Why do we talk about Space Environment Capacity?

Definition & applications to support Space Sustainability

Francesca Letizia

ESA ESOC

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Why and how do we measure sustainability in space?

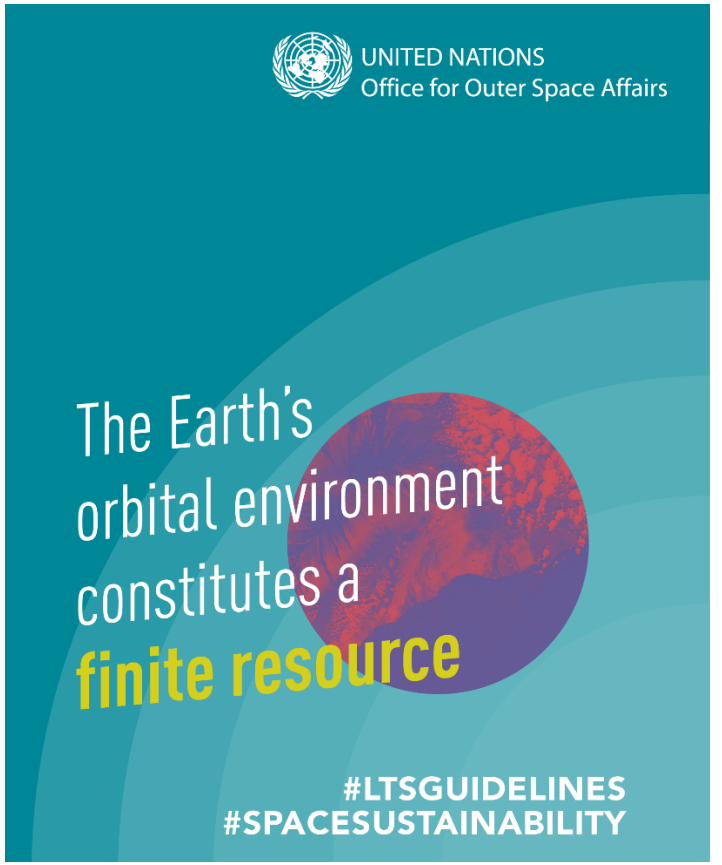
The remarkable change in the use of the LEO region has prompted several studies into the **sustainability** of space operations

Definition: What do we mean with **Space Sustainability**?

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

Compliance to **existing guidelines** often used as proxy for sustainability, but several studies advocate for more stringent guidelines for constellations.

Idea: Is it possible to define **reference targets** (~2° for climate change)? How do we carry out more **robust assessments** of the environment? Can we find an approach that helps limiting the **lag** between technological developments and regulatory tools?



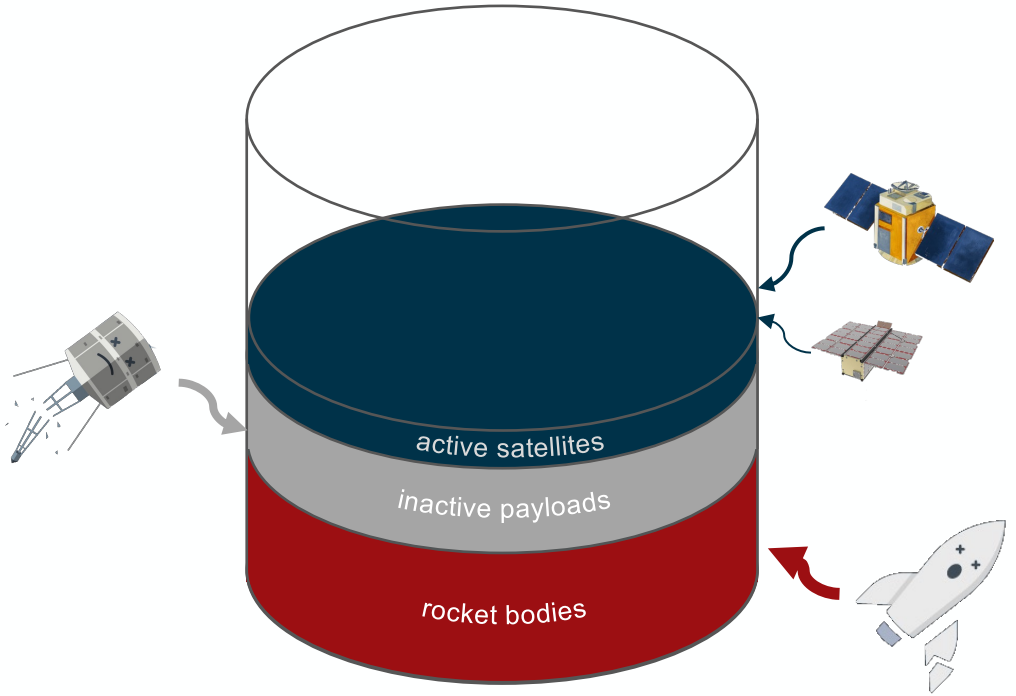
Earth’s orbits as a finite resource

Interpretation of Earth’s orbital environment as a **common-pool resource**, i.e. natural resources that are:

- **Universally accessible** and **not excludable**, i.e. the exclusion of users is difficult by nature *(Outer Space Treaty)*
- **Rival**, i.e. the use of an orbit by one user decreases resource benefits for other users *(limited number of satellites that can operate safely in the same orbit + effect of own behaviour to others)*

In economic theory, *“when individuals exploit CPRs, each is driven by an inexorable logic to withdraw more of the resource units (or invest less in the maintenance of the resource) than is Pareto optimal.”*

ESPI, Space Environment Capacity, 2022



We cannot **manage** what we cannot **measure**
We cannot measure what we cannot **define**

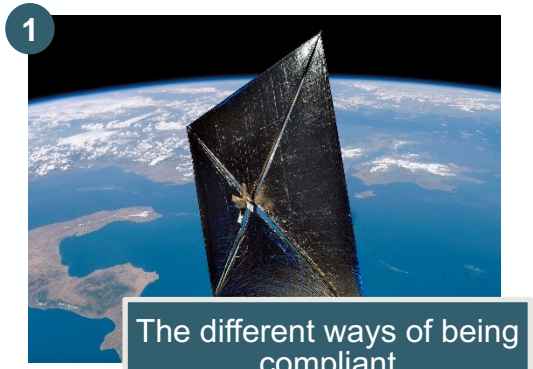
Space Environment Capacity

Drivers for our approach to Space Environment Capacity

Limits of current guidelines

Missing links with

1



The different ways of being compliant

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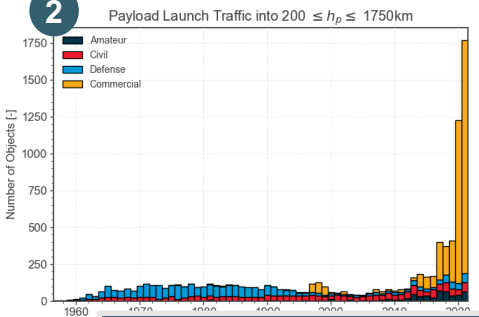


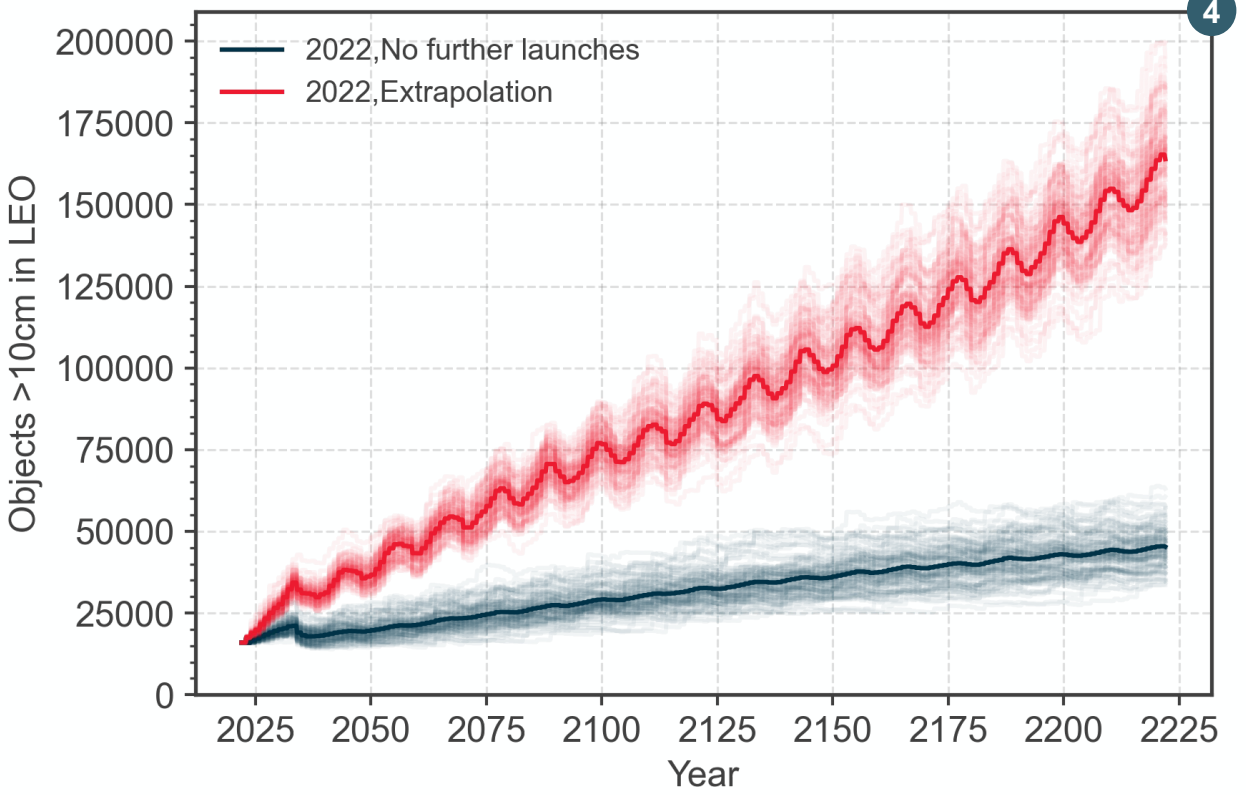
The dynamics of the space environment

3

The objective of sustainable spaceflight

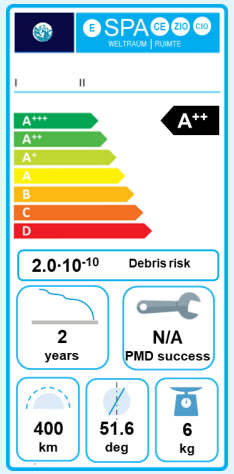
Implementation of guidelines

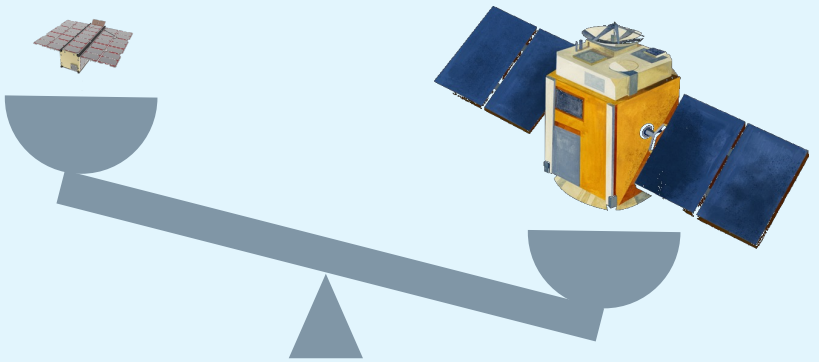
4

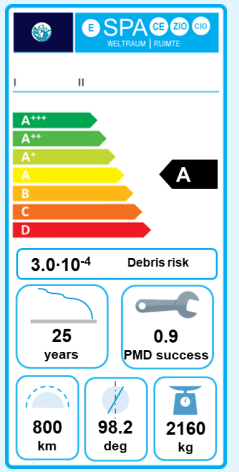


ESA's Space Environment Report, 2022

Towards space environmental impact assessments







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

Can one measure for each mission

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

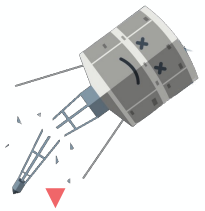
Use of a **risk metric** at single mission level

EOL: End-Of-Life

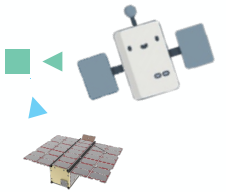
F. Letizia et al, ASR 58(7), 2016
F. Letizia & S. Lemmens, 8th ECSD, 2021

Typical values

Large satellite **stranded** in a densely populated (debris & satellites) orbit ~ 10^{-2}



Smaller platform implementing **disposal** with **high reliability** ~ 10^{-5}



Cubesat operating in a **naturally compliant** orbit ~ 10^{-8}

Mission evaluation available through ESA's space debris index frontend

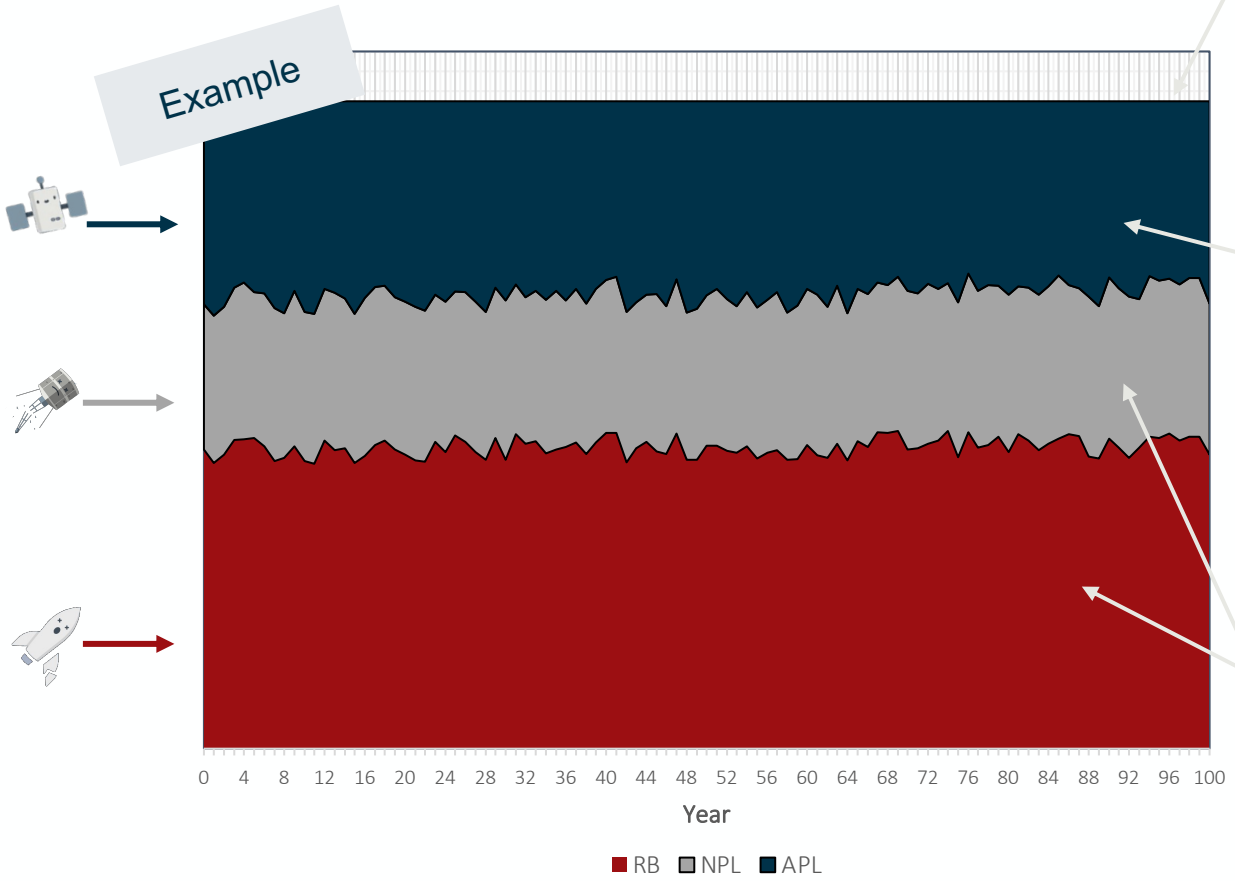
What's acceptable?

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, 1st ICSSA, 2017

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



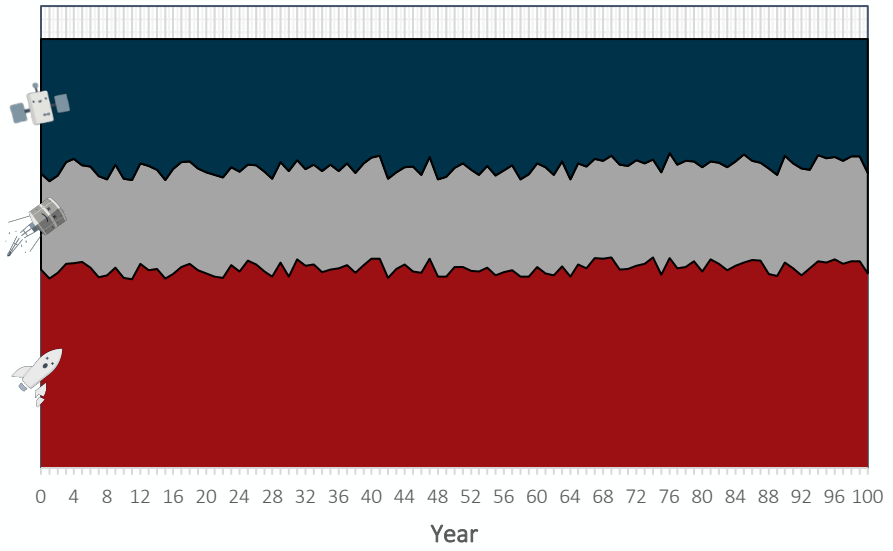
RB: Rocket Bodies | **NPL**: Inactive payloads | **APL**: Active payloads

Ceiling (total aggregated risk) — Can be defined through long-term simulations of the environment

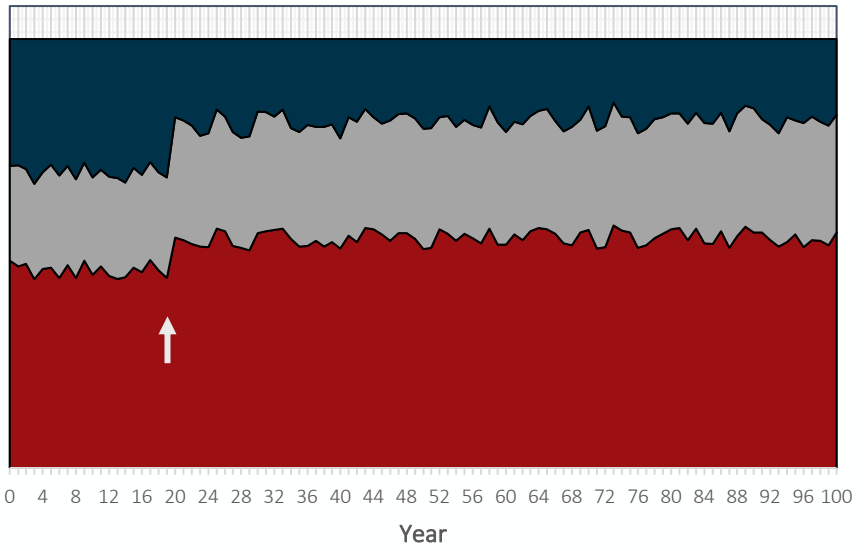
Capacity available for new&active missions — Could use allocation mechanism

Capacity consumed by non-functional objects — Changes dynamically with the evolving environment

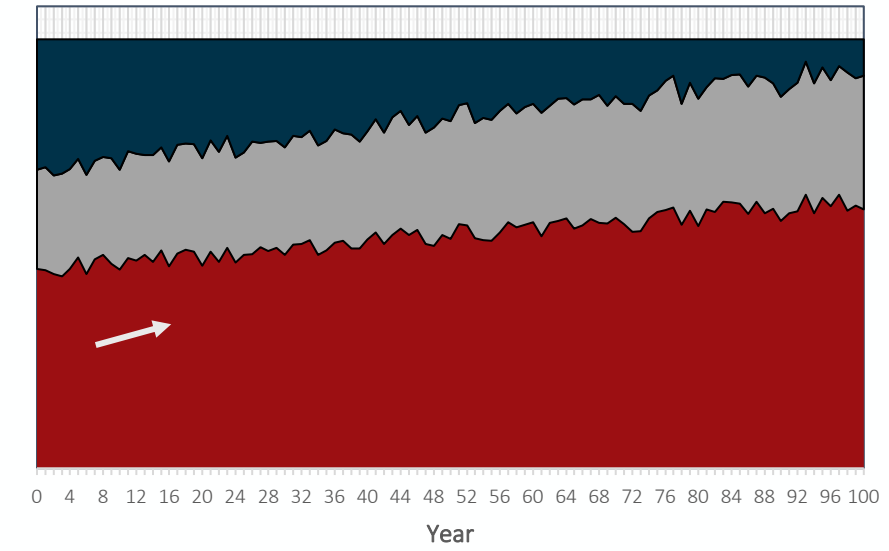
Space Environment Capacity - scenarios



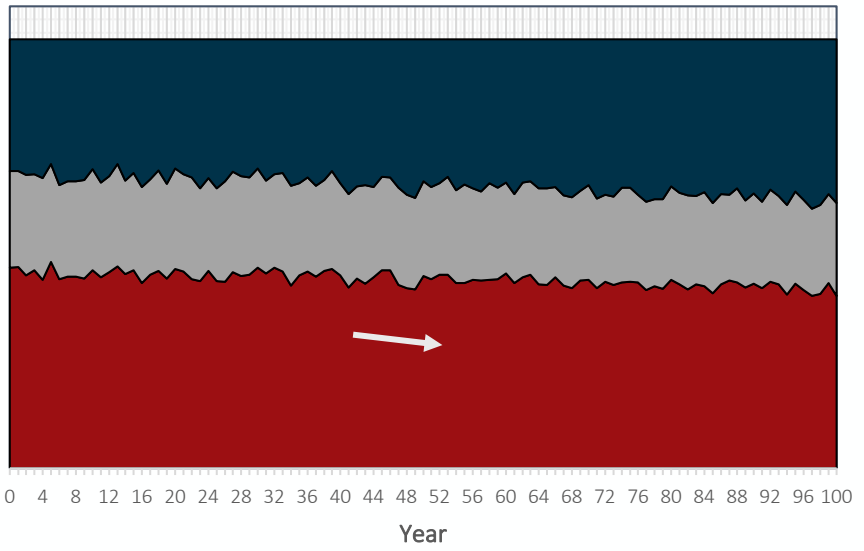
Reference



Fragmentation



Low PMD



ADR

RB: Rocket Bodies | **NPL**: Inactive payloads | **APL**: Active payloads | **PMD**: Post-Mission Disposal | **ADR**: Active Debris Removal

Long-term simulations of the environment

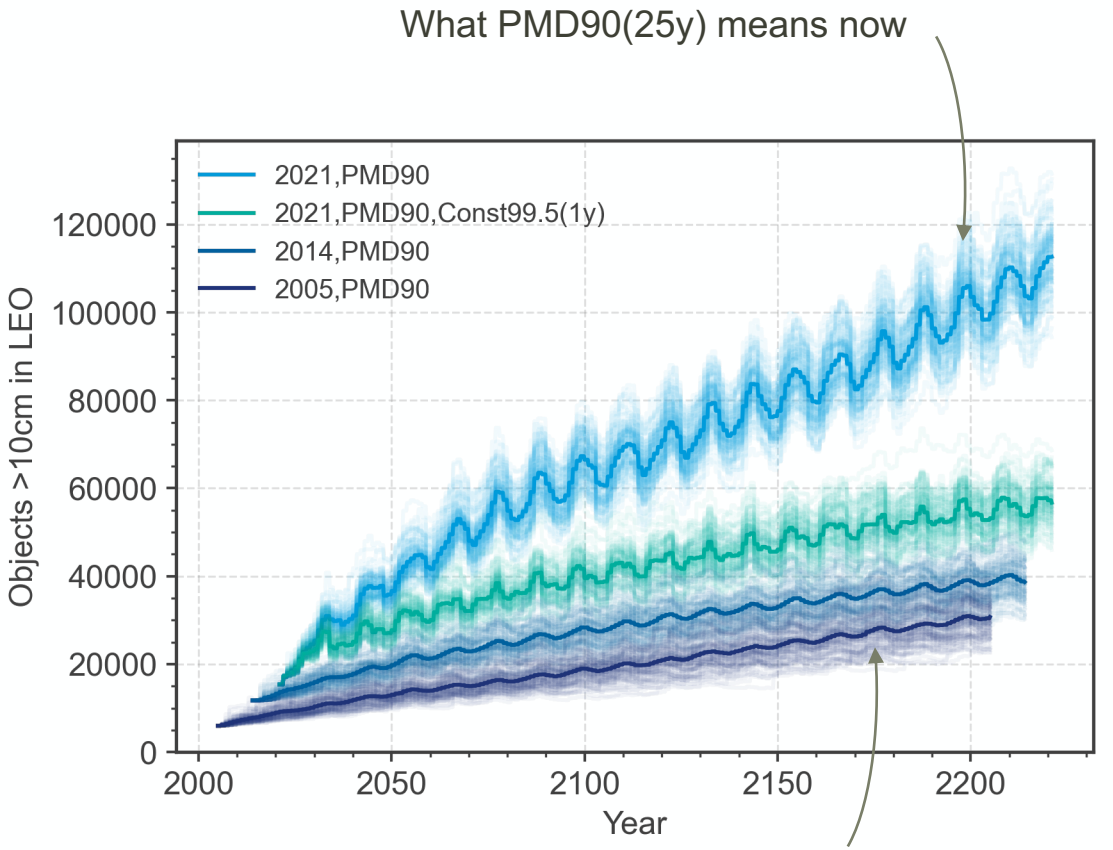
Long-term (200 years) simulations on the environment to quantify the impact of parameters such as

- Launch traffic
- Explosion rate
- Disposal approach

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

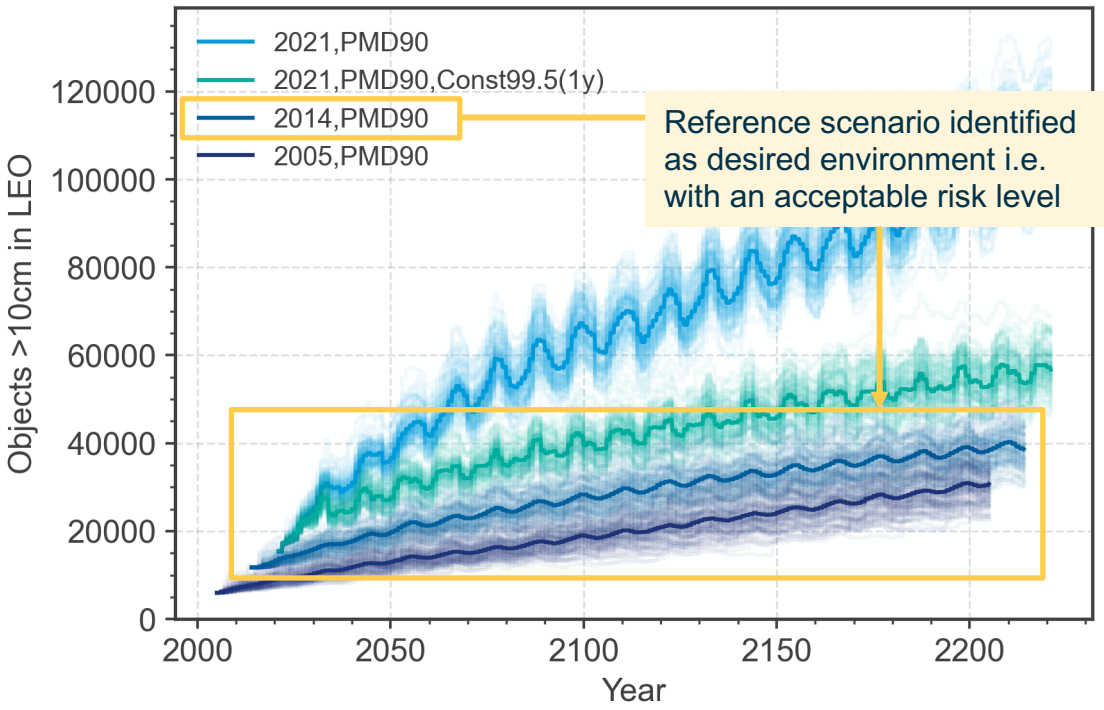
What does this rule mean now for the environment?

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%



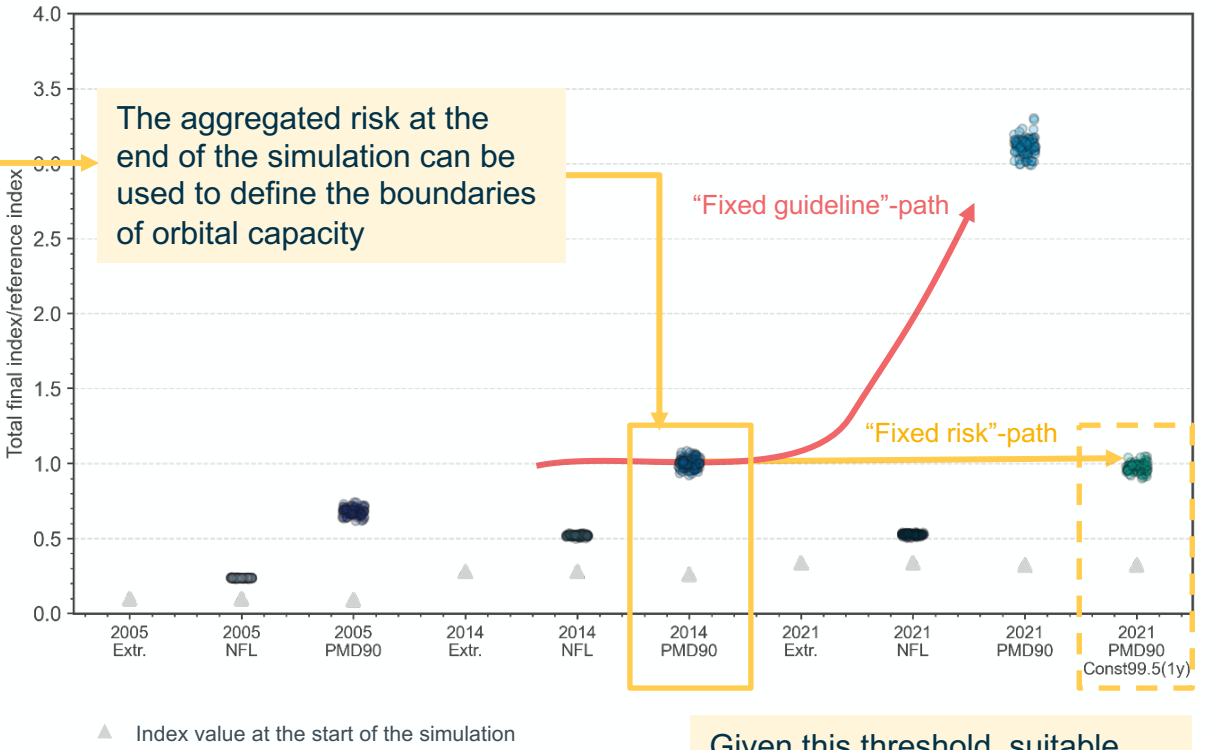
Derivation of a threshold-based model

Number of objects



Reference scenario identified as desired environment i.e. with an acceptable risk level

Aggregated risk metric



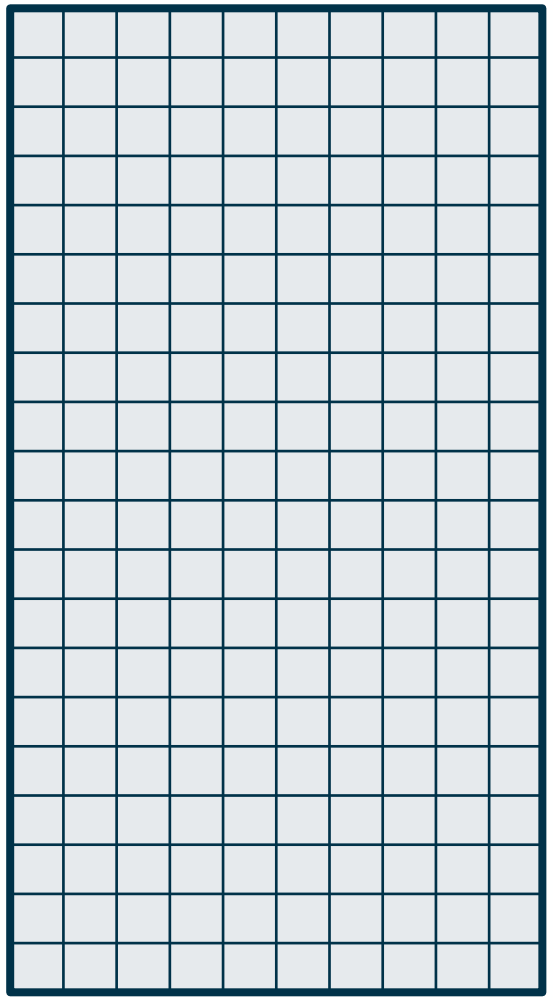
The aggregated risk at the end of the simulation can be used to define the boundaries of orbital capacity

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

F. Letizia et al, ASR, 2022, 10.1016/j.asr.2022.06.010

Typical values and acceptable ones

Max risk to be added in one year



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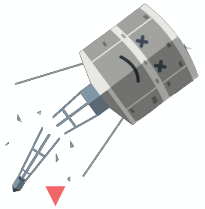
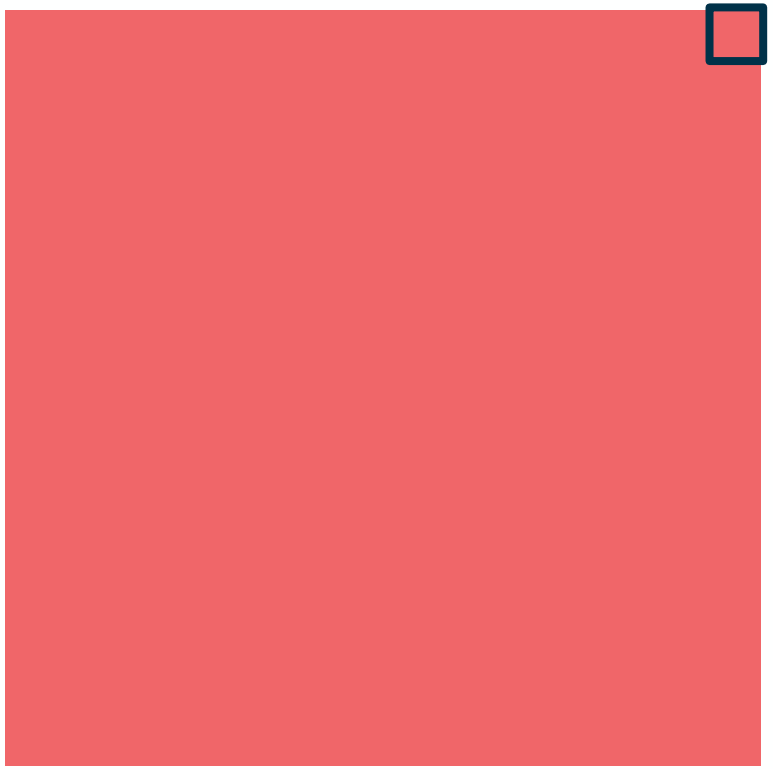


Max risk per mission (considering an equal allocation among operators) ~ $5 \cdot 10^{-5}$

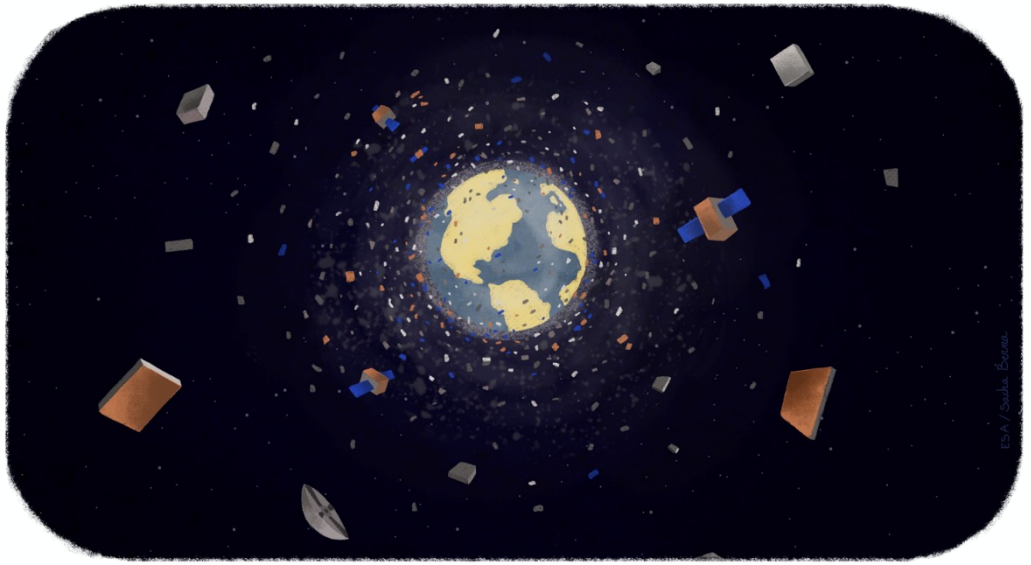


Smaller platform implementing **disposal** with **high reliability** ~ 10^{-5}

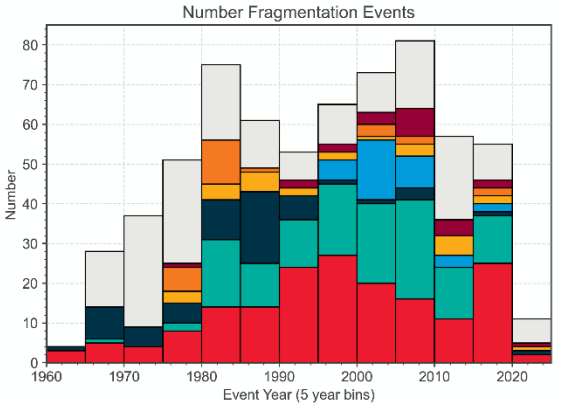
Unused allocation could then be traded among operators, similarly to what happens with CO_2 emissions

ESPI, Space Environment Capacity, 2022

Framework for capacity management



In practice, guidelines even if existing show still a insufficient level of **adoption**



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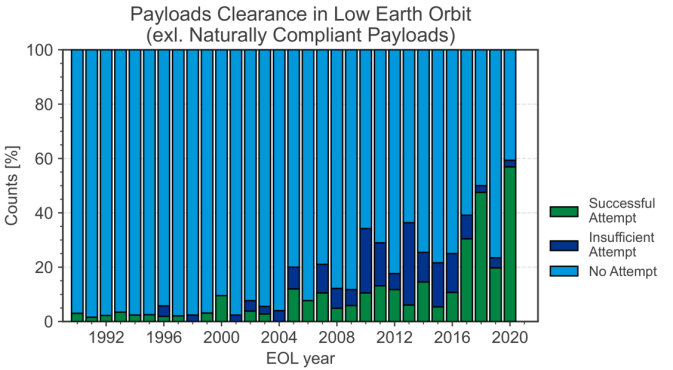


In theory, space debris environment as a dynamical system where equilibrium & stability can be **mathematically** defined (e.g. no growth)

Governance appears to be still needed, so a more plausible scenario is the one where the **community** agrees on a **desired environment** and its related risk level considered to be **acceptable**.

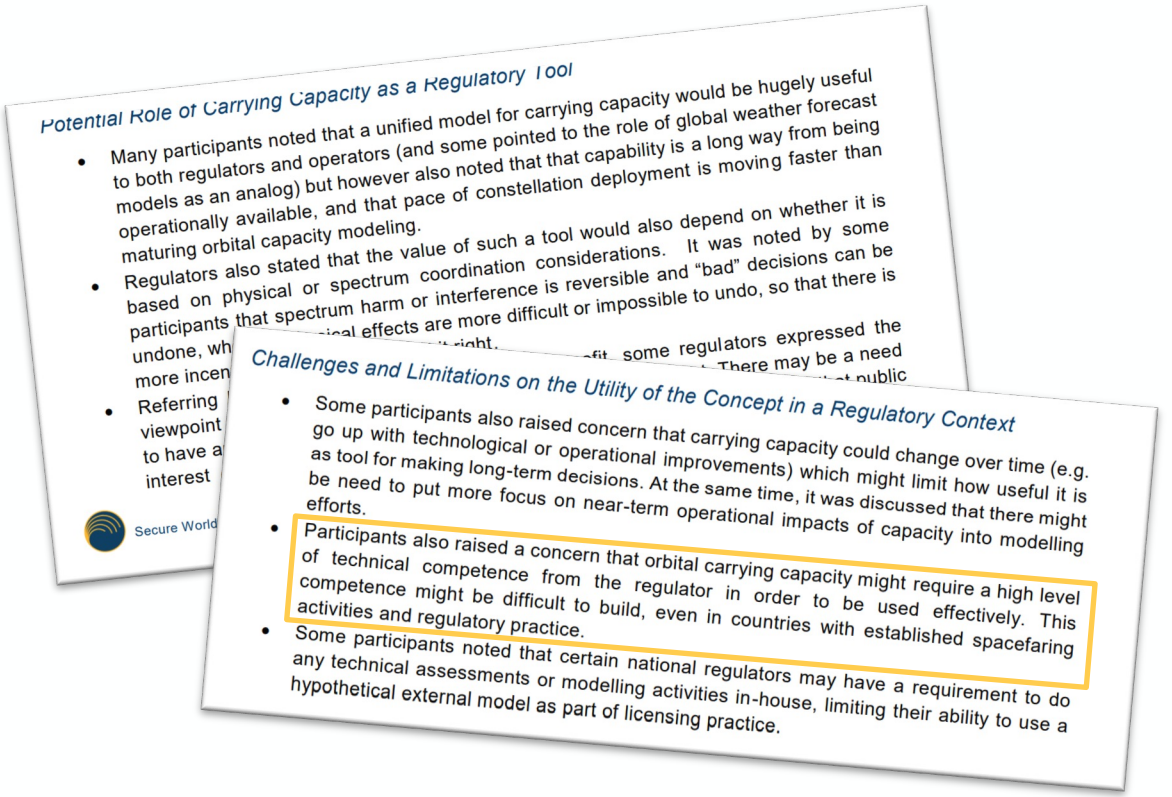
Our approach as a tool to track the desired trend

A technical concept with policy implications

ESPI - Limited Orbital Environments: Capacity Approaches to Outer Space (April 2022)

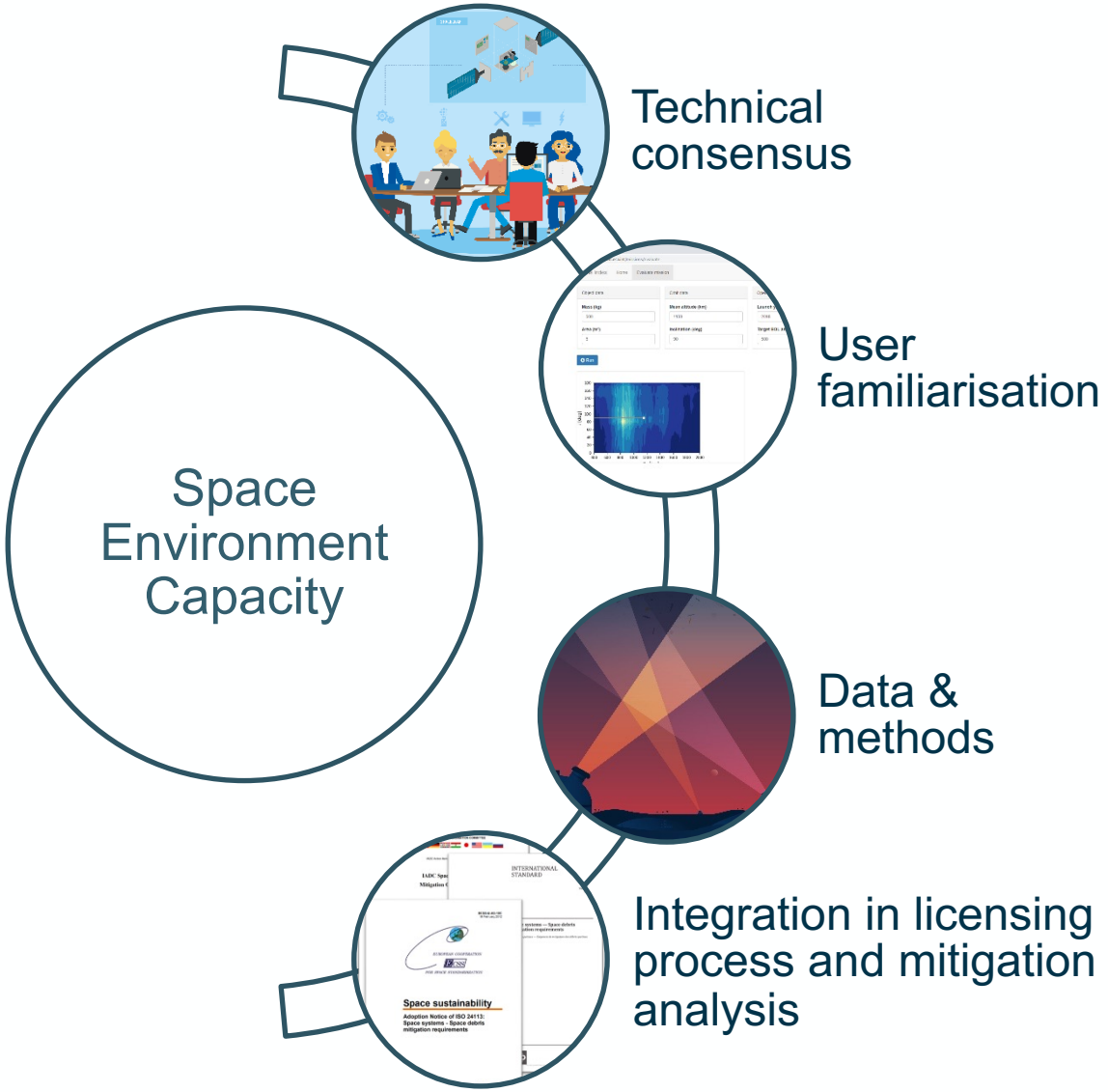
Full report

SWF - Regulator Dialogue on Approaches to Licensing of Large Constellations (June 2022)



Full report

Steps for maturation



Engagement in different international fora; application to the methodology to own missions, making results available

Deployment of ESA's frontend to all users and related support

Development of a software infrastructure through ESA's Space Safety Programme

Application to CDF studies, long-term simulation campaigns, etc.

Conclusions

Wider recognition of the **space environment** as a **limited shared resource** and interest in **metric** to quantify its **capacity**

ESA's approach based on the **aggregation** of a **risk metric** computed for **individual missions**. Ability to capture the **dynamic evolution** of the environment in terms of (changing) debris density, quantity of active satellites, adopted mitigation measures, etc. Link to **long-term simulations** of the environment to define the **boundaries** of the environment capacity and evaluate current/future trends

What's an **acceptable** environment still defined by the **community** – proposed methodology useful to track a desired trend

Several steps needed for maturation: **engagement** with **technical** and **policy** experts, development of suitable **tools** and identification of relevant **applications**

Francesca Letizia
ESA/ESOC Space Debris Office (OPS-SD)
Robert-Bosch-Str. 5, 64293 Darmstadt, Germany
T +496151902079
francesca.letizia@esa.int
http://www.esa.int/debris