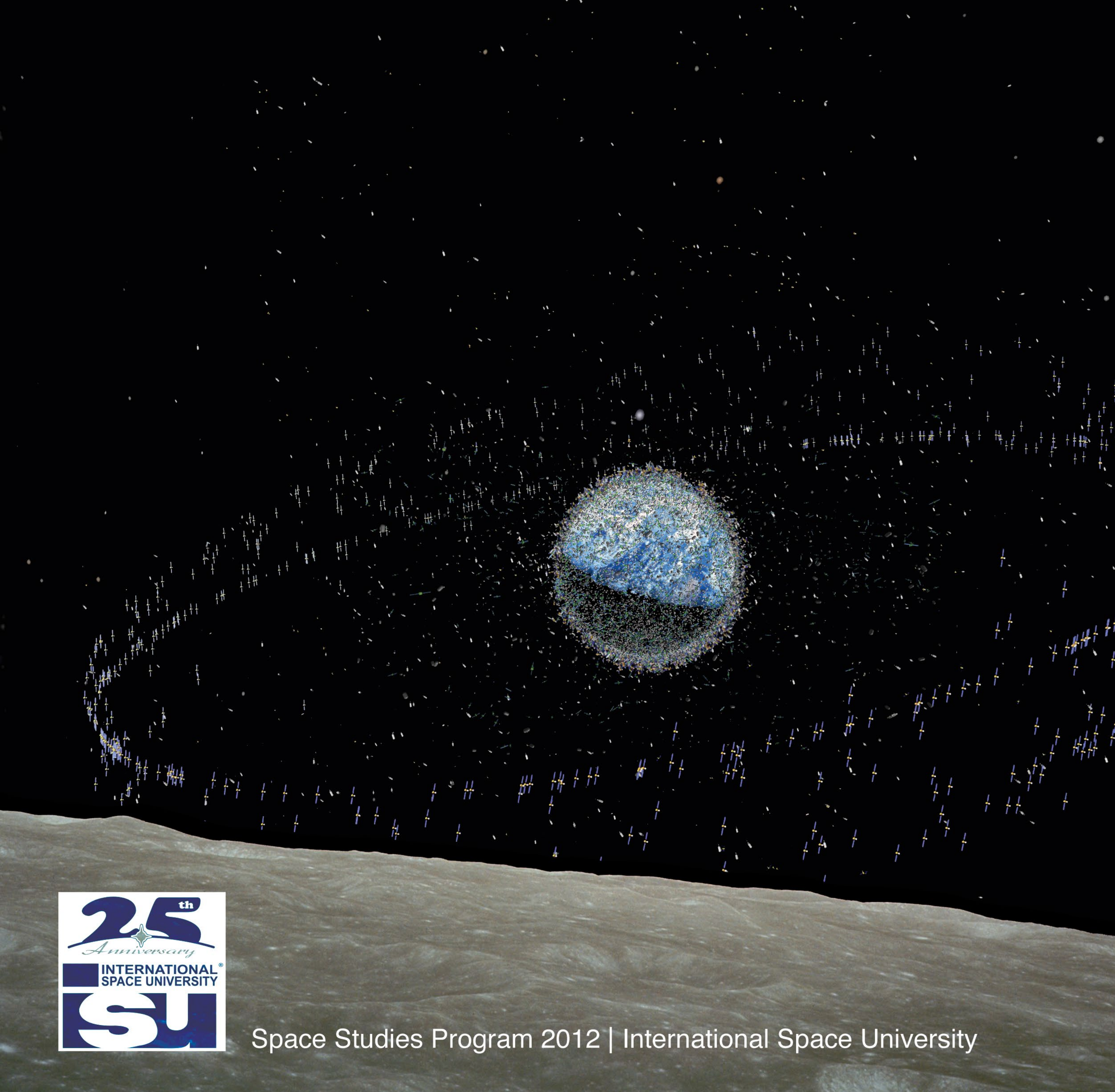
SPACE DEBRIS

executive summary



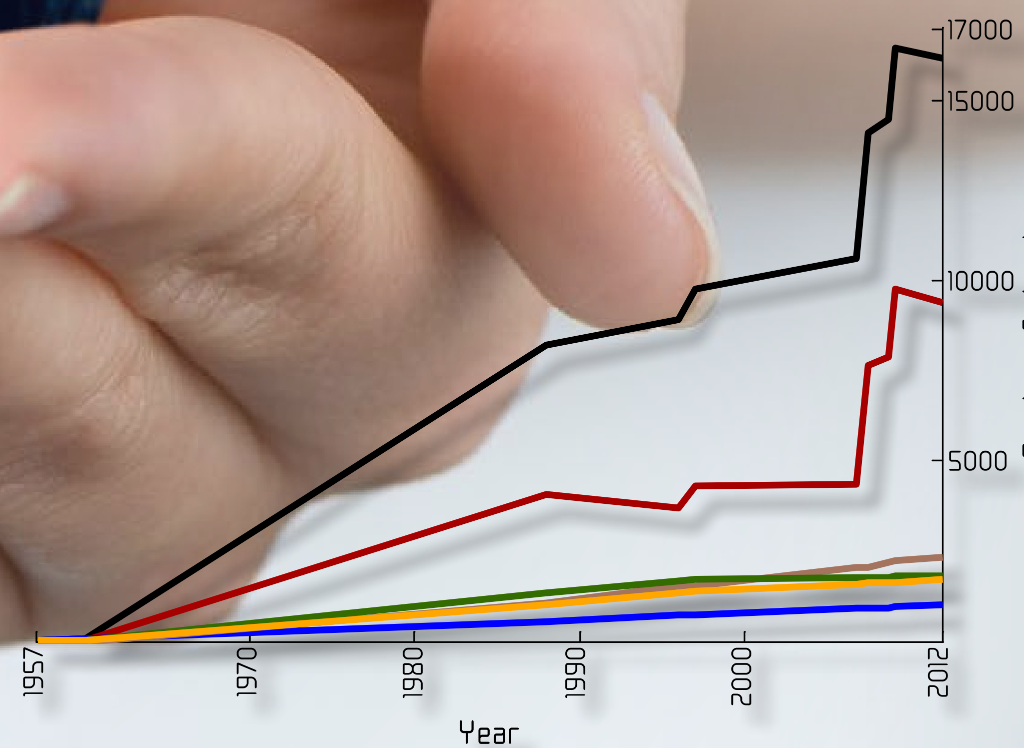
Space Studies Program 2012 | International Space University

OUR MISSION

To propose a solution to the problem of Earth orbital debris. We will discuss economic and environmental rationales while addressing political, financial, and legal frameworks, along with technical solutions and methods of raising awareness.

ORBITAL DEBRIS – A CALL TO ACTION

The Earth's space environment is in danger. Since the launch of Sputnik 1 in 1957, Earth's orbital environment has been continually polluted with man-made, non-functional debris posing an ever-increasing risk to current and future space activities. According to the U.S. Space Surveillance Network (SSN), there are about 17,000 objects officially cataloged in orbit, and an estimate of up to a few thousand billion non-cataloged items, with a combined mass of millions of kilograms. The debris population is constantly growing as larger debris collide, creating the conditions for a self-sustained collisional cascading process, named Kessler Syndrome, that would prevent access to space. From the time when the issue has surfaced, there have been no indications that an effective solution will be implemented in the near future. Such a solution will require MITIGATION and REMOVAL of orbital debris. We addressed technological development, POLITICAL and LEGAL frameworks, FINANCIAL and BUSINESS aspects, and strategies of raising awareness at the political and public levels. **The Space Debris Team Project** proposes a solution with the goal to preserve access to space for current and future generations.



"The current debris population in the Low Earth Orbit region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future."
- Liou & Johnson, Science, 2006

ORBITAL DEBRIS MITIGATION

is a set of cost-effective measures to reduce the creation of new orbital debris. The consensus among satellite operators is to implement debris mitigation measures throughout the mission life. The UN COPUOS[1] and the IADC[2] actively promote debris mitigation. In 2007, they agreed upon SEVEN ORBITAL DEBRIS MITIGATION GUIDELINES, which are to be voluntarily COMPLIED by the member states. The guidelines here are represented by color-coded level of compliance.

100%

90%

80%

70%

60%

50%

40%

30%

1 LIMIT RELEASE DURING OPERATIONS

Common countermeasures:

- Limited release of bolts, lens covers, etc.
- Active capture of components
- Waste disposal mechanisms

Scope for improvement:

- Avoid ejection of large grains for solid rockets
- Enlarging mass-to-area ratios of adaptors

7 LIMIT LONG-TERM PRESENCE IN GEO

Remove non-functioning spacecraft from Geostationary Orbit (GEO) into “graveyard orbits” 300km above. The maneuver typically requires up to 3 months of station keeping fuel. In the long-run, it will even be necessary to bring GEO spacecraft back to Earth to avoid the congestion of the graveyard orbit.

6 LIMIT LONG-TERM PRESENCE IN LEO

Remove non-functioning spacecraft from Low Earth Orbit (LEO) by either deorbiting them with a controlled propulsive maneuver or by accelerating their orbital decay with propulsive or non-propulsive technologies in compliance with the UN COPUOS’ “25 year rule.”

4 AVOID INTENTIONAL DESTRUCTION

Deliberate destruction of orbiting satellites, in experiments and military testing, creates a multitude of debris. If unavoidable, it shall be confined to an altitude low enough to ensure prompt debris re-entry. A prior approval should be requested from the UN COPUOS.

2 MINIMIZE BREAKUP POTENTIAL

Compliance with ISO[3] structural design standards, improved armor, and re-entry requirements.

SMALL < 1cm	1cm < MEDIUM < 10cm	LARGE > 10cm
armor shielding	armor sheilding	tracking
-	advanced design	conjuction analysis
-	operational procedures	collision avoidance

5 PREVENT POST-MISSION EXPLOSIONS

End-of-mission passivation via:

- Propellant venting
- Depressurization of highly pressured systems
- Permanent battery discharge
- Powering off momentum wheels
- Prevent accidental trigger of self-destruct command

3 PREVENT ACCIDENTAL COLLISIONS

Since collision avoidance maneuvers demand advanced planning for operators, accuracy of collision prediction by conjunction analysis is crucial. Space Situational Awareness (SSA) capability shall be increased and in Space Traffic Management (STM) effectiveness shall be enhanced. Public sharing of orbital and spacecraft data, as outlined by the Space Data Association (SDA) is critical.

[1] United Nations Committee on the Peaceful Uses of Outer Space
[2] Inter-Agency Space Debris Coordination Committee
[3] International Organization for Standardization

image credit: Museum History of Science

ACTIVE DEBRIS REMOVAL TECHNOLOGIES

Projection of the orbital debris population in LEO has demonstrated the need for Active Debris Removal (ADR) in order to keep the orbital environment sustainable and accessible for future space activities. In the last decade, many proposals for ADR technologies were developed, each with a unique set of strengths and weaknesses depending on the intended orbit, debris size, and operating principles. Some of these technologies were compared in a trade-off study to identify the potential candidates to be used for ADR of satellites in LEO. Special attention was given to extra-large debris in high-inclination LEO because they are the main cause of population growth.

Various removal technologies were assessed and compared according to SEVEN basic parameters. The most promising ones were chosen as part of recommendations for removal missions.

1. Technology Readiness Level
2. Feasibility
3. Risk
4. Total Cost
5. Reusability
6. Time To Deorbit
7. GEO Adaptability

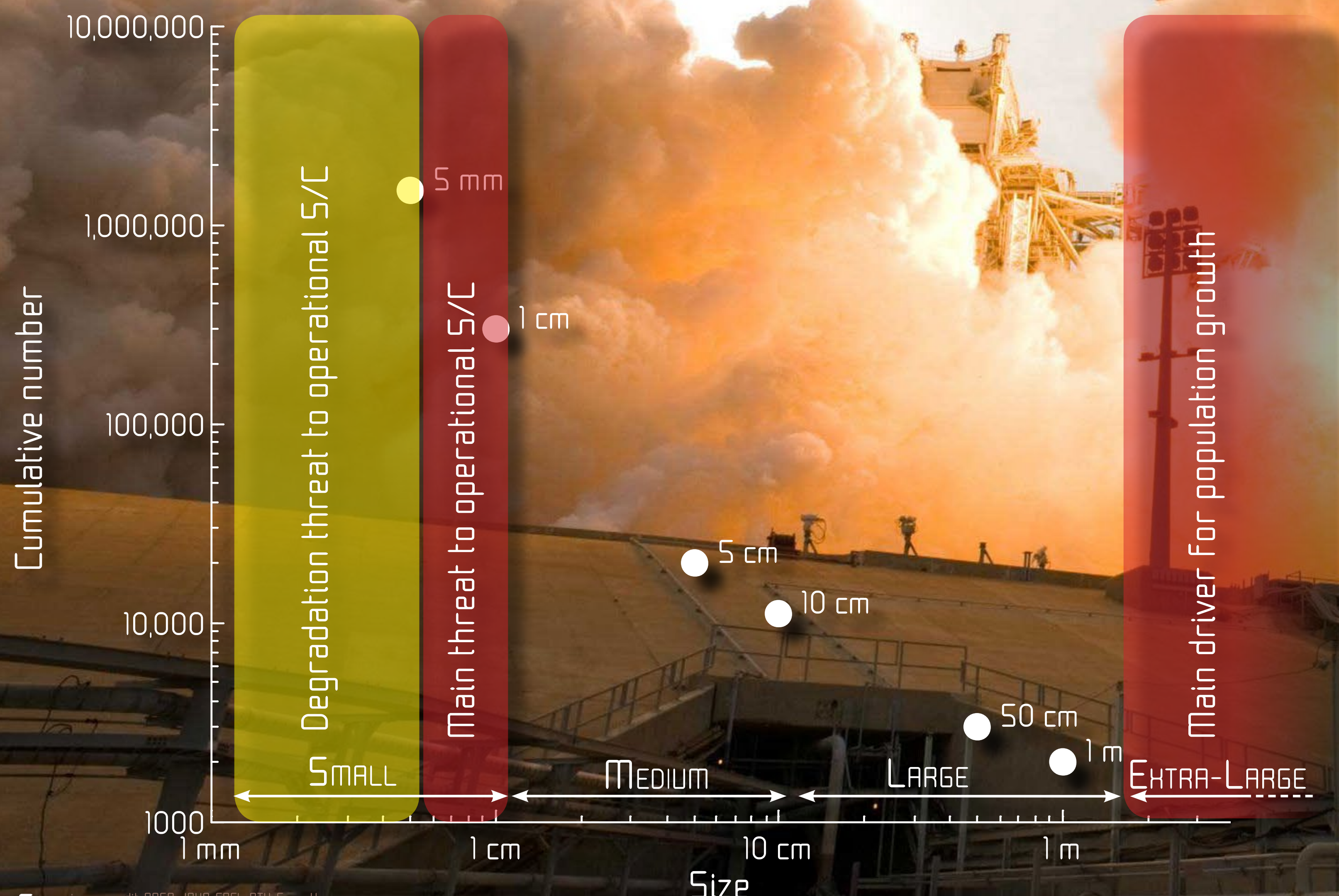


image credit: NASA, JAXA, EPFL, ATK, SpaceX

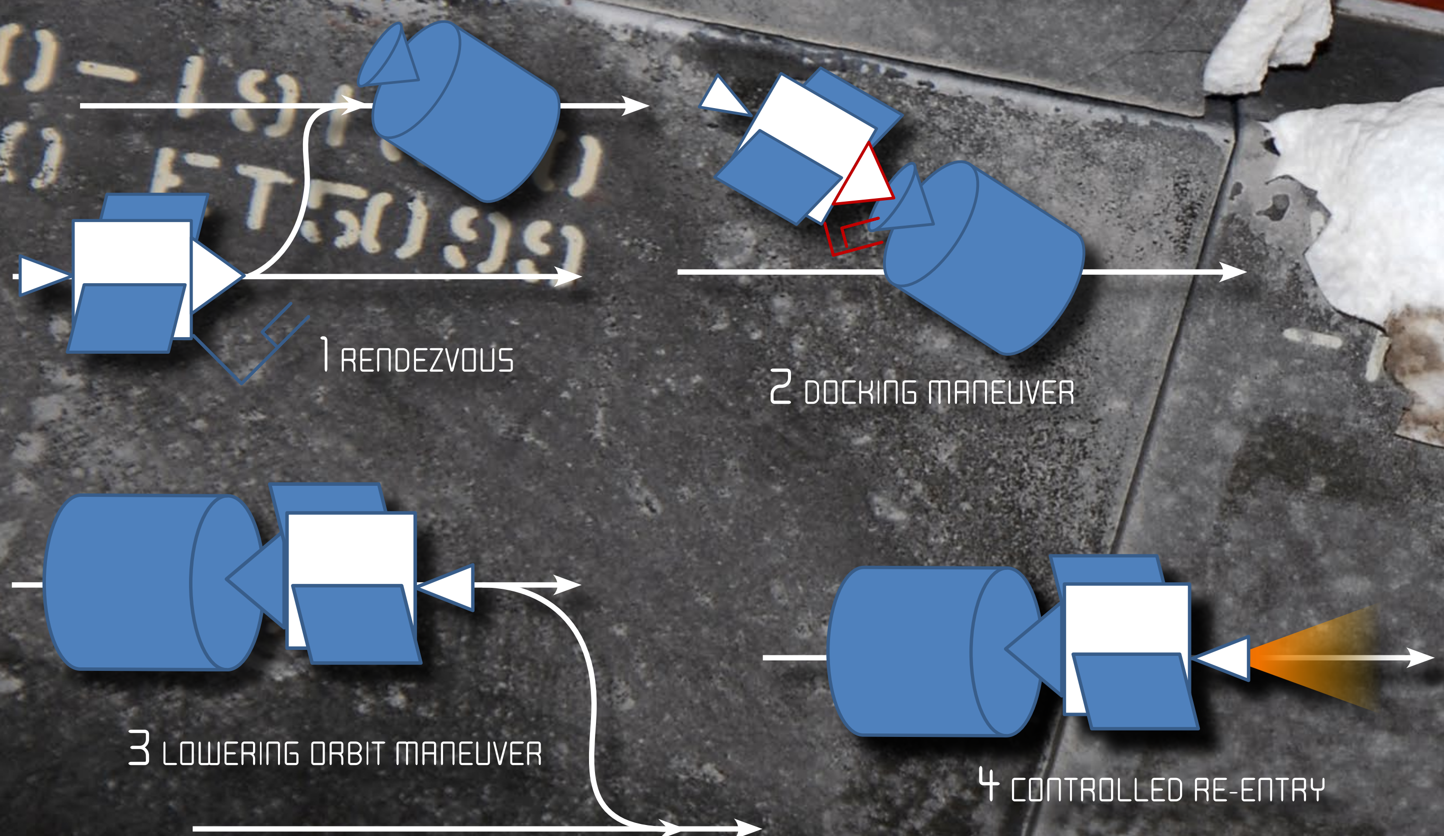
ACTIVE DEBRIS REMOVAL SOLUTIONS

Defining a single solution addressing each category of debris is a challenging problem as removal technologies have different effectiveness depending on debris size. For this reason, the trade-off comparison has led to the selection of three ADR solutions: Lasers for MEDIUM (M) debris; SpiderSat for LARGE (L) debris; and Chasers for EXTRA-LARGE (XL) debris.

All three concepts have considerable legal challenges, including ownership, responsibility and liability, Intellectual Property Rights (IPR) and licensing as well as political issues with regard to military applications of ADR technologies, export control and geopolitical considerations.

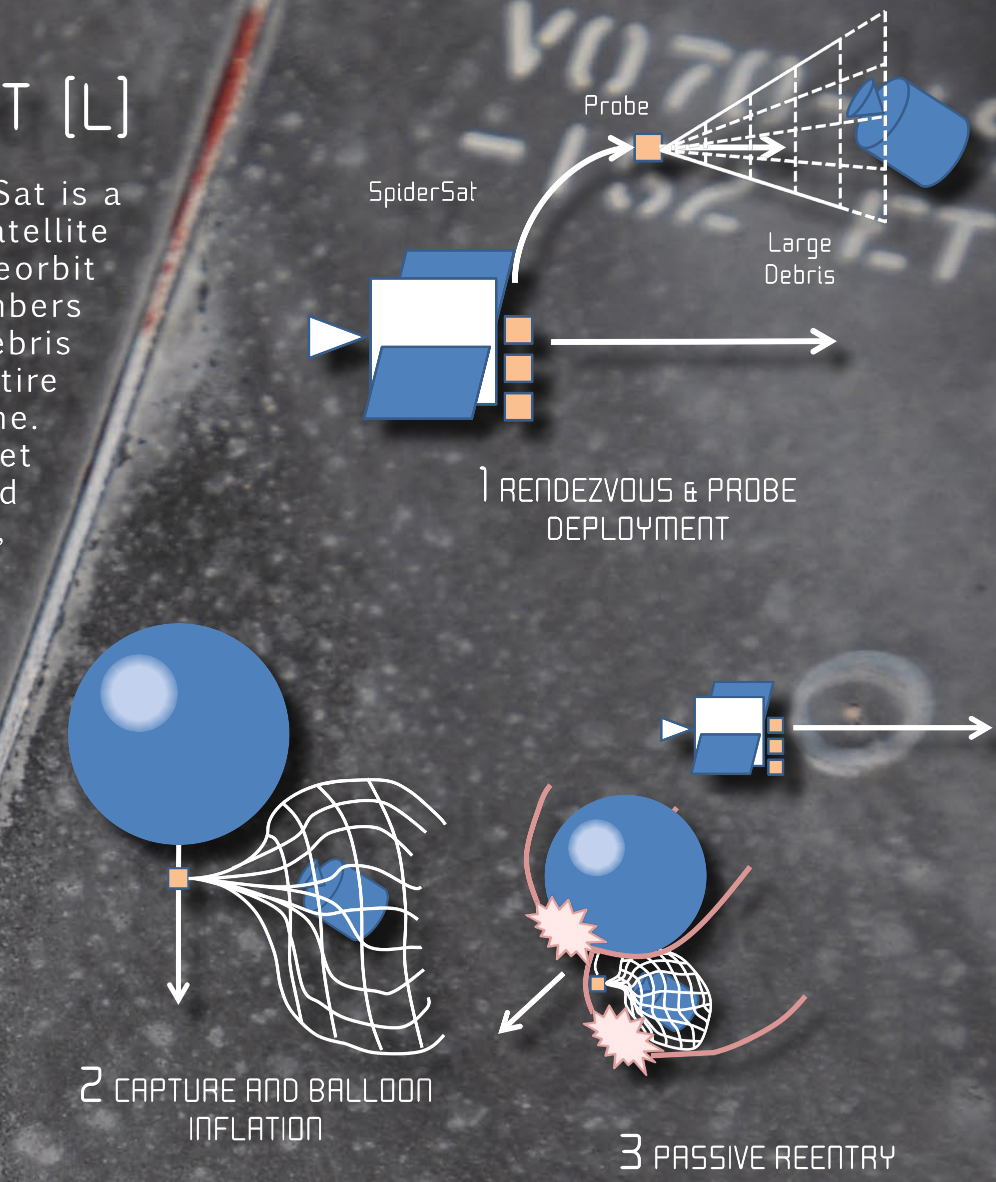
CHASERS (XL)

Chasers are small spacecraft with robotic arms using electrical propulsion to capture extra-large (XL) debris and chemical propulsion to perform controlled deorbit. This type of spacecraft allows deorbiting a single XL debris object, but multiple chasers may be packed in a single launch to save costs.



SPIDERSAT (L)

SpiderSat is a reusable satellite that can deorbit large numbers of space debris during its entire mission lifetime. It combines net capture and balloon deorbit, addressing debris larger than 10cm. The simplicity of the concept makes it very likely to be developed in the near future.



LASERS (M)

The Laser Orbital Debris Removal (LODR) uses a ground-based laser to slow down debris objects forcing them to rapidly descend and burn up in the atmosphere. This approach might be the most cost-effective way to mitigate the debris problem.

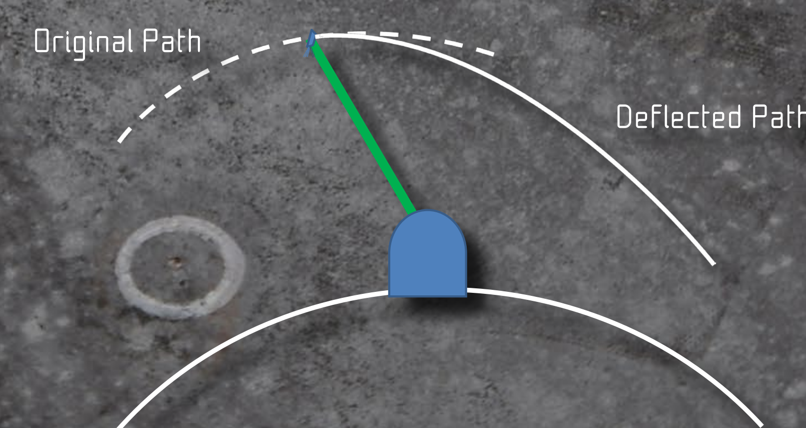


image credit: NASA

SOLUTIONS

1 Improve orbital debris trajectory prediction.

2 Create an international Space Situational Awareness system.

3 Develop enhanced spacecraft armor

4 Passivation of launch vehicles and satellites at its end of life.

5 Non-functional and post-mission vehicle elements should be removed from LEO.

6 Put into action ground-based lasers addressing medium debris.

7 Develop and implement the SpiderSat for the *in situ* capture and deorbit of large debris objects.

8 Develop and implement large debris deorbiting missions with fully controlled re-entry trajectories.

9 Details of nations and organizations not following guidelines should be made visible in publications from FAA[1] and ITU[2].

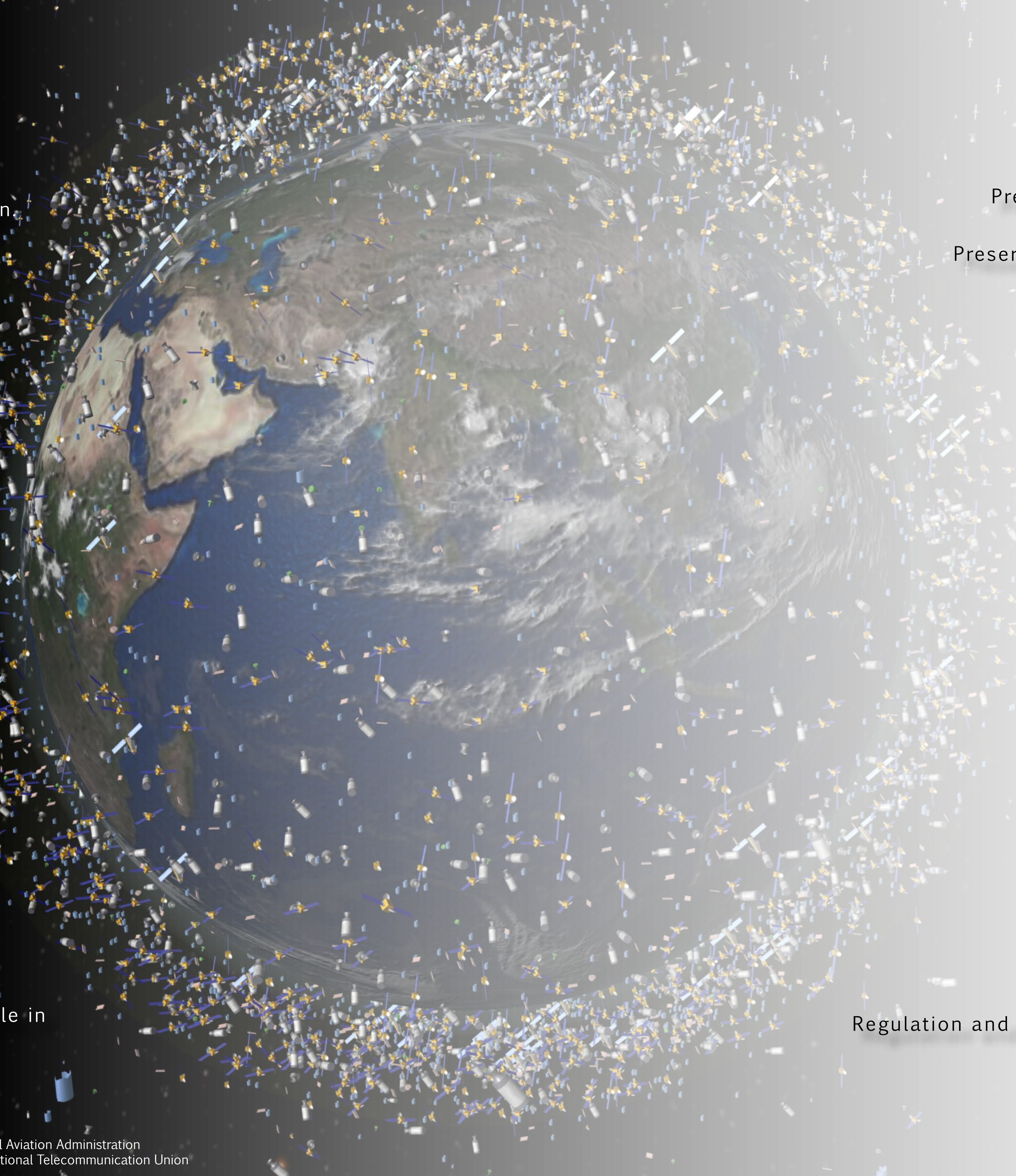


image credit: ESA

[1] Federal Aviation Administration
[2] International Telecommunication Union

CONTRADICTIONS

Preservation of the space environment
vs.
Preservation of continued space activities

Sustainable use of outer space
vs.
Maintaining minimal current costs

Public/Government
vs.
Private/Industry

Global concerns
vs.
National concerns

Exclusive peaceful purposes
vs.
"Dual use"/Militarization

Developed
vs.
Developing spacefaring nations

Free access to outer space
vs.
Regulation and restriction of access to outer space

CHALLENGES

The challenges caused by the increase of Earth orbital debris and the risk they pose to space, air and ground, are not correctly addressed by the legal regime created during the Cold War era.

EXPORT CONTROLS

- National regulations such as International Traffic in Arms Regulations (ITAR) prohibit transfer of technology to countries that may be involved in debris removal.

RESPONSIBILITY

- States are internationally responsible for launch of removal systems and for risks associated with the removal phase, including collision and fragmentation.

LICENSING

- Licensing agreements between the launching state and authorized removal entities are not foreseen by the current space treaties.
- There is no precedent for the removal of orbital debris of un-known origin.

OWNERSHIP

- Request of consent of the launching state owning an orbital debris before its removal is necessary.

IADC LIMITATIONS

- The guidelines are not legally binding and do not take into consideration orbital debris removal.
- They do not address liability and insurance and do not cover the creation of orbital debris in a non-peaceful context.

LIABILITY

- Fault-based liability of the launching state applies in case of damage in space. Fault is difficult to prove.
- Absolute liability of the launching state applies in case of damage on Earth or to aircraft in flight.

WEAPONIZATION

- Space technology has potential ‘dual-use’ nature in the context of competition for military and/or technological dominance.

INTELLECTUAL PROPERTY RIGHTS

- Debris removal may raise concern of unauthorized acquisition of commercially-sensitive intellectual property.

LEGAL VACUUM

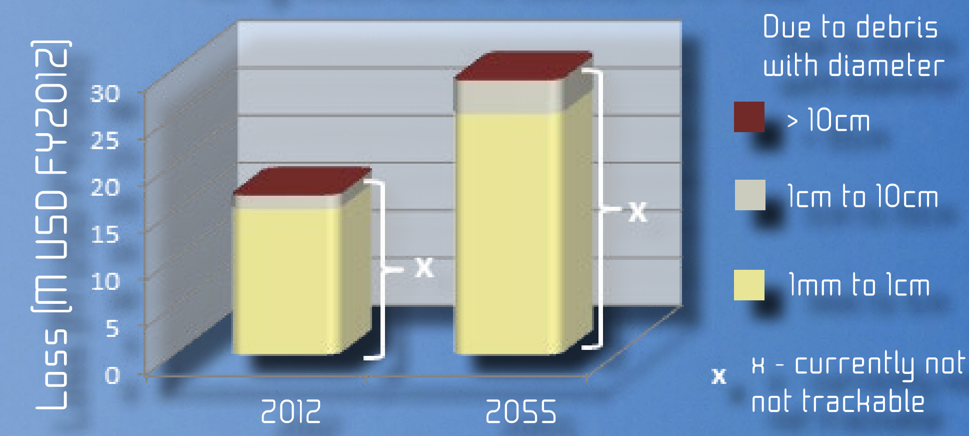
- No orbital debris removal organization.
- No legal definition of orbital debris.
- No ADR guidelines exist.

RATIONALES

WHY CLEAN UP?

The economic loss in Sun-Synchronous Orbit (SSO) alone will account for more than USD 25M per year by 2055. Since most of it is caused by collisions with objects too small to be tracked, it will be unavoidable.

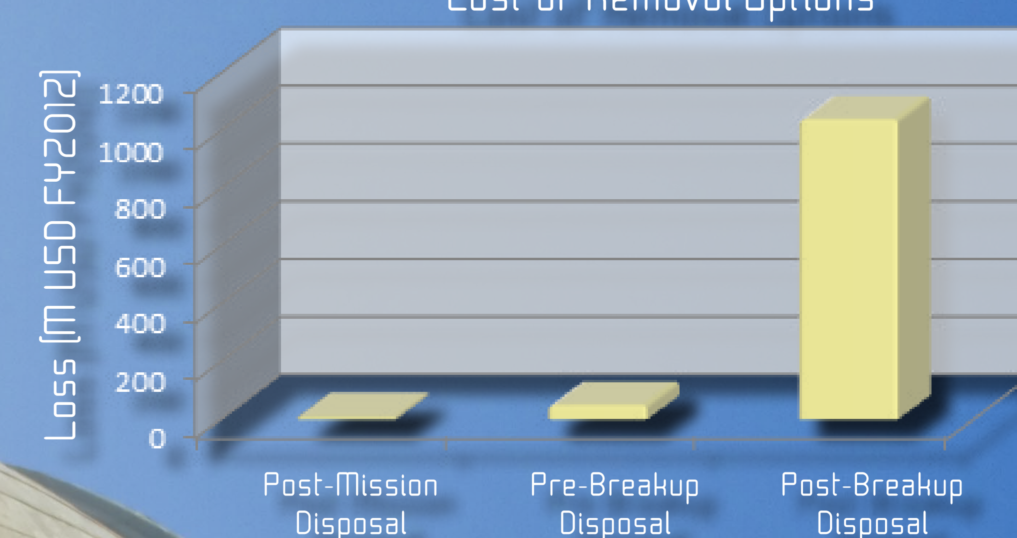
Yearly Loss due to Collisions in SSO



WHY NOW?

To ensure the growth and development of space programs and the use of Earth’s orbit, we need to clean up the growing amount of debris before it escalates beyond our control. We can do so by removing the fragments of a space object after it has been hit or by designing for safe removal before the launch of the object. The first option would increase removal costs by two orders of magnitude.

Cost of Removal Options



REMOVAL GUIDELINES

1 The launching state (registered debris owner) shall authorize a domestic, foreign or international governmental or non-governmental entity to remove its orbital debris.

2 The launching state and the authorized removal entity shall negotiate an agreement for orbital debris removal to be authorized by IODRO[1] prior to launch.

3 Entities providing a debris removal service shall be certified by ISO and licensed by a state or entity, such as IODRO.

4 The launching state or authorized removal entity shall contact 'ICAO-Space[2]' to accurately identify debris that is planned for removal.

5 The launching state or authorized removal entity shall follow the orbital debris mitigation guidelines and applicable international law.

6 IODRO shall authorize the ADR re-entry profile, prior to removal, and inform any potential victim in space, in air, and on Earth to minimize risk or damage in these areas.

7 The launching state or authorized removal entity shall not use technologies that are deemed to violate international space law.

8 The launching state and the removal entity shall be adequately insured.

9 The launching state and the authorized removal entity shall agree, prior ADR mission authorization, on how to share liability via an indemnity clause.

WE RECOMMEND

the establishment of a dedicated debris removal agency as an intergovernmental organization governed by consensus of its member agencies, the 12 current IADC states. Similarly to the European Space Agency (ESA), this new agency would be established as a space agency in its own right, with its own funding and official status as a launching entity. It would have the mandate to develop, procure, license and operate ADR missions, monitor compliance to international guidelines and national laws, and administer the orbital debris fund.

[1] International Orbital Debris Removal Organization
[2] International Civil Aviation Organization
[3] Office for Outer Space Affairs
[4] Italian Space Agency
[5] National Centre for Space Studies
[6] China National Space Administration
[7] Canadian Space Agency
[8] German Aerospace Center
[9] Indian Space Research Organisation
[10] Japan Aerospace Exploration Agency
[11] National Aeronautics and Space Administration
[12] State Space Agency of Ukraine
[13] Russian Federal Space Agency
[14] United Kingdom Space Agency

REMOVAL ORGANIZATION

ICAO

Standards And Recommended Practices (SARP) for:

- Space Traffic Management
- Safety
- Security

Voluntary global Space Situational Awareness (SSA) data sharing

UN OOSA[3]

- Registry
- Adoption resolution on orbital debris mitigation and removal guidelines

ISO

- Mitigation standards
- Debris removal guidelines

WE PROPOSE

that the IADC could author ADR guidelines, in coordination with the UN COPUOS, who would act as the legal power behind these guidelines. Nations could then ratify these guidelines to make them the law under their jurisdictions.

Mission

Funding, development, management, operations and licensing of ADR missions

International Orbital Debris Removal Organization (IODRO)

Funding

- USD 180m base funding
- USD 442m proportional funding depending on number of orbital debris (> 10cm)
- USD 50m launch tax

Members

ASI[4], CNES[5], CNSA[6], CSA[7], DLR[8], ESA, ISRO[9], JAXA[10], NASA[11], NSAU[12], ROSCOSMOS[13], UKSA[14]

Operations

- Legal personality and status as launching state (responsibility and liability)
- Consensual decision process
- "Juste Retour"
- Liability cross-waivers for in-orbit damage

ROADMAP

2013-2017

- ADR Technology Demonstration
- IADC ADR Guidelines Preparation
- Mitigation Guidelines Adherence

2017-2020

- ADR (In Orbit) Validation
- IADC ADR Guidelines Approval
- ISO-certified 'debris-free'

2020-2050

- 10 XL Debris Removed Per Year
- IODRO & Fund
- Null Debris Balance

Image credit: NASA

SPACE: THE FINAL JUNKYARD?

The Space Debris Team Project goal was to propose a way to forward the orbital debris problem by recommending MITIGATION MEASURES and a preferred ADR TECHNICAL SOLUTION based on our literature survey and analysis, and suggesting amended or new POLITICAL, LEGAL, and FINANCIAL FRAMEWORKS to implement it.

We have presented the alarming evolution scenarios of the debris population, and put forward our recommendations for mitigation guidelines and active debris removal technologies that are candidates for immediate development or implementation. In the areas of policy, finance and law, we recommend concrete measures to move from international-level guidelines to enforceable national policy.

We have demonstrated that the "Big Sky Theory," where space is considered a vast, empty area where objects can be placed and disposed of without further thought, is simply invalid. Earth-orbital space is a precious and limited resource, one economically, culturally, and scientifically valuable that must be managed and protected. The orbital debris problem and threat to operational satellites will continue to worsen, unless significant, proactive, and comprehensive measures are taken. Action must begin NOW to have even a small chance of making a difference in time to halt the exponential growth of debris. Orbital debris is no longer simply an interesting area of theoretical study or simulated projects, something conveniently neglected until a mission has reached end-of-life. The next big collision is coming. More spacecraft are going to be lost. We may be the last generation that can take access to space for granted.

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Image credit: NASA

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