TACKLING THE SPACE DEBRIS PROBLEM: A GLOBAL COMMONS PERSPECTIVE

Daniel Lambach[(1)], Luca Wesel[(2)]

[(1)] Research Centre Normative Orders, Goethe University Frankfurt/Main, Max-Horkheimer-Strasse 2, 60629 Frankfurt/Main, Germany, Email: lambach@normativeorders.net
[(2)] German Corporation for International Cooperation (GIZ), Friedrich-Ebert-Allee 32, 53113 Bonn, Germany, Email: luca.wesel@giz.de

ABSTRACT

This paper approaches the issue of space debris as a collective action problem in a global commons environment. Based on Elinor Ostrom's research into commons management, we propose a system of polycentric governance that is no less effective and more politically feasible than the reform or creation of existing institutions like intergovernmental bodies or major treaties. Using Paul Stern's "adapted design principles" we analyze shortcomings of the current governance structure relating to space debris and derive recommendations. The aim of these is to facilitate communication among governance nodes, empower lower-level decision-making, and build trust among stakeholders.

1 INTRODUCTION

The problem of space debris has been well-known among technical experts and the space policy community for the past three to four decades. And yet, despite mounting pressures on the sustainable use of outer space, very little progress has been made in tackling this problem. Standards for space debris mitigation are insufficient, there is no space traffic management in Low Earth Orbit (LEO), and active debris removal technologies are only starting to be tested. This paper takes a political economy perspective to explain why space debris has thus far resisted attempts to solve or even substantially mitigate the problem. We argue that Elinor Ostrom's work on the co-operative governance of shared resources can be applied to space as a global commons and space debris as a problem of collective action.

We argue that current efforts to remove debris or mitigate its creation are hampered by four mutually reinforcing hurdles. First, the existing legal framework does not adequately deal with debris and does not allocate responsibility for the minimization and removal of debris objects. Second, despite improvements in space situational awareness over the past decades, information about debris objects is still incomplete and insufficiently precise. Third, costs for debris removal are still relatively high and there is no mechanism how these costs can be allocated to debris creators. Fourth, there is political resistance owing to the "dual use" nature of removal techniques and the economic advantages accruing to countries with lower mitigation standards. These hurdles are closely interdependent, creating a "wicked problem", which has not been appropriately handled by the international community.

Overcoming the current regulatory deadlock is difficult but possible, especially as the escalating severity of the problem increases pressures to cooperate. However, a centralized structure, e.g. a new international organization or treaty, is unlikely to be created. Instead, we draw on Ostrom's notion of polycentric governance, which we consider to be more viable. Polycentricity refers to a system consisting of many independent centers of decision-making that jointly produce governance outputs through cooperation and coordination. Other examples of polycentric governance at the global level include internet governance which is collectively organized as a network of lower-level governance arrangements. In contrast to centralized, public forms of governance, polycentric governance is capable of marshalling different stakeholders and can, in the right circumstances, provide more effective governance outcomes. We argue that this would also obtain in the field of space debris.

To move towards polycentric governance we offer the following recommendations: for one, create more governance nodes by empowering lower-level forums and institutions to make decisions about specific issues. For another, increase the density of linkages among nodes. And finally, create a culture of cooperation among nodes. More specifically, we have to make the current system of outer space governance less top-heavy and centered around the United Nations Committee on the Peaceful Uses of Outer Space and similar intergovernmental bodies. One avenue would be to supplement existing institutions with informal deliberative forums and networks to facilitate multistakeholder engagement, empower lower-level actors, and build trust.

2 THE SPACE DEBRIS PROBLEM

The UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) defines space debris as "all man-made

objects, including their fragments and parts, whether their owners can be identified or not, in Earth orbit or re-entering the dense layers of the atmosphere that are non-functional with no reasonable expectation of their being able to assume or resume their intended functions or any other functions for which they are or can be authorized" [1]. The nature and origin of space debris is diverse, ranging from tiny chipped paint particles to screwdrivers lost by astronauts during field missions and to uncontrollable satellites whose active mission was terminated. Following Hall, the origin of individual objects can be divided into three groups: Those that arise as an necessary byproduct of missions (e.g. rocket stages), others that are generated by accident or oversight, and objects that are the result of intentional actions such as anti-satellite weapons (ASAT) tests [2].

2.1 Scope and Impact

When quantifying debris objects, a fundamental distinction must be made between those that are large enough to be tracked and cataloged, and those that are too small for tracking. The information on the former comes primarily from the US Space Surveillance Network and similar surveillance efforts, which use powerful radar systems to permanently monitor about 28,200 objects larger than ten centimeters (as of January 2021). In addition, experts estimate that there are 900,000 smaller objects (1-10cm), 128 million tiny objects (1mm-1cm) and countless objects <1mm.[1]

The number of satellites in Low-Earth Orbit (LEO) has also increased, especially in recent years with the widespread adoption of microsatellite technology. Fig. 1 demonstrates that 2020 alone has seen almost triple the amount of payload traffic to LEO compared to previous years, which themselves had exceeded earlier periods by substantial margins. Fig. 1 starkly illustrates that satellites have become an important sector of the global economy and represent a backbone of economic globalization. For example, the terrestrial networks of communications and digital data transmission rely heavily on satellites. A loss of the satellite infrastructure, even if only temporary, would have a major impact on many sectors of everyday life.

Without a robust system of Space Traffic Management (STM) in LEO, the growing number of satellites itself generates collision risks. At the moment, satellite operators have to organize evasive maneuvers on an *ad hoc* bilateral basis – and these occur with increasing frequency. Coupled with the growing number of debris fragments, the carrying capacities of LEO are exhausted, with every further payload adding to the already elevated risk of a "Kessler syndrome" of cascading collisions [3].

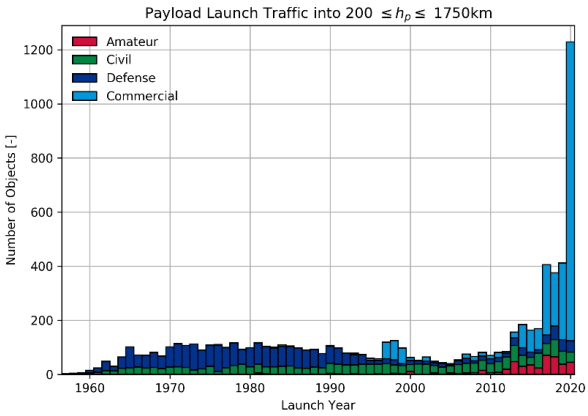

Figure 1. Payloads to LEO[2]

2.2 Tackling the Problem

There are two main strategies for attacking the space debris problem: debris mitigation and active removal. The first is a preventive measure that seeks to minimize the creation of further debris objects, primarily through regulations how space missions and payload must be designed [4]. National space agencies have begun to develop guidelines which provide frameworks for avoiding space debris [5] and in 1993 set up the Inter-Agency Space Debris Coordination Committee (IADC) to coordinate their efforts and exchange information. In 2002, the IADC published a set of guidelines that, while non-binding, were nonetheless an important milestone.

The IADC guidelines served as the basis for the work of the Scientific and Technical Subcommittee (STSC) of UN COPUOS, which was to formulate global standards for the prevention of space debris. The STSC completed its work in 2007 with the publication of the Space Debris Mitigation Guidelines, which were ratified by the UN General Assembly later that same year [6]. However, although the Mitigation Guidelines are incorporated into the mission planning of many space agencies, and some countries even go beyond the guidelines, the UN requirements are not binding and non-compliance cannot be reviewed or sanctioned. The Mitigation Guidelines' non-binding legal status has led to a multitude of individual sets of rules by states and private organizations (such as the ISO) and ambiguity within the space community [5].

While preventive measures aim to prevent the creation of new debris, active debris removal (ADR) refers to all actions taken to remove existing space debris from space [7]. Although there have been discussions about the

[1] https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

[2] Source: https://sdup.esoc.esa.int/discosweb/statistics/

ADR's potential and feasibility for decades, the development of concrete approaches has gained decisive momentum only in the last 15 years. Models indicate that five to ten major objects would need to be removed from high-risk LEO regions each year to stabilize the population and mitigate risks of the Kessler syndrome [8]. Moreover, ADR missions must be developed as soon as possible – the later they are deployed, the less useful they will be. Unfortunately, ADR technology is still in the pilot phase, with national space agencies testing a variety of prototypes in recent and upcoming missions.

In short, international measures to alleviate the space debris problem are insufficient to deal with the ever escala1ating overcrowding of LEO. Even after decades of knowing about the problem, there is no internationally binding set of rules that prescribes uniform prevention measures, nor have successful mitigation strategies been established. ADR technology is still far from being usable at scale.

2.3 Obstacles to Sustainable Management

A key barrier to sustainable LEO use is the multidisciplinary nature of the problem. Dealing with space debris is a legal, technical, economic, and political challenge. In *legal* terms, space debris is not covered by the existing framework of the "Five Treaties", which offer little guidance for mitigation and removal alike. On the *technical* side, while mitigation has seen marked improvements (e.g. through "Design for Demise" guidelines), ADR systems are still only at a prototype stage, and space surveillance systems are incapable of tracking many smaller fragments. *Economically*, there are too few incentives for satellite operators to invest in mitigation. In addition, developing ADR technology is costly and there are unresolved questions about who should bear these costs [9]. Finally, there are *political* impediments, such as fears about the dual-use capabilities of ADR technology, gridlock in international bodies such as UN COPUOS, and diverging policy preferences about mitigation standards.

In the language of public policy, this makes space debris is a "wicked problem" [10]. Wickedness principally results from three aspects of a problem: a) its complexity, b) the uncertainty relating to risks and consequences of action, and c) a divergence in viewpoints and values. The worse these aspects are, the more intractable a problem becomes. We are unlikely to ever get rid of space debris, so the only realistic goal is to aim for a sustainable management of the problem – but at what level of risk and which mechanisms are acceptable for all stakeholders? These questions have not yet been resolved.

3 THEORY: GOVERNING THE SPACE COMMONS

The wicked and multidisciplinary nature of the space debris problem does not make a resolution impossible, but it should caution us against monocausal explanations for its intractability. Instead, we argue that the problems should be approached through the theoretical lens of "commons management" which offers a holistic perspective as well as examples of sustainable resource management from other fields that might be of use.

3.1 The Space as a Global Commons

The "commons" are a concept from political economy denoting a shared resource with communal ownership. In contrast to public goods, which can be freely enjoyed by everyone, the commons can be depleted through overuse. Economic theory argues that this inevitably leads to the "tragedy of the commons" [11] wherein every actor will try to maximize their individual return at the cost of overusing the common-pool resource. Accordingly, economists typically recommend that common-pool resources can only be efficiently and sustainably managed through either their privatization and enclosure or via centralization under the authority of a state. However, empirical evidence from the "Governing the Commons" project [12] shows that while *unregulated* commons might fall prey to this tragedy, communities all over the world have found myriad ways of sustainably governing common-pool resources like fish stocks, grazing land, or water sources. Hence, Ostrom and her collaborators have argued that communal, co-operative governance represents a third way of commons management besides privatization and centralization [12, 13].

However, it is not clear how well these results can be applied to large-scale resources. The case studies of the "Governing the Commons" project focused on local communities within the framework of states, leading to questions how to "scale up" the project's findings [14, 15]. This is where the notion of "global commons", i.e. "resource domains to which all nations have legal access" [16] has emerged. Space is one example of a global commons, with others being the high seas and the seafloor, the poles, and the atmosphere.

The challenge of governing the global commons lies in their scale and their supranational nature. Their immense scale makes many well-known strategies of commons management unviable, such as the development of reputation and trust systems as well as the emergence of a shared culture of "commoning" [17]. Their supranational nature exacerbates the underlying collective action problems. In the absence of a superior political authority, states face few sanctions for not agreeing to, or not complying with a governance regime [18]. Hence, any analysis of the global commons must

pay attention to issues of power – more so than standard approaches to commons management [19].

3.2 Polycentric Governance

In her late works, Elinor Ostrom argued for systems of "polycentric governance" [13, 20], a concept that has become very influential in environmental governance [21]. In contrast to hierarchical ("monocentric") forms of governance, polycentricity refers to a network of independent nodes that can make decisions independently and coordinate among themselves to produce a joint output. Polycentric governance can bring together different stakeholders and – under the right circumstances – be very effective. This requires that governance nodes are empowered to make decisions on substantive issues within their sphere of influence (subsidiarity). Furthermore, connections between nodes need to be increased and strengthened (linkage). Finally, polycentric governance requires a culture of trust to facilitate communication, cooperation and collaboration among nodes and to improve information sharing and collective decision-making (self-organization).

If functioning properly, a polycentric system of governance offers several potential advantages over a monocentric system. First, they are better at accessing distributed knowledge among actors which enhances capabilities for innovation and learning. Second, polycentric systems are capable of mobilizing a broader variety of stakeholders and may be seen as more legitimate due to the "liquid" nature of authority [22]. Third, building on the previous points, polycentric systems may respond quicker to emergencies or changing circumstances and thereby improve capabilities for adaptation. Fourth, polycentric system are multi-scalar and can integrate and connect actors and processes from the local to the global level. Finally, a polycentric system of governance may be more politically feasible than a centralized system within a supranational context, where states are often leery of the introduction of new international agreements and organizations.

However, not every system that is decentralized is also polycentric. The literature on international environmental regimes discusses this problem in terms of "fragmentation", i.e. the emergence of a patchwork of regulations with little interaction within a regime complex [23]. Decentralized systems need to develop robust linkages among nodes and a culture of trust. Failure to do so creates key hurdles obstructing the emergence of "true" polycentric systems in global policy-making.

4 TOWARDS A POLYCENTRIC GOVERNANCE OF LOW-EARTH ORBIT

4.1 Existing Proposals

There are numerous proposals for solving or managing the space debris problem, especially from the academic community. Some international legal scholars have called for new treaties or significant modifications to existing ones [24, 25, 26], while others argue that existing treaties are sufficient but need to be interpreted or contextualized differently [27, 28]. From an economic perspective, scholars point to the unrealized potential for free market solutions and argue for the provision of incentives to the commercial sector to address the space debris problem [29, 30, 31]. Still others focus on the engineering challenges and argue that R&D is the best way of moving beyond the current impasse [4].

These are merely snapshots of a much wider debate. Our interest here is not to discuss these proposals in detail, but to make two points. First, space debris is a wicked problem and any attempt to solve it through the identification of a single "master variable" is doomed to fail. Second, while the above proposals diverge in substance, they are similar in that they envision the governance architecture of space debris in broadly the same terms as it exists today by implicitly or explicitly presupposing a high degree of international cooperation among spacefaring nations. However, it is precisely the lack of such cooperation that is a major contributing factor to the problem they identify. Lack of international cooperation is precisely the reason why the legal framework has not evolved to address the debris problems, why we lack incentives for commercial actors to invest in mitigation and ADR, and why the technical challenges thereof still have not been satisfactorily resolved. These questions are most directly addressed in contributions focusing on the political aspects, for example the "securitization" of debris [32, 33, 34]. These works agree that international cooperation is necessary for dealing with space debris but very difficult to achieve in practice.

A number of authors have come forward with proposals on how more intensive cooperation can be ensured by the international community. Fundamentally, these proposals are united by the call for multilateral, institutional solutions, such as an international forum or organization that acts as a central, regulatory body. An early contribution in this regard is by Williams [35], more recent ones are by Gupta [36] as well as Munters and Wouters [37], who see the establishment of an international organization as a promising approach. Similarly, Jakhu et al. elaborate a framework for international cooperation in ADR [38].

Although these contributions have made useful points, they do not sufficiently address the political feasibility of

their recommendations, nor do they conduct a critical analysis of existing but unsuccessful international instruments. For example, it is important to consider that a central body already exists in the form of UN COPUOS, which could theoretically take over some required functions, but does not seem to be able to do so. Furthermore, many contributions lack a theoretical grounding in the expansive literature on International Relations theory. Regarding this latter point, some authors have engaged with theories of international regimes, i.e. sets of cooperation agreements which govern issues of international concern. An early contribution in this regard came from Perek, who suggested an international regime to deal with the problem into the debate as early as 2004 [34]. More recent work drawing on international regime theory has been done by McCormick [39]. But these contributions are small in number and are often more concerned with the normative question how an international agreement should be designed rather than how the international community could actually arrive at such an agreement in the first place.

As the above review shows, there have been many academic works discussing ways to solve, manage or mitigate the space debris issue. Many of these works correctly identify the issue as a collective action problem of the sustainable use of a common-pool resource [28, 31]. However, most of them fall into the trap of classical economic thinking about the tragedy of the commons and see only two options: either the privatization and enclosure of LEO or management through a central regulatory body entrusted with the requisite authority by the international community. The latter is, at present, not a realistic option. The international political environment has changed since the 1960s and 1970s, which were a heyday for making international law and creating international institutions. Today, there is little interest among major spacefaring nations, in particular the United States, to create binding international rules. But as Ostrom and her collaborators have shown, privatization and centralization are not the only two options for managing the commons. Instead, we should explore the potential of cooperative polycentric governance.

4.2 A Polycentric Approach

Based on this critique of monocentric governance, several authors have advanced proposals for less centralized ways of governing space debris. For instance, Shackelford [40] draws on Ostrom's work to offer a polycentric structure as a solution to both the debris problem and the threat of militarization of space. In addition, Munters [41] and Tepper [42] discuss polycentricity as a solution to the space debris problem. Because these works eschew centralization and address the complexity of the problem with a complex system of different forms and levels of governance, they provide a promising approach that will be taken up in the subsequent discussion.

Polycentrism is only one component of Ostrom's theories, albeit a very important one. Importantly, it is a highly abstracted way of describing system structure, not a political blueprint. For that, Ostrom and her collaborators had developed a set of eight design principles which describe institutional properties that enable problems of collective action to be overcome in a cooperative manner [12]. The potential of applying these design principles to the sustainable use of space has been recognized most recently by Brian Weeden [43, 44]. Although his work yielded interesting results, he himself identified a critical shortcoming of his approach. The problem arose from the transferability of Ostrom's principles to outer space, since the design principles were developed from research on the self-governance of local resources and are only conditionally applicable to global commons. Similar problems were faced by Chaddha who also attempted to use Ostrom's principles to design an institutional framework in the form of an international organization [45]. Although Chaddha goes into more detail than Weeden and his collaborators, he similarly concludes that the original design principles have to be adjusted to be applicable to outer space governance.

5 DESIGN PRINCIPLES

The inapplicability of Ostrom's design principles to global commons was the starting point of the so-called "scaling up" debate which started with the (unsurprising) realization that local public goods have entirely different characteristics and basic conditions than global public goods, such as the number of people involved, their cultural diversity, or the geographic extent of the good [15]. Hence, while some lessons learned from the study of local goods may be relevant to global systems, global commons present a different set of challenges that arise primarily from their extreme size and complexity [14]. In other words, the institutional frameworks that give a small number of pastoralists the chance to use a single pasture sustainably are only conditionally suited to enable, for example, humanity to sustainably manage the global climate. This succinct observation gave rise to a debate that divided research on the sustainable use of public goods into two camps: While some commentators dismissed the utility of Ostrom's work for understanding and managing global ecological issues, an opposing camp argued that her findings could be modified to become relevant for larger-scale resources [15, 46, 47]

To move beyond the limitations of Weeden's and Chaddha's analyses, we draw on the work by Stern, who, building upon Ostrom's approach, identifies seven "adapted design principles" (ADPs) for the institutional design of global commons management [15]. We apply these seven principles to the current state of governance

regarding space debris in LEO and identify steps towards a more robust polycentric governance thereof.

ADP 1: Invest in science to understand the resource and its interactions with users and those affected by its use.

The first design principle refers to the fact that global resources and their complex interactions with users are often poorly understood. However, a comprehensive understanding of the resource is an important prerequisite for its sustainable use. In our view, this principle is adequately fulfilled within the present system. The problem of space debris and the properties of LEO are well understood so that actors have access to good knowledge about the resource. Many countries have also increased investments in space science in recent years, although additional funding would still be useful.

ADP 2: Establish independent monitoring of the resource and its use that is accountable to the range of interested and affected parties.

A resource that cannot be monitored cannot be managed. But effective monitoring alone is insufficient if it is not independent and accountable to all stakeholders. This is the domain of space situational awareness (SSA) which Weeden defines as "information about the space environment and activities in space that can be used to operate safely and efficiently […] and understand the evolution of the space environment" [48]. There are a multitude of parallel SSA systems run by the United States, Russia, the European Union, China, India and other spacefaring nations [45, 48]. But while the quality of data has improved substantially over the past decades, there are important limitations. Many countries do not share the data they are collecting, and those that do (e.g. the United States), keep parts of the data classified. Hence, we have a multitude of different SSA programs that run parallel to each other and overlap in parts, but are not joined into a coordinated or cooperative approach. Instead, what emerges is a patchwork of national databases which obstructs attempts of a more collaborative and holistic monitoring.

This has spurred the commercial sector into action, since the lack of reliable data is putting space assets at risk. In a comprehensive analysis of recent SSA developments and trends, Lal et al. conclude that private and commercial actors are becoming more relevant in the field [49]. While private and commercial SSA undoubtedly has the potential to improve monitoring of LEO, the development of additional databases will not alleviate the underlying problem of the fragmented nature of global SSA. This fact has also been recognized by private actors. In 2010, three of the largest satellite communications companies launched the Space Data Association (SDA), an open, non-profit platform in which a large number of private and government satellite operators are now organized to share information and data amongst the members. Although the SDA is a promising concept, it is far from being a global network.

In short, technological progress and additional investment have significantly improved the potential of SSA in recent years and offer, at least in theory, the chance to monitor space and its use more comprehensively than was ever possible before [49, 50]. However, as Weeden argues, the problem lies not in the quality or quantity of data but the lack of interoperability between SSA systems [48]. To sum up: the monitoring of space and space activities is by no means global, but is fragmented and only selectively cooperative. There are a variety of different SSA systems, databases, and other information sources maintained by both new and established actors. Information sharing is insufficient, and monitors are only accountable to their funders.

Our recommendations are fourfold: 1) develop shared standards for data collection and implement application programming interfaces to improve interoperability of data and systems, 2) encourage information-sharing among SSA systems both at the political level (through high-level agreements) and the working level (by strengthening horizontal networks among experts), 3) expand public-private collaboration through a standing forum or working group that develops norms and standards (similar to the annual AMOS Dialogue organized by the Secure World Foundation), and 4) develop procedures for independent verification of monitoring systems (e.g. through expert review, possibly under the auspices of a competent international body like UN COPUOS).

ADP 3: Ensure meaningful participation of the parties in framing questions for analysis, defining the import of scientific results, and developing rules.

The assumption underlying this ADP is that decisions involving as many stakeholders as possible have greater legitimacy and that resulting rules enjoy greater acceptance [20]. Stern's use of the word "meaningful" is somewhat vague and there are questions who should be considered as a "party", but whichever definitions one uses, it becomes very clear that the current system of LEO governance fails to achieve this criterion by a considerable margin. Outer space governance is institutionally top-heavy – substantial decisions can only be made through intergovernmental deliberations in official forums (such as UN COPUOS) or through unofficial channels (such as the ongoing discussions of the proposed Artemis Accords). On the one hand, this creates inequities among states, with the major "space powers" usually getting their way; on the other, it excludes other actors, such as commercial actors, civil society and the scientific community from meaningful participation. This is not to say that these actors do not matter. In fact, they do play an important role when it comes to more technical questions where their input and

advice are valued. However, final decision-making authority rests with state governments.

To ensure that this ADP is fulfilled would require reforms that go far beyond the space debris issue, encompassing the whole of outer space governance. We have already expressed our scepticism about the feasibility of proposals arguing for a revision of the Five Treaties or the UN system of space governance. Hence, our recommendations here are smaller and more incremental, even if they do not reach the level required to fulfil the ADP: 1) set in motion a consultative process including all stakeholders to generate consensus about the shape of the space debris problem, likely scenarios and policy options, 2) support the emergence of and strengthen "watchdog" non-governmental organizations to hold governments and space agencies accountable, 3) encourage the growth of a transnational public sphere among business, science and civil society to provide a counterweight to the state-dominated system of outer space governance.

ADP 4: Integrate scientific analysis with broad-based deliberation.

With this ADP, Stern refers to the need to bring scientific knowledge into decision-making. This necessity arises, among other things, from the fact that imperfect knowledge leads to different interpretations depending on the interests and values of the actors. In our view, this is already achieved – actors in the space debris community generally base their assessments on the best available science. Some aspects could still be improved, such as the level of funding for space science (ADP 1), information-sharing among practitioners (ADP 2), or the breadth and inclusiveness of deliberation (ADP 3) but we are confident that future discussions will continue to be based on sound scientific analysis.

ADP 5: Higher-level actors should facilitate participation of lower-level actors.

Similar to ADP 3, this ADP is based on the assumption that rules whose creation involves a broad spectrum of actors have greater legitimacy and are more readily accepted. Actors at higher levels who are entrusted with rule-making should therefore enable the participation of actors at formally lower levels. In the environment of space governance, this aspect is of particular interest, due to the entrance of a large number of new actors in recent years, especially from the private sector.[3] Yet again similar to ADP 3, we find that the current architecture of outer space governance obstructs, rather than facilitates participation of lower-level actors.

The core institutions of outer space governance in the UN system are UN COPUOS and, for certain security issues, the UN Conference on Disarmament (UNCD). Non-governmental memberships are not provided for in COPUOS. In addition to official members, there are a number of permanent observers, including other intergovernmental organizations, NGOs, and scientific institutes and associations, but these are excluded from formal decision-making processes. Commercial actors are not eligible for observer status and Johnson-Freese and Weeden argue that they have in the past been actively shut out from deliberations [43]. UNCD is, if anything, even more restrictive than UN COPUOS, not even offering observer status to non-members. There is also the International Telecommunications Union (ITU), a specialized UN agency which is responsible for the allocation of the radio frequency spectrum and thus controls which and how many satellites can be active in certain areas of space in order to avoid physical and electromagnetic interference. In addition to its current 193 member states, the ITU includes over 900 members from the private sector, academia, and other international organizations. Commercial stakeholders can participate in discussions and are integrated into rule-making, making the ITU significantly more inclusive than COPUOS and UNCD [43].

Overall, space governance does not meet the requirement for participation of private actors arising from ADP 5. In particular, the state-centeredness and complete exclusion of private actors at UN COPUOS, by far the most important body of formal governance, is a major impediment. Although the ITU does better at integrating commercial actors, its competence is limited to the distribution and control of radio frequencies. The rule-making processes of formal space governance are thus decidedly state-centric, and there is no question of far-reaching vertical integration. This finding is particularly problematic given the increasing relevance of private actors in the practice of space and their responsibility for a significant portion of space activities today [4].

But again similar to ADP 3, meeting the standard for ADP 5 would require far-reaching reforms of governance structures which are unlikely to be achieved. Therefore, we offer the following limited recommendations: 1) reform UN COPUOS to allow for observer status for commercial actors, either individually or through industry associations, and revise internal procedures to be as inclusive as possible within the UN system, 2) set up a deliberative forum (similar to ADP 2 and possibly in conjunction with the forum proposed there) bringing together representatives of governments, space agencies, the business sector, academia and civil society. This forum would have no formal authority but could issue

[3] This could also be discussed in terms of the inequities among established and newly spacefaring nations that is captured in Paikowsky's notion of a "Space Club" [51] or the participation of civil society organizations.

recommendations, develop norms and standards and give a voice to lower-level actors.

ADP 6: Engage and connect a variety of institutional forms from local to global in developing rules, monitoring, and sanctioning.

This ADP directly engages with the multi-level nature of polycentric governance. The intent here is to allow for decentralized action that is nonetheless connected into a wider system. We find evidence of such a variety of institutional forms for the governance of space debris [40, 41, 42]. Besides the high-level political institutions we discussed above, there are many other forums, networks and specialized organizations working at the international level. For example, the IADC was founded in 1993 to provide a forum for national space agencies to coordinate efforts to understand and mitigate the space debris problem. The International Organization for Standardization (ISO) developed Standard 24113 (Space Systems-Space Debris Mitigation) in 2010. The International Astronautical Federation (IAF) is an international multistakeholder organization that engages in knowledge sharing, advocacy and facilitating dialogue. The International Academy of Astronautics (IAA) represents the scientific community and has been influential through the publication of targeted reports representing the best available knowledge on specific topics of current concern. On the national level, we can also find national governments, space agencies and the space industry engaged in various constellations of policy-making.

However, while there may be a multiplicity of institutions, they are insufficiently connected. The IADC, the IAF, the IAA and other networks have been very important in the development of shared assessments and standards but their impact has been limited by the top-heavy and monocentric design of outer space governance. The same holds true for national-level institutions which space law mainly treats as the implementation channel through which global agreements are transmitted. Hence, our recommendations are aimed at decentralizing the system and making interconnections more numerous and more dense: 1) encourage forms of private governance, e.g. in the coordination of space assets, 2) empower lower-level decision making through national space laws that define appropriate roles for non-state actors, 3) reform the IADC to facilitate participation by non-state actors or create a parallel forum for public-private deliberation, and 4) leverage existing norms of cooperation and collaboration in space activities to argue for more cooperative, cross-cutting ways of decision-making.

ADP 7: Plan for institutional adaptation and change.

This principle is of particular relevance here, since human use of space is undergoing a fundamental transformation. This concerns not only the number of actors, the rapidly increasing intensity of space activity, or technological progress, but also the growing number of purposes for which space is used. While spaceflight initially served mainly civilian research and military purposes, nowadays economic aspects play an increasingly important role. The market for telecommunications satellites is evolving rapidly and new business opportunities in space tourism or asteroid mining are expected to become commercially viable soon. At the same time, risks of overuse, worsened by the growing number of space objects, are becoming more apparent. All this shows the fundamental changes that space and its use are undergoing and underlines the importance of adaptable governance structures.

Unfortunately, we see little evidence of adaptability in the current system of governance. UN COPUOS is frequently described as gridlocked [42], the same applies to UNCD, and even the ITU has done little to adapt its procedures to a changing environment. Too many institutions represent the geopolitical bargains of the 1950s and 1960s, when the majority of them were created. The last major international treaty, the Moon Agreement, was signed in 1979 (and languishes due to a lack of ratifications). The lack of adaptability of space governance is particularly serious since space debris, undoubtedly one of the greatest challenges for the future of LEO usage, is not addressed in any of the international treaties. The lack of a uniform definition of space debris and a legal clarification about ownership and liability of debris objects are major lacunae in this regard.

The main reason given for the inability to establish new binding agreements is the consensus principle under which UN COPUOS operates, which stymies most political initiatives [40, 43]. Although it is difficult to imagine that UN COPUOS will adopt new binding regulations or transform itself into a more adaptable and inclusive institution, there seems to be at least some willingness to address relevant issues: in 2010, the Working Group on the Long-term Sustainability of Outer Space Activities (LTSOSA) was established to address challenges around the sustainable use of outer space. Based on the working group's findings, COPUOS adopted 12 guidelines for the sustainable use of outer space in 2016, supplemented by an additional nine guidelines in 2018. Although the guidelines are voluntary, non-binding recommendations and by no means represent an institutional adaptation, they are at least a step in the right direction.

But by and large, the UN system is badly suited for adaptation in a rapidly evolving environment, a point that other authors have also made with reference to outer space law [24, 25, 52]. Hence, it seems more constructive to ask how the institutional framework of the UN could be complemented with other institutions to make the overall system more adaptable. Much as with our recommendations for ADPs 3, 5 and 6, we would argue

for a more polycentric approach that empowers lower-level actors and creates additional avenues for deliberation. Such a more decentralized and informal system would also be significantly more adaptable. If any new institutions are created in the process, they should have built-in review requirements so that their statutes can be adapted, preferably through qualified majorities rather than by unanimous consent.

6 CONCLUSION

In this paper, we have discussed the problem of space debris from a commons management perspective. Using insights from the literature on global commons, we have argued that space debris is not just a technical, economic or legal problem but that there is also a political dimension that has obstructed attempts to sustainably manage LEO. In our view, these problems are interconnected and therefore require a holistic approach. To this end, we have used the notion of polycentricity and the adapted design principles for commons management by Stern to analyze the limitations of the current system of space debris governance. We also offer policy recommendations how the system could become more polycentric while being mindful of the difficulties of meaningful reform. Our analysis shows that the current system of outer space governance, especially as it pertains to LEO and space debris, is badly suited to a rapidly worsening situation. Institutions are too centralized and top-heavy, lower-level actors are insufficiently integrated, and linkages between institutions and actors need to be strengthened.

REFERENCES

1. UN Committee on the Peaceful Uses of Outer Space (1999). *Technical Report on Space Debris. Text of the Report adopted by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space.* New York: United Nations, p. 2.
2. Hall L. (2014). The History of Space Debris. In: *Space Traffic Management Conference*, 6 November 2014, https://commons.erau.edu/stm/2014/thursday/19/, pp. 2-5.
3. Kessler D.J. & Cour-Palais B.G. (1978). Collision frequency of artificial satellites: The creation of a debris belt. *Journal of Geophysical Research: Space Physics*. **83**(A6), 2637-46.
4. Pelton J.N. (2015). *New solutions for the space debris problem*, Springer, Cham.
5. Rajapaksa C.R. & Wijerathna J.K. (2017). Adaptation to Space Debris Mitigation Guidelines and Space Law. *Astropolitics*. **15**(1), 65-76, pp. 66-8.
6. Alby F. (2015). The Issue of Space Debris. In: *Handbook of Space Security: Policies, Applications and Programs*. (Eds. K.-U. Schrogl, P.L. Hays, J. Robinson, D. Moura & C. Giannopapa). Springer, New York, pp. 679-97, p. 692.
7. Chen S. (2011). The Space Debris Problem. *Asian Perspective*. **35**(4), 537-58.
8. Liou J.-C. (2011). An Update on LEO Environment Remediation with Active Debris Removal. *Orbital Debris Quarterly News*. **15**(2), 4-6.
9. Ansdell M. (2010). Active space debris removal: Needs, implications, and recommendations for today's geopolitical environment. *Journal of Public and International Affairs*. **21**, 7–22.
10. Head B.W. (2008). Wicked Problems in Public Policy. *Public Policy*. **3**(2), 101-18.
11. Hardin G. (1968). The Tragedy of the Commons. *Science*. **162**(3859), 1243-8.
12. Ostrom E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge.
13. Ostrom E. (2010). Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*. **20**(4), 550-7.
14. Ostrom E., Burger J., Field C.B., Norgaard R.B. & Policansky D. (1999). Revisiting the Commons: Local Lessons, Global Challenges. *Science*. **284**(5412), 278-82.
15. Stern P.C. (2011). Design principles for global commons: Natural resources and emerging technologies. *International Journal of the Commons*. **5**(2), 213-32.
16. Buck S.J. (1998). *The Global Commons: An Introduction*, Island Press, Washington D.C., p. 6.
17. Brando N., Boonen C., Cogolati S., Hagen R., Vanstappen N. & Wouters J. (2019). Governing as commons or as global public goods: Two tales of power. *International Journal of the Commons*. **13**(1), 553-77.
18. Vogler J. (1995). *The Global Commons: A Regime Analysis*, Wiley, Chichester.
19. Orazgaliyev S. & Araral E. (2019). Conflict and Cooperation in the Global Commons: Theory and Evidence from the Caspian Sea. *International Journal of the Commons*. **13**(2), 962-76.
20. Ostrom E. (2010). Beyond Markets and States: Polycentric Governance of Complex Economic Systems. *The American Economic Review*. **100**(3), 641-72.
21. Dorsch M.J. & Flachsland C. (2017). A Polycentric Approach to Global Climate Governance. *Global Environmental Politics*. **17**(2), 45-64.
22. Krisch N. (2017). Liquid authority in global governance. *International Theory*. **9**(2), 237-60.
23. Biermann F., Pattberg P., van Asselt H. & Zelli F. (2009). The Fragmentation of Global Governance Architectures: A Framework for Analysis. *Global Enrivonmental Politics*. **9**(4), 14-40.
24. Pusey N. (2010). The Case for Preserving Nothing: The Need for a Global Response to the Space Debris Problem. *Colorado Journal of International*

Environmental Law and Policy. **21**, 425-50.
25. Imburgia J.S. (2011). Space Debris and Its Threat to National Security: A Proposal for a Binding International Agreement to Clean Up the Junk. *Vanderbilt Journal of Transnational Law*. **44**, 589.
26. Rihl D.P. (2019). Cleaning up the Mess: Incentivizing the Salvage of Orbital Debris. *George Mason Journal of International Commercial Law* **10**(2), 68-92.
27. Punnakanta L. (2012). Space Torts: Applying Nuisance and Negligence to Orbital Debris. *Southern California Law Review*. **86**, 163–92.
28. Muñoz-Patchen C. (2018). Regulating the Space Commons: Treating Space Debris as Abandoned Property in Violation of the Outer Space Treaty. *Chicago Journal of International Law*. **19**, 233–59.
29. Roberts L.D. (1992). Addressing the Problem of Orbital Space Debris: Combining International Regulatory and Liability Regimes. *Boston College International and Comparative Law Review*. **15**(1), 51-73.
30. Salter A.W. (2016). Space Debris: A Law and Economics Analysis of the Orbital Commons. *Stanford Technology Law Review*. **19**, 221.
31. Taylor J.B. (2011). Tragedy of the Space Commons: A Market Mechanism Solution to the Space Debris Problem. *Columbia Journal of Transnational Law*. **50**, 253-79.
32. Gallagher N. (2010). Space Governance and International Cooperation. *Astropolitics*. **8**(2-3), 256-79.
33. Bowen B.E. (2014). Cascading Crises: Orbital Debris and the Widening of Space Security. *Astropolitics*. **12**(1), 46-68.
34. Perek L. (2004). Space Debris Mitigation and Prevention: How to Build a Stronger International Regime. *Astropolitics*. **2**(2), 215-26.
35. Williams C. (1995). Space: The Cluttered Frontier. *Journal of Air Law and Commerce*. **60**(4), 1139-89.
36. Gupta V. (2016). Critique of the International Law on Protection of the Outer Space Environment. *Astropolitics*. **14**(1), 20-43.
37. Munters W. & Wouters J. (2017). *The Road Not Yet Taken for Defusing Conflicts in Active Debris Removal: A Multilateral Organization*. Leuven: Leuven Centre for Global Governance Studies.
38. Jakhu R.S., Nyampong Y.O.M. & Sgobba T. (2017). Regulatory framework and organization for space debris removal and on orbit servicing of satellites. *Journal of Space Safety Engineering*. **4**(3), 129-37.
39. McCormick P.K. (2013). Space debris: Conjunction opportunities and opportunities for international cooperation. *Science and Public Policy*. **40**(6), 801-13.
40. Shackelford S.J. (2014). Governing the Final Frontier: A Polycentric Approach to Managing Space Weaponization and Debris. *American Business Law Journal*. **51**(2), 429-513.
41. Munters W. (2016). *Space Debris: Towards an International Organization?* Leuven: Leuven Centre for Global Governance Studies.
42. Tepper E. (2019). *Polycentric Governance in Global Affairs: The Case of Space Governance*. http://dx.doi.org/10.2139/ssrn.3400217.
43. Johnson-Freese J. & Weeden B. (2012). Application of Ostrom's Principles for Sustainable Governance of Common-Pool Resources to Near-Earth Orbit. *Global Policy*. **3**(1), 72-81.
44. Weeden B.C. & Chow T. (2012). Taking a common-pool resources approach to space sustainability: A framework and potential policies. *Space Policy*. **28**(3), 166-72.
45. Chaddha S. (2013). *Elinor Ostrom Goes to Outer Space - An Association of Space Appropriators*. https://dx.doi.org/10.2139/ssrn.2293581.
46. Dietz T., Ostrom E. & Stern P.C. (2003). The Struggle to Govern the Commons. *Science*. **302**(5652), 1907.
47. McGinnis M.D. & Ostrom E. (2008). Will Lessons from Small-Scale Social Dilemmas Scale Up? In: *New Issues and Paradigms in Research on Social Dilemmas*. (Eds. A. Biel, D. Eek, T. Gärling & M. Gustafsson). Springer, Boston, pp. 189-211.
48. Weeden B. (2015). SSA Concepts Worldwide. In: *Handbook of Space Security: Policies, Applications and Programs*. (Eds. K.-U. Schrogl, P.L. Hays, J. Robinson, D. Moura & C. Giannopapa). Springer, New York, pp. 985-98, p. 986.
49. Lal B., Balakrishnan A., Caldwell B.M., Buenconsejo R.S. & Carioscia S.A. (2018). *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)*. Alexandria, VA: Institute for Defence Analyses.
50. Pelton J.N. (2019). A path forward to better space security: Finding new solutions to space debris, space situational awareness and space traffic management. *Journal of Space Safety Engineering*. **6**(2), 92-100.
51. Paikowsky D. (2017). *The Power of the Space Club*, Cambridge University Press, Cambridge.
52. Button M. (2013). Cleaning Up Space: The Madrid Protocol to the Antarctic Treaty as a Model for Regulating Orbital Debris. *William & Mary Environmental Law and Policy Review*. **37**(2), 539-68.