6 February 2023

English only

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Sixtieth session
Vienna, 6–17 February 2023
Item 7 of the provisional agenda
Space debris

Research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris

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IADC-23-01
Jan 2023

Inter-Agency Space Debris Coordination Committee

IADC Report on the Status of the Space Debris Environment

Issued by IADC Working Group 2 / Steering Group

Internal Task 39.2

Issue 1 Revision 0

Table of Contents

Revision History

Issue	Revision	Date	Reason for Revision
1	0	Jan 2023	First Release, reference epoch for the report is 31 Dec 2021

List of Abbreviations

Abbreviation	Description
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CSA	Canadian Space Agency
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ESA	European Space Agency
GEO	Geostationary Earth Orbit
IADC	Inter Agency Space Debris Coordination Committee
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
LEO	Low Earth Orbit
MRO	Mission Related Object
NASA	National Aeronautics and Space Administration
ROSCOSMOS	Space State Corporation “Roscosmos”
SSAU	State Space Agency of Ukraine
UKSA	UK Space Agency

List of Definitions

Term	Description
Catastrophic collision	Collision leading to the complete destruction of target and impactor
Constellation	Set of at least 20 individual satellites, released into orbit over more than 2 events and covering more than 1 year in time from first to last event, sharing the same objective as a combined system
Mission related object (MRO)	Space objects released as space debris which served a purpose for the functioning of a spacecraft or of a launch vehicle
Naturally compliant	Space objects that operate in an orbit such that they naturally re-enter within 25 years (i.e., without requiring any manoeuvre)
Spacecraft	Space object designed to perform a specific function in space excluding launch functionality. This includes operational satellites as well as calibration objects
Launch vehicle	Space object constructed for ascent to outer space, and for placing one or more objects in outer space. This includes the various orbital stages of launch vehicles, but not spacecraft which release smaller spacecraft themselves
(Launch vehicle) orbital stage	Any stage of a launch vehicle left in Earth orbit

1 Executive summary

As space debris poses a problem for the near-Earth environment on a global scale, only globally supported solutions can be the answer. This creates the need for internationally accepted space debris mitigation measures: a major step in this direction was taken in 2002, when the Inter-Agency Space Debris Coordination Committee (IADC) published its Space Debris Mitigation Guidelines, which have been updated more recently in 2021 [1]. This document has since served as a baseline for non-binding policy documents, national legislation, and as a starting point for the derivation of technical standards.

While mitigation measures have found broad consensus, it is of increasing importance to verify their effect in practice and to monitor their level of implementation. In response to this, in 2022 the IADC commissioned the report on the status of the space environment. The intention is for this report to be released at regular intervals to raise the awareness of space farers, decision takers and the interested public on the status of the environment and help develop a common understanding and route towards a sustainable space environment.

The main findings of the status of the space environment report are summarized below:

Increase in the number of debris objects: Statistical models estimate more than 30000 space debris objects larger than 10 cm in Earth orbit and around 900000 objects larger than 1 cm. The smaller fragments are considered to be large enough to be able render spacecraft inoperable or destroy sensitive spacecraft components, whereas larger fragments could cause spacecraft to completely break-up and in Low Earth Orbit (LEO) lead to the creation of hundreds to thousands of new debris objects.

Significant increase in launch traffic: The most significant change in launch traffic has been seen in LEO, principally from 2010, with the deployment of large constellations and a shift towards commercial operators. As a result, the current launch traffic is around 10 times the level observed in 2000. The increase in the number of spacecraft that have been launched has also resulted in an increasing trend in the number spacecraft and orbital stages re-entering per year .

Enhanced manoeuvrability: The deployment of large constellations has led to the majority of the catalogued objects in some altitude bands having the capability to manoeuvre . This has implications, for example, for collision avoidance operations, as spacecraft operating in such altitude bands will need to adopt coordination mechanisms.

Significant number of fragmentation events: Six fragmentation events were observed in 2021 and, on average over the last two decades, around 12 non-deliberate on-orbit fragmentations occurred every year .

Decrease in the number of mission related objects: The number of mission related objects (MRO) released by spacecraft during normal operations has decreased significantly since the 1990s, whereas for orbital stages the number of MRO released remains relatively stable.

Post-mission disposal compliance remains low: One of the core principles of the space debris mitigation guidelines is to remove objects from the LEO and GEO protected regions with a high success rate for those orbits where a natural disposal mechanism is absent [1]. Between 85% and 100% of all spacecraft reaching end-of-life for any given year during the last decade in the GEO protected region attempt to comply with space debris mitigation measures and between 60% and 90% do so successfully, with the compliance trend asymptotically increasing .

Between 20% and 70% of the orbital stages delivering spacecraft in or near the GEO protected region for any given year during the last decade are in compliance with space debris mitigation measures, with the compliance trend increasing also in this case .

Between 45% and 90% of all spacecraft reaching end-of-life for any given year during the last decade in the LEO protected region are in compliance with space debris mitigation measures, with the compliance trend increasing . However, this increase in absolute numbers is mainly due to the growth in the rate of spacecraft operating in naturally compliant orbits. If those objects are discarded in the analysis, one can observe that until 2017 only between 10% and 40% of the spacecraft reaching end-of-life for any given year during the last decade are compliant with space debris mitigation measures, which is a very low compliance rate. After this, with peaks in 2018 and 2020 respectively, values reached higher relative compliance rates mainly due to the de-orbiting of one constellation and a low number of satellites reaching end-of-life in a non-compliant orbit.

Between 30% and 90% of the orbital stages delivering spacecraft in the LEO protected region for any given year during the last decade are in compliance with space debris mitigation measures, with an increasing compliance trend mainly due to an increasing number of spacecraft operating in naturally compliant orbital altitudes.

Towards a sustainable space environment: The widespread adoption of the IADC space debris mitigation guidelines and the IADC recommendations for large constellations of satellites continue to remain the most effective method to reduce the long-term environmental impacts of global space activity by slowing the rate of growth of the space debris population observed. However, the adoption of the IADC space debris mitigation guidelines is not yet at a level that is sufficient to induce substantial benefits or slowing of the space debris population growth. The environmental evolution results identify that a doubling of the space debris population may occur within 25 years and an increase of 10 times over the longer term due to an increasing rate of catastrophic collisions. Critically, even in the case of no further launches into orbit, it is expected that collisions among existing space debris objects will lead to a further growth in space debris population. Consequently, even with widespread adoption of these guidelines and recommendations, or even stricter behaviours, the consensus is that the environmental impacts cannot be removed completely and additional steps may need to be taken, such as enabling the technology for active debris removal. Further research and discussions are encouraged within the global community to develop a consensus view on the definition and route towards a sustainable space environment.

2 Introduction

More than 20 years have passed after the *IADC Space Debris Mitigation Guidelines* have been issued first in 2002. While mitigation measures have found broad consensus, it is of increasing importance to verify their effect in practice and to monitor their level of implementation. Therefore, the members of the IADC have decided on a collaborative effort in analysing and documenting the state of the environment in this comprehensive report and publish it at regular intervals for the awareness of space farers, decision takers and the interested public.

To this end, the information in this report is structured into three parts:

1. A presentation of the current state of the environment, as a result of measurement and modelling efforts and a presentation of the current launch. This also includes updates on the space traffic, which provides important indications for the future dynamics of the environment.
2. A presentation of latest debris generating events in combination with statistics on the conduct of apparent mitigation actions (like post mission disposal, mission related object release), relying on observation data accessible to IADC members.
3. An outlook on the evolution of the environment, projecting the consequences of the current behaviour and attempting to present an overall environment health status.

The IADC considers this information to be a solid reference for the state of the environment and as a tool to identify new traffic or environmental trends and to analyse the need for corrective and additional measures.

3 Current status

This section provides an estimate of the number of objects in classical Keplerian Earth bounded orbits at the reference epoch. The estimate is provided both in terms of object counts and models.

Launch statistics and in orbit release, are also reported, with a breakdown in top-level mission classification and mass range.

The reference epoch for the report is 31/12/2021.

3.1 Objects in the environment

According to space debris environment models, at the reference epoch November 1st 2016, the estimated number of debris objects in orbit in the different size ranges is the following:

- 34000 objects greater than 10 cm,
- 900000 objects from 1 cm to 10 cm,
- 128 million objects from 1 mm to 1 cm.

The distribution of the number of objects as a function of their size is shown in Figure 1: the plot shows the number of objects larger than the threshold size indicated in x-axis.

Figure 2 shows the density profiles with altitude corresponding to different minimum debris sizes (respectively 10 cm in dark blue and 1 cm in light blue), considering only the LEO region. The logarithmic scale is used in the y-axis to take into account the different orders of magnitude corresponding to the two populations.

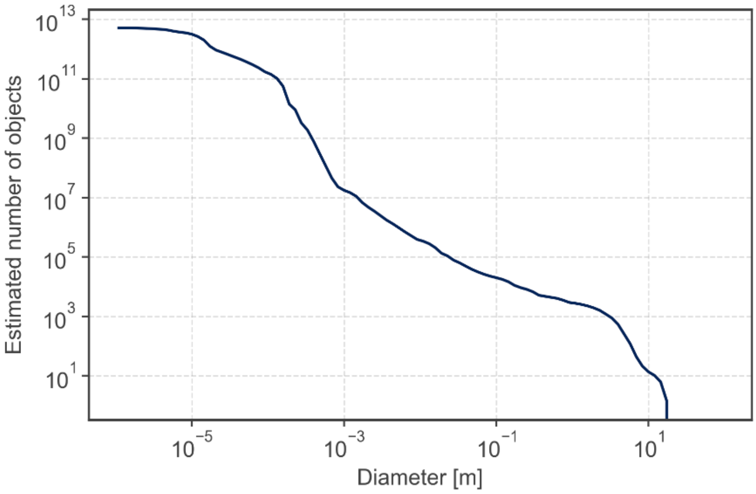

Figure 1 Estimated number of objects as function of object size.

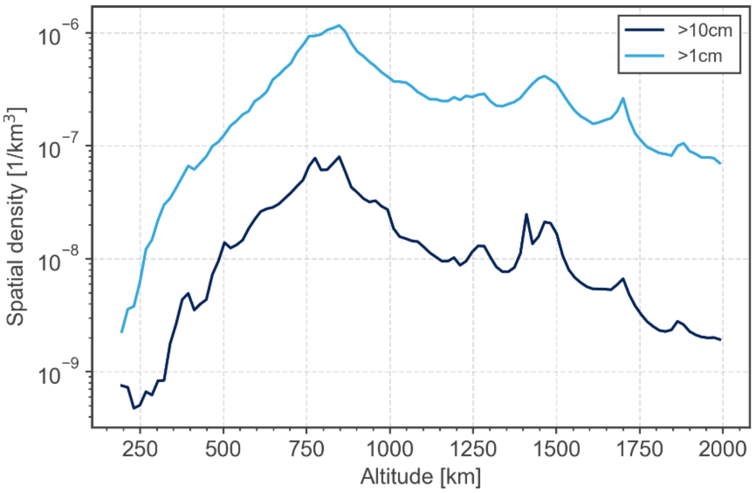

Figure 2 Density profiles in LEO as a function of altitude for different size ranges

3.2 Launch traffic

This section provides statistics on the number of spacecraft launched in the LEO (Figure 3 and Figure 4) and GEO region (Figure 5 and Figure 6) by looking at the altitude of the perigee (h_p). Two classifications are shown. In the first one, the launch traffic of spacecraft can be categorized in terms of the main funding source (Civil, Defence, Commercial, Amateur, where the Amateur category includes those spacecrafts associated by academic institutions when none of the other entities are the driving contributor). The second classification is based on the satellite dry mass.

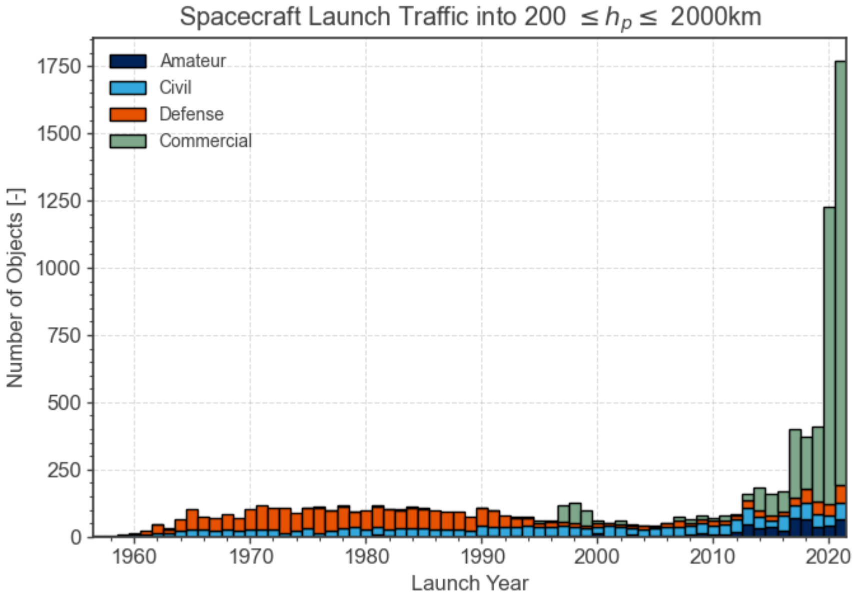

Figure 3 Launch traffic into LEO by mission class.

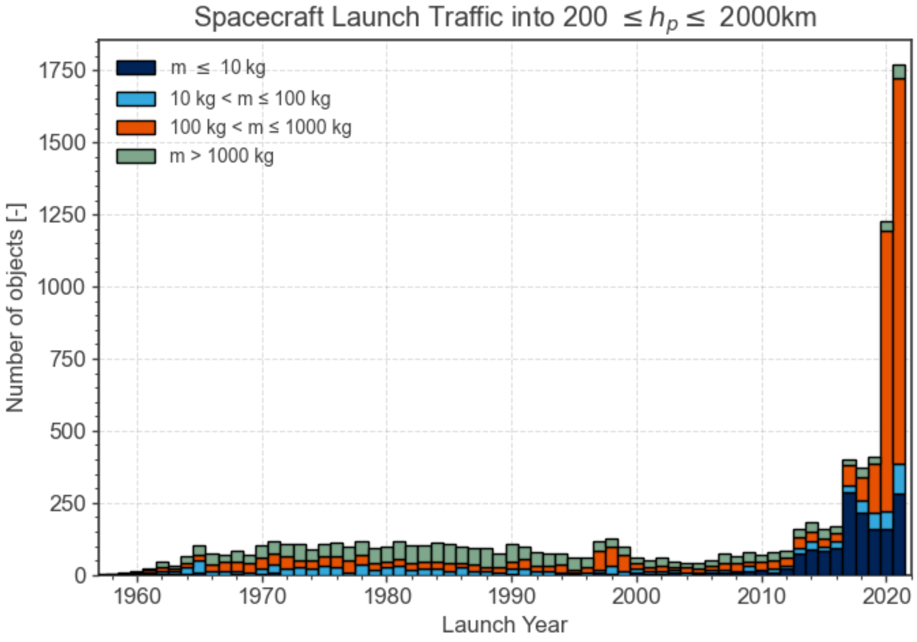

Figure 4 Launch traffic into LEO by mass class.

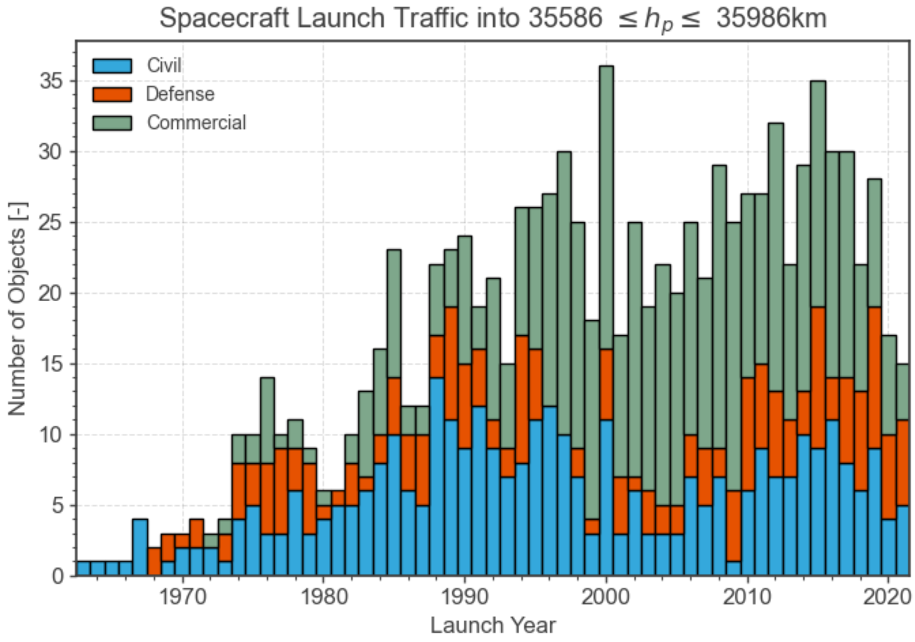

Figure 5 Launch traffic into GEO by mission class.

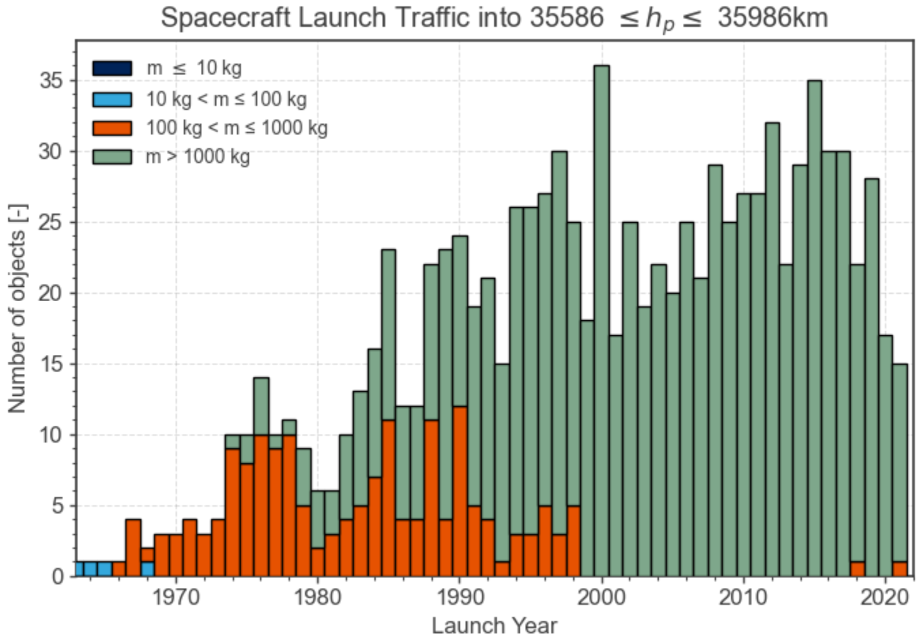

Figure 6 Launch traffic into GEO by mass class.

3.3 Re-entries

Figure 7 shows the evolution in time of the number of re-entering objects each year by object type, excluding space objects related to human spaceflight.

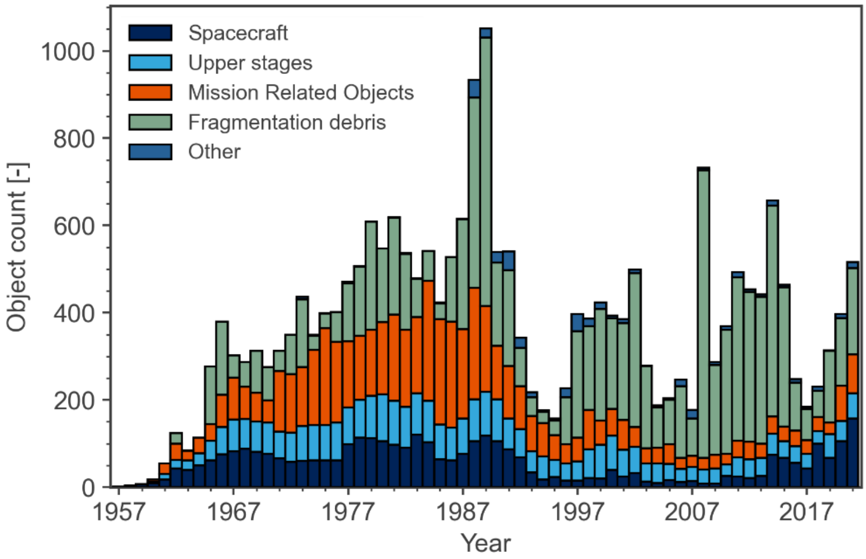

Figure 7 Re-entries of catalogued objects by object type.

3.4 Manoeuvrable objects

Figure 8 shows the distribution of manoeuvrable spacecraft in LEO as a function of altitude together with the distribution on non-manoeuvrable objects. The manoeuvrability status is estimated based on space surveillance data, so only spacecraft exhibiting recurring manoeuvre capabilities are classified as manoeuvrable.

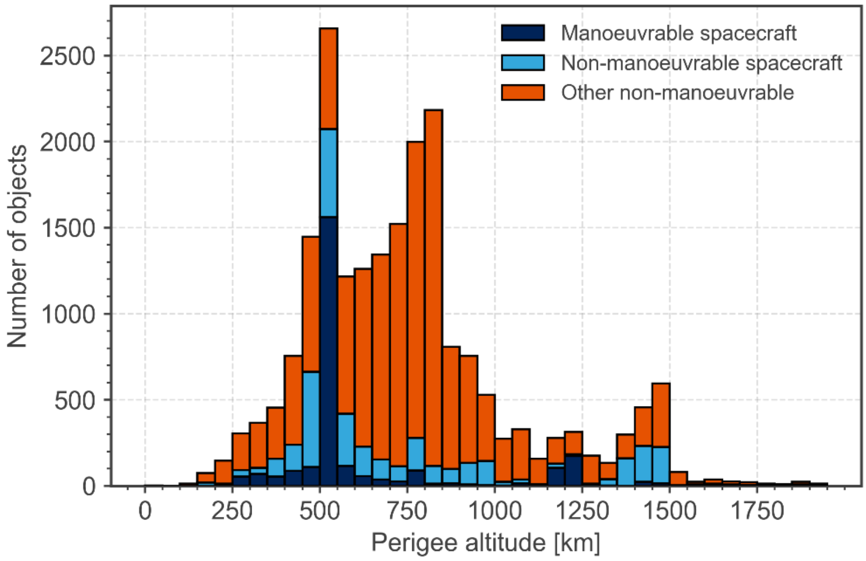

Figure 8 Distribution of manoeuvrable and non-manoeuvrable objects in LEO as a function of altitude

4 Contributors to the space debris issues

4.1 Fragmentations

4.1.1 Fragmentations in period of analysis

Table 1 lists the fragmentations reported in the period of analysis (year 2021), with information on the event epoch and cause, together with the parent type and orbit. The table also reports the total number of catalogued debris objects: this indicates the total number of fragments associated to the break-up event, which may include objects that have already decayed at the time of compilation of the report. Many more debris too small to be catalogued but which could still cause serious damage and threaten missions were also generated from each breakup event. A range of values is provided for this entry when the sources available for this analysis present different values.

Table 1: Fragmentation Events in the period of analysis (year 2021).

Event Epoch	Event cause	Total debris objects catalogued	Parent orbit	Parent type
10-Mar-2021	Unknown	[113 - 115]	LEO	Spacecraft
18-Mar-2021	Unknown/Collision Accidental	37	LEO	Spacecraft
23-24/10/2021	Unknown	22	LEO	Spacecraft
15-Nov-2021	Unknown/Collision Deliberate	[1688 - 1692]	LEO	Spacecraft
18-Nov-2021	Unknown	11	LEO	Spacecraft
26-Nov-2021	Unknown	21	LEO	Spacecraft

4.1.2 Historical fragmentations

Figure 9 shows the historical trend of the number of fragmentation events per year.

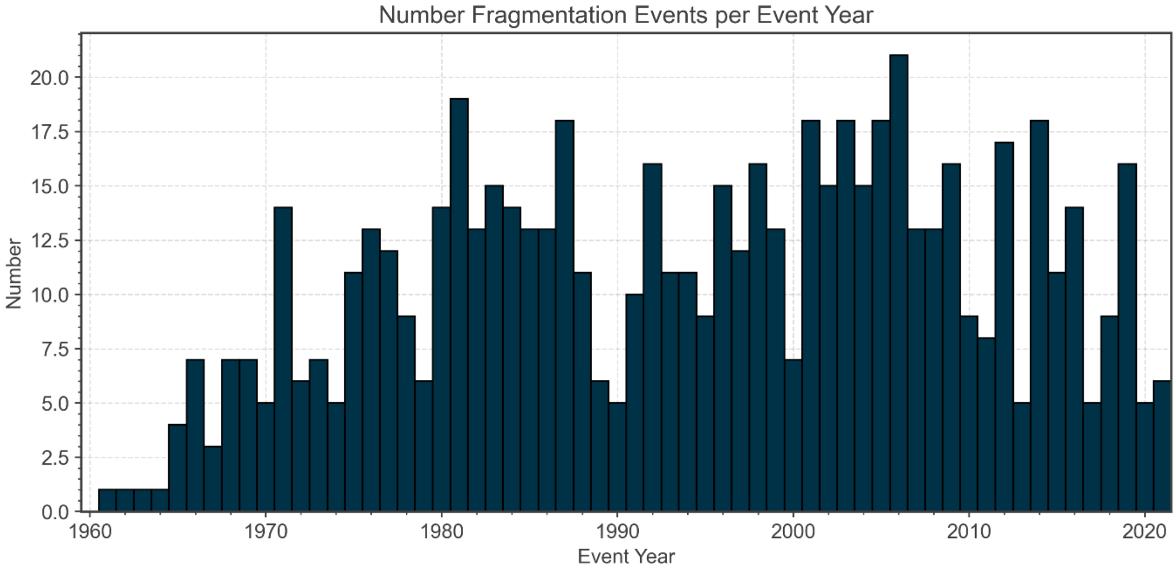

Figure 9 Number of fragmentation events per event year.

4.2 Mission Related Objects Release

Figure 10 shows the absolute number of released and catalogued mission related objects (MROs) by spacecraft and orbital stages. Figure 11 shows instead the yearly fraction of MRO release events over the total amount of payloads and rocket bodies injected into the space environment during that year.

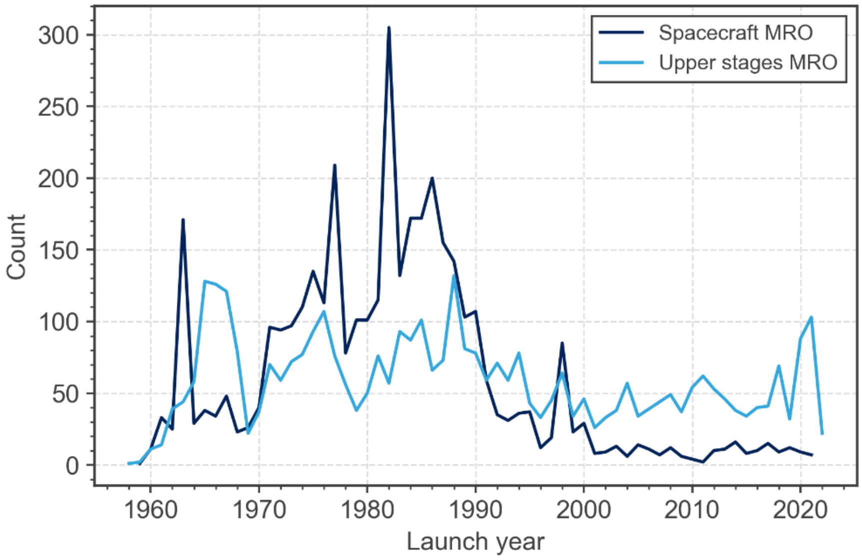

Figure 10 Total number of catalogued mission related objects released.

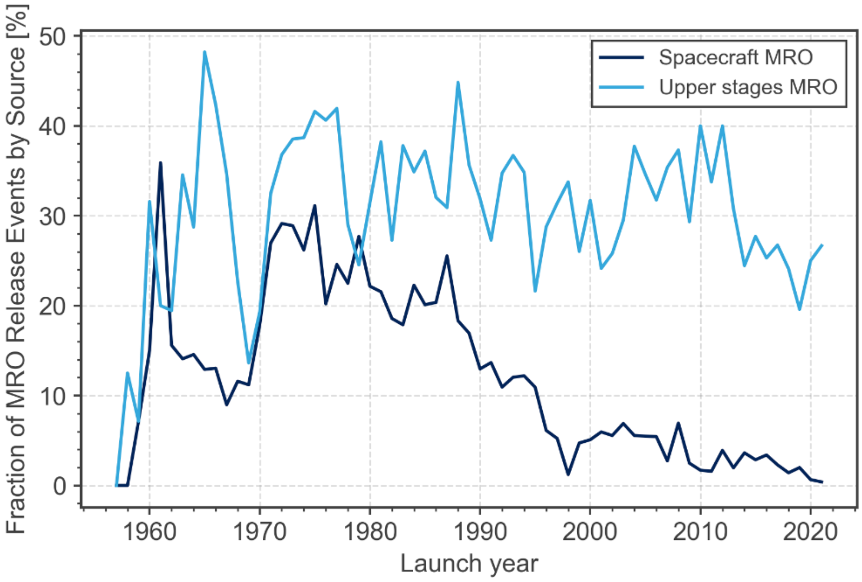

Figure 11 Fraction of mission related objects releases per year w.r.t. the total amount of payloads and rocket bodies injected into the space environment during that year.

4.3 Disposal statistics

The analyses by different agencies are summarised showing the mean value of the analysed parameter (e.g., compliance rate, no attempt rate) for each year with a round marker, whereas the interval indicates the spread of minimum and maximum values recorded. Across different editions of this report, reclassification of past data can occur. A description of the compliance assessment methodology can be found in [2].

4.3.1 GEO

This section covers:

- Disposal of spacecraft operating in GEO (Figure 12, Figure 13),
- Disposal of launch vehicle orbital stages used for the insertion of spacecraft targeting GEO (Figure 14).

In particular, Figure 12 and Figure 14 show the rate of compliance, i.e., the number of spacecraft disposed of in a given year being compliant with the IADC Space Debris Mitigation Guidelines over the total number of spacecraft that reached end of life in that year. Figure 13 shows instead the rate of no disposal attempts for the analysed years.

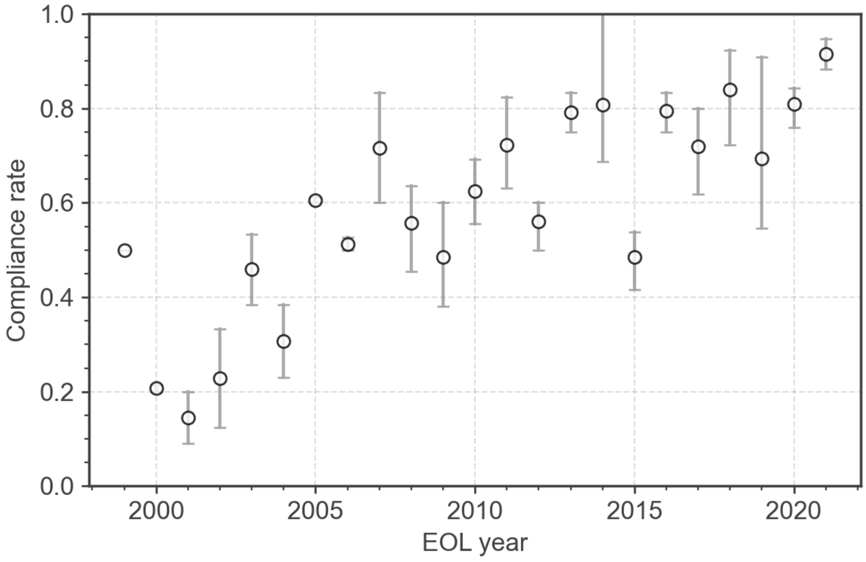

Figure 12 General rate of successful disposal attempts for spacecraft in GEO as assessed by the contributing agencies.

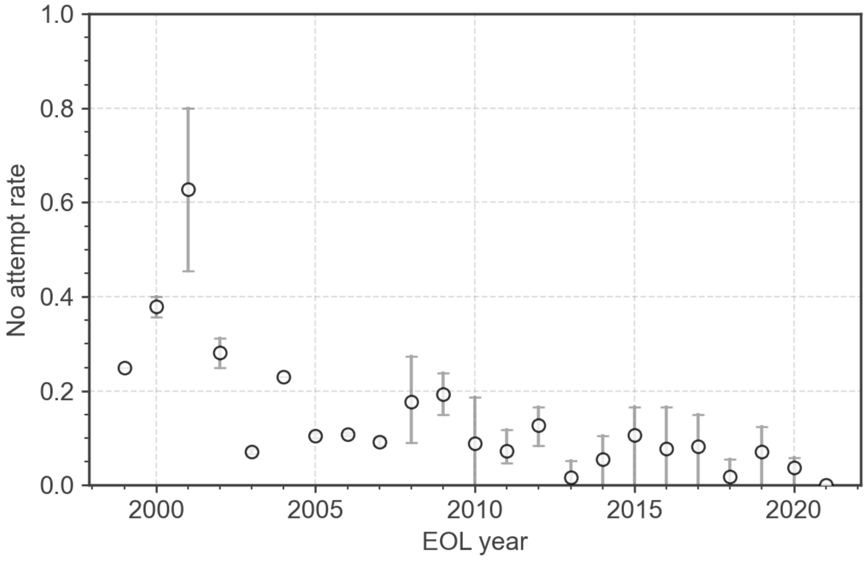

Figure 13 General rate of no disposal attempts for spacecraft in GEO as assessed by the contributing agencies.

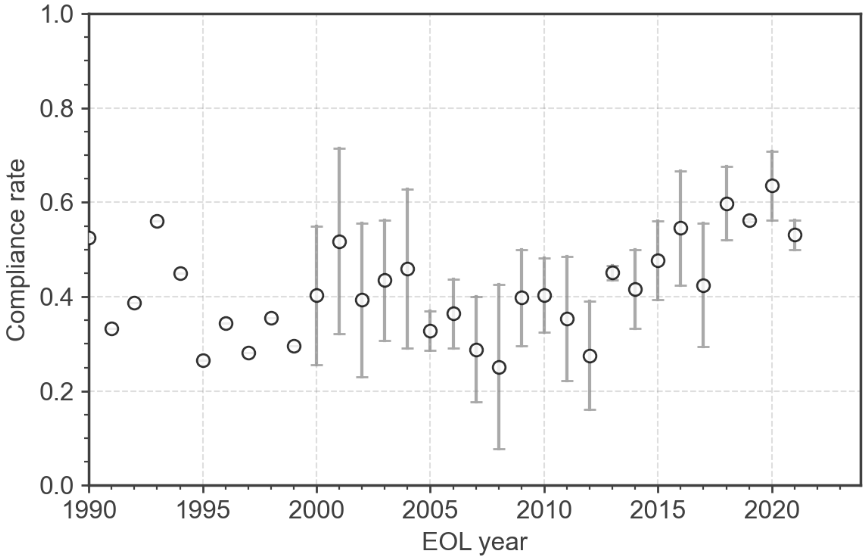

Figure 14 General rate of compliant objects for orbital stages used to insert spacecraft in GEO as assessed by the contributing agencies.

4.3.2 LEO

This section covers:

- Disposal of spacecraft operating in LEO,
- Disposal of launch vehicle orbital stages in LEO,
- Disposal of spacecraft and launch vehicle orbital stages crossing LEO.

For the classification, above-LEO graveyard disposal is considered as non-compliant, in accordance with the IADC guidelines [1]. Human spaceflight related objects (including space tugs) are excluded from the analysis.

The notation *naturally compliant* is used to indicate orbital stages and spacecraft that operate in an orbit such that they naturally re-enter within 25 years (i.e. without requiring any manoeuvre).

Figure 15 shows the general rate of compliance for spacecraft in LEO, i.e., the sum of the number of naturally compliant objects and of the number of successful disposal attempts over the total number of spacecraft reaching End-of-Life in a given year. Figure 16 shows instead the rate of compliance considering only non-naturally compliant satellites. The 90% level represents the minimum probability of success for disposal manoeuvres, as stated in the IADC guidelines [1]. In other words, spacecraft that need to manoeuvre in order to be compliant shall succeed with a probability of least 90%. On the other hand, Figure 17 shows the share of naturally compliant spacecraft over the total number of spacecraft reaching End-of-Life in the year of analysis.

Figure 18 shows the general rate of compliance for spacecraft in LEO considering the classification in main funding source introduced in Section 3.2. Figure 19 shows the general rate of compliance for spacecraft in LEO considering whether they belong to a constellation (see List of Definitions).

Finally, Figure 20 shows the general rate of compliance for upper stages targeting or crossing LEO.

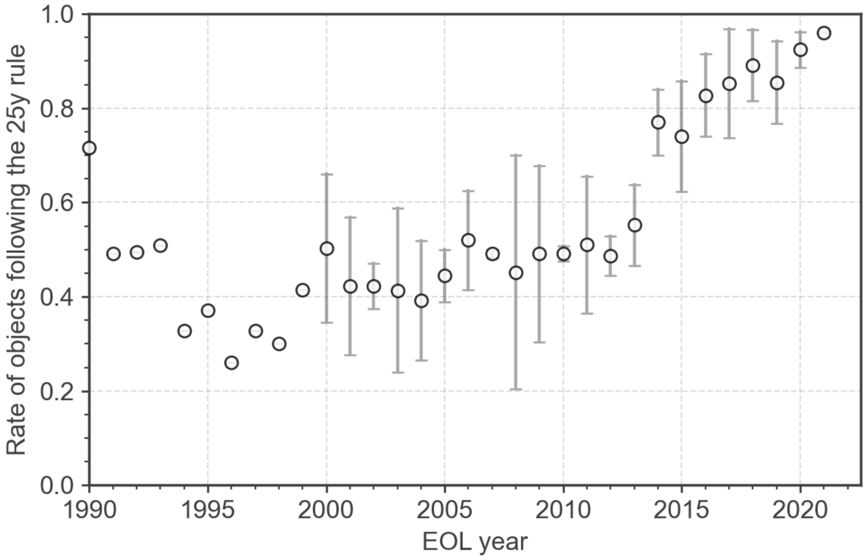

Figure 15 General rate of compliant spacecraft in LEO as assessed by the contributing agencies. This includes naturally compliant objects and successful disposal attempts.

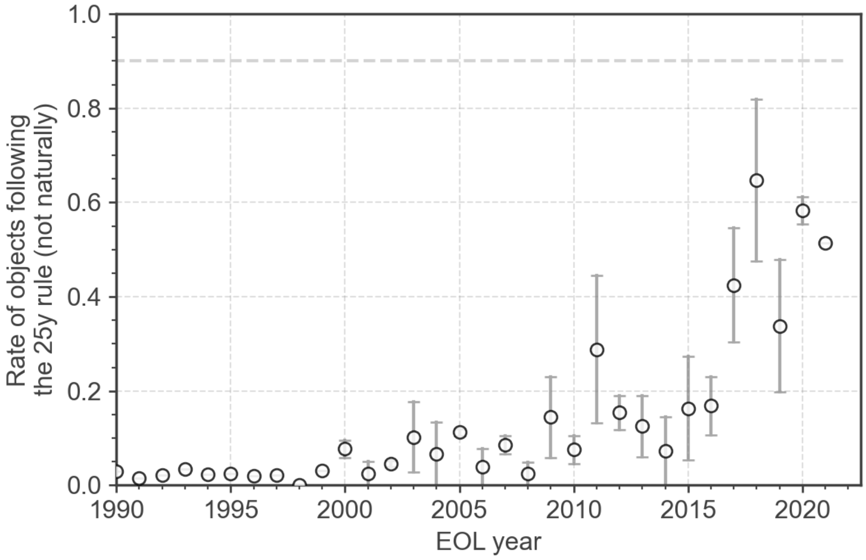

Figure 16 General rate of compliant spacecraft in LEO considering only not naturally compliant objects as assessed by the contributing agencies. The dashed horizontal line at 90% represents the minimum probability of success for disposal manoeuvres, as stated in the IADC guidelines.

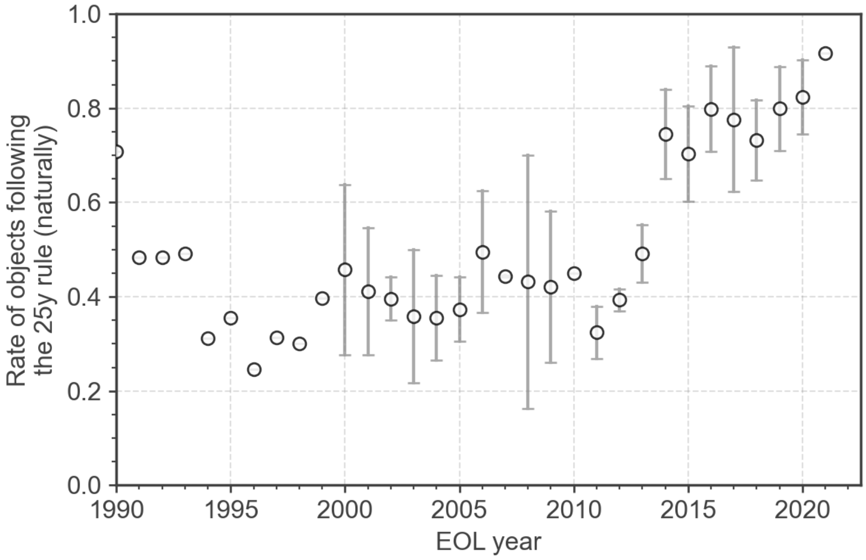

Figure 17 General rate of naturally compliant spacecraft in LEO over total as assessed by the contributing agencies.

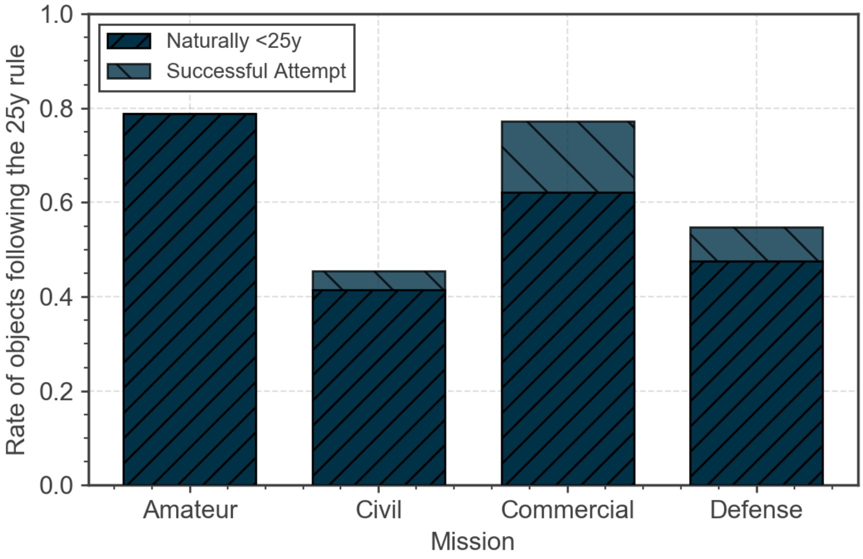

Figure 18 General compliance rate for spacecraft in LEO by mission type as assessed by the contributing agencies.

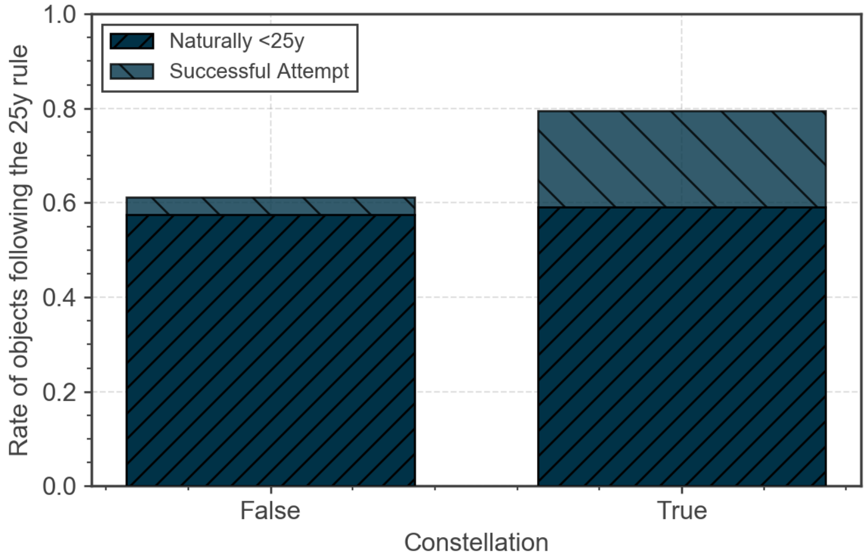

Figure 19 General compliance rate for constellation and non-constellation objects as assessed by the contributing agencies

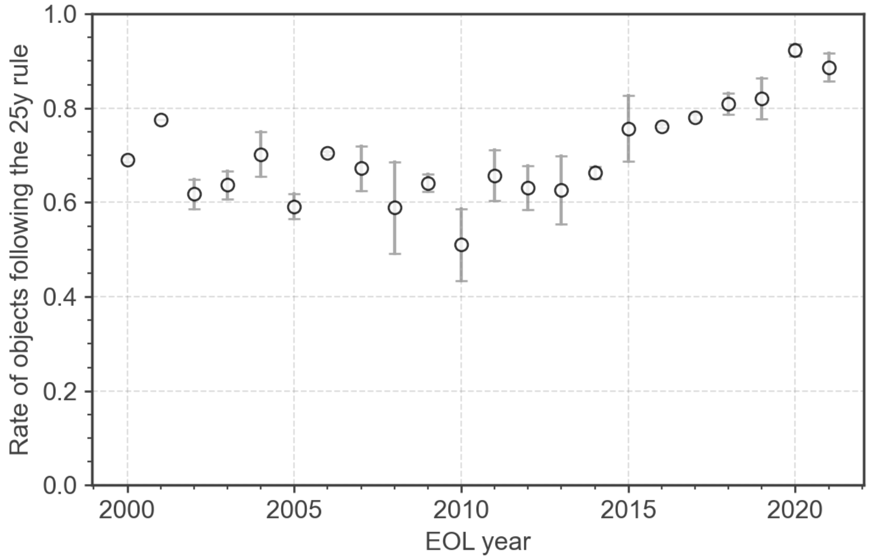

Figure 20 General rate of compliant orbital stages in LEO as assessed by the contributing agencies. This includes naturally compliant objects and successful disposal attempts.

5 Environment Evolution

The simulation of the future evolution of the debris population can be used to assess the efficacy of proposed mitigation actions and of current behaviours. In particular, two scenarios are presented in this section:

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

The definition of trends in launch traffic, explosion rates, and disposal success rates is based on the data available to the contributing agencies and on the analysis contained in this report. The same inputs are used for each simulated scenario, whereas each agency uses its own model for the simulation of the long-term evolution of the environment over 200 years, performing at least 100 Monte Carlo runs per scenario.

The parameters for the scenario definition are summarised hereafter.

For both scenarios, the reference population used for the analysis is an extraction of the DISCOS population at the reference epoch. For each object, physical characteristics such as mass, cross-sectional area, and orbital parameters are retrieved. For orbital stages and spacecraft, launch information is also stored. And for spacecraft specifically, it is also stored in which orbital region they are active and whether they belong to a constellation.

The yearly explosion rate is taken from the last decade statistics on non-system related fragmentations. In addition, for the *NFL* scenario, no explosion event is simulated after the first 18 years; indeed, it has been observed that 95% [3] of the non-system related fragmentation events occur within that time interval from launch.

For the *extrapolation* scenario, a launch traffic model is also needed as input for the simulations. This was obtained by repeating the launch traffic between 2017 and the reference epoch, discounting the contribution from constellations. For each of the constellations currently in orbit, a model of deployment and replenishment was defined using the publicly available data. A capability to successfully perform collision avoidance manoeuvres is assumed for as long as a spacecraft is active in the simulation.

A fixed operational lifetime of eight years is assumed for spacecraft not belonging to a constellation instead of the values derived in this report, in-line with current long-term space debris environment modelling practices. Specific values are used for spacecraft belonging to constellations, based on the available information on the current constellation designs where possible. Post-mission disposal success rates are derived from the observed values reported in Section 4.3, considering the performance for objects with End-Of-Life equal or later than 2015. A value of 90% is used for constellation objects, which is above the historically observed rates, but statistically valid rates could not yet be derived from the current active population. As such, it is set to the bare minimum identified in the IADC guidelines.

The evolution of the number of objects larger than 10 cm and the cumulative number of catastrophic collisions, i.e., collision leading to the complete destruction of target and impactor, are shown in Figure 21 and Figure 22: the dark line represents the mean value over all the Monte Carlo runs and the light coloured lines indicate the outcome of the single run. This representation was selected to visualise the variability across the single runs without introducing standard deviation bands as they may be not representative of the result distribution [4].

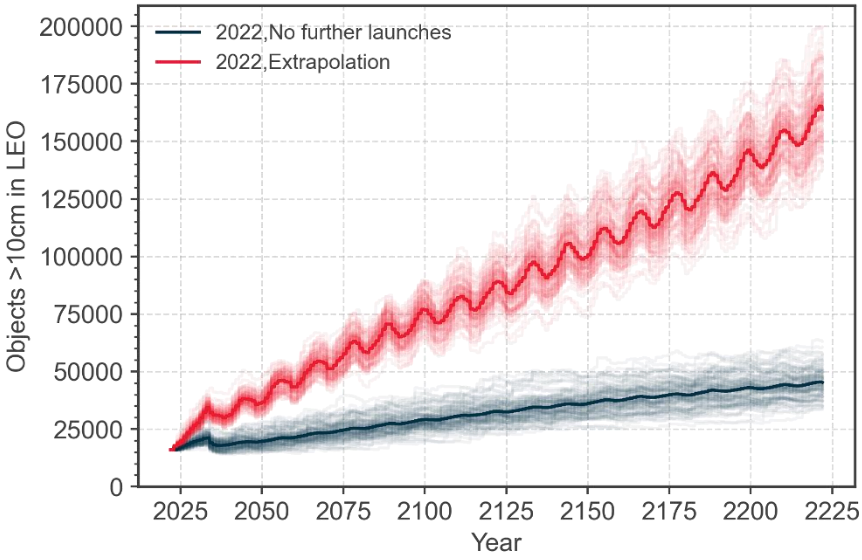

Figure 21 Number of objects larger than 10 cm in LEO in the simulated scenarios of long-term evolution of the environment.

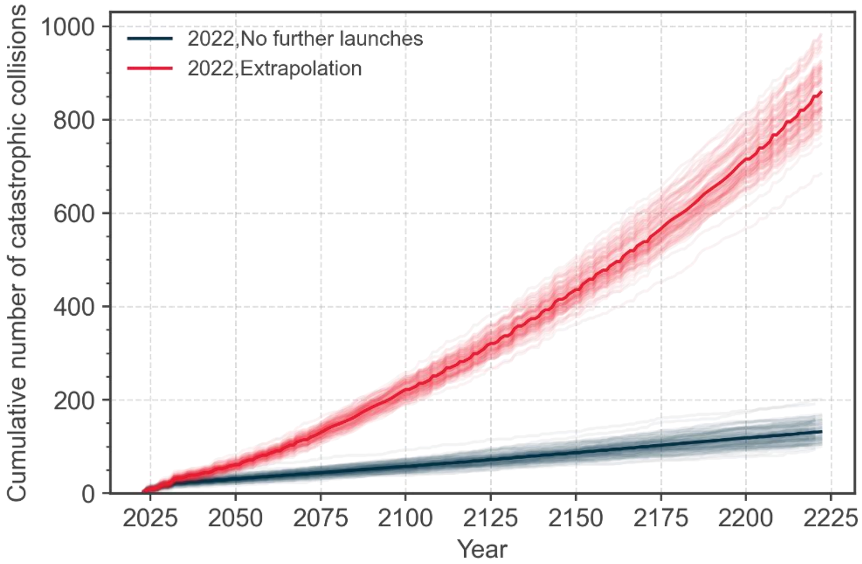

Figure 22 Cumulative number of catastrophic collisions in LEO in the simulated scenarios of long-term evolution of the environment.

Figure 23 and Figure 24 show a perspective of these scenarios focused on the first 25 years of simulation. While Figure 21 and Figure 22 give indications of the long-term environmental impact of space operations, Figure 23 and Figure 24 allow an analysis more oriented towards future operations in the next decades.

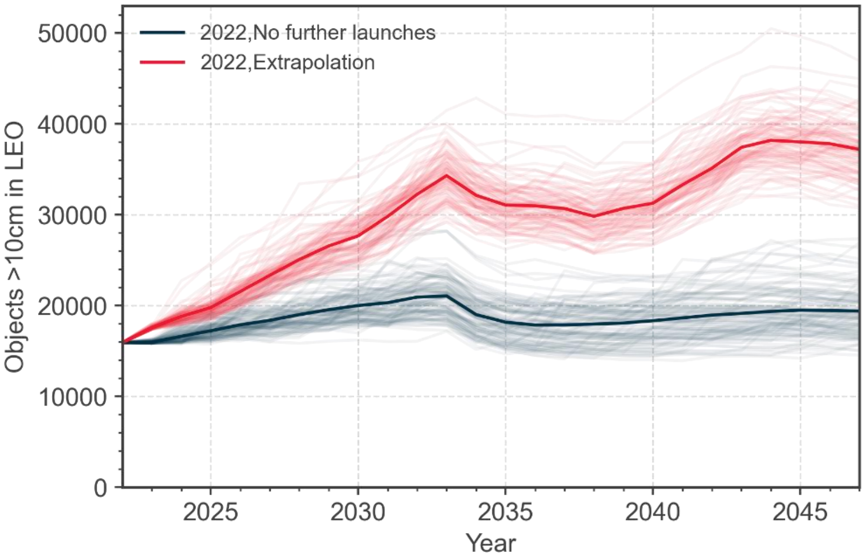

Figure 23 Number of objects larger than 10 cm in LEO in the simulated scenarios of long-term evolution of the environment – zoom over the first 25 years of simulation.

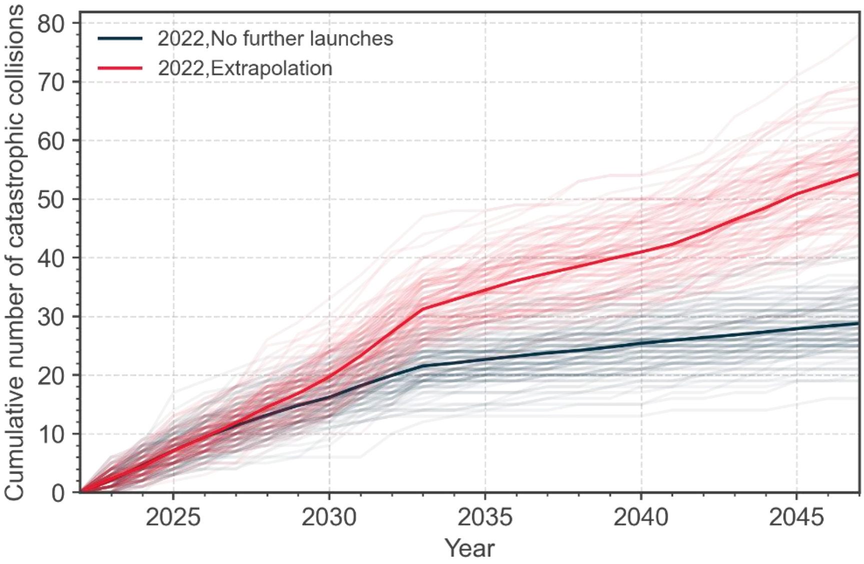

Figure 24 Cumulative number of catastrophic collisions in LEO in the simulated scenarios of long-term evolution of the environment – zoom over the first 25 years of simulation.

6 Sustainable space environment

The United Nations has previously defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Building upon this, the IADC is performing work to set metrics to define a sustainable space environment. It is hoped that future releases of this report will include the outcome of this work and this section will build upon this research by providing a quantitative interpretation of the space environment status and forecasts. Ahead of this and using the results provided in this report, the following observations can be made concerning the current and future state of the space environment:

- The most significant change in the launch traffic has been seen in LEO, principally from 2010, due to the deployment of large constellations and a shift towards commercial operators, as shown in Figure 3 and Figure 4;
- The widespread adoption of the IADC space debris mitigation guidelines and the IADC recommendations for large constellations of satellites continue to remain the most effective method to reduce the long-term environmental impacts of global space activity by slowing the rate of growth of the space debris population observed;
- With an increasing number of active satellites collision avoidance is also becoming increasingly important;
- Adoption of the IADC space debris mitigation guidelines is not yet at a level that is sufficient to induce substantial benefits or slowing of the population growth;
- With the current level of adoption of the IADC guidelines and recommendations, the extrapolation of current space launch activity could lead to the rapid growth of the orbital object population. The environmental evolution results in Section 5 identified that a doubling of the space debris population may occur within 25 years and an increase of 10 times over the longer term due to an increasing rate of catastrophic collisions;
- Critically, in the case of no further launches into orbit, it is expected that collisions among space debris objects already present will lead to a further growth in space debris population;
- The IADC continues to encourage widespread adoption of the IADC guidelines and its recommendations. However, even with widespread adoption of these guidelines and recommendations, or even stricter behaviours, the consensus is that the environmental impacts cannot be removed completely and additional steps may need to be taken, such as enabling the technology for active debris removal;
- Further research and discussions are encouraged within the global community to develop a consensus view on the definition of a sustainable space environment. The IADC will continue to perform research in this area and will provide regular releases of this environment report to support these discussions.

7 References

[1] IADC, "IADC Space Debris Mitigation Guidelines," 2021.

[2] IADC, IADC - Status of the Environment: Supporting document, 2023.

[3] ESA Space Debris Office, "ESA's Annual Space Environment Report (GEN-DB-LOG-00288-OPS-SD)," 2022.

[4] A. A. Lidtke, H. G. Lewis and R. Armellin, "Statistical analysis of the inherent variability in the results of evolutionary debris models," *Advances in Space Research,* vol. 59, no. 7, p. 1698–1714, 2017.

[5] S. Lemmens, B. Bastida Virgili, V. Braun, T. Flohrer, Q. Funke, H. Krag, F. McLean and K. Merz, "End-of-Life to Impact on Ground: An Overview of ESA's Tools and Techniques to Predict Re-entries from the Operational Orbit to the Earth's Surface," in *6th International Conference on Astrodynamics Tools and*, Darmstadt, 2016.

[6] IADC WG4, "Support to the IADC Space Debris Mitigation Guidelines," 2021.

[7] C. Le Fèvre, H. Fraysse, V. Morand, A. Lamy, C. Cazaux, P. Mercier, C. Dental, F. Deleflie and D. A. Handschuh, "Compliance of disposal orbits with the French Space," *Acta Astronautica,* vol. 94, no. 1, pp. 234-245, 2014.