Forecasting Re-entry Traffic and Single Events

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Understanding the Atmospheric Effects of Spacecraft Re-entry
ESA ESTEC
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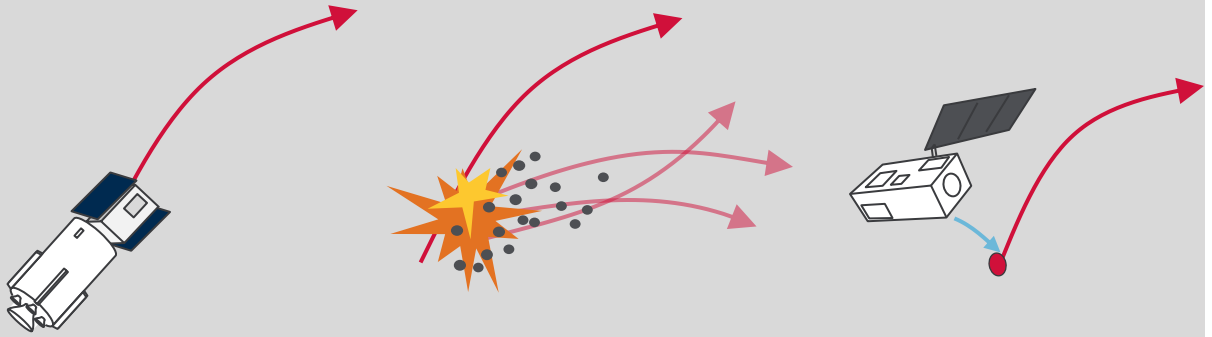
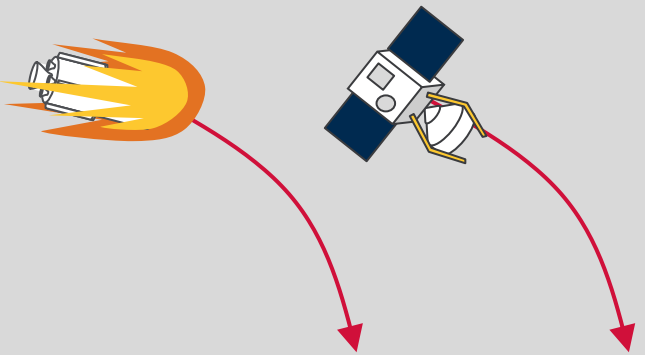
Agenda

- Space Traffic Contributions
- Current Space Environment
- Model of Space Environment
- Debris Environment Long-Term Analysis (DELTA)
- Single events
- Conclusions

Space Traffic contributions



Launches: rocket bodies, payloads, mission related objects
Fragmentations: explosions, collisions



Natural decay: drag, luni-solar, photon pressure
Active removal: de-orbit, non-propulsive

Current Space Debris Environment – Launch traffic

Launch traffic:

The major changes happened in LEO.

From 2010 on, the deployment of large constellations marked a significant shift towards commercial operators. The result is that the current launch traffic is around 10 times the level observed in 2000 [1].

Increment on spacecraft and orbital stage re-entries.

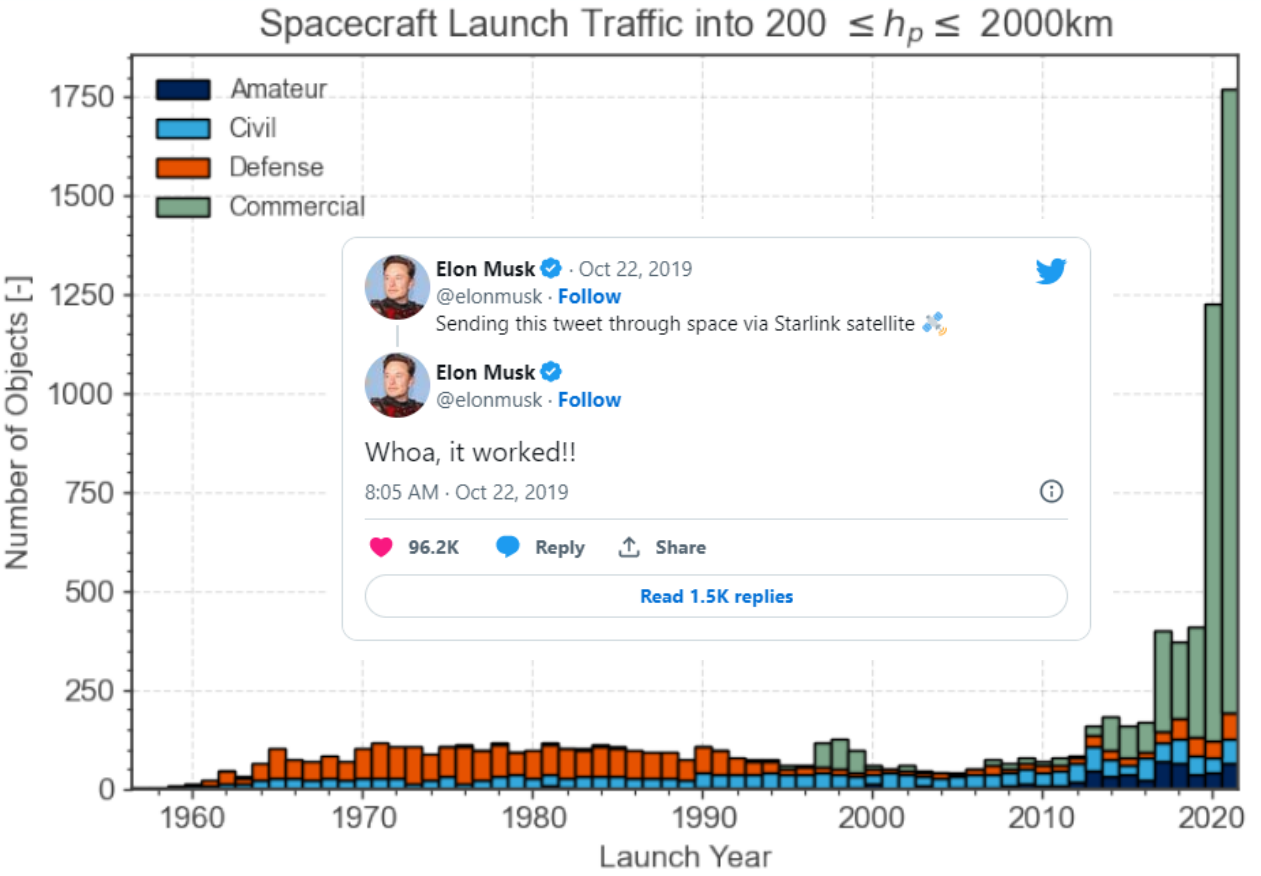
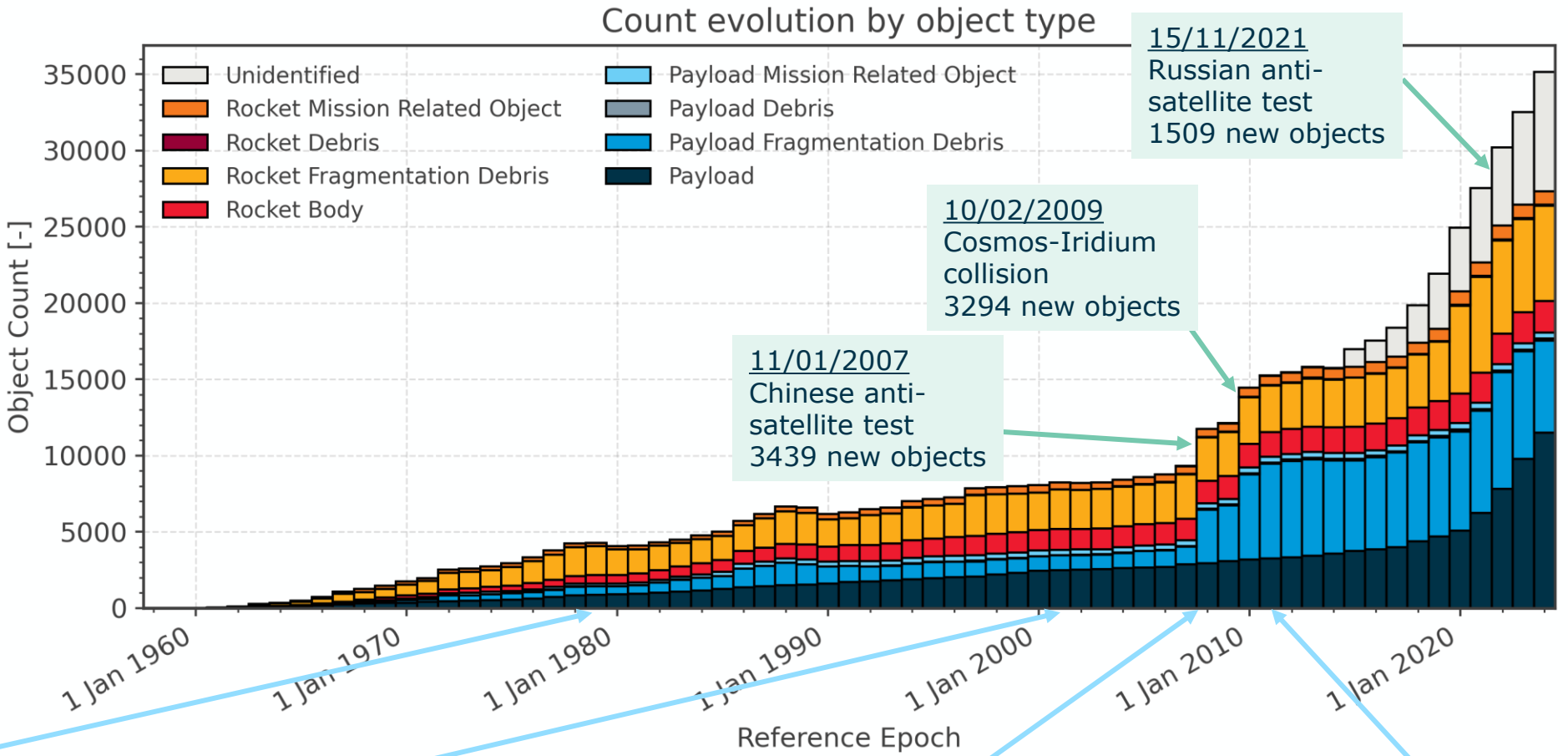


Figure 3 Launch traffic into LEO by mission class.

[1] IADC-23-01_IADC_Report_on_the_Status_of_the_Space_Debris_Environment, https://www.iadc-home.org/documents_public

Current Space Debris Environment – Objects



Kessler's Syndrome formulated

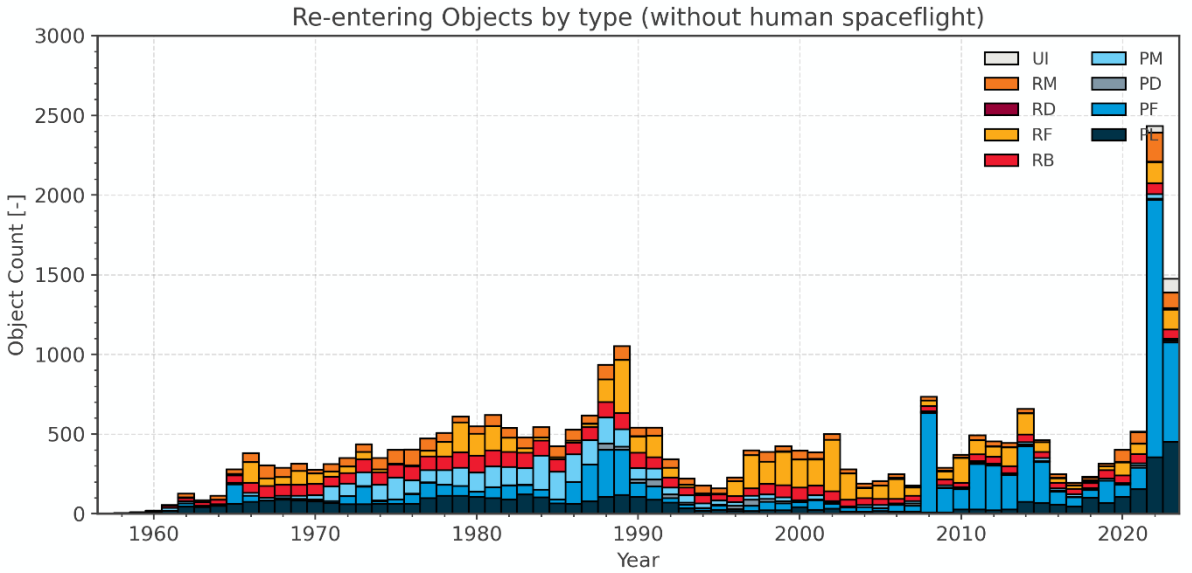
U.S. Government established guidelines stating 1e-4 threshold for on-ground casualties

ESA –SDM policy enforces the 1.e-4 threshold for casualty risk

NASA-STD enforces the 1.e-4 threshold for casualty risk

Current Space Debris Environment – Re-entries

Re-entries (excluding space objects related to human space flight)[1]:



Lottie Williams holds a piece of a Delta II rocket that fell from the sky and hit her in the back while she was walking on a trail in Tulsa, Okla., in 1997

1. 02/04/2022 - third stage of rocket launched in 2021
2. 12/05/2022 - third stage of rocket launched in 2021 (killed a lamb?)
3. 09/07/2022 - trunk of SpaceX CrewDragon spacecraft
4. 31/07/2022 - rocket debris punctured house roof

Models for Space Debris Environment– Model Future

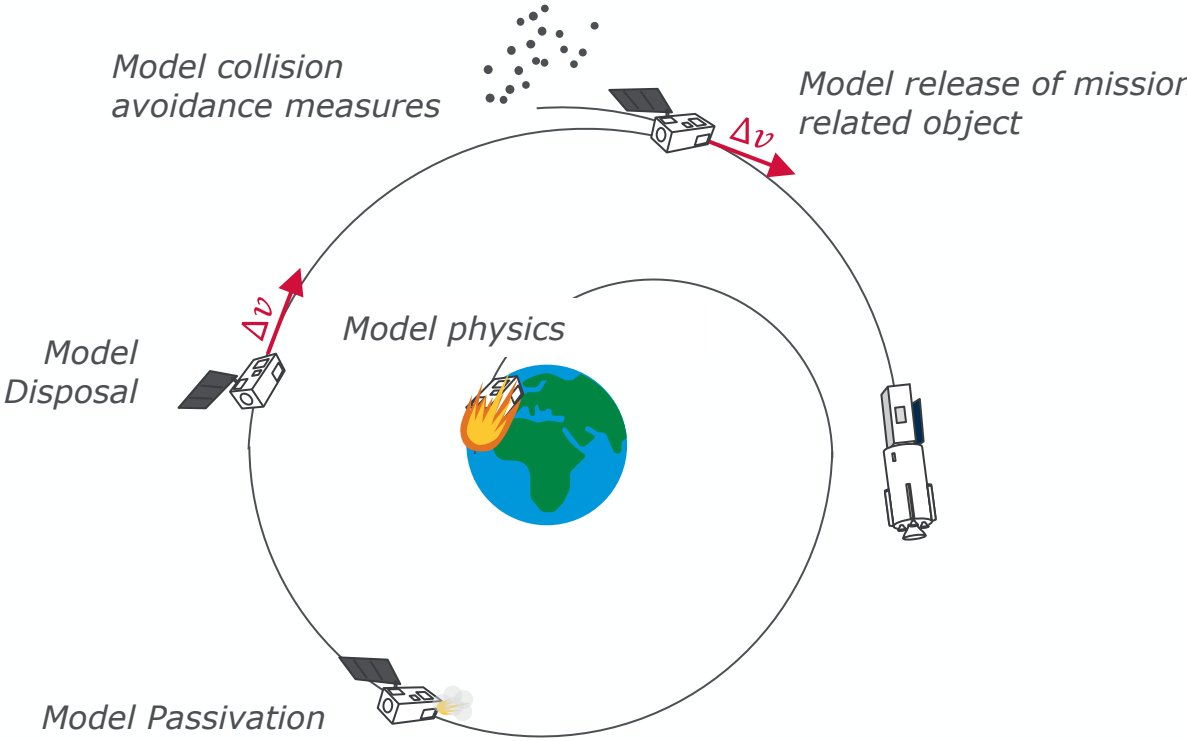
"All models are wrong, but some are useful"

Future environment model:

- Propagation of an initial population with inclusion of new objects
- Detect and mode conjunctions between objects
- Perform post-mission disposal (PMD) actions
- Vary the conditions stochastically (Monte Carlo)

Uncertainties in future environment model:

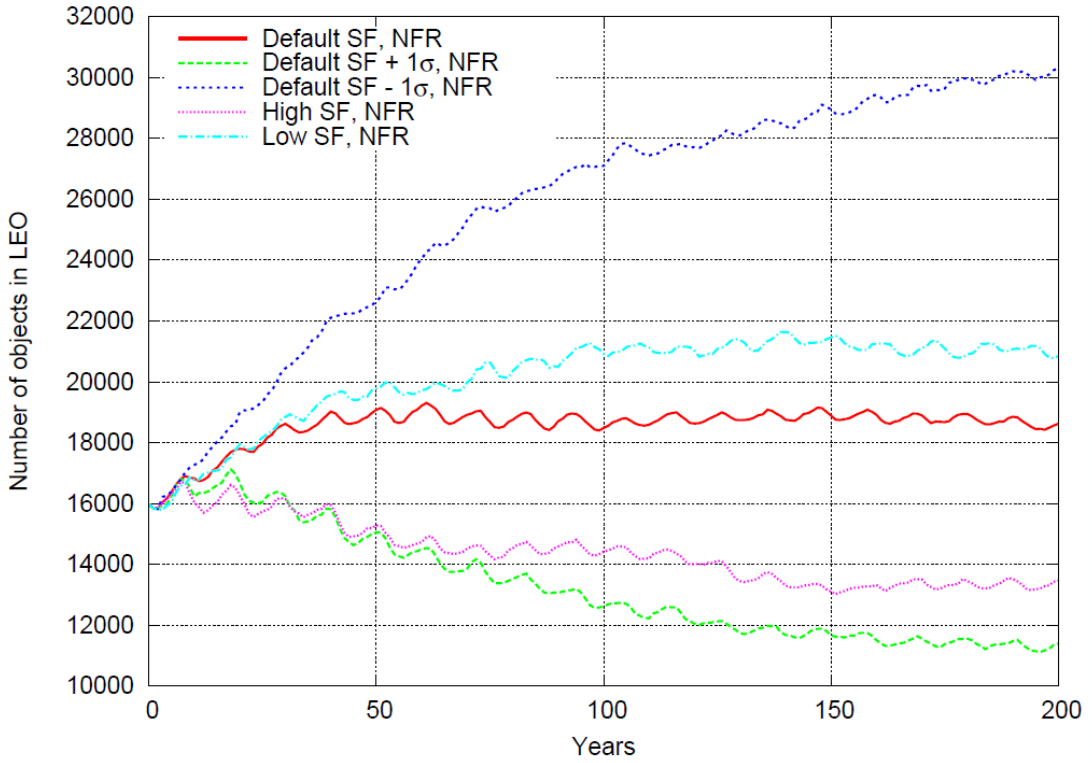
- Initial debris environment
- Evolution of space weather activity
- Evolution of the upper atmosphere
- Future launch traffic and space technology evolution
- Quality of mitigation measures adopted
- Deliberate actions endangering the environment
- …



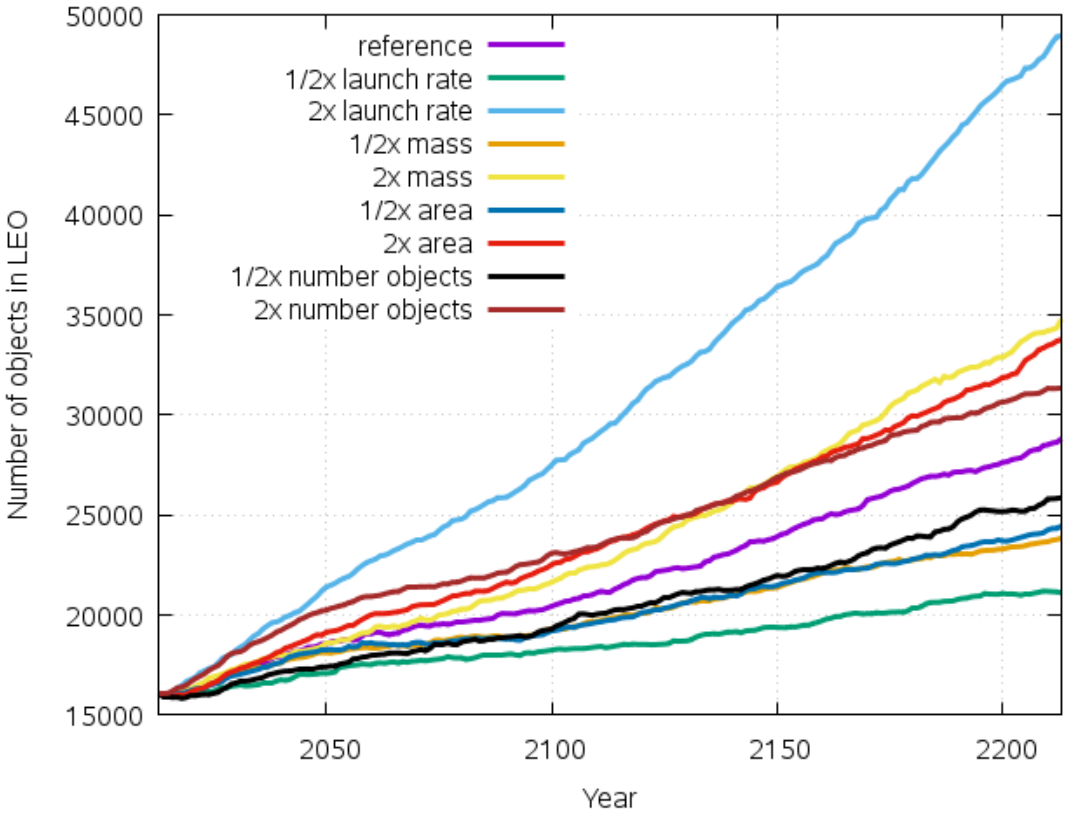
Models for Space Debris Environment– Model Future

Examples from 2014 – Sensitivity Study

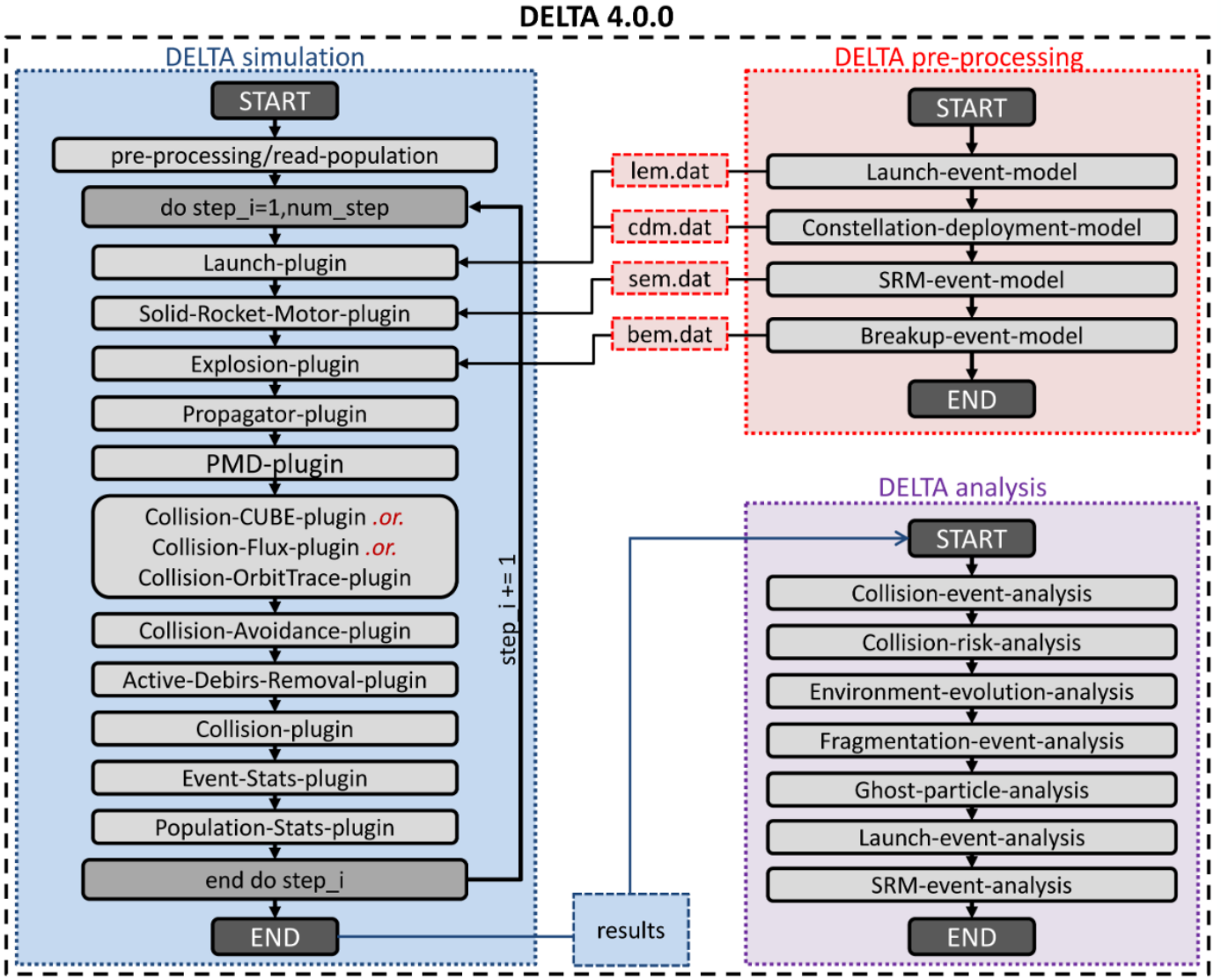
Varying Space Weather
(SF: Solar Flux, NFR: No new space traffic)



Varying launch traffic



Debris Environment Long-Term Analysis (DELTA)

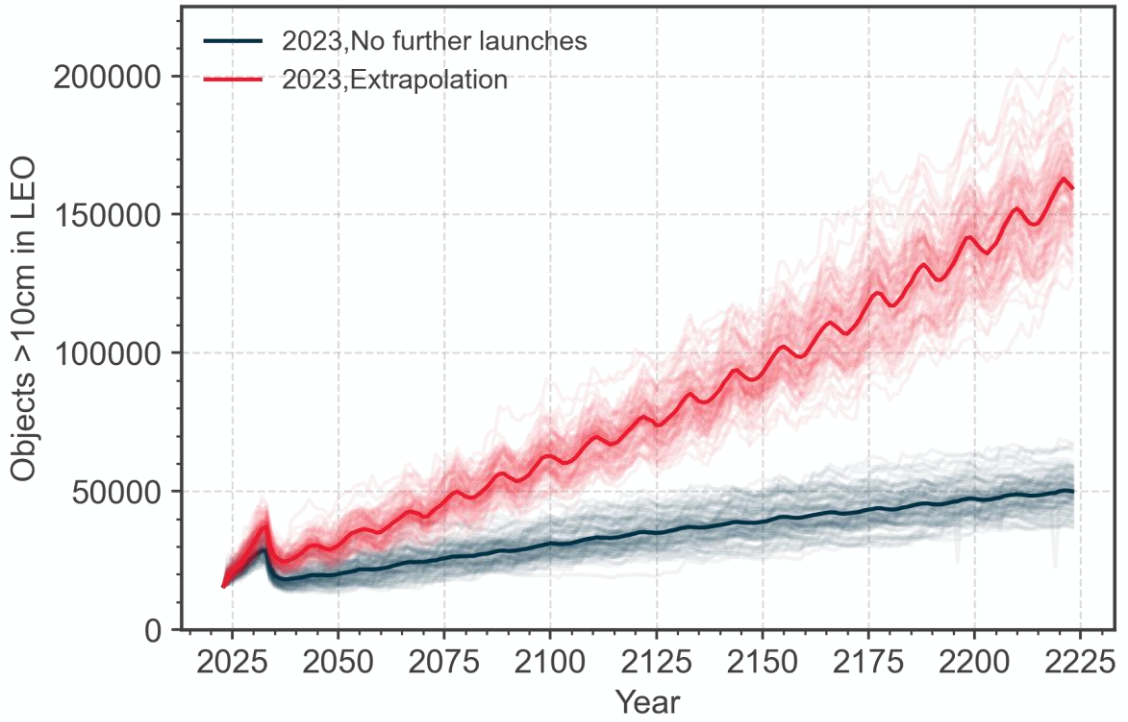


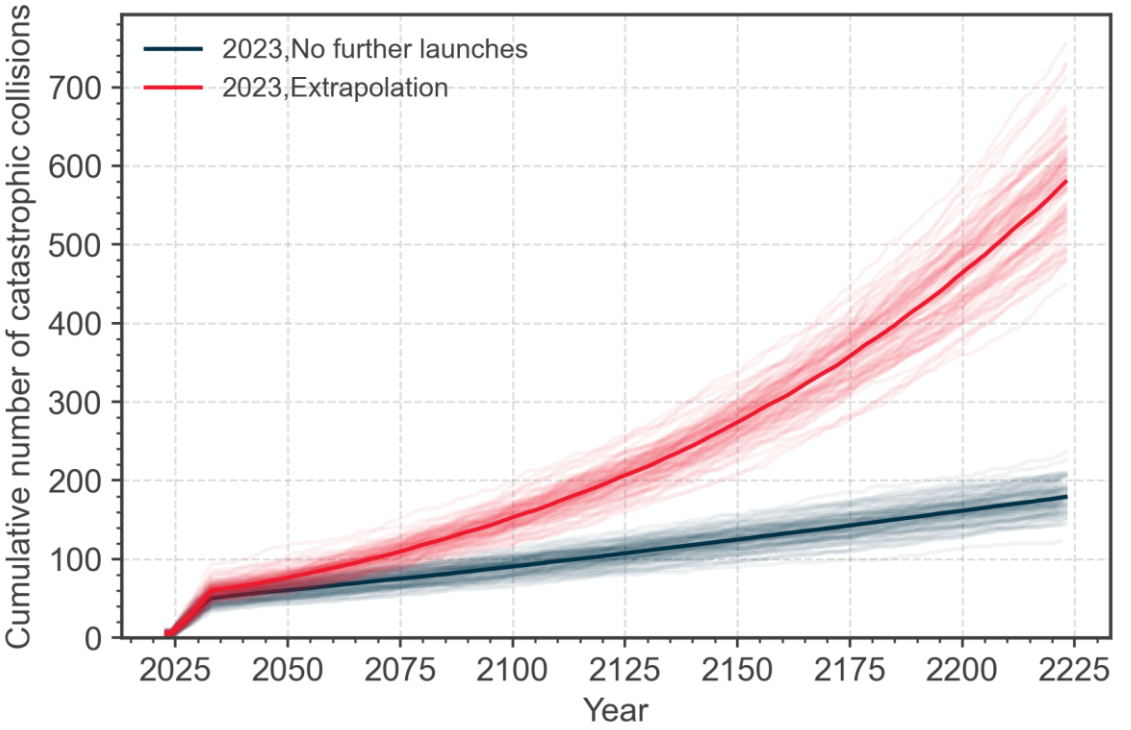
- Objects larger than 1 mm size, based on MASTER population
- future events for launches (also constellations), solid-rocket-motor burns and explosions.
- Forecasting of collision events.
- debris mitigation measures, such as passivation, disposal at end-of-life and active-debris-removal.

⇨ historic population snapshots for each object type (Object types include explosion fragments, collision fragments, launch-related objects, sodium-potassium droplets, and solid rocket motor slag particles.)

Debris Environment Long-Term Analysis (DELTA)

Extrapolation of the current behaviour in terms of launch traffic, explosion rates, and disposal success rates.
VS
No future launches **(NFL),** where it is assumed that no launch takes place after the reference epoch.





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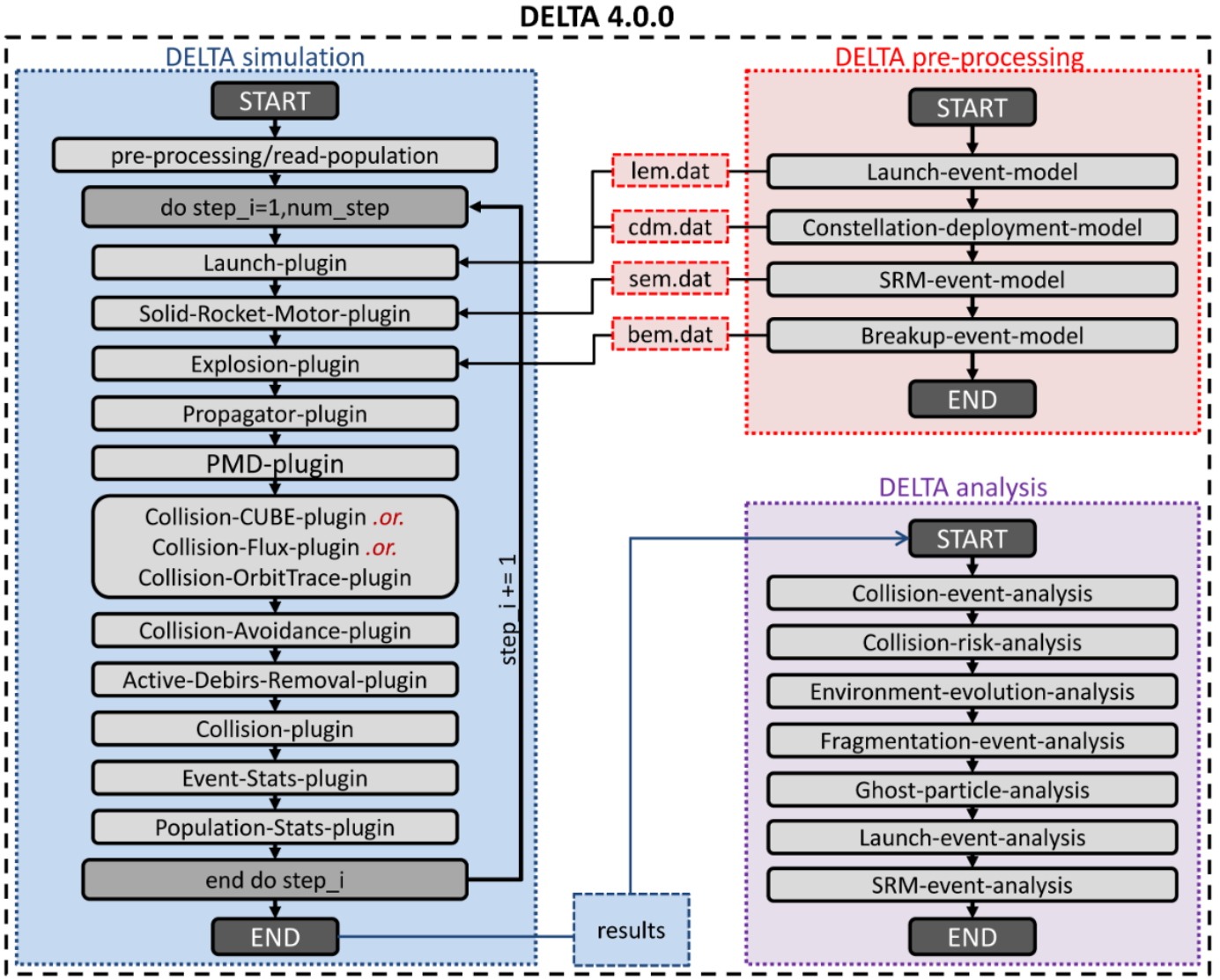
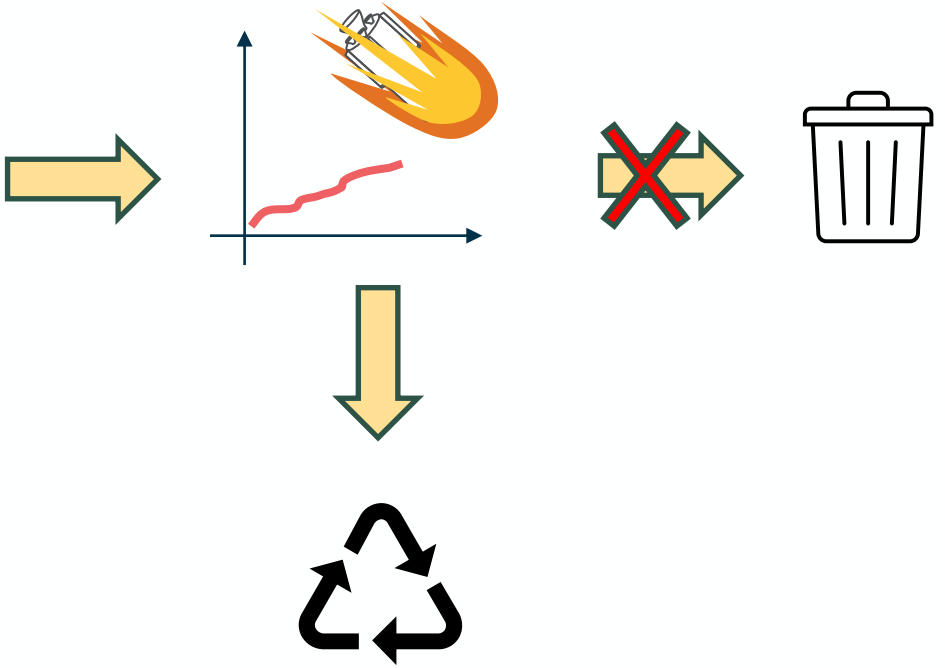
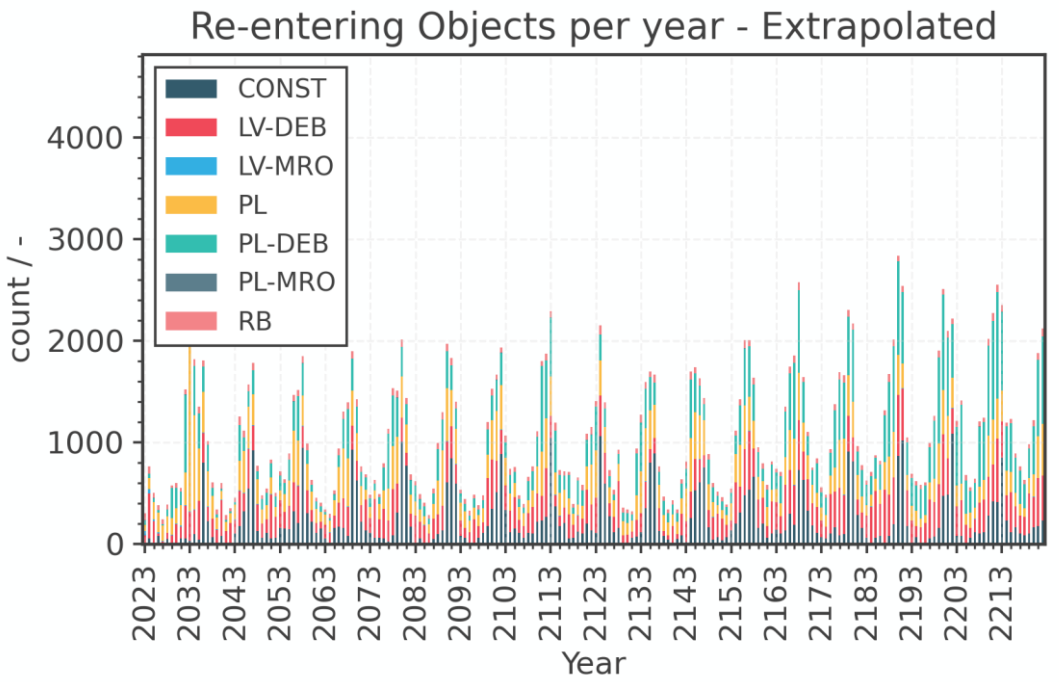


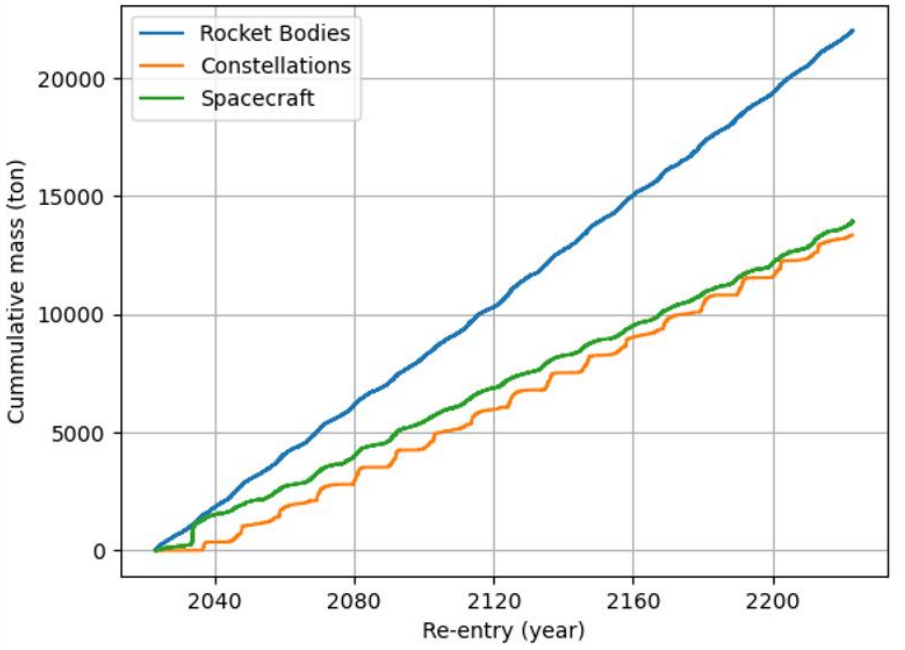
Forecasting of the re-entry traffic is a “collateral” output of the analysis



Debris Environment Long-Term Analysis - Output

- Distribution or cumulative spectrum of the re-entry objects as whole population over years, or divided by object type
- Object properties, like mass, area, diameter
- Orbital parameters
- ….

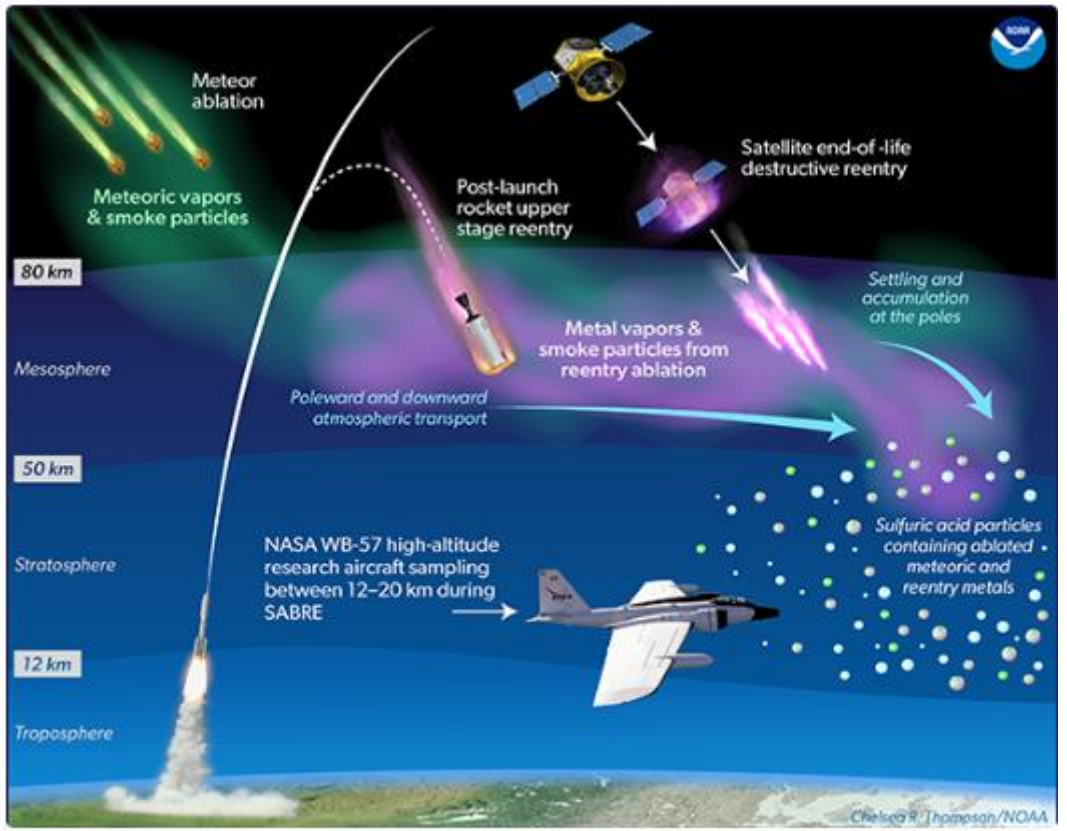




By-product emission linked to re-entries

Now

About 10% of the aerosol particles in the stratosphere contains aluminium and other metals that originates from the burn-up of satellites and rocket stages during re-entries. [1]



Incorporation of metals from re-entry into stratospheric particles. Graphic: Chelsea Thompson, NOAA

What about future scenarios?

Can the re-entry traffic forecasting be useful for shaping the future impact on atmosphere?

[1] Daniel M. Murphya, et. Al Metals from spacecraft reentry in stratospheric aerosol particles, Proceedings of the National Academy of Sciences, October 2023

[2] Troy Thornberry and Eric Jensen, SABRE Mission Scientists and the SABRE 2023 Science Team, SABRE 2023 High Latitude Deployment End-of-Mission Summary, https://csl.noaa.gov/projects/sabre/pubs/2023eoms.html

Cluster-II - Overview

Four spacecraft to provide a detailed three-dimensional map of the magnetosphere.

- Dry mass: ~ 450kg
- Spinning at 15 rpm.

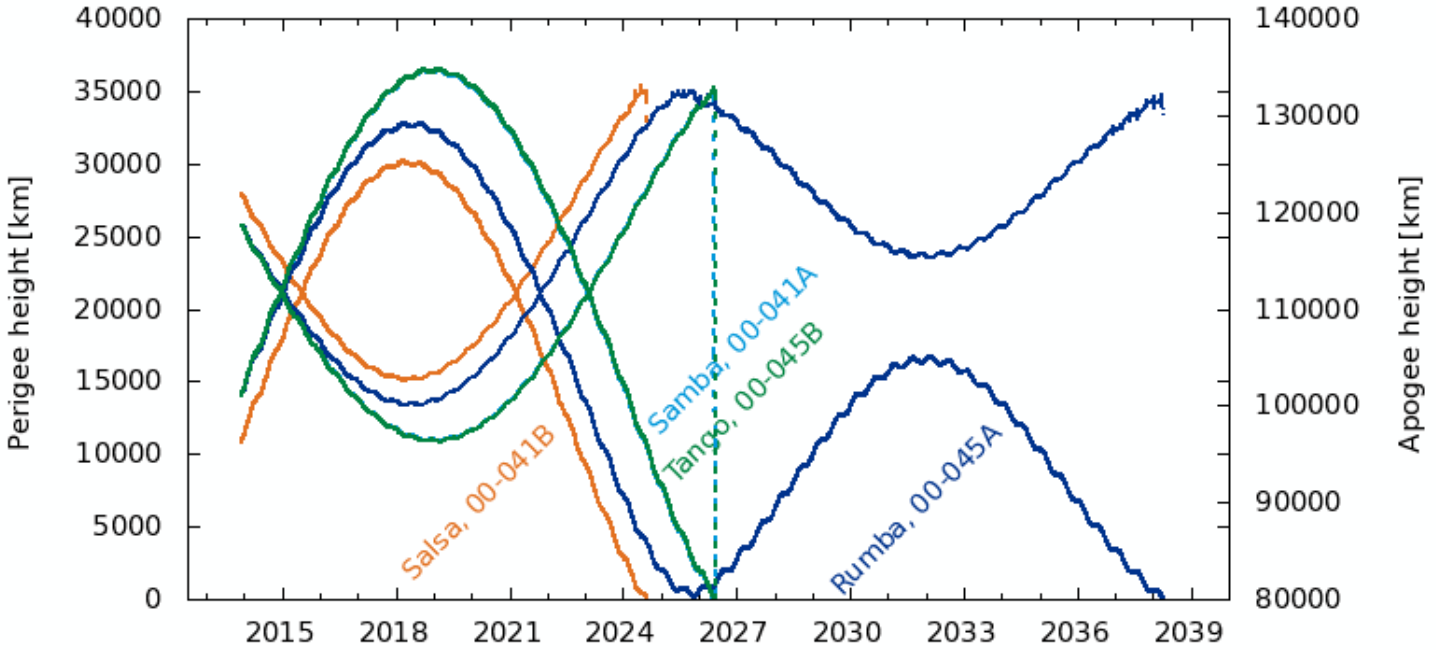
Launched successfully in 2000.

Elliptical initial orbit:

- Period: 57 h,
- Perigee: 19000 km, Apogee: 119 000 km,
- Inclination 135 deg.

Debris story started in 2013

- Orbit of Rumba modified in 2014 to re-enter
- Extended at least until end 2023.



Cluster-II - Re-entries

Cluster 1

Falls into the SPOUA

Cluster 2

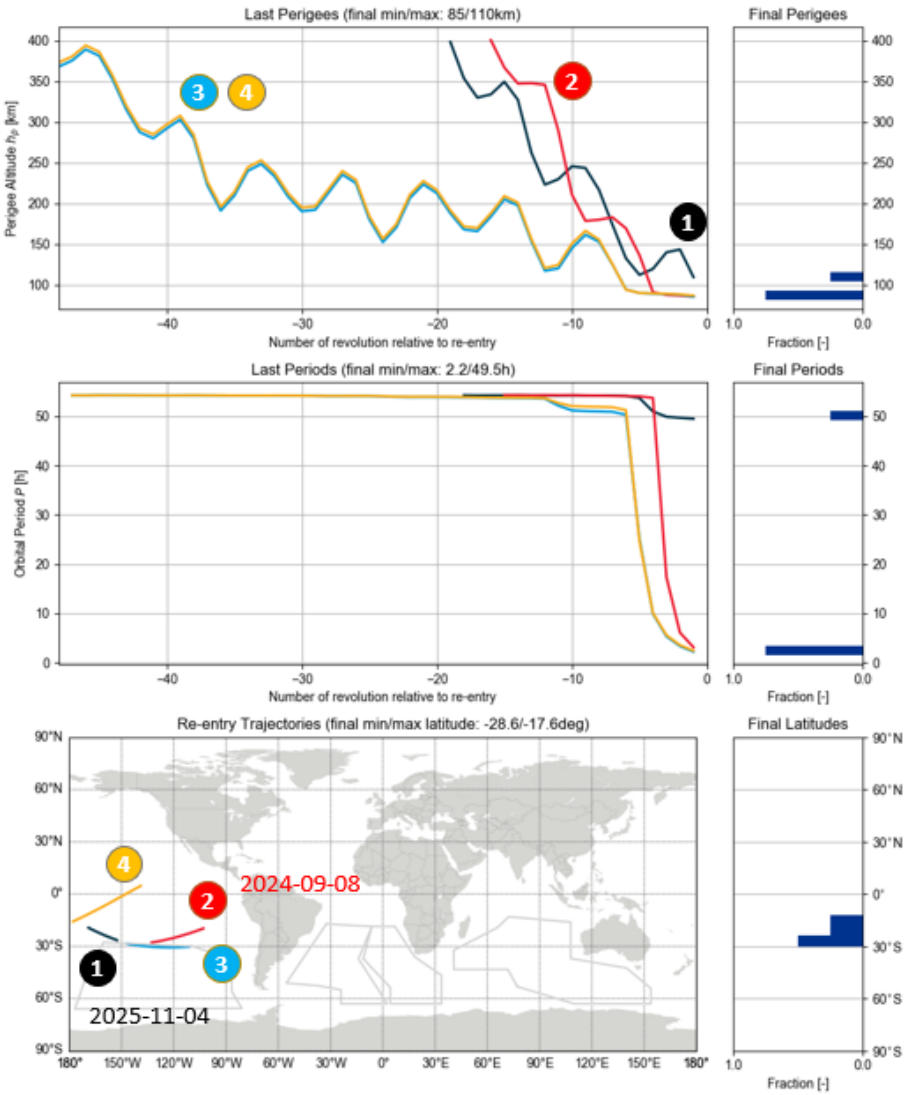
Falls into the SPOUA

Cluster 3

On-going optimization of the re-entry strategy

Cluster 4

On-going optimization of the re-entry strategy



Cluster-II - Flight Observation Campaigns

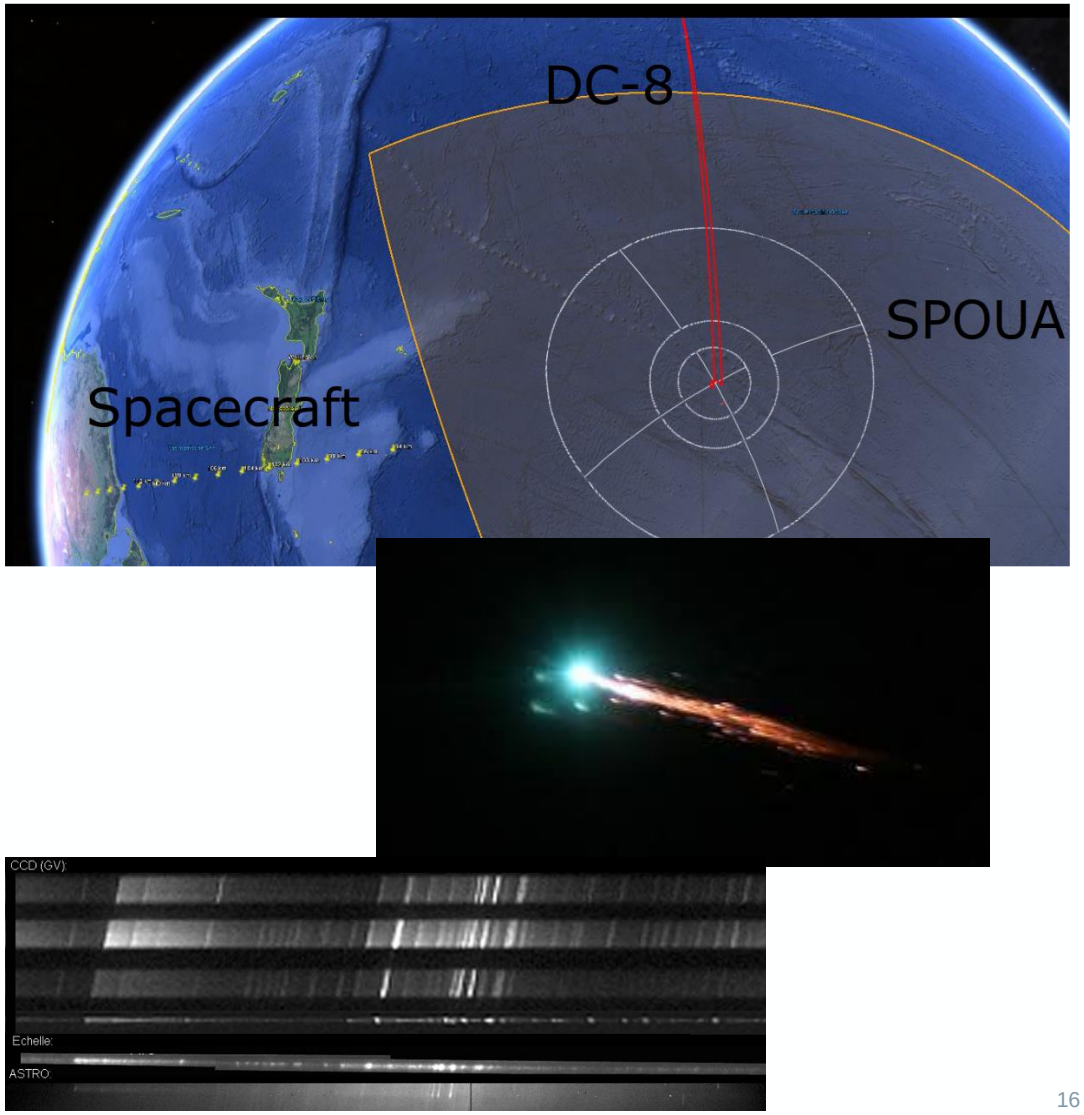
HEO Re-entry are predictable and hence provide rare global observation opportunity of representative spacecraft.

Small aircraft have been used to record the break-up event for meteors and cargo vehicles:

- Allow-up close assessment of fragments
- Spectrographic identification of parts for model validation

Cluster specific:

- Four identical spacecraft on different tracjectory -> Same object cross-comparison was never done gloablly
- Low risk and precursor identified spectrography in ground facility.
- International campaings proposed for 2024 and 2025 re-entries (S2P Programme entry approved for 1)



DRACO (Destructive Re-entry Assessment Container Object)

Conclusions

- The increment in commercial use of the space has clearly an impact on the future space traffic, with an expected increase on the number and frequency of re-entries.
- We do have a gap of knowledge/methodology for fully understanding the by-product emission in the stratosphere due to re-entries, but extrapolation of future re-entries traffic is available, and ESA is willing to discuss ideas for user cases.
- Some of the upcoming re-entry can be particularly suitable for observations campaigns and gathering data.

Thank you!
Questions?

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