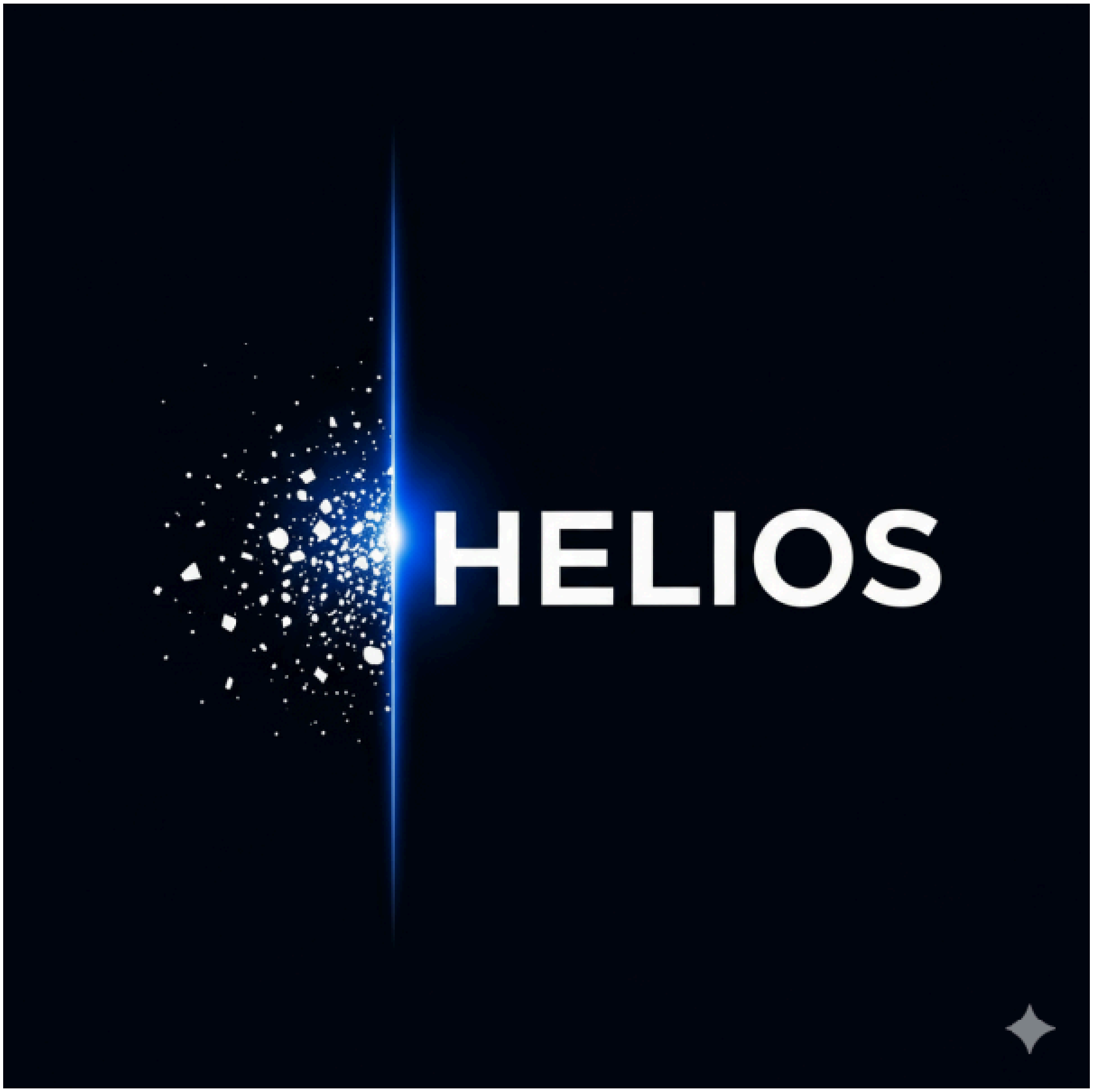
HELIOS — High Energy Laser Inter Orbital System



1. General Context

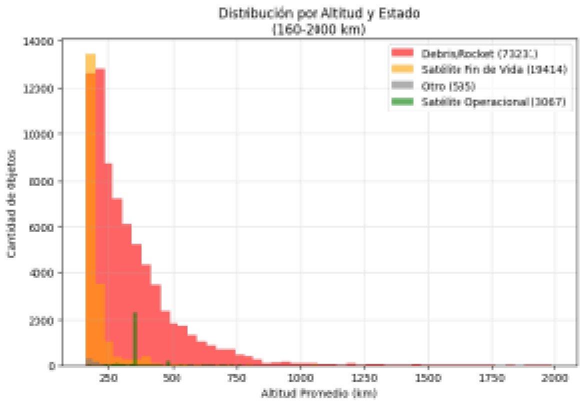
Problem to solve

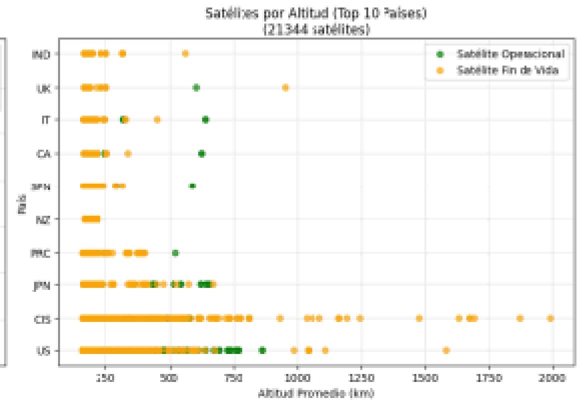
The accumulation of space debris in **Low Earth Orbit (LEO)** has become one of the main threats to the safety and sustainability of space operations. Currently there are more than **36,000 trackable objects (>10 cm)** and millions of smaller fragments that can damage or destroy operational satellites.

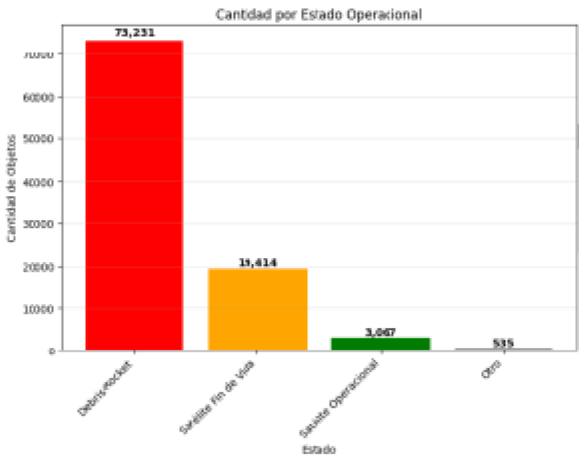
The **central risk** is the occurrence of cascading collisions—known as **Kessler syndrome**—where the impact of one object generates more fragments, exponentially increasing the probability of new collisions. This can lead to entire swaths of space becoming inoperable for decades.

The economic and strategic impact is enormous:

- Affects the **satellite industry** (telecommunications, GPS, meteorology, Earth observation).
- Puts the **International Space Station** and future private/commercial stations at risk.
- Compromises **space exploration and defense** projects.

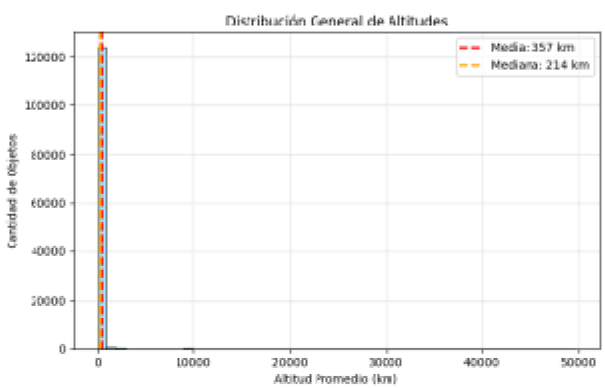


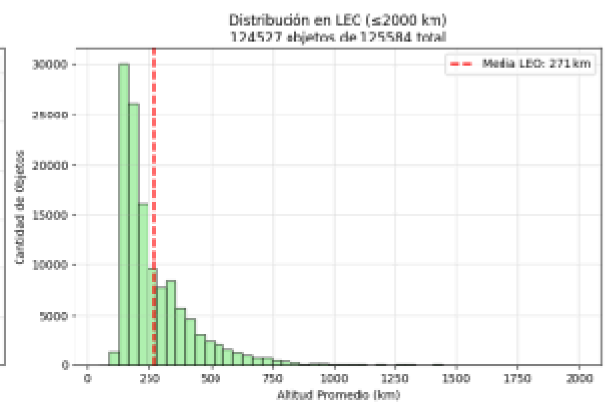


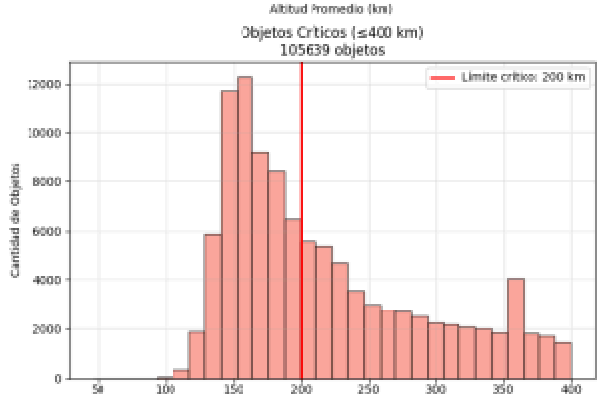


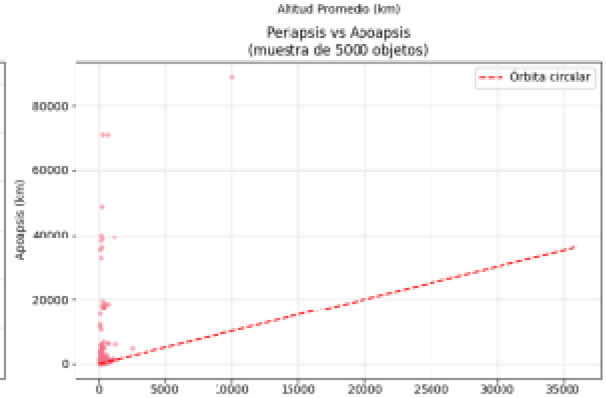
Resumen por Estado
(160-2000 km)

Estado	Cantidad	Percentaje
Debris/Rocket	73,231	76.1%
Satélite Fin de Vida	19,414	20.2%
Satélite Operacional	3067	3.2%
Otro	535	0.6%









The presented graphs clearly show the magnitude of the space debris problem. More than **76% of objects in low orbit (LEO)** correspond to rocket debris and satellites already out of service, while barely **3.2% are operational satellites**. The highest concentration is found at critical altitudes below 600 km, where most current constellations orbit. This imbalance shows that space infrastructure is surrounded, for the most part, by **inactive junk that increases the risk of collisions** and threatens both ongoing and future missions.

Hypothesis / main solution

The HELIOS project proposal **(High Energy Laser Inter Orbital System)** is the design of a **hybrid, modular and scalable** system that combines different technologies to address space debris based on its **mass, size and orbit**.

Main components of the hypothesis:

1. **Flexible and multi-scale deorbiting**

    - Sub-kilo objects: autonomous bots with electrospray propulsion, capable of adhering and generating localized impulses.

    - Medium objects (10–500 kg): remote interaction with **bidirectional plasma** (like the Japanese Tohoku engine).

    - Large objects (>1 t): approach with mothership systems and combined technologies (high-energy laser for surface ablation, magnetic coupling, ion thrusters).

2. **Energy efficiency and temporal scalability**

    - **Short term:** use of solar energy (deployable panels) with powers of 1–10 kW per module.

    - **Medium term:** modular scaling (swarms, motherships) with tens of kW.

    - **Long term:** incorporation of **compact nuclear reactors (Kilopower, Topaz, MW evolutions)** to sustain large-scale operations.

3. **Modular and swarm architecture**

    - A **mothership** with deployment, logistics and energy support capacity.

    - **Swarms of chasers** smaller and specialized for different missions (laser, plasma, bots).

- Possibility of progressive orbital assembly and scaling according to demand.

4. **Orbital coverage optimization**

    - Preferential operation in **polar orbits**, which allow greater coverage with less energy expenditure in plane changes.

    - Local adjustments from poles to reach objects in any quadrant, reducing costs compared to tropic-to-tropic strategies.

5. **Strategic vision of the project**

    - Offer an **orbital cleanup infrastructure** for agencies, private companies and international consortiums.

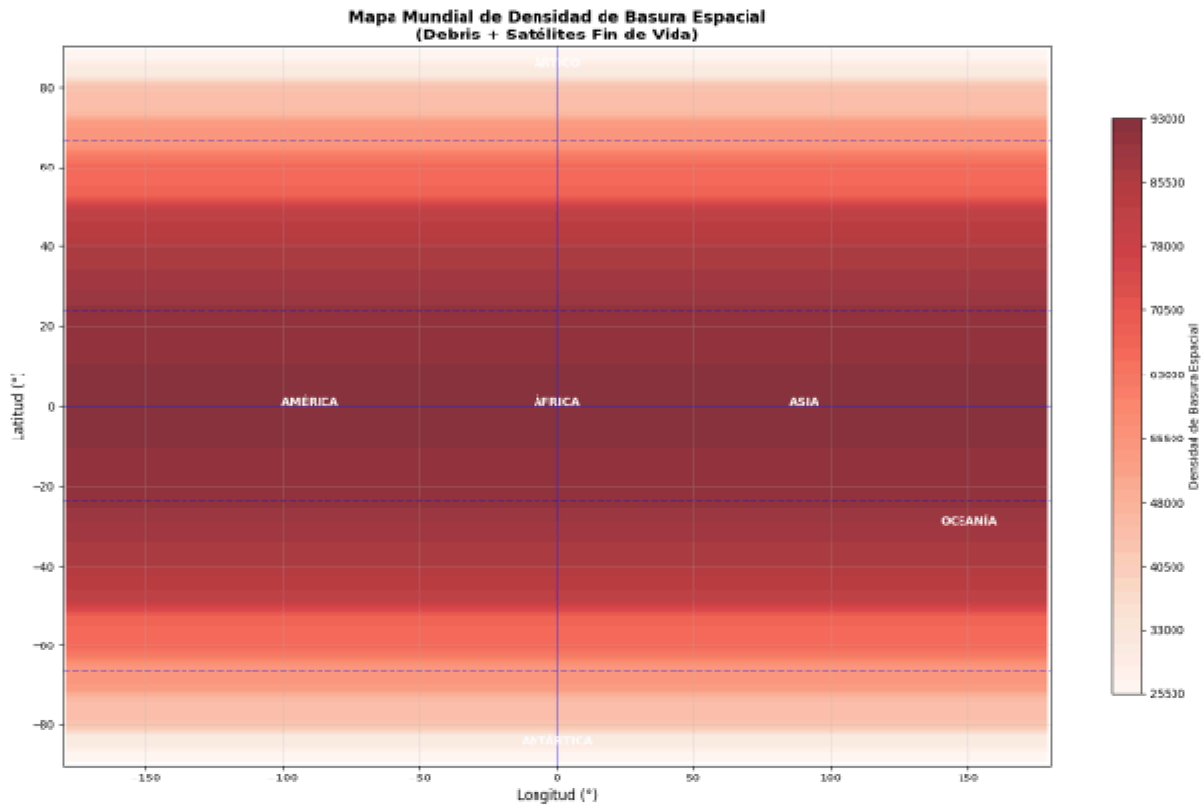
    - Position HELIOS as a **technological standard** in active space debris mitigation, aligned with international legislation.

2. Density maps and optimization for space cleanup

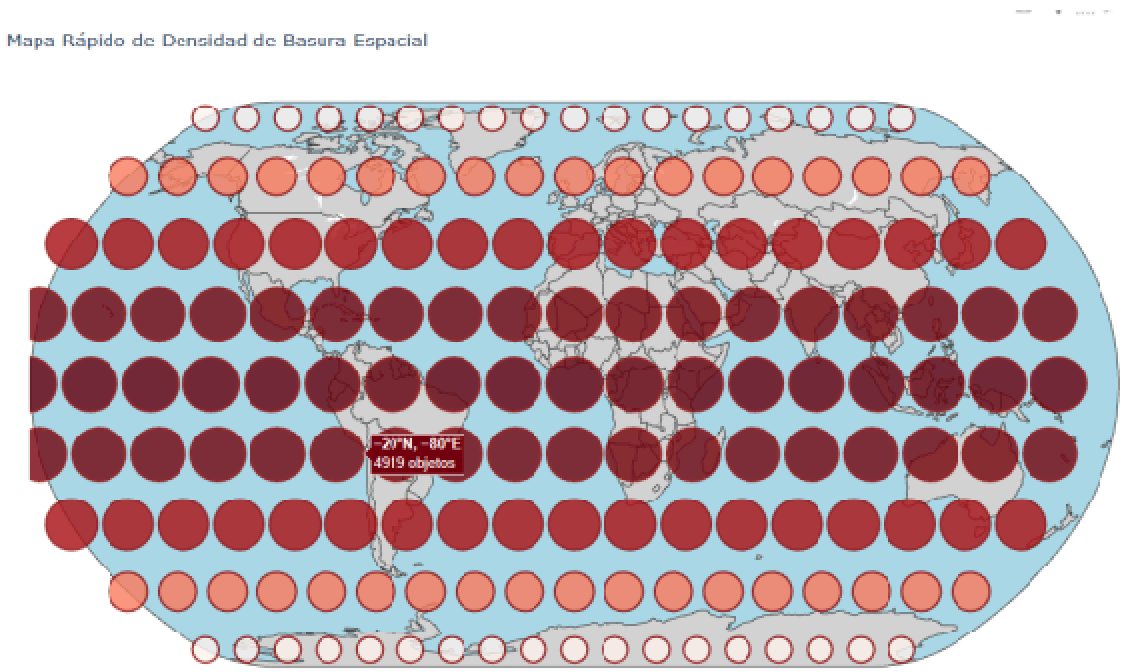
The following graphical representations show the magnitude of the space debris problem and serve as foundation for the need for active mitigation systems like **HELIOS**.

- **World Map of Space Debris Density:**
  Reflects the global concentration of orbital debris and out-of-service satellites. It is observed that equatorial regions concentrate most objects, due to the presence of highly

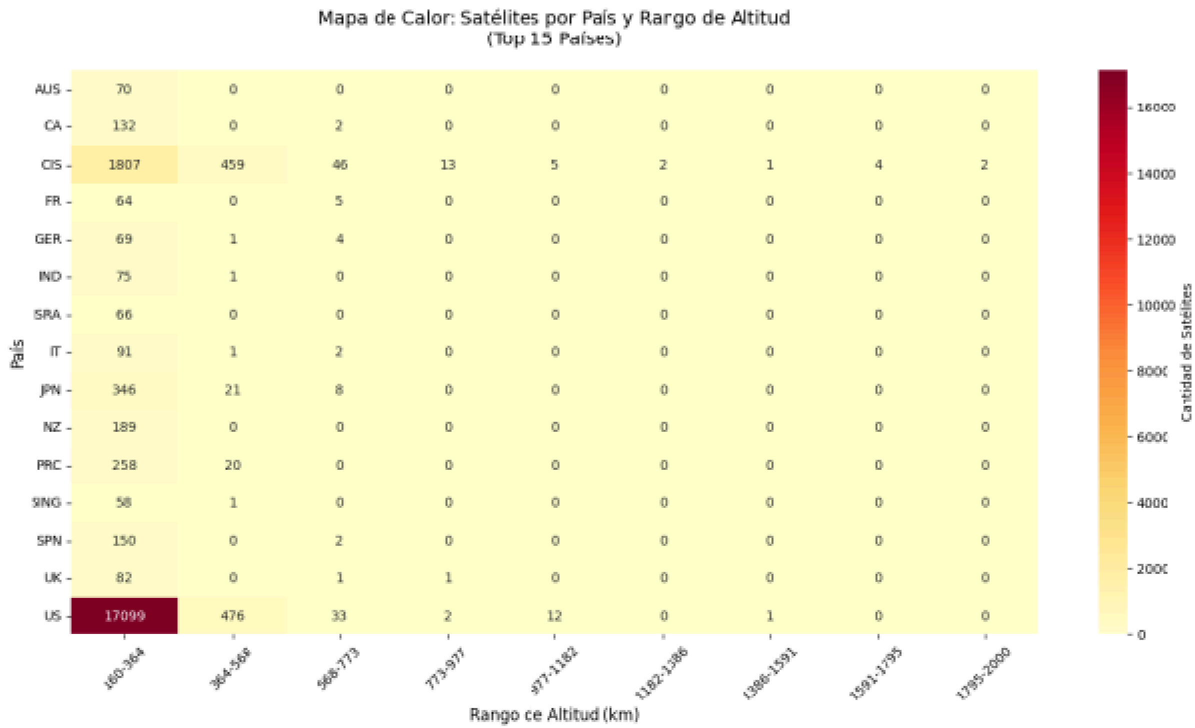
utilized commercial and military orbits.



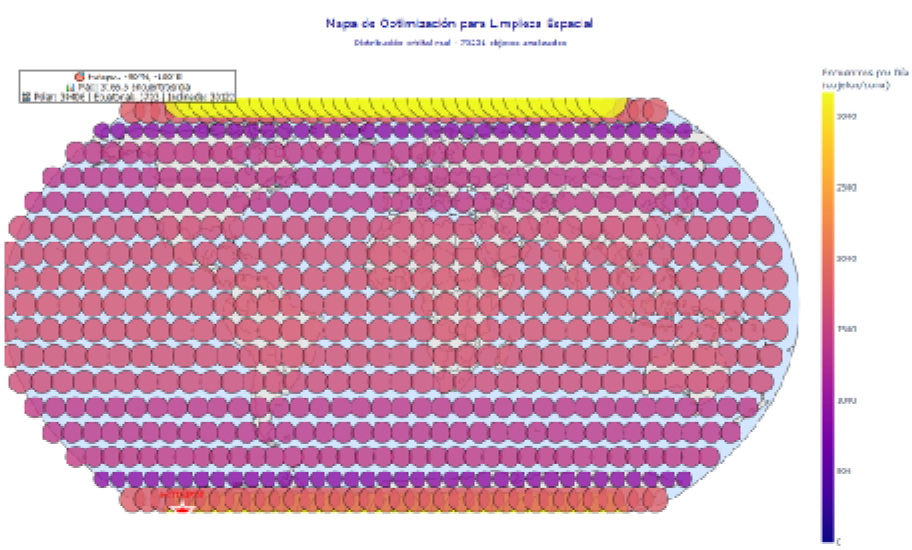
- **Quick Density Map (by quadrants):**
  Segments the Earth's surface into cells, showing how many objects accumulate in each sector. This reveals critical zones with thousands of pieces of debris in low orbits, where congestion is greatest.



- **Heat Map by Country and Altitude:**
  Presents the distribution of satellites according to their country of origin and altitude. The United States and the former USSR are the main historical contributors to accumulation, especially in LEO. This introduces a key geopolitical component: those who contributed most to the problem are also the most interested in its solution.



- **Optimization Map for Space Cleanup:**
  Simulates daily orbital encounters between objects. The most intense areas (yellow and orange) represent "hotspots" with higher probability of collisions. These points are priorities for deploying motherships and cleanup swarms.



Conclusion

The four visualizations converge on the same message: space debris is not randomly distributed, but is concentrated in **critical zones of high density and risk of cascading collisions**. This not only threatens the safety of space operations, but also the sustainability of global orbital infrastructure.
A scalable and targeted system like **HELIOS** becomes essential to act at the highest risk points, optimizing resources and ensuring long-term stability of the orbital environment.

3. Key Concepts

Multiple technological and strategic ideas emerged during the development of the HELIOS project. Some are central and viable in the short, medium and long term.

Viable and project-relevant technologies

✅ **Orbital lasers**

- **Function:** surface ablation → vaporize part of the debris material, generating a subtle thrust in the opposite direction.
- **Application scale:** small fragments (cm–dm).
- **Advantages:** no physical contact required; good precision when combined with adaptive optics.
- **Limitations:** energy dissipation, required power (MW for large debris), risk of additional fragmentation if not applied in a controlled manner.

✅ **Bidirectional plasma propulsion (Japan, 2025)**

- **Concept:** electrodeless engine that expels plasma in two directions → generates thrust on an object and compensates recoil on the chaser.
- **Application scale:** medium objects (10–500 kg).
- **Advantages:** no contact needed, avoids complex mechanical couplings.
- **Limitations:** low thrust rate → requires weeks/months to deorbit an object.

✅ **Electro-spray bots (mini-satellites from mothership)**

- **Function:** autonomous microbots equipped with electrospray propulsion (liquid or colloidal ions).
- **Application scale:** micro-debris (<1 kg), which today cannot be tracked well with radar.
- **Advantages:** possibility of adhering (nanoadhesives, magnets, micro-harpoon) and applying controlled impulses.
- **Potential:** great commercial differentiator → today almost no one addresses debris <10 cm.

✅ **Mothership + swarm of chasers**

- **Modular architecture:**
    - Mothership: support vessel with power, logistics and deployment.
    - Swarm of chasers: specialized vehicles (laser, plasma, bots).
- **Advantages:** scalability → modules can be added/removed according to demand.
- **Provides redundancy:** if one chaser fails, the mission continues.

✅ **Polar orbits**

- **Use of polar/sun-synchronous orbits:**
    - Greater global coverage → pass over almost the entire planet in each orbit.
    - Plane corrections energetically cheaper at the poles.
- **Advantages:** flexibility to intercept debris at multiple inclinations without spending as much delta-v.

✅ **Compact and modular nuclear generation (Kilopower → MW)**

- **First phase:** Kilopower (NASA), reactors of 1–10 kWe → feasible and tested in prototypes.
- **Historical:** Soviet Topaz (~5 kWe, operational in the 80s–90s).
- **Second phase:** reactors of 100 kWe–1 MWe in conceptual design.

- **Third phase:** scalable MW modules, assembled in orbit or installed on the Moon/MEO, to power high-energy lasers and massive swarms.
- **Relevance:** they become the energy pillar of HELIOS at industrial scale.

✅ Compact and scalable nuclear generation (Kilopower → MW)

Short term (1–10 kWe)

- **Examples:** Kilopower (NASA), Soviet Topaz (~5 kWe).
- **Use in HELIOS:** basic support in small-scale motherships → minimum power to maintain operations during eclipses and energize small swarms of electro-spray bots and chasers with bidirectional plasma.
- **Application in cleanup:** enables continuous 24/7 operations without depending on the sun → critical in polar orbits and zones with prolonged eclipses.

Medium term (100 kWe – 1 MWe)

- **Status:** conceptual designs at NASA/DOE; require advanced radiators and orbital assembly.
- **Use in HELIOS:** second-generation motherships, capable of simultaneously sustaining:
    - Medium swarms of laser/plasma chasers.
    - Drones with parallel rendezvous capability.
    - Electro-spray microbots in massive deployment.
- **Application in cleanup:**
    - Allows increasing the **deorbiting rate** (process several objects in parallel).
    - Possibility of operating **100s of kW lasers**, useful for larger fragments that would be unfeasible with solar today, however, thanks to advances in small nuclear reactors in space, one of them could be coupled to the proposed system to power the system.

Long term (300 MW+)

- **Viability:** plausible in MEO, HEO and lunar bases → reduces LEO radiological risks.
- **Challenges:** mass >100 t, radiators of thousands of m², international approval (COPUOS/UNOOSA).
- **Potential for HELIOS:**
  - **Real MW power orbital lasers** → capable of deorbiting not only small fragments, but also complete satellites through prolonged ablation.
  - **High-intensity plasma propulsion:** massive swarms of chasers can "tow" objects of several tons without the need for direct contact.
  - **Shared energy infrastructure:** nuclear motherships serve as "orbital power plants," feeding multiple swarms in different orbital layers.
- **Application in cleanup:**
  - Enables **industrial deorbiting operations**, processing thousands of objects per year.
  - Supports **"orbital mining"** scenarios: reusing metallic parts or orbital components instead of just deorbiting them.

We bet **directly on a nuclear roadmap**: start with Kilopower and compact reactors → advance towards 100 kWe–1 MWe reactors → culminate in **300 MW+ reactors**, which are considered **one of the most viable and strategic options for the future of the system**, especially if platforms outside LEO (MEO, HEO, Moon) are leveraged to mitigate regulatory risks and maximize energy efficiency.

📌 Conclusion of block 3

The core of HELIOS relies on **five clear technological axes**:

1. **Orbital lasers** → small fragments.
2. **Bidirectional plasma** → medium objects.
3. **Electro-spray bots** → microdebris.
4. **Modular architecture (mothership + swarm) in polar orbits.**

5. **Compact and modular nuclear generation as a long-term strategic enabler.**

3. Technical Analysis

A) Energy Generation

Solar:

- Viable in the short term for motherships and chasers.
- Achievable power: up to 10–100 kW with large panels.
- Limitation: scaling to MW requires giant masses and surfaces (~100–300 t for 10 MW).

Nuclear:

- **First phase (0–10 years):**
    - Kilopower and derivatives (1–10 kW).
    - Viable for small chasers or experimental modules.
- **Second phase (10–25 years):**
    - Designs of 100 kW – 1 MW in development (NASA, DOE, ESA).
    - Possible for motherships in LEO/MEO, assembled modularly.
- **Third phase (+25 years):**
    - Reactors >100 KW.
    - **In LEO** → *not very viable* due to mass, radiators and safety on reentry.
    - **In MEO/HEO or lunar surface** → *feasible* if assembled in orbit or built in situ, taking advantage of absence of atmosphere and more flexible legal restrictions.

✅ Relevant: HELIOS could rely on modular reactors like *scaled Kilopower*, and in the future on orbital/lunar reactors that supply stations or motherships.

B) Orbits and Maneuvers

- **Poles:** efficient for plane changes and global coverage (minimal correction at poles → great effect at equator).
- **Tropics:** more debris concentration, but less efficient for repositioning.
- ✅ Conclusion: polar orbits for global coverage + motherships in specific planes for high debris density.

C) Deorbiting Methods

- **Orbital laser (HELIOS core):** small fragments through surface ablation.
- **Bidirectional plasma (Japan 2025):** remote thrust, useful for medium (~tens-100s kg).
- **Ionic/plasma pulse with mothership:** option for large objects, momentum transfer.
- **Electro-spray bots:** fixation and thrust of <1 kg.

D) Coupling Mechanics

- **Magnetic:** useful for satellites with ferromagnetic material.
- **Electro-adhesion / sprays:** viable for small debris.
- **Safe velocities:** rendezvous maneuvers at low delta-v; minimize fragmentation.
- **Kinetic energy absorption:** chasers must gradually dissipate object energy.

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4. Commercial Factors

🔹 Business model

- **Orbital cleanup contracts (orbital debris mitigation as-a-service):**
    - Offered to agencies (NASA, ESA, JAXA, CNSA) and private operators (SpaceX, OneWeb, Amazon Kuiper).
    - Added value: not only removal, but also life extension (repositioning, energy assistance, in-orbit maintenance).

- **Multi-actor approach:**

  HELIOS positions itself as the first private company focused on space debris removal to maintain the balance of orbital service ecosystems.

Market opportunity

- **HELIOS as integral service:**
  - **"Debris + support"** contracts: debris cleanup + constellation assistance (repositioning, life extension, collision management).
  - "Insurance-linked" model: space insurers are a stakeholder whose interests are aligned with HELIOS's mission, generating strategic synergy that leads to project financing. In turn, promoting a safe LEO ecosystem can guarantee orbital lanes for future missions of different magnitudes.

Scalability

- **Modular architecture (Mothership + swarm):**
  - Allows dimensioning missions according to debris density and criticality in each orbital region.
  - **Modular and scalable** system: main motherships can be positioned in polar orbits to maximize coverage, while chasers and bots are deployed according to debris density in different planes.
    The **strategy of using polar orbits** is justified because they allow covering any quadrant with less energy expenditure in plane changes.
    At the energy level, **large reactors** (hundreds of MW) are projected in **MEO, HEO or lunar bases**, while in LEO the initial motherships would operate with solar energy or compact reactors (Kilopower, Topaz).
- **Progressive growth:**
  - First phase: small contracts with agencies to relocate or deorbit small objects.
  - Medium term: deployment of specialized swarms by debris type (micro, medium, large).
  - Long term: global network of motherships energized by compact reactors → permanent orbital management infrastructure.

🔹 HELIOS commercial differentiating factors

1. **Comprehensive coverage:** Offers services tailored to customer needs, comprising the micro-debris market (<1 cm) to potential markets of inactive satellites and large tonnage space debris.

2. **Energy scalability:** nuclear roadmap that allows transitioning from kWe operations to hundreds of MW.

3. **Catastrophic risk reduction:** Since the launch of Sputnik in 1957, outer space has not been subject to accountability, generating a large space junkyard that puts all of society as we know it at risk. We must consider technological dependence in the framework of telecommunications, weather predictions, scientific, astronomical, navigation aid, among others that are in jeopardy due to sustained negligence in outer space. Helios, aware of the imperative need for constant advancement of our society, considers as priority to focus on sustainable, democratic and innovative outer space.

4. **Strategic positioning:** first operator of "critical orbital infrastructure" → market similar to roads or electrical networks on Earth.

📌 **Conclusion:**

In conclusion, Helios positions itself as an innovative leader in the removal of potential threats against the advancement of LEO utilization and optimization. Additionally, in accordance with the vision of each of its members, promoting a multi-actor ecosystem, both state and private, with a central focus on orbital safety as a service to ensure the continuity of exploration, research and promotion of different services

5. Legal and Regulatory Factors

- **Outer Space Treaty (1967):** prohibits nuclear weapons in orbit, but allows peaceful reactors.

- **UN 1992 (Nuclear Power Sources in Outer Space):**

    - Use permitted if reasonably safe.

    - Requires safety studies and international notification.

    - Disposal orbit or escape trajectory must be provided for at end of life.

- **Practical limitations:**

- LEO → powerful reactors = high risk.
- MEO/GEO → more acceptable for MW reactors.

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6. Realistic Roadmap

- **Short term (0– 10 years):**
    - Chaser demonstrators with plasma engine (solar 1–10 kW).
    - Tests with debris <100 kg.
    - Validation in polar orbits.
- **Medium term (10–25 years):**
    - Swarms of chasers (10–50 kW).
    - Integration of bots with electro-spray engine for debris <1 kg.
    - Modular mothership with propellant storage.
- **Long term (+25 years):**
    - MW nuclear reactors for continuous power.
    - Advanced radiators (droplet / heat-pipe).
    - Orbital assembly of modules → multi-MW cleanup stations.

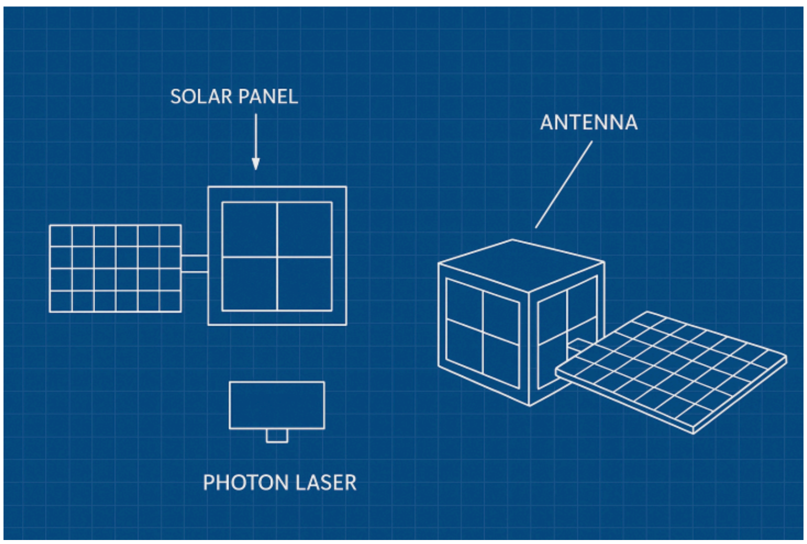
7. General Conclusion of the HELIOS Project

The **HELIOS (High Energy Laser Inter-Orbital System)** project emerges as a response to the growing threat of space debris in low Earth orbit (LEO), which compromises the safety of satellites, space stations and future interplanetary missions. The risk of cascading collisions, known as *Kessler syndrome*, makes an active, scalable and sustainable system for orbital waste mitigation essential.

The presented images synthesize the final vision of the HELIOS system: a **modular and scalable** architecture, based on motherships and swarms of specialized chasers/bots, which combine multiple deorbiting technologies according to the type of waste.

Central elements of the system

1. **Laser modules with solar generation**

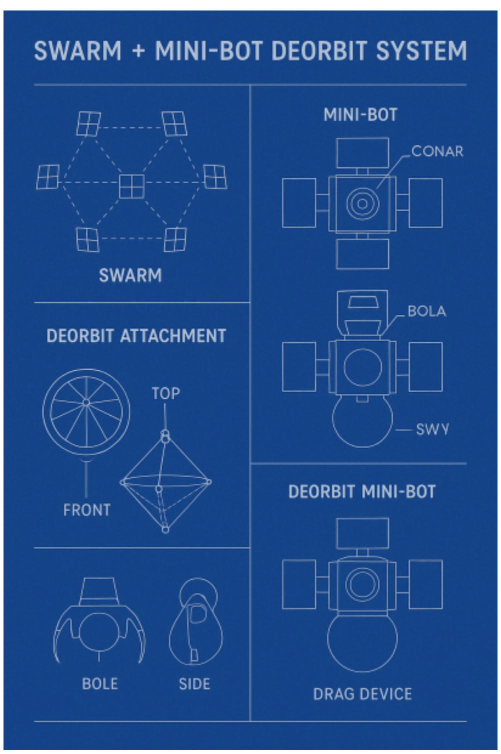


Designed to act on small fragments (cm–dm).

They operate with solar energy in the first stage, with the projection of being powered by **compact nuclear reactors** in advanced phases to sustain large-scale operations.

(AI-generated image)

2. **Swarm of chasers and mini-bots**



The **chasers** perform precise interceptions in polar orbits, optimizing coverage and minimizing correction maneuvers.

The **mini-bots with electro-spray systems or drag devices** adhere to microdebris (<1 kg), providing a unique solution for the most dangerous and neglected range of space debris.

(AI-generated image)

3. **Modular and scalable architecture**

    - The **mothership** deploys, coordinates and powers the chasers and mini-bots, ensuring operational continuity even in case of individual failures.

    - This design allows transitioning from initial low-power demonstrators to industrial platforms with swarms powered by **100 kWe – MW nuclear modules**, capable of sustaining high-energy lasers and global operations.

4. **Orbital flexibility**

    - The choice of polar orbits ensures planetary coverage and efficiency in plane changes.

    - In the future, expansion towards MEO and GEO is contemplated, with more powerful platforms.

Response to the need

HELIOS presents itself as a **viable, scalable and differentiating** system, by integrating multiple mitigation technologies in the same modular framework:

- **Orbital lasers** → small fragments.

- **Bidirectional plasma** → medium objects.

- **Electro-spray bots** → microdebris.

- **Modular nuclear reactors** → energy support to scale the system to planetary level.

The result is a **"as-a-service" commercializable** platform, capable of offering space agencies and private operators a comprehensive orbital cleanup service. More than a single system, HELIOS is a **long-term energy and technological infrastructure**, marking a clear path towards the safety and sustainability of space operations.

8. Bibliography (links used)

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