ESTIMATING THE POTENTIAL IMPACT OF SPSs ON SPACE ENVIRONMENT STABILITY VIA STOCHASTIC NETWORK ANALYSIS

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University of Strathclyde Glasgow

AEROSPACE CENTRE of EXCELLENCE

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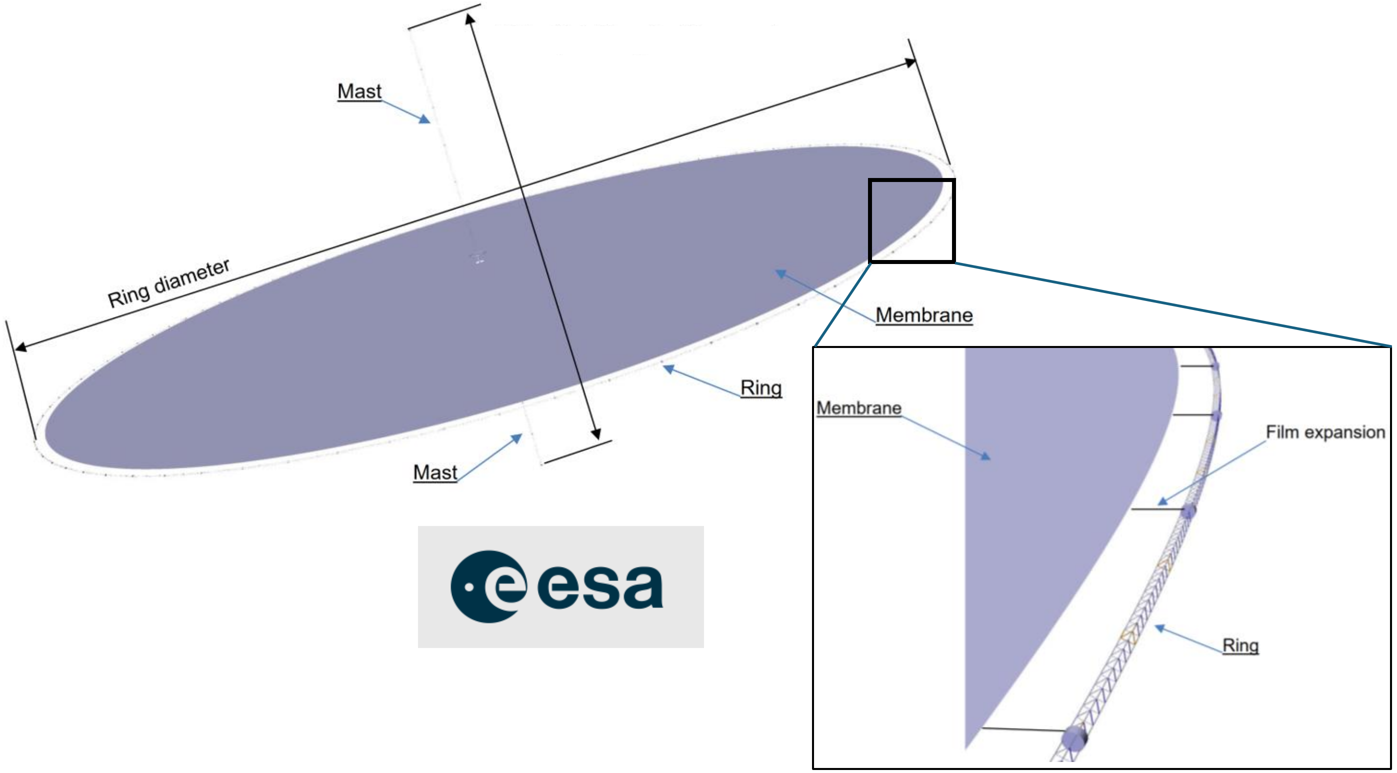
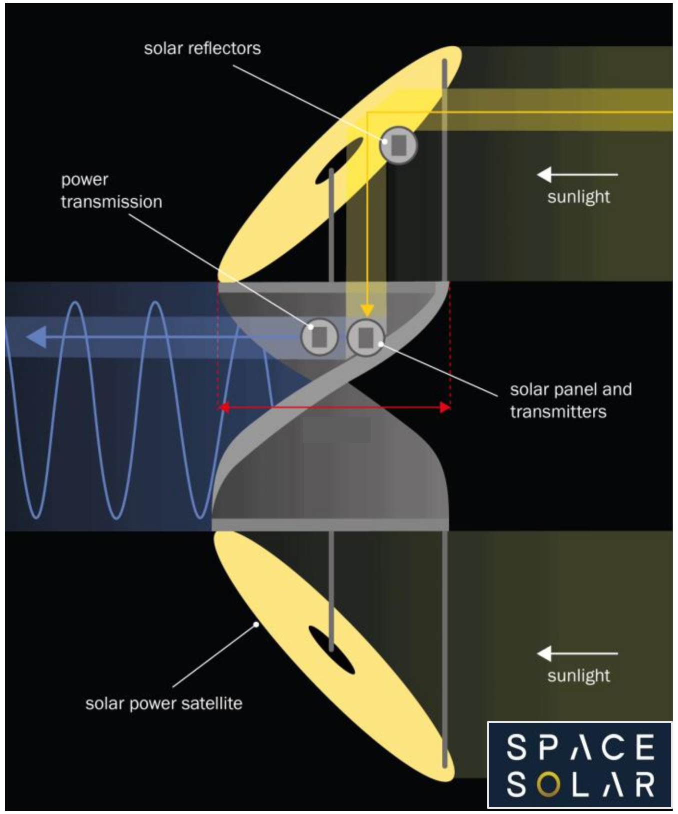
INTRODUCTION



Credits: ESA



CASSIOPeiA concept. Credits: Space Solar

Sun Reflector

Operative orbit: LEO SSO 890 km

Constellation

Components: membrane, central body, ring

CASSIOPeiA

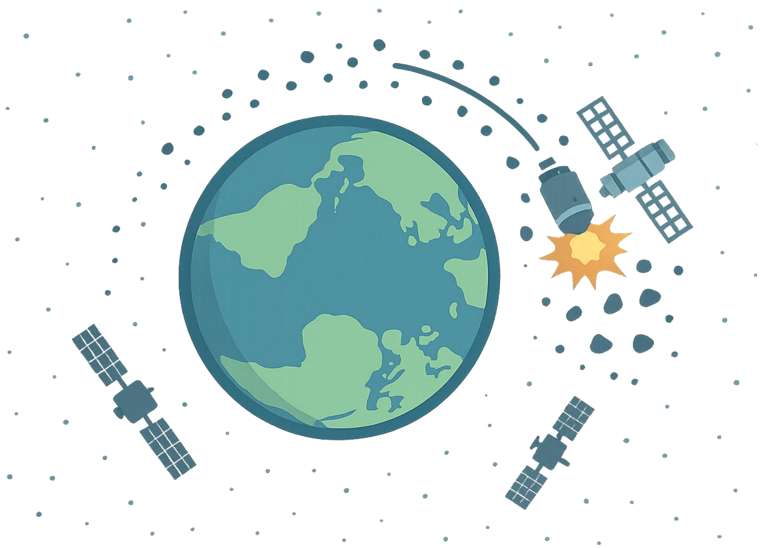
Operative orbit: GEO

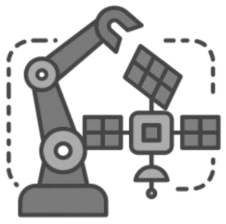
Single satellite

Components: helix, reflectors

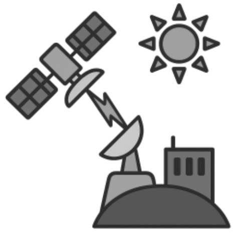
LITERATURE GAP

SPSs
(Solar Power Satellites)
main studies

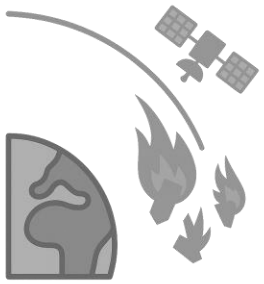




Assembly



Power collection / transfer



Re-entry

Mission analysis

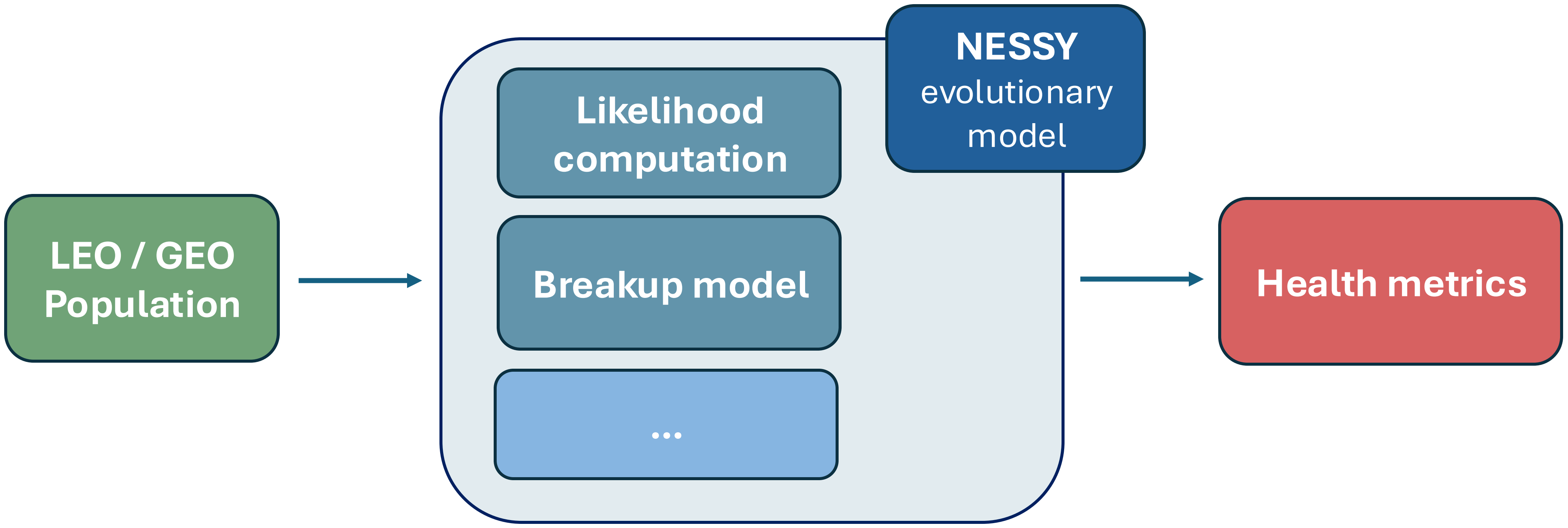
MAIN GOALS

Develop a framework to simulate the evolution of the space environment with SPSs, for space sustainability:

- Better quantifying the risk (*encountered & induced)* for an SPS mission
- Developing a custom breakup model
- Defining some metrics to assess the environmental impact of an SPS

METHODS

Framework for space missions' risk and impact estimate.

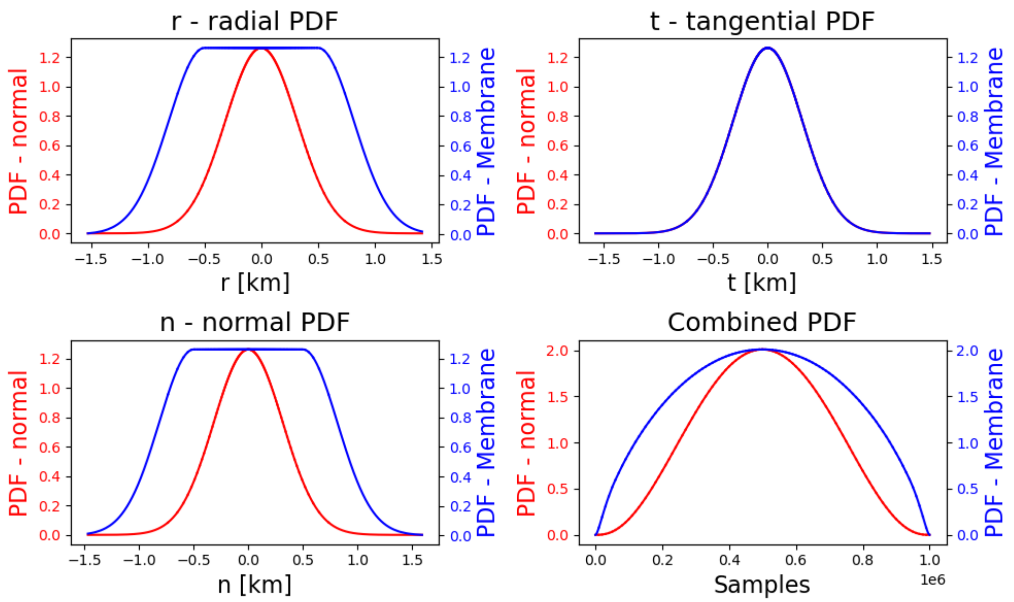


METHODS

Collision Likelihood

Definition of adequate PDF (Probability Density Functions) to better account for SPSs' geometry position uncertainty.

Defined against a snapshot of the space environment.

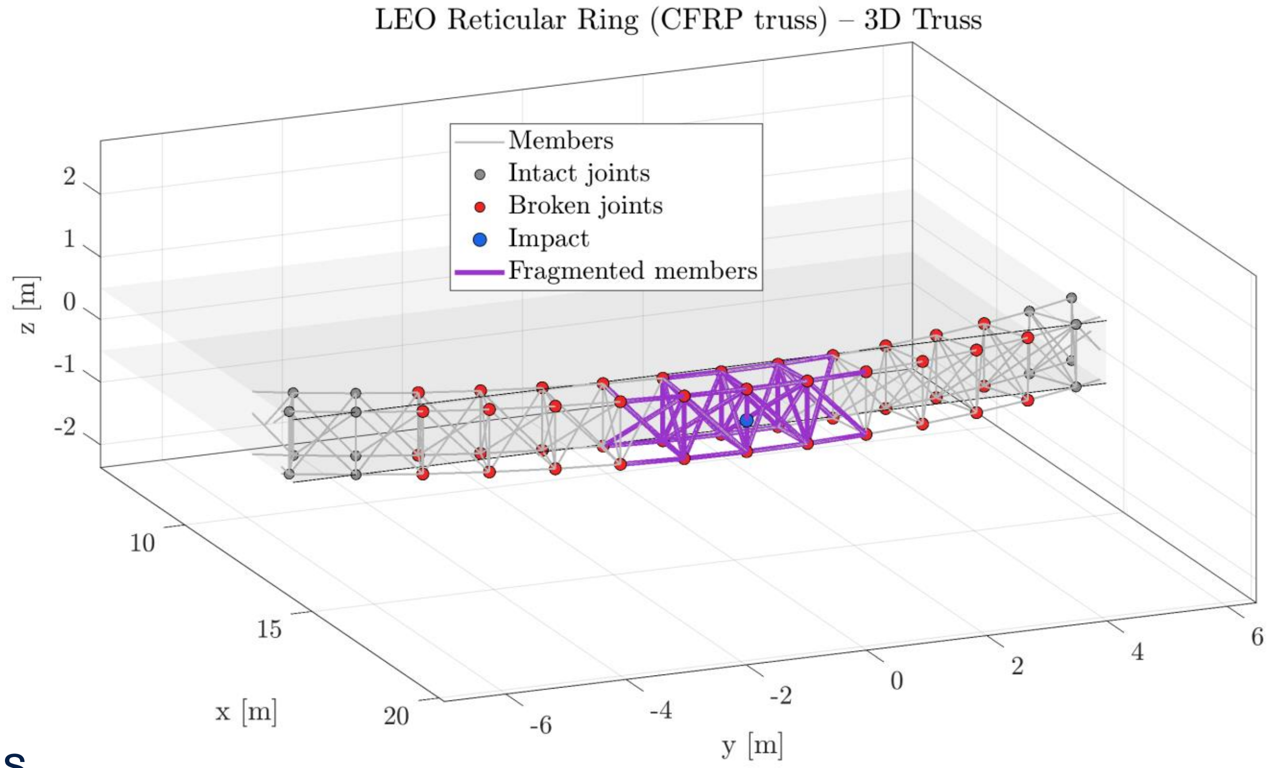


*tailored for large space structures

METHODS

Breakup model

Definition of a custom breakup model to better account for fragmentations in case of large structures.

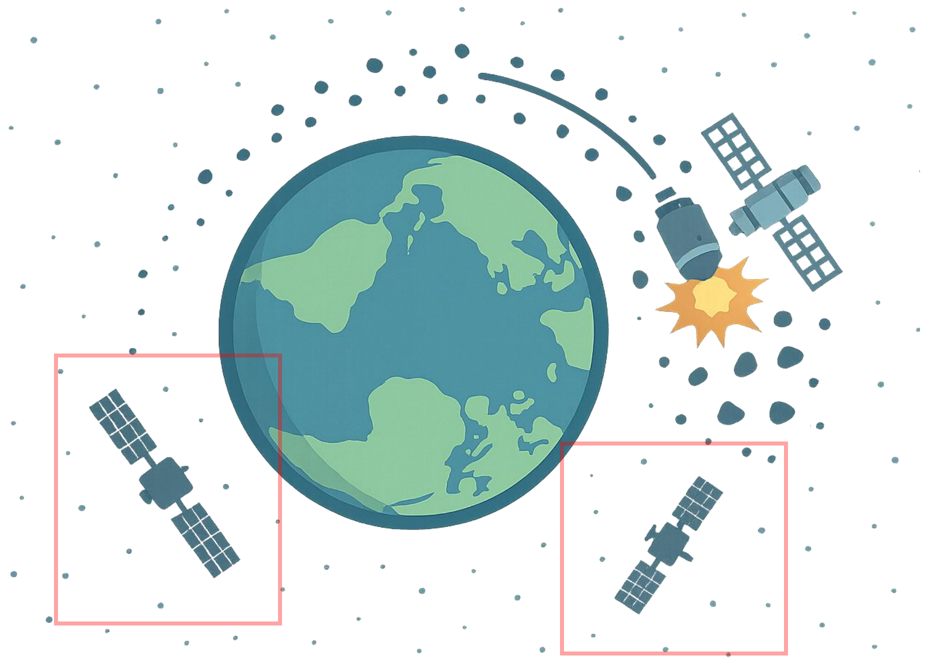


*tailored for large space structures

METHODS

Health metrics

Definition of a series of metrics capable of quantifying the consequence of fragmentation events at certain orbital shells. These allow measuring both fragments' spreading and the new risk for other missions.



This method is applicable to any space mission in LEO / GEO orbit

METHODS

NESSY evolutionary model for LEO and GEO regimes

Y. Wang, P. De Marchi, and M. Vasile, "A Stochastic Dynamic Network Model of the Space Environment", Advances in Space Research, Sept. 2025

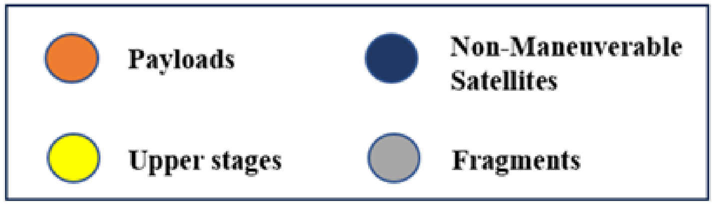
Payloads: CAM + PMD

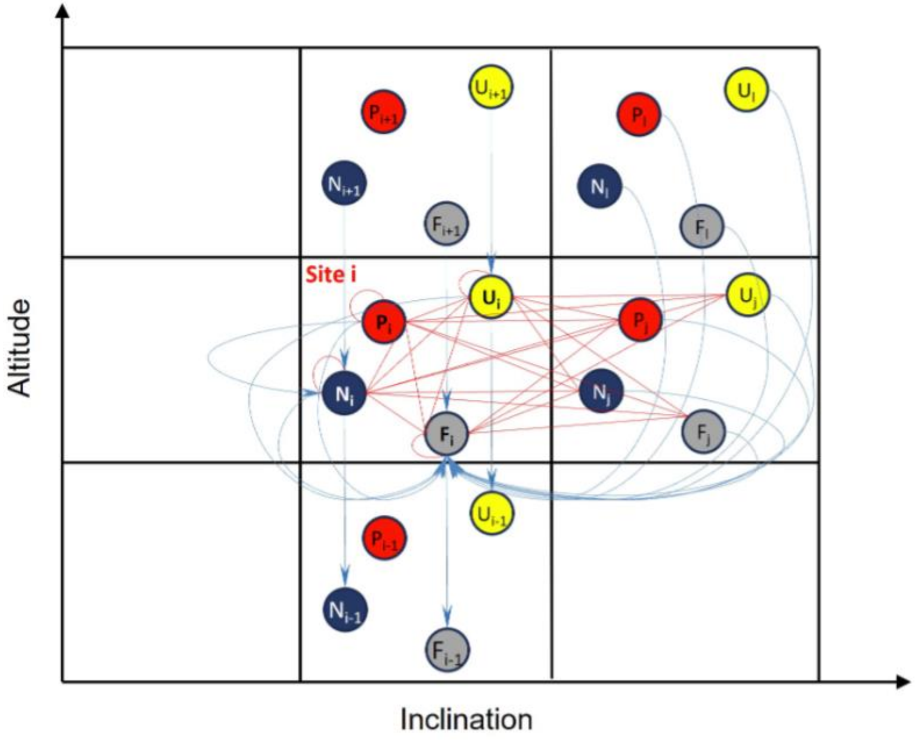
Non-manoeuvrable objects

Upper-stages

Fragments: small ($1mm < d$) & major ($d > 10cm$)

SPS: SK+ CAM





NESSY network model representation.

METHODS

NESSY network analysis

Framework of a series of metrics for the analysis / forecast of the effects of the critical events in space along time

Spatial connectivity: capability of a collision event can spread inside the network

$$\alpha^n = \frac{1}{n}\sum_{i}^{n}\left(\frac{\sum_j^n \rho_{ij}^*}{n}\right)$$

Local connectivity: capability of an event related to a single site can spread through the neighbourhoods

$$R_i = R_{P_i} + R_{U_i} + R_{F_i} + R_{N_i}$$

MAIN RESULTS

NESSY evolution analysis for LEO and GEO regimes

LEO) Different SSOs 3 reflectors

h_{sso}= 567, 894, 1262 km

Station keeping: 7 years
Decay @ max drag

Validation

- nominal LEO evolution: validated with MOCAT MIT (1)
- nominal GEO evolution: compared with Ref. 2

Major objects population
Satcat, ESA DISCOS (2023)

1. D. Jang, D. Gusmini, P. M. Siew, A. D'Ambrosio, S. Servadio, P. Machuca, and R. Linares, "*Monte Carlo Methods to Model the Evolution of the Low Earth Orbit Population*", American Astronautical Society, Jan. 2023
2. D. L. Oltrogge, S. Alfano, C. Law, A. Cacioni, and T. S. Kelso, "*A comprehensive assessment of collision likelihood in Geosynchronous Earth Orbit*", Acta Astronautica, Vol. 147, 2018
3. P. De Marchi, Y. Wang, M. Vasile, "Space Environment Impact of Solar Power Satellites", Space Flight Mechanics Meeting, Hawaii, January 2025

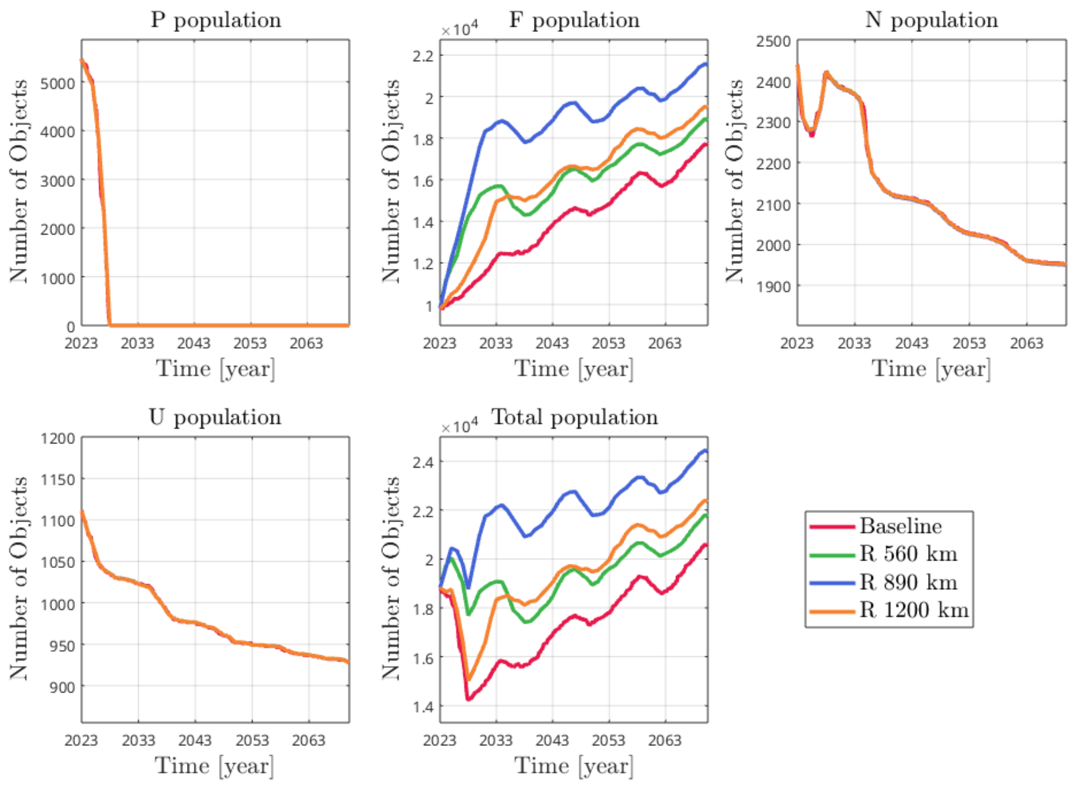
MAIN RESULTS

LEO regime: altitude sensitivity analysis (SPS, no collision avoidance)

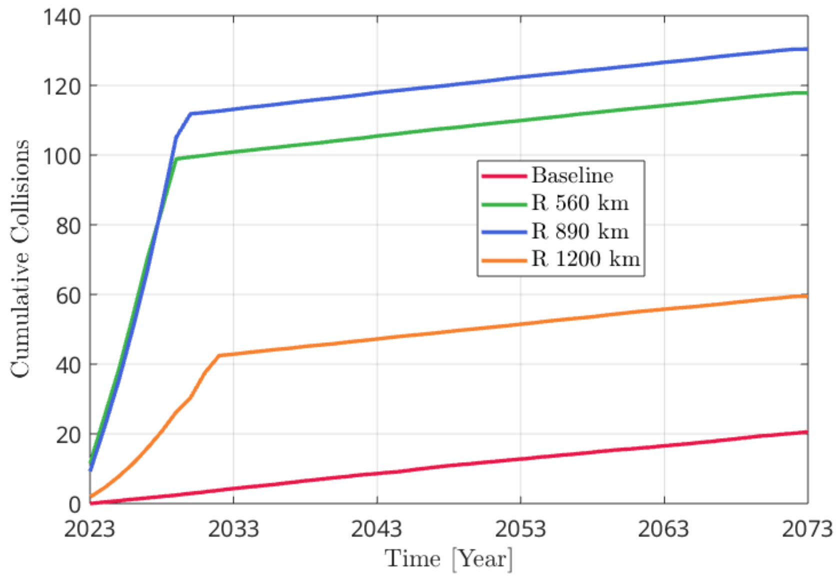
Duration: 50 years

$h = [200, 2200]$ km, Δh = 50 km

$i = [0^\circ, 180^\circ]$, Δi = 60°



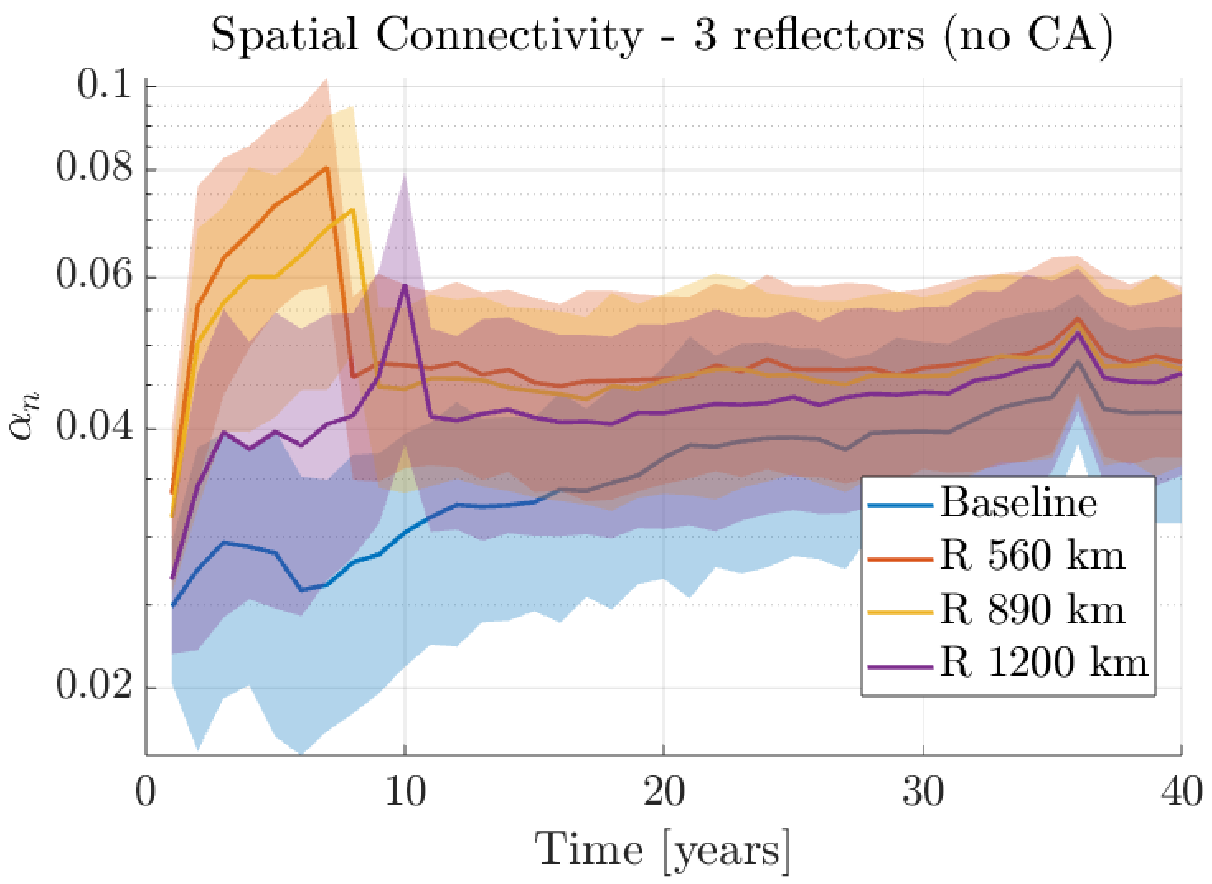
NESSY LEO environment average evolution for the altitude sensitivity analysis along 50 years (d>10*cm*).



Average cumulated collisions along 50 years (d>10*cm*).

MAIN RESULTS

NESSY network analysis



Spatial connectivity α^n

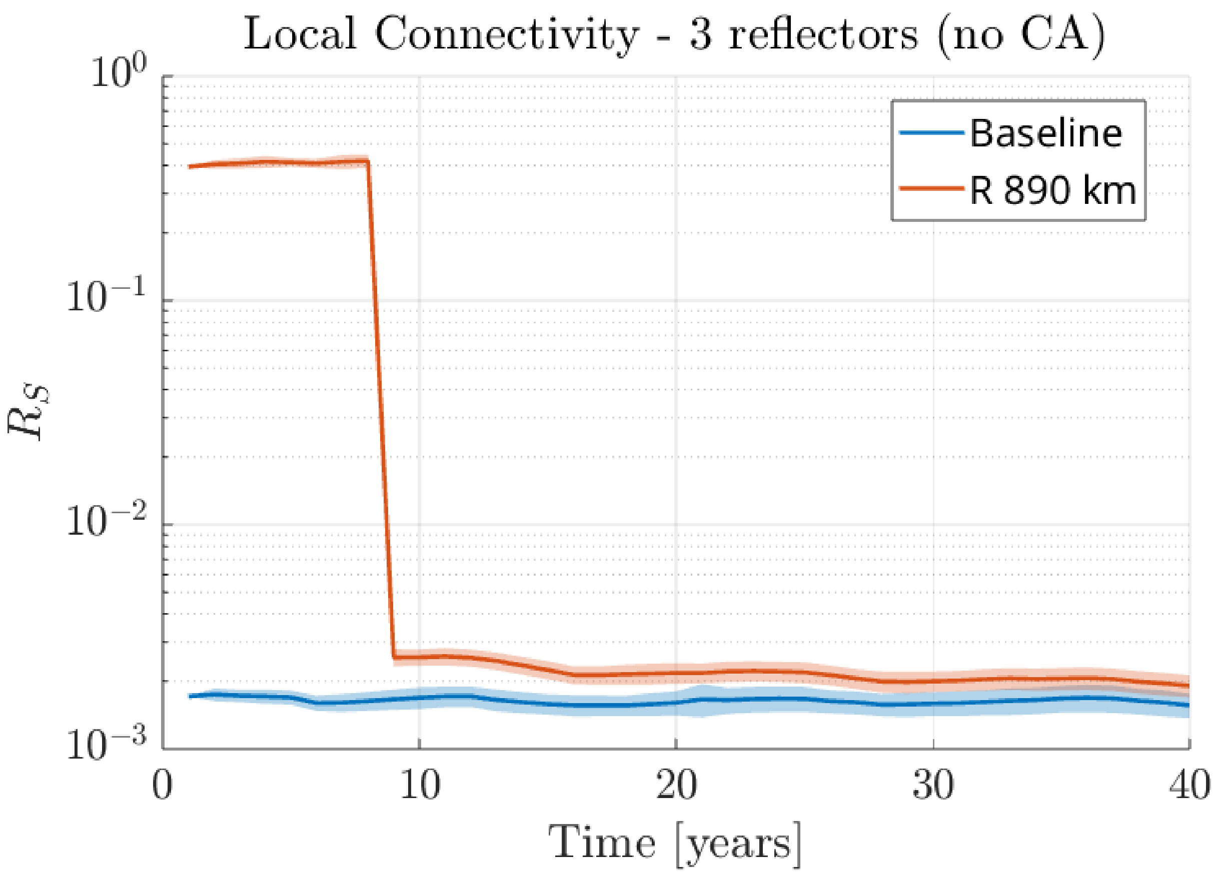
Settings:
- Objects d > 10*cm*
- No collision avoidance

This indicator provides a global idea of the connectivity of the network in time.

Introducing the SPS increases the global connectivity of the environment. The gap between the two scenarios decreases in time because of the decrease of the average objects' dimension, but always with a general increasing trend.

MAIN RESULTS

NESSY network analysis



Local connectivity R_i

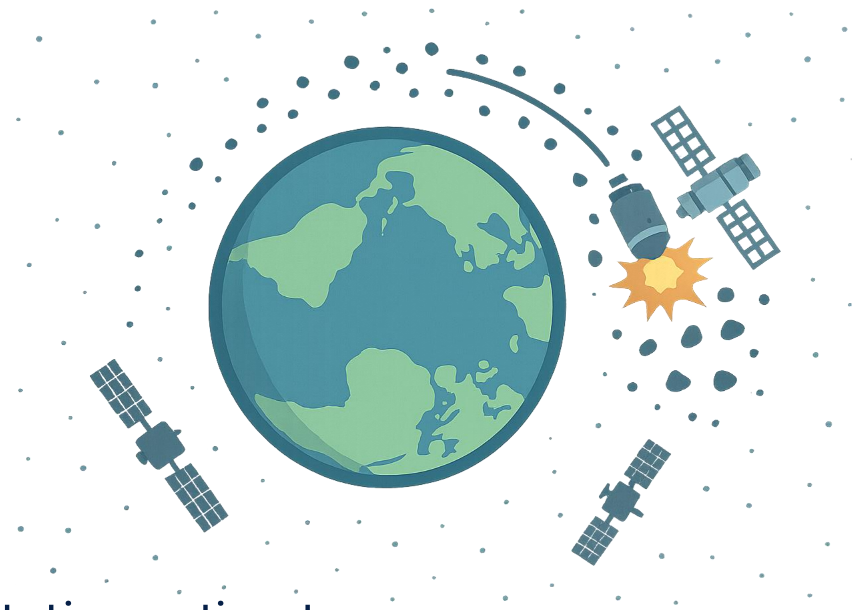
Settings:

- Objects d > 10*cm*
- No collision avoidance

This indicator provides the information of the connectivity of the local site considered (the one with the reflectors).

The huge increase in the reflector-scenario connectivity coincide with the period in which the SPS performs orbit maintenance and remains in the same node of the network. SPSs decay after 7 years making the local connectivity dropping but remaining higher than the baseline case without reflector.

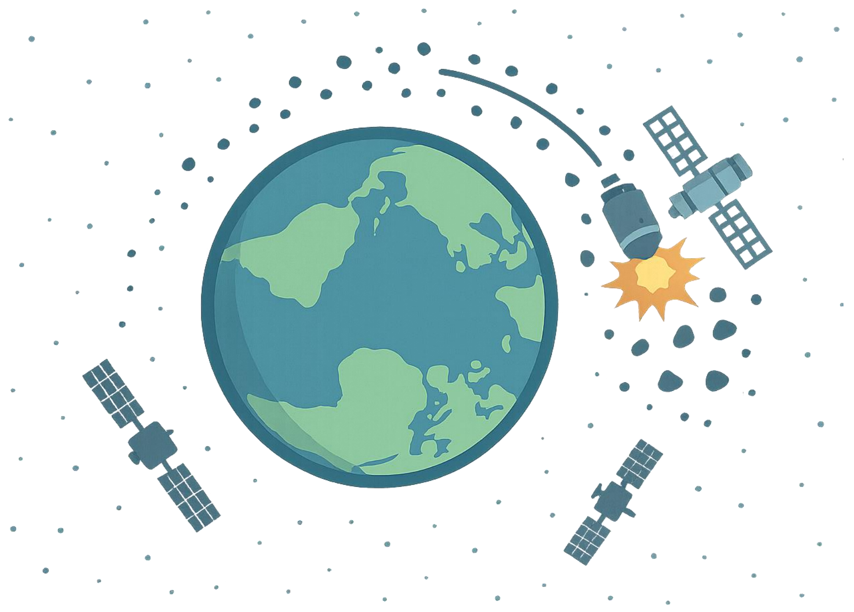
CONCLUSIONS



The current pipeline allows:

- an adequate modelling of SPS collision risk and fragmentation estimate
- to assess in detail the consequences of impacts on all the other orbital regions
- to assist operators in the orbit selection for a certain mission

FUTURE WORKS



- Further analysis of the breakup model improvements
- “Special local connectivity” analysis (SPS follow-up)
- Analyse the impact of small fragments on connectivity
- Include highly eccentric orbit for SPSs & cislunar orbits analyses

THANK YOU FOR YOUR ATTENTION

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