Collision risk from space debris

Current status, challenges and response strategies

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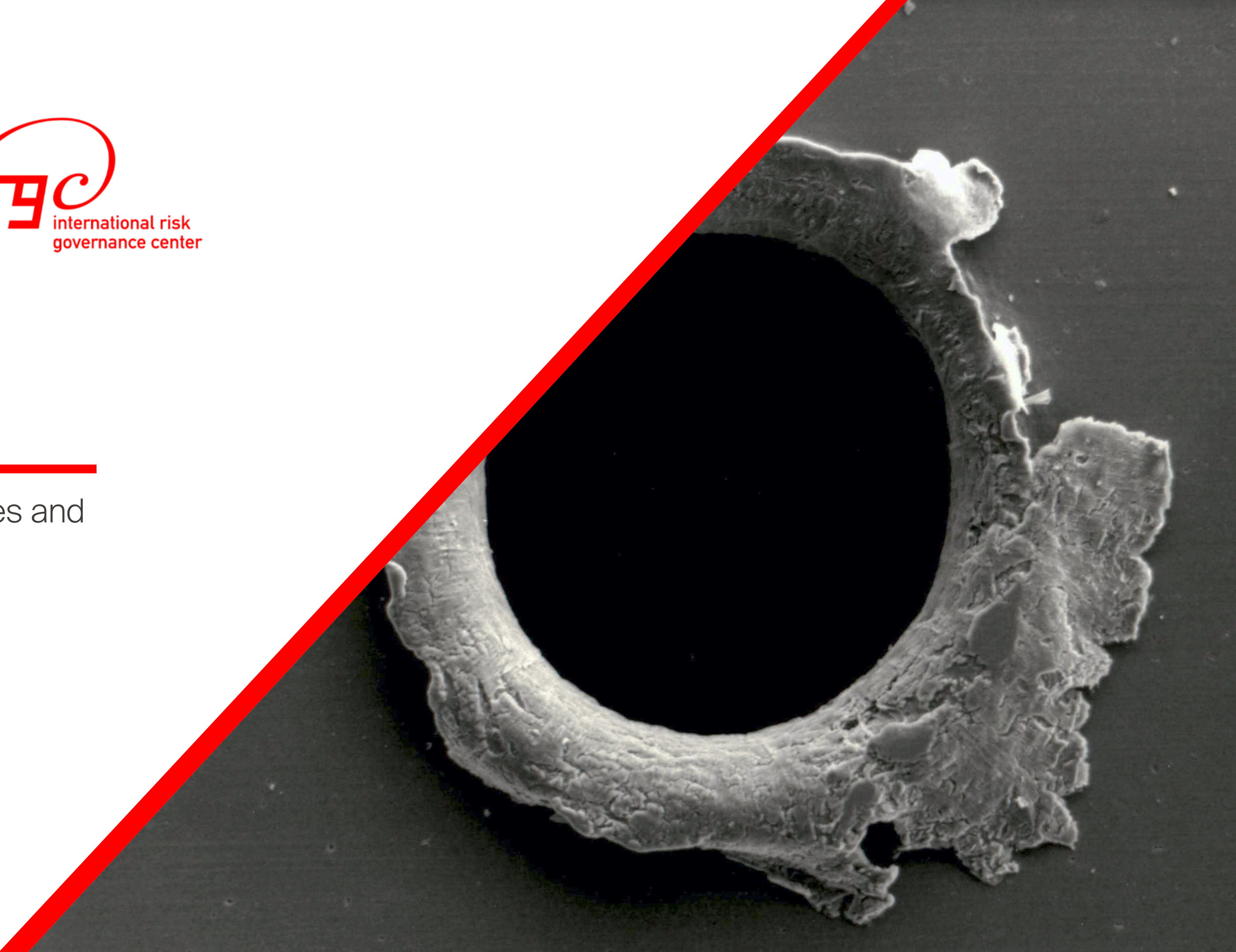

Presentation outline

1. From the space age to the New Space era
2. Collision risk from space debris
3. The current response strategy
4. Response strategies for the future

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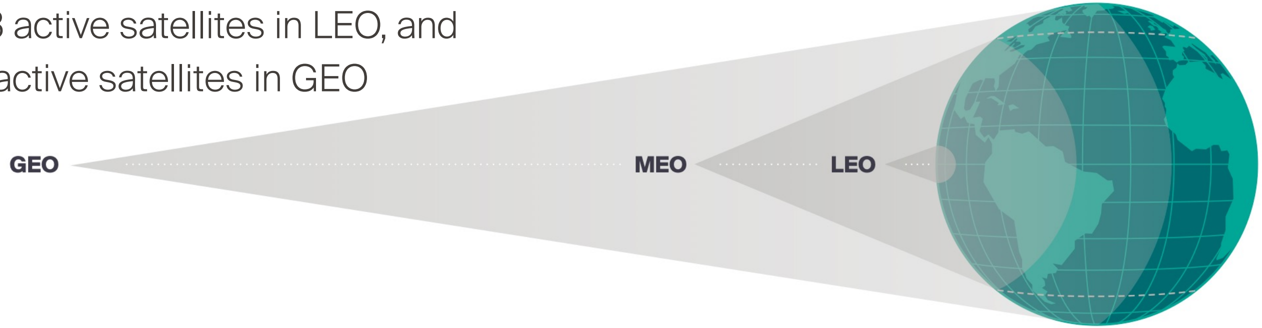
From the space age to the New Space era

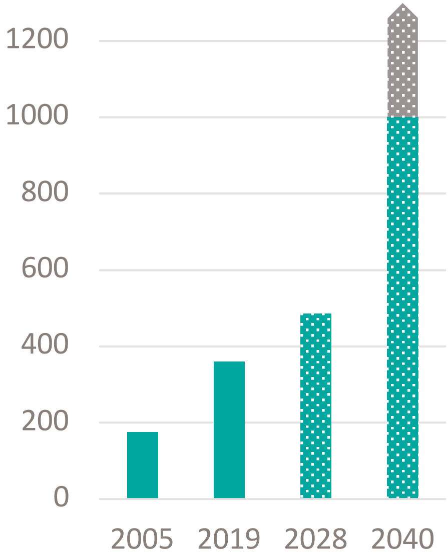
Different orbits for different applications

- Satellites provide a wide range of critical services, including Earth observation (e.g., environmental monitoring, weather forecasting), navigation (e.g., GPS) and communications (e.g., broadband internet)
- Two regions of orbital space are of special interest for human activities: geostationary Earth orbit (GEO) and low Earth orbit (LEO)
- GEO and LEO are the most used orbital regions and are thus the most congested. As of August 2021, there were
  - 3833 active satellites in LEO, and
  - 563 active satellites in GEO



New actors and business models

- An increasing share of space activities are conducted by private actors
- Two major trends are characteristic of New Space: small satellites and large constellations
- Revived interest for LEO satellite internet constellations is driven by
  - Increase in demand for internet-based services
  - Decrease in launch and manufacturing costs
  - Miniaturisation of satellite components
  - New architectures
- Companies have plans for placing over **60,000 satellites** in orbit in the coming decade



Space sector revenues in USD billions

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Collision risk from space debris

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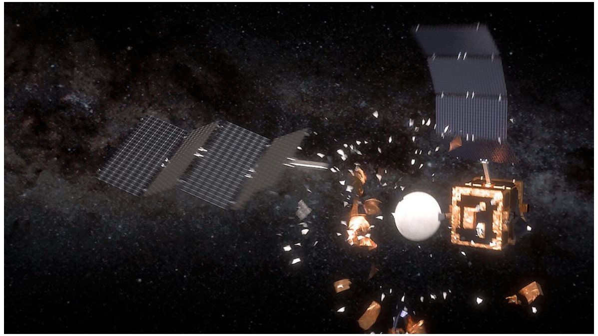
A balance of sources …

- Space debris: **"all artificial objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional"** (IADC)

Sources	Definition
Inactive payloads	Former active payloads which can no longer be controlled by their operators
Mission-related objects	Objects associated with space activities remaining in space
Fragmentation debris	Debris generated when space objects break up through explosions and collisions
Micro particulate matter	Debris ranging between 1 and 100 microns (e.g., degradation of space assets)



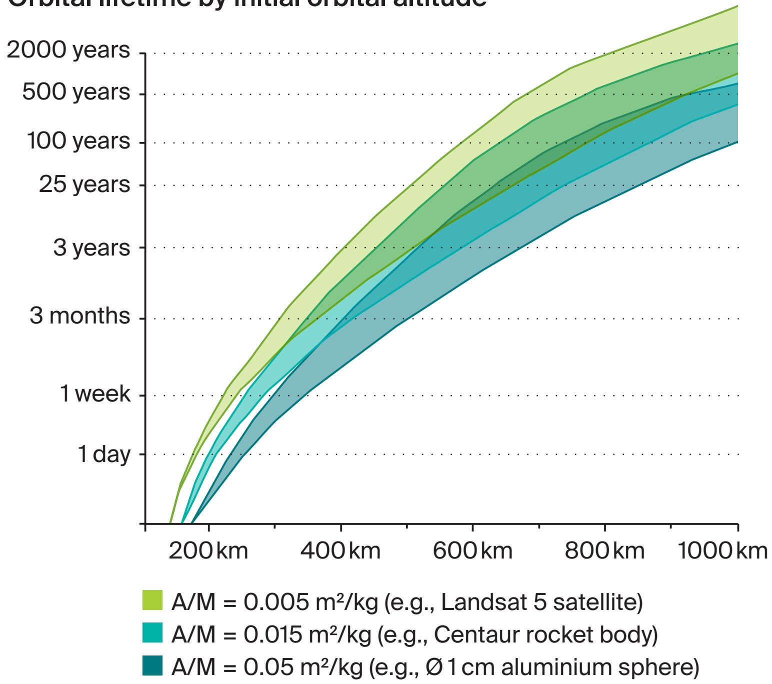
Simulation of collision with debris (Credit: ESA)

... and sinks

Sinks	Definition
Atmospheric drag	The residual atmosphere slowly drags objects down
Direct retrieval	Direct retrieval of large pieces of debris from orbit is in its infancy with first missions planned in the next five years

The ClearSpace-1 mission to be conducted in 2025
(Credit: ClearSpace SA)

Orbital lifetime by initial orbital altitude



The Kessler syndrome

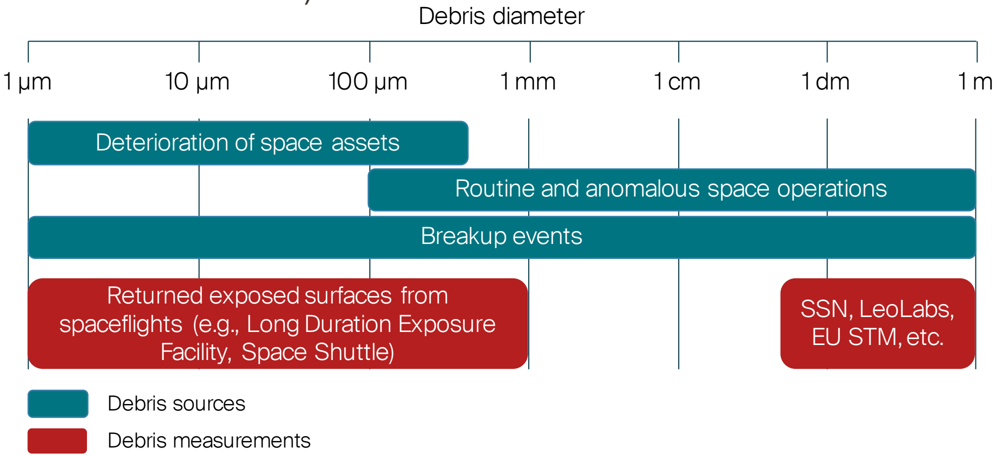
- Seminal paper by Kessler and Cour-Palais (1978)
- “Satellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the Earth”
- Cascade of collision lead to an exponential growth of the debris population threatening the feasibility of future space operations
- The exponential growth happens on a very long time scale

Monitoring and cataloguing space debris

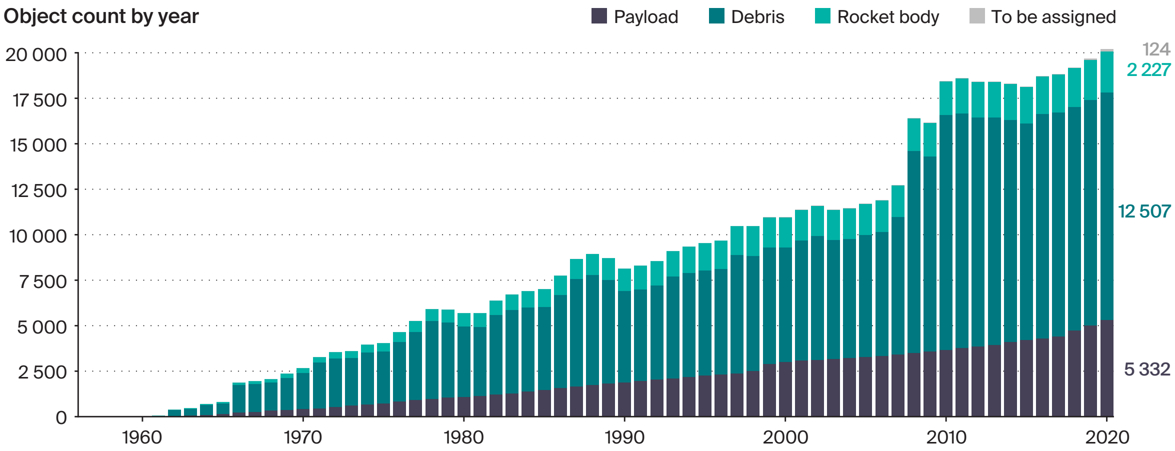
- The space debris population is monitored using radars and electro-optical sensors placed on the ground and in orbit
- With current technology only objects approximately larger than 10 cm in LEO can be reliably tracked and catalogued (assets are being deployed to bring the detectability threshold down to about 2 cm)

Size range	Number
> 10 cm	36,500
1 cm – 10 cm	1 million
1 mm – 1cm	330 millions

Statistical modelling (ESA)



The current debris population



Evolution of the number of objects in orbit by type (Combined Force Space Component Command)

- Since the launch of Sputnik I, there have been more than 500 fragmentation events
- The dominant causes of break-ups are deliberate destruction, propulsion-related explosions, battery explosions and accidental collisions

The largest fragmentation events

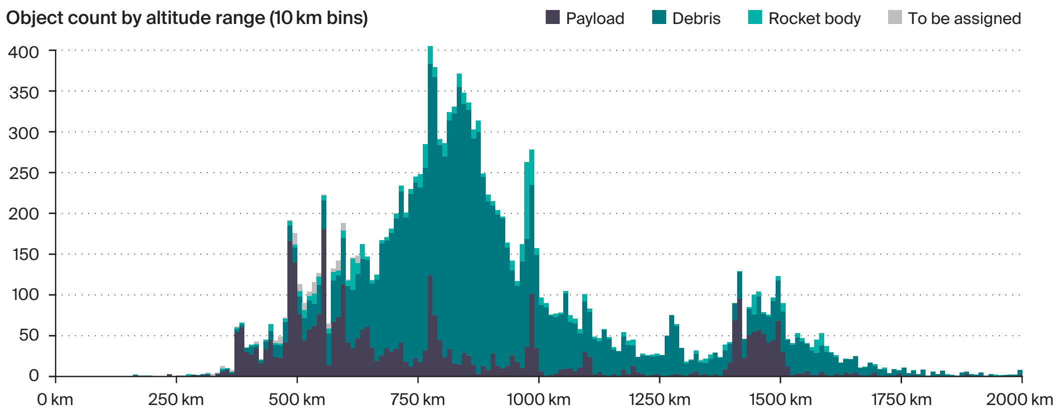
Fengyun-1C

- Date: 11 January 2007
- Type: Anti-satellite test
- Altitude: 865 km
- Debris catalogued: 3,433
- Details: Destruction by China of one of its own weather satellite using a direct ascent kinetic kill vehicle

Iridium 33 - Kosmos 2251

- Date: 10 February 2009
- Type: Collision
- Altitude: 789 km
- Debris catalogued: 2,296
- Details: Accidental collision between the active commercial satellite Iridium 33 and a derelict Russian military satellite Kosmos 2251

Clusters of derelict objects

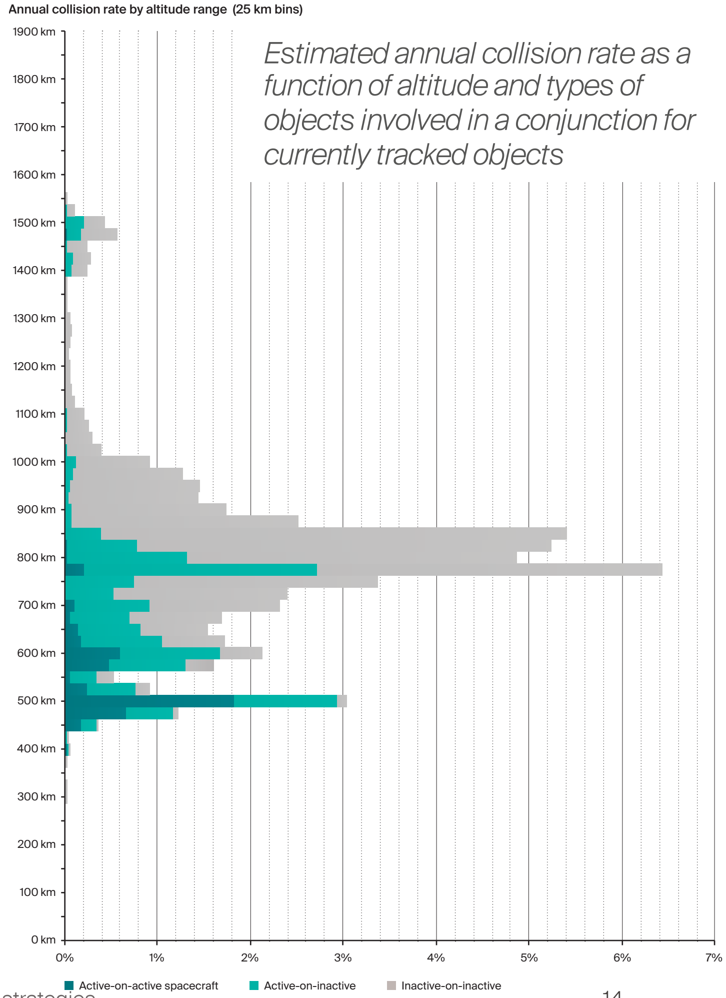


Publicly available catalogue of space objects tracked by the US Space Surveillance Network as of 22 May 2020

- A quarter of the nearly 2,000 massive derelict objects abandoned in LEO are contained within four clusters centered at 775, 850, 975, and 1500 km
  - Annual probability of collision ranges from 1/90 to 1/1200
  - Conjunctions with miss distance <1 km occur on average 1,000 times a year
  - A collision would generate 4,500-16,000 trackable and 60,000-200,000 LNT debris

Risks to operational spacecraft and human spaceflight

- Operational spacecraft face a collision risk from other spacecraft and the space debris population
- LEO has the highest collision probability of all orbital regions, and hosts two crewed space stations
- The threshold for catastrophic collisions for a 150 kg satellite is reached for impactor debris with diameters of about 3 cm in LEO
- Objects too small to be tracked cannot be dodged but can still cause lethal collisions
- Lethal non-trackable objects make up more than 95% of the mission terminating collisional risk for a typical LEO satellite



The future debris population

- Modelling studies of the orbital debris population in LEO suggest that the current environment has already reached the level of instability
- High compliance with the current international mitigation standards are a prerequisite for keeping space activities sustainable in the long term
- A collision among the nearly 2,000 large-derelict objects abandoned in LEO would result in the creation of thousands of trackable pieces of debris and many more lethal non-trackable debris pieces
- For LEO orbits above 600 km, the major contributors of large-derelict objects are Russia (68%), the US (20%), and China (2%)
- The debris-generating threat posed by large-derelict objects has triggered studies aimed at establishing priority lists for active debris removal missions

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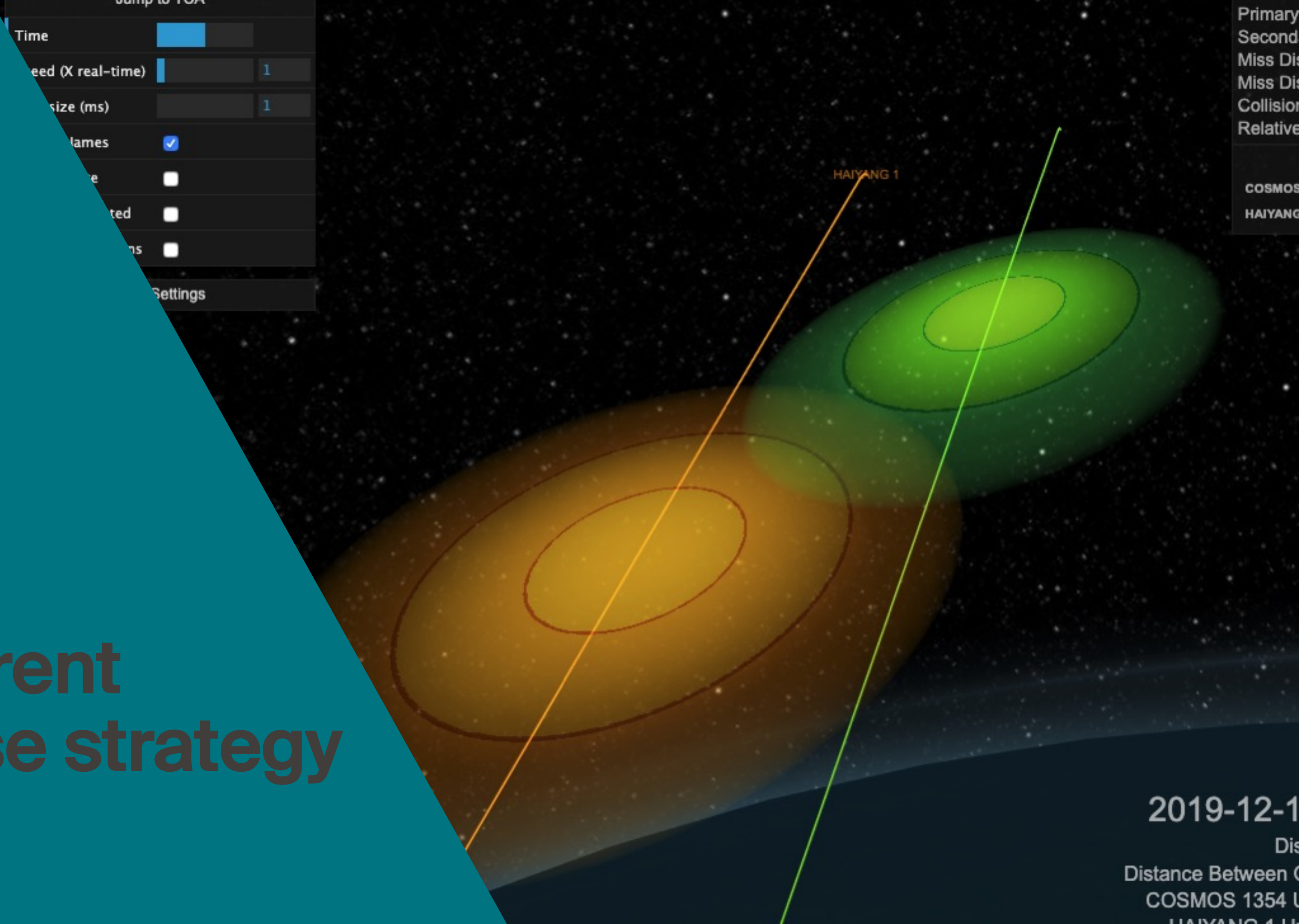
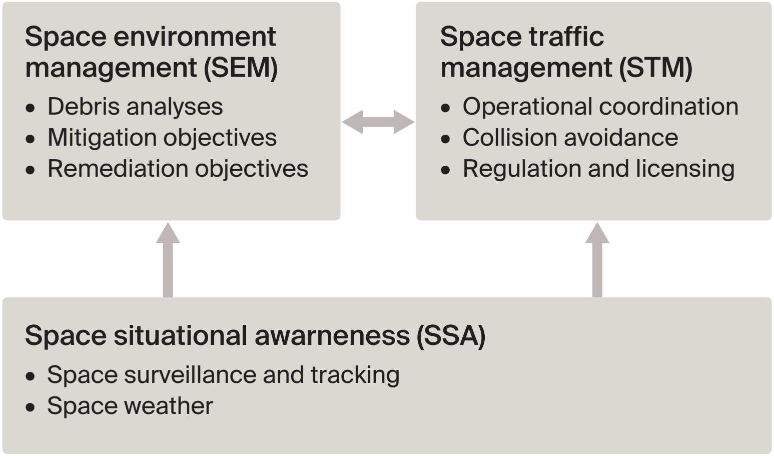
The current response strategy



Space debris related activities

- **Space situational awareness (SSA)** is the foundation of all debris related action. It "includes perceiving orbital anomalies or threats, maintaining an inventory of objects as completely as possible, and developing and providing timely information for collision avoidance and safe operation" (Bonnal & McKnight, 2017).
- **Space traffic management (STM)** is "the planning, coordination, and on-orbit synchronisation of activities to enhance the safety, stability, and sustainability of operations in the space environment" (The White House, 2018).



- **Space environment management (SEM)** encompasses activities aimed at ensuring both the near-term safety of operations and the long-term stability of the environment (Maclay & McKnight, 2020), and comprises *mitigation* and *remediation*.

Technical approaches

- *Mitigation* refers to technical procedures or requirements for operational spacecraft aimed at reducing the risk that they become or generate debris
- *Remediation* activities can take three broad forms:
  - **Active debris removal**: removing debris from orbit
  - **Just-in-time collision avoidance**: slightly changing debris trajectories before predicted collisions
  - **Nano-tugs**: upgrading derelict objects with collision avoidance capabilities

Mitigation	Before launch	Mission design (e.g., orbit selection)
		Satellite design (e.g., shielding, redundancies)
	In orbit	In-orbit servicing
		Collision avoidance
		Passivation
		Post-mission disposal
Remediation	Post spacecraft loss	Active debris removal
		Just-in-time collision avoidance
		Nano-tugs

Regulatory approaches

Top-down

International level

United Nations

Treaties
- Outer Space Treaty
- Rescue Agreement
- Liability Convention
- Registration Convention
- (Moon Agreement)

Guidelines
- Space Debris Mitigation Guidelines
- Guidelines for the Long-term Sustainability of Outer Space Activities

NGOs

Standards, guidelines
- IADC Space Debris Mitigation Guidelines
- ISO 24113:2019 Space systems – Space debris mitigation requirements

National level

Regulations and licensing requirements

Industry initiatives
- The Space Sustainability Rating
- The Best Practices for the Sustainability of Space Operations by the Space Safety Coalition

Bottom-up

Non-binding

Binding

IADC space debris mitigation guidelines

- Established in 2002, revised in 2007 and 2021
- Define two protected regions with regard to the generation of space debris: the LEO and GEO regions
- Focus on four areas:
  - Limitation of debris released during normal operations
  - Minimisation of the potential for on-orbit break-ups
  - Post-mission disposal
  - Prevention of on-orbit collisions
- For post-mission disposal in LEO:
  - **Manoeuvre into an orbit with an expected residual orbital lifetime of 25 years or shorter with a probability of success of at least 90%**

Key challenges

- Low compliance with internationally agreed-upon mitigation guidelines
- Mechanisms address only the creation of new pieces of debris (mitigation), but do not address the legacy of derelict objects (remediation)
- National requirements involve the evaluation of a mission's potential space debris creation *before* launch. Mechanisms in place only weakly incentivize operators to reduce the risk of debris creation once in orbit
- Slow pace of discussion at the international level with no binding or more detail agreement in sight

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Response strategies for the future

Market-based approaches

Insurance

- First-party and third-party liability insurance
- In LEO, only 3% of satellites have first-party insurance
- First-party insurance cover all risks
- Risk of technical failure still far greater than collision
- Weak liability regime for collision in orbit
- Assessment of causes of failures is difficult

Regulatory fees

- Pigouvian tax
- Per-unit compliance cost that is guaranteed and independent of the amount of activity performed
- Define unit of regulated activity that would drive fee liability and set efficient fee level

Tradable permits

- Government-created licenses or obligations for a specific level of a particular activity
- Used to ration the use of common-pool resources
- Two categories: cap-and-trade and credit trading

- What is the fungible unit of risk/harm that drives fee/permit liability?
- When fees/permits would be required?
- Could generate funds for remediation

Other ideas

- Allocation of orbital space in LEO
- Moratorium or limitation of satellite launches
- Corporate reputation and social responsibility

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Appendix

The International Risk Governance Center (IRGC)

- IRGC is an interdisciplinary unit dedicated to extending knowledge about the increasingly complex, uncertain and ambiguous risks that affect society.
- We develop risk governance strategies that involve all key stakeholder groups, including citizens, governments, businesses and academia.
- Our work is rooted in the IRGC Risk Governance Framework, as well as subsequent guidelines that were developed to more specifically address the challenges posed by governance of emerging and systemic risks.
- We apply these guidelines to a wide range of specific risk domains, and in recent years we have focused increasingly on risks associated with emerging technologies.

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IRGC's work on space

Buchs, R. (2021). *Intensifying space activity calls for increased scrutiny of risks*. Lausanne: EPFL International Risk Governance Center.
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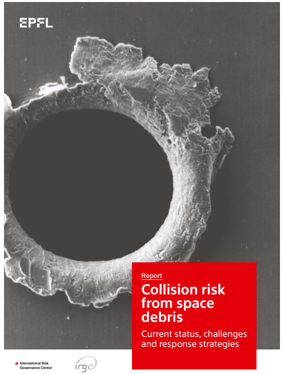

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References

- See references and figures credit in *Collision risk from space debris: Current status, challenges and response strategies*.
- Selected references:

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