SPECIAL REPORT

Clean It Up: A Special Report on Artificial Space Debris

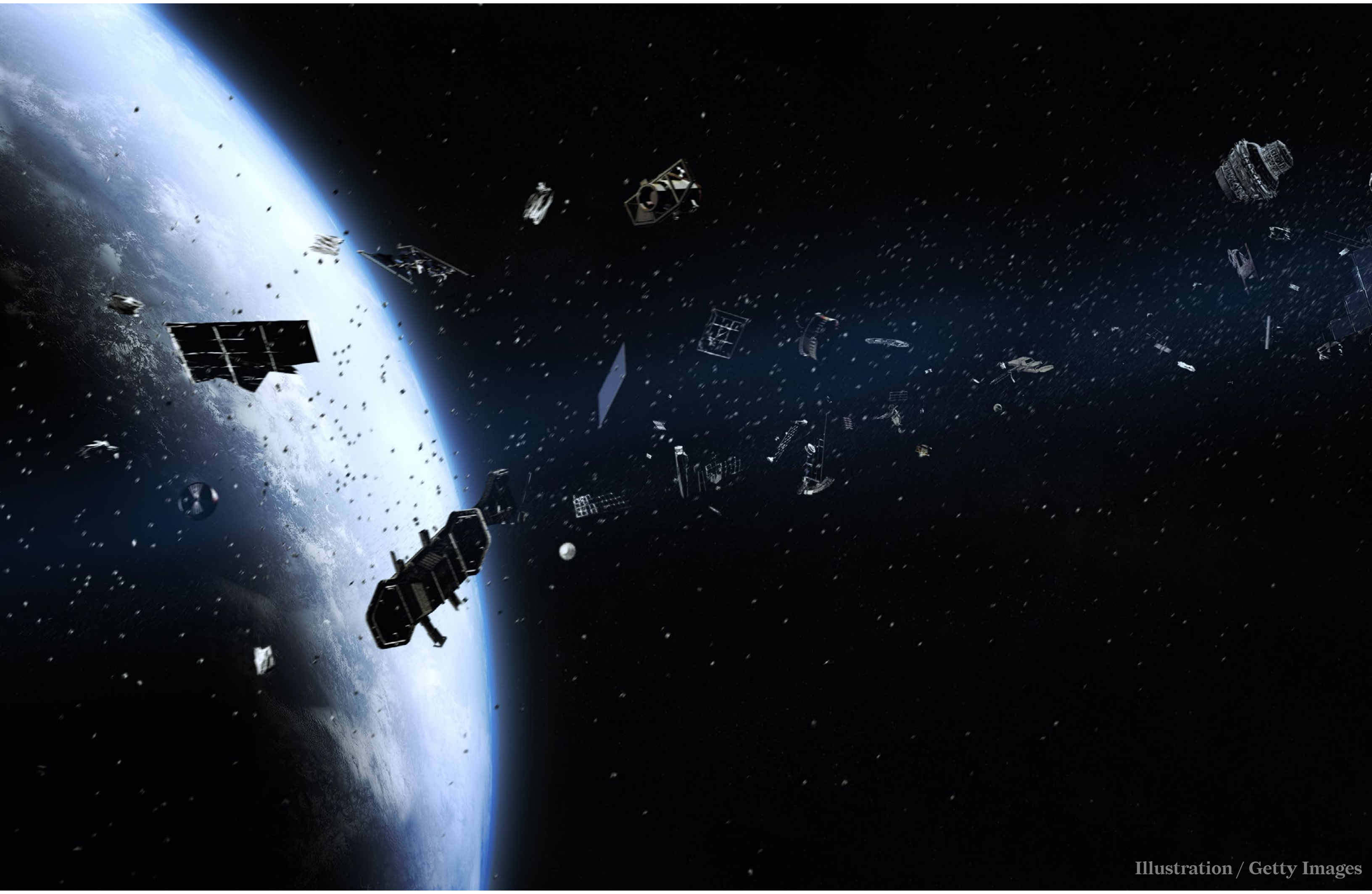

Illustration / Getty Images

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Clean It Up: A Special Report on Artificial Space Debris

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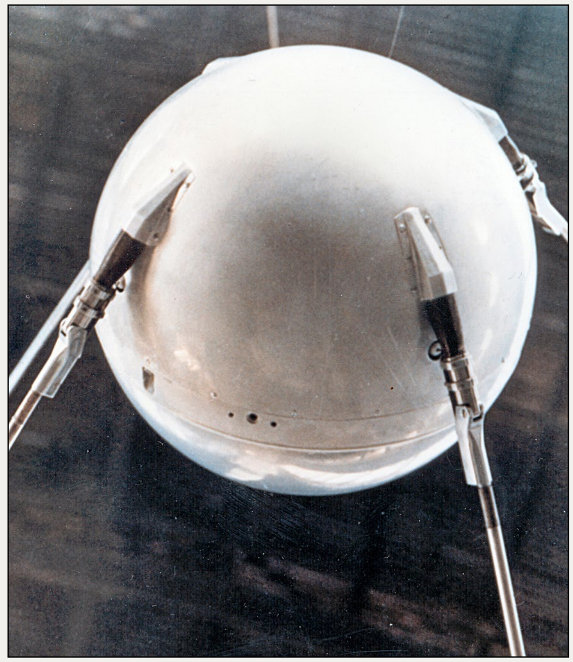
COVER: Artist's depiction of the cosmic junkyard (janiecbros / iStock/ Getty Images Plus)

Overview

In their early spacefaring age, humans have already cluttered Earth's orbital bands with artificial space debris. Indeed, they've created an important and urgent challenge even as they've increased their interests in and dependence on this future frontier. Artificial space debris is a threat to safety, security, peace, and prosperity around the world.

In this special report, the Future Frontiers team at the New Lines Institute explains how spacefarers have congested and cluttered the parts of outer space they find most useful; considers the way states and companies have created artificial space debris through negligent, reckless, or purposeful practices; analyzes the consequences of and early measures to address such debris; and provides legal, regulatory, commercial, and technical recommendations for American and other leaders who may counter space debris by adopting a full-spectrum approach to prevent, manage, and remove it over time.



The Soviet Union's Sputnik 1 satellite launched in 1957. It was the first satellite put into orbit. There are now more than 7,000 active assets orbiting the Earth. (Fine Art Images / Heritage Images / Getty Images)

Spacefarers Have Cluttered Earth's Orbital Bands

After gazing at the stars for millennia, humans have raced to space in just a few decades. Doing so, they haven't necessarily created clear regulations for activities beyond Earth. Of course, states have considered space-specific rules since at least the 1950s, but few have had the strategic interests, political ambitions, technical capabilities, and required resources to engage in space-related activities. Moreover, spacefarers didn't necessarily concern themselves with removing objects once they'd placed them in the heavens.[1]

Since the Soviet launch of Sputnik I in 1957, spacefarers have been increasing their activities in outer space. Humans were operating about 770 active satellites at the turn of the millennium, and they now rely on more than 7,000 active assets in space. Already on track to hit 10,000 soon, they've also been designing and developing complex space systems, including constellations with hundreds or thousands of satellites operating together.[2] Launching more assets into space every day, humans are also increasing the rate of relevant increases across the board:[3] current launches, planned programs, required facilities, allocated funds, active and inactive assets, and so on. Despite limits and bottlenecks in the short run, humans will continue increasing space activities, the intricacy of space assets and systems, and general interest in outer space. By 2030, spacefaring entities will likely be operating tens of thousands of active assets around Earth. More states and companies will identify interests, develop capabilities, and join the fray in outer space. For the foreseeable future, humans will be increasing space activities "in an aggressive, non-linear way … and even exponentially."[4]

Congesting space with active assets, spacefarers have also cluttered Earth's orbital bands with other objects: artificial space debris – space junk. For every satellite that they've put up into orbit, spacefarers have simultaneously littered Earth's near-afar with useless, dangerous, and harmful objects.[5] Almost all artificial objects orbiting the Earth are junk: fuel droplets, paint chips, metal bits, rocket phases, inactive satellites, and more. About 95% of observed objects are debris; so, too, are 90% of the largest objects that civilian agencies, military units, companies, and organizations are able to track.[6] After launching more than 19,000 satellites into orbit from 1950 to 2020, spacefarers must now navigate an environment cluttered with 13,000 defunct satellites[7] and hundreds of millions of pieces of debris.[8]

Humans are aware of tens of thousands of artificial objects larger than 10 centimeters in diameter; assess more than 500,000 artificial objects from 1-10 centimeters; and estimate at least 100 million artificial bits at least 1 millimeter, – too small to see yet large enough to damage space assets when traveling at the hypervelocities of space.[9] Tracking 40,000 larger objects, the vast majority of which are debris, space agencies assess that perhaps 170 million pieces of dangerous debris race around Earth's useful orbital bands today.[10]

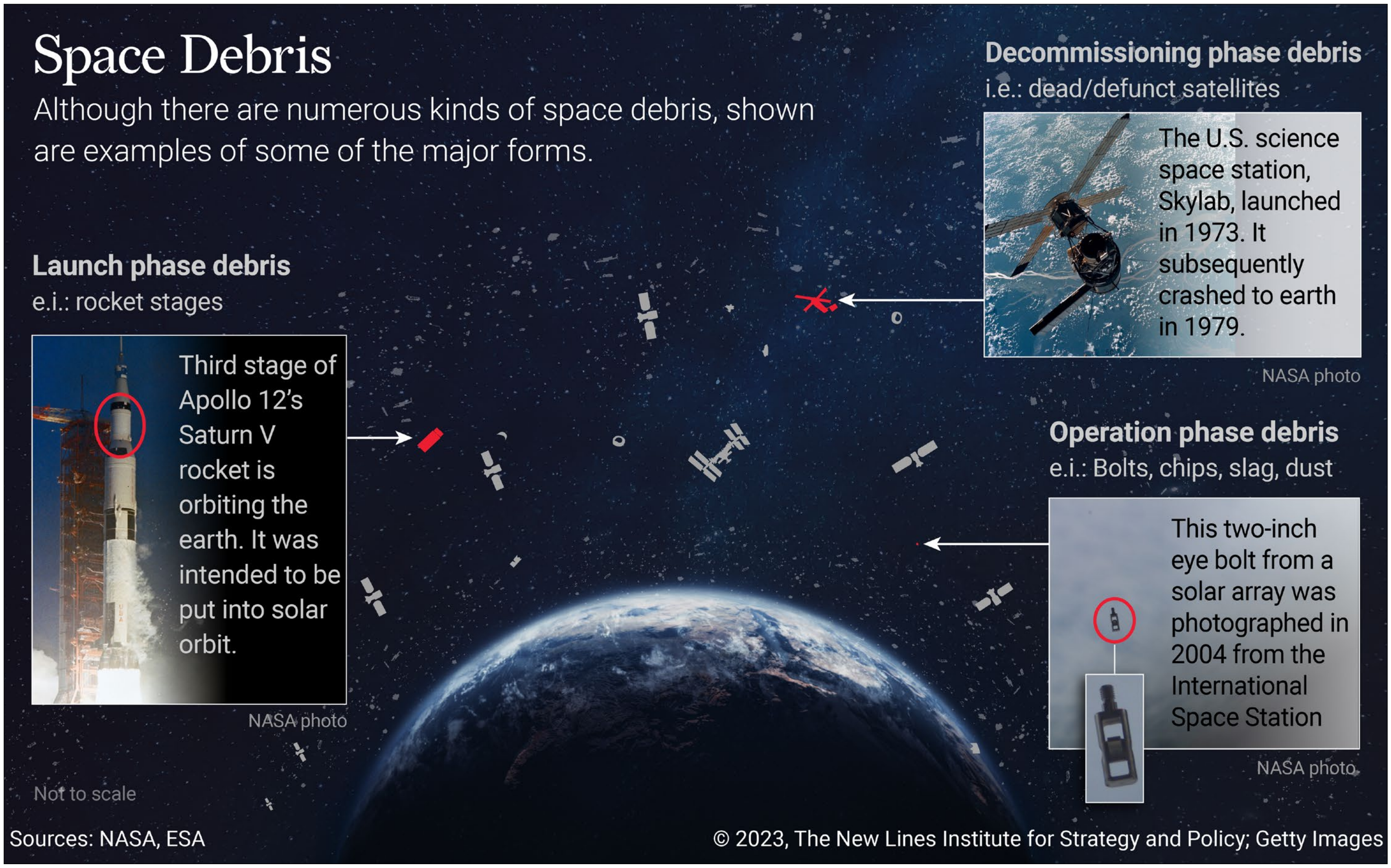
The amount of debris is "astounding"[11] given where it is concentrated and the brief time in which humans have created it.[12] Humans only operate in certain areas of space due to physics, purpose, and feasibility.[13] Almost all satellites fly around three orbital bands: low-Earth orbits, from 300-2,000 kilometers above Earth; medium-Earth orbits, from 2,000-35,000 kilometers; and geosynchronous orbits, starting at 36,000 kilometers. Operators use these bands to accomplish various aims. They may place satellites in lower orbital bands for many scientific research purposes, such as NASA's Earth Observing System satellites. They may use mid-Earth orbits to enable navigation on, observation of, and monitoring of missions pertaining to Earth. Operators may use higher orbital bands for meteorological and certain telecommunications systems.

Because "celestial mechanics and human uses of space"[14] differ in each orbital band, spacefarers must adopt nuanced approaches while identifying threats, managing risks, and contemplating solutions.[15] For instance, they must act urgently in lower orbital bands, even as doing so will be more difficult. In lower orbital bands, assets move around the planet faster, maneuver more frequently, and are closer to other objects. Besides increasing uncertainty, risk, and consequence in lower bands,[16] this could obstruct and complicate human access to space more generally because lower orbital bands are essentially staging zones for launching positioning assets and a screen through which humans conduct earthbound observation of outer space (now warped by debris and satellite light pollution). Other orbital bands, or what are essentially tracks or space-lanes within them, are also congested with active assets and could become cluttered with debris, too.[17]

Humans have thus created threats and risks while broadening and deepening dependance on space, including in communications, logistics, navigation, and meteorology. Even if they maintain current levels of activity, states and companies could create as many as 50 large pieces of space debris per year for the foreseeable future.[18] Not only are these large pieces problematic, but each of them is essentially a debris "field or cloud waiting to happen."[19] With continued collisions, explosions, and/or basic degradation, such observable objects will eventually create thousands of smaller objects through cascading collisions.

Spacefaring states and companies have created challenges for themselves now and in the long run; for individual assets, larger systems, and aggregations or combinations of both;[20] and in space and throughout space-dependent sectors on Earth. The threats aren't theoretical; humans have already paid the price for space debris.

Increasingly, collisions between artificial objects have had consequences for human activity in space and space-related systems on Earth. In 1996, for instance, an operational French microsatellite collided with part of what was once an Ariane rocket. Then, in 2009, a large piece of debris destroyed an operational satellite: The Cosmos 2251, an inactive Russian military satellite, smashed into the Iridium 33 satellite, which the U.S.-based company Motorola had been operating to provide telecommunications services. These collisions created hundreds



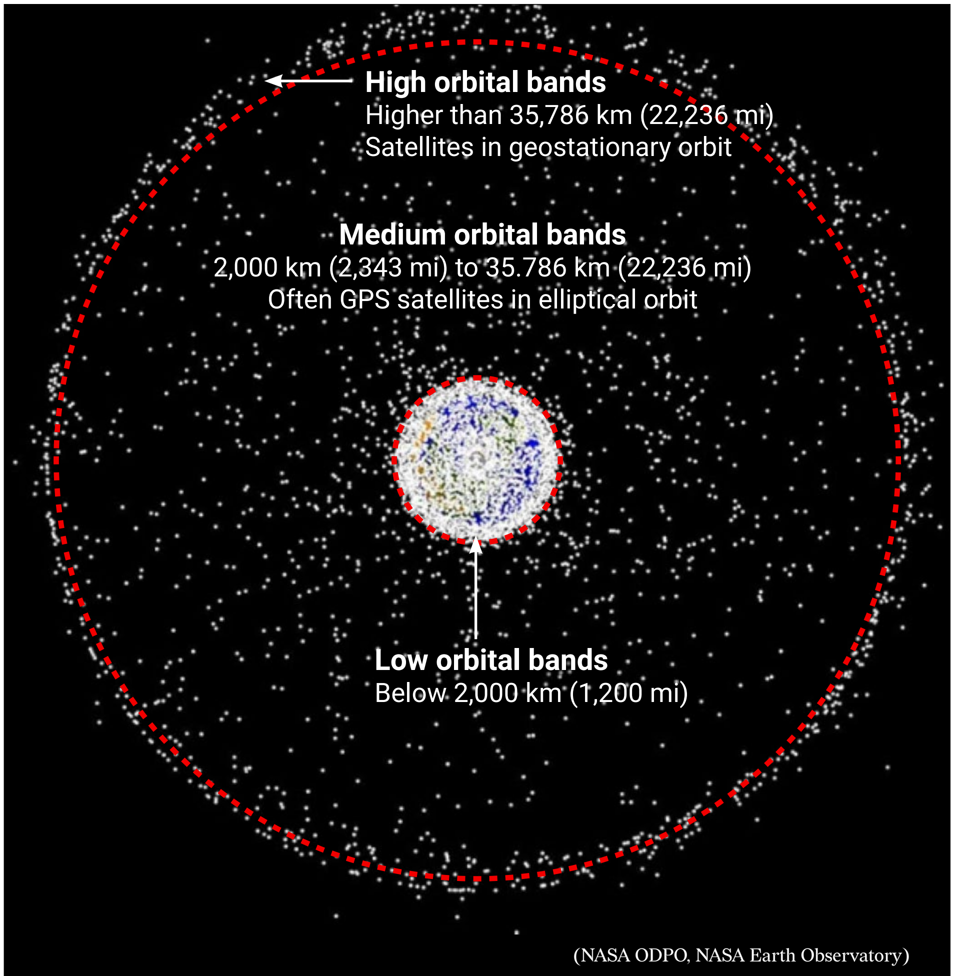
or thousands of pieces of debris, which have raced around Earth, colliding or threatening to collide with other objects.

Working in congested and cluttered bands, operators must maneuver active assets more frequently to avoid collisions. For every maneuver, they must use resources such as fuel, power, money, bandwidth, and capital. Moreover, each maneuver creates new risks due to uncertainty of positions, trajectories, knock-on effects, and unknown variables. Usually, operators maneuver assets if they determine that the probability of a collision exceeds a set threshold.[21] Because of incomplete information and inadequate modeling, communication, and more, operators must move assets more frequently than they'd prefer. A few decades ago, leading space agencies had to avoid (dangerous) debris about 100 times a year. Over the past year and change, though, SpaceX alone maneuvered assets about 25,000 times.[22]

Crewed space vehicles are at risk, too. When it operated space shuttles, NASA always accounted for debris as risks to vessels, crewmembers, and related assets. Generally, NASA replaced about two windows per mission. Over the shuttle program's lifecycle, they replaced at least 70 windows due to debris hits at a direct cost of $50,000 per window.[23] At least once, the agency had to replace shuttle windows damaged by "flecks of paint, traveling at up to 17,500 miles per hour."[24] Throughout its life cycle, the International Space Station has "regularly tweak(ed) its orbit" to avoid space debris. In decades of operation, the space station's crewmembers have had to take cover repeatedly. In 2009, for instance, they evacuated the space station due to debris risks. In 2011, when unidentified space junk nearly collided with the facility, they sheltered aboard a Soyuz spacecraft essentially rendered into a lifeboat.[25] Having had to repeatedly dodge debris from Chinese and Russian kinetic, destructive anti-satellite tests,[26] crewmembers in 2021 needed to shut the space station's hatches and shelter in their spacecraft while passing through debris clouds originating from similar Russian actions.[27] As humans continue to commercialize outer space, they'll increase the individual, aggregate, and compounding costs – including more risk to people in space – of cluttered orbital bands.[28]

Objects have collided or come close to colliding during basic commercial operations. Operators must manage active assets while navigating environments of active and inactive or uncommunicative assets in addition to debris. Besides basic collision risks, spacefaring entities complicate matters more by declining to share information; refusing to respond to others who try to deconflict generally or avoid collisions specifically; and maneuvering in imperfect environments, including around other objects with uncertain positions, trajectories, and characteristics.[29]

Civilian agencies, militaries, and companies alike have sometimes provided information in good faith only to find themselves "stuck playing chicken or trying to maneuver (active assets) not knowing if others (will) also move."[30] In April 2021, for instance, satellites for SpaceX[31] and U.K.-based OneWeb came within 190 feet of each other. Sometimes, objects have zipped within a few hundred feet of each other while being much closer than operators assessed.[32] Other times, including in what would have been a "catastrophic" collision, different active assets and debris objects have shot past each other with as little as 20 feet of space between them.[33]



Tracking Debris

The U.S. Space Surveillance Network tracks debris larger than 10 cm to minimize collision risk. The image shows tracked man-made objects. Of the more than 25,000 objects being tracked, most orbit close to the Earth. There are also countless pieces too small to be tracked, but can still damage or destroy satellites in a collision.

Source: NASA

Debris may also smash into the Earth's surface. Indeed, more than 6,000 tons of artificial material have already fallen from space back to Earth during the spacefaring era. In 1978, the Soviet satellite Cosmos 954 reentered Earth's atmosphere, contaminating Canada with about 50 kilograms of uranium. Launching a campaign to clean 124,000 square kilometers of territory,[34] Canada also was the first, and still only, country to invoke the Liability Convention.[35]

In 1979, Skylab crashed to Earth. The American space station, still the largest artificial object ever sent into orbit and weighing about 80 tons when intact, broke up upon reentry and scattered more than 20 tons of debris in Australia.[36] (The debris hit the sparsely populated Australian desert. No people died or suffered injuries.)

The United States hasn't been free of debris, either. In the 1990s, a Delta II rocket "brushed" a woman's shoulder in Oklahoma, the only time so far that artificial space debris has hit a human on Earth.[37] The same rocket's 250-pound fuel tank landed near a farmhouse in Texas. In 2003, after the space shuttle Columbia disintegrated while reentering Earth's atmosphere, about 85,000 pieces hit parts of Texas and Louisiana.[38]

For decades, metallic balls have been falling on populated parts of southern Africa; some of them have probably been parts of rockets used in uncrewed launches, such as one that slammed into Namibia in 2011. (Scientists and engineers are not always able to identify or confirm such objects.) In July 2023, part of a rocket washed up on the shores north of Perth, Australia. Australian and Indian space agencies have confirmed that the debris was part of an Indian Space Research Organization satellite launch vehicle.[39]

All states and societies may suffer from the consequences of space debris beyond damage done in orbital bands or on the Earth's surface. Sharing in the fruits of responsible and productive space activities, humans in polities around the world have entwined their earthbound polities, economies, and societies with space-based systems.[40] When debris damages or destroys space assets or systems, it will have negative and compounding consequences on vital services, systems, and sectors on the ground.[41] Over time, space debris will become a more significant problem for all humanity.

From "Kessler Syndrome" as a Theory to Artificial Space Debris as a Threat

Humans have created most space debris through lax launch practices, inadequate asset management, and anti-satellite actions. Although spacefarers have engaged in deliberate and even aggressive actions, they've done most of their harm through naive, negligent, and reckless practices. Agencies and companies have been creating debris during launches and related operations: rocket phases, chemical byproducts, dust, and slag.[42] Space asset operators have not accounted for or addressed how degradation, explosions, and collisions create debris during an asset's active phase. From the beginning, artificial satellites have been breaking apart due to degradation even without collisions or explosions).[43] Meanwhile, explosions due to excess fuel, onboard batteries, or other components have probably been the "biggest contributor[s]" to the current space debris problem."[44] Spacefaring states also have engaged in destructive actions including kinetic, destructive anti-satellite tests. American, Chinese, Indian, and Russian spacefarers have done so in different decades. In all instances, unknown causes have created more debris: unobserved or unattributed explosions of or collisions between active assets and debris hitting more debris and fragmenting further.

As they became more familiar with space, scientists and engineers theorized a problem: Humans were creating debris faster than debris was disappearing. What's more, humans could create debris in an instant that could last centuries. By the late 1970s, including in a seminal paper on satellite collisions, NASA scientists were assessing that spacefarers had created challenges for themselves by cluttering Earth's orbital bands.[45] They also theorized the risk of cascading collisions between active assets and debris. In this doomsday scenario, which scientists call the Kessler Syndrome, orbital bands around Earth could become inaccessible due to debris. Even setting aside worst-case scenarios, spacefarers have since assessed that just a few significant collisions could render orbital bands unsafe for humans and assets alike.

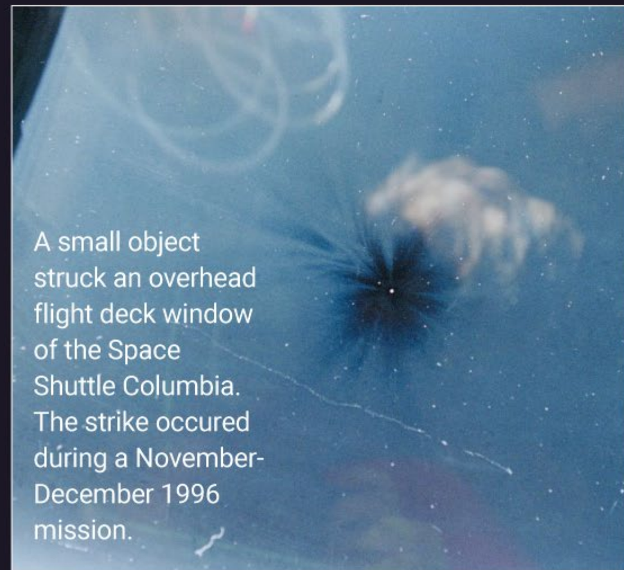
Scientists and engineers have projected that a catastrophic collision, creating more hazardous debris, could occur once every five to 10 years, even before accounting for increases in space activity and operational complexity.[46] Indeed, in recent years orbital bands have only become more congested with active assets and more cluttered with debris.[47] No longer a theoretical development, artificial space debris is now an urgent threat.[48]

Sustainability Practices

Creating at least one virtuous circle in the early spacefaring age, humans have improved space situational awareness, elevated their standards for such awareness, and become adept at monitoring hazards around Earth.[49] Awareness has also been necessary for better behavior; it will remain

Space Debris Numbers

- **Active assets in space: 7,000+**
- **Tracked, human-made objects**
  - Pieces of debris: **Hundreds of millions**
  - "Large" objects: **40,000 pieces**
  - "Small" objects: **500,000 pieces**
  - "Dangerous" debris: **170,000,000 pieces**
- **Significant, confirmed in-orbit fragmentation "events": About 650**



A small object struck an overhead flight deck window of the Space Shuttle Columbia. The strike occured during a November-December 1996 mission.

NASA

Sources: New Lines interviews, space agencies such as NASA and ESA, and think tank reports cited in this publication.

necessary, though not sufficient, for better behavior in the future. After all, spacefarers won't be able to identify and solve problems if they can't see, sense, detect, or otherwise observe outer space.[50]

In the U.S. government, armed services, and connected enterprises, scientists and engineers developed contemporary observation through initiatives such as Project Space Track and the North American Air Defense's Space Object Catalog.[51] Improving their awareness in their early spacefaring years, humans began to understand that they could congest the areas around Earth. Then, they began to understand that debris due to degradation, even without explosions and collisions, could be a problem for future spacefarers.

Leaders have adopted better practices to prevent and manage problems such as artificial space debris. They've done so domestically and internationally; using legal, commercial, and technical tools; and through public platforms and closed channels alike. Since 1988, American administrations have declared, designed, and implemented policies to avoid creating new space debris.[52] Governments of other spacefaring polities have done the same, including Japan, the United Kingdom, the European Union and member states, and the Soviet Union and successor states such as Russia and Ukraine. In the late 1980s, European and American government agencies released reports related to orbital debris. By the mid-1990s, generalists and specialists alike were trying to classify artificial debris as a "pressing problem" in low-earth and geostationary orbits and predicted that it would become a serious challenge elsewhere, too.[53]

As American, European, and Asian spacefarers developed their programs, they began adopting and adhering to responsible practices unilaterally while working to set standards multilaterally and even globally. They also began creating issue groups in their respective polities and on the international stage. As the Reagan, Bush, and Clinton administrations crafted their space policies, they directed agencies to produce debris-related reports and eventually established a U.S. interagency working group on debris.[54] In 1989, U.S. officials recommended that American leaders create mechanisms for and share information on debris with counterparts in other states. By the mid-1990s, they had created the frames through which Americans have since seen space debris: measurement, monitoring, and modeling, perhaps with a focus on risk management rather than removal; distinctions between lower orbital bands and other orbital bands, usually while seeing the former as having more urgent debris problems than the latter; and preferences for guidelines, best practices, and careful rulemaking, rather than strict, binding, or reactive approaches.

Globally, diplomats, officials, and technical leads worked to find viable solutions without unduly increasing venture costs. For instance, they suggested and sometimes required spacefarers to eliminate excess fuel after launch to reduce risks of debris-creating explosions. After American agencies recommended international initiatives, spacefaring agencies formed committees and working groups dedicated to debris. The United States entered bilateral working groups with Japan, Europe, and Russia. By 1999, American, French, and Japanese space agencies had each adopted policies on debris mitigation and the U.N. Committee on the Peaceful Uses of Outer Space had published a technical report on debris.

States then created a multilateral committee initially including the space agencies of the United States, Europe, Japan, and Russia: the Inter-Agency Space Debris Coordination Committee (IADC).[55] In 2002, the IADC issued consensus guidelines from which international organizations and states have since developed rules.[56] In 2007, the U.N. Committee on the Peaceful Uses of Outer Space issued guidelines on the mitigation of orbital debris.[57]

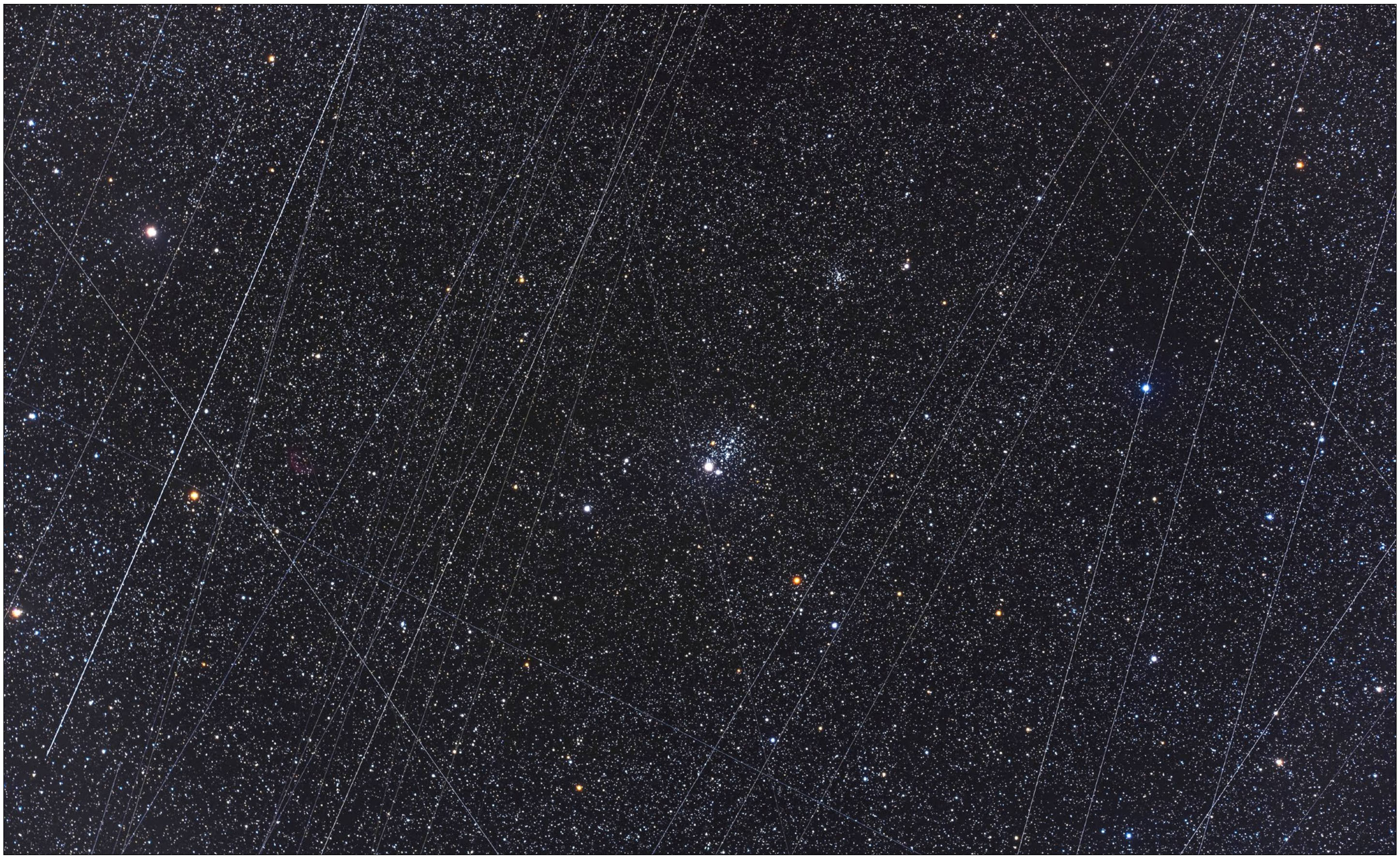
Other organizations have done the same, including in specific sectors or while standardizing practices generally.[58] The U.N. International Telecommunications Union has released guidelines pertaining to geosynchronous orbital bands – including placing inactive assets in so-called "graveyard areas" at least 200 kilometers above the highest used orbital bands, reducing risks of collisions or other interference.[59] Meanwhile, the International Organization for Standardization has issued several international standards and technical reports on space debris, including an accepted, though not necessarily implemented or enforced, 25-year window to decommission assets after ending their use.[60]

Despite taking small steps, spacefarers failed to enter into international agreements on debris-creating behavior, such as destructive, kinetic anti-satellite actions, or otherwise to counter debris effectively. By the mid-2000s, leaders were close to some debris-related agreements or understandings. But they hit a "pivot point" when the Chinese conducted a destructive, kinetic anti-satellite test in 2007.[61] Engaging in a direct-ascent, on-orbit strike, they destroyed one of their own inactive weather satellites in an orbital band that American and allied agencies may use for intelligence imagery,[62] scattering thousands of pieces of observable, long-lasting debris and more than 30,000 bits of smaller debris.[63] They also helped shatter two decades of international restraint in practice and nascent rule-making in principle.[64]

After the Chinese test, three spacefaring states conducted similar actions in the ensuing years. During Operation Burnt Frost,[65] American officials struck a satellite with a ship-based missile defense interceptor in early 2008.[66] They declared that they needed to destroy a defunct intelligence satellite full of dangerous propellant, preventing greater harm on Earth. Calibrating the strike carefully, above all by hitting the satellite in a very low orbital band, they created about 175 pieces of observed debris, all of which had burned up in the Earth's atmosphere by 2009.[67] However, despite declarations then and since, U.S. officials were responding directly to the Chinese test[68] while engaging in a "strut" to show they could hit space assets "from any ocean on [Earth]."[69]

Indian leaders reconsidered their policies toward outer space, too.[70] Deliberating for a decade,[71] the Indian government executed Mission Power in 2019. Trying to minimize long-lasting debris, Indian spacefarers nonetheless created hundreds of fragments that stayed in space for months. They ended up blasting bits as far as 1,000 kilometers above Earth, well above any area that spacefaring states consider safe due to natural deorbiting or degradation that could eradicate some debris.

Having conducted several destructive tests since completing the world's first one in 1968, Russian officials hit a satellite in 2021 and created more than 1,500 pieces of identified, tracked debris. Debris due to such tests, specifically the Chinese and Russian ones, will for decades "pose a threat to activities in outer space … putting satellites and space missions at risk, as



Numerous satellite trails frame this photo of the Owl Cluster in the constellation Cassiopeia. The lines were recorded over a 36-minute shutter exposure during an October 2022 night. (Alan Dyer /VW Pics / Universal Images Group via Getty Images)

well as forcing more collision avoidance maneuvers."[72]

Against that backdrop, states have struggled to shape rules on debris-related issues, anti-satellite testing, responsible space activities, and space sustainability. They've yet to establish specific international norms, let alone enter treaties or crystallize customary international law, on even the most indiscriminate, destructive, and counterproductive sorts of debris-creating space actions.[73]

Far from perfect,[74] American and allied leaders have nonetheless set standards for and adopted responsible practices in outer space. Having long created, published, and updated policies and guidelines such as the Orbital Debris Mitigation Standard Practices,[75] U.S. civilian agencies and armed forces have worked together to set standards at home and cooperate with similarly responsible European, Asian, and other spacefarers abroad.

For decades, the U.S. Defense Department has shared information generally and specifically at no direct financial cost to others. So, too, have units in the armed forces. For instance, the 18th Space Defense Squadron of the U.S. Space Force has provided other spacefarers with collision warnings regardless of whether they respond, acknowledge, or appear to change behavior due to new knowledge.[76] It and other units continue to do so while American officials reorganize space-related institutions and transfer responsibility to civilian agencies, including in the U.S. Commerce Department. Declaring its "tenets" of responsible behavior in space, the U.S. Defense Department emphasized communication and safety generally while committing specifically to "limit the generation of long-lived debris."[77] By 2022, the

Biden administration had declared a unilateral moratorium on certain anti-satellite testing and committed itself to shaping an international norm to that effect.[78]

European and Asian states, companies, and other stakeholders have also been leading efforts to control the debris problem for decades. Besides union charters and policies,[79] for instance, Europeans have proposed voluntary, multilateral arrangements such as an International Code of Conduct.[80] Having never conducted anti-satellite tests, the French have long pushed for an international ban on kinetic, destructive, and irreversible actions.[81] The Japanese have for decades boosted responsible practices[82] while also supporting research and demonstration programs for active debris removal.[83]

Other states have tried to create different rules. Rejecting treaty bans, preventing principles from crystallizing as customary law, and declining to declare unilateral moratoriums, the Chinese and Russians have conducted destructive tests while proposing rules that neither restrict nor discourage such behavior in space.[84] In addition to testing technology and demonstrating capabilities at home and abroad, they may also be trying to actively shape rules in space, rather than reject or resist them once established, as they have in other domains like Earth's seas.[85] For instance, they've co-drafted, introduced, and pushed a Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects.[86] Trying to ban only space-based weapons, they've not included any provisions or accepted amendments to restrict reckless, knowing, or purposeful debris-creating behavior such as direct-ascent anti-satellite actions they've each conducted since the mid-2000s.[87]

Spacefarers Must Mitigate and Remove Artificial Debris

Spacefarers must prevent, manage, and remove artificial space debris. For starters, they must recognize that these issues are both important and urgent and begin or resume relevant rule-making as a priority.[88] As they do so, American and other leaders may shape strategies, laws, and rules for every phase of the space asset life cycle; adopt different approaches in each useable band of space; and reject false choices between preventing, managing, and eliminating relevant problems. Even if they must live with certain debris in some areas, essentially engaging in risk management for different assets and systems, stakeholders must embrace the full spectrum of counter-debris options for longer-range human endeavors in space.

Despite differences, the most influential and sophisticated spacefaring states have a clear, shared interest in controlling artificial debris around Earth. American leaders have significant interests in "leading the norm development process" in outer space.[89] European and Asian leaders, especially in France and Japan, have long done the same.[90] Although states such as India have adopted complex positions over the past decade, they've generally behaved responsibly and tried to balance acute strategic concerns against the longer-range development of principles.[91] Regardless of rivalry or purported comfort in space-related asymmetries, even states such as China and Russia would suffer significantly from debris-related disruption or destruction around Earth.[92]

Moreover, all states have interests related to space, regardless of their engagement in spacefaring. As part of more active and creative diplomacy, U.S. leaders must engage all states on such space-related issues while integrating efforts into bilateral and multilateral relationships.

Beginning at home, American lawmakers and officials must craft laws to effectively prevent, manage, and remove space debris. They may adopt a two-pronged approach to compel and coax spacefaring entities into more effective decommissioning, including but not limited to deorbiting. On one front, until U.S. legislators enact specific laws on these matters,[93] regulators may work within their respective departments and agencies – ideally in a timebound, evidence-based, outcome-oriented, broad interagency process – to consider changing rules. They may reduce the time that owners and operators must decommission assets at the end of their life cycles. Around the world, separate agencies[94] regulate different space assets, phases of the space asset life cycle, and/or space-based

> “Because they’ve already cluttered Earth’s orbital bands, spacefaring states and companies must actively remove – not only prevent and cope with – artificial space debris.”

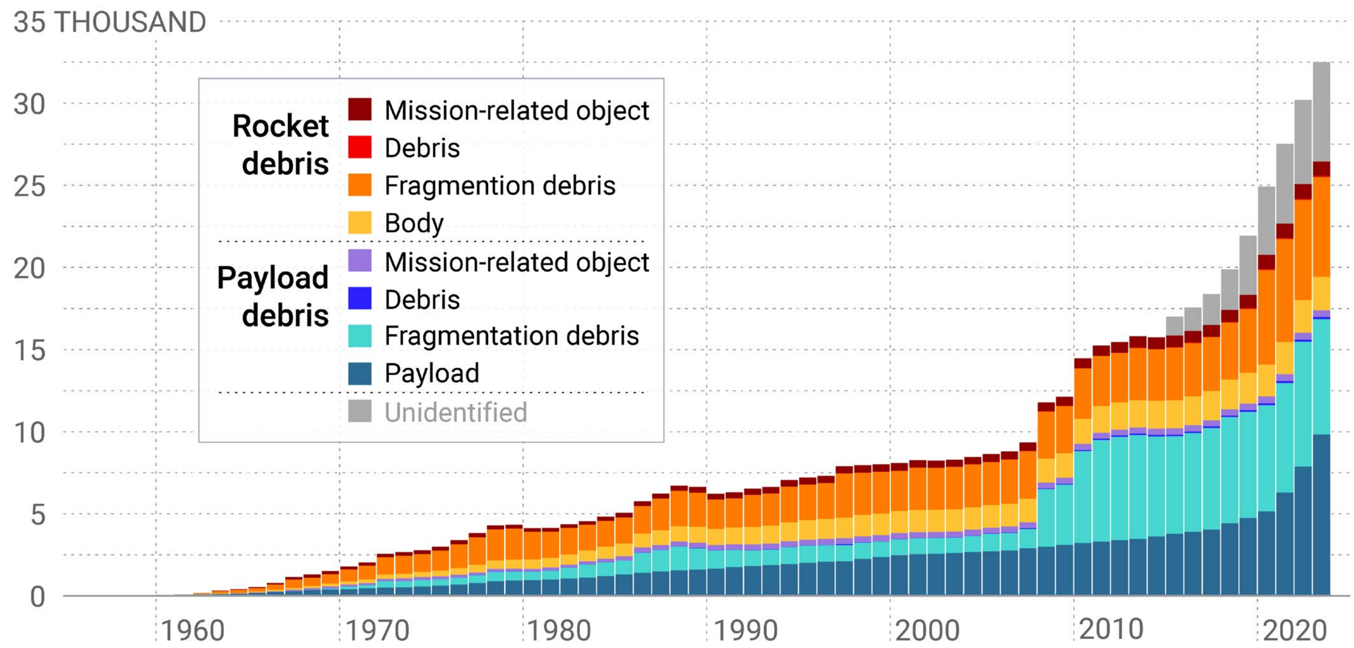
or space-related activities. In the United States, the Federal Aviation Administration grants launch licenses and regulates reentry to Earth, while the Federal Communications Commission regulates telecommunications satellites and spectrum use. On the other front, with or without rule changes, regulators must improve enforcement as companies must improve compliance.[95] Indeed, if regulators enforced and companies complied with even the existing 25-year rule, they could cut space debris growth significantly in the decades to come (perhaps even by 110% in the next two centuries, whereas continuing current practices could result in 330% growth in that time).[96]

Besides trying to prevent debris creation, spacefarers must manage assets in the orbital environment. To do so, they must work on at least three fronts: earthbound object observation, space-based monitoring, and asset maneuverability. For instance, they'll need to keep building and using more facilities beyond the northern swathes of the Northern Hemisphere while positioning satellite systems for in-orbit monitoring and modeling. Using everything from ground-bound radar posts to space-based satellite monitoring systems, governments and companies alike are contributing solutions for the future.[97] Eventually, if they're able to combine comprehensive awareness, artificial intelligence, and autonomous maneuverability, spacefarers may at least shift burdens involved in daily orbital management and reduce uncertainty for human operators and autonomous systems alike.[98]

In addition to adopting new technologies and techniques, states and companies must improve basic asset management and traffic coordination practices. Having failed to communicate even during conjunctions,[99] agencies and large companies would do well to reconsider their interests holistically and share more information regarding objects and trajectories. To encourage better behavior, international organizations and civilian agencies may create, improve, and expand existing cooperative, shared, secure platforms for spacefarers to keep sharing information.[100]

Because they've already cluttered Earth's orbital bands, spacefaring states and companies must actively remove – not only prevent and cope with – artificial space debris. While authorities refine rules and companies improve practices in space,[101] American leaders must boost debris removal on different fronts. Above all, Congress may enact draft laws such as the Orbital Sustainability Act ("ORBITS Act"). Although they'd ideally improve and expand its provisions, Congress has declined to enact relatively rudimentary legislation specific to space debris. As they identify space debris as an important and urgent issue, American lawmakers may pass an expanded version of the ORBITS Act. For instance, they may improve Section 6 on Uniform Orbital Debris Practices for United States Space Activities. Although military and commercial entities have led spacefaring so far, lawmakers would do well to assign and recognize responsibilities of agencies such as the departments of State, Justice, and Transportation.[102] They may also amend their definition of "appropriate committees" to include at least the U.S. Senate Committee on Foreign Relations and the U.S. House Committee on Foreign Affairs alongside those for appropriations, science, and technology.[103] To establish removal programs and allow for more technical and commercial competition, they may allow relevant authorities like NASA more time to shape demonstration programs (draft Section 4(b)(1), which now provides only 180 days for a demonstration program)

Space Debris by Object Type 1957 to 2023



Source: European Space Agency

and allocate more money for active remediation (draft Section 4(e), which makes available only $150 million across five fiscal years). If they're unable to secure support for specific legislation, including but not limited to the ORBITS Act, lawmakers and policymakers may push relevant principles into other laws and provide debris-removal funding for space agencies, companies, and research institutions more generally. Administrators and officials in the federal government may do the same, pushing forward on debris-related initiatives with their own tools. For instance, they may increase funding and other resources for longer-range research related to autonomous maneuvering and, in doing so, ideally build upon existing programs on operational protocols for distributed space systems.[104]

As Americans refine rules at home, they may cooperate with technical and policy counterparts to adopt standard practices globally. Not only will they improve practice, but they'll also prevent or make it more difficult, more costly, and less attractive for companies to evade laws and regulations by shopping for more permissive launch sites.[105] Building upon recent initiatives, American, allied, and other officials may declare multilateral[106] moratoriums on problematic practices – especially anti-satellite actions.[107]

After adopting norms voluntarily, establishing practice, and bringing other states into the informal fold, they may work to enter a specific treaty on the most dangerous, indiscriminate practices while including reasonable mechanisms for expanding agreements on debris and sustainability. Applying lessons from other areas, they could enter formal, temporary treaty bans on purposeful or knowing debris-creating behavior, thereby allowing states to participate, build trust, and cede some narrow rights in exchange for cooperative safety and security.[108] While they need not stop at one form of irreversible action, they may begin by banning kinetic, destructive anti-satellite tests.[109] They may also consider specific rules in different orbital bands. For instance, they could adopt stricter, binding rules in lower and geosynchronous orbital bands while continuing with voluntary, ad-hoc approaches elsewhere.

Matrix of Actions and Conceivable Consequences in Outer Space

Representation of space actions that could create debris directly or indirectly

Action/consequence	Kinetic	Non-kinetic
Reversible	Robotic arm	Jamming
Irreversible	Missile strike	Commandeering
Reversible or irreversible	Co-orbital anti-satellite action	Dazzling

Sources: New Lines interviews, space agencies such as NASA and ESA, and think tank reports cited in this publication

Matrix of Solutions to Counter Artificial Space Debris

Matrix of relevant phases and approaches to counter space debris

	Prevent	Manage	Remediate
Legal	Licensing requirements	Codified practices	Incentives
Institutional	Better launch practices	Information sharing	Voluntary fund
Technical	Passivation and deorbiting	Avoidance or hardening	Various technologies

Sources: New Lines research and analysis and interviews with policymakers, lawyers, and technical experts

American, European, and Asian leaders may be more creative while remaining realistic. to minimize misunderstanding and adverse reactions to active debris removal and other useful orbital activities, such as asset servicing or material recycling, that are likely to become more common in the coming decades.[110] Domestically and globally, including with voluntary financial contributions, pooled resources, and credits for diplomatic, technical, or other participation and support, spacefaring agencies in the United States, Europe, and Asia may use existing capabilities to share responsibility for cleaning debris. Examining the differences between debris, policymakers may continue to create lists or matrices to classify items according to risk. For instance, they may remove large debris in certain orbital bands, especially if the debris is high-risk due to its type, trajectory, and other factors. If spacefaring states and companies remove just a few large objects per year as part of a full-spectrum response to the debris problem, they may control debris proliferation immediately and manage risks more effectively down the line – even if they otherwise increase their activities in space. Of course, they'd need to be more aggressive to clean up[111] orbital bands because they'd be trying to reverse the problem by removing debris as others continue to create it.[112] Meanwhile, if humans "learn to live with small debris [while they increase] activities in outer space and as operations become much more complex,"[113] they may combine commercial, technical, and prudential practices to improve active avoidance and reduce knock-on consequences. Besides boosting comprehensive awareness and effective traffic management, spacefarers may also design assets to minimize debris creation, including by hardening components against space degradation and certain collisions; consider constructing and using lightweight transponders, perhaps for certain classes of satellites; engage in regular cleaning operations; and properly plan, budget, and obligate or deposit funds to decommission space assets in certain risk classes.[114]

Humans have taken familiar challenges beyond Earth. They've succumbed to the tragedy of the commons. They've externalized costs and consequences, being particularly prone to negative externalization in their policies and practices. They've repeated failures regarding decisions, time, costs, and consequences. Turning this future frontier into a market, arena, laboratory, and sanctuary, humans will inevitably see space in different lights and thus make different choices. No matter their differences, spacefarers need to see that they have made a mess in the heavens. They need to clean it up now, lest they look back with regret while venturing beyond an Earth that will forever be their cradle, even if it may not always be their only home. ☐

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103 At least 12 standing committees or designated subcommittees of Congress have direct authority over or relevance in American space-related activities. While the drafters of the ORBITS Act have done well to tailor the law, they need to include more relevant entities as part of the necessary effort to reshape space policy as a mainline concern.

104 They may dedicate a debris-related fund for NASA through specific allocations to the Orbital Debris Program Office and/or the Space Technology Mission Directorate and general increases to Safety, Security, and Mission Services, Space Communications and Navigation, and Planning, Challenges, and Crowdsourcing.

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