AstroSweep: The Anti-debris Laser Broom

V0.1, February 5th, 2026

One Sentence Summary:

The authors propose a device (AstroSweep), the purpose of which is to mitigate space debris in Low Earth Orbit (LEO), specifically, the area ranging 300km to 2300km above Earth's surface.

Overview

AstroSweep is a commercial space debris management solution which addresses small debris currently undetectable from Earth. In January 2026 alone there have been billions of dollars in damages caused by space debris of this kind, and the problem is growing rapidly with the expanded use of space.

Each AstroSweep free-orbiting satellite hosts a 10 kilowatt laser, with optical+radar debris detection, laser targeting systems, stabilizers, power electronics including batteries, and communication arrays. Each satellite hosts solar panels to generate power for onboard electronics and reboosting. Four AstroSweep units orbit at a configurable distance of 100 meters to 1km of one another, providing 3d debris tracking capability and multiple debris disposition options.

AstroSweep will detect debris as small as 1mm in diameter from as far away as 30km. The future orbit of each debris will be modeled to a high accuracy so that its position can be forecast to any future point in time. This model will be used to determine its disposition and schedule an appropriate action: leave as-is, ionize, or adjust orbit (including de-orbiting).

The onboard lasers will completely ionize the vast majority of debris - that which is less than 5mm in diameter, dispersing it as a harmless plasma. For larger debris up to 10cm in diameter, pulses will be targeted so that the ablated ejecta's momentum 'rockets' the debris into a more desirable path; i.e., one with lower consequences. When feasible, paths which lead the debris to deorbit rapidly will be selected.

A single system is capable of clearing the most populated LEO orbits from 400km to 1000km in altitude in less than 10 years. AstroSweep will launch 10 such systems to provide orbit cleaning services in less than 24 hours to any LEO orbit.

The Problem: Space Debris

As of August 2024, there are estimated to be over 1.2 million space debris objects >1cm diameter, and more than 140 million smaller but still hazardous >1mm debris. Only the 42 thousand largest debris, >10cm, are tracked. This means there is more than 3000x as much hazardous, untracked debris as there is tracked debris. [1] NASA has stated that this small, untracked debris accounts for more than 99% of mission ending risk. [2]

The majority of debris is aluminum; the source being fragmentation remnants from collisions and explosions of satellites, rocket stages, and anti-satellite ballistic missile tests.

How much damage can each piece of debris wreak? Aluminum has a density of ~2.7 grams per cubic cm (g/cm^3) [3]. A 1 cm diameter sphere of aluminum has a mass of 11.31 grams. At a typical impact velocity of ~10,000 meters per second (m/s), this 1 cm diameter sphere stores ~344,000 Joules (J) of kinetic energy. This is 4 times the energy of a .50 caliber machine gun round! Even a 1mm piece of debris has the kinetic energy of a handgun bullet.

Table 1: Debris Characteristics and Quantities by Diameter

Diameter	Quantity [1]	Description	Energy Example	Impact Consequence	Mitigation	Tracked Today?
> 10cm	42,000	Active + defunct satellites, rocket boosters, large chunks	More than an M183 C-4 explosive charge used to destroy buildings	Destruction generating 10s of millions of debris	A) Select orbit which does not overlap B) Maneuver	Yes
> 5 cm	200,000+	Racquetball-size chunks of metal	2 kg of TNT explosive	Destruction generating millions of debris	None	**No**
> 1 cm	1,200,000+	Marble-size chunks of metal	4x .50 caliber machine gun rounds	Mission ending if key component. Potential to generate thousands more debris	None	**No**
> 5mm	10,000,000+	Birdshot-size chunks of metal	2x 30-06 (hunting rifle) rounds	Mission ending if key component. Potential to generate thousands more debris.	Whipple Shield [2]	**No**

> 1mm	140,000,000+	Paint chips, aluminum flakes	.22 short	Cracked windows, damaged radiators, degraded solar panels, increased maintenance	Whipple Shield [2]	**No**
[1] Estimated as of 2025. Volume growing exponentially with activity.						
[2] Whipple shields are only used on $1bn+ spacecraft, and only over most sensitive locations. Solar panels, radiators cannot be protected by whipple shields.						

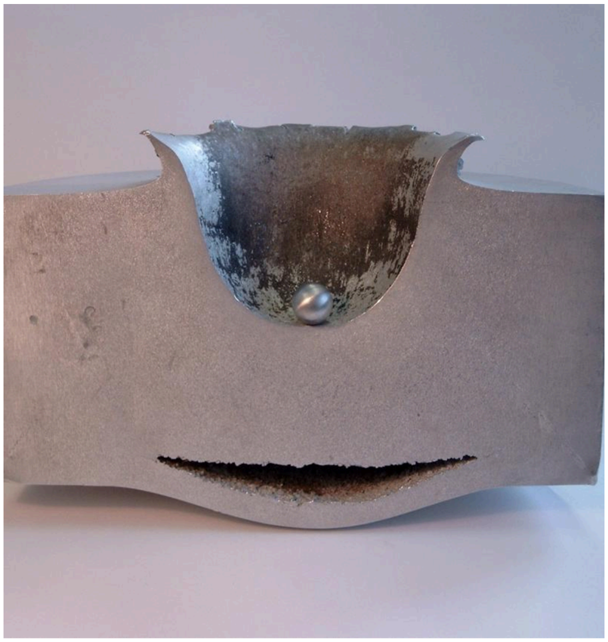


Figure 1: Hypervelocity Impact Example. Credit: European Space Agency. Used under fair use for educational purposes.

Debris does not resolve quickly on its own. While debris in orbits below 600 km normally reenters Earth's atmosphere within several years, at 800 km, the time is measured in centuries, and above 1,000 km, orbital debris will orbit for a millennia or more.[4] These orbital lifetimes are much longer than a typically intact spacecraft because the individual debris particles have a greater mass to surface area ratio than an intact spacecraft.

Operational satellites maneuver frequently to avoid collision with space debris. As of September 2025, on average, each SpaceX satellite operated its thrusters 41 times per year to avoid collisions.[5]

In addition to requiring the use of costly propellant ($1400+ per kg), each maneuver causes an increased risk of future collisions, because each maneuver creates a gap between the satellite's assumed position and its actual position of up to 40km (25 miles) lasting several days, until precise tracking is re-established and is communicated across all satellite operators. This effect led to a catastrophic collision in 2009 between the US communications satellite Iridium 33 and Russia's defunct Kosmos-2251; debris from which remains in orbit today. [6]

As of early 2026, Starlink operates nearly 10,000 active satellites, contributing to a total active satellite population exceeding 14,000. The explosive growth in satellite population, while delivering tangible societal benefits, requires technological stewardship which has not kept pace. LEO has transitioned from a relatively sparse domain to a densely populated and increasingly fragile ecosystem. The increase in satellite population, combined with legacy debris from decades of space operations, has in recent years increased collision probabilities by multiple magnitudes of order. In 2025, close conjunctions among tracked objects including operational satellites in Low Earth Orbit occurred once every 36 seconds on average. [7]

Kessler Syndrome

First articulated by NASA scientist Donald Kessler in 1978, Kessler Syndrome is defined as a cascading condition in which collisions generate debris that lead to even more collisions. The exponential increase in hazardous fragments would render space fully inaccessible for centuries or millennia, with debris from higher orbits replenishing any which deorbit in lower ones.

The “Collision Realization and Significant Harm (CRASH)” clock quantifies the expected time for a debris-generating catastrophic collision to occur if satellites abruptly cease active collision avoidance maneuvers. A severe solar storm has the potential to temporarily disable the communication, navigation and propulsion systems of existing spacecraft; the failure of any of which would trigger a countdown of the CRASH clock.

A January 2026 study set the current CRASH clock at 2.8 days; meaning humanity should expect Kessler Syndrome to develop within a mere 2.8 days of any catastrophic control failure. There is currently a ~30% chance of irreversibly triggering Kessler Syndrome in the first 24 hours. This is much worse than in 2018 (before the first satellite constellation began operations), when the CRASH clock was at 82 days. [7]

Each year, thousands of new satellites are being launched, which will further reduce the crash clock and increase the odds of incurring Kessler Syndrome.

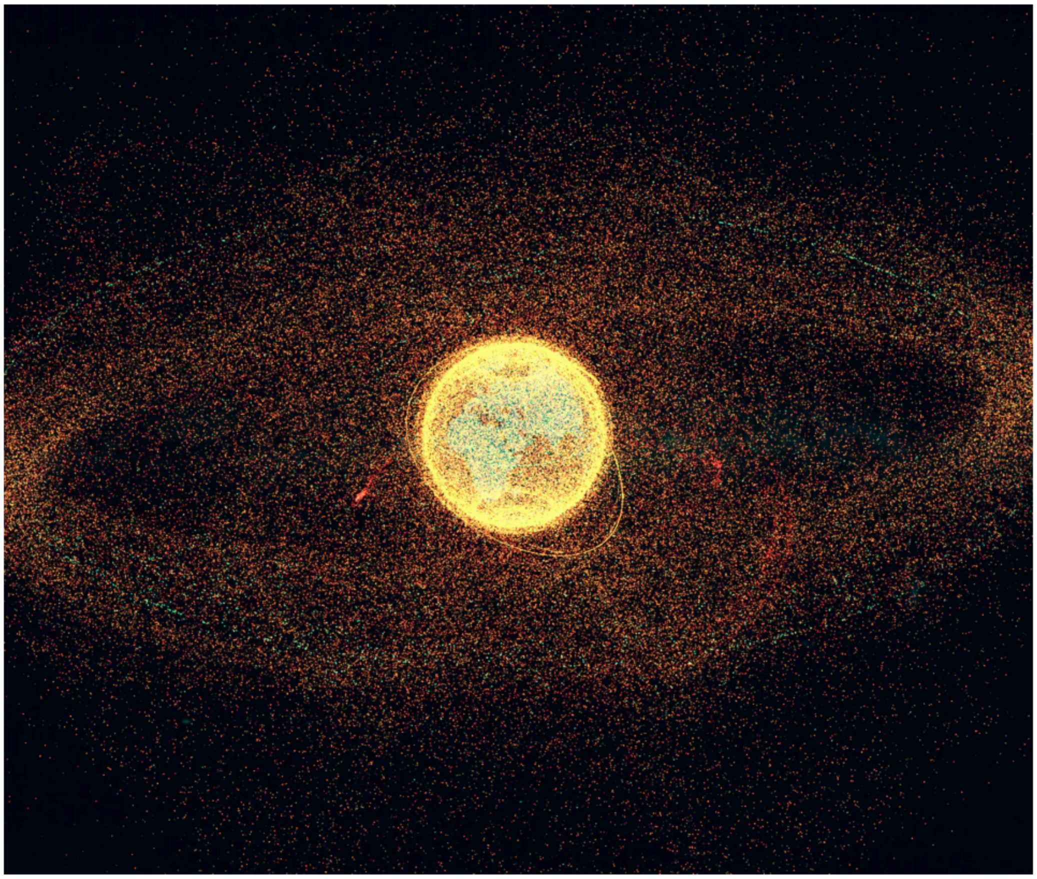


Figure 2: Artistic depiction of Kessler Syndrome. The cloud of space debris enveloping Earth prevents access to space for decades or centuries. Credit: IEEE Spectrum. Used under fair use for educational purposes.

The Tracking Challenge

Only ~40k of the objects in space are tracked (inclusive of ~25,000 satellites; ~14,000 of which remain active). There are no earth-based observatories capable of tracking debris <10cm. Only an estimated ~50,000 of the 140MM dangerous objects above Earth are >10cm, hence the headroom for improving tracking from Earth is limited.

Tracking debris from the surface of Earth is difficult because it requires line of sight, entails vast distances (a minimum of 300km+ to the relevant section of sky), and requires the signals bounced back from the debris to be strong enough to still be detectable even after traversing twice through the atmosphere. The signal strength required varies by the inverse 4th power of distance (1/D^4), because the signal intensity is diminished by the inverse square of distance both on the way to a tracked object, and on the way back. [8]

The US has only built two arrays which were capable of tracking space debris that is smaller than 10cm (with perfect conditions, as small as 3mm). The first was the Arecibo telescope, completed in 1963. Unfortunately this telescope was critically damaged by a hurricane in 2018 and is not planned to be restored. The other is NASA's Goldstone array. The primary purpose of this array is to facilitate communications with NASA's deep space probes; hence it performs debris tracking only in 'spare' time.

The US has fallen behind China on this critical capability, which has implications for national defence and global geopolitics. China's 500 meter diameter FAST telescope was brought online in 2016 with a collecting area 2.5x that of Arecibo. While China ostensibly uses FAST to map galactic pulsars and hydrogen nebulae, if it is being used to track small debris, that data is not being shared with the global community. That said, doing so would not be particularly scalable since scanning a wide swath of sky with a fixed antenna is a slow process.

For the vast majority of debris <10cm, only a statistical density estimate exists, rather than precise tracking.[1] To precisely and scalably track this debris requires a space based solution.

Solution: Enter, AstroSweep

AstroSweep is a system for space debris detection, tracking, and management. It consists of four satellites flying in formation.

AstroSweep tracks debris using onboard sensor arrays, including radar, LiDAR, and optical wavelengths. Optical sensors detect solar reflections from space debris, which are captured as low resolution streaks due to their distance and weak power relative to the speed at which the debris are traveling. These streaks, in conjunction with statistical debris forecasts, tell AstroSweep where to scan its high power, medium angle radar and LiDAR systems. With repeated scans, the debris' trajectory is calculated so that its position can be predicted accurately at any future time.

AstroSweep acts upon the debris via laser ablation. As previously stated, very small space debris (<5mm in diameter) will be ionized, dispersing it as a harmless plasma (which joins the existing ionospheric plasma). For larger debris up to 10cm in diameter, pulses will be targeted so that the momentum exchange from the ablated ejecta 'rockets' the debris into a more desirable path; i.e., one with lower consequences. When feasible, paths which lead the debris to deorbit rapidly will be selected.

AstroSweep maneuvers frequently in all 6 orbital parameters. It can move to any orbit to provide cleanup service within ~7 days notice.

The following sections detail each of the major functions of 1) detection, 2) laser ablation, and 3) propulsion in greater detail.

AstroSweep's Detection Solution

The radar follows the "Search Radar Equation":

$$S/N = \frac{P_{av} A_e t_s \sigma}{4\pi \Omega R^4 k T_s L}$$

Where:
P_{av} = average power
A_e = Antenna Area (in sq. meters)
Ω = Angular Coverage
R = Range Coverage (in meters)
σ = Target Size (in sq. meters)
t_s = Time Required (scan time)
S/N = Measurement Quality
S=Signal
N=Noise

Re-written so that f (design parameters) = g (performance parameters):

$$\frac{P_{av} A_e}{k T_s L} = \frac{4\pi \Omega R^4}{\sigma t_s}$$

Re-written to derive power required:

$$P_{av} = \frac{4\pi\Omega R^4 kT_s L(S/N)}{A_e t_s \sigma}$$

A medium power, low angle radar is used to track debris once found. This radar follows the "Track Radar Equation":

$$S/N = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 kT_s B_n L}$$

Because the phased array layout of receivers are separated by a substantial distance (10km vertically and between 100 meters - 1km horizontally), detected debris is expected to have near-field radar characteristics. Hence the above formulas are simplified and those actually used take into effect the additional near field radar features.

Information gathered on debris trajectories is used to develop a proprietary model of the space environment. This model predicts the debris' orbit to within 1 meter at any future time, and in doing so, also models expected collisions among both debris and satellites.

A benefit of operating in space is that velocity and altitude are related. Most debris follows a circular orbit, in which if altitude is known, velocity can be known. For example, if we know the debris is between 470km and 500km altitude, we can know the debris' velocity (relative to the surface of Earth) is between 7629 meters per second and 7612 meters per second. [9] The same holds true for elliptical orbits, although it requires establishing at least roughly the eccentricity of said orbit. Additionally, debris moves in a straight line, with such momentum that external factors such as the atmosphere, ionosphere, magnetosphere, solar winds, etc. all produce minimal differences in trajectory (until below our target altitude, that is). We will be able to track debris more quickly and efficiently, and project its future path faster and more accurately due to these natural phenomena.

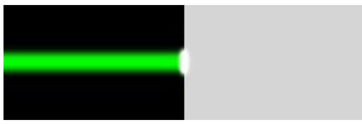
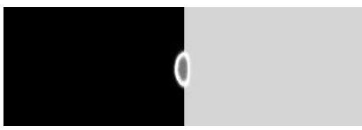
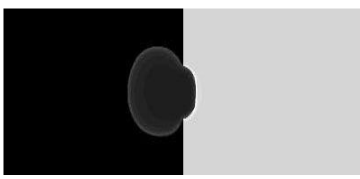
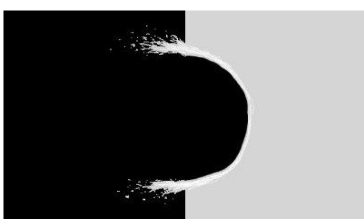
Laser Ablation: Playing Billiards with Debris

We will use a ~10kW class laser. There will be one laser for each satellite, for a total of four lasers available to each AstroSweep system. Each laser's half-meter diameter primary mirror optics deliver a beam spot size of 3mm (or larger when desirable) at a range of 10km, with focal points as short as 1 meter available via adaptive optics.

Because the average debris velocity (relative to our satellite) is 10km/s, we anticipate having ~1 second to influence the debris.

The energy required to completely vaporize a 5mm diameter sphere of aluminum is ~2.5 kJ. With a single 10kW laser, 250ms on target is sufficient to remove the threat posed by this debris. This time is reduced linearly if additional lasers are focused on the debris.

Besides vaporizing small debris, the orbits of larger debris can be influenced through laser ablation. By concentrating the laser into a small area, the area can be heated so rapidly that it gasifies. The area around the gas is melted. The high pressure of the hot evaporated vapor jetting from the molten surface acts like a piston to squirt the melt layer off to the side, where it is then broken up into droplets and blown out of the hole by the high speed jet. This removes the molten material without evaporating it. Since melting takes much less energy than vaporization, the more melt ejection that occurs, the faster the laser can drill at a given energy. [10] The following demonstrates the effect:

	The beam is initially incident on the target. A thin layer of target material is flashed to plasma, and the plasma absorbs the rest of the pulse. At this point, the plasma is at extremely high pressure, much greater pressure than the strength of the target material.
	The expanding plasma launches a blast wave. A shell of hot vapor blasts out into the air, while a shell of super-hot, highly compressed material propagates into the target. Pressures are so high the target material flows like a fluid.
	As the blast front propagates into the material, it slows down.
	Eventually, the blast wave has done so much work pushing through the target material and has spread out so much that the pressure is no longer far in excess of the material strength. The flowing blast wave, no longer able to bull its way through the target material, is instead re-directed along the crater walls and splashes out into the air.
	Once the fluidized material that made up the blast wave has squirted out of the crater along the crater sides and into the air, what is left is a permanent crater, surrounded by a layer of compressed and deformed material, and beyond that the mostly undamaged target material.

A microsecond duration pulse from a 10kw laser would blast ~0.2 grams of material from aluminum debris. In the low atmospheric pressure at 400km altitude, this vapor+melt would exit the debris at ~830 meters per second. Due to the conservation of momentum, this blasted debris would alter the orbit of the remainder of the debris. Notably, conservation of momentum is the same physical principle by which rockets operate. If aimed perfectly against the direction of travel, this momentum exchange would decrease the orbital velocity of a 1cm debris such that it loses ~230km of altitude. For a 5cm debris it loses 1.6km and for a 10cm debris it loses

0.2km. We expect to be able to deliver hundreds of thousands of such pulses per second, so even a 10cm debris would be able to be put into a deorbit trajectory via laser ablation in less than 1 second.

These results are for steady state beams. In practice, melt ejection can be significantly enhanced by illuminating the target surface with a relatively long but low intensity pulse to make a sizable melt pool, and then deliver a short but very high intensity driver pulse to blast the melt pool away. This is not yet accounted for in the calculations above. [10]

In the event that fully deorbiting the debris in one pass is for some reason or another undesirable or impractical (perhaps it would cross paths with a customer satellite on the way down), we will use laser ablation to shift the debris into an orbit of lower consequence; e.g., one which is not expected to overlap with other objects. We also have the option to coax the debris to return to a specific zone in future orbits so that it may be targeted again.

Based on the average density of space debris, AstroSweep expects to encounter ~28 debris objects >1mm in diameter per minute. Assuming a single encounter is sufficient to eliminate the debris (which, as demonstrated above, should be the case the vast majority of the time), a single AstroSweep unit would be able to entirely clear all orbits from 400 to 1000km altitude in less than 10 years.

However, we anticipate launching multiple systems in order to benefit from improved situational awareness and more rapidly address emergent issues such as the collision between two constellation satellites - before the debris has the chance to develop into Kessler Syndrome. Further, a network AstroSweep systems can coordinate to hit any given piece of debris exponentially more frequently by coordinating their targeting information, and passing the debris across their multiple targeting zones, enabling adjusting the orbits of debris even larger than 10cm. A network of 10 AstroSweep systems, spread latitudinally, would be able to maneuver to any orbit of concern in less than a day with sweeping capacity to spare.

Some larger debris, depending on its profile and composition, survives re-entry and poses a danger to people and property in the air and on the ground. Another benefit AstroSweep can deliver to its customers is influencing the re-entry trajectories of this survivable debris in order to minimize harm. We can, for example, adjust the debris trajectory so that it lands at a known location in the Pacific Ocean where it can be later collected and sold at auction.

Propulsion

REDACTED. We have something very interesting cooking here. Want to learn more? Contact us via Astro-Sweep.com/contact or via e-mail AstroSweep@proton.me

Economic Analysis of AstroSweep

A January 2026 report by the World Economic Forum forecasts $25.8bn to $42.3bn in cumulative space debris related losses between 2026-2035. [11] This report conservatively assumes no cascade events - an assumption which is increasingly unlikely, as already conjunction events happen every 36 seconds in LEO.[7] Given that so far, 3% of the ~27k satellites launched have been destroyed by space debris[1], and that the Space Industry is expected (by McKinsey & Company) to grow to $1.8Tn in 2035[12], one would expect the costs of space debris to grow to roughly 3% * 1.8Tn = $54Bn per year; again assuming no cascade events. These estimates provide a sense of the magnitude of order of the space debris management economic opportunity; and with small debris being >99% of mission ending risk, they do not need further adjustment to apply to AstroSweep's mission.

Assuming AstroSweep captures 10% of the economic value for itself, we project revenues on the order of billions of dollars per year by 2035, and in the hundreds of millions as early as 2028.

The benefits to AstroSweep's customers are myriad:

- Reduced mission failures
    - at launch
    - in transit
    - while performing mission
- Extended mission durations
- Reduced maintenance
    - for satellites - longer part lifetimes, especially lower solar panel degradation
    - for reusable launch vehicles - less repairs, extended reuse counts
    - for orbital habitats / space stations - fewer repairs
- Improved Safety
    - Especially for orbital habitats/space stations/manned missions
- Reduced component expenses
    - Solar panels - no need for sapphire coating
    - Reduced need for whipple shields & associated engineering expenses
- Reduced launch weight
    - Thinner armor/shell
    - Reduced whipple shield
- Reduced Insurance Costs
- Unlocks in-space construction
    - Projects never before feasible. Building the unexpected.

The economic value of in-space construction in particular is difficult to overestimate. Our team intends to capitalize on AstroSweep's unique ability to clear orbits to make feasible projects which today would be impossible or at least implausible, and to capture this value through driving our own in-space construction projects.

Conclusion

AstroSweep is a timely and needed solution to the 140MM+ currently undetectable space debris. It is able to completely solve the risk of small debris - from detection to vaporization, deorbiting, and orbital adjustments. This means AstroSweep eliminates what today makes up more than 99% of mission-ending risks. And, it does so efficiently and quickly; with a single system able to clear the entirety of popular orbits in less than 10 years. AstroSweep intends to launch at least 10 such systems, to provide quick response times and avert the otherwise increasing risk of humanity losing access to space for thousands of years. Clearing space debris unlocks new possibilities in space, including in-space construction.

References

[1] https://www.esa.int/Space_Safety/Space_Debris/ESA_Space_Environment_Report_2025
[2] https://ntrs.nasa.gov/api/citations/20230010751/downloads/Space%20Debris%20and%20ISS.pdf
[3] https://physics.nist.gov/cgi-bin/Star/compos.pl?matno=013
[4] https://orbitaldebris.jsc.nasa.gov/faq/
[5] https://www.fcc.gov/document/impact-potential-lapse-funding-commission-operations-0
[6] https://www.space.com/satellites-collision-avoidance-maneuvers-increase-collision-risk
[7] https://arxiv.org/pdf/2512.09643
[8] https://www.ll.mit.edu/sites/default/files/outreach/doc/2018-07/lecture%202.pdf
[9] https://www.satsig.net/orbit-research/orbit-height-and-speed.htm
[10] http://panoptesv.com/SciFi/LaserDeathRay/DamageFromLaser.php
[11] https://reports.weforum.org/docs/WEF_Clear_Orbit_Secure_Future_2026.pdf
[12] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth

Appendices

Appendix 1: List of Recent Space Debris Incidents

January 30th, 2026: Russia's Luch Olymp, a suspected signals intelligence satellite which since launched in 2014 had repeatedly maneuvered within GEO to be in proximity to other nations' communication satellites was destroyed by suspected space debris on this day. It had earlier maneuvered to a graveyard orbit (several hundred km above GEO) in October 2025.

January 2nd, 2026: NATO's $2.3bn SpainSat 2, a terrestrial spy satellite; one of two planned for the newest generation, was destroyed by untracked space debris en-route to GEO. This satellite was insured for only $400MM, as only some of the participating governments required insurance for their spend commitments. This has enduring geopolitical consequences for NATO's ability to maintain terrestrial awareness.

December 17th, 2025: Starlink's satellite 35956's propellant tank was punctured, generating additional debris, as either a direct result of a space debris impact or an indirect result of damage to the battery system by space debris.

November 5th, 2025: a Chinese crewed spacecraft, Shenzhou 20, was struck by space debris, cracking a window. Crew being rotated from the Chinese Tiangong space station (a newer, larger space station than the ISS) were unable to return by this vehicle, and China had to send a different vehicle to retrieve them. The vehicle was eventually returned to Earth empty, 3 months later (on January 19th, 2026).