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REGULATING SPACE DEBRIS: LEGAL CHALLENGES AND THE PURSUIT OF SUSTAINABILITY

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ABSTRACT

The launch of Sputnik-1, the first artificial satellite, on 4 October 1957, signified an important turning point in the history of human civilisation. It triggered significant political, military, technological, and scientific advancements and heralded the dawn of the **Space Age.** This milestone also laid the foundation for the **Space Race** between the United States and the Soviet Union, as both nations competed for dominance in space exploration. Over time, the traditional space race paradigm evolved with new players, including private spaceflight entities, giving rise to a modern **"New Space Race"** characterized by diverse participants and broader objectives. These activities accelerate space exploration and the launching of more satellites, which generates the problem of space debris, causing significant threats to the sustainability of outer space. The risk of collision of debris in earth orbit has been escalating catastrophically, eventually leading to a chain reaction of breaking it, referred to as Kessler Syndrome. The development of ASAT technology and China's test on the FY-1C weather satellite (COSPAR 1999-025A) substantially increased the debris risk. This research is designed to analyze space debris issues regarding the existing international legal regime and its efficacy in regulating the challenges of space debris.

Keywords: Outer Space, Debris, Sustainability, Low Earth Orbit (LEO), Active Debris Removal (ADR), International Law etc.

1 BACKGROUND

Space debris, also known as space junk, space pollution, space waste, space trash, space garbage, or cosmic debris, refers to the collection of defunct human-made objects orbiting Earth (ESA, 2020). The intensification of this debris in outer space is causing one of the most crucial challenges for the sustainability of outer space and ongoing exploration of outer space. The current international framework for regulating

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activities in outer space fails to address it effectively (Joseph & al, 2021) (Akers, 2012). Approximately 10,019 functional satellites, two-thirds (6,646) of which are attributed to Starlink, the satellite constellation operated by SpaceX. These satellites' dominant number (9,254) is in low-Earth orbits, mostly around altitudes ranging from 400 to 1,200 km from the Earth (Faleti, 2024). It is important to note that each satellite launched into orbit is accompanied by one or more non-functional objects, referred to as space debris (Gregersen, 2024). According to the US Space Surveillance Network, more than 15000 pieces of space debris are larger than 10 cm (4 inches) across. Approximately 200,000 fragments between 1 and 10 cm (0.4 and 4 inches) across, and potentially millions of pieces smaller than 1 cm are regularly tracked in Earth's orbit (Gregersen, 2024). The minimal average quantity of debris per cubic km accumulates densely in Earth's orbit. As a result, it constitutes a serious threat to the functional satellite and falling debris into the earth also poses serious threats to life, property, and the environment, especially in densely populated regions. However, in late 1970, two renowned NASA scientists, Burt Cour-Palais and Donald Kessler, closely observed the debris issue and propounded a scientific theory on the multiplication of space debris, later known as the "Kessler syndrome" (Wall, 2022). They have observed that the risk of satellite collisions escalates with the growing deployments of satellites into orbit. Each collision would significantly affect the orbital environment. The *"Satellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the Earth,"* the duo wrote. *"The debris flux in such an Earth-orbiting belt could exceed the natural meteoroid flux, affecting future spacecraft designs"* (Wall, 2022). Their hypothesis is anticipating that at a certain point, the growth of the artificial debris will reach a critical threshold, increasing at a rate beyond that rate of removal would naturally decay out of orbit and enter the Earth's atmosphere. Their approach to debris also demonstrates that substantial pieces of space debris may collide with smaller junk, resulting in hundreds or thousands of new small debris pieces that could impact further massive pieces. The "collisional cascading" phenomenon could exponentially augment the quantity of space debris, substantially elevating the hazards and expenses associated with space activities. The precise tipping point for the onset of the collisional cascade is debatable. The research and simulations conducted by NASA and the ESA indicate that the proliferation of space debris will intensify, primarily due to collisions among the debris (Liou & Nicholas L. , 2009). The Kessler Syndrome illustrates a cascade of

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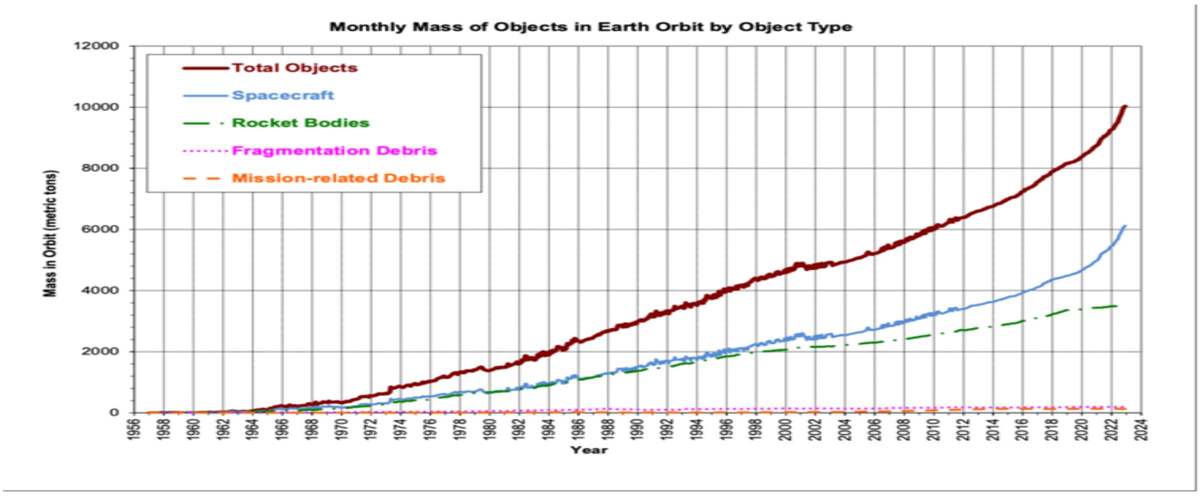
orbital debris that could hinder humanity's future space aspirations and activities. Moreover, the issue of debris further worsened On 11 January 2007, when China conducted a ground-based missile test, destroying the Fengyun-1C satellite. This weather satellite has been in orbit at an altitude of over 500 miles since 1999 (Weeden, 2024). The destruction of Fengyun-1C generated a substantial amount of debris, creating an estimated 3,000 pieces (David, 2024) (Fleck, 2022). China is not the first state to conduct the ASAT test, US was the first state to conduct the ASAT test back in the 1950s, and according to Data Center Dynamics, it has since conducted at least three ASAT debris-creating tests: two in the mid-1980s and one in 2008 (Fleck, 2022). Hence, a coherent legal regime is required to regulate activities in outer space, and the current regime is not effective to regulate activities in outer space (Fleck, 2024).

Figure: 1



lonthly Mass of Objects in Earth Orbit by Object Type as of 03 February 2023. This chart displays the mass of all objects in Earth orbit officially cataloged by the U.S. pace Surveillance Network.

Source: National Aeronautics and Space Administration
https://ntrs.nasa.gov/api/citations/20230003009/downloads/ODQN%2027-1_final.pdf

Figure: 1.2

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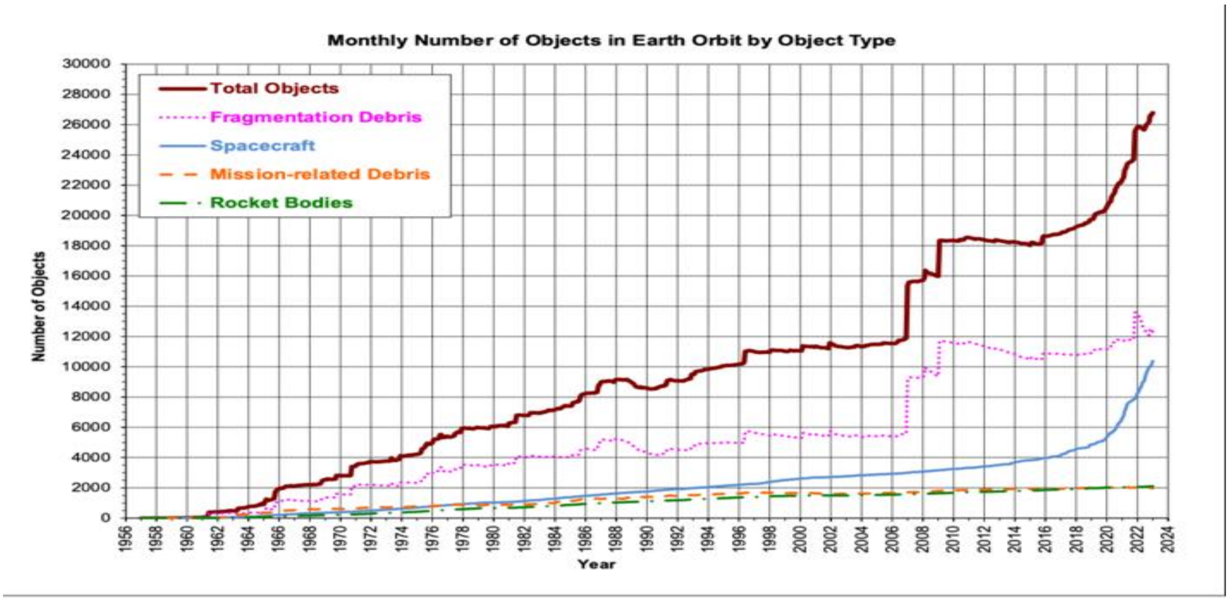

onthly Number of Cataloged Objects in Earth Orbit by Object Type as of 03 February 2023. This chart displays a summary of all objects in Earth orbit officially taloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related bris" includes all objects dispensed, separated, or released as part of the planned mission

Source: National Aeronautics and Space Administration

https://ntrs.nasa.gov/api/citations/20230003009/downloads/ODQN%2027-1_final.pdf

2 CONCEPT OF SPACE DEBRIS

The term debris is derived from the French word "Debrister" which means breaking down (Mani & et al, 2016). Debris has a wide connotation due to its origin, ranging from little paint particles that have been chipped to screwdrivers that astronauts misplaced while on field missions, and there are uncontrolled satellites whose functions cease to exist. It can be characterised as non-functional and artificial, situated in or around Earth's orbit. Space trash refers to non-functional, human-made items in or around Earth's orbit. It also includes non-operational satellites, expended rocket stages, debris from space collisions, and minute particles resulting from the disintegration or erosion of bigger entities. It poses substantial threats to all non-operational satellites and space vehicles, including The International Space Station (ISS), due to its potential for collisions that could generate additional debris, thereby exacerbating space debris formation through the Kessler Syndrome (Kelvey, 2024). Debris can be classified into four categories (i) inactive payloads (accounting for 20 % of trackable debris population, (ii) Operational debris (accounting for 26%, (iii) fragmentation debris (accounting for 49% and (iv) microparticulate matter (Mani & et al, 2016). Further, Space agencies and enterprises generate these sorts of debris

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by abandoning launch vehicles or obsolete satellites in orbit and constructing spacecraft with components that may detach; debris can also result from astronauts inadvertently dropping objects during extravehicular activities (UNGA, 2008). There is a possibility that more debris particles could cause collisions with existing objects as space grows more congested (Muñoz-Patchen, 2018). The most prevalent kind of trackable debris is "fragmentation debris," which comprises microscopic matter fragments resulting from collisions between space objects or accidental explosions. This type of debris accounts for forty-nine per cent of all trackable debris (Muñoz-Patchen, 2018).

2.1 DEFINITIONS OF SPACE DEBRIS

There is no universally accepted definition of space debris, but different agencies have tried to define it. In common parlance, debris generally comprises decommissioned space objects, including rocket stages, separation devices, shrouds, clamps, and various fragments, encompassing particles that persist following the breakup of a space object (Qizhi, 1988). Qarl Q. Christol proposes that debris comprises tangible, physical properties that may be observed, handled, weighed, and processed in factories or studied in laboratories. In 1982, the Report of the Second UN Conference on the Exploration and Peaceful Uses of Outer Space embodied that space debris comprises various items, such as expended rocket motors, nuts and bolts, and satellites that have lost their ability to function (UN, 1982). The UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) also defines debris as the most acceptable, such as "all man-made objects, including their fragments and parts, whether their owners can be identified or not, on Earth orbit or re-entering the dense layers of the atmosphere" (UNGA, 1998). The Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space provided that "Space Debris" is "all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional (UNFOSA, 1982). The definition provided by the ESA also resembles the previous definition, which stated that "all non-functional, man-made objects, including fragments and components, in Earth orbit or re-entering the Earth's atmosphere." Artificial space debris predominates over the natural meteoroid environment, with the exception of particles approximately one millimeter in size" (ESA).

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3 THE PROBLEM OF SPACE DEBRIS

Space debris comprises defunct satellites or rockets' components employed to launch them into orbit. The objects are predominantly located in two distinct regions of space: low-Earth orbit (LEO) and geostationary orbit (GEO). It poses serious threats to functional satellites and astronauts in outer space and also may cause life and property damage while entering the earth. The debris in orbit approximately travels at a speed of up to 17,500 miles per hour (Munoz-Patchen, 2018). With this rate, there is the potential for even very small bits of debris to inflict significant damage, which poses a threat to a spacecraft and can result in costly damage (Joseph Kurt, 2015). When debris with a diameter of 10 centimeters or more collides with a functional satellite, there is a high probability that the satellite will be completely destroyed (Joseph Kurt, 2015). Large, non-functional objects that remain in orbit pose a risk of collision because they have the potential to generate enormous quantities of space debris and consume orbit space that could otherwise be put to better use (Joseph Kurt, 2015). Furthermore, there are many instances in which satellites have been destroyed due to debris in space that human activity in space. Another factor contributing to the unfavorable influence of space debris on astronomical observations is the accumulation of debris through space. Concerns have been raised over the potential of astronomical satellites, such as the Hubble Space Telescope, to be impacted by light-reflected space trash. This debris can potentially cause damage or degradation to the detectors included within the telescope's spectrograph (Mani & et al, 2016). While mitigating excessive debris is a prevalent difficulty for all countries, debris removal may remain a contentious political issue. Active debris removal provides a dual-use technology. The capacity to alter the course of debris suggests the capability to manipulate active satellites as well, rendering any debris remediation technique a possible space weapon (Picard, 2024).

Table:1Satellite Incidents Table

No	Satellite ID	Name	Year	Mass (kg)	Speed (m/s)	Pieces (generated)	Debris	Incident Type
	1999-025A	Fengyun-1C	2007	865	845	3532	2739	Anti-satellite (ASAT) test
3	1993-036A	Cosmos 2251	2009	800	775	1715	1021	Accidental collision (with Iridium 33)

5	1997-051C	Iridium 33	2009	780	775	657	300	Accidental collision (with Cosmos 2251)
7	2006-026A	Cosmos 2421	2008	420	400	509	0	Unknown
9	1981-056A	Cosmos 1275	1983	1015	960	479	418	Accidental explosion

Source: National Aeronautics and Space Administration
https://ntrs.nasa.gov/api/citations/20230003009/downloads/ODQN%2027-1_final.pdf

3.1 SPACE DEBRIS: THREAT TO LIVES ON EARTH

Space debris, often perceived as a remote hazard confined to outer space, is emerging as a safety concern on Earth. In 1961, Cuban Prime Minister Fidel Castro claimed that a re-entering fragment from a defunct American satellite had resulted in the death of a Cuban cow. A medium-sized metallic piece of an American spacecraft descended upon a traffic intersection in Manitowa, Wisconsin, in 1962. In early 1970, a German ship in the Atlantic Ocean was struck by a part of the Saturn-V rocket utilized in the US Apollo 9 mission to facilitate a lunar landing (Mani & et al, 2016) (Forden, 2007). The initial instance of fatality or injury resulting from the collision with descending space debris was documented in China in early 1995 (OSTP, 1995). On January 26, as India celebrated its Republic Day, the Chinese Long March-1 vehicle, with Apstar-2 communications satellites, collapsed mid-flight, resulting in the descent of rocket stages that caused the demise of a couple and injuries to numerous others. Moreover, space activities are being held accountable for atmospheric contamination. Environmentalists have long asserted that the exhaust from the American space shuttle contributes to ozone depletion (Mani & et al, 2016) (Forden, 2007). The risks related to space exploration captured public attention during the unplanned reentry of NASA's Skylab in July 1979. Fortunately, the 77-ton Skylab met its demise in the ocean off the Australian coast. In the first quarter of the previous year, the United States successfully de-orbited its partially impaired defence satellite, which had raised concerns about potential catastrophic impacts on Earth landing (Mani & et al, 2016) (Uri, 2024).

Table:2 Timeline of Space Debris Incidents Impacting Earth

Year	Incident	Impact/Details
1969	Japanese ship struck	Five sailors injured by debris from a suspected Soviet

	by debris	spacecraft.
1978	Kosmos 954 reentry	Radioactive debris scattered over Canada.
1979	Skylab reentry	Debris fell in Australia; NASA fined $400 for littering.
1987	Kosmos 1890 debris	Metal debris landed between homes in California; no damage.
1997	Woman hit by Delta II rocket debris	No injury reported; incident occurred in Oklahoma.
2003	Columbia disaster	Debris across Texas and Louisiana caused property damage and contamination risks.
2020	Long March-5B reentry	Rocket core crashed in Côte d'Ivoire, damaging property.
2022	Long March 3B debris in India	Debris killed livestock and injured others; metal fragments found in Maharashtra and Gujarat.
2024	Dragon spacecraft debris in U.S.	Struck homes in Florida and North Carolina, causing property damage.

Source: https://en.wikipedia.org/wiki/List_of_space_debris_fall_incidents

4 SPACE DEBRIS AND INTERNATIONAL LAW

There are five Magna Carta treaties, known as Space treaties, and five United Nations resolutions intended to regulate the activities in outer space. The Outer Space Treaty (1967), The Rescue Agreement (1968), The Liability Convention (1972), The Registration Convention (1976) and The Moon Agreement (1984). Due to the failure to adequately resolve the debris issues, these treaties are considered obsolete (Brian Beck, 2009) (Singh, 2014) without imposing the responsibility on states to remove them (Ames D. Rendleman, 2010). The Outer Space Treaty (OST) is a cornerstone piece of legislation on outer space. It specifies that space exploration is accessible to all states and promotes the peaceful utilisation of outer space. The convention does not explicitly mention space debris, but it mandates that nations refrain from causing harmful contamination of space and celestial bodies. The "no harmful interference" phrase has been included in Art.7 states that the *“State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies.”* (OST, 1967). Further, these treaties also impose no duty on spacefaring nations to internalise the externalities of their space debris, resulting in excessive debris accumulation. As a result of it, other states are not obligated to intervene and may prefer to avert provoking an international controversy by displacing another nation's debris (James D. Rendleman, 2010). The treaties instituted stringent property rights for "space objects" and their components but did not define "space

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debris," which remained ambiguous until the formulation of the nonbinding Debris Mitigation Guidelines in 2007, resulting in scholarly uncertainty regarding the ownership of space debris as a component of space objects (Li, 2015). Moreover, no clear and absolute prohibition exists against creating space debris by one's actions, nor is there a requirement to remove it once it has been produced. The international community has failed to address debris issues adequately.

4.1 LACK OF A CLEAR LEGAL DEFINITION

The fundamental distinction between space debris and space objects also poses significant challenges within the framework of international law. These issues generally stem from uncertainties in legal terminology and deficiencies in treaties such as the Outer Space Treaty (1967) and the Liability Convention (1972). Art.1(d) of the Liability Convention,1972 and Art.1 (b)Registration Convention, 1974, both defined "space objects include components of such objects as well as their launch vehicles and parts." However, it fails to categorically define the distinction between functional and non-functional objects. International law lacks a formal, globally recognized concept of space debris. Space debris generally denotes non-operational entities, yet there is no threshold to define in treaties. As a result, there is an ambiguity over the legal classification of debris as a "space object."

Further, the Liability Convention establishes liability for damage inflicted by space objects. However, it does not specifically address space debris. This issue raises concerns about the liability of states for harm inflicted by debris that is no longer within their control. In general, space-faring nations must register space objects with the United Nations in accordance with the Registration Convention. Nonetheless, numerous antiquated objects and waste bits remain unrecorded, complicating the assignment of responsibility (UN, 1974). Moreover, as a result, there is less discrepancy against the notion that large portions of a satellite after an explosion has destroyed it would likewise form component pieces and would, therefore be considered to be space objects. In this way, any damage produced by such component parts would be included within the purview of the Liability Convention, which would, at the very least, lead to the possibility of compensation in theory. This is the most significant advantage of this arrangement (Convention, 1974). Moreover, Practical difficulties could remain due to the fact that the dispute settlement system under the Liability

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Convention does not inherently result in a binding conclusion if the liable state(s) refuse to pay following diplomatic consultation. A binding decision can only occur if both parties to the dispute consent in advance, which may not frequently happen (Convention, 1974). A further basic issue emerges involving another legal facet of space objects. Classifying a specific metal as a "space object" is essential (but not sufficient) for enforcing the Liability Convention and may also invoke Art's provisions. VIII of the OST and the Registration Convention.

4.2 Liability Convention

The 1972 Convention on International Liability for Damage Caused by Space Objects is called the “Liability Convention.” It establishes regulations concerning personal harm and property damage, as well as the resolution of these matters at the international level. It mostly deals with damages inflicted by space objects and does not specifically address damage resulting from space debris unless it is classified as a "space object." It also does not sufficiently address the rising issues of non-functional debris and fragmentation incidents. This convention is based on the ***fault-based liability system*** (Radi, 2023), which primarily demands proof that the launching state acted negligently or intentionally. Art I and II of the agreement clearly stipulate that a country that launches or facilitates the launch of a space object, or from whose territory a space object is launched, is accountable for damages caused by its space object on the Earth's surface or to aircraft in flight. However, it is silent on damage outside the Earth's surface, and the concept of culpability remains ambiguously defined (Kerrest, 2001).

4.3 NON-BINDING GUIDELINES

The non-binding guidelines on removing outer space debris are the most important soft laws in regulations of activities in space affairs and mitigating the risk. The United Nations developed these guidelines from the Inter-Agency Space Debris Coordination Committee (IADC) and the European Space Agency (ESA). The **United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)** 2007 has developed **guidelines on space debris** to promote the sustainable use of outer space. However, these non-binding characters have many shortcomings that cause difficulties regulating states’ activities in outer space. These guidelines include some rules and principles observed under soft normality and are not enforceable. Moreover, their

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acceptability is absolute; some advanced states may partly implement these guidelines. Developing or emerging nations cannot do so due to insufficient financial resources or technology. The absence of a global organisation that monitors compliance and imposes penalties on individuals who disobey the regulations is noteworthy. Due to the fact that domestic regulations are frequently lacking or insufficient, private space enterprises are also not adequately held accountable in accordance with these principles.

5 CONCLUSION AND SUGGESTIONS

The problem of space debris poses an alarming threat to the sustainability of outer space and life and property on Earth. The existing international framework is obsolete to effectively regulate activities in outer space. There is the inherent flow of the non-binding guidelines, lack of enforcement measures, and the absence of accountability for both governmental and commercial entities. As space exploration has proliferated rapidly, especially with the emergence of commercial enterprises and mega-constellations, current regulatory frameworks have struggled to keep pace with technological improvements and new concerns, including uncontrolled re-entry incidents and orbital congestion. Similarly, disparities in financial, technological, and political capacities among states have resulted in the uneven implementation of debris reduction methods, exacerbating inequalities in space governance. Unestablished, enforceable global regulations have led to fragmentation, intensifying inconsistent behavior among operators and the proliferation of space debris. Access to space, a common global common, is at risk unless there are thorough and legally binding structures to ensure its sustainability. In order to address these challenges, it is essential to establish a comprehensive international legal framework for space debris regulation and reduction. This framework should include binding obligations, accountability mechanisms, and enforcement tools. In order to promote equitable access to space, a system must strike a balance between the interests of governments, businesses, and emerging spacefaring nations. For removal and a safer orbital environment, it is vital to improve international coordination, encourage innovation in active debris removal technologies, and incentivize sustainable activities. Legislative

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reforms are important, but everyone must do their part and commit to long-term space management if space travel is to be sustainable.

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