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"SPACE DEBRIS AS ENVIRONMENTAL POLLUTION: THE KESSLER SYNDROME AS THE CASSANDRA OF GLOBAL COMMONS GOVERNANCE"

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1. Abstract

Outer space, once professed as an infinite and self-regulating frontier, is ever more threatened by the increase of orbital debris. Despite escalating scientific warnings, space debris continues to be portrayed as an exterior technical concern rather than a form of environmental pollution. This paper conceptualises space debris as a distinct category of environmental pollutant and argues that its obstinate neglect reflects the '*Cassandra effect*' in global commons governance, where credible warnings are thoroughly ignored until irreversible damage occurs. The intensifying risk of the Kessler Syndrome, which predicts a self-sustaining cascade of collisions in turn making Earth's orbit unusable, highlights this governance failure.

Using doctrinal and comparative analysis, this study assesses international space law frameworks, including key treaties and national policies, and finds that reliance on soft-law and voluntary compliance leads to weaker enforcement and limited accountability for debris generation. By reframing orbital debris as a global environmental issue, it highlights the urgent need to move from fragmented, voluntary approaches to a binding international regime supported by harmonised national laws and clear liability mechanisms for sustainable use of outer space before irreversible damage occurs.

Keywords:- Space Debris**,** Kessler Syndrome**,** Pollution**,** Governance**,** Cassandra effect

2. Introduction

When the term 'pollution' is discussed in environmental concepts or discussions, it generally refers to terrestrial forms of pollution such as air, water, etc. Academic texts, policy frameworks, and public awareness campaigns majorly focus on these categories. Nevertheless, a less visible yet significant form of pollution exists beyond Earth's atmosphere, which are termed as "space debris**"**. In the face of the rapid growth of human activity in space, the environmental degradation of orbital regions remains fundamentally absent from mainstream discussions.

The growing concern surrounding orbital debris is reflected in the words of S. Thuy Nguyen-Onstott:

"The Universe is infinite But space has its limits Rockets a launching Satellites are orbiting Explosions in Space Oh what a waste Fragments go flying And we go crying "Space junk we've got" Man-made or not Then comes Kessler Who knows the better When things collide
Their debris do multiply Thanks to partnering And NASA's gathering We look for ways To manage the spray" (NASA, 2023)

This poetic depiction captures a reality which says that although the universe may appear limitless, the usable orbital regions surrounding

Earth are finite and increasingly congested. Orbital debris consists of defunct satellites, rocket fragments and other human-generated objects that remain in orbit after completing their missions. These debris travelling at high speed which exceeds 18,000 miles per hour, makes even small fragments pose significant risks to operational spacecrafts (NASA, 2023).

Modern civilizations depend on satellites for navigation, telecommunications, weather forecasting, scientific observation, and military operations, making the safety of Earth's orbital environment critically important. However, the increasing accumulation of debris prompts the probability of cascading collisions known as the "Kessler Syndrome", a scenario pioneered by NASA scientist Donald Kessler in 1978. In such a setting, collisions between space objects generate further debris, potentially rendering certain orbital regions unusable (Kessler and Cour-Palais, 1978).

This paper examines space debris as a form of environmental pollution within the framework of global governance, explores the Kessler Syndrome through the lens of the Cassandra effect, and evaluates whether existing legal frameworks are sufficient to address this growing challenge.

Research Questions

1. Can space debris be conceptualized as environmental pollution within global commons governance?
2. Does the Kessler Syndrome represent a Cassandra effect in international space governance, where scientifically validated warnings continue to be ignored by policymakers?
3. Should space debris governance transition from voluntary guidelines to a binding regulatory regime?

3. Literature Review

3.1 Space Debris Research

Scientific research on the topic of orbital debris has expanded since the late twentieth century, mostly with the help of the studies conducted by major space agencies such as NASA and European Space Agency (NASA, 2023; ESA, 2025). These studies primarily focus on the growth of debris populations, collision probabilities, and the long-term sustainability of Earth's orbital environment. Current estimates point out that millions of debris fragments exist in orbit, ranging from millimetre-sized particles to defunct satellites and rocket stages (ESA, 2026). Researchers highlight that even extremely small fragments can cause catastrophic damage because orbital debris travels at velocities exceeding 17,000 – 18,000 miles per hour (NASA, 2023).

Scientific models also warn that persistent space activity could significantly increase debris density in Low Earth Orbit (LEO). Simulation studies have proved that these debris may continue to grow even if new launches were reduced, due to collisions among existing objects (Kessler and Cour-Palais, 1978; ESA, 2025). These studies emphasise the need for mitigation strategies such as improved satellite disposal practices, passivation of spacecraft, and debris tracking technologies (IASDCC, 2007).

3.2 Legal stand point on Space Governance

Legal studies and discourse has inspected space debris within the broader framework of international space law. Scholars frequently analyse the regulatory structure created by the Outer Space Treaty and subsequent legal instruments that govern outer space activities (United Nations, 1967). They establish principles such as the peaceful use of outer space, state responsibility for national activities, and liability for damage caused by space objects.

However, most discussions focus on operational safety and liability rather than environmental protection. Contemporary governance instruments rely heavily on non-binding mitigation guidelines established by international bodies such as the United Nations Committee on the Peaceful Uses of Outer Space and the Inter-Agency Space Debris

Coordination Committee (UNOOSA, n.d.; IADC, 2007).

3.3 Environmental Governance of Global Commons

Theoretical perspective on environmental governance often examines the regulation of shared global resources such as the oceans, atmosphere, and polar regions. These studies underline principles such as collective responsibility, precaution, and sustainable management of global commons. Despite clear conceptual similarities, outer space has rarely been analysed within environmental governance frameworks.

3.4 Identified Research Gap

Present literature primarily frames space debris as a technical or operational challenge rather than a form of environmental pollution. Additionally, the juncture between environmental governance theory and space law remains underdeveloped. This research seeks to bridge this gap by conceptualising orbital debris as environmental pollution and analysing its governance through the lens of global commons management.

4. Methodology

This research adopts a doctrinal and comparative legal research methodology to study the governance of space debris within the framework of international environmental regulation. The doctrinal approach encompasses a systematic analysis of existing legal instruments, treaties, policy guidelines, and institutional frameworks governing activities in outer space. Crucial legal documents related to international space law and debris mitigation were studied to assess their scope, enforceability, and effectiveness in addressing the environmental risks posed by orbital debris.

In addition to this, the study also uses comparative legal analysis to evaluate the correlation between international space governance and domestic regulatory approaches adopted by spacefaring nations. By comparing international principles with national mitigation policies and standards, the research attempts to identify strengths, weaknesses, and regulatory gaps in the current governance structure.

The study also incorporates conceptual analysis, applying environmental law principles such as pollution control, precautionary principle, and global governance to the issue of space debris. Through this framework, the research attempts to inspects whether orbital debris can be categorized as a form of major environmental pollution and whether existing governance mechanisms adequately address the long-term sustainability of outer space activities.

The sources for this research include international treaties, policy documents issued by space agencies, reports from international organizations, and academic literature on space law, environmental governance, and space sustainability.

5. Historical Background

The concern of orbital debris arose alongside the development of modern space exploration during the mid-twentieth century. Since the launch of the first artificial satellite, Sputnik 1, by the Soviet Union in 1957, human activity in outer space has expanded significantly (The Aerospace Corporation, 2022). Initially motivated by geopolitical rivalry during the Cold War, space exploration soon evolved into a complex system involving civilian, commercial, and military actors. Thousands of satellites have since been launched into orbit for telecommunications, navigation, scientific research, weather forecasting, and national security purposes.

As the number of space missions grew, so did the increase of non-functional objects in orbit. These objects include defunct satellites, fragments from explosions, discarded rocket stages, and other remnants of human space activities. These objects, collectively referred to as ‘space debris’ or ‘orbital debris’, remain in the

orbit long after their operational lifespan. The problem is predominantly significant in Low Earth Orbit (LEO), which hosts a large proportion of operational satellites and space infrastructure.

The concern of sustainability of the orbital environment was first expressed in 1978 through the concept of Kessler Syndrome, proposed by Donald J. Kessler of NASA. According to this theory, once the density of objects in orbit reaches a critical threshold, collisions between objects could generate cascading chains of debris, possibly creating a self-sustaining cycle of collisions that would make certain orbital regions unusable (Kessler and Cour-Palais, 1978).

Over the past two decades, several major incidents have contributed to the growth of orbital debris and highlighted the risks associated with orbital congestion.

5.1 Major Space Debris Incidents

a) China's Anti-Satellite Missile Test (2007)

In January 2007, China conducted an anti-satellite (ASAT) missile test targeting the defunct weather satellite Fengyun-1C. The satellite was destroyed at an altitude of approximately 865 km in Low Earth Orbit. The test generated more than 3,000 pieces of trackable debris and an estimated 32,000 smaller fragments that cannot be tracked. This event produced the largest amount of debris ever generated by a single space event. The test was widely condemned by the international community due to its long-term impact on orbital safety (Rumage, 2025).

b) Iridium–Cosmos Satellite Collision (2009)

In February 2009, the operational communications satellite Iridium 33 collided with the inactive Russian satellite Kosmos 2251. The collision occurred at an altitude of approximately 790 km above Siberia. Both satellites were completely destroyed during the impact. The collision generated more than 2,000 trackable debris fragments and thousands of smaller particles. This event marked the first recorded 'accidental collision' between two satellites in orbit (Rumage, 2025).

c) Russian Anti-Satellite Missile Test (2021)

In November 2021, Russia conducted an anti-satellite missile test that destroyed the defunct Soviet spy satellite Kosmos 1408. This generated over 1,500 pieces of trackable debris and hundreds of smaller fragments. The resulting debris cloud threatened nearby spacecraft, including the International Space Station. Astronauts aboard the station were temporarily instructed to take shelter inside emergency lifeboat capsules as a precautionary measure (Rumage, 2025).

d) Fragmentation and Satellite Explosion Events

Several satellites and rocket bodies have exploded due to leftover fuel, battery failures, or structural stress. These fragmentation events generate debris clouds that spread across multiple orbital paths. Early spacecraft design often lacked mechanisms to safely release stored energy after mission completion, increasing the likelihood of explosions (Rumage, 2025).

5.2 Risks Associated with Space Debris

The accumulation of orbital debris presents multiple risks for space infrastructure, astronauts, and even individuals on Earth.

I. Damage to Satellites

Space debris are a constant threat to satellites used for navigation, telecommunications, weather forecasting, scientific observation, and military surveillance. Even extremely small fragments travelling at velocities exceeding 17,000 miles per hour or more can cause severe harm. Spacecraft such as the International Space Station are protected by specialised 'Whipple shields', which can survive impacts from objects up to approximately 3 millimetres in size. Yet, not all satellites have maneuvering

capabilities or protective shielding. Collision avoidance drills also consume fuel, making space operations increasingly costly (Rumage, 2025).

II. Risks to Astronauts

Astronauts conducting spacewalks are particularly vulnerable to small fragments of debris. Though modern space suits offer some protection against tiny particles, untraceable fragments traveling at extremely high velocities can potentially puncture a suit and cause severe injury (Rumage, 2025).

III. Objects Re-Entering Earth's Atmosphere

Most orbital debris burns up during atmospheric re-entry, but some larger fragments survive and reach the Earth's surface. According to reports from the European Space Agency, approximately 1,200 intact objects re-entered Earth's atmosphere in 2024 alone (Rumage, 2025).

IV. Documented Debris Impact Incidents

The probability of an individual on earth being struck by falling debris is approximately one in a trillion. The only confirmed case occurred in 1997 in Oklahoma, where a woman was struck by a small fragment of space debris but was not injured. In March 2024, a 1.6-pound piece of debris crashed through the roof of a home in Florida, passing through two floors of the house. Investigations revealed that the debris originated from a pallet of old batteries released from the International Space Station in 2021. The debris were expected to burn up during atmospheric re-entry, but portions of it survived (Rumage, 2025).

6. Constitutional Relevance and Global Governance Dimensions

The emergent concern of space debris raises important questions regarding the responsibility of states to protect shared environmental resources. Although outer space exists beyond the national territorial jurisdiction, constitutional principles related to environmental protection provide a useful framework for understanding state obligations in addressing orbital pollution.

6.1 Right to a Healthy Environment

The Indian Constitution invokes article 21 to address this right. Similarly, many modern constitutions recognise the right to a clean and healthy environment as a fundamental or directive principle of governance. This right sets an obligation upon states to ensure that developmental and technological activities don't lead to environmental degradation (EVS Institute, 2025). As human activities exponentially extend past Earth's atmosphere, the orbital protection may be viewed as a natural addition of environmental protection duties. The sustainability of outer space is relevant because satellite infrastructure provides essential services such as navigation, climate monitoring, disaster management, and global communication, which directly affect human welfare on Earth.

6.2 Public Trust Doctrine

The 'public trust doctrine' states that certain resources of common importance, such as air, water, and natural ecosystems, must be preserved and managed by states for the benefit of sustainable development (M.C. Mehta v. Kamal Nath, 1997). Although traditional application is towards terrestrial resources, the doctrine has increasingly been interpreted in broader environmental contexts. From this standpoint, outer space can be understood as global commons, where states act as trustees responsible for ensuring its sustainable use and preventing environmental degradation such as orbital debris accumulation.

6.3 State Responsibility for Environmental Protection

Constitutional environmental principles also emphasise the responsibility of governments to regulate activities which may cause environmental harm. In the context of space activities, states endure international responsibility for both governmental and private actors functioning under their

jurisdiction (United Nations, 1967, Art. VI). This principle points the need for states to adopt national regulatory frameworks which ensure respo-nsible satellite operations, debris mitigation, and post-mission discarding practices.

6.4 Global Governance and International Regulatory Frameworks

Outside domestic constitutional principles, the governance of outer space is shaped by international legal frameworks and multilateral institutions. Numerous international instruments address the regulation of space activities, including the Outer Space Treaty, which establishes foundational principles such as the peaceful use of outer space and state responsibility for national space activities (United Nations, 1967). Other legal instruments such as the Liability Convention and the Registration Convention further regulate state accountability for damage caused by space objects (United Nations, 1972, Art. II; United Nations, 1975).

Similarly, technical coordination bodies such as the Inter-Agency Space Debris Coordination Committee have developed mitigation standards and best practices for debris prevention (IADC, 2007).

7. Analytical Framework

7.1 Space Debris as Environmental Pollution (RQ1)

Environmental pollution is generally defined as the "introduction of harmful substances or energy into the environment that causes adverse effects on ecosystems, human life, or shared resources" (United Nations Environment Programme, 2019). Pollutants typically possess characteristics such as persistence, accumulation, mobility, and the potential to disturb natural or operational systems. Traditionally, environmental law has focused on terrestrial forms of pollution, but with the rise of human activity into outer space, 'Orbital Pollution' has emerged as a new category of pollution.

Space debris consists of defunct satellites, fragments from collisions, discarded rocket stages, and other fragments of space missions that remain in Earth's orbit (Rumage, 2025; Iberdrola, n.d.). Much like airborne particulate matter in air pollution or floating plastics in marine ecosystems, space debris continue in the environment for long durations and can accumulate over time (The Aerospace Corporation, n.d.). The comparison is salient when considering how debris fragments can travel at extremely high velocities of 18,000 - 28,000 km per hour. creating risks to operational satellites, crewed missions, and future space exploration activities (NASA, n.d.; ESA, 2026).

Environmental law principles offer a useful framework for analysing this issue. The precautionary principle advises that preventive action should be taken even when scientific certainty about long-term harm is incomplete (United Nations, 1992). Similarly, the polluter pays principle obliges those responsible for environmental harm to bear the cost of mitigation or remediation (Organisation for Economic Co-operation and Development, 1972). Applying these principles to outer space implies that states and private actors conducting space activities must take responsibility for preventing debris generation, ensuring safe satellite disposal, and contributing to debris mitigation efforts.

Despite the severity of these risks, space debris are rarely discussed within the broader discourse of environmental pollution. The absence of categorical classification of orbital debris as environmental harm weakens regulatory and policy urgency. Recognising space debris as a distinct form of environmental pollution would support the legal framework governing space activities to emphasize sustainable management of the orbital region as a shared global resource.

7.2 Kessler Syndrome and the Cassandra Effect (RQ2)

The concept of the Kessler Syndrome describes a scenario in which the density of objects in

Earth's orbit becomes so high that collisions between them generate additional debris, triggering a cascading chain reaction that could make certain orbital regions unusable for decades. This risk is particularly important in "Low Earth Orbit (LEO)", where most satellites used for communication, navigation, and Earth observation are currently positioned (Kessler and Cour-Palais, 1978; European Space Agency, 2026).

The growth of debris in LEO isn't merely theoretical but has been driven by several major events. For instance, the calculated destruction of the Chinese Fengyun-1C weather satellite in 2007 during an anti-satellite test produced thousands of debris fragments (Rumage, 2025; Space News, 2009). Similarly, the accidental collision between the American Iridium-33 satellite and the Russian Cosmos-2251 satellite in 2009 increased the number of debris fragments in orbit (Space News, 2009). Together, these incidents alone increased the large orbital debris population in Low Earth Orbit by approximately 70 percent, critically elevating collision risks for operational spacecraft (NASA, n.d.).

Current statistical data validates the scale of the problem. According to the European Space Agency Space Debris Office, since the beginning of the space age in 1957, approximately 7,170 rocket launches have positioned around 25,170 satellites into orbit, of which about 16,910 remain in space and roughly 14,200 are still functioning. Space surveillance networks currently track about 44,870 space objects, while statistical models estimate the presence of 54,000 objects larger than 10 cm, approximately 1.2 million debris fragments between 1 cm and 10 cm, and nearly 140 million particles between 1 mm and 1 cm. In addition, more than 650 fragmentation events, including explosions and collisions, have occurred in orbit, contributing to a total orbital mass exceeding 15,800 tons (ESA, 2026).

These warnings from scientists and space agencies reflect what governance scholars term as the 'Cassandra Effect'. In Greek mythology, Cassandra was granted the power to foresee disasters but cursed so that no one would believe her warnings. In modern policy, the Cassandra Effect refers to circumstances where credible scientific warnings are ignored or inadequately addressed by decision-makers. The concept is explored extensively in the book *Warnings: Finding Cassandras to Stop Catastrophes* by Richard A. Clarke, which analyses cases where societies failed to act on early warnings of systemic threats (Clarke, 2017).

The current trajectory of orbital debris mirrors a similar pattern of delayed governance. Despite repeated scientific alerts regarding orbital congestion, regulatory responses have remained slow (ESA, 2026; World Economic Forum, 2023). This pattern mirrors earlier environmental governance failures, such as delayed responses to climate change and ozone layer depletion. Therefore, the space debris crisis represents another example of a global commons problem where technological expansion has overtaken the development of effective regulatory mechanisms.

8. Comparative Legal Analysis (RQ3)

The governance of space debris is shaped by a combination of international treaties, soft-law instruments, and national regulatory frameworks. A comparative analysis of these legal mechanisms helps assess their effectiveness in addressing the growing risks associated with orbital pollution.

8.1 International Space Law Treaties

The foundational framework for space governance is established by the Outer Space Treaty of 1967, which shapes principles such as the peaceful use of outer space and state responsibility for national space activities. While the treaty recognises that states bear international responsibility for governmental and non-governmental space operations, it does not specifically regulate the production of orbital debris (United Nations, 1967, Art. VI).

Additional legal instruments include the Liability Convention, which establishes rules for state liability in cases of damage caused by space objects, and the Registration Convention, which involves states to maintain registries of objects launched into outer space (United Nations, 1972; United Nations, 1975). Although these treaties create a basic accountability framework, they were developed before the contemporary scale of commercial satellite activity and therefore provide limited guidance on debris mitigation (World Economic Forum, 2023).

8.2 Soft Law Instruments

Recognising the limitations of existing treaties, international organisations developed voluntary guidelines to address the issue of orbital debris. The United Nations Committee on the Peaceful Uses of Outer Space adopted Space Debris Mitigation Guidelines that encourage responsible satellite design, mission planning, and end-of-life disposal strategies (United Nations, 2007). Similarly, the Inter-Agency Space Debris Coordination Committee formulated procedural standards aimed at minimising debris generation (IADC, 2007).

However, these instruments are principally non-binding and depend on voluntary compliance by states and private actors (World Economic Forum, 2023).

8.3 National Space Regulations

Different countries have begun integrating debris mitigation requirements into domestic space regulations. The United States mandates debris mitigation plans for satellite licensing through regulatory authorities such as the Federal Communications Commission (FCC, 2020). The China has also introduced guidelines for responsible satellite operations as its space industry expands (World Economic Forum, 2023).

Similarly, India has adopted debris mitigation standards through its national space regulatory framework, while the European Union promotes sustainability principles through regional space policies and coordination mechanisms (Indian Space Research Organisation, n.d. ; European Space Agency, n.d.).

9. Findings and Conclusion

The analysis undertaken in this study highlights several critical governance challenges posed by orbital debris regulation. By examining space debris through environmental law principles, scientific risk assessments, and comparative legal frameworks, the study identifies structural gaps in the current regulatory system governing outer space activities.

i. First, the analysis confirms that space debris display key characteristics commonly associated with environmental pollution, including persistence, accumulation, and the potential to cause systemic harm (Rumage, 2025; The Aerospace Corporation, n.d.). Despite these similarities, orbital debris has rarely been recognised within conventional environmental law discourse. Conceptualising space debris as a form of conventional environmental pollution aids the argument regarding the need for outer space governance under sustainability principles similar to those applied to terrestrial and marine environments.

ii. Second, scientific warnings concerning the 'Kessler Syndrome' exhibit the increasing vulnerability of orbital regions, particularly Low Earth Orbit, to cascading collision events. The rapid extension of satellite deployments and the growing volume of debris fragments prove that orbital congestion is no longer a distant theoretical concern but an emerging environmental and technological risk (European Space Agency, 2026; Kessler and Cour-Palais, 1978). These warnings reflect what governance scholars describe as the 'Cassandra Effect', where credible early warnings about catastrophic risks are acknowledged but

not sufficiently acted upon by policymakers (Clarke, 2017).

iii. Third, the comparative legal analysis exposes several structural weaknesses within the current governance framework. Enforcement mechanisms remain limited at the international level. The existing legal framework is largely based on broad principles rather than detailed operational obligations. Although treaties such as the Outer Space Treaty establish that states bear international responsibility for national space activities, they do not provide concrete enforcement procedures or sanctions for states that fail to implement effective debris mitigation measures (United Nations, 1967). Thus, compliance largely depends on voluntary adherence and good-faith cooperation rather than binding legal accountability (World Economic Forum, 2023).

iv. Another challenge is concerned with accountability for debris generation. The acknowledgement of responsibility presents both legal and technical difficulties because debris fragments often originate from fragmentation events, satellite collisions, or decades-old spacecraft whose ownership may have changed over time. Even when fragments can be traced to a specific launch, establishing liability under instruments, such as the Liability Convention, is complicated by evidentiary requirements and the absence of clear standards addressing long-term orbital pollution (United Nations, 1972). These limitations weaken the ability of affected states or satellite operators to seek compensation or enforce responsibility for debris-related damage.

v. Furthermore, the current governance system relies heavily on soft-law frameworks rather than binding international obligations. Guidelines developed by bodies such as the United Nations Committee on the Peaceful Uses of Outer Space and the Inter-Agency Space Debris Coordination Committee provide valuable technical recommendations, including post-mission disposal procedures and collision avoidance practices (UN, 2007; IADC, 2007). But, because these instruments are voluntary in nature, their implementation differs considerably among states and private actors (World Economic Forum, 2023). This uneven compliance reduces the effectiveness of the regulatory framework and allows debris-generating activities to continue without stable global oversight.

Collectively, these findings prove that while existing international instruments establish foundational principles for the governance of outer space, they remain inadequate to address the rapidly expanding scale of space activities and the long-term sustainability of the orbital environment. The growing accumulation of debris highlights the urgent need for stronger international coordination, clearer legal obligations, and more effective regulatory mechanisms to ensure responsible and sustainable use of outer space.

10. Recommendations

In light of the findings presented in this study, several policy and governance reforms are essential to ensure the sustainable management of outer space and to diminish the growing risks associated with orbital debris.

A. **Adoption of a Binding International Treaty on Space Debris Mitigation –**

There is a pressing need for the formation of a binding international regulatory framework governing space debris mitigation and orbital sustainability. Existing treaties offer important foundational principles but

lack detailed provisions addressing debris generation, satellite disposal obligations, and orbital sustainability. A modern international agreement or protocol could establish clear operational standards, mandatory debris mitigation measures, and cooperative monitoring systems.

B. **Harmonisation of National Regulatory Frameworks for Space Activities** –

This is crucial to ensure steady implementation of debris mitigation practices across jurisdictions. Countries with advanced space capabilities such as the United States, China, India, and members of the European Union, have already introduced domestic regulatory measures addressing orbital debris (FCC, 2020; ESA, n.d.). However, these frameworks differ considerably in scope and enforcement. Greater coordination among national regulatory regimes would help institute uniform global standards for responsible space operations.

C. **Creation of a Global Space Debris Monitoring and Enforcement Authority** –

Stronger enforcement and monitoring mechanisms must be established at the international level. A dedicated global monitoring body operating under existing institutions such as the United Nations framework could track debris generation, monitor compliance with mitigation standards, and facilitate information sharing among states and private space operators.

D. **Reform of International Liability and Accountability Mechanisms** –

The development of clear liability and compliance mechanisms is needed to ensure accountability for debris-generating activities. Strengthening liability frameworks and improving the traceability of space objects through advanced tracking technologies would enhance the ability of states to attribute responsibility for debris-related damage (United Nations, 1972).

E. **Encouragement of Technological Innovations for Active Debris Removal** –

The promotion of technological innovation for debris mitigation and removal must be a central factor of future space governance strategies. One emerging initiative known as "OMLET" (Orbit Maintenance via Laser Momentum Transfer), is developed under the European Space Agency Space Safety Programmed (ESA, n.d.). This concept proposes the use of ground-based high-power laser systems capable of directing laser pulses toward debris objects in Low Earth Orbit. By transferring momentum to the debris, the system could subtly alter the trajectory or velocity of debris fragments, thereby preventing potential collisions with operational spacecraft.

F. **Encouraging International Cooperation for Sustainable Space Governance** –

In addition to such emerging technologies, several operational standards and mitigation frameworks have already been developed by space agencies. For example, the NASA has implemented policies such as the NASA Procedural Requirements for Limiting Orbital Debris (NPR 8715.6B) and the NASA Technical Standard 8719.14, which establish technical requirements for debris mitigation in spacecraft design and mission planning (NASA, n.d.). Complementary tools such as Debris Assessment Software (DAS) assist mission planners in assessing potential debris impacts and ensuring compliance with mitigation guidelines. Similarly, the U.S. Government Orbital Debris Mitigation Standard Practices

(ODMSP) deliver wide-ranging operational strategies aimed at reducing the creation of prolonged debris during space missions (U.S. Government, 2019).

Encouraging collaborative research, technological innovation, and information sharing among spacefaring nations will be indispensable for addressing the growing challenge of orbital debris. Through coordinated legal reforms and collective technological efforts, the international community can move toward a more sustainable and responsible model of space governance.

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