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Fixing the Problem of Space Debris before It's Too Late

Imagine you're driving down a busy highway on your way to work. Everything seems normal, just like any other day, until you drive over a nail and your tire pops. You are now stuck in the middle of the road and the car behind you is unable to slow down, resulting in a rear-end collision with your car. In a cascade of events, a small, tiny piece of a nail causes a huge traffic jam on the entire highway. Now instead, replace the cars with satellites and the nail with a grain of space debris, and you have a picture of what is going on right now in Earth's orbit. Tens of thousands of satellites orbiting the Earth and even more debris floating around from the size of a marble to a dead satellite, a disaster waiting to happen — or more accurately, a disaster that is happening right now. Space debris is any artificial object in space that no longer serves a useful purpose. That includes defunct satellites, parts of rocket stages, and fragments from the breakup or collision of spacecraft. Most debris orbits the Earth, and satellites, if struck by this debris, will be broken instantly. This will impede us from maintaining our current, convenient lifestyle, which is dependent on satellite services. Without satellites, services vital to the modern world, such as GPS, weather forecasting, and air traffic control, would not be possible. Unfortunately, as a by-product of space activities, the problem of space debris is not going anywhere, since the number of satellites around the Earth is only projected to increase in the future. The only way to maintain a long-term sustainable space environment is to minimize the threat of space debris. To do this, we must raise awareness regarding this issue. By garnering public support, we can persuade the government to pass laws that can prevent the further generation of space debris and provide funding to agencies and private sectors to develop debris removal technology.

Space debris has begun to amass since the dawn of the space race. On October 4th, 1957, the Soviet Union launched Sputnik 1, “the first artificial satellite to enter orbit around the Earth.” Sputnik 1 remained in orbit for “a mere 3 months” before it “fell back to Earth… due to atmospheric drag” and burned up in the atmosphere (Siegel). During its three months in space, “[Sputnik 1’s] transmitters operated [only] for three weeks,” effectively making it the first piece of space debris after it ceased operations (NASA, “Sputnik 1 Information”). Although Sputnik 1 fell back to Earth after a relatively short time in orbit, this is not always the case for dead satellites. Satellites orbiting in “altitudes of 36,000 kilometers,” the orbit in which most communications and weather satellites are placed, can remain in orbit around Earth for “hundreds or even thousands of years” (O'Callaghan). For this reason, if nothing is done to intentionally change a satellite's orbit, such as a deorbit burn at the end of its mission, dead satellites (essentially space debris) will begin to clutter the available orbits. As soon as humans launched the first satellite into orbit, the problem of space debris had begun.

By 1970, merely 13 years after the launch of Sputnik 1, the number of objects in orbit around Earth, including spacecraft, rocket bodies, and debris had increased to about 3000 (NASA, “LEGEND”). This alarming increase highlights the fact that space debris is an inevitable by-product of human space activities. As with any sort of advancement in technology, satellites became involved in warfare, providing essential services such as “targeting… navigation,” and “battle assessment” (Grego 1). Therefore, it is not surprising that technology to counter such satellites has emerged. The “development, testing, and deployment” of anti-satellite (ASAT) weapons began in the 1970s and was led by the United States and the Soviet Union

(Grego 1). These ASAT weapons work by sending up a missile to destroy the target spacecraft. The problem is that a spacecraft struck by a missile will instantly disintegrate into pieces, creating debris that tumbles uncontrollably through space. Such debris could remain in orbit for centuries, posing threats to other satellites. This is evidenced by the ASAT tests conducted by the Soviet Union. Of the "more than 700 pieces of large debris" produced by the ASAT tests, "roughly 300… remain in orbit" to this day (Wright). Furthermore, much of the debris created by the destruction of satellites are too small to be tracked. These debris can travel at speed "up to 17,500 mph," and at such a high speed, even debris "the size of a marble" can damage or destroy a spacecraft in the event of a collision (NASA, "Space Debris and Human Spacecraft"). Essentially, ASAT tests create debris that is unpredictable and poses a great threat. To make matters worse, there are "no international restrictions on the testing or use of military systems intended to destroy satellites" (Wright). Even the Outer Space Treaty (1967), a set of principles intended to promote the peaceful use of space, "does not explicitly prohibit… ASAT weapons tests" (Grego 3). The development of ASAT weapons comes at the cost of space debris, and the lack of regulations only exacerbates the problem, as there is no legal way to hold anyone accountable for the debris generated. If a piece of debris hits another debris or spacecraft, it will in turn create more debris. However, since there are no laws limiting ASAT tests in regard to the creation of space debris, there is no way to prevent such incidents from occurring.

Over the course of 40 years (1970 to 2010), the number of satellites in orbit around the Earth increased from less than 500 to more than 3000 (NASA, "LEGEND"). With the number of satellites increasing exponentially, a collision is bound to happen. The first collision of two satellites in space occurred on February 10, 2009, when an old, "non-functional" Russian communications satellite collided with "Iridium 33, an operational U.S. communications satellite." More than "200,000" pieces of debris "1 to 10 cm" in size were produced, many of which still remain in orbit today (NASA, "The Collision of Iridium 33 and Cosmos 2251"). But this was only the first of the 630 "fragmentation" incidents caused by break-ups, explosions, or collisions of satellites (ESA, "Space Environment Statistics"). The debris from satellite collisions is deadly. They can form debris clouds that spread out over time, posing a collision threat to spacecraft in a range of orbits. And the threat did not stop there. Over the course of about 50 years, 6 countries — USSR, Russia, the United States, China, and India — had conducted numerous ASAT tests (Grego). In 2007, China conducted an anti-satellite missile test that destroyed a weather satellite named FengYun-1C. The debris created by this indecent single-handedly "increased the trackable space object population by 25%" (ESA, About Space Debris). Clearly, if we don't do anything, there's only going to be more and more space debris. More satellites launched into space means more chance of accidental collisions. Along with more ASAT tests, more debris will continue to pollute Earth's orbit.

One thing to note is that ASAT tests and satellite collisions are not the only sources of space debris. Another major cause of space debris is the accidental explosions of satellites and rocket bodies. Over time, "the harsh space environment can reduce the mechanical integrity" of satellites, causing fuel leaks that may eventually trigger an explosion (ESA, About Space Debris). But regardless of the source, the amount of space debris is growing at an alarming rate. From 1970 to 2010, the number of debris in low Earth orbit increased from about 1500 to about 11500, a staggering >650% increase (NASA, "LEGEND"). An increase in space debris meant an increase in the threats they pose to space infrastructures, as evidenced by the Space Shuttle Program, one of the victims of space debris. By 1998, the space shuttle fleet "had flown more than 60 missions." Over the course of its missions, "177 impact features" attributed to "space debris and micrometeoroids" have been found on the shuttle windows, "forty-five" of which were "large enough to warrant a replacement of the window" (Edelstein 1). Another example of the threat posed to astronauts by space debris is that the International Space Station had to perform plenty of debris avoidance maneuvers over its lifetime to avoid getting damaged by space debris. For instance, a "collision-avoidance maneuver" was performed when a fragment of the 2009 Russian and American spacecraft collision "drew too close" to the station (NASA, "Space Debris and Human Spacecraft"). The Hubble Space Telescope has also fallen victim to space debris. Its solar panels are littered with "tiny impact craters" caused by debris, and the chances of it colliding with "debris fragments ranging from about 1-10 cm" had doubled from "a 0.15% chance per year to a 0.3% chance" (ESA, "Hubble's life"). These are just a few examples of the threat space debris poses to astronauts and spacecraft. Although most encounters with space debris are skirmishes, the chances of a catastrophic collision are steadily increasing due to an increase in the amount of space debris resulting from increased space activities.

Over the years, several treaties regarding the regulation of space debris have been signed. The one similarity that they all share is that they are only guidelines, not mandatory requirements. The Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, signed in 2010, provided guidelines for the "mission planning, design, manufacture and operation… of spacecraft and launch vehicle." These are guidelines that would help reduce the generation of space debris (UNOOSA). However, these are merely recommendations and cannot be enforced. The same is true of the IADC Space Debris Mitigation Guidelines signed by 13 space agencies. One significant guideline is the so-called "25-year rule," which states that a satellite at the end of its service should be placed in an orbit that gives it a "[remaining] lifetime of 25 years or shorter" (IADC). Shortening the time a dead satellite spends in orbit will lower the chances of it breaking up over time or colliding with other satellites or debris. But due to the impossible-to-enforce nature of these legal frameworks, it is difficult to administer liability in the event that collisions result in the creation of further debris.

Today, space debris continues to pose a threat to spacecraft and crews. About 13630 satellites have been placed into Earth's orbit, out of which 65% (~8850) still remain in space as of August 2022 (ESA, "Space Environment Statistics"). More objects in space mean more debris as well. Over the last two decades, on average, "12 accidental 'fragmentations' have occurred in space every year," and the number is projected to increase (ESA, "state of space debris"). More collisions are expected to occur, and space debris is not going anywhere. On May 12, 2021, it was discovered that a piece of space debris had collided with and "punched a five-millimeter-wide hole" in Canadarm2, a robotic arm of the International Space Station (ISS). Although the debris luckily "only damaged the thermal blanket" of the arm, this incident serves as a reminder that the threat of space debris is still very much real (Machemer). As recently as November 2021, an anti-satellite test conducted by Russia created a "debris cloud" with more than "1,500 pieces of trackable space debris." The debris posed a significant threat to the ISS, and the seven astronauts on board were directed "to board their lifeboats," where they remained for about "two hours". Several hatches were closed and a planned spacewalk was delayed (Clark). Evidently, the issue of space debris had worsened over the years, posing threats to spacecraft and humans. If we maintain the status quo, the threat of space debris, whether generated by ASAT tests or accidental collisions, will only increase in the future.

Despite these incidents, there is still some good news. As the issue of space debris becomes more apparent, countries and agencies have started to look at ways to mitigate space debris. Starting in 2022, the United States has committed "not to conduct destructive, direct-ascent anti-satellite (ASAT) missile testing" (Panda and Silverstein), although it remains unclear just how committed the U.S. actually is, as the commitment is not written into law. The FCC also has a new proposal that calls for shortening the "post-mission disposal" time for low Earth orbit satellites from 25 years to 5 years (FCC). Still, this is not good enough. While international policies and regulations may help prevent the creation of more space debris, existing space debris continues to be an issue. This is where active debris removal (ADR) technology comes into play. Further space debris mitigation relies on technologies that can remove space debris already in orbit, such as sending a spacecraft to collect debris, or using a ground-based laser system to shoot down debris.

Currently, about "one third to one half of the LEO capacity to sustain long-term space activities… has already been saturated" (Pardini and Anselmo). This means that Earth's orbit has become increasingly crowded, with a limited number of satellites it can sustain before the risk of collision becomes too high. By the end of 2035, the risk of low Earth orbit satellites colliding is expected to occur at the rate of "a handful of events per year" (Krisko). Although this number may seem low, it is only projected to increase. All this means that the space around Earth will become increasingly busy with more satellites, more debris, and more collisions. A "few decades from now," collision will be "prevailing," making the 2020s a crucial time for space debris mitigation. At one point, "collision fragments will collide with [other] collision fragments," creating a cascade of collisions until the "entire population" of space infrastructure is decimated. This "self-sustained process" is known as the 'Kessler syndrome" (ESA, About Space Debris). If we get to that point, the Earth's orbit will become so dense with debris that not only will space exploration become incredibly dangerous, if not impossible, life as we know it will be gone forever. Despite being hundreds or even thousands of kilometers above us, satellites permeate almost every aspect of our lives. They provide services ranging from "Earth observations," such as providing data on "climate change and its impacts," to "communications" and "navigation" applications that are "critical" in "supporting first responders... in emergency situations" (CSA, "Satellites in everyday lives"). These are the things that our society depends on in order to function. And the impact of satellites is not limited to pressing world issues.

Satellites are a vital component of the Global Positioning Systems (GPS), the world's most used navigation system that is "used by almost anyone that has a modern smartphone or a navigation system in their car" (Shepherd). Every day, we rely on GPS-based mapping applications to travel; it's how we are able to get anywhere without getting lost along the way. It's also how airplanes are able to communicate with traffic control, as "satellites have been used to track aircraft over oceans and remote areas for decades" (ESA, "Satellite-enabled air traffic control"). Weather analysis and forecasting are one of the most significant daily uses of satellites. Not only do weather satellites allow you to know what to wear for tomorrow's weather, they "keep watch over rapidly evolving" natural disasters such as "hurricanes" and "wildfires" which helps to assess disaster response. Furthermore, bank transactions such as "ATM transactions" would not be possible without the "timing signal" system of satellites (Shepherd). So imagine a world where all satellites suddenly stop working. Sure, the loss of satellite television may be inconvenient, but the implications go far beyond that. The lack of a secure satellite communications system poses a threat to national security, as military aircraft and ships cannot communicate safely. Meanwhile, over the ocean, thousands of pilots struggle to talk to air traffic control. In an emergency where all communication networks are down, first responders are vulnerable because they cannot effectively communicate without satellite phones. This is the future that we are looking at if the problem of space debris is not addressed. We've placed a vital component of modern infrastructure into a danger zone filled with millions of bullets. In the case of Kessler syndrome, if we don't act soon, life as we know it will be gone forever.

The catchphrase is to maintain a sustainable space environment around our home planet, Earth. Space debris has started to amass since the beginning of human space activities and will only continue to increase in the future. They are mostly created by ASAT tests, satellite collisions, and the explosion of spacecraft (fragmentation events). The two ways that we can mitigate space debris, are to develop active debris removal technology to deal with the existing population of space debris and establish enforceable international standards for satellite de-orbiting and ASAT testing to prevent further space debris creation. If nothing is done to address the problem of space debris, clouds of debris will continue to pose threats to spacecraft and astronauts and have the potential to start a chain of collisions that may one day destroy all satellites and create a cloud of debris around Earth. At that point, it would be impossible to send more satellites into space, leaving us without the ability to maintain the modern world, which is very much dependent on the valuable services provided by satellites. Still, space debris is seen as a far-off issue for most people, even though it affects literally everyone on Earth. This needs to change. Spreading awareness about the issue of space debris is, without a doubt, critical to the advancement of active space debris removal (ADR) technology, as many ADR missions can only happen if there is enough public support to incentivize governments and space agencies to fund them. Space debris is an issue impacting all of humanity. By informing more people about this issue, especially the threat it poses to satellites, and thus to our convenient way of life, we can get people to care and take action. From there, we can solve the problem before the impending doom becomes a reality. Space technology is the key to improving our lives on Earth and the orbit around Earth is our gateway to exploring the universe. Let’s keep it that way.

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