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Beyond Gravity: Analyzing the Threat of Space Debris in the New Space Age

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Space debris, a byproduct of scientific-technological advancement, economic interests, and geopolitics, is a growing concern we have long observed. Since technological societies rely heavily on space infrastructures, the debris issue must be addressed. The space community has recently come to recognise space debris's significant impact on space operations and terrestrial facilities. This is attributed, in part, to the futuristic and commercially-driven hopes of the so-called New Space Age, which include the colonization of other planets like the Moon and Mars. Satellites, post usage, hold no utilisation but keep orbiting around the earth, and this has led the space environment to be filled with such space-deployed objects that we call 'space debris. If not resolved, space debris around the Earth can become the most dangerous problem for future space exploration programmes and research. International regulatory and technical solutions must be developed and implemented to reduce space debris. In light of the fear of a future avalanche of space debris that can cascade out of control, many steps are suggested for space debris mitigation. An analysis of the drawbacks of various space treaties, which are non-binding and are signed at different points in time to curb the issue of space debris, is presented, and their results are also discussed. Why is there no strict implementation of space laws? Is it because of their non-binding nature, or is it a soft law that can't be binding? Then, we will discuss the environmental aspect of space debris and how it will backfire on the aspiring technological developments we have been achieving for a long time.

Keywords: *space debris, space infrastructure, debris mitigation, new space age, space environment.*

INTRODUCTION

Aerospace missions face a major risk from space debris. Active space debris is a known concern in space activities. Non-functional artificial space objects in Earth's orbit are dubbed space garbage. Any deployed equipment or tool lost by astronauts in orbit; fragmentation occurrences, whether deliberate or not; or a full spacecraft, launch vehicle, or component that has gone off-mission. They come in all shapes and sizes, from tiny particles to enormous ones like whole inactive spaceships. *They are located between 160 and 36,000 kilometers above the surface of our planet.* Most space debris results from collisions and explosion-related breakup events, many of which are intentional.[1] The main source of space debris is fragmentation debris. Specifically, China (42%), the United States (27.5%), and Russia (25.5%) are to blame for nearly 95% of the fragmented debris that is currently in Earth's orbit.[2] In general, the term 'space debris' refers to artificial material in orbit that is no longer useful. Even tiny pieces of debris can be very harmful in a collision due to the high speeds of objects in orbit[3] (7.5 km s-1 is typical in low earth orbit).[4] Several spacecraft were purposefully destroyed in the 1960s using antisatellite tests (ASAT) or self-destruct mechanisms. There are several types of debris:

[1] Habimana Sylvestre & V R Ramakrishna Parama, 'Challenges and Opportunities at the Dawn of the New Space Age' (2017) 46 IJRSP 20-26 <http://op.niscpr.res.in/index.php/IJRSP/article/download/15316/465464645#:~:text=Most%20space%20debris%20come%20from,collisions%2C%20many%20of%20them%20deliberate.&text=Fragmentation%20debris%20is%20the%20largest%20source%20of%20space%20debris> accessed 22 November 2023

[2] 'Tackling the growing risks of space debris in Earth orbit' (*Clear Space*, 06 November 2023) <https://space.blog.gov.uk/2023/11/06/tackling-the-growing-risks-of-space-debris-in-earth-orbit/> accessed 22 November 2023

[3] Shkelzen Cakaj et al., 'The Coverage Analysis for Low Earth Orbiting Satellites at Low Elevation' (2014) 5(6) IJACSA <https://thesai.org/Downloads/Volume5No6/Paper_2-The_Coverage_Analysis_for_Low_Earth_Orbiting_Satellites_at_Low_Elevation.pdf> accessed 22 November 2023

[4] Jonathan O'Callaghan, 'What is space junk and why is it a problem?' (*National History Museum*) <https://www.nhm.ac.uk/discover/what-is-space-junk-and-why-is-it-a-problem.html#:~:text=Space%20junk%2C%20or%20space%20debris,have%20fallen%20off%20a%20rocket> accessed 22 November 2023

- Defunct spacecraft, such as satellites, have ended their useful life. Commercial satellites have an average lifespan of around 15 years due to the harsh radiation environment in space;
- Spent rocket bodies used to launch satellites into orbit;
- Objects released during missions, such as waste vented from the Space Shuttle;
- Small fragments caused by collisions, explosions or deterioration of active satellites or larger pieces of debris.[5]

Even minute debris fragments can have disastrous effects on operating spacecraft due to the immense kinetic energy of objects circling at speeds many times faster than the fastest rifle bullet.[6] The damage caused by orbital debris depends on the velocity and mass of the debris fragments. For debris fragments measuring under 0.01cm, surface pitting and erosion are the primary effects of impact.[7] The most significant environmental issue associated with space activities is space debris, which is currently considered a serious concern.[8] The vast number of satellites steadily expanding in our earth's orbit will eventually create a significant threat to space activities.[9] Millions of pieces of space junk orbit the Earth at speeds of many kilometers per second.[10] All space agencies worldwide launch satellites, spacecraft, and other objects for various purposes essential to developing the communications, defense, weather forecasting, and space exploration industries.[11]

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[5] Habimana Sylvestre and Ramakrishna Parama, 'SPACE DEBRIS: REASONS, TYPES, IMPACTS AND MANAGEMENT' (2017) 46(1) Journal of Radio and Space Physics 20, 22

[6] Stephen Karl Remillard, 'DEBRIS PRODUCTION IN HYPERVELOCITY IMPACT ASAT ENGAGEMENTS' (DPhil Thesis, AIR FORCE INSTITUTE OF TECHNOLOGY 1990)

[7] Irene Atney-Yurdin, 'Space Debris Legal Research Guide' (1991) 3 PILR 167

[8] Charlotte Luke, 'Explainer: What Is Space Junk and How Does It Affect the Environment?' (*Earth.ORG*, 06 September 2021) <https://earth.org/space-junk-what-is-it-what-can-we-do-about-it/#:~:text=But%20how%20does%20space%20junk,detrimental%20effects%20on%20Earth's%20environment> accessed 23 November 2023

[9] Anelí Bongers and José L. Torres, 'Orbital debris and the market for satellites', Ecological Economics' (2023) 209 Ecological Economics <https://doi.org/10.1016/j.ecolecon.2023.107831> accessed 23 November 2023

[10] 'What is space junk?' (*McKinsey & Company*, 28 July 2023) <https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-space-junk> accessed 23 November 2023

[11] Prabhat Singh et al., 'STUDY OF CURRENT SCENARIO & REMOVAL METHODS OF SPACE DEBRIS' (2020) 10 IJMPERD 224

Future space operations are becoming increasingly dangerous due to debris left in numerous orbits around Earth due to exploration and utilization of the space environment.[12] Future space activities could only recover capacity, income, and even life due to collisions between spacecraft and trash if nations minimize the quantity of orbital debris they produce yearly.

SPACE DEBRIS AND SPACE LAW

Safety Regulations and Treaties: Since the beginning of the Space Age in 1957, the international regulatory regime governing space activities has predominantly been developed through the *Committee on Peaceful Uses of Outer Space*[13] (COPUOS) of the General Assembly of the United Nations. As created in 1958, the Committee has been mandated to address the legal problems deriving from the exploration and use of outer space. The Scientific and Technical Subcommittee addresses more technical space-related issues. The Committee has formulated five international treaties and five declarations that establish the fundamental principles of the global regulatory regime governing space activities.

The *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*[14] (the 'Outer Space Treaty') regarded as the constitution of outer space, establishes several fundamental and general legal principles. Some of them specify that: (a) the exploration and use of outer space must be carried out for the benefit and in the interests of all humanity; (b) outer space and celestial bodies are free for exploration and use by all States based on equality and by international law; (c) outer space and celestial bodies are not subject to national appropriation by any means, and (d) States parties to the Treaty are obligated not to place in orbit around the Earth any object that could threaten. In addition, Article VIII of the Treaty allows the registering state of a space object to retain

[12] Roopashree Sharma, 'What is Space Junk (Debris) and why is it a global threat?' Jagran Josh (26 September 2023) <https://www.jagranjosh.com/general-knowledge/what-is-space-junk-1688640690-1> accessed 24 November 2023

[13] 'Committee on the Peaceful Uses of Outer Space' (*United Nations Office for Outer Space Affairs*) <https://www.unoosa.org/oosa/en/ourwork/copuos/index.html> accessed 24 November 2023

[14] 'Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies' (*United Nations Office of Outer Space Affairs*) <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html> accessed 24 November 2023

jurisdiction and control over the thing and its personnel. The ownership of space objects and their constituent elements is unaffected by their location in space. If discovered outside its borders, these objects or component elements must be returned to the registration state.

The 1975 *Convention on Registration of Objects Launched into Outer Space*[15] (the Registration Convention) and the 1968 *Agreement on the Rescue of Astronauts, the Return of Astronauts* and the Rescue Agreement expanded the provisions of Article VIII. In the absence of an international treaty to specifically regulate space safety, the provisions of Article VIII of the Outer Space Treaty and the Registration Convention may be interpreted as establishing a legal link or basis for assigning responsibility and possibly liability for the unsafe conduct of space transportation.

The 1979 *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*[16] (the Moon Agreement) contains no additional safety-related provisions. It has been ratified by a few states, none of which are major space-faring nations.

The 1992 *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (the NPS Principles), adopted as a UN Resolution and drafted by the Scientific and Technical Subcommittee of the COPUOS, contain the first set of principles and guidelines intended to ensure the safe use of nuclear power sources in outer space, particularly for the generation of electric power on board space objects for non-propulsive purposes. According to this Resolution, nuclear power sources in outer space should be based on a comprehensive safety assessment, including probabilistic risk analysis and to reduce the risk of accidental public exposure to harmful radiation or radioactive material. States that launch space objects with nuclear power sources must safeguard individuals, populations, and the biosphere from radiological dangers. It is possible to operate nuclear reactors (i) on interplanetary missions, (ii) in sufficiently high orbits, and (iii) in low-Earth orbits if they are stowed in sufficiently high orbits after the operational portion of

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[15] 'Convention on Registration of Objects Launched into Outer Space' (*United Nations Office of Outer Space Affairs*) <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introregistration-convention.html> accessed 25 November 2023

[16] 'Agreement Governing the Activities of States on the Moon and Other Celestial Bodies' (*United Nations Office of Outer Space Affairs*) <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/intromoon-agreement.html> accessed 25 November 2023

their mission. Moreover, the Fuel for nuclear reactors may have used only highly enriched uranium 235.

A launching state is required to conduct a comprehensive and exhaustive safety assessment. Before every launch, the results of this evaluation must be made public. After the re-entry into the earth's atmosphere of a space object carrying a nuclear power source or its components, the launching State is obligated to offer and, if requested by the affected State, provide the necessary assistance to eliminate actual and potentially harmful effects. These principles have been adhered to consistently. For instance, the United States informed the United Nations of the launch of the Cassini spacecraft, which is powered by 33 kilograms of plutonium. To investigate Saturn's magnetic and radiation environment, Cassini was launched by NASA, the European Space Agency, and the Italian Space Agency.[17] It is well known that the current environment of space debris poses a threat to earth-orbiting spacecraft and space travel. As the amount of waste increases, the likelihood of collisions that could result in potential damage will rise. In February 2007, the Scientific and Technical Subcommittee of the COPUOS endorsed the *Space Debris Mitigation Guidelines*[18] after several years of deliberation. These Guidelines apply to the mission planning, design, and operational phases (launch, mission, and disposition) of spacecraft and space transportation systems. According to the Guidelines, space systems should be constructed so they do not emit debris during normal operations. Additionally, avoiding the deliberate devastation of spacecraft and space transportation systems is prudent. States and international organisations must take measures, through national or their applicable mechanisms, to ensure that these Guidelines are implemented to the maximum extent possible through practices and procedures for space debris mitigation.[19]

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[17] 'Cassini-Huygens' (*NASA*) <https://solarsystem.nasa.gov/missions/cassini/overview/> accessed 25 November 2023

[18] 'Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space' (*United Nations Office of Outer Space Affairs*) <https://www.unoosa.org/pdf/publications/st_space_49E.pdf> accessed 25 November 2023

[19] Ram S. Jakhu and Yaw Nyampong, 'Are the Current International Space Treaties Sufficient to Regulate Space Safety, and Establish Responsibility and Liability?' (2nd IAASS Conference: Space Safety in a Global World, 14-16 May, 2007)

SPACE DEBRIS MITIGATION: STRATEGIES AND TECHNIQUES

- The design of spacecraft and orbital stages must prevent debris discharge during normal operations. The potential for break-ups throughout all phases of the mission has been reduced.
- Spacecraft or orbital stages completing their operational phases in orbits that pass through the LEO region should be de-orbited or, if necessary, manoeuvred into an orbit with a reduced lifetime (studies have determined that 25 years is a reasonable limit).
- If a spacecraft or orbital stage is to be disposed of by re-entry into the atmosphere, debris that reaches the Earth's surface should not pose an excessive risk.
- Missions should estimate and limit the likelihood of a collision occurring by accident during their orbital duration. Avoidance of manoeuvres for spacecraft and launch window coordination should be considered.[20]
- *Move satellites in higher orbits (particularly GEO), which are too far away to re-enter the atmosphere, into a mortuary orbit well outside the active satellite region.* This would establish a few hundred-kilometre-wide protected zone on either side of the GEO ring.

1. PREVENTIVE MEASURES

The most effective short-term measures consist of designing and operating launch vehicles and spacecraft with the least potential for explosion or disintegration. After a launch vehicle's upper stages have fulfilled their mission, their propellants and pressurants should be exhausted. Batteries should be equipped with electrical protection circuits to prevent detonation caused by electrical shorts. These measures reduce or eliminate the possibility of chemical combustion and reduce the severity of collisions when they occur, as they also remove excess energy from the object.

Since 1981, NASA's upper stages have been operated in a manner that drastically reduces the likelihood of them exploding in space. Japan and the ESA have recently adopted similar

[20] LEONARD DAVID, 'Space Junk Removal Is Not Going Smoothly' (*Scientific American*, 14 April 2021) <https://www.scientificamerican.com/article/space-junk-removal-is-not-going-smoothly/> accessed 25 November 2023

operational procedures. The costs of these procedures differ depending on the design of the upper stages and spacecraft. Still, they can be measured regarding the equivalent weight of the spacecraft that would have to be sacrificed to implement these procedures or the costs required to reduce the spacecraft's dry mass. Other preventative measures include designing and constructing spacecraft to resist environmental degradation from atomic oxygen and solar radiation and developing spacecraft and upper-stage separation procedures that restrict the spread of operational debris. [Below given Table 1 summarises the preventive measures and current mitigation activities].

Abandoning intentionally fragmenting inactive satellites in orbits where atmospheric drag is highly feeble and debris lifetime is correspondingly long would significantly reduce future orbital debris production. On timescales of a few months to a year, objects in shallow orbits (less than 250 km) descend into the atmosphere and burn up or plummet to the surface due to atmospheric drag. Although exceedingly small, drag forces as far as 500 to 600 kilometres may slow down space objects over a few years. High levels of solar activity induce an expansion of Earth's upper atmosphere, increasing atmospheric drag and a significant decrease in LEO debris. On 2 December 1989, the scientific satellite Solar Maximum recently demonstrated this phenomenon. The present cycle of heightened solar activity, remarkably intense, brought it down much faster than anticipated. The atmospheric drag experienced at these altitudes has frequently been used to evacuate upper stages and other objects whose missions have concluded.[21] For instance, the Strategic Defense Initiative Organization's Delta 180 experiment was conducted in low orbit so that the many small things deployed as part of the experiment could be removed from rotation within a few days.[22] With a redesign of the upper stages, it would be possible to position them in elliptical orbits that bring them into the upper atmosphere at perigee, resulting in a rapid deorbit.[23]

[21] 'What Is Atmospheric Drag? Learn How Atmospheric Drag Works and Its Impact on Space Missions' (*MasterClass*, 30 September 2021) <https://www.masterclass.com/articles/what-is-atmospheric-drag> accessed 25 November 2023

[22] Dwayne A. Day, 'Smashing satellites as part of the Delta 180 Strategic Defense Initiative mission' (*The Space Review*, 17 July 2023) <https://www.thespacereview.com/article/4622/1> accessed 26 November 2023

[23] Sylvestre (n 5)

Table 1 — Summarized current mitigation activities: prevention

S. No.	**Prevention activities Effectiveness**	
1	Limitation of debris release during operations	Low
2	Minimization of potential fragmentation during operations	Low
3	Limitation of the probability of accidental collision	High
4	Avoidance of intentional destruction and other harmful activities	Medium
5	Minimization of potential post-mission fragmentations	Medium
6	Limitation of abandoned spacecraft and launchers in the LEO region	Medium

[Source: Inter-Agency Space Debris Coordination Committee (IADC), 53rd Session of the Scientific and Technical Subcommittee United Nations Committee on the Peaceful Uses of Outer Space, 2016]

2. ACTIVE REMOVAL PROCEDURE

A few observers have proposed the active removal of existing debris. Some suggested methods would be prohibitively expensive and might even be counterproductive.[24] One proposed plan would use an orbiting object with a large cross-section, perhaps a spherical balloon filled with

[24] Day (n 22)

foam, to sweep up small debris over time. The use of space tethers has also been suggested. This technique would require attaching a tether between the debris object and a remover spacecraft and letting the tether out, causing the remover spacecraft to move higher in orbit, and the debris to move lower. Eventually, the debris object moves close enough to the upper atmosphere that, after being released from the tether, spirals and burns up. Satellites can be shielded against smaller debris pieces and attempt to avoid larger tracked debris. It is also essential to reduce the gap between these two regimes by improving shielding and tracking. In the 1960s, Astronomer Fred Whipple suggested using a dual-wall system to protect space systems from micrometeoroid impacts.[25] In this design, the outer wall (bumper) sacrifices itself to break up the impacting projectile. As a result, the inner wall is subjected only to the impact of many smaller fragments travelling at lower velocities. This inner wall is often a pressure vessel for the primary satellite structure. According to NASA, the following are some of the proposed methods of debris removal.[26]

3. SHIELDING AND OTHER PROTECTIVE MEASURES

Lasers: Objects are slowed using high-powered lasers launched from Earth, where space debris can be incinerated, allowing them to exit orbit. Today, China plans to clear up space debris using Laser-universe.

Space tugs: Using a mechanised grappling device on another spacecraft to tug an object to a new orbit or cause it to re-enter the atmosphere destructively is called space tug. A space tug is a spacecraft that transports multiple debris fragments from geosynchronous orbit to disposal orbits. In this procedure, Artificial Intelligence applications should be utilized.

Tethers: Tethers refer to 'using a momentum exchange tether that acts as a swing to draw objects out of orbit or an electrodynamics tether that causes drag on the satellite due to the earth's magnetic field. A conductive tether, or electrodynamics tether, is a long conducting wire whose

[25] 'Orbiting Debris: A Space Environmental Problem' (1990) US Congress Office of Technology Assessment <https://ota.fas.org/reports/9033.pdf> accessed 26 November 2023
[26] Nicholas L. Johnson, 'ORBITAL DEBRIS: THE GROWING THREAT TO SPACE OPERATIONS' (2010) ARES <https://ntrs.nasa.gov/api/citations/20100004498/downloads/20100004498.pdf> accessed 26 November 2023

motion through the earth's magnetic field generates electric potential. This tether can be affixed to the orbital debris of interest. Effective for de-orbiting large objects in low Earth orbit, the current generated by the rope produces a charge that de-orbits the thing, causing it to re-enter the Earth’s atmosphere more rapidly.’ This procedure is difficult and expensive to employ.

Iron Beam Shepherd: The space dynamics departments of the Technical University of Madrid (SDG-UPM) were the first to investigate this concept by creating analytical and numerical control models. It is a concept in which the orbit or characteristics of a spacecraft or a generic orbiting body are modified by having a beam of quasineutral plasma produce a force and torque on the target's surface. Ion and plasma thrusters, commonly used to propel spacecraft without physical attachment to the target, offer an intriguing solution for space applications such as debris removal and asteroid deflection.

Solar Sail: A photon or light sail is another name for a solar sail. This method for spacecraft uses pressure, radiation, and the impact of sunlight on big mirrors. The cube sail would use a solar sail's drag to pull space junk into lower orbits.

Net Capturing: The net is supposed to rotate around the Earth and collect the orbital debris; once the net is pulled on the planet, gravity would pull it down to the Earth, and it will burn up as it re-entered the atmosphere in the Earth. A British satellite has successfully deployed a net in orbit to demonstrate how to capture space debris.

4. SATELLITE DISPOSAL

Satellite disposal is a technique used to mitigate space debris, which refers to artificial objects in Earth's orbit that are no longer useful and can pose a risk to operational spacecraft. There are several methods used for satellite disposal, including:

Graveyard Orbit: This method involves manoeuvring the satellite into a higher orbit than its operational orbit. The satellite's remaining fuel propels it to this orbit, where it will remain stable for many years. This allows the satellite to be safely out of the way of operational spacecraft and reduces the risk of collisions.

Deorbiting: This method involves intentionally causing the satellite to re-enter Earth's atmosphere and burn up upon re-entry. This is typically done for satellites too large to be safely placed in a graveyard orbit or for satellites that have reached the end of their operational life and have no remaining fuel to manoeuvre.

Earth Escape Trajectory: This method involves propelling the satellite away from Earth and into an orbit around the sun or deep space. This method is typically reserved for spacecraft that cannot be deorbited or placed in a graveyard orbit.

In addition to these methods, it's important to note that satellite disposal is just one aspect of mitigating space debris. It is also essential to design spacecraft and launch vehicles with debris mitigation in mind and minimise the creation of new space debris through responsible satellite operations.

5. COLLISION AVOIDANCE MANOEUVRES

Tracking information can predict a collision in time for a satellite to manoeuvre out of the way. For example, the International Space Station (ISS) performs around one avoidance manoeuvre yearly. However, the relatively crude information from the SSN makes it challenging to predict collisions accurately, and there are so many close approaches that only some can be acted on. This problem may grow as the number of debris items increases. Modelling work has suggested that comparative approaches may rise from 13,000 a week in 2009 to 20,000 by 2019 and more than 50,000 by 2059, meaning satellite operators may have to make five times as many avoidance manoeuvres in 2059 as in 2019. Since each trick requires fuel, this shortens the active life of satellites or requires additional fuel to be carried into orbit, thus increasing the launch cost.

ENVIRONMENTAL ASPECT OF SPACE DEBRIS

Military, commercial, and scientific space operations may be hampered by space debris. Debris deposited today may impact these operations far in the future in some orbits. This section summarises the risks of orbital debris and describes its creation.

1. Hazards to Space Operations from Orbital Debris

Functional spacecraft face a variety of potential hazards from orbital debris:

1. Collisions A spacecraft's or its subsystems' performance may be significantly hindered by damage caused by collisions with functional satellites by space debris. For instance, a calculation found that over its planned 17-year lifespan, the April 1990-launched Hubble Space Telescope has a one in 100 chance of suffering severe orbital debris damage.37 Active payloads have already been struck by orbital debris. A Soviet spokesman claimed that the fall of Kosmos 954 was caused by an earlier collision with another object in January 1978 after the spacecraft's reentry in 1978. It is possible that Kosmos 1275 was obliterated in a collision with space junk.40 Further evidence suggests that some spacecraft fragmentation may have resulted from high-velocity impacts, primarily from statistical analyses of increases in orbital debris and other circumstantial evidence. In GEO, where the current ability to catalogue fragments is limited to objects larger than one meter, there is no way to determine if collisions have occurred because tracking technology's capability declines as the tracked objects' altitude increases.

2. Pollution The exhaust clouds formed when second-stage rockets boost a payload from LEO to GEO contain pollutants in the form of gases and particles. Millions of aluminium oxide particles can be launched into space by a single solid rocket motor, forming clouds that may linger for up to two weeks before dissipating and reentering the atmosphere. Therefore, the particles pose a serious risk to spacecraft during that time for surface erosion and contamination.

3. Interference with scientific and other observations can occur due to orbital debris. For example, the combination of byproducts from second-stage firings – gases, tiny solid particles and space glow (light emitted from the gases) – will often affect the accuracy of scientific data. Debris may also contaminate stratospheric cosmic dust collection experiments or interfere with the debris tracking process. The presence of artificial objects in space complicates the observations of natural phenomena. Astronomers are beginning to have difficulty determining whether a thing under observation is scientifically significant or if what they observe is just a piece of debris. As the number of debris particles increases, the amount of light they reflect also

increases, causing light pollution, a further interference with astronomers' efforts. Space debris has also disrupted the reception of radio telescopes and has distorted photographs from ground-based telescopes, affecting the accuracy of scientific results that might be obtained.

2. Difficulty in Proving harm to the Territory

In considering the inability to prove harm to a state's territory, we have the fact that outer space cannot be a State's territory via Article II of the Outer Space Treaty. Beyond that, an additional problem remains: States cannot establish harm to the outer space environment and cannot show impairment to their extreme space rights by orbital debris. In general, as noted by Brunnde, environmental concerns have legal relevance only to the extent that they coincide with an interference with States' sovereign rights, usually related to their territorial sovereignty. The fact is that the Outer Space Treaty structure is focused on the State's rights rather than protecting the environment. Only one reference is made to the environment in Article IX, but many commenters have noted that it remains woefully inadequate for preventing debris as it is also State-centric. This includes a lack of definition of harmful contamination, a lack of standing for nonparty States, no requirement of even reaching an agreement and a lack of a forum in case of a deadlock. As orbital debris tends to only interfere with States' rights after a collision with an object over which the State has jurisdiction, there remains a significant gap in protecting Earth's orbits from pollution. Assuming a State is a party to the Outer Space Treaty, it has the freedom to use and explore outer space. While Article I explicitly says that such use should be in the interest of all States, the current debris issue suggests that States are unlikely to hold one another to account where that debris impacts their freedom of use. This may be partly due to the difficulty of tracing a specific piece of debris back to a single launching State. However, States remain inactive even when a cause of action may exist under the Liability Convention.

CONCLUSION

Space debris poses a significant hazard to active satellites, particularly high-value spacecraft. Influential space organisations are constantly monitoring debris with the space debris environment model. In addition, researchers propose several techniques for removing the debris, such as using a claw, net, or gecko-adhesive tool to capture the debris and deploying a ground-based or space-based laser to deorbit the debris. However, spacecraft will require significant fuel to pursue and catch up with the debris. Therefore, the debris engine proposed in this paper is a potential thruster for spacecraft to remove debris and convert it into propellant continuously. As implied, it is reasonable to assume that approximately 90% of the fragmentation debris is medium density. Specifically, alloys comprise a sizeable portion of the medium-density material.

This paper has demonstrated that the current international space regimes on safety, responsibility, and liability (treaty provisions and non-binding principles and guidelines) need to be revised to regulate emergent trends in space transportation. It has also demonstrated the effectiveness of extant comparative regimes in international civil aviation, particularly in safety regulation. As the problem of orbital debris originates from legal freedom, the only sure way to prevent the tragedy of the orbital commons is for all states to agree to a restriction on this legal liberty. Since the creation of the last space treaty, international environmental law has evolved significantly. Other regimes demonstrate that a regime's rejection of common heritage does not preclude adopting the idea of common concern. Clarity regarding which space objects can be remedied, a legal definition of orbital debris, an update to reporting obligations, and mandatory mitigation measures are urgently required.