SPACE SUSTAINABILITY RATING

Utilization of a risk index to incentivize satellite operators to follow best practices for post mission disposal

2023 Clean Space Industry Days

19 October 2023

ESTEC, The Netherlands

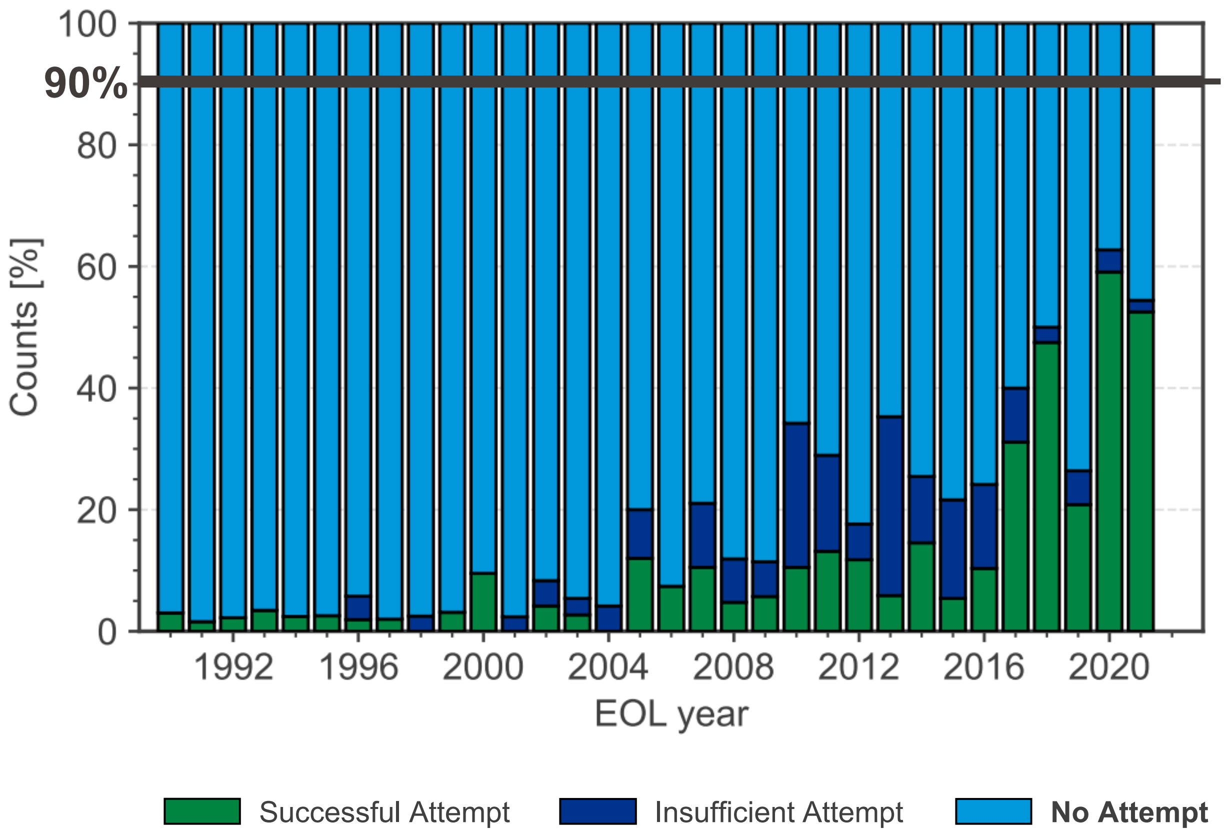
2023 Clean Space Industry Days

SPACE SUSTAINABILITY RATING

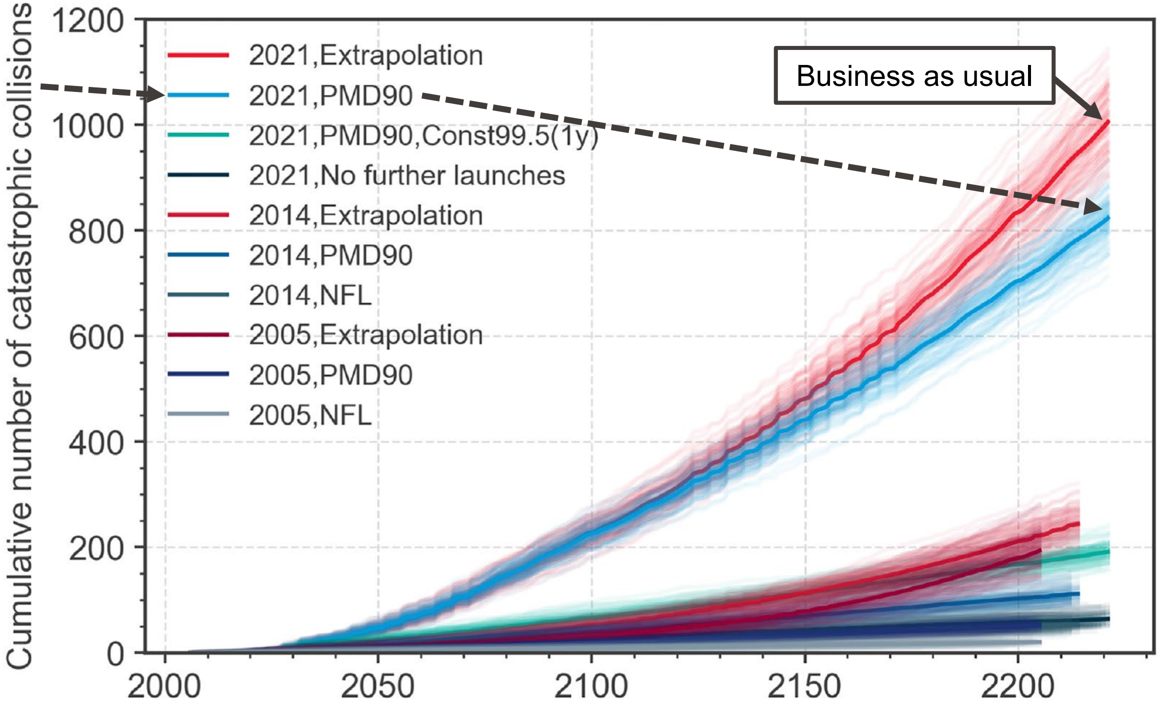
*WE ARE **NOT** DOING ENOUGH*

and doing "enough" is not enough anymore…

Payload Clearance in LEO **excluding natural compliance (1)**



Long-term simulation of the space environment (2)



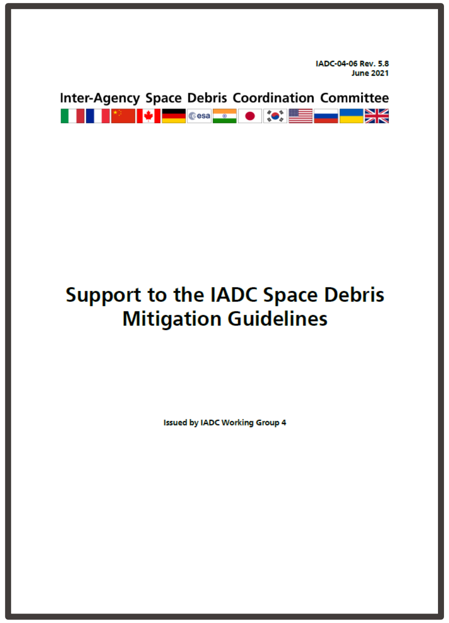
*"The extrapolation of the current behaviour to the future results in an unstable environment, with **collision rates increasing exponentially**"*

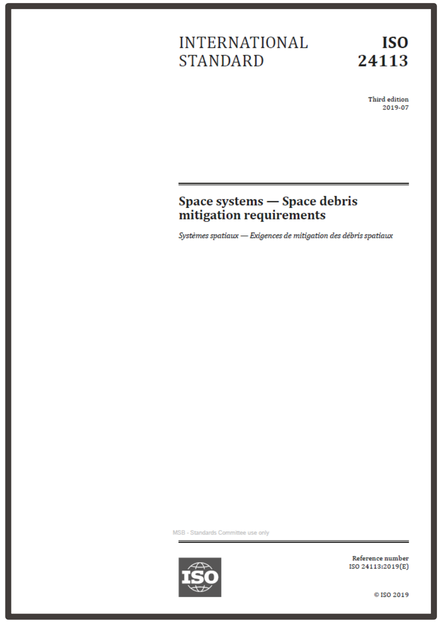
(1) ESA, Space Environment Report, June 2023 release

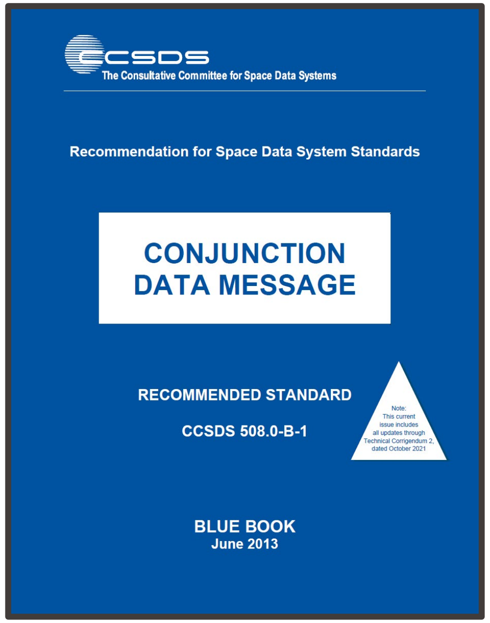
(2) F. Letizia et al., Assessment of orbital capacity thresholds through long-term simulations of the debris environment, Advances in Space Research, https://doi.org/10.1016/j.asr.2022.06.010

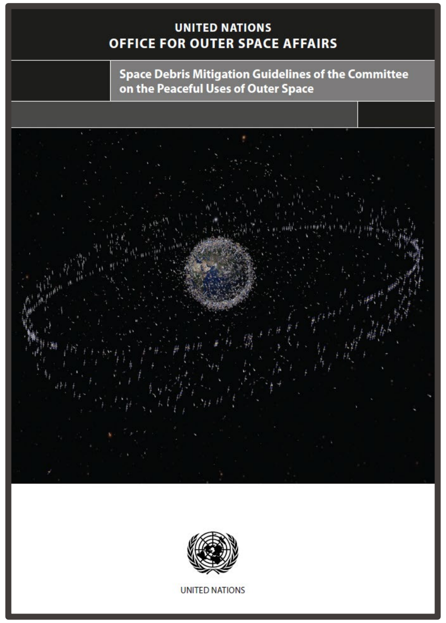
A NEED TO INCENTIVIZE FURTHER ADOPTION OF BEST PRACTISES

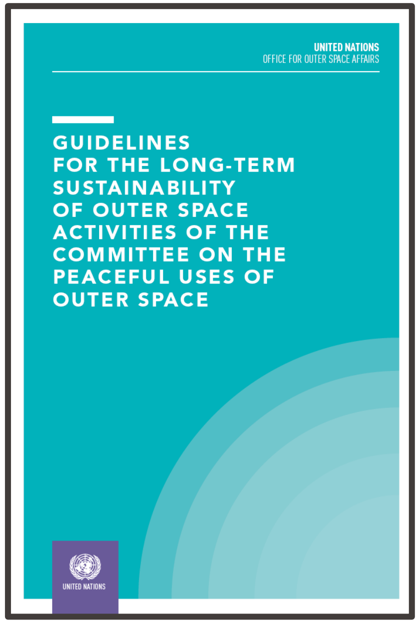
There are no legally binding space debris mitigation instruments (at international level)











THE SSR AS AN INCENTIVE TOOL

Encouraging space actors to **design & implement sustainable & responsible space missions** for the long-term **sustainability of the space environment**

SPACE SUSTAINABILITY RATING

BRONZE

SILVER

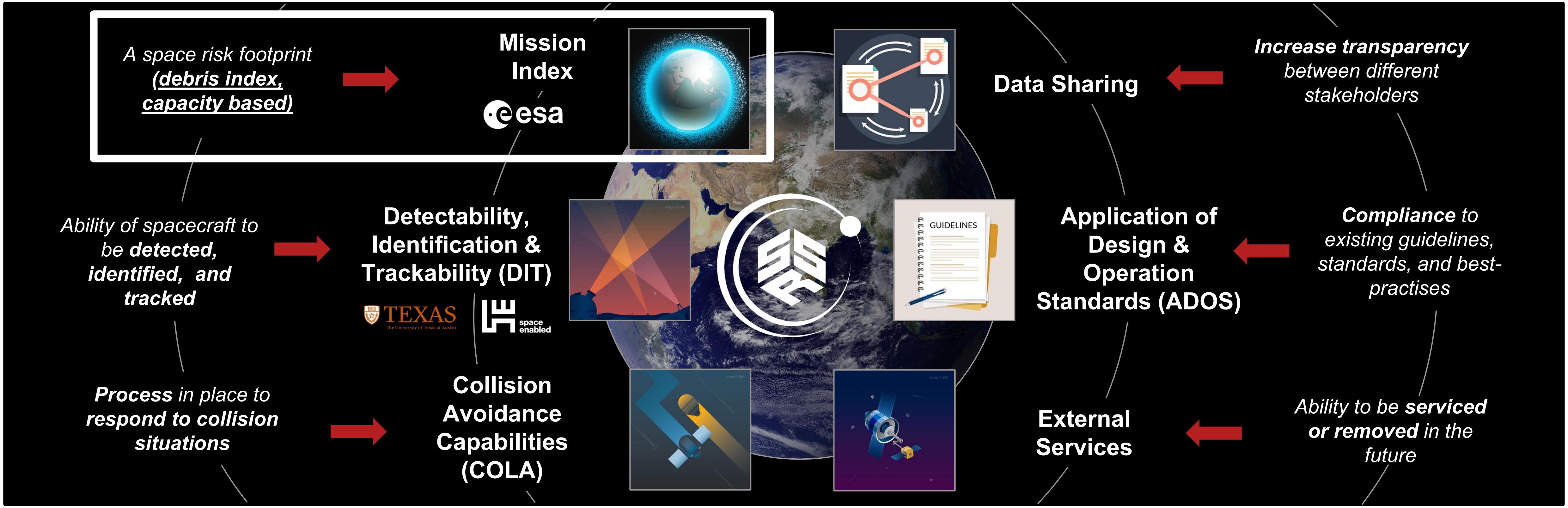
GOLD

PLATINUM

SSR MODULES IN A NUTSHELL

Space environment (C:)

Available capacity almost full



ACKNOWLEDGEMENT

The Mission index module methodology of the Space Sustainability Rating heavily relies on research that have been performed in the past years by several entities such as ESA Space Debris Office and Politecnico di Milano.

MISSION INDEX - INPUTS

A **space risk footprint**

- Quantifies the **collision risk** using an index metric;
- Evaluates the risk contribution of a mission to the debris environment **compared to a capacity target;**
- Uses **high level parameters** that can be obtained early in the mission development;

Satellite & mission design

- Number of satellites
- Spacecraft mass
- Cross-sectional area
- Operational lifetime
- Deployment duration

Orbital parameters (at deployment epoch)

- Semi-major axis
- Eccentricity
- Inclination

Collision avoidance strategy

- Accepted collision probability level
- Lead time

Disposal strategy

- Success rate
- Target apogee and perigee
- Description

MISSION INDEX - FORMULATION

Index formulation for one object, at a given epoch

Probability of collision p_c

$$I = \overbrace{p_c}\cdot \underbrace{e_c}$$

Severity of collision e_c

High I ⇔ High risk ⇔ Low Score

I depends on orbital parameters and spacecraft physical properties

Environment simulated with MASTER

Cumulative collision probability

$$p_c = 1 - e^{-\rho \cdot \Delta V \cdot A \cdot \Delta t}$$

- ρ the density of object large enough to trigger a catastrophic collision (1)
- ΔV the relative impact velocity
- A the cross-sectional area
- Δt the timestep increment value

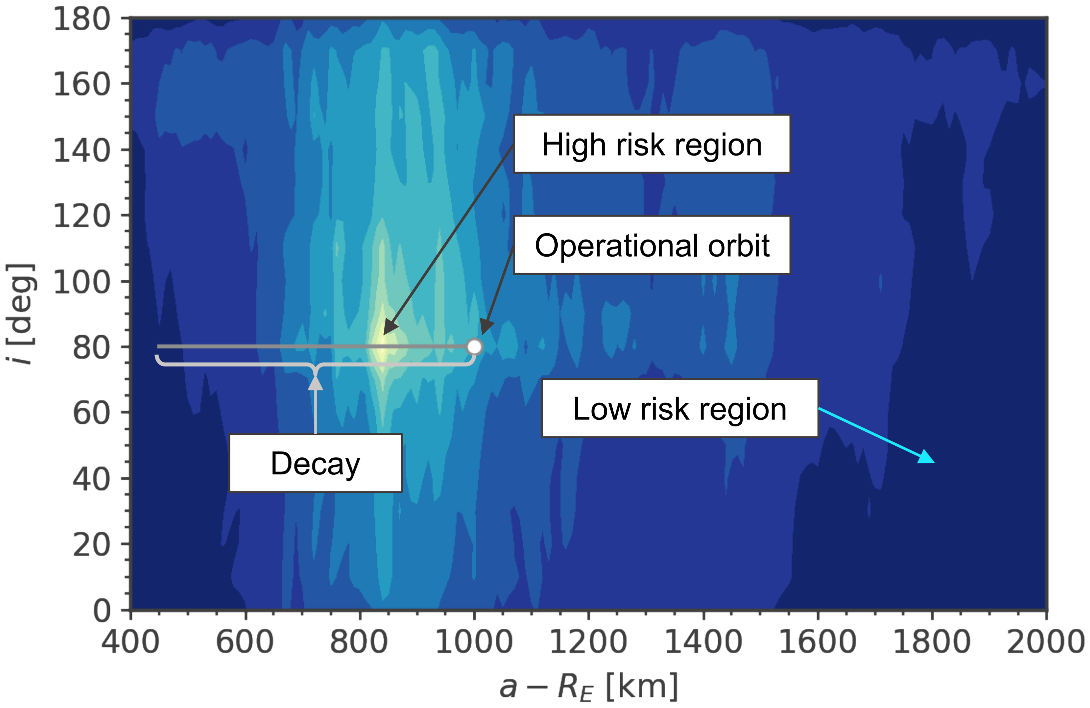
Collision severity (2)

- Synthetic fragmentation triggered and modelled (reformulated NASA breakup model)
- Propagation of the debris cloud (phase space density)
- Quantification of the **increased probability of collision for a set of representative objects**

(1) Categorized as collisions with an energy-to-mass ratio above the 40 J/g threshold
(2) Colombo et al. *Tracking the health of the space debris environment with THEMIS*, section 2.1

MISSION INDEX – INDEX MAPS

Index value heatmap (LEO region)



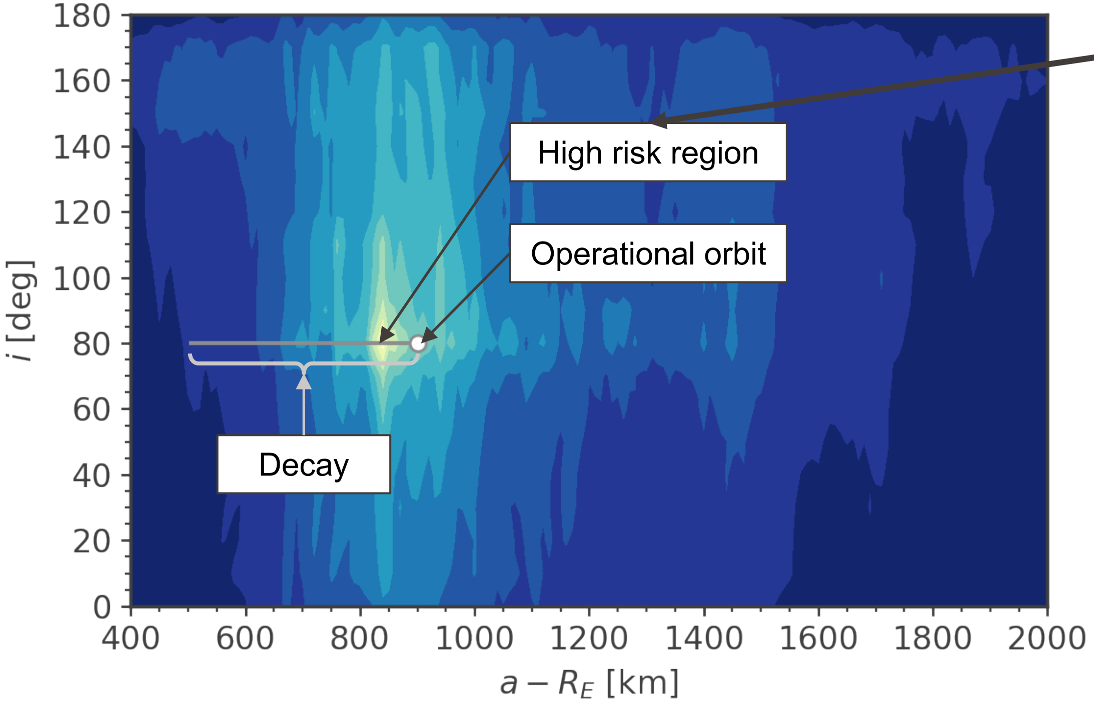
The index value is discretized, and integrated over the object's lifetime

$$I = \int_{t_0}^{t_f} (p_c \cdot e_c)\, dt$$

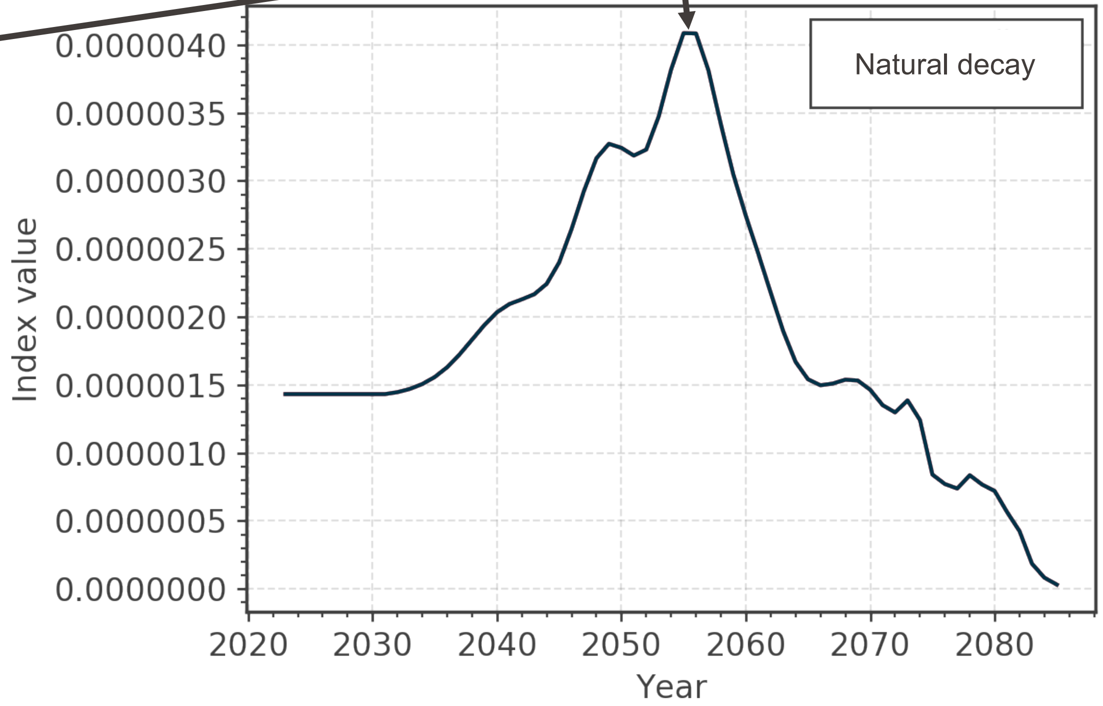
Discretized index allows to account for the spacecraft trajectory evolution (e.g. orbit raising, disposal manoeuvres, orbital decay)

MISSION INDEX – TRAJECTORY EVOLUTION

<u>Mock mission data:</u>
$A/m = 0.1$ (to highlight impact of trajectory evolution)
Initial altitude 900km
No post mission disposal (natural decay)



Result of satellite is crossing high risk regions during decay



MISSION INDEX – TRAJECTORY EVOLUTION

Mock mission data:
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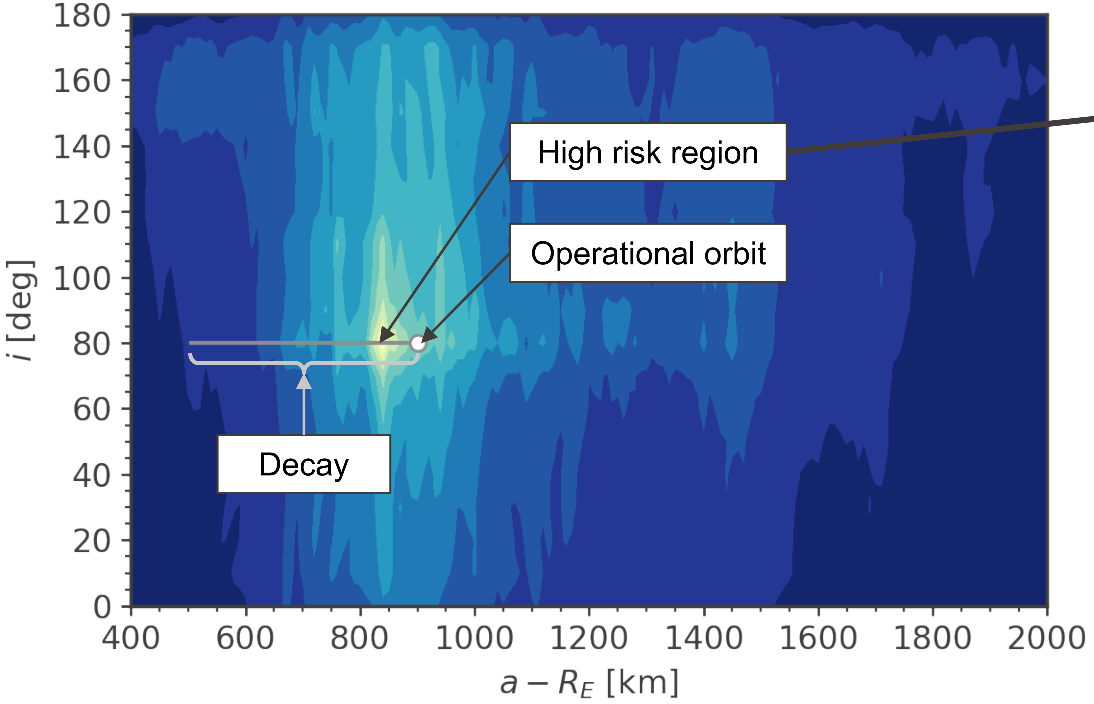
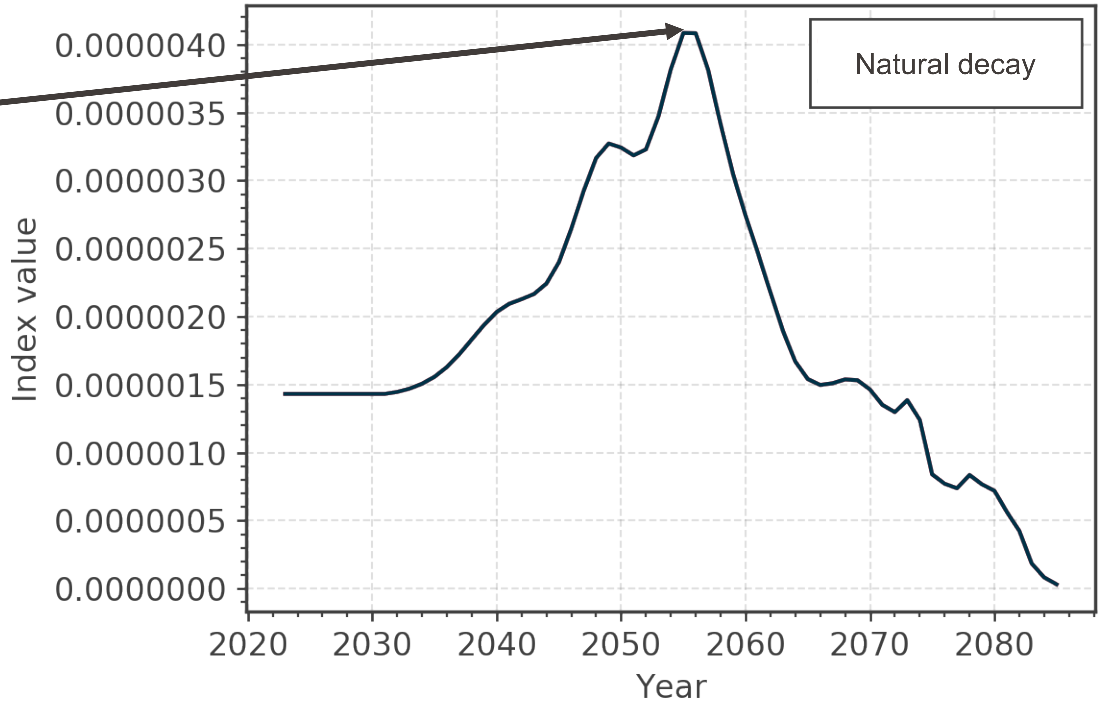


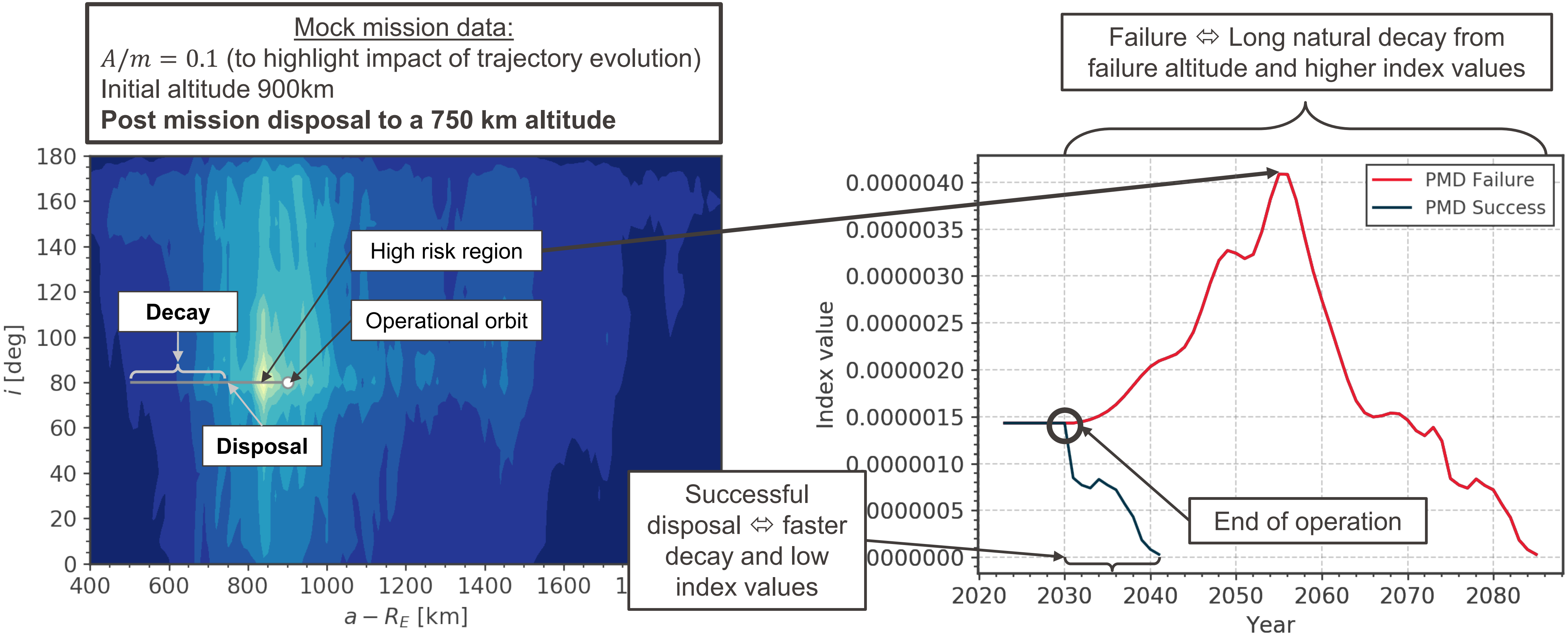
What about disposal manoeuvres?



Courtesy: debris index frontend, ESA space debris office

MISSION INDEX – TRAJECTORY EVOLUTION AND PMD

<u>Mock mission data:</u>
$A/m = 0.1$ (to highlight impact of trajectory evolution)
Initial altitude 900km
Post mission disposal to a 750 km altitude



MISSION INDEX – DISPOSAL RELIABILITY

Accounting for disposal failure scenario:

$$I_{disposal} = \underbrace{\alpha \int_{t_{EOL}}^{t_{f_D}} I_{disposal}\, dt}_{\text{PMD Success}} + \underbrace{(1-\alpha) \int_{t_{EOL}}^{t_{f_{ND}}} I_{abandonned}\, dt}_{\text{PMD Failure}}$$

α: Post Mission Disposal Success Rate*

Before launch:

α is obtained from spacecraft reliability analysis

During operation

α is set to 0 if a spacecraft fails
α is set to 1 if a spacecraft is successfully deorbited

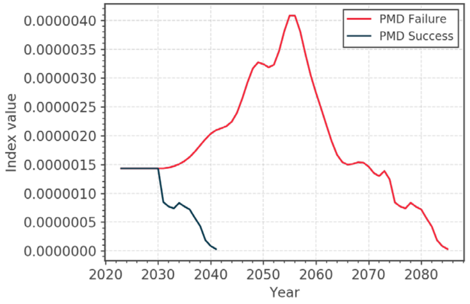
* For a constellation, the value of α is aggregated for the entire fleet (i.e. weighted average)

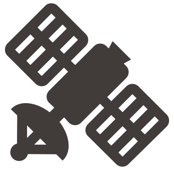
MISSION INDEX – NORMALIZATION

How to output a score?

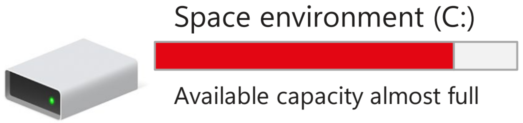
Mission parameters Satellite(s) physical properties → Index computation (spacecraft level) → Index at fleet level → Normalization

- Index computation (spacecraft level) ← Disposal scenarios; Risk Reduction achieved through collision avoidance*
- Index at fleet level ← Number of satellites
- Normalization ← Absolute index (80%); Relative index (20%)





$\times N_{sat}$



* No time to present it! More details in the backup slides at the end of the presentation

MISSION INDEX – NORMALIZATION

Space environment (C:)

Available capacity almost full

What is "full"?

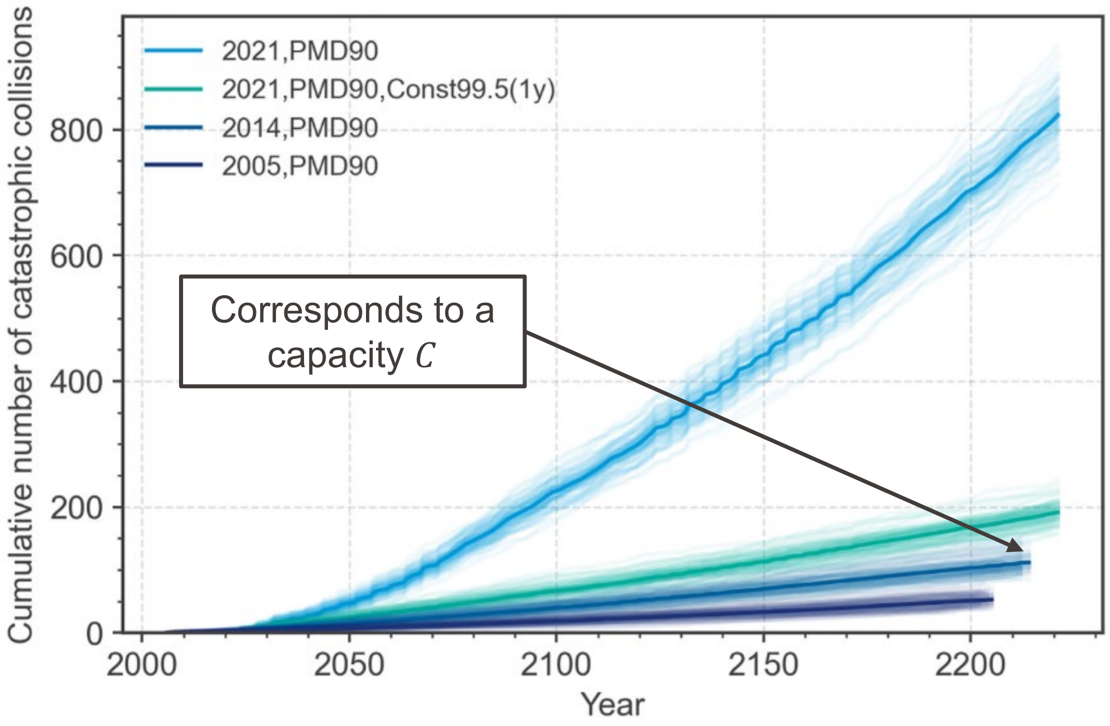
Capacity identified from long term extrapolation scenarios (the "capacity" C)

A normalized score is computed based on the **share of yearly available capacity** consumed by the mission

$$\hat{I} = I_{mission}/(C - I_{already\ used})$$

$$S_{abs} = 0.5 - \frac{1}{10}\log_{10}(\hat{I}) - \frac{\hat{I} - 1}{50}$$

(1)



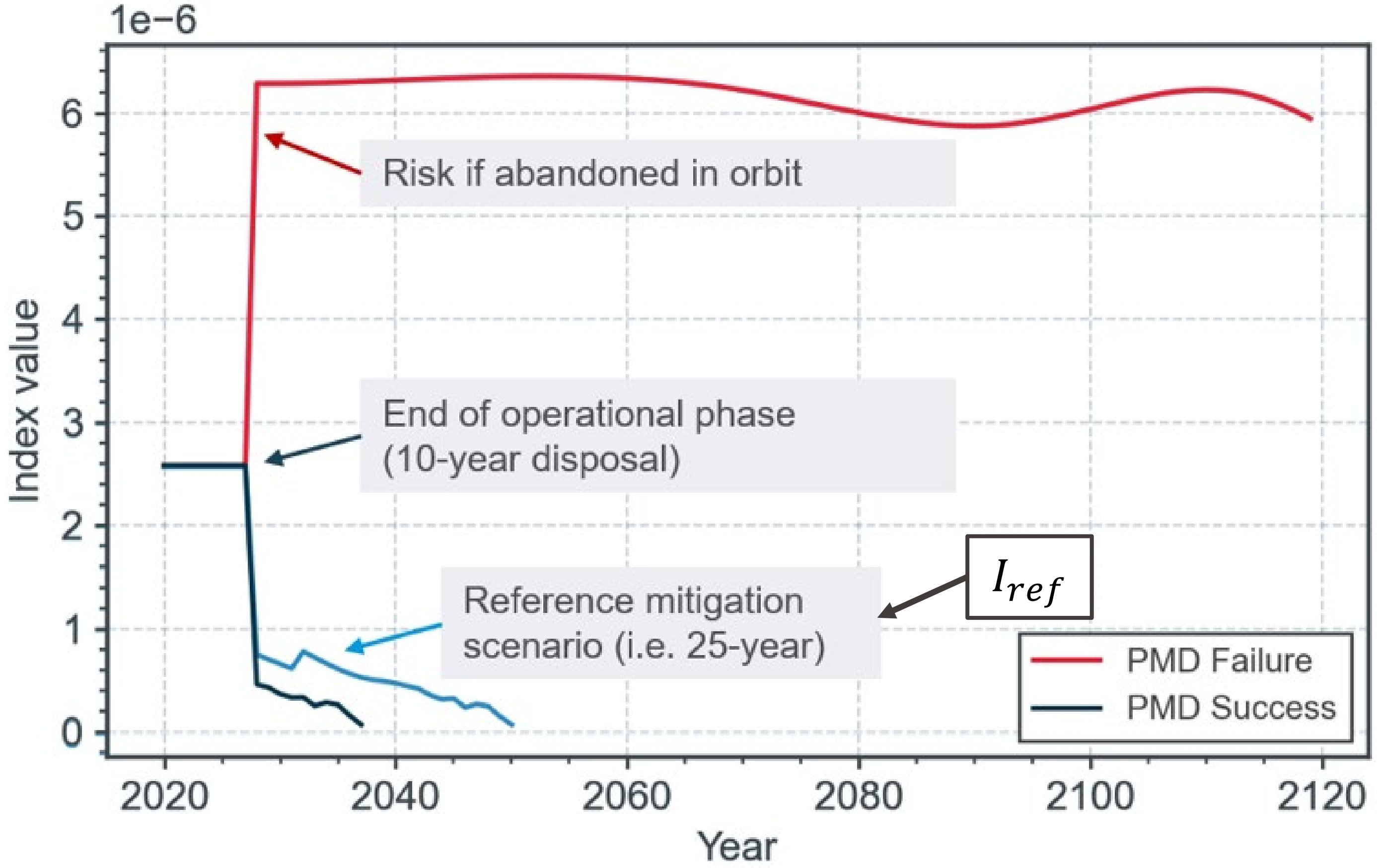
"Absolute" index score, 80% of the mission index score (2)

(1) F. Letizia et al., Assessment of orbital capacity thresholds through long-term simulations of the debris environment, Advances in Space Research, https://doi.org/10.1016/j.asr.2022.06.010
(2) Saada et al., Promoting responsible space practices: A primer on the Space Sustainability Rating

MISSION INDEX – NORMALIZATION

“Relative” mission index: going beyond recommendations

- Definition of a reference case
- Comparison to the reference case

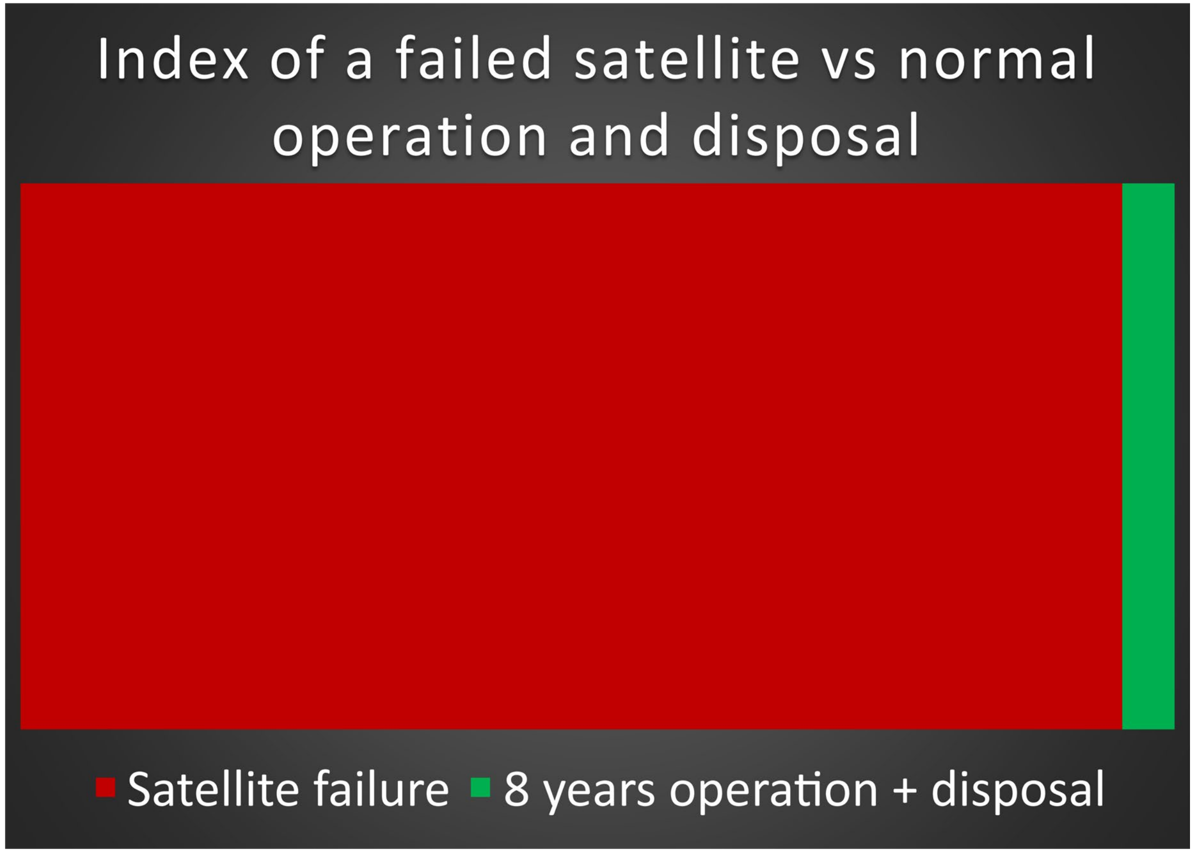


$$I_{relative} = I_{mission}/I_{ref}$$

$$S_{rel} = 1 - (I_{rel})^{\varepsilon}$$ ⟵ “Relative” index score, 80% of the mission index score

MISSION INDEX - APPLICATIONS

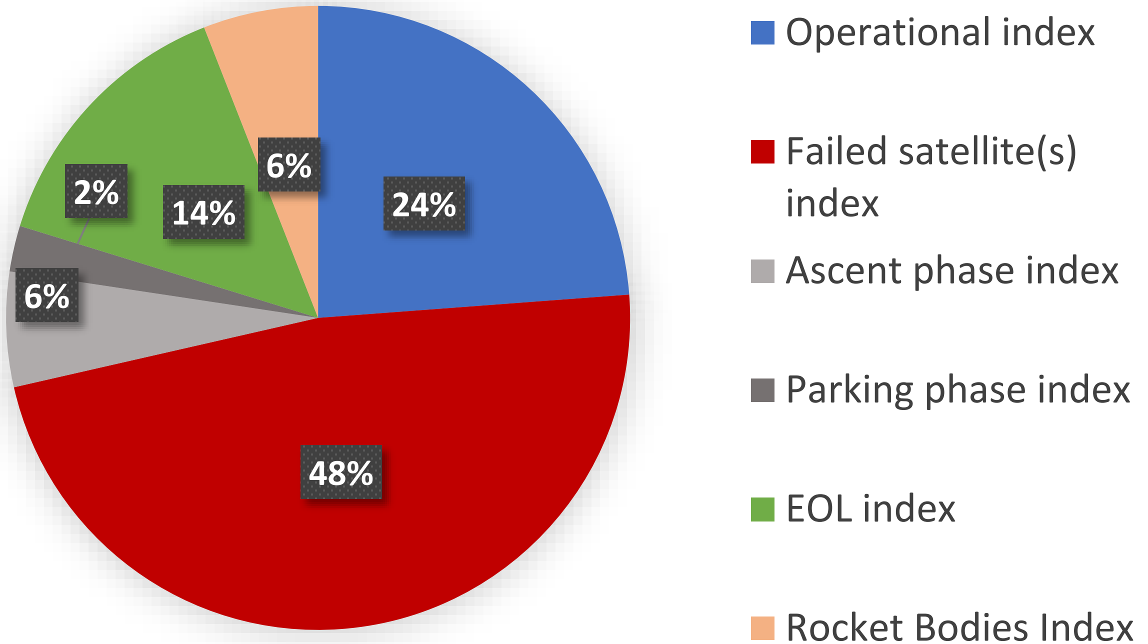
- Raise awareness: **Quantify** the impact of a spacecraft failure(s) on the space environment



MISSION INDEX - APPLICATIONS

- Raise awareness: Quantify the impact of a spacecraft failure on the space environment
- Analysis: Identification of **critical phases** (parking, raising, disposal) within mission. Derive different raising and disposal scenarios…
- PMD success rate sensitivity analysis for constellations

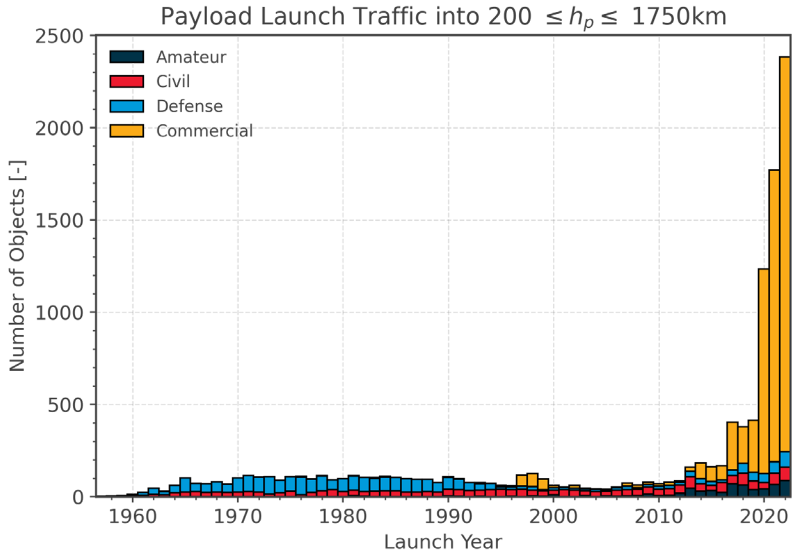
Absolute index share per scenario*



*Mock data

CONCLUSION

- <u>Risk based approach:</u>
  - More robust considering the increasing launch rate
  - Available capacity value can evolve (e.g. due to fragmentations, removal)



- <u>Applicability to a rating scheme:</u>
  - Can be applied now!
  - Easier scoring threshold establishment
  - Complementary with compliance based modules

SPACE SUSTAINABILITY RATING

GOLD

SSR as a tool to incentivize further adoption of the zero debris approach?

1 Definition of valuable orbits

- Extend orbital protection to other earth orbits e.g., **GNSS operational orbits**

2 Guarantee successful disposal

- Improve probability of successful **self-disposal**
- **Prepare for removal**
- **Removal services**

3 Improve orbital clearance

- **Reduce time** left in protected regions **below 5 years** *
- Improve clearance in **other Earth orbits**

4 Avoid in-orbit collisions

- Improve **collision avoidance strategy**
- Cumulative probability of **collisions after EoL < 10^{-3}** *
- **Share maneuver data**
- Improve **trackability**

5 Avoid internal break-ups

- **Mandatory** passivation features
- **0.99 * probability of successful passivation**

6 Prevent intentional release of space debris

- **Prevent release** of launcher related objects and interference with valuable orbits

7 Improve on-ground casualty risk assessment

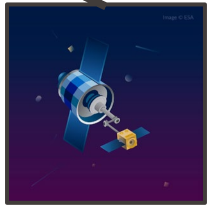
- **Standardize** models and methods to assess demise
- **Impact on ground** of launcher related objects

8 Guarantee dark and quiet skies

- Mitigate impacts on **astronomy**

* final numerical values under consolidation

2 **Guarantee successful disposal**

3 **Improve orbital clearance**

4 **Avoid in-orbit collisions**




5 **Avoid internal break-ups**

8 **Guarantee dark and quiet skies**

Development of a Dark and Quiet Skies module for the Space Sustainability Rating

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[1] *Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland*
[2] *Space Sustainability Rating, Switzerland*
[3] *Space Enabled Research Group, Massachusetts Institute of Technology (MIT), United-States*
[4] *Institut Polytechnique de Paris (IPP), France*

Credit: [ESA - SHORT INTRODUCTION TO ESA'S ZERO DEBRIS APPROACH]

2023 Clean Space Industry Days

EPFL continuing education for professionals – Space Sustainability Course: "How to design more sustainable missions?"

LEARN MORE

GET IN TOUCH

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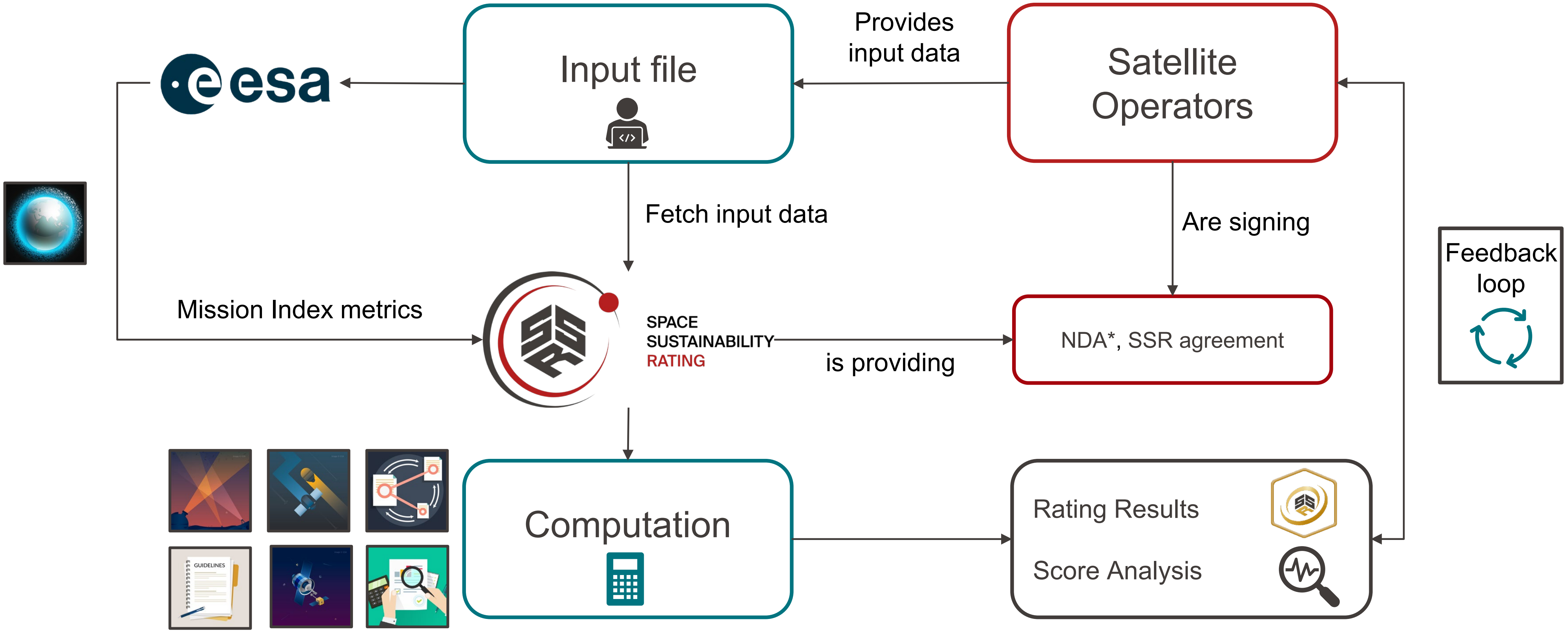
spacesustainabilityrating.org

SPACE SUSTAINABILITY RATING

BACKUP SLIDES

SSR PROCESS

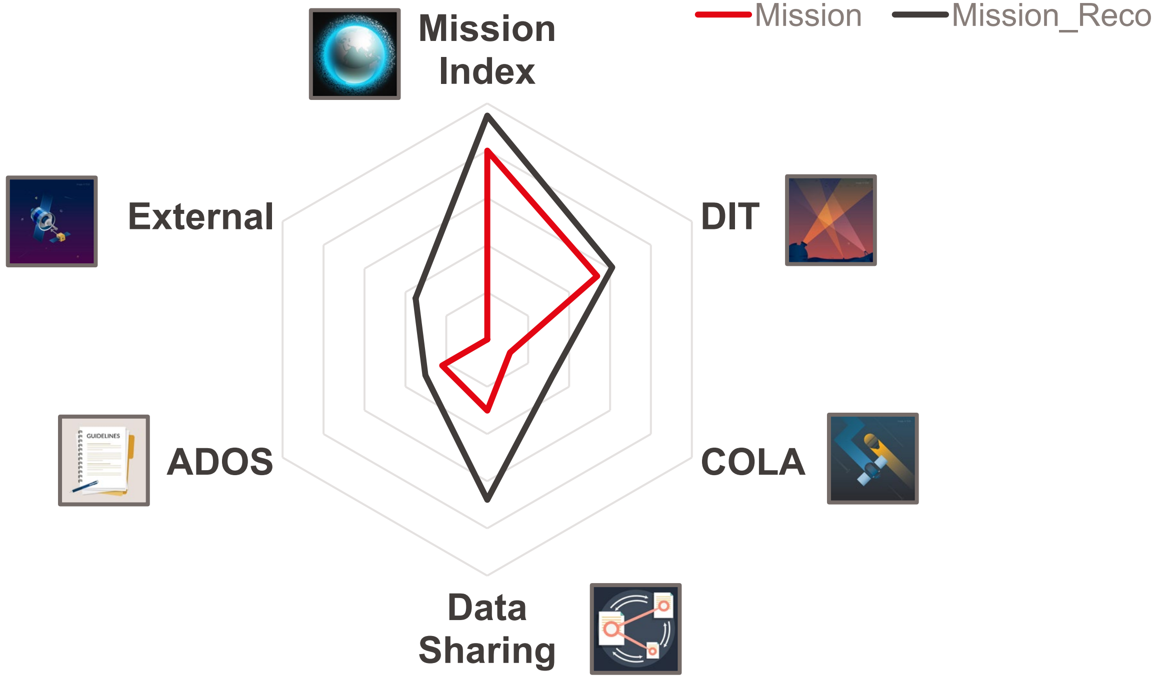
THE RATING PROCESS IN A NUTSHELL



*Non-Disclore Agreement

SPACE SUSTAINABILITY RATING

SSR FEEDBACK LOOP



Reco.	Description	Score increase (module)	Score increase (Tier)
MI_1	Comment	+3.5%	+1.75%
DS_1	Comment	+4%	+0.66%
COLA_1	Comment	+12%	+1.98%
DIT_1	Comment	+5%	+0.6%
…	…	…	…
Total SSR Score increase			**+8.29%**
New tier			**Gold**

Metric	Score	Previous	Change
Tier Score	87.71 %	from 64.65 %	↑ 23.06 %
Bonus Score	79.85 %	from 57.71 %	↑ 22.14 %
Mission Index	96.67 %	from 61.03 %	↑ 35.64%
Collision Avoidance Capabilities	100 %	from 89.44 %	↑ 10.56%
Data Sharing	95.95 %	from 52.93 %	↑ 43.02%
Detection, Identification and Tracking	33.33 %	from 69.17%	↓ -35.83%
Application of Design and Operation Standards	60.92 %	from 46.88%	↑ 14.05%
External Services	100 %	from 50 %	↑ 50%

BACKUP SLIDES

RISK REDUCTION FROM COLLISION AVOIDANCE IN THE INDEX COMPUTATION

MISSION INDEX – COLLISION AVOIDANCE

$$I_{phases\ COLA} = \int_{t_0}^{t_{EOphase}} \left[\underbrace{(1-\gamma)\left(p_{c_{trackable}} \cdot e_c\right)} + p_{c_{non-trackable}} \cdot e_{c_{non-trackable}} \right] dt$$

$t_{EOphase}$: End of phase

γ: Mitigated Collision Risk

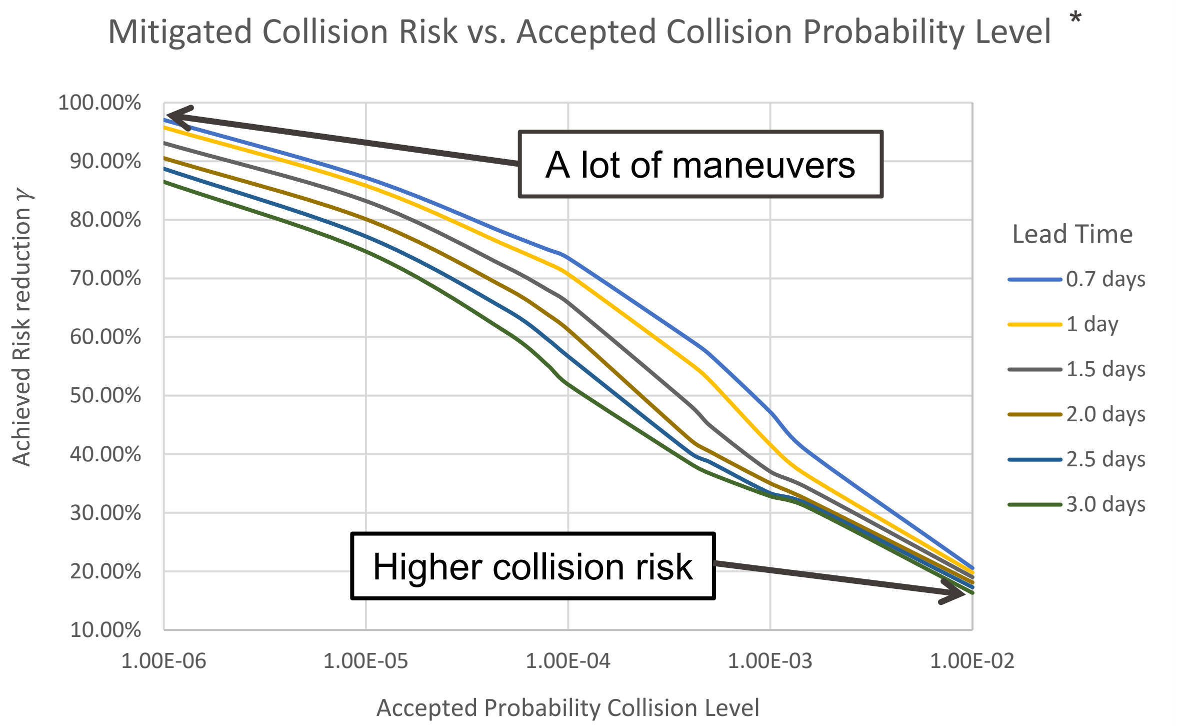
Collisions with trackable debris can be avoided

Risk reduction achieved by the implemented collision avoidance strategy **with respect to the case where no maneuver is performed**

mainly driven by two parameters:

Time required to perform a maneuver

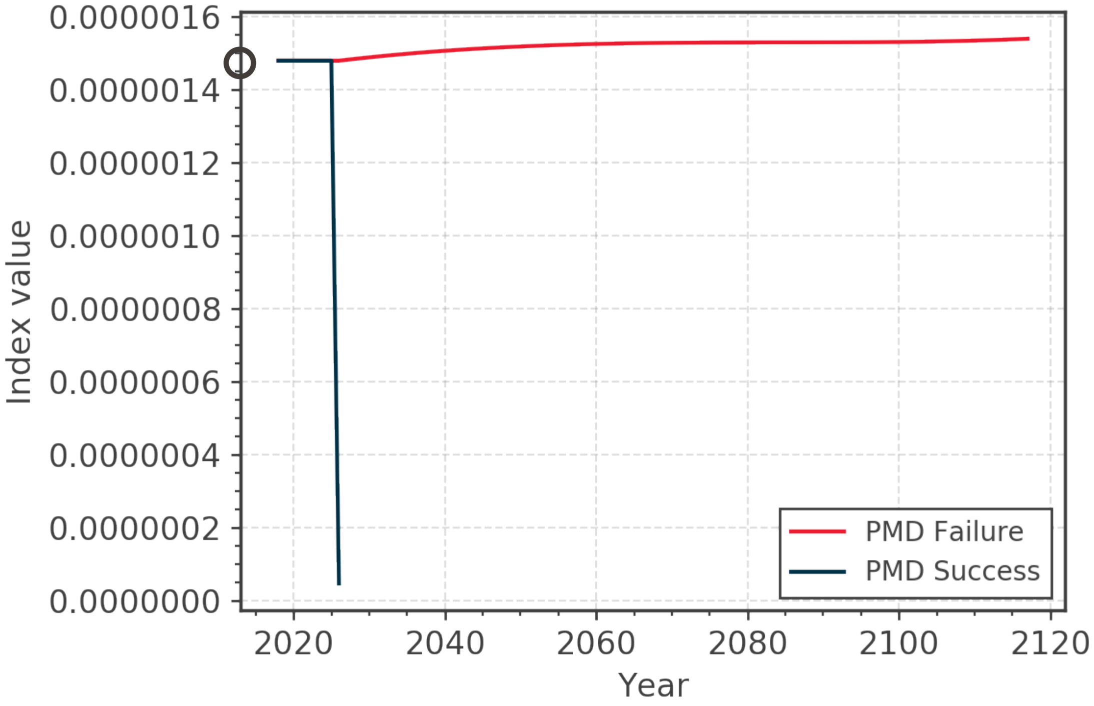
Accepted Collision Probability Level



Test case used: 0.5m radius spacecraft operating at a near circular, near sun-synchronous, 400km altitude orbit

MISSION INDEX – COLLISION AVOIDANCE

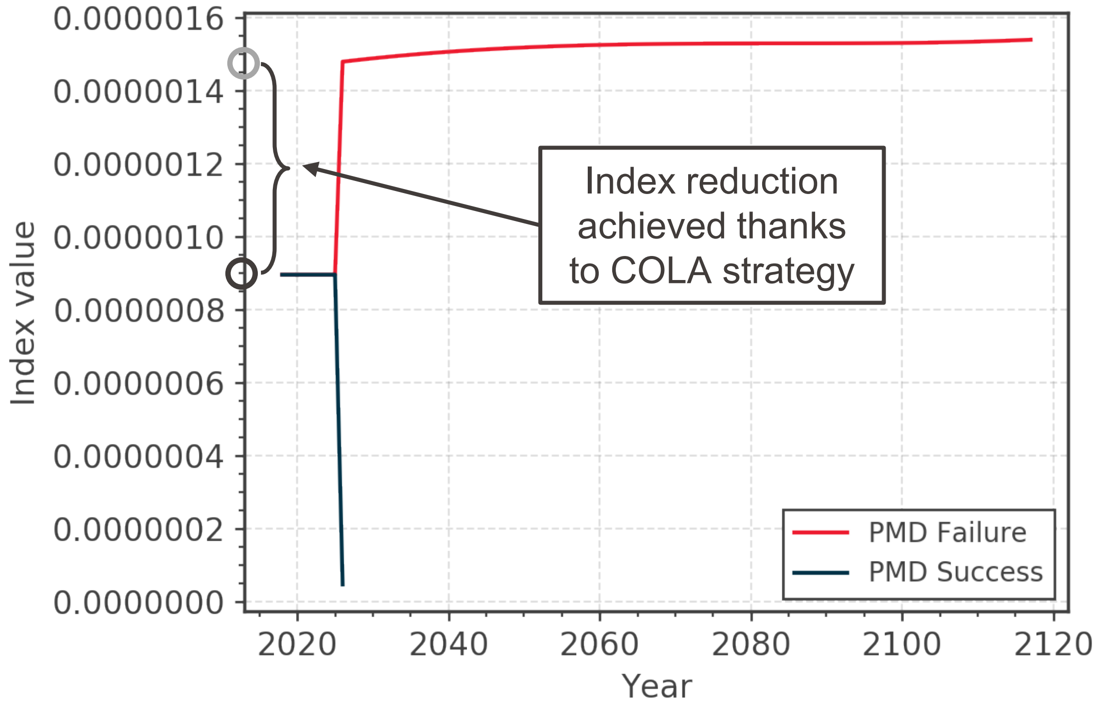
Index value over time, no collision avoidance*



*Courtesy: [debris index frontend](), ESA space debris office

MISSION INDEX – COLLISION AVOIDANCE

Index value over time, with collision avoidance*



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