AstroSweep: The Anti-debris Laser Broom

V0.5, March 22nd, 2026

One Sentence Summary:

The authors describe AstroSweep, the purpose of which is to mitigate small space debris in-situ.

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 system comprises four AstroSweep satellites orbiting Earth at a configurable distance from one another, providing 3D debris tracking capability and multiple debris disposition options. Each satellite hosts a medium power laser, with optical+radar debris sensors, laser targeting systems, stabilizers, power electronics including batteries, compute electronics, communication arrays, and solar panels.

Radar returns from across the satellites are collected, and advanced signal interferometry used to observe debris as small as 1 mm in diameter. From these observations, the future orbit of each debris is modeled to a high accuracy so that its position can be forecast to any future point in time. This forecast is used to determine disposition and schedule an appropriate action: leave as-is, ionize, or adjust orbit (including de-orbiting).

For the vast majority of debris - that which is less than 5 mm in diameter - the onboard lasers ionize the debris completely, dispersing it as a harmless plasma.

For larger debris - up to 10 cm in diameter - laser pulses are 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 are selected.

AstroSweep is both capable and maneuverable. A single system is capable of clearing the most populated LEO orbits from 400 km to 1250 km in altitude in less than 11 years. Because rapid response is critical to averting chain reactions, AstroSweep will launch 10 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 >1 cm diameter, and more than 140 million smaller but still hazardous >1 mm debris. Only the 42 thousand largest objects in space, >10cm, are tracked. This means there is more than 3000x as much hazardous, untracked debris as there are tracked objects overall. [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 centimeter [3]. A 1 cm diameter sphere of aluminum has a mass of ~11 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 1 mm piece of debris has the kinetic energy of a handgun bullet.

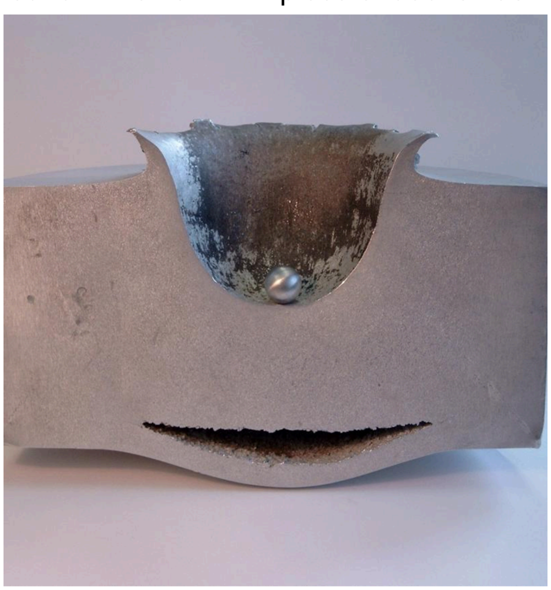


Figure 1: Hypervelocity Impact Example. Credit: European Space Agency. Used under fair use for educational purposes.

Table 1: Debris Characteristics and Quantities by Diameter

Diameter	Quantity [1]	Description	Energy Example	Impact Consequence	Mitigation	Tracked Today?
> 10 cm	42,000	Active + defunct satellites, rocket boosters, large chunks	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 of debris	None	**No**
> 5 mm	10,000,000+	Birdshot-size chunks of metal	2x 30-06 (hunting rifle) rounds	Mission ending if key component. Potential to generate thousands of debris	Whipple Shield [2]	**No**
> 1 mm	140,000,000+	Paint chips, aluminum flakes	.22 short	Mission ending if key component. 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.

Debris does not resolve quickly on its own. While debris in orbits below 600 km normally re-enters 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 an intact spacecraft at the same altitude, because when a satellite explodes, a portion of the resulting debris particles end up having a greater mass to coefficient of drag adjusted surface area ratio compared to the intact spacecraft.

Operational satellites maneuver frequently to avoid collision with space debris. As of September 2025, on average, each SpaceX Starlink satellite operated its thrusters 41 times per year to avoid collisions. [5] Starlink satellites primarily operate between 480 km and 550 km.

In addition to requiring the use of costly propellant ($1,400+ 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 40 km (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 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 at least one catastrophic, debris-generating collision among tracked objects to occur in low Earth orbit if active collision-avoidance maneuvers were suddenly halted. A severe solar storm could, in principle, disable spacecraft communication, navigation, or propulsion systems, and such a loss of control would effectively start the CRASH countdown.

As of early 2026 the CRASH clock is estimated at 3.8 days, meaning that if collision avoidance stopped, a major debris-generating collision would be expected on a timescale of a few days, not months. This does not mean Kessler Syndrome would fully develop in 3.8 days, but it does indicate a roughly 25% chance that at least one catastrophic collision would occur in the first 24 hours without avoidance, significantly increasing debris and long-term risk.

In 2018, before mega constellations (i.e., Starlink) were deployed, the same methodology yielded a much longer CRASH time on the order of months (164 days), showing how dramatically the collision risk environment has worsened; even among tracked objects. [8]

Each year, thousands more new satellites are being launched than deorbited, which will continue to increase vulnerability of the space industry to Kessler Syndrome.

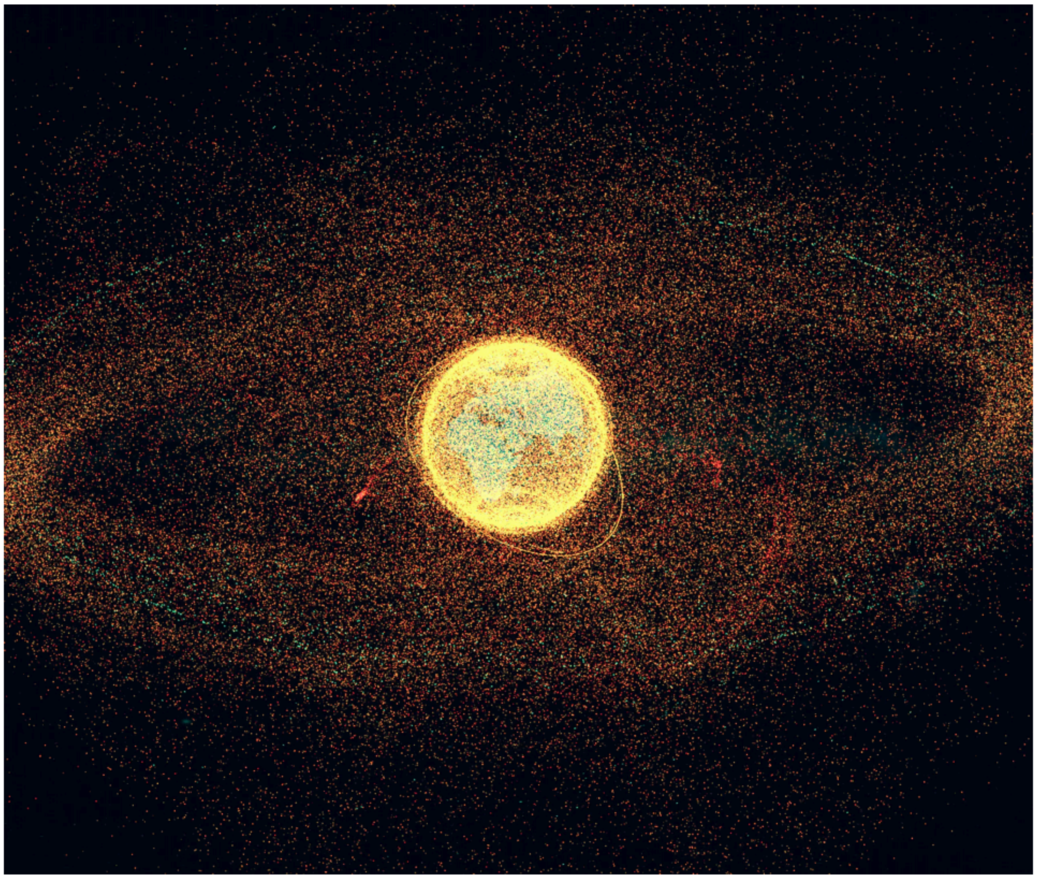


Figure 2: Artistic depiction of Kessler Syndrome. The cloud of space debris enveloping Earth prevents access to space for decades, centuries, even millennia. Credit: IEEE Spectrum. Used under fair use for educational purposes.

The Tracking Challenge

Only ~42k 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 300 km+ to the relevant section of sky), and requires the signals which bounce back from the debris to be strong enough to still be detectable even after traversing twice through the atmosphere. Even before atmospheric losses, the signal strength required varies by the inverse 4th power of distance, 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 10 cm (with perfect conditions, as small as 3 mm). 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.

Figure 3: China's FAST radio telescope. Credit: CFP. Used under fair use for educational purposes.

For the vast majority of debris <10 cm, 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

Figure 4: AstroSweep mockup.

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 radar. 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. Very small space debris (<5 mm in diameter) will be ionized, dispersing it as a harmless plasma (which joins the existing ionospheric plasma). This very small debris makes up 92% of all potentially mission ending debris. 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 trajectory; i.e., one with lower consequences. When feasible, a trajectory which leads 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:
S/N = Measurement Quality (Signal/Noise in a unitless ratio)
P_{av} = average power
A_e = Antenna Area (in sq. meters)
t_s = Time Required (scan time)
σ = Target Size (in sq. meters)
Ω = Angular Coverage
R = Range Coverage (in meters)
k = Boltzmann's Constant
T_s = System Temperature (kelvin)
L = Losses

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

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

Which adds the additional terms:
λ = Wavelength (meters)
G = Gain = η $* (4 * pi * A_e)$ / (λ^2) where η = antenna efficiency
B_n = Bandwidth (in hertz)

Because radar receivers are separated by a substantial distance, radar returns from debris will have near-field characteristics (that is, the return wavefront will be parabolic; not flat). Hence the above formulas are simplified and those actually used take into account the additional near field radar features.

Debris trajectories are used to develop a proprietary model of the space environment. This model predicts the debris' orbit to within several meters at any future time, and in doing so, also models expected collision probabilities among both debris and active 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 470 km and 500 km altitude, we can know the debris' velocity (relative to the surface of Earth) is between 7,629 meters per second and 7,612 meters per second. [9] The same holds true for elliptical orbits, although it requires establishing, at least roughly, the eccentricity of said orbit. Additionally, unlike tracking drones, aircraft, missiles, or even active satellites; debris does not turn under its own power… instead it moves in a 'straight line', with such momentum that nearly all external factors such as the ionosphere, magnetosphere, solar pressure, etc. all produce minimal differences in trajectory. 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.

The primary modeling uncertainty stems from atmospheric drag, which varies depending on A) the debris' coefficient of drag adjusted surface area (aka, the debris ballistic profile), and B) atmospheric density.

A) We estimate the debris ballistic profile based on our direct radar observations.

B) Atmospheric density varies by altitude above Earth, and is affected materially by space weather (especially solar activity and solar flares) which can cause density at affected latitudes and altitudes to vary by a factor of 3 (that is, up to 3x or as little as ⅓ as dense as is typical). Our debris orbit forecast accounts for space weather by utilizing a range of third party space weather (and therefore, atmospheric density) forecasts, and outputting a cone of uncertainty. The debris position forecast is regularly updated by backfilling with actual atmospheric density data from onboard sensors as well as that provided by third parties.

Laser Ablation: Playing Billiards with Debris

There is one laser on each satellite, for a total of four lasers available to each AstroSweep system. Each laser's optics deliver a configurable spot size. Beam pointing is achieved through a series of mirrors: 1 for the X axis, another for the Y axis, while an adaptive spot size will be achieved by a shiftable focus lens placed before the mirrors, as in the diagram below. Mirrors and the adaptive optics are mounted to electric motors and galvanometers (essentially a limited motion linear electric motor), for near instantaneous and precise fully electrodynamic control.

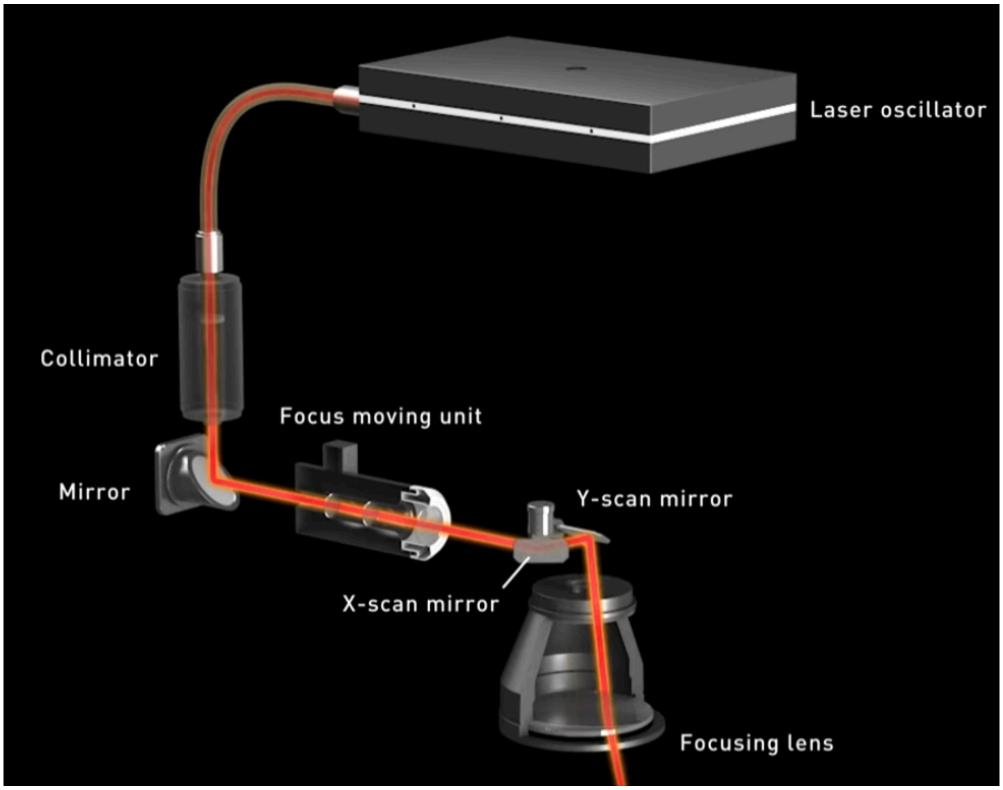
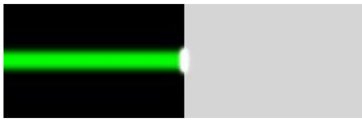
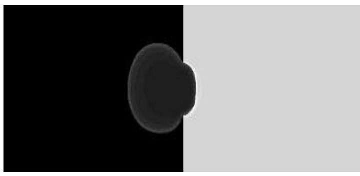


Figure 4: Laser scanning system diagram. Credit DMG MORI Japan. Retrieved from https://www.youtube.com/watch?v=69n4lzw2JUQ&t=18s. *Used under fair use for educational purposes.*

The energy required to completely vaporize a 5 mm diameter sphere of aluminum is ~2.5 kJ, well within our specifications.

Besides vaporizing small debris, Astrosweep influences the orbits of larger debris 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.

Diagrams and accompanying text from http://panoptesv.com. Used under fair use for educational purposes.

In the low atmospheric pressure at 400 km+ altitude, this vapor+melt exits the debris at ~830 meters per second. Due to the conservation of momentum, this ejecta alters the orbit of the remainder of the debris. Notably, conservation of momentum is the same physical principle by which rockets operate. When aimed perfectly against the direction of travel, this momentum exchange is sufficient to put even a 10 cm debris into a deorbit trajectory well within our targeting dwell time window.

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 (flux) of space debris, AstroSweep expects to encounter ~28 debris objects >1 mm in diameter per minute. Assuming a single encounter is sufficient to eliminate the debris (which should be the case for the vast majority of debris), a single AstroSweep unit will be able to entirely clear all orbits from 400 to 1250 km altitude (the busiest zone) in less than 11 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 considerably larger than 10 cm. A network of 10 AstroSweep systems, spread latitudinally, are 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, survive re-entry and pose 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. AstroSweep can, for example, adjust the debris trajectory so that it lands at a known location in the Pacific Ocean (e.g., Point Nemo) 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. We review all contacts within 1 business day.

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.

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.

93% of spacecraft are uninsured today, despite international treaties requiring strict liability for any terrestrial damage caused by spacecraft launching nations. While manufacturers and operators would prefer to control their financial risk through insurance, current premiums are as high as 50% of the insured value. This is because insurers are unable to distinguish between losses due to operator or manufacturer failures vs. those due to space debris, space weather, or micrometeoroids; and so are susceptible to negligence and fraud. AstroSweep, through the substantial information advantage gained through tracking and management of the small debris which makes up 99% of mission-ending risk (absent said negligence and fraud), has the opportunity to enter the insurance market directly through becoming a broker on the Lloyd's of London Insurance Exchange, partnering with existing insurers, or simply passing cleaning and maintenance information on to a customer's insurer, helping the customer to secure improved rates (which may be of equal or greater value than the cost of AstroSweep's service!).

The economic value of in-space construction in particular is difficult to overestimate. AstroSweep's unique ability to clear orbits makes feasible projects which have historically been impossible or at least implausible. AstroSweep will capture this value through developing our own in-space construction projects.

AstroSweep is well-positioned in a market where first mover advantages compound through becoming a driving force for favorable regulatory activity. Conservatively assuming AstroSweep captures a mere 10% of the economic value for itself, profits will be on the order of billions of dollars per year by 2035, and in the hundreds of millions as early as 2028. Unlocking in-space construction has the potential to multiply these figures, and the space economy as a whole, by several magnitudes of order.

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 11 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).

Appendix 2: Document Changelog

V0.1: Released February 5th, 2026.
V0.2: Released February 9th, 2026. Several adjustments in the first 4 pages to improve readability.
V0.3: Released February 25th, 2026. Expanded radar, laser, and economic analysis sections.
V0.4: Released March 3rd, 2026. Tightened wording, improved format consistency.
V0.5: Released March 22nd, 2026. Updated Kessler Syndrome section for latest CRASH clock figures.