sustainable development (Galli and Losch, 2019), in addition to the 17 Sustainable Development Goals (SDG) defined in the 2030 Agenda for Sustainable Development (UN, 2015). This would raise political awareness, and treating space as an independent SDG would prevent it being considered a mere means to meet the other SDG. Building on an idea already voiced in 2018 (Losch, 2018), Losch (2020) argued to"add an 18th Sustainable Development Goal called 'Space Environment' to the current 17 Global Goals, as a sort of a political demand to complete what then could better be called the 'Planetary Plan'".

On the SDG18.Space workshop, Thomas Schildknecht proposed an example for such an SDG modelled after the COPUOS Long-Term Sustainability guidelines (Committee on the Peaceful Uses of Outer Space, 2010), expanding on a first draft by Nick Barracuda:

- Reduce space debris
- Integrate Long-Term Sustainability measures in national policies, strategies and planning
- Increase scientific knowledge, research, and technology to support sustainable exploration and use of outer space
- Improve education, awareness-raising, and promote and facilitate international cooperation in support of the long-term sustainability of outer space activities
- Implement international space traffic management and coordination; efficiently collect, share and disseminate "space situational awareness" information
- Universal adoption of COPUOS Space Law

This preliminary outline would need to be revised considering the existing additional challenges in our space environment like space resources. The idea of declaring space the 18th SDG was also supported by the head of JAXA at the IAC2022 in Paris and by Claude Nicollier (former astronaut and professor emeritus at the Ecole Polytechnique Fédérale de Lausanne) in a public talk at the Double Anniversary of the Astronomical Institute of the University of Bern on November 25, 2022.

On the other hand, this approach also faced some criticism at the workshops on planetary sustainability and the COSPAR 2022 assembly: First, adding space as 18th SDG cannot be formally implemented before 2030. Moreover, it is yet unclear if and how a follow up to the UN sustainable development goals 2030 will be defined and negotiated. Reaching a consensus on space-related topics on UN level in the coming years will not be easy given the current mutual distrust between several states and different priorities in geopolitics. More generally, it was questioned if adding space as 18th SDG would be the best course of action to raise political awareness and to initiate policy changes in UN member states. However, it was found difficult to formulate specific alternative approaches how to raise awareness of the wider public and international policy makers. One possible alternative may be to visibly channel the guidelines listed earlier into the relevant existing groups operating with COPUOS (in particular the Working Group on Long-Term Sustainability of Space Activities (Office for Outer Space Affairs, 2023)), and asking that the overall aspect be coordinated by the UN Office for Outer Space Affairs.

Although a SDG18 or space could formally only be proposed by an UN member state, raising awareness at the UN for the role of space for sustainable development will have to be led by the COPUOS. In February 2022, COPUOS submitted the "Space2030" Agenda and to reaffirm and strengthen "the contribution of space activities and space tools to the achievement of global agendas, addressing long-term sustainable development concerns of humankind" (Committee on the Peaceful Uses of Outer Space, 2022). In their input, the committee identified four overarching objectives: (1) Enhance space-derived economic benefits and strengthen the role of the space sector as a major driver of sustainable development, (2) Harness the potential of space to solve everyday challenges and leverage space-related innovation to improve the quality of life, (3) Improve access to space for all and ensure that all countries can benefit socioeconomically from space science and technology applications and space-based data, information and products, thereby supporting the achievement of the Sustainable Development Goals, and (4) Build partnerships and strengthen international cooperation in the peaceful uses of outer space and in the global governance of outer space activities (Committee on the Peaceful Uses of Outer Space, 2022).

6. Recent developments in the committee on space research

The Committee on Space Research (COSPAR) is a non-governmental scientific organization, established by the International Science Council in 1958 (https://cosparhq.cnes.fr/). It is widely recognized by space researchers as a forum to discuss science and also non-science issues that may affect space research. COSPAR has been instrumental in formulating space policy related to Planetary Protection, e.g. Coustenis et al. (2019), Fisk et al. (2021)

In the last few years, COSPAR has implemented several new panels addressing issues around sustainable development. The Panel on Establishing a Framework for Scientifically-based Stewardship of Celestial Bodies (PEX.1) mentioned for the first time explicitly "planetary sustainability" as one of the aims at the COSPAR assembly 2021. For the follow-up assembly in 2022 in Athens, the purpose of the panel was stated as follows: "In the present climate of scientific exploration and potential scientific/commercial exploitation of celestial bodies ranging from the Moon and Mars through asteroids and comets, it is incumbent on humankind to consider environmental stewardship as an essential aspect of 'planetary sustainability'. Accepting that future exploitation of celestial bodies can provide an essential ingredient in the survival of the human species, and that outer space is not limitless with respect to the investments required, now is the time to address the conditions under which those investments will best be made, as well as the mechanisms that will be effected to avoid negative, and potentially irreversible changes, resulting from human activities. This future calls for discussion of the benefits of scientific exploration of the celestial bodies potentially in forming a basis for the evaluation of future investments and their collateral economic aspects, coupled to legal considerations of what measures can, and should, be undertaken to assure sustainable stewardship and use of celestial bodies" (Westall and Rummel, 2022).

In addition to the Panel on Exploration (PEX), other science panels relevant to the topic of planetary sustainability in the COSPAR framework comprise PPP (Panel on Planetary Protection), PEDAS (The Science of Human-Made Objects in Orbit: Space Debris and Sustainable Use of Space), and PSSH (Engaging Space in Society: the new COSPAR Panel on Social Sciences and Humanities) (Worms, 2022b).

The longest standing of these COSPAR panels is the Planetary Protection Panel (Coustenis et al., 2019). One motivation for the set-up of new panels such as PEX PEDAS and PPSH was to also cover wider sustainability goals than just the biological contamination issues covered traditionally by PPP (Fisk et al., 2021; Worms, 2022a). The Panel on Exploration was first chartered around 2008. Science protection was one of its tenets with that consideration comprising a variety of related aspects. Roger-Maurice Bonnet was the instigator of the Panel as COSPAR President. (John Rummel, pers. comm. 2022)

This development of COSPAR and COSPAR panels addressing a wider range of concerns for space research was also reflected by Jean-Claude Worms at the COSPAR assembly 2022: "Even though COSPAR's

PP Panel is establishing planetary protection guidelines enacted upon by all major space agencies, these new aspects are not covered by any international law, treaty or commonly accepted guidelines. Their obvious societal impact as well as their high interdisciplinary content call for COSPAR to initiate a discussion and propose suggestions and, possibly, recommendations for new guidelines or new regulations. The conversation initiated in late 2021 between COSPAR panels PSSH, PEX, PEDAS and PPP, aims to provide a forum for debating these subjects and call to action." (Worms, 2022a).

7. Conclusions

The interest in Near-Earth space and its resources is set to increase in the coming years. Thereby the differing goals of space actors (scientists, NGOs, commercial actors, space agencies, and policy makers) may lead to contradictory demands. The concept of planetary sustainability is useful to identify and defuse potential conflicts by balancing the contrasting needs, keeping in mind the ultimate goal to which all space actors do subscribe: a sustainable human presence in space, necessary for a long-term survival of humankind. In this decade, more open talk (beyond space science) and action in the form of guidelines and binding legal rules where necessary are needed. This applies in particular to the main areas where user conflicts are foreseen or already exist: the near-Earth orbit, the Moon, and the usage of space resources in general.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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