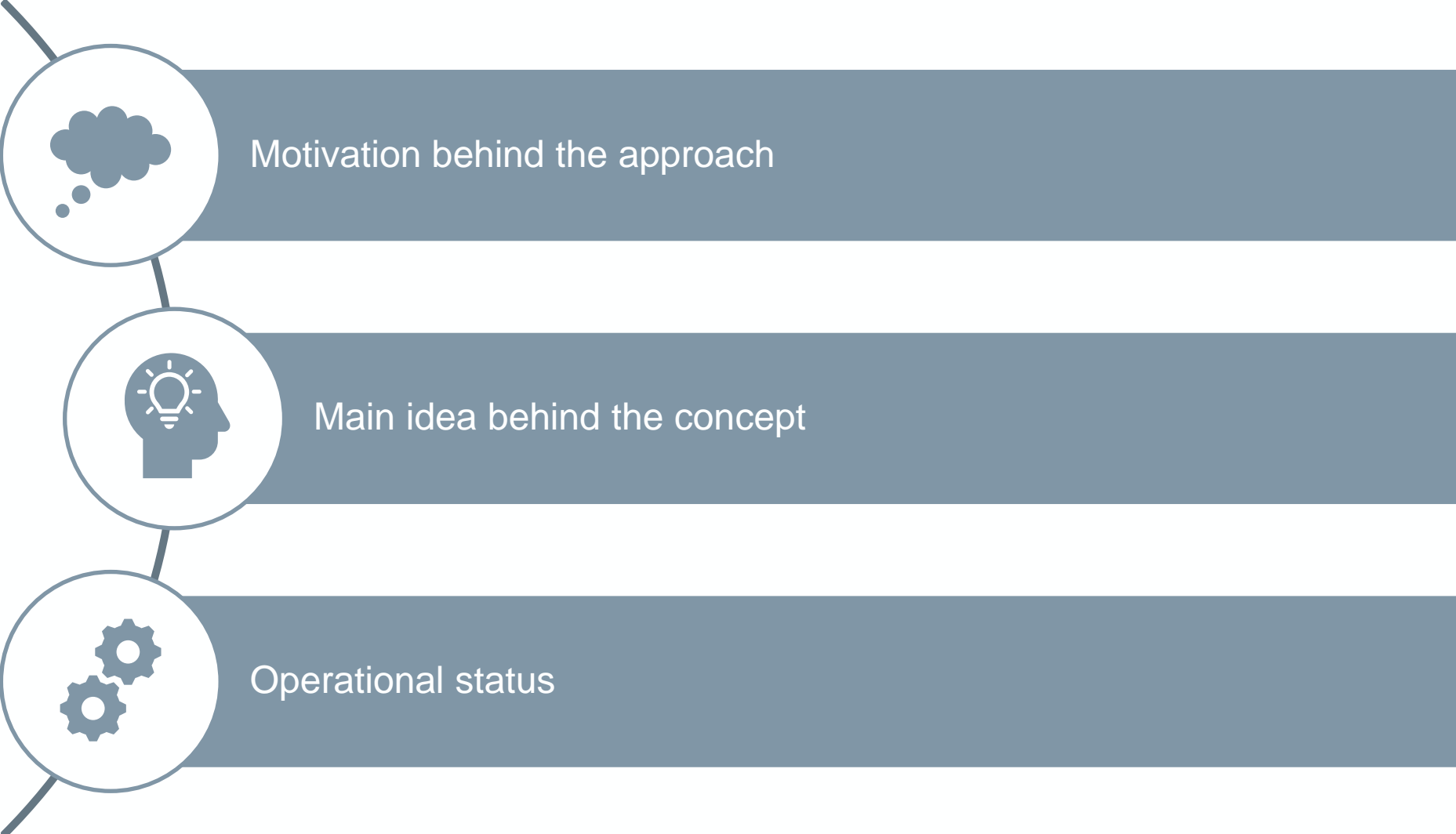


# Space Environment Capacity at the European Space Agency

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Francesca Letizia, Stijn Lemmens

07/06/2023



# What do we mean with Space Sustainability?

The remarkable change in the use of the LEO region has prompted several studies into the **sustainability** of space operations

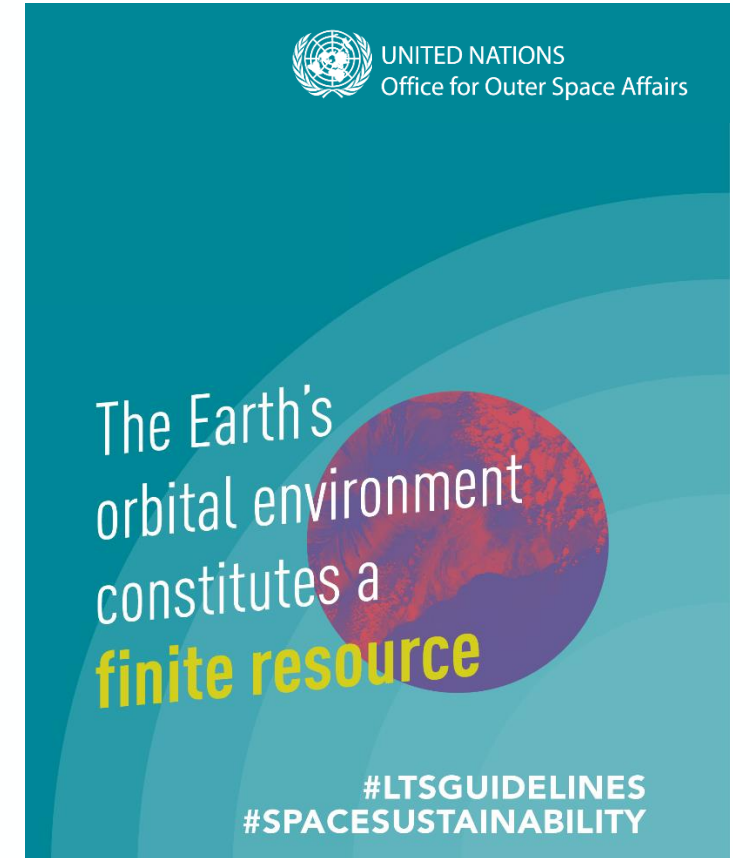
## Definition:

equitable access to safe operations in space, now and in the future

Compliance to **existing guidelines** often used as proxy for sustainability, but no longer adequate for today

## Idea:

Is it possible to define **reference targets** (~2° for climate change)?  
How do we carry out more **robust assessments** of the environment?



# Earth's orbits as a finite resource



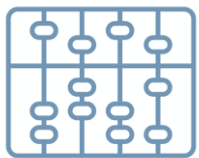
ESPI,  
Space Environment Capacity,  
2022



Earth's orbital environment as a **common-pool resource**:

- **Universally accessible** and **not excludable**,  
i.e. the exclusion of users is difficult by nature
- **Rival**,  
i.e. the use of an orbit by one user decreases  
resource benefits for other users

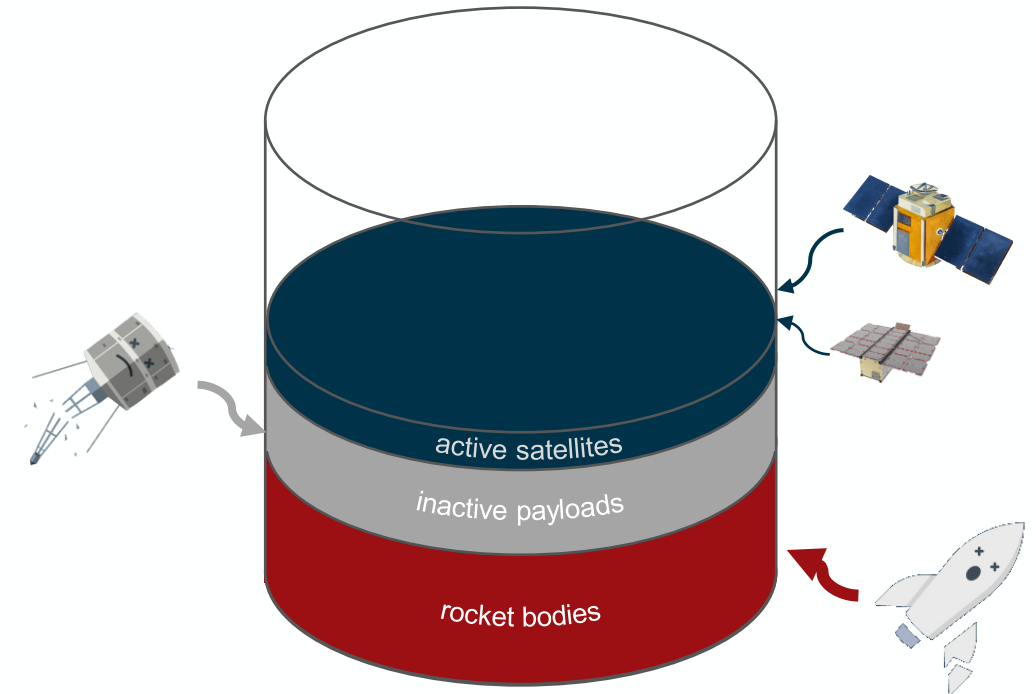
## Lessons from resources management



you cannot manage what  
you cannot measure ⇒  
you cannot measure what  
you cannot define



less-than-perfect systems can  
provide immense value for  
international collaboration



Space Environment Capacity

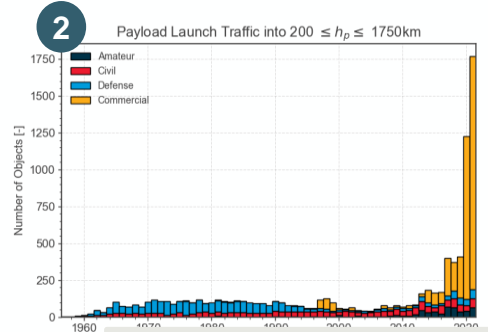


# Technical drivers for our approach

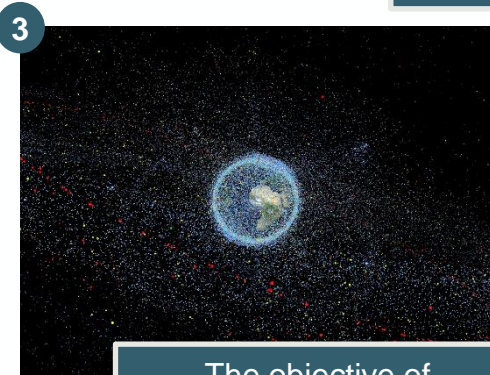
## Missing links of current guidelines



1 The different ways of being compliant

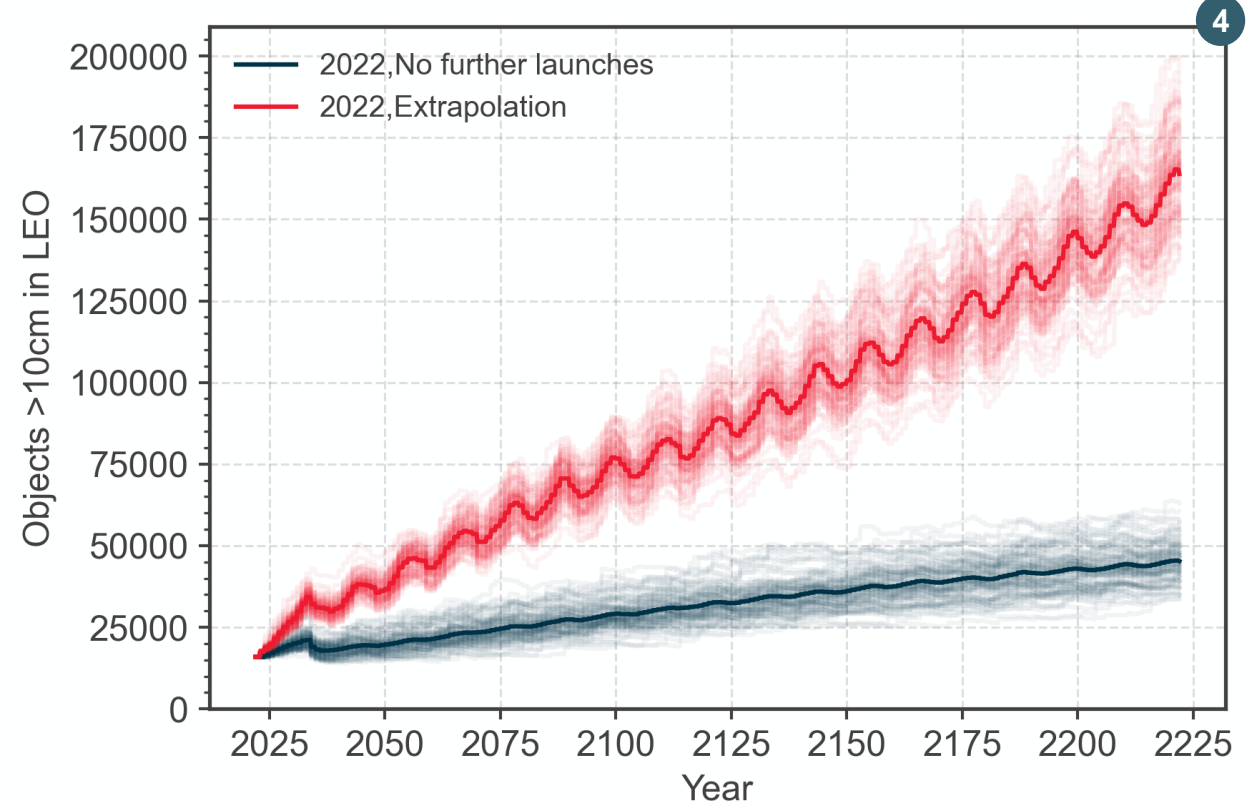


2 The dynamics of the space environment



3 The objective of sustainable spaceflight

## Implementation of guidelines

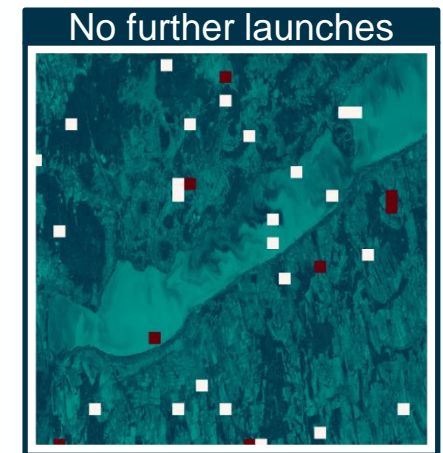
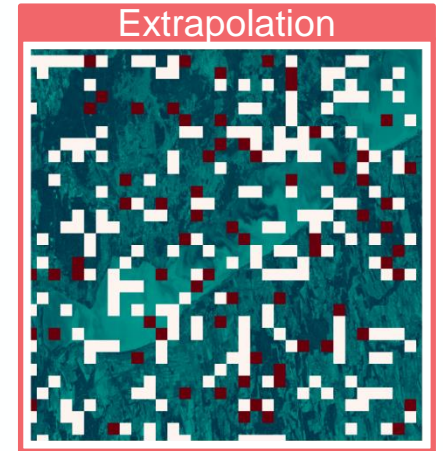
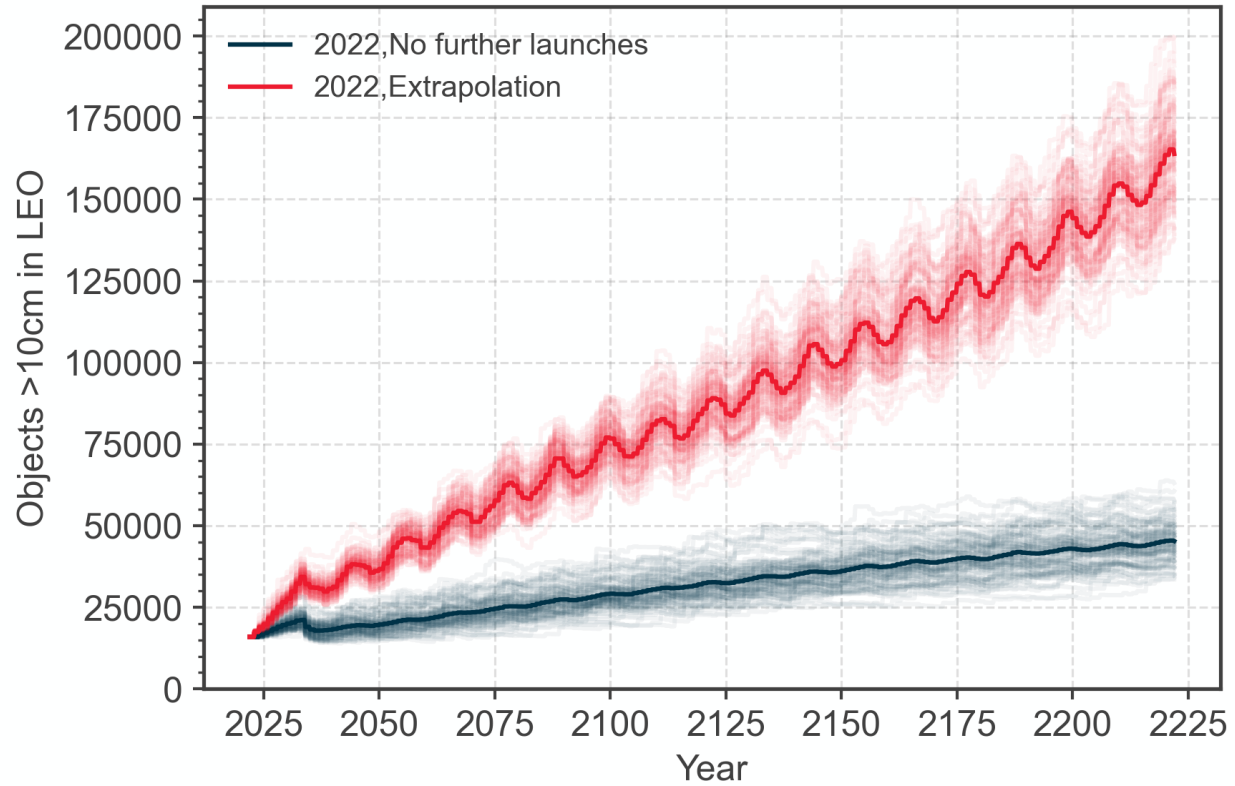
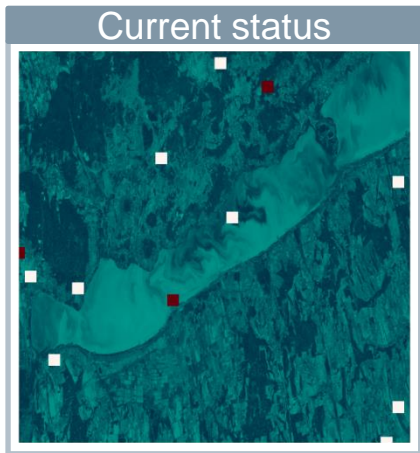


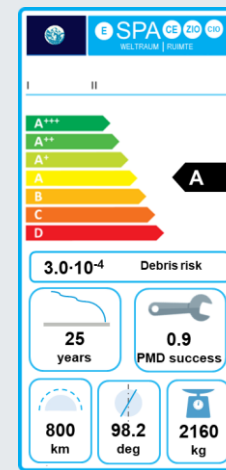
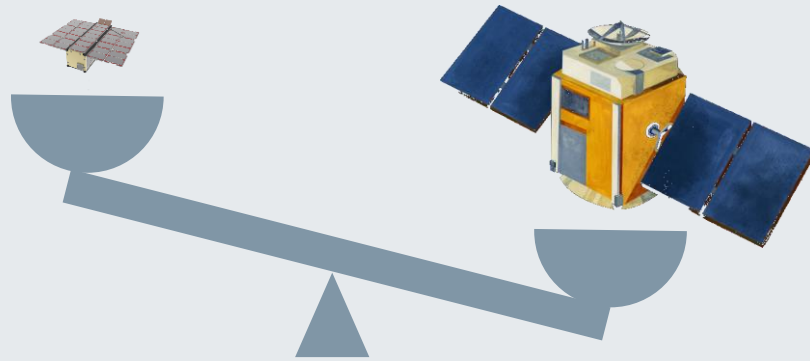
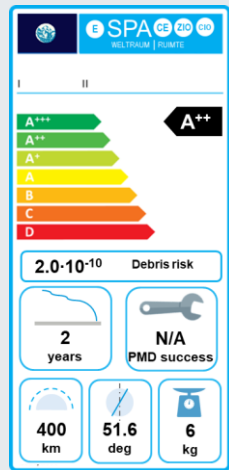
ESA's Space Environment Report, 2022

# What does it mean?

=1 year

- CAM (Collision Avoidance Manoeuvre)  
visualised as an 8-hour outage of operations
- Escalated event  
i.e. monitored conjunction notified to the mission team that did not result in a CAM



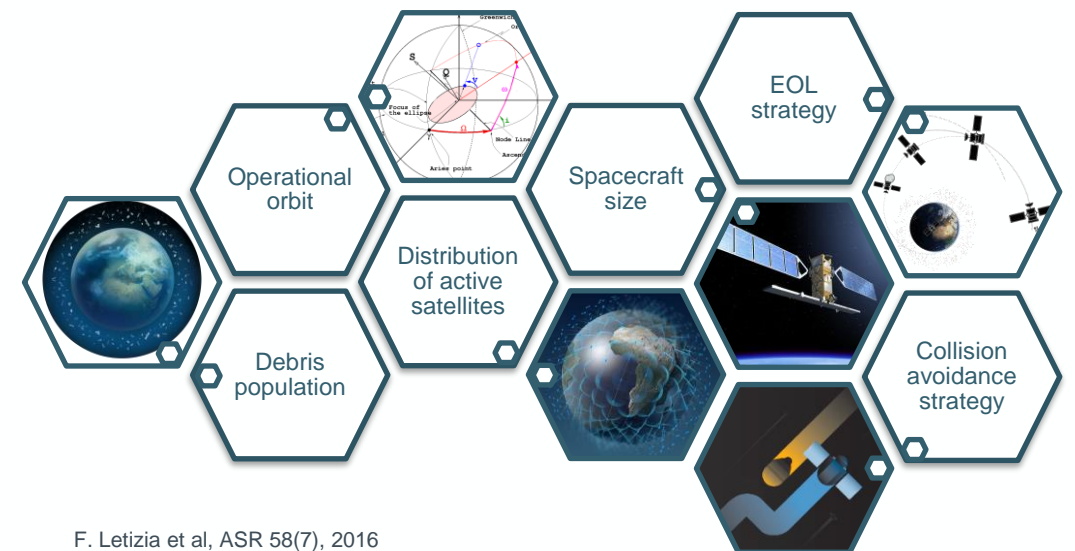


Missions **compliant** with space debris mitigation guidelines can still have significant different **risk levels** in terms of potential **debris generation** and **debris environment impact**

We want to measure for each mission

- How detrimental is it to its **orbital neighbours?** (short-term)
- How does it contribute to the **Kessler syndrome?** (long-term)

Use of a **risk metric** at single mission level

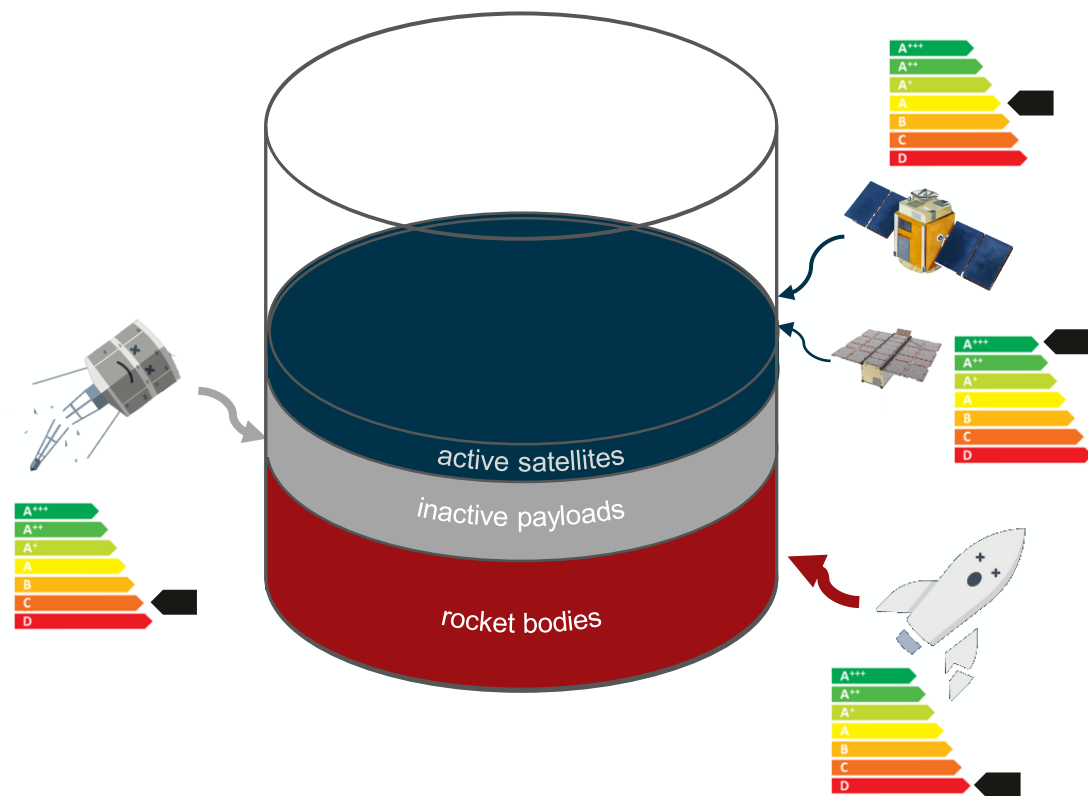


# Space Environment Capacity - concept

number & type of missions compatible with the stable and low risk evolution of the environment

H. Krag, S. Lemmens, F. Letizia, 1<sup>st</sup> ICSSA, 2017

The space debris risk is **additive**: a population is evaluated summing the contribution of all its members



Capacity consumed by non-functional objects

Changes dynamically with the evolving environment

Capacity available for new&active missions

Could use allocation mechanism

Envelope (total aggregated risk)

Can be defined through long-term simulations of the environment



# Space Environment Capacity - example

Long-term (200 years) simulations on the environment to quantify the impact of parameters such as

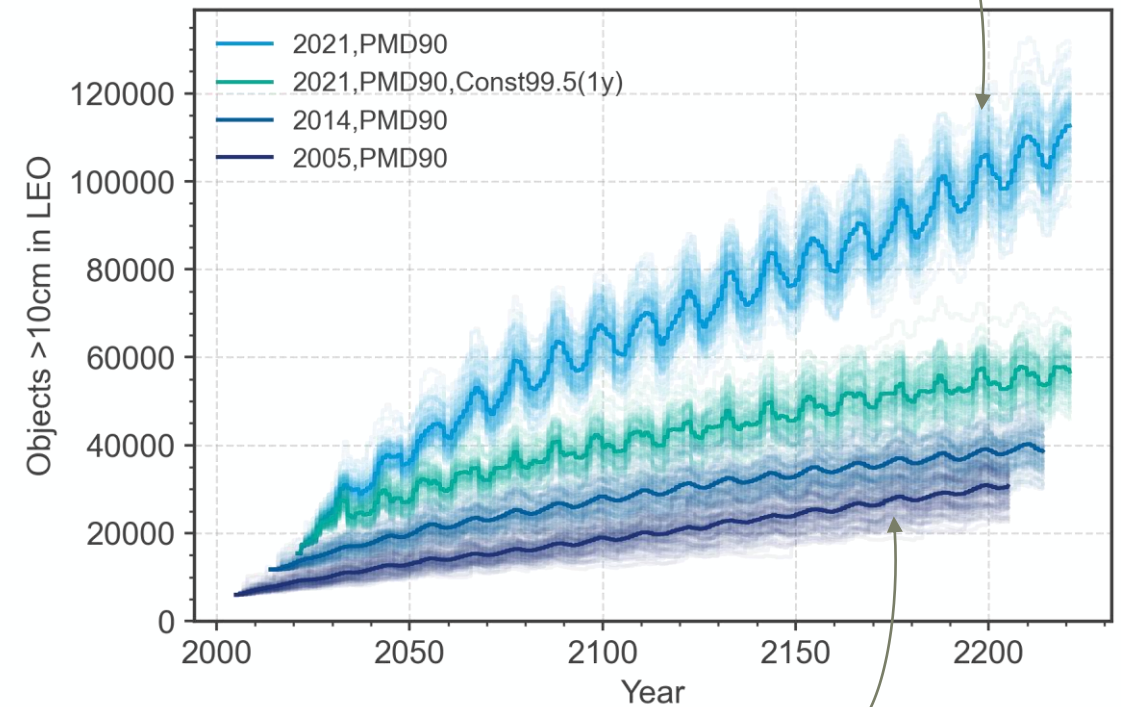
- Launch traffic
- Explosion rate
- Disposal approach

Approach used to derive the **25-year rule**, by comparing it to alternative disposal options

What does this rule mean now for the environment?

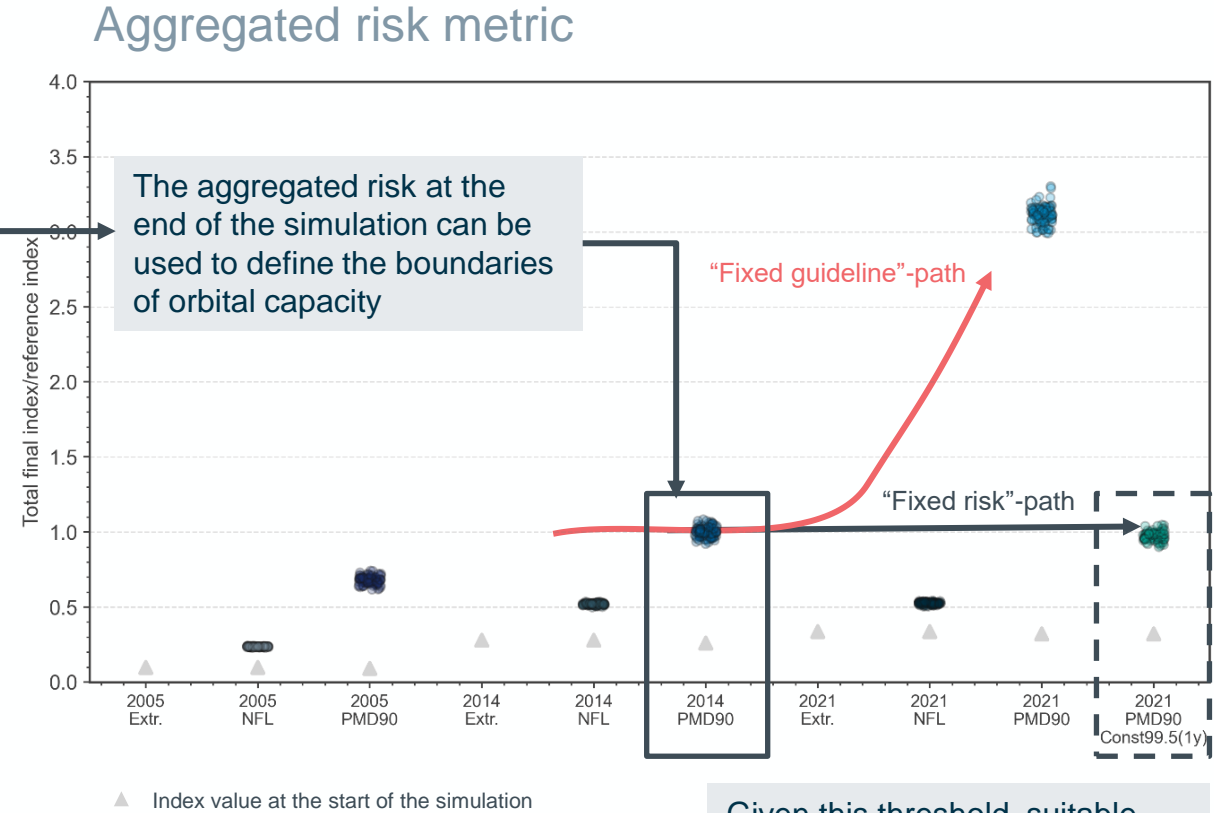
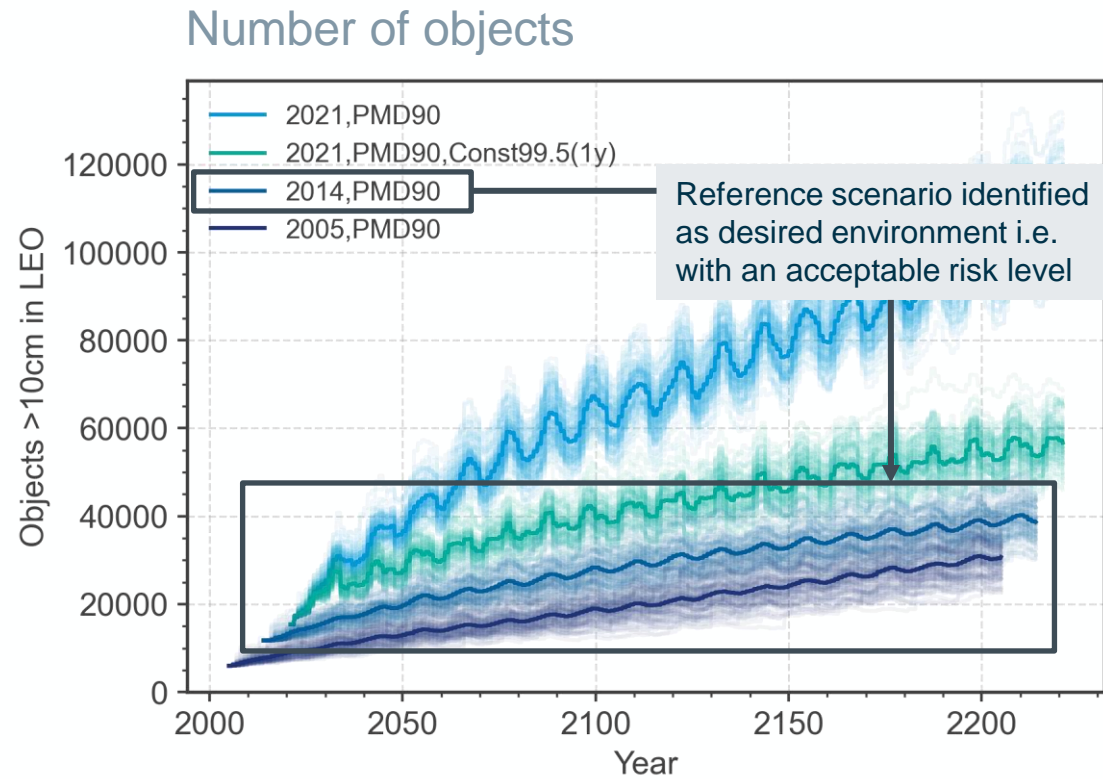
Results show the evolution of the environment using different years as starting point for the simulations, extrapolating respective levels for launch traffic and considering a disposal success rate of 90%

What PMD90(25y) means now:  
is this acceptable?



What PMD90(25y) meant when  
IADC drafted their recommendation

# Derivation of a threshold-based model

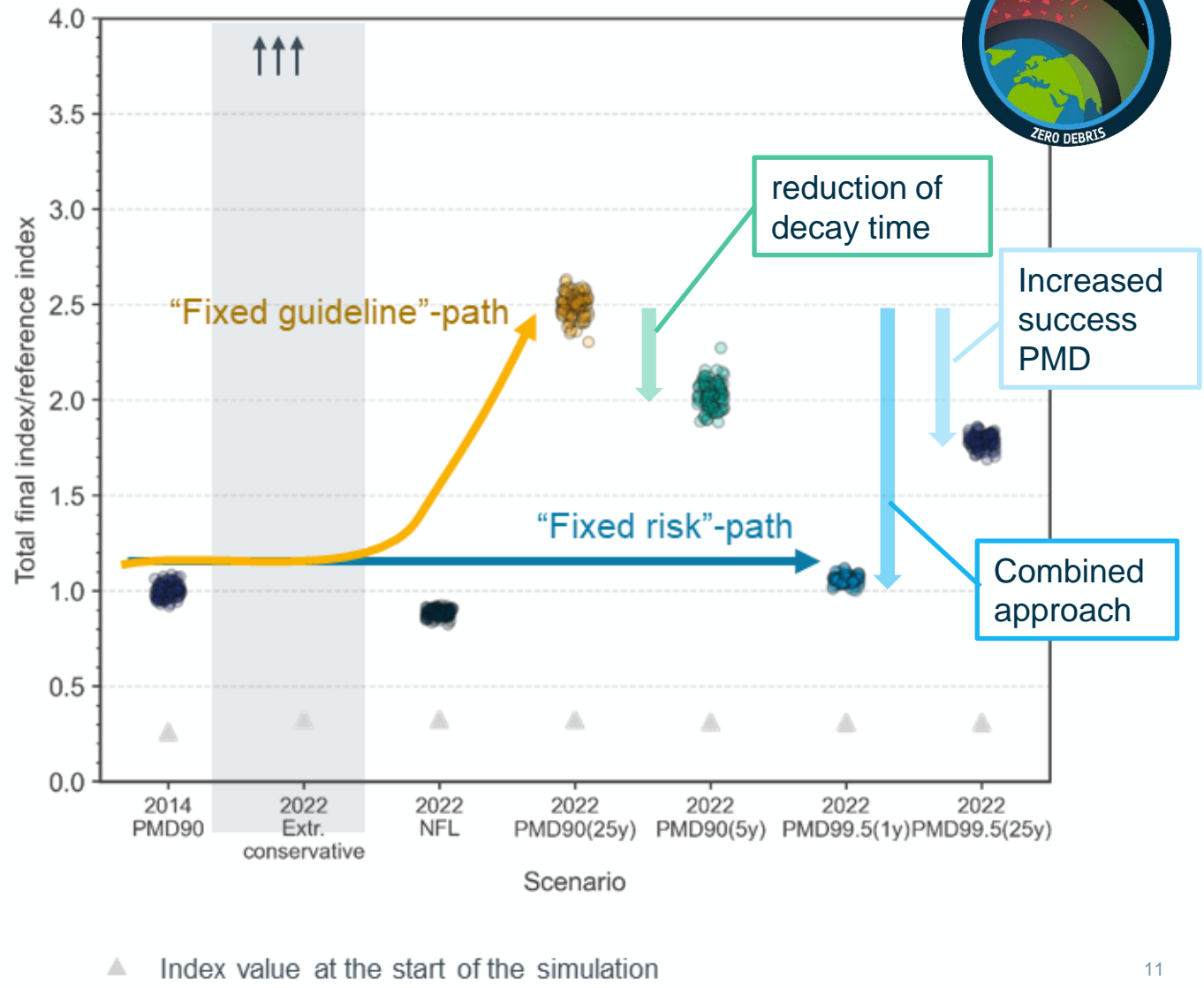


Given this threshold, suitable mitigation strategies, matching the observed launch traffic and disposal rates, can be identified

# Zero Debris is focused on limiting the risk



- 1 One of the **Zero Debris principles** aims at developing debris mitigation requirements **beyond proxies as lifetime limitation**
- 2 **Zero Debris** aims at setting a **risk limit** for future missions
- 3 This is only feasible through a **combined approach**:
  - 1) Improving the **probability of post mission disposal**: going towards ~100% where needed
  - 2) **Improving the orbital clearance**: reduced time and collision risk threshold



# Operational status: index frontend

<https://index.sdo.esoc.esa.int/>

The screenshot displays the Debris Index frontend interface. The left sidebar shows 'Outputs' for a 'Large Earth Observation satellite' with the following data:

- Object data:** Mass [kg] 2000, Area [m<sup>2</sup>] 20
- Orbit data:** Mean altitude [km] 800, Inclination [deg] 98
- Operations:** Launch year 2018, Target EOL altitude [km] 500, PMD success rate 90%, COLA capabilities True, Index value: 2.2405e-04

The main area shows the 'Evaluate mission' form with input fields for Mass (kg), Area (m<sup>2</sup>), Mean altitude (km), Inclination (deg), Launch year, PMD success rate (60%), and Target EOL altitude (km). A 'Run' button is visible. Below the form are two heatmaps showing risk maps for LEO as a function of mean altitude ( $a - R_E$ ) and inclination ( $i$  [deg]). The left heatmap includes labels for 'Trajectory during disposal/natural evolution', 'Operational', 'High-risk region', and 'Low-risk region'. The right heatmap shows a circular marker for the operational orbit. Below the heatmaps are two line graphs: the left one plots 'Index value' (scaled by  $10^{-7}$ ) against 'Year' (2020 to 2120), showing 'PMD Failure' (red) and 'PMD Success' (blue) curves; the right one plots 'Index value' (scaled by  $10^{-4}$ ) against ' $\rho_c$ ' (scaled by  $10^{-3}$ ), also showing 'PMD Failure' and 'PMD Success' curves. A QR code is present on the right side of the interface.

Access requires

- a (ESA) **space debris user account** (same as for other ESA's tools, e.g. DISCOS, DRAMA, etc)
- **specific request to** [space.debris.support@esa.int](mailto:space.debris.support@esa.int)

Computation restricted to **LEO**, **simplified orbit evolution** and mission architecture

**Ad-hoc support** can be requested at [space.debris.support@esa.int](mailto:space.debris.support@esa.int)



# Operational status: THEMIS

Developed by Politecnico di Milano and DEIMOS



The screenshot displays the THEMIS software interface, which is used for mission evaluation and impact assessment. The interface is divided into several sections:

- IMPACT EVALUATION:** Includes fields for Mission Name, Spacecraft design (Mass [kg], Cross-area [m2], Object Type), and Mission operations (ORBITAL REGION, CAM capabilities, Status, ACP L (0-1)).
- Mission architecture:** Includes a Launcher service selection.
- Propulsion technology:** Includes a Drag sail selection and Effective area [m2].
- Mission phases:** Includes Launch phase, Operational orbit injection phase, and Start epoch.
- Keplerian parameters:** Includes Semi-Major Axis [a] and Right Ascension of the Ascending Node.

The main dashboard, titled "EVALUATE MISSION", provides a comprehensive overview of mission performance and capacity. Key metrics include:

- INDEX VALUE (x1000):** 0.456
- SHARE OF THE CAPACITY OF THE YEAR:** 3%
- SHARE OF THE TOTAL CAPACITY:** 1%
- INDEX TOTAL VALUE FOR EACH MISSION PHASE:** A donut chart showing the distribution of index values across four phases: Phase 1 (10.9%), Phase 2 (28.0%), Phase 3 (26.1%), and Phase 4 (35.0%).
- EACH SPACECRAFT FOR DISTRIBUTED ARCHITECTURE:** A donut chart showing the distribution of index values across four spacecraft: Spacecraft 1 (10.9%), Spacecraft 2 (28.0%), Spacecraft 3 (26.1%), and Spacecraft 4 (35.0%).
- INDEX TIME EVOLUTION FOR EACH MISSION PHASE:** A bar chart showing the index time evolution for each phase from 2012 to 2017.
- EACH SPACECRAFT FOR DISTRIBUTED ARCHITECTURE:** A bar chart showing the index time evolution for each spacecraft from 2012 to 2017.
- TOTAL INDEX TIME EVOLUTION:** A bar chart showing the total index time evolution from 2012 to 2017.

Multi-year activity through ESA's **Space Safety Program** to create a **software infrastructure**, fully integrated in ESA's tool ecosystem and with augmented analysis capabilities (e.g. any orbital regime, complex mission architectures)

Activity to be concluded in **2023**, with planned release of the computation **frontend**, where users can define, store and assess their missions

Open research questions on managing (and trading) mechanisms



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