A DEBRIS INDEX AS A METRIC OF THE ENVIRONMENT CAPACITY

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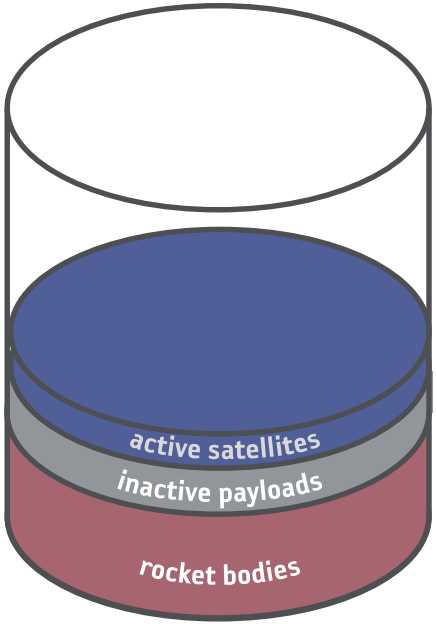
How to measure the impact of a mission on the space debris environment?



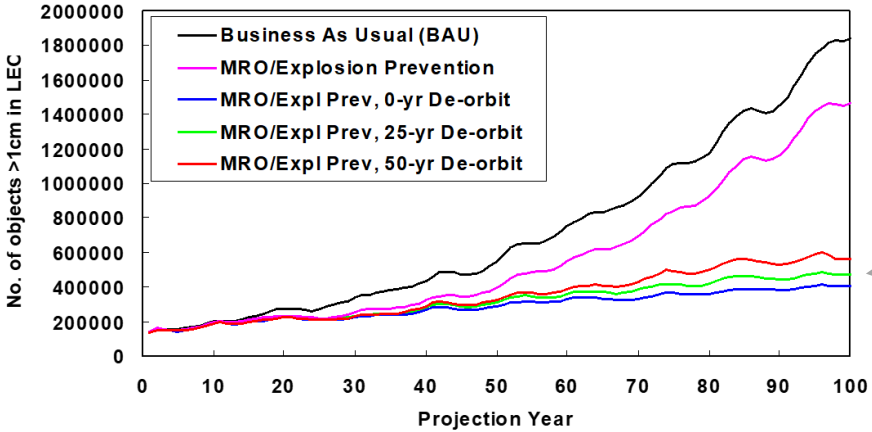
Orbital capacity

typology & orbital regimes of artificial space objects compatible with a *stable* evolution of the environment

- Krag et al., 1th ICSSA, 2017

- IADC Supporting Document

Population evolution with EVOLVE



Space debris index

▸ Letizia et al., 7th ESDC, 2017

$$I = p_c \cdot e_c + e_e \cdot p_e$$

Collision probability

Explosion probability

Collision effect

Explosion effect

Debris population

Object type

Spacecraft size

Orbit

Distribution of operational satellites

+ **Reliability**
(PMD success rate)

▸ Letizia et al., 69th IAC, 2018

$$I_\alpha = \alpha \left(\int_{t_0}^{\Delta t_{oper}} I(a,i)dt + \int_{\Delta t_{oper}}^{t_e} I(a,i)dt \right) + (1-\alpha) \left(\int_{t_0}^{\Delta t_{oper}} I(a,i)dt + \int_{\Delta t_{oper}}^{t_l} I(a,i)dt \right)$$

Risk in operational phase

Risk during disposal

Risk if abandoned

Collision avoidance

EOL design

Orbit (lifetime)

Space debris index

$$I = p_c \cdot e_c + p_e \cdot e_e$$

Collision probability

resulting from the **flux** of **background** debris population

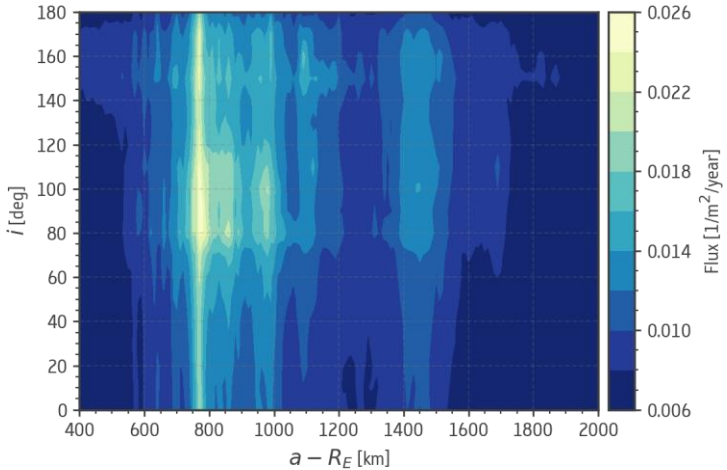
Collision effect

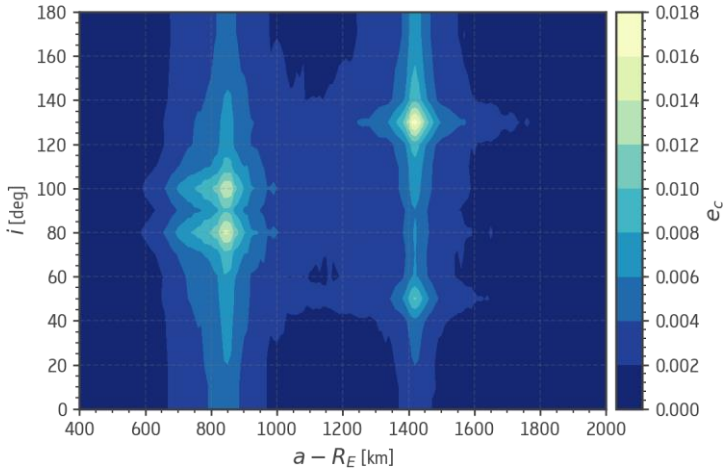
increased collision probability for **operational satellites**

$$p_{c,\mathrm{bkgd}} = 1 - \exp(-\rho \Delta v A \Delta t)$$

$$e_c = \sum p_{c,\mathrm{break-up}}$$

Debris flux as a function of semi-major axis and inclination (MASTER)





Effect of breakups on operational satellites (CiELO)

Space debris index

$$I = p_c \cdot e_c + p_e \cdot e_e$$

Work in progress

Explosion probability

historical data on orbital fragmentations + Kaplan-Meier estimator

- Jankovic&Kirchner, 2018

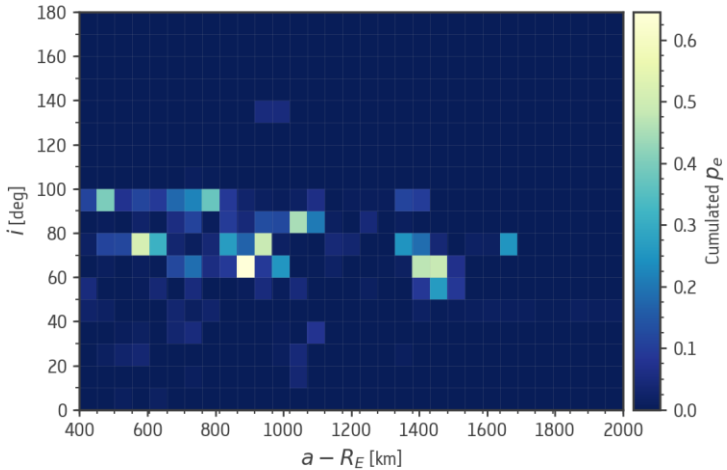
Explosion effect

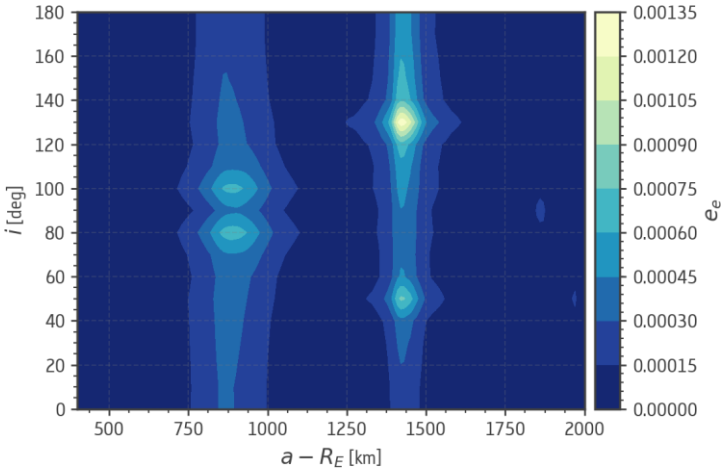
increased collision probability for **operational satellites**

$$p_e = f(\mathrm{obj}_{\mathrm{family}}, \Delta t)$$

$$e_e = \sum p_{c,\mathrm{break-up}}$$

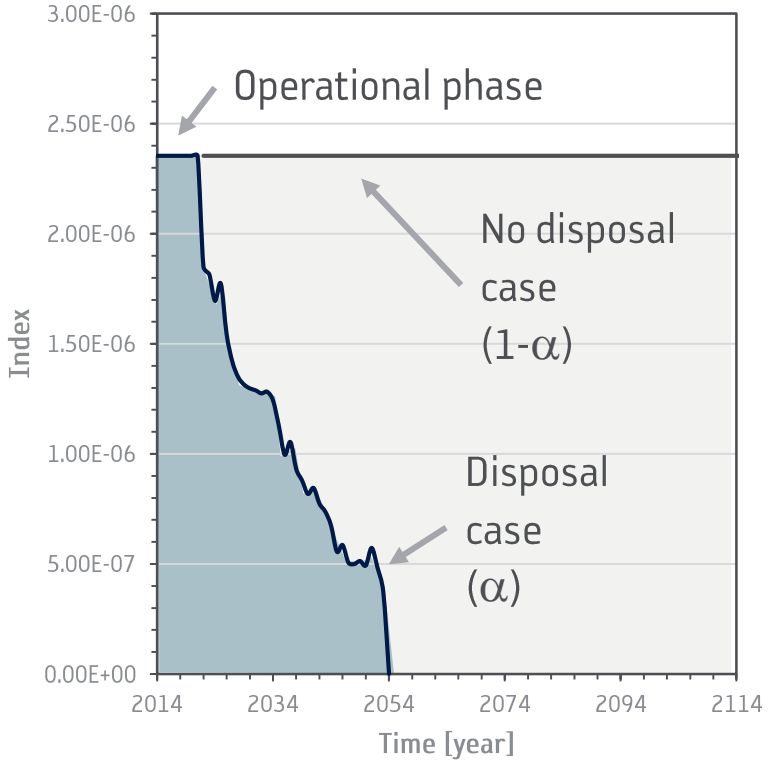
Cumulated explosion probability for objects in orbit in 2017



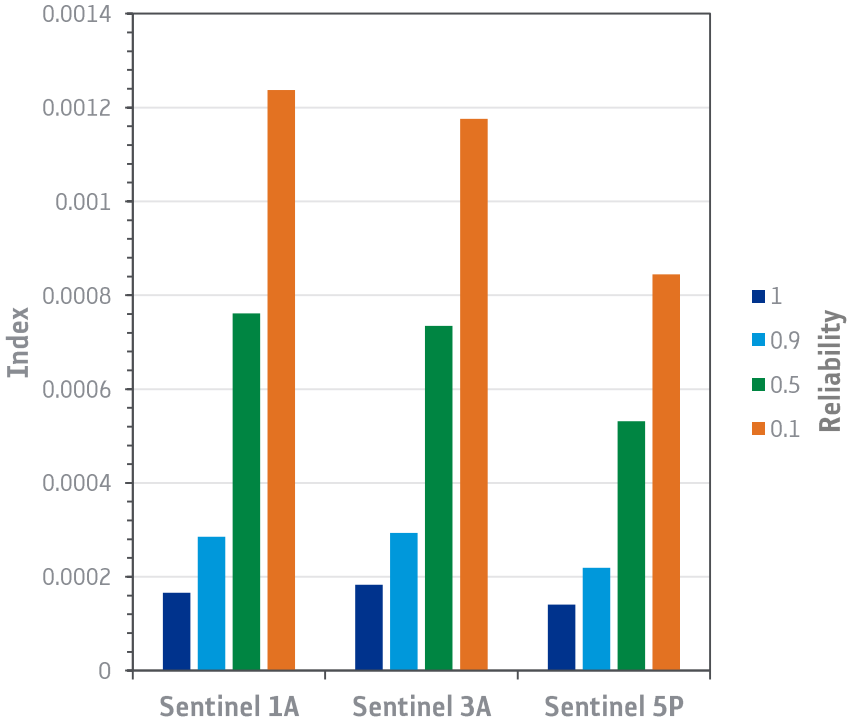


Effect of breakups on operational satellites (CiELO)

The role of reliability

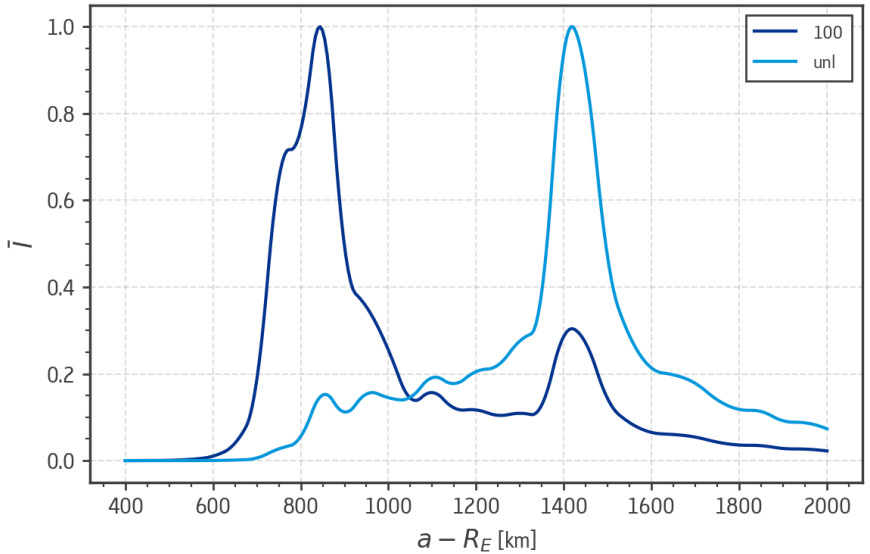


Reference time span: 100 years

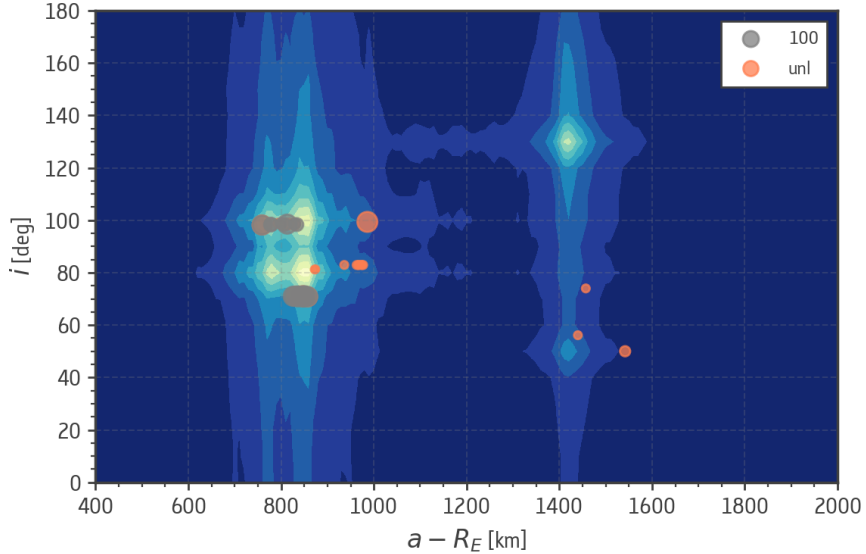


The role of reliability: temporal horizon

Index for Envisat-like SC

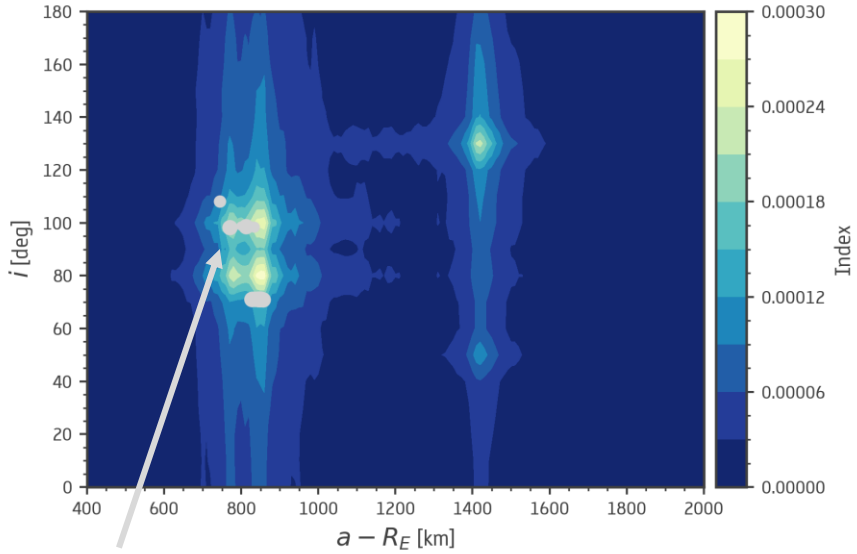


Top objects



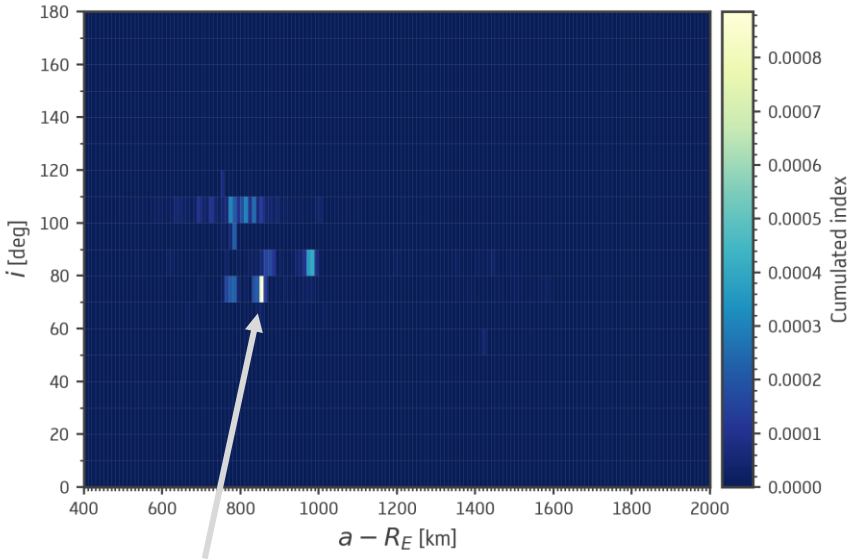
Objects & environment

Top objects



❶ Envisat

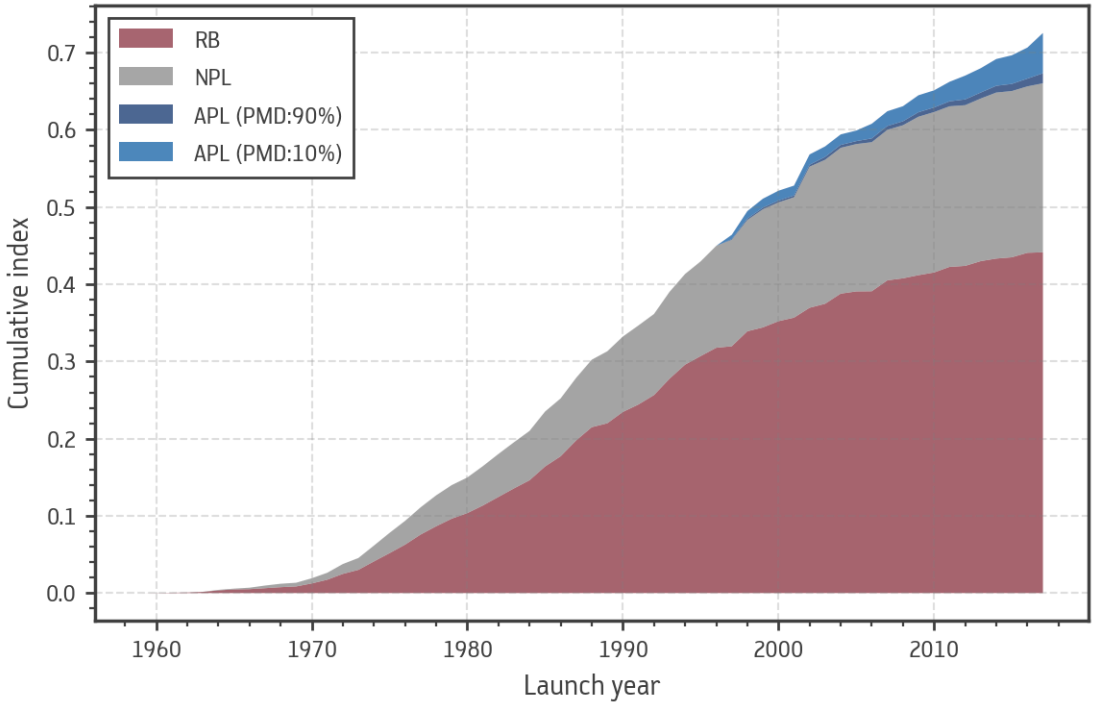
Top regions

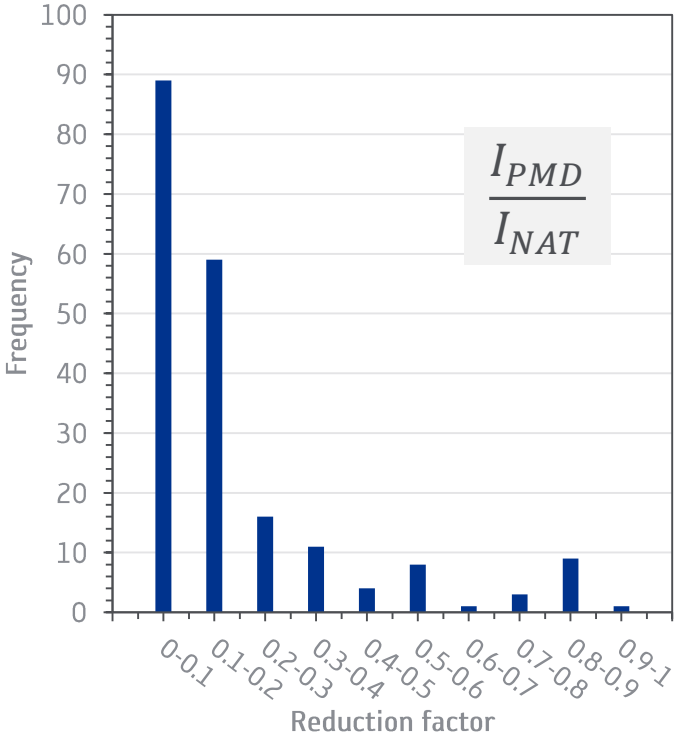


❶ Tselina fleet

Objects & environment

RB: Rocket Bodies | **NPL:** Not-active Payloads | **APL:** Active Payloads | **PMD:** Post-Mission-Disposal





Long-term evolution: scope & setup

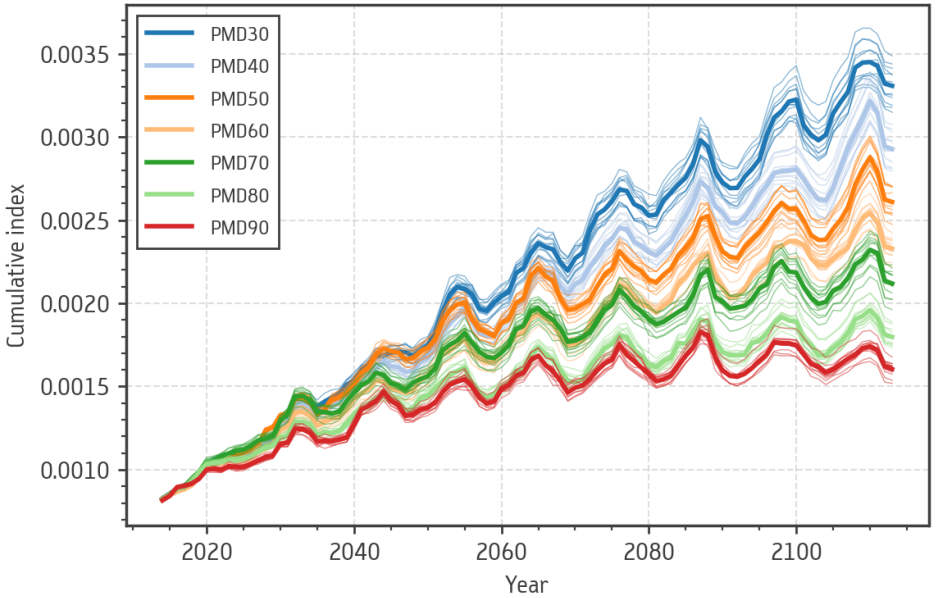
Analyse long-term simulations with

- different **PMD** success rates
- different **explosion** rates
- a large **constellation**

with the following reference values for the environment evolution

Starting population: 2013
Launch traffic: 2016-2017
Explosions: 2016-2017
PMD: 10-90%

Average temporal evolution over 12 runs



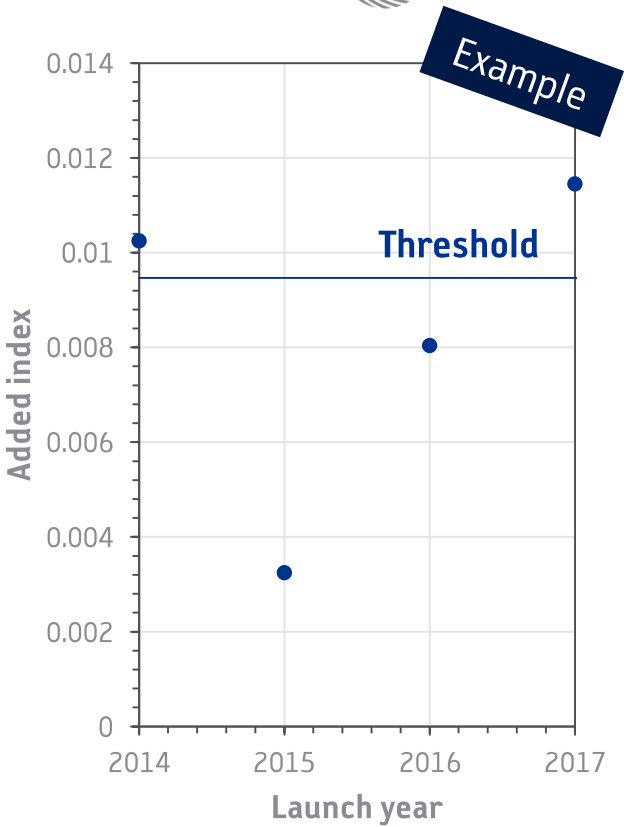
Capacity allocation: threshold definition - example

- Define an **acceptable trend** for the population [*]
- Derive from the long-term simulations the **final index value** after 100 years (I_f)
- Estimate the capacity that is already in **use** (I_u) [**]
- Define the portion of capacity that can be spent in one **launch year**:

$$(I)_{20XX} = \frac{I_f - I_u}{\#\text{years}}$$

[*]
Consensus-based approach.
Here: PMD90

[**]
Estimation of the **reliability** of objects already in orbit
Here: PMD = 60% (all objects)



Capacity allocation: contributors - example

Simplifying assumptions

All objects have the same PMD **success rate** and the same PMD **strategy**

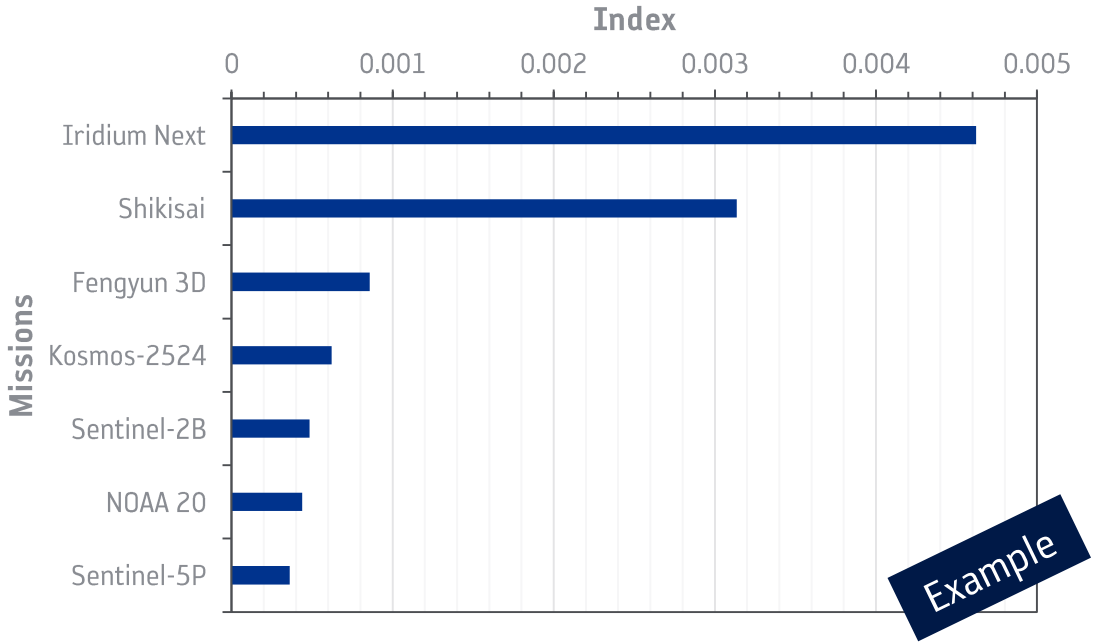
Discussion points

- **max** value per mission?
- priority for certain **mission typologies**?

Suggested approach

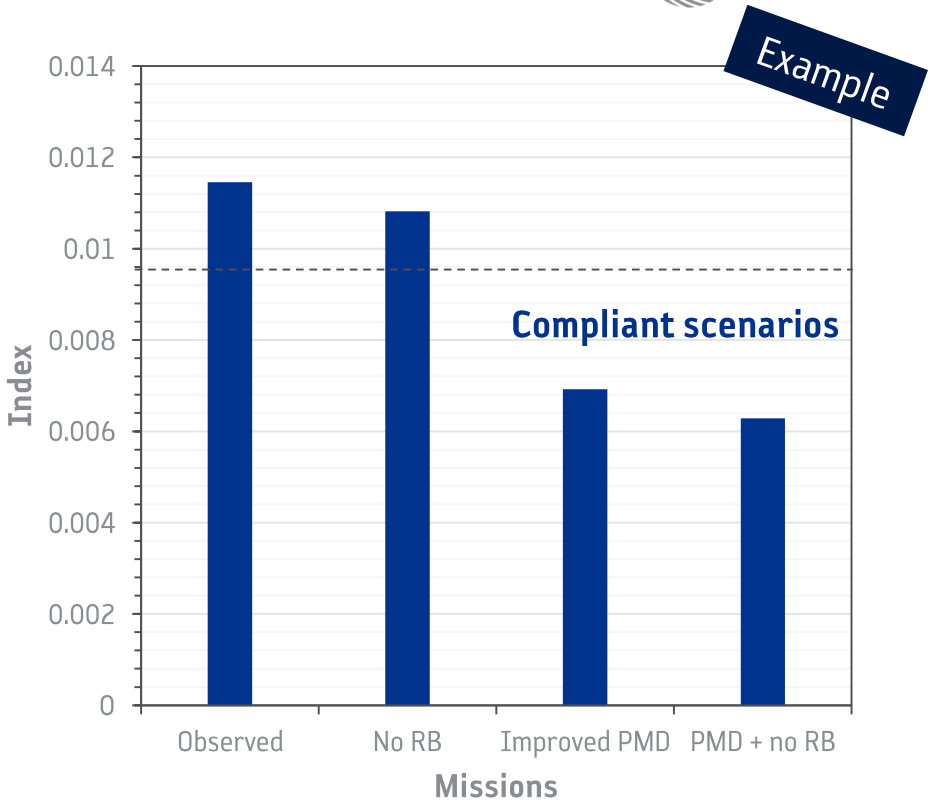
first-come, first-served

Mission contributing to 90% of the added index in 2017



Capacity allocation: mitigation strategies - example

- **No RB**
  no rocket body is left in orbit after launch,
- **Improved PMD**
  PMD success rate increased from 60% (used for all other objects) to 90% (only for the objects launched in the analysed year),
- **PMD + no RB**
  both mitigation measures are applied

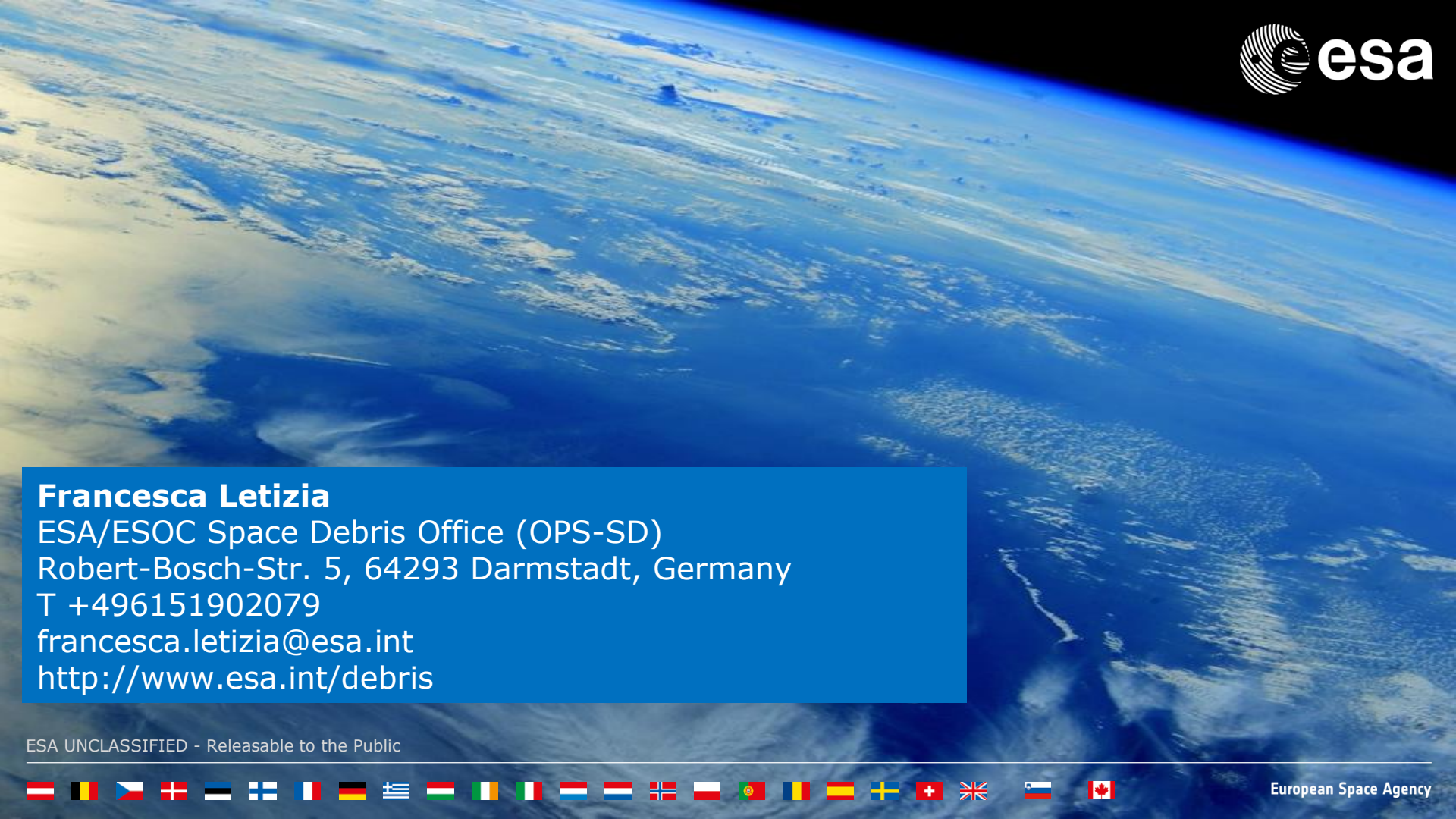


Conclusions

The concept of **environment capacity** can be used to strengthen current **space debris mitigation** implementation requirements by considering the **global evolution** of the environment.

An indicator based on the **collision risk** for **operational satellites** is used as a metric of the capacity: it can be used to evaluate the criticality of **single objects** and of the whole **environment**. The index is computed along mission profiles and the expected **reliability** of the execution of PMD strategies is considered.

Long-term simulations were carried out to test the index evaluation under different **scenarios** and to define a preliminary scheme for the **quantification** of the **environment capacity**, which was applied on recent historical data.



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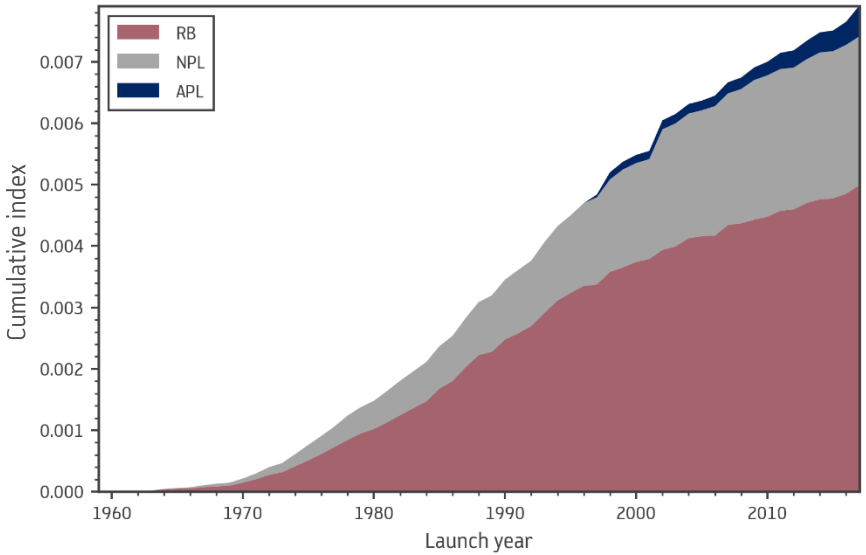
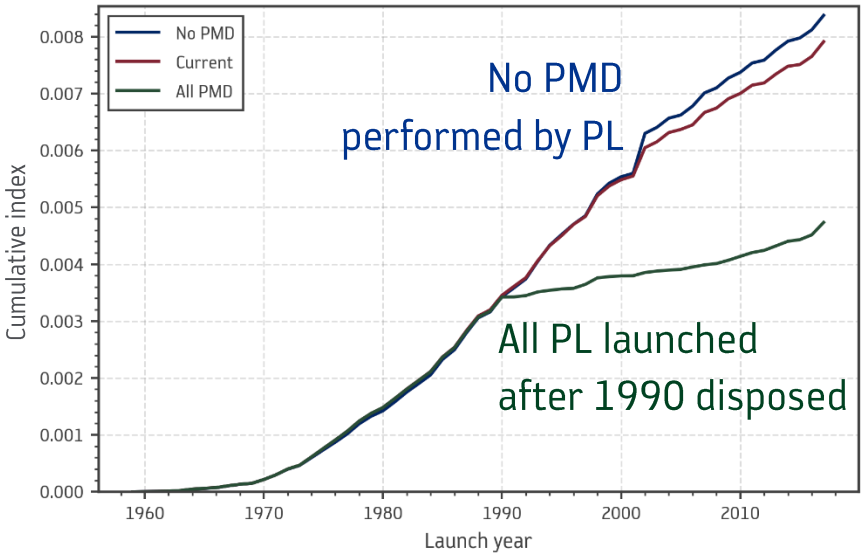
Cumulative index

Current environment



PMD scenarios

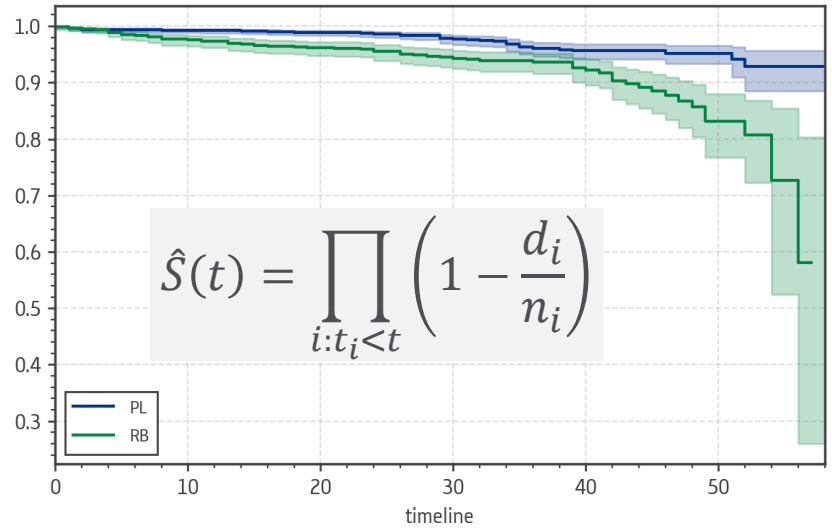


RB: Rocket Bodies | **NPL**: Not-active Payloads | **APL**: Active Payloads | **PMD**: Post-Mission-Disposal

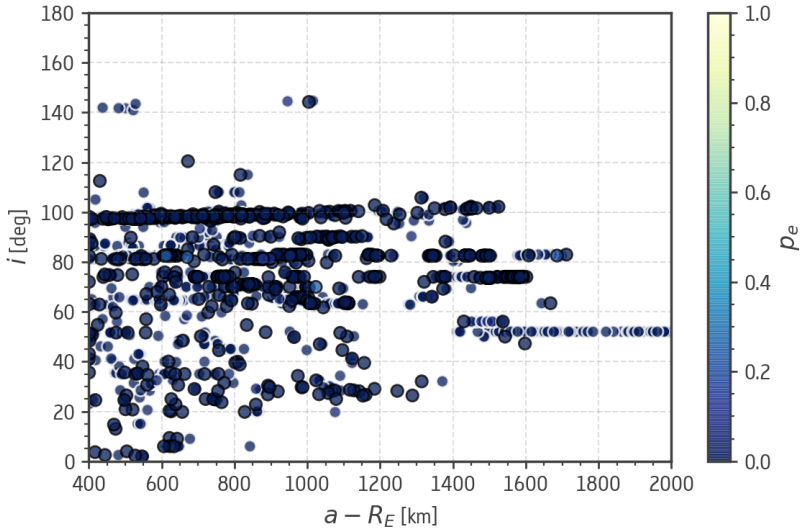
Explosion probability: Kaplan-Meier

Non-parametric estimator to obtain the survival curve from a population sample, including incomplete observations

- Jankovic&Kirchner, 2018



PL (white) – RB (black)



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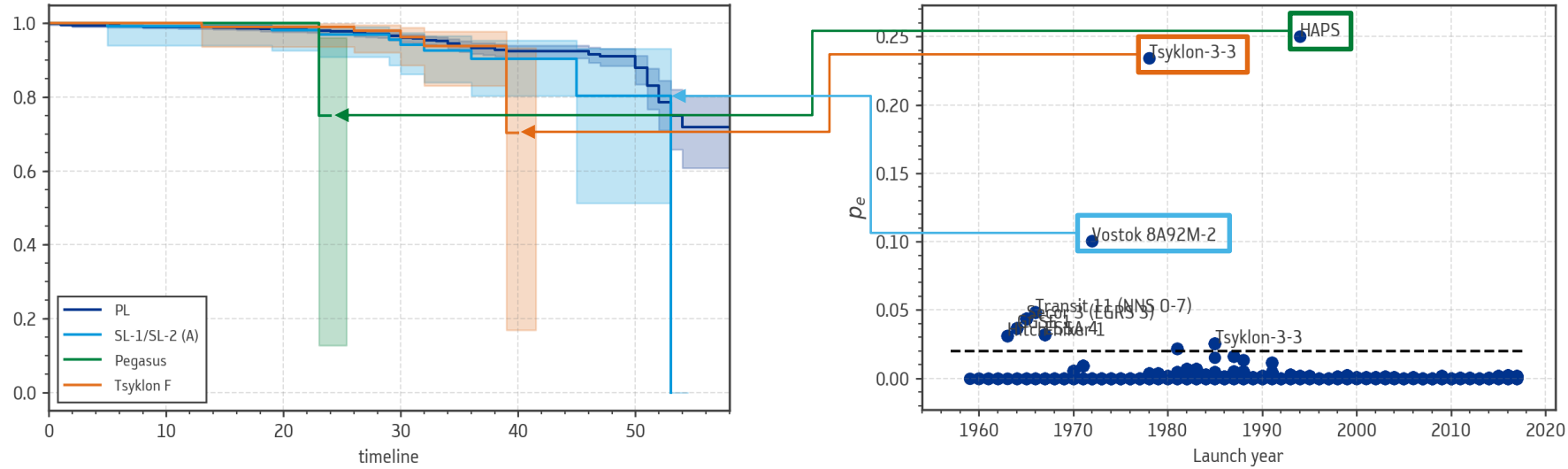
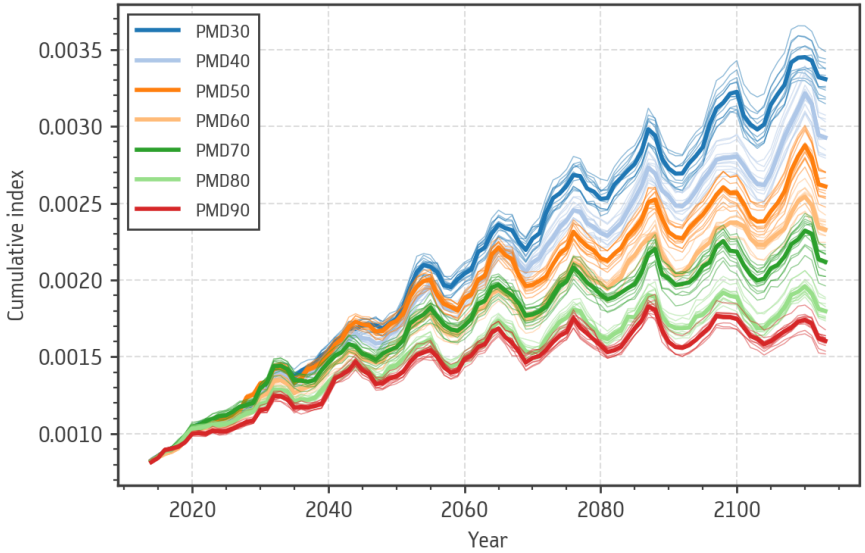
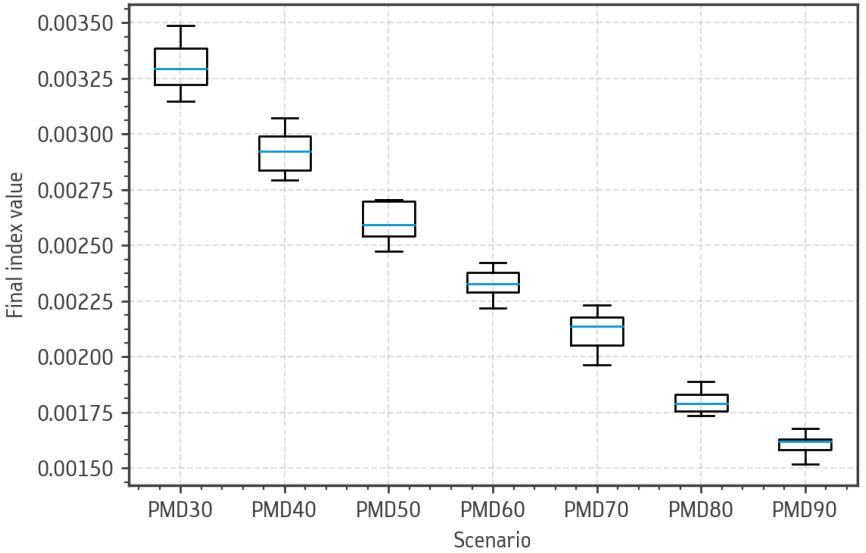


Long-term evolution: PMD scenarios

Average temporal evolution over 12 runs



Variability of the final state (100 years)



Long-term evolution: # objects & collisions