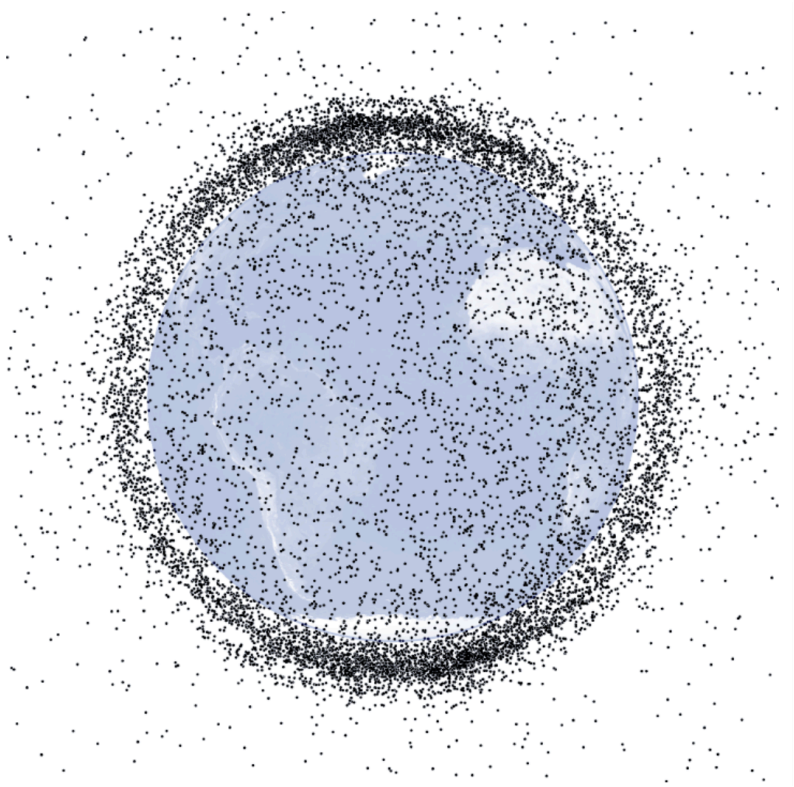
The Escalating Problem of Space Debris in Low Earth Orbit

Izzy Perez

University of Colorado, Boulder, Department of Astronomy and Physics

November 18, 2024



This graphic shows the density of space debris surrounding Earth, particularly concentrated in Low Earth Orbit (LEO). The debris, represented by black dots, highlights the growing accumulation of space litter that poses risks to satellite operations and space missions. GRAPHIC BY NASA EARTH OBSERVATORY

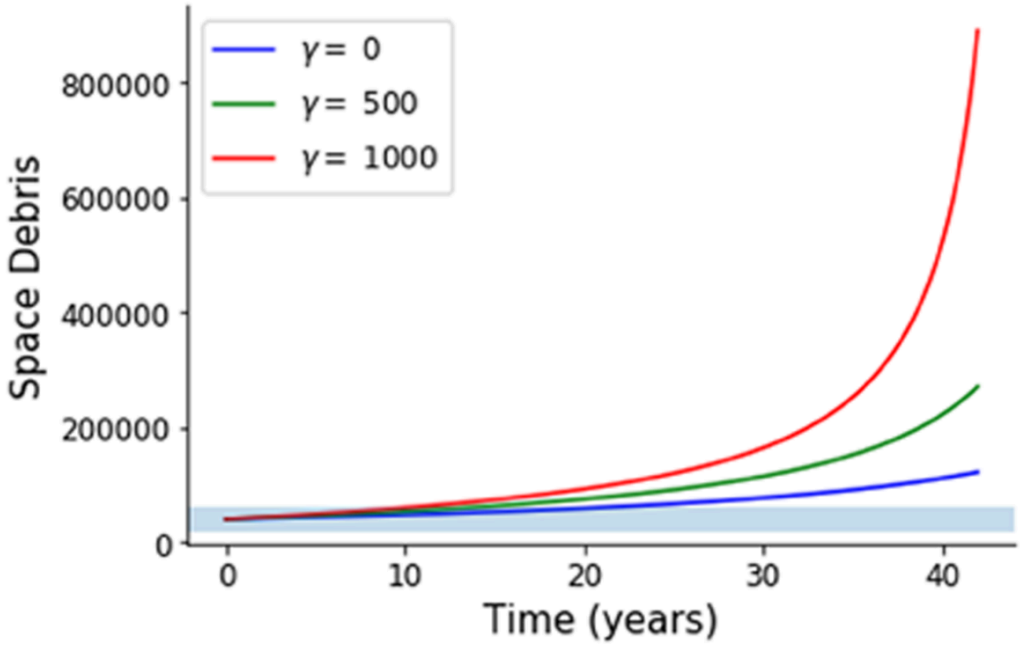
The Escalating Problem of Space Debris in Earth's Orbit

By Izzy Perez Undergraduate student in the astronomy department at CU Boulder

Humans have set out on a new frontier of exploration: space. Unsurprisingly, like Earth's oceans and land, space is suffering from a human-made debris problem. This is especially problematic in Low Earth Orbit (LEO), where "space junk" is accumulating at an alarming rate. But without plants or animals in space, can it really be that big of a problem? While this debris may seem far removed from everyday life, it endangers essential satellite-dependent functions, from GPS to weather monitoring. There's also the ongoing threat of catastrophic chain reactions known as Kessler Syndrome, where each collision generates countless new fragments. These fragments could ultimately render LEO unsafe for future missions. However, we are not at a point of no return. With adequate action taken on a global scale, we can hinder the impacts of this problem.

Kessler Syndrome: The Domino Effect in Space

Kessler Syndrome is a theory introduced by NASA scientist Donald J. Kessler that it describes a catastrophic chain reaction of space litter. He showed that one big piece of space trash, such as a piece of rocket, orbits at such high speeds that if it collided with another piece of litter, it will split up many more smaller pieces. Those smaller pieces collide with other debris creating even more debris. This is detrimental because one tiny particle of space debris is traveling so fast it can severely damage satellites and other spacecraft or technology. According to a 2024 article in Acta Astronautica, the Hubble Space Telescope sustained more than 5000 instances of damage 3.5 years after its launch due to small particles. This damage can range from particles less than 1mm, affecting sensitive surfaces of optical instruments; any bigger particles have the potential to penetrate spacecraft skin.



This graph shows how space debris could accumulate over time with different launch rates (γ values of 0, 500, and 1000). Higher launch rates lead to faster debris buildup, pushing the system closer to a tipping point where collisions cause a chain reaction, known as Kessler Syndrome. Without cleanup efforts, debris levels could reach unsustainable heights.
DIAGRAM BY NOMURA

Global Collaboration for Space Debris Prevention

As space exploration grows on a global scale, the contributors to space litter accumulating in LEO also grow on a global level. Addressing this issue requires more than individual country efforts… it demands global cooperation. Space is a shared environment, and effective prevention of space debris must integrate universal policies that everyone agrees with.

According to Keiko Nomura, a researcher on space debris, LEO is a finite resource at risk of overuse, where the rapid increase of satellites and space missions heightens the potential for collisions and debris. To maintain LEO as a viable space for future activity, international

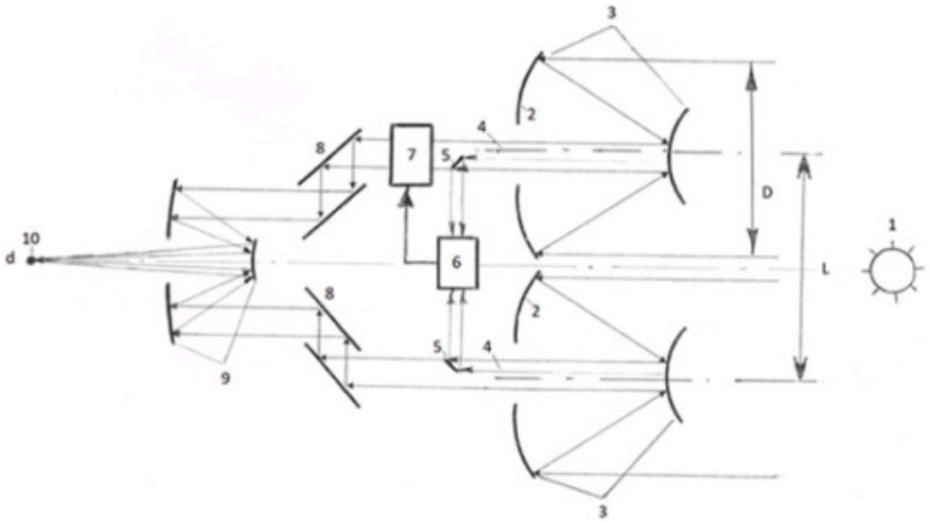
treaties and clear definitions of space debris are essential. Without globally recognized standards, managing and preventing space littering becomes nearly impossible, as every space agency could act without considering the impact on the orbital environment.

Ledkov & Aslanov, researchers at Samara National Research University, further highlight how legal ambiguities surrounding space debris contribute to challenges in implementing regulations. Currently, no framework defines who is responsible for debris created by collisions or abandoned satellites, and this lack of accountability hurts long-term mitigation efforts. The need for a coordinated international response is obvious. A global agreement that holds all space-faring companies accountable for preventing debris would promote safer and more sustainable space activity.

Active Cleanup Efforts: Technologies to Remove Space Litter

Various technologies are being developed to actively remove litter from orbit. These methods vary in approach, ranging from physical capture to contactless techniques, each with its own advantages and challenges.

Shown below is one promising contactless approach using laser-optical technologies. This diagram created by Khomich, Shakhmatov, and Sviridov who are researchers with expertise in physics and engineering shows just how solar energy can be used to target debris. The diagram shows how mirrors and telescopes are used to concentrate sunlight directly onto space debris. This method either burns the debris or nudges it into lower orbits, where it eventually burns up in Earth's atmosphere. Unlike ground-based lasers from NASA's Orion project, this technique operates without additional energy sources, harnessing solar power.



This diagram illustrates a system of mirrors and telescopes designed to focus the Sun's energy into a concentrated beam. This beam can be directed at space debris, altering its orbit and causing it to burn up upon re-entry into Earth's atmosphere.
DIAGRAM BY KHOMICH, SHAKHMATOV, AND SVIRIDOV

There are also contact-based approaches developed to capture and remove debris from orbit. Shan, Guo, and Gill associated with Delft University of Technology (TU Delft) in the Netherlands, explain that these methods involve getting close to the debris and then capturing it, which is challenging because space debris moves quickly and often spins unpredictably. Contact-based techniques, like using drag systems or electro-dynamic tethers, directly interact with debris to change its orbit or bring it down. These methods are effective for larger pieces of debris, but they aren't as useful for handling the many smaller fragments that make up most of the space debris in LEO.

Though each of these cleanup methods has its limitations, combining various approaches may yield the most effective solution. By employing a mix of physical capture and laser-based technologies, the space community can gradually reduce the volume of debris in LEO and the effect of the Kessler Syndrome.

Monitoring Space Debris: Tracking and Preventing Future collisions

Effective cleanup and prevention efforts rely on the accurate monitoring and tracking of space debris. Systems like the US Space Surveillance Network (SSN) and European networks, including EISCAT, are essential for detecting and cataloging debris in LEO. According to Giacomo Muntoni from the Department of Electrical and Electronic Engineering at the University of Cagliari, advanced radar systems, such as monostatic and bistatic radars, allow for detailed tracking, helping operators identify potential collision risks and avoid debris in real-time.

However, tracking every piece of space debris remains a daunting challenge. The majority of debris consists of small particles, many of which are too tiny to be tracked with current technology. These small fragments, though seemingly harmless, still pose a risk due to their high speeds. Improving tracking systems and expanding global data-sharing practices can prevent collisions, even if complete tracking remains out of reach.

What Can the Government Do?

Governments play a huge role in tackling the space debris problem. Agencies like NASA and ESA are already doing a lot in terms of tracking debris and studying ways to reduce it, but we need more widespread action. One major step is creating and enforcing policies that prevent new debris from forming. NASA, for instance, has standards that require spacecraft to be designed with debris reduction in mind, such as NASA-STD-8719.14. If more countries adopted similar rules, we'd see a decrease in new debris being added to LEO.

Beyond national regulations, governments need to work together to establish a global agreement on space debris. Right now, there are guidelines from organizations like the United Nations Office for Outer Space Affairs, but they're voluntary. An international treaty with actual accountability could ensure that countries stick to responsible practices and share the responsibility of cleanup. This kind of policy also lays out who's

accountable for existing debris and require nations to pitch in for removal efforts, distributing the costs and benefits.

Funding for research in debris removal is another area where governments can make a difference. If public funding goes towards advancing these technologies, it could help bring down costs and make routine debris cleanup more practical. Providing tax cuts or economic incentives to space companies to not leave space debris in space would also increase industry participation in debris mitigation efforts without the immediate need to implement laws or regulations. These incentives would encourage private companies to adopt more sustainable practices, such as designing spacecraft that can deorbit safely or implementing systems that capture and remove debris at the end of a satellite's life.

What can the individual do?

While the solution to this space debris problem may seem out of reach to individuals, this is far from the truth. The general population can play a huge role. By staying informed and advocating for responsible policies, individuals help shape public opinion, which can influence the actions of governments and space agencies. Supporting legislation aimed at environmental protection in space, raising awareness about the risks of space debris, and supporting responsible space programs are all ways individuals can contribute. Even more simply, spreading knowledge about the consequences of space litter can lead to a big impact. This issue is not widely talked about in our government, and that should change.

Conclusion: Securing a Sustainable Future in Space

This is a challenge that impacts the entire future of space exploration and affects humanity as a whole. However, we can take steps to secure a sustainable future in space exploration, telescope advancements, and space technology. Global cooperation, technological innovation, and individual awareness are all critical to tackling this issue. By taking action now, we can protect space for future generations. Preserving this new frontier will ensure that space remains a realm of exploration, innovation, and opportunity for all.

References

European Space Agency. (n.d.). *About space debris*. ESA Space Safety. Retrieved November 8, 2024, from https://www.esa.int/Space_Safety/Space_Debris/About_space_debris

Khomich, V. Y., Shakhmatov, E. V., & Sviridov, K. N. (2024). Laser-optical technologies for space debris removal. *Acta Astronautica, 226*, 78–85. https://doi.org/10.1016/j.actaastro.2024.10.027

Ledkov, A., & Aslanov, V. (2022). Review of contact and contactless active space debris removal approaches. *Progress in Aerospace Sciences*, *134*, 100858. https://doi.org/10.1016/j.paerosci.2022.100858

Muntoni, G., Montisci, G., Pisanu, T., Andronico, P., & Valente, G. (2021). Crowded space: A review on radar measurements for space debris monitoring and tracking. *Applied Sciences*, *11*(4), 1364. https://doi.org/10.3390/app11041364

NASA. (2023). *Space debris bibliography*. NASA Headquarters Library. Retrieved November 8, 2024, from https://www.nasa.gov/headquarters/library/find/bibliographies/space-debris/

NASA Earth Observatory. (2009, August 25). *Space debris*. Retrieved from https://earthobservatory.nasa.gov/images/40173/space-debris

Nomura, K., Rella, S., Merritt, H., Baltussen, M., Bird, D., Tjuka, A., & Falk, D. (2024). Tipping points of space debris in low Earth orbit. *International Journal of the Commons*, *18*(1). https://doi.org/10.5334/ijc.1275

Shan, M., Guo, J., & Gill, E. (2015). Review and comparison of active space debris capturing and removal methods. *Progress in Aerospace Sciences*, *80*, 18–32. https://doi.org/10.1016/j.paerosci.2015.11.001