KiboCUBE Academy

Lecture 20

Introduction to Space Debris Problem and Countermeasures

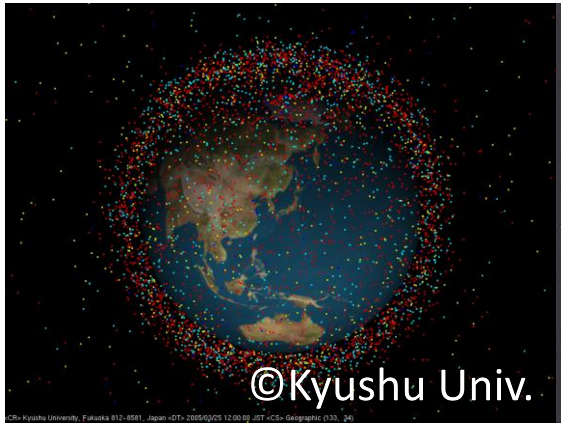
Kyushu University

Department of Aeronautics and Astronautics

Professor Dr. Toshiya HANADA

This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

Lecturer Introduction



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Position:

2022 - Vice Director (add.) at the International Center for Space and Planetary Environmental Science, Kyushu University

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Research Topics:

Long-term Sustainability of Outer Space Activities, Space Debris Modeling, Space Situational Awareness

Contents

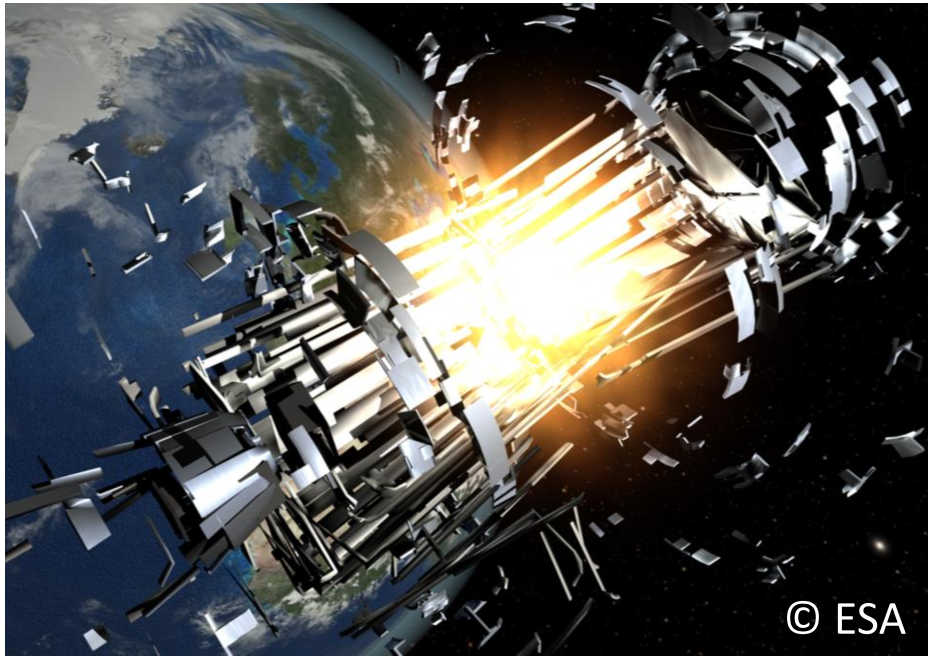
1. Introduction

1. Introduction

What Is Space Debris?

All non-functional and human made space objects

- Fragmentation debris
  - ✓ satellites break up due to unused fuel, dead batteries, etc.
  - ✓ production of deterioration such as paint flakes, thermal blankets, etc.
- Rocket bodies
- Mission-related debris
  - ✓ refuse from human missions
  - ✓ objects released from spacecraft
  - ✓ deployment and operation
- Non-functional spacecraft

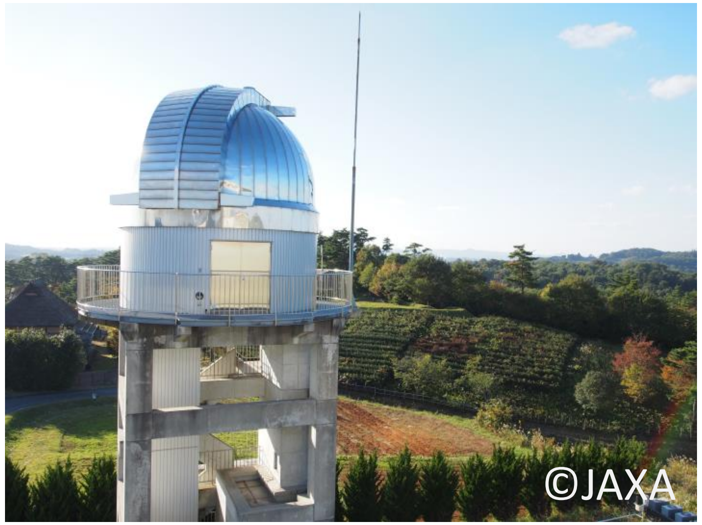


1. Introduction

How Do We Find the Space Debris?

Radar and Optical Measurements (for objects > 0.2 cm)

- ☐ Stare at the sky using a telescope and look at what flies through the field of view
- ☐ Objects that are bright or big can be observed from the ground
  - ✓ Objects > 10 cm are followed (tracked), so that spacecraft can maneuver away from those objects
  - ✓ Objects between 0.2 and 10 cm are observable but not tracked (too small to predict orbit accurately)



1. Introduction

How Much Space Debris Is Out There?

5 728 launches have been conducted since the launch of Sputnik 1 (October 5th, 1957)

The total number of space objects catalogued is 49 695

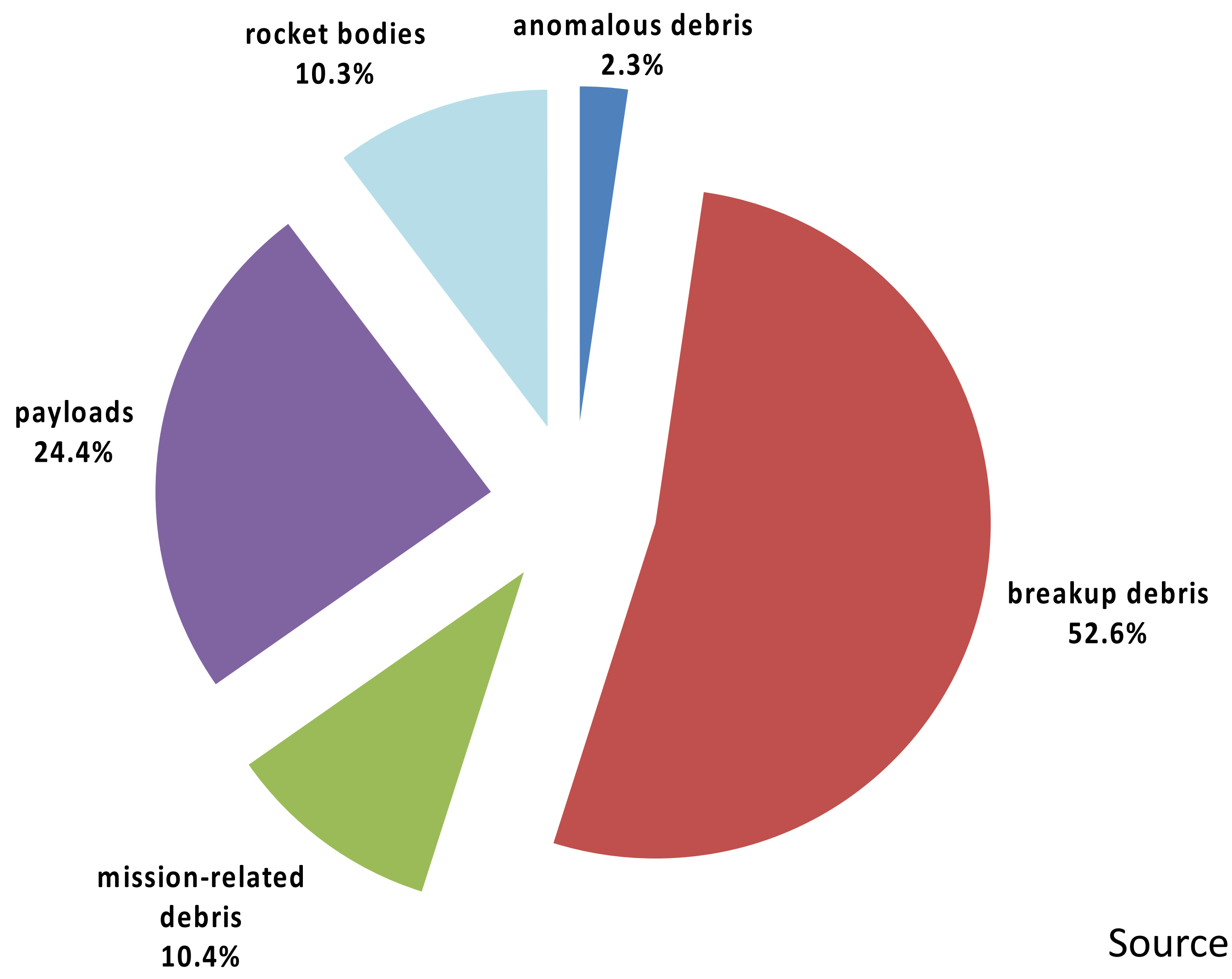
Approximately 24 000 of them are still orbiting the Earth

It is estimated that there are 5 100 satellites in operation.

SPACE-TRACK.ORG, https://www.space-track.org/ (accessed December 1st, 2021)

1. Introduction

Relative Segments of the Cataloged In-orbit Earth Satellite Population



As of July 4th, 2018

Source: NASA/TM–2018–220037

1. Introduction

How Long Will Space Debris Remain in Earth Orbit?

The answer to this question depends upon the altitude of the orbit

- A few days if the altitude is less than 200 km
- A few years if the altitude is between 200 and 600 km
- Decades if the altitude is between 600 and 800 km
- Centuries if the altitude is greater than 800 km
- Forever if the altitude is 36,000 km or greater

Vanguard 1, the world oldest known piece of space debris, launched on 17 March 1958 to observe the Earth’s oblateness, continental drift, and upper atmospheric drag.

1. Introduction

Example of Fragmentation Experiment

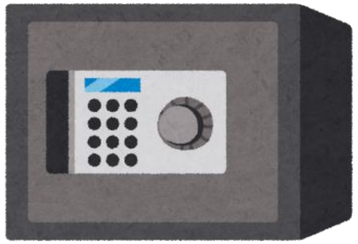
1. Introduction

Dangerous Even If Small

1 cm aluminum sphere (similar to a nickel in size) @ 10 km/sec (36 000 km/hr) = energy which compares to:

- ☐ a sport utility vehicle (SUV) traveling at 40 km/hr

- ☐ a 30 kg safe hitting you at 250 km/hr

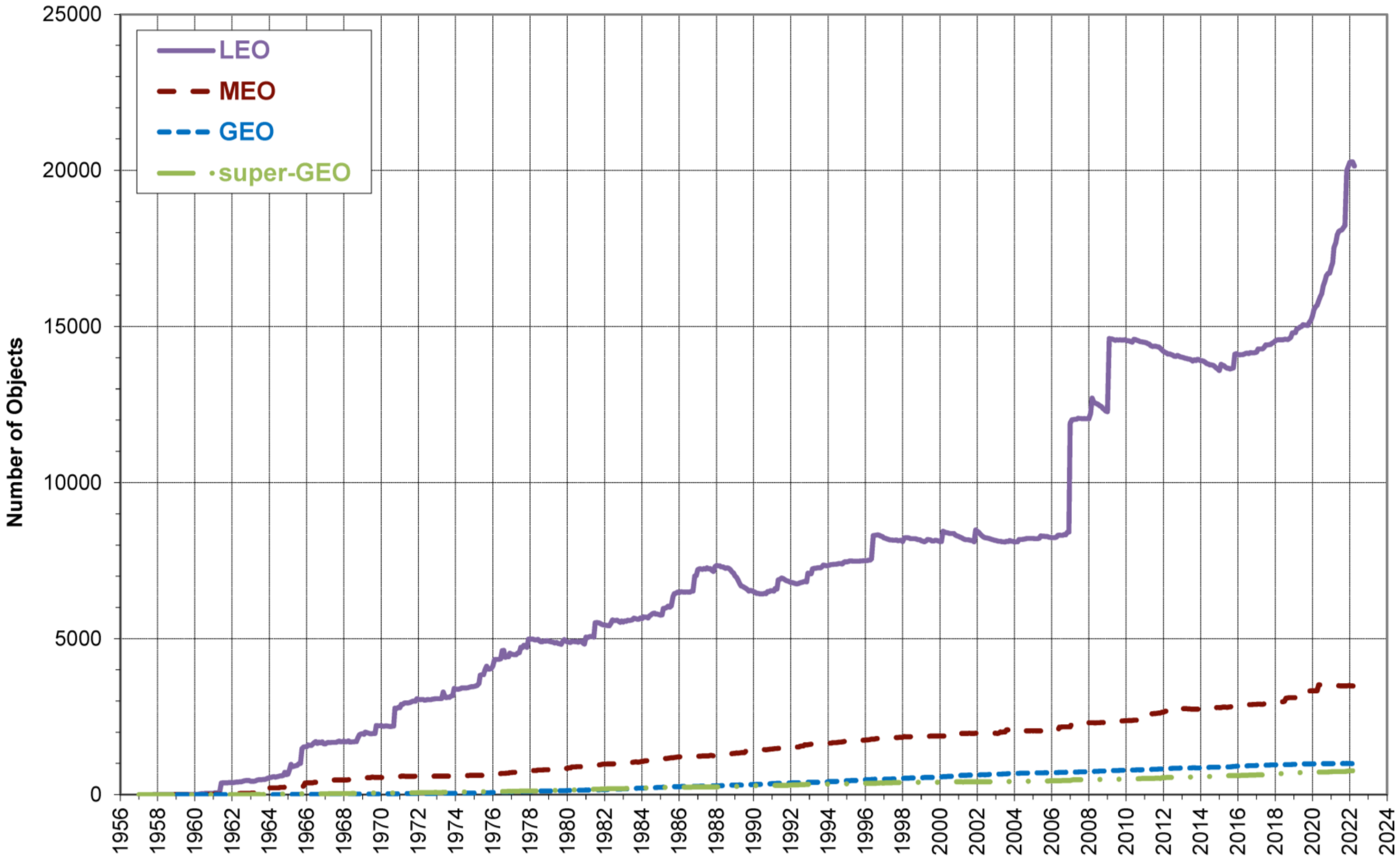


- ☐ a bowling ball hitting you at 500 km/hr

2. Current Situation

2. Current Situation

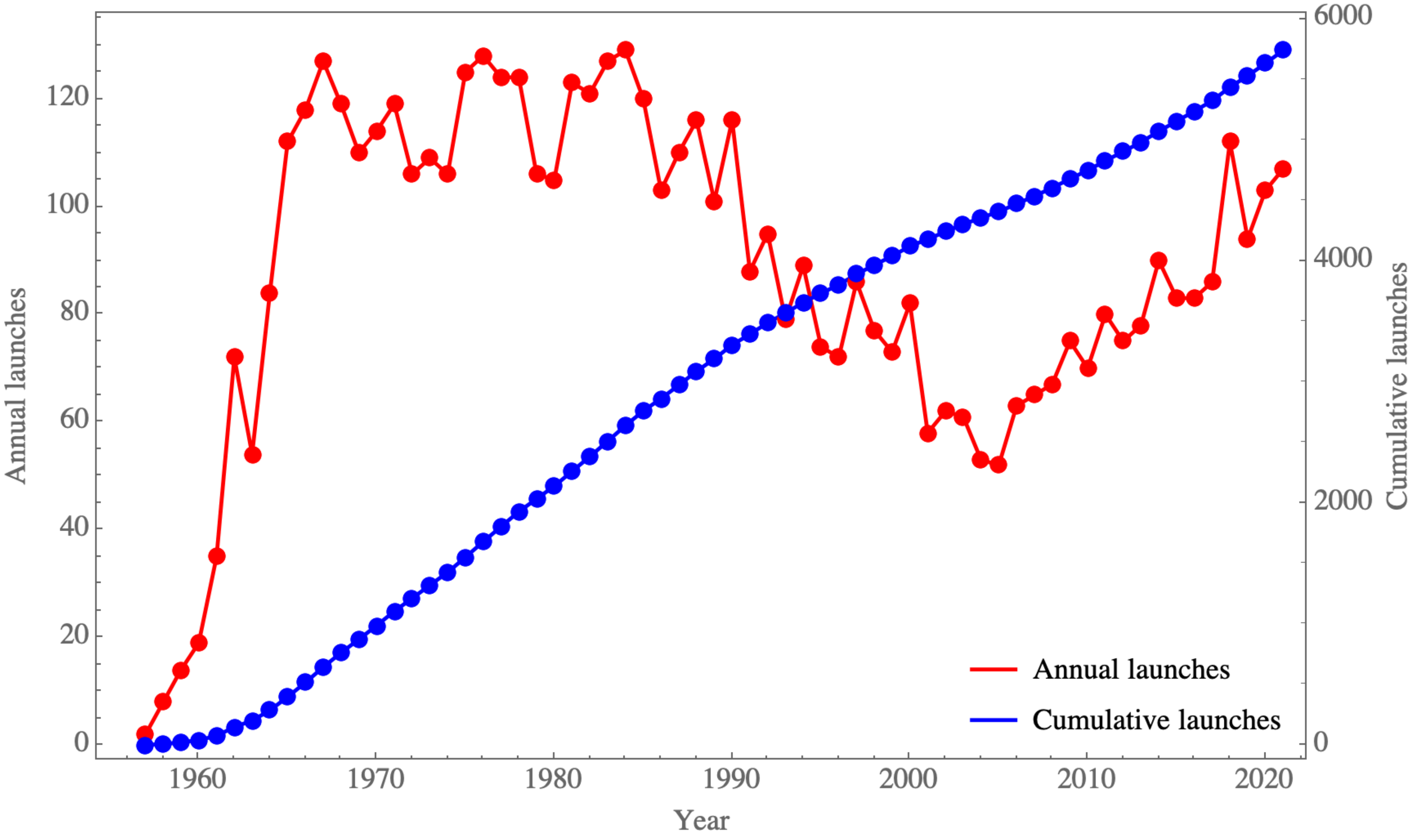
Monthly Effective Number of Objects in Earth Orbit



Source: NASA ODQN Vol.26, Issue 2

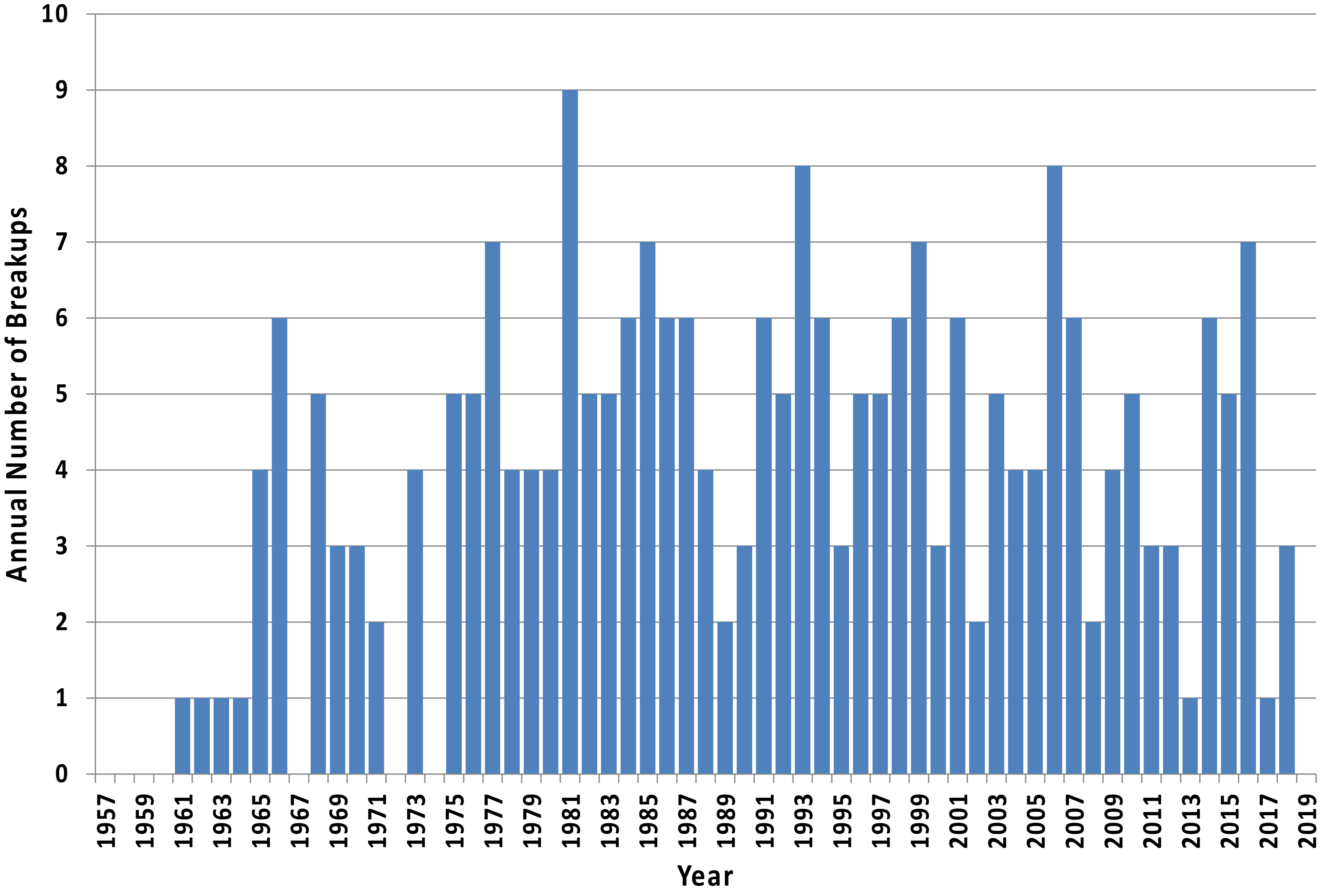
2. Current Situation

Annual and Cumulative Launches



2. Current Situation

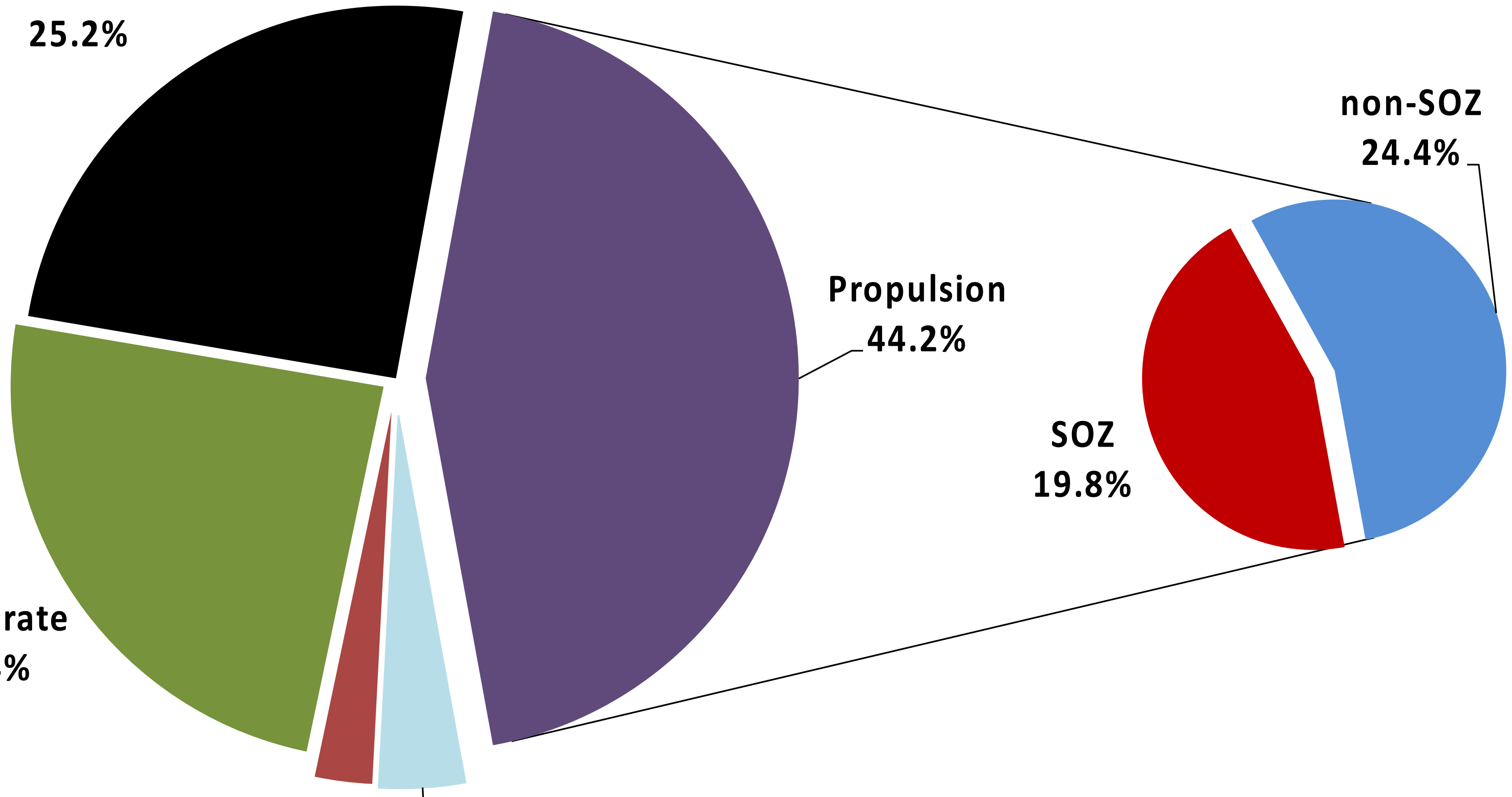
Number of Breakups by Year since 1961



Source: NASA/TM–2018–220037

2. Current Situation

Causes of Known Satellite Breakups



As of July 4th, 2018

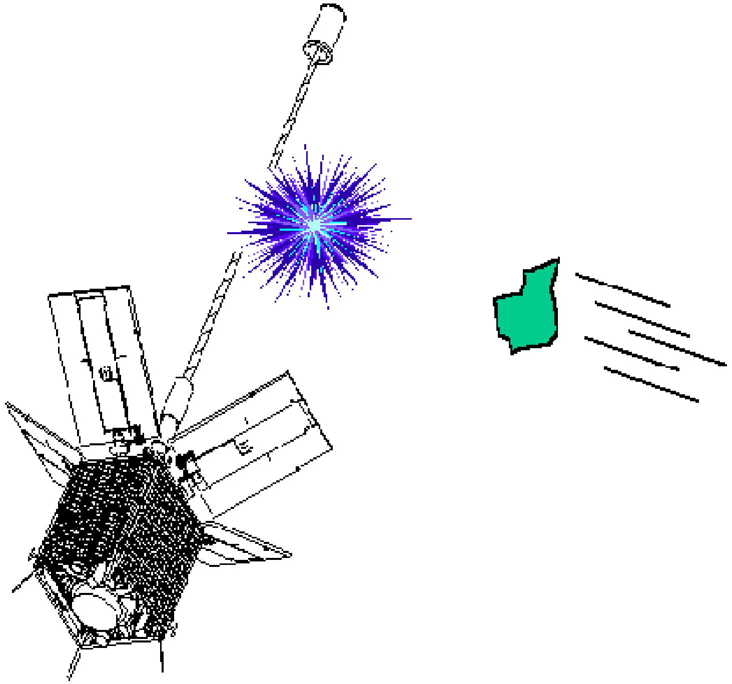
Source: NASA/TM–2018–220037

2. Current Situation

First Identified Accidental Collision between Two Catalogued Objects

French Cerise (active communication satellite) collided with a fragment of debris from a French Ariane 1 rocket body on 24 July 1996

- 6-meter-long stabilization boom was severed
- Fragment was
  - ✓ size of a briefcase
  - ✓ traveling at a relative velocity of 14 km/sec
- Following the collision, the satellite’s on-board computer was reprogrammed for attitude control

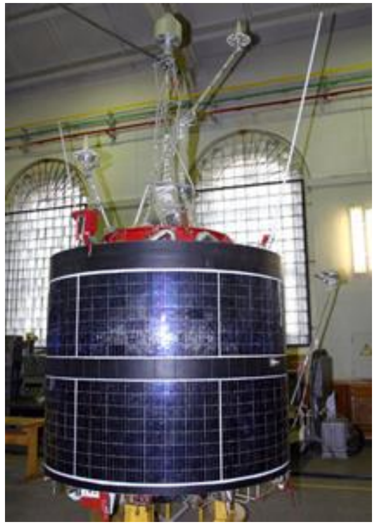


2. Current Situation

First Ever Accidental Collision between Two Intact Objects

U.S. Iridium 33 (commercial communication satellite) and Russian Cosmos 2251 (defunct communications relay station) ran into each other above northern Siberia on 10 February 2009

- They were traveling at a relative velocity of 11.6 km/sec
- By 1st August 2022, the United States Space Surveillance Network (SSN) had officially catalogued 2 369 fragments
- Estimated number of fragments > 1 cm in diameter are > 62 000
- The event highlighted the orbital debris problem in the low Earth orbit (LEO) region



Source: NASA ODQN Vol.13, Issue 3

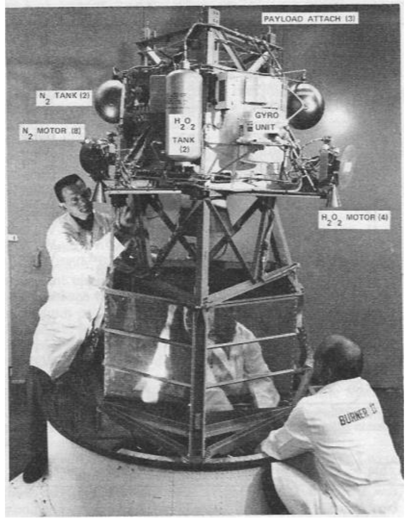
2. Current Situation

Three More Accidental Collisions between Cataloged Objects

Thor Burner 2A rocket body collided with a fragment of debris from a Long March 4 rocket body on 17 January 2005.

Cosmos 1934 (non-functional navigation satellite) collided with a fragment of debris from Cosmos 926 (also non-functional navigation satellite) in late December 1991.

BLITS (small laser-ranging retroreflector satellite) collided with a fragment of debris from Fengyun 1C satellite in January 2013.



Source: NASA ODQN Vol.9, Issue 2

2. Current Situation

Known Accidental Collisions in Space

Year	
1991	Inactive Cosmos 1934 satellite hit by cataloged debris from Cosmos 296 satellite
1996	Active French Cerise satellite hit by cataloged debris from Ariane rocket stage
1997	Inactive NOAA 7 satellite hit by uncatalogued debris large enough to change its orbit and create additional debris
2002	Inactive Cosmos 539 satellite hit by uncatalogued debris large enough to change its orbit and create additional debris
2002	Active JASON-1 satellite hit by uncatalogued debris large enough to change its attitude and create additional debris
2005	U.S. rocket body hit by cataloged debris from Chinese rocket stage
2007	Active Meteosat 8 satellite hit by uncatalogued debris large enough to change its orbit
2007	Inactive NASA UARS satellite believed hit by uncatalogued debris large enough to create additional debris
2009	Active Iridium 33 satellite hit by inactive Cosmos 2251
2013	Active BLITS satellite hit by cataloged debris from Fengyun 1C satellite
2014	Active Iridium 47 satellite believed hit by uncatalogued debris large enough to create additional debris

3. Future Concern

3. Future Concern

What Is Chain Reaction?

The **Chain Reaction** is a scenario in which the density of objects in low Earth orbit (LEO) is high enough that collisions between objects could cause a cascade—each collision generates space debris that increases the likelihood of further collisions.

- Proposed by Prof. Dr. Dietrich Rex from Braunschweig University of Technology in Germany
- Called **Collisional Cascading** by the NASA scientist Donald J. Kessler

One implication is that the distribution of debris in orbit could render space activities and the use of satellites in specific orbital ranges unfeasible for many generations.

3. Future Concern

What May Cause the Chain Reaction?

Source ＝ **Debris generation**

- Launch, collision, explosion, disintegration

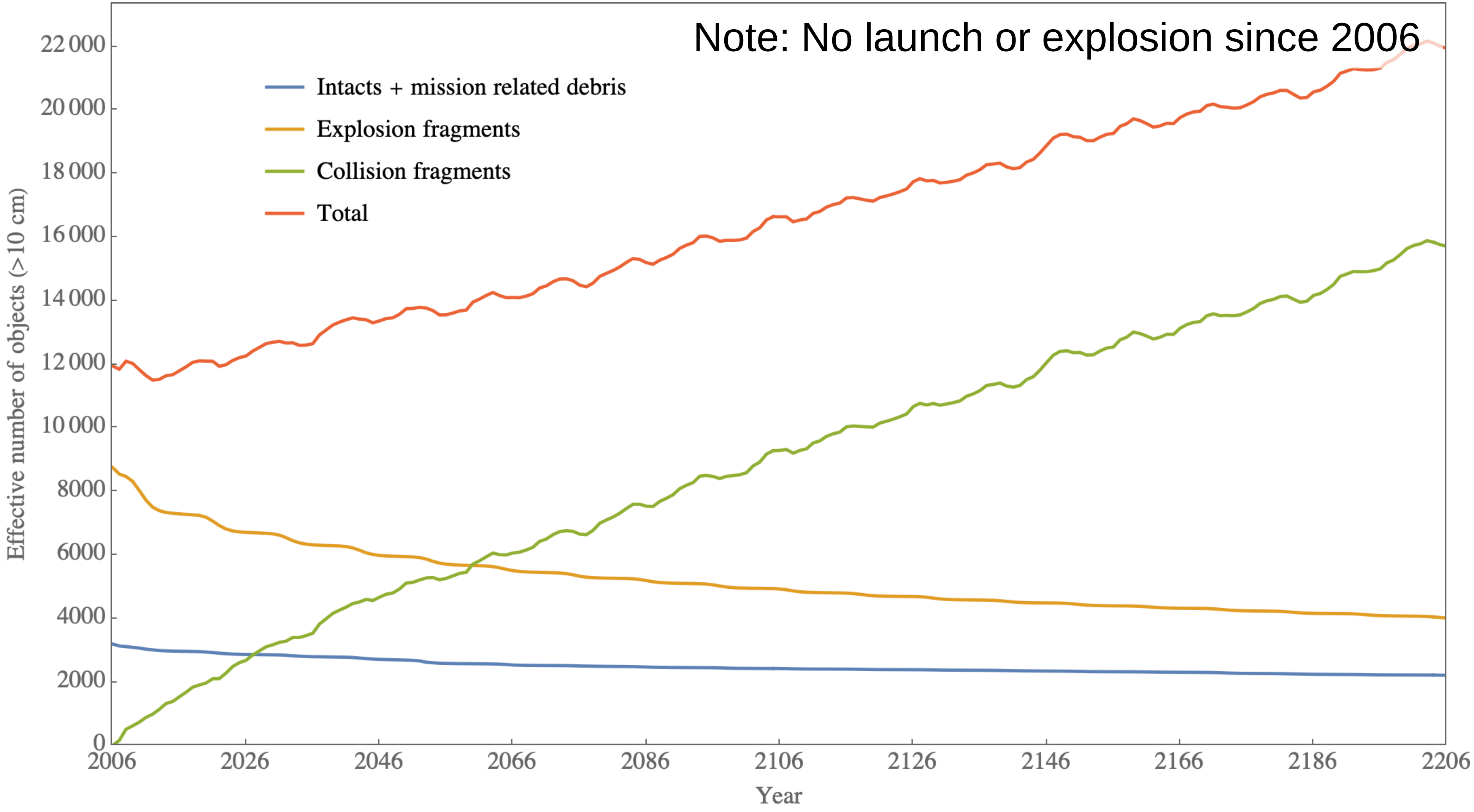
Sink ＝ **Debris reduction**

- Natural decay due to upper atmosphere
- Return to the ground, or escape from the Earth’s gravity

Source > Sink may cause Chain Reaction.

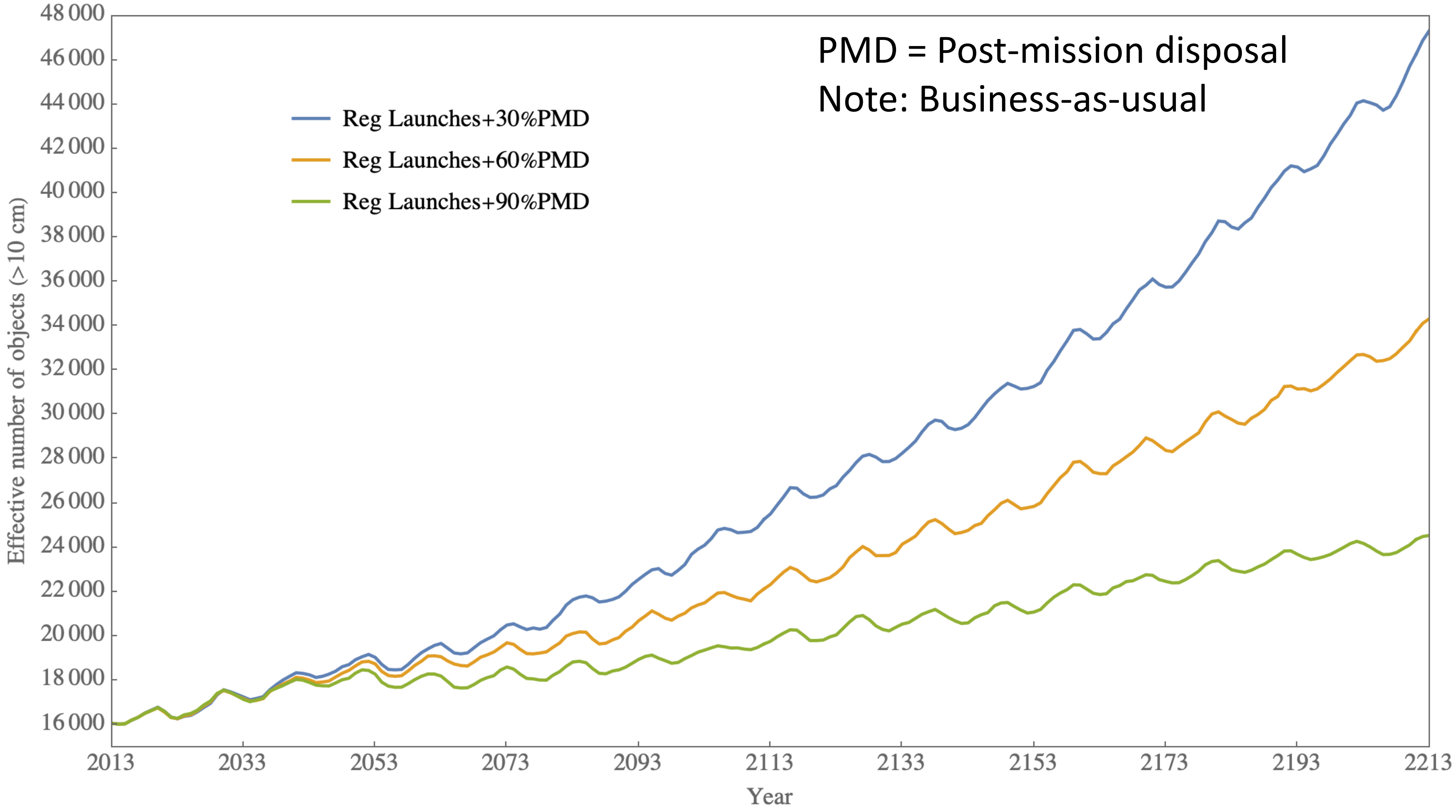
3. Future Concern

Instability of the Current LEO Environment



3. Future Concern

Effectiveness of Space Debris Mitigation



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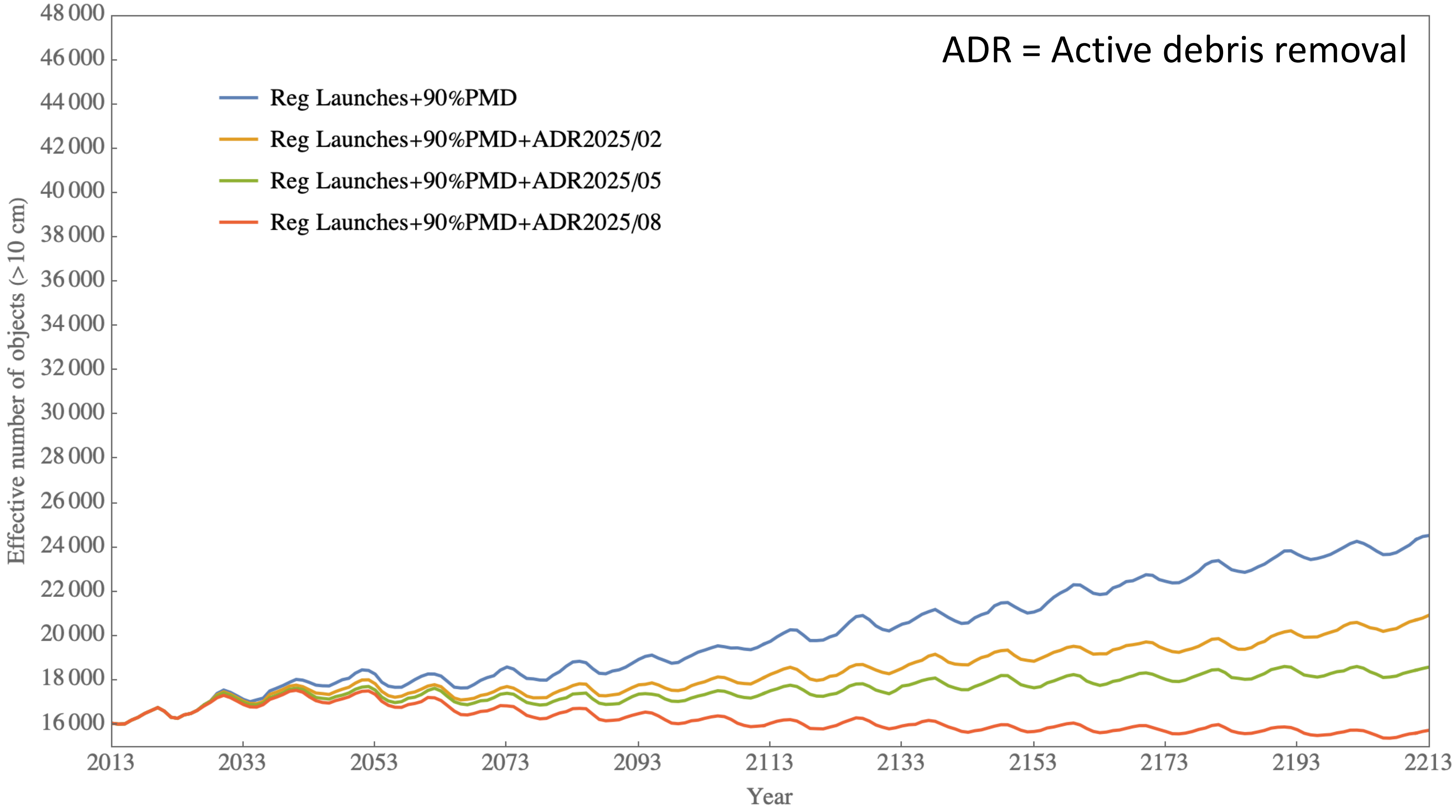
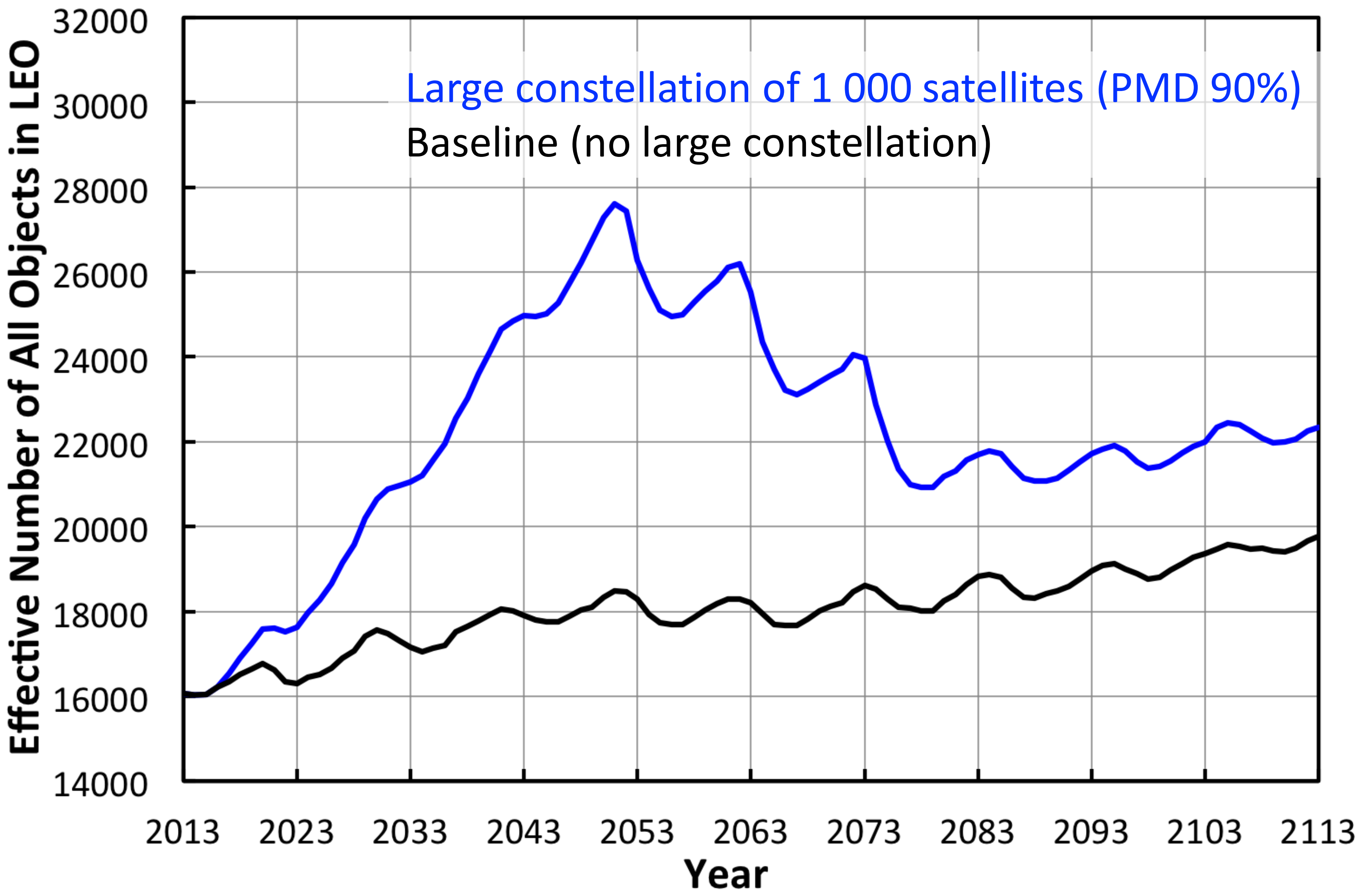
3. Future Concern

Effectiveness of Environmental Remediation



3. Future Concern

Impact of Large Constellations



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4. Guidelines

IADC Space Debris Mitigation Guidelines

The IADC Space Debris Mitigation Guidelines describe existing practices that have been identified and evaluated for limiting the generation of space debris in the environment.

The Guidelines cover the overall environmental impact of the missions with a focus on the following measures:

- Limit Debris Released during Normal Operations
- Minimize the Potential for On-Orbit Break-ups
- Post-mission Disposal
- Prevention of On-Orbit Collisions

IADC-02-01 Rev. 3
June 2021

Inter-Agency Space Debris Coordination Committee

IADC Space Debris Mitigation Guidelines

Issued by IADC Steering Group and Working Group 4

https://www.iadc-home.org/documents_public/file_down/id/5249

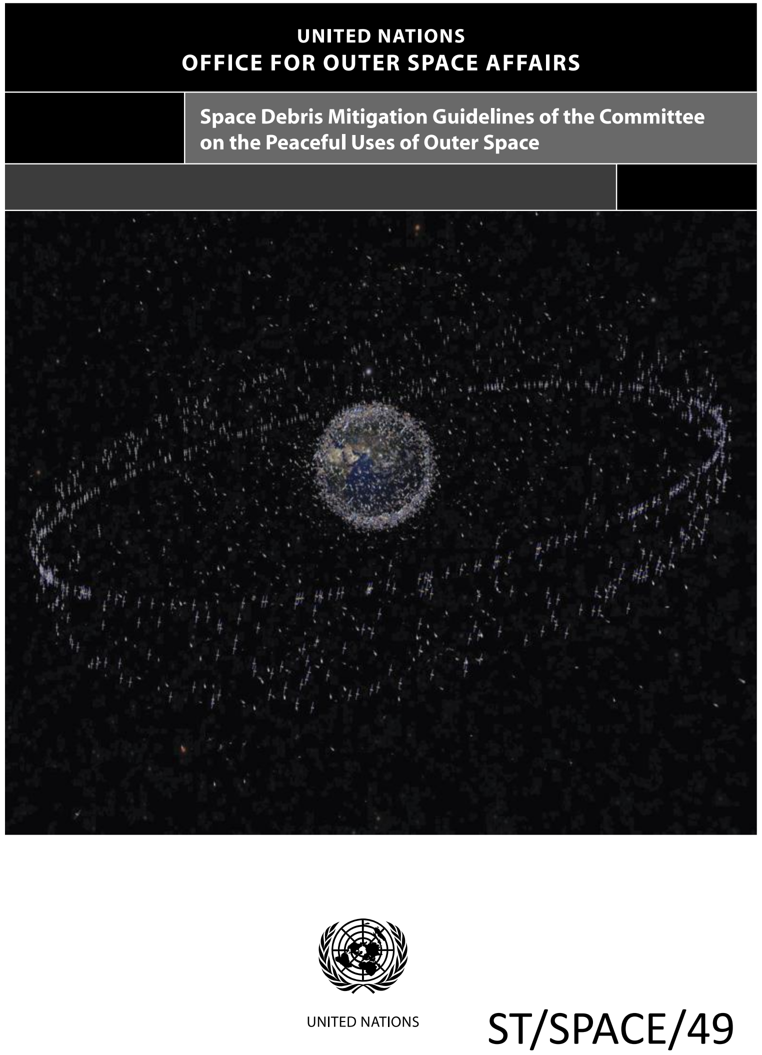
4. Guidelines

UNCOPUOS Space Debris Mitigation Guidelines

The Scientific and Technical Subcommittee (STSC) of the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) developed a set of recommended guidelines based on the technical content and the basic definitions of the IADC space debris mitigation guidelines, taking into consideration the UN treaties and principles on outer space.

The guidelines were adopted by consensus in February 2007, and the full COPUOS endorsed the guidelines in June 2007, followed by General Assembly endorsement later in 2007.

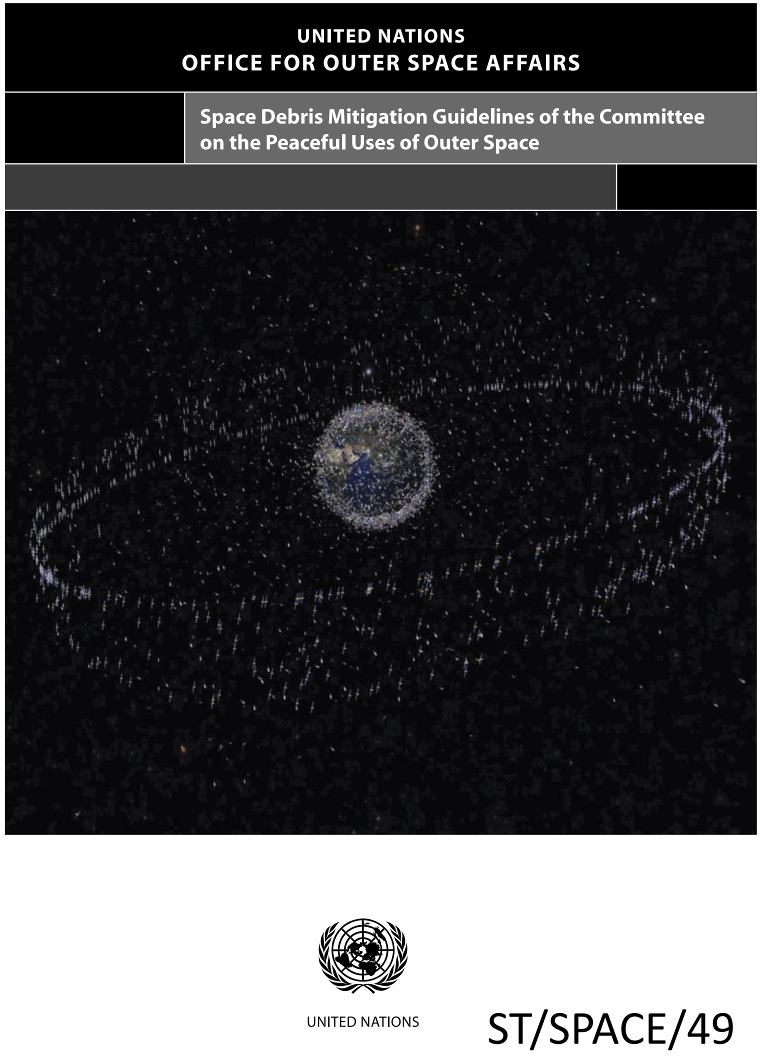
The space debris mitigation guidelines of the STSC of the UNCOPUOS consist of seven guidelines to be considered for the mission planning, design, manufacturing and operational (launch, mission and disposal) phases of spacecraft and launch vehicle orbital stages.



UNCOPUOS Space Debris Mitigation Guidelines, cont'd

Guideline 1: Limit debris released during normal operations

Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.

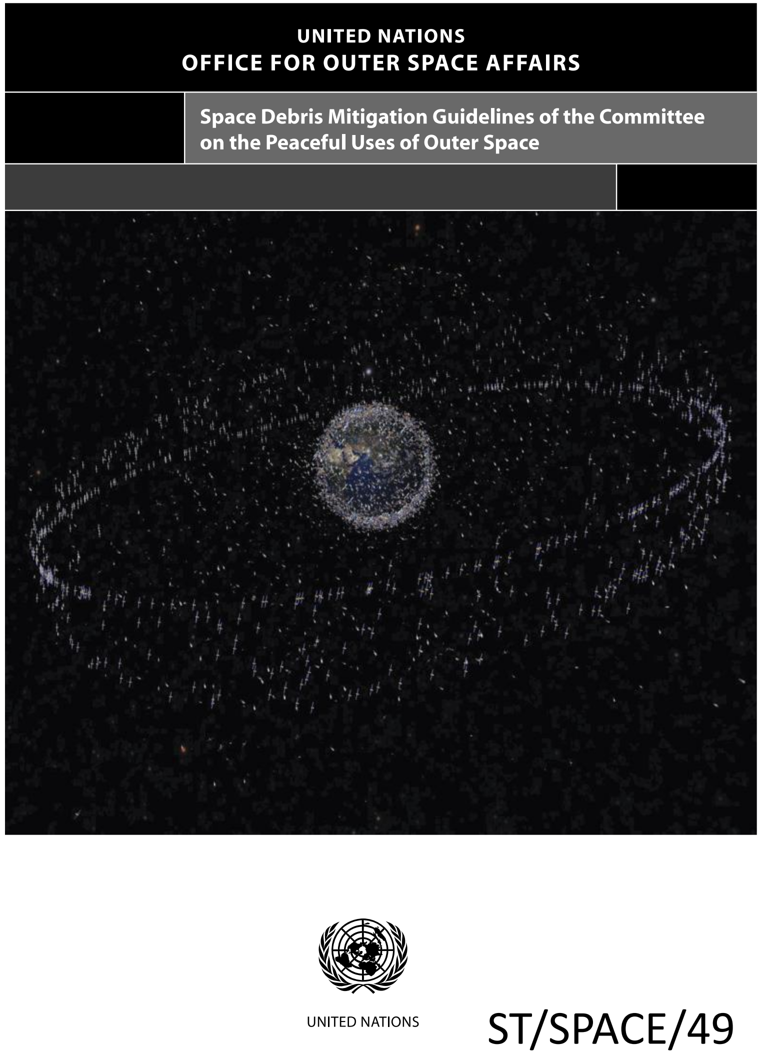


4. Guidelines

UNCOPUOS Space Debris Mitigation Guidelines, cont’d

Guideline 2: Minimize the potential for break-ups during operational phases

Spacecraft and launch vehicle orbital stages should be designed to avoid failure modes which may lead to accidental break-ups. In cases where a condition leading to such a failure is detected, disposal and passivation measures should be planned and executed to avoid break-ups.



4. Guidelines

UNCOPUOS Space Debris Mitigation Guidelines, cont'd

Guideline 3: Limit the probability of accidental collision in orbit

In developing the design and mission profile of spacecraft and launch vehicle stages, the probability of accidental collision with known objects during the system's launch phase and orbital lifetime should be estimated and limited. If available orbital data indicate a potential collision, adjustment of the launch time or an on-orbit avoidance maneuver should be considered.

UNITED NATIONS

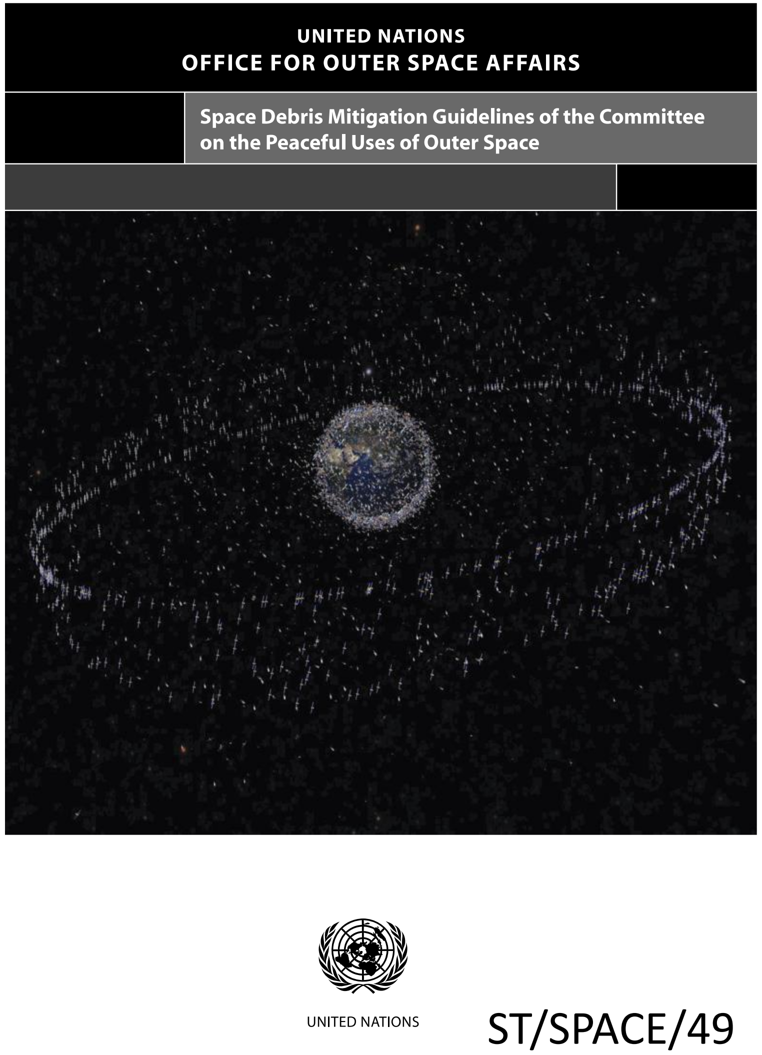
ST/SPACE/49

4. Guidelines

UNCOPUOS Space Debris Mitigation Guidelines, cont'd

Guideline 4: Avoid intentional destruction and other harmful activities

Recognizing that an increased risk of collision could pose a threat to space operations, the intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided. When intentional break-ups are necessary, they should be conducted at sufficiently low altitudes to limit the orbital lifetime of resulting fragments.



Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy

In order to limit the risk to other spacecraft and launch vehicle orbital stages from accidental break-ups, all on-board sources of stored energy should be depleted or made safe when they are no longer required for mission operations or post-mission disposal.

UNITED NATIONS

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4. Guidelines

UNCOPUOS Space Debris Mitigation Guidelines, cont’d

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission

Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the LEO region should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits that avoid their long-term presence in the LEO region.

UNITED NATIONS

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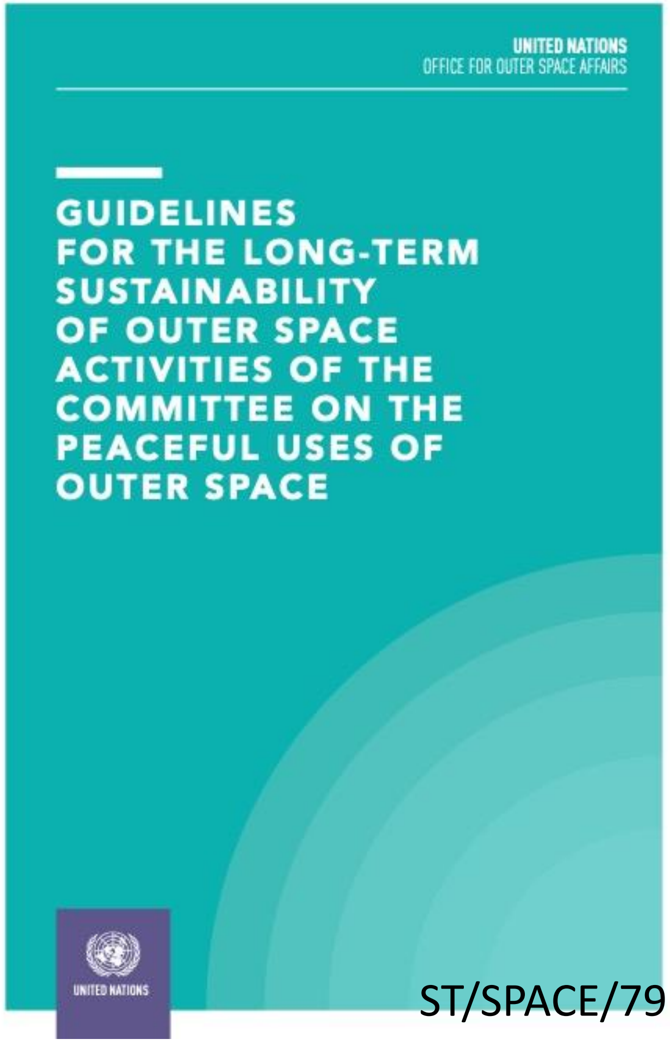
UNCOPUOS LTS Guidelines

The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) adopted, by consensus, a preamble and 21 Guidelines, demonstrating how States collaborate multilaterally to prioritize space sustainability.

The Guidelines for the long-term Sustainability of Outer Space comprise a compendium of internationally recognized measures for, and commitments to, ensuring the long-term sustainability of outer space activities.

The preamble of the Guidelines defines the long-term sustainability of outer space activities, explains their voluntary and non-legally binding status, and shares how the guidance they provide is to be reviewed and update.



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5. Tools Available

NASA DAS 3.2 - Debris Assessment Software

The NASA Debris Assessment Software (DAS) utility provides assessments that can verify compliance of a spacecraft, upper stage, and/or payload with NASA's requirements for limiting debris generation, spacecraft vulnerability, **post-mission lifetime**, and entry safety. Successful verification of a design in DAS demonstrates compliance with NASA debris mitigation requirements. Historically, DAS analysis has proven acceptable in meeting compliance requirements of many other agencies in the U.S. and around the world. It does not address the inherent design reliability facets of NASA requirements but addresses all Earth-related orbital debris requirements that make up the bulk of the requirements in the NASA Technical Standard 8719.14C.

ESA DRAMA - Debris Risk Assessment and Mitigation Analysis

The ESA Debris Risk Assessment and Mitigation Analysis (DRAMA) is a comprehensive tool for the compliance analysis of a space mission with space debris mitigation standards. For a given space mission, DRAMA allows analysis of:

- Debris and meteoroid impact flux levels (at user-defined size regimes)
- Re-orbit and de-orbit fuel requirements for a given initial orbit and disposal scenario
- Geometric cross-section computations
- Re-entry survival predictions for a given object of user-defined components
- The associated risk on ground for at the resulting impact ground swath

5. Tools Available

CNES STELA - Semi-analytic Tool for End-of-life Analysis

The CNES Semi-analytic Tool for End-of-life Analysis (STELA) has been designed to support the French Space Operations Act. It reflects the standard concerning the protection of LEO and GEO regions (lifetime and protected regions crossing of disposal orbits) and provides the user with tools to assess compliance with the requirements. The software allows efficient long-term propagation of LEO, GEO, and GTO based on a semi-analytical models and assessment of protected regions criteria. STELA produces a report file that summarizes the computation (spacecraft characteristics, initial and final orbits, computation parameters, criteria status) and optionally an ephemeris file.

Note: CNES is an acronym for the French Space Agency.

5. Tools Available

NASA ORDEM 3.2 - Orbital Debris Engineering Models

The NASA Orbital Debris Engineering Model (ORDEM) is appropriate for those engineering solutions requiring knowledge and estimates of the orbital debris environment (debris flux, impact directionality, etc.). The latest version, ORDEM 3.2 has been updated to include fragments from the Cosmos 1408 anti-satellite test conducted by the Russian Federation on 15 November 2021.

5. Tools Available

ESA MASTER - Meteoroid and Space Debris Terrestrial Environment Reference

The ESA Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) allows to assess the debris or meteoroid flux imparted on a spacecraft on an arbitrary earth orbit. MASTER also provides the necessary computational and data reference for ESA DRAMA and needs to be installed before ESA DRAMA is installed.

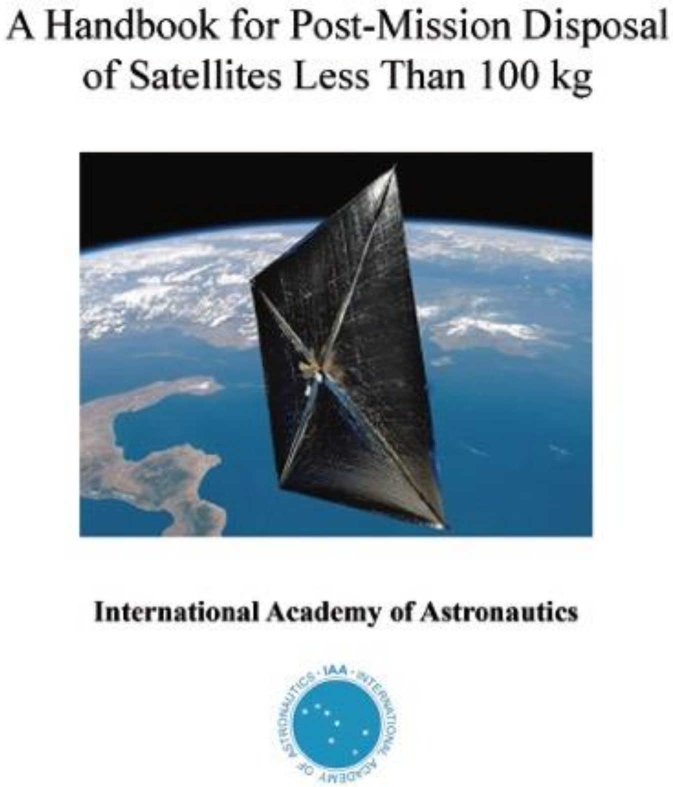
6. References

6. References

A Handbook for Post-mission Disposal of Satellites Less Than 100 kg

The Handbook:

- Identifies debris mitigation guidelines and engineering options to satisfy requirements via post-mission disposal
- Is applicable to satellites less than 100 kg in mass, including CubeSats
- Was written by experts in the field of debris mitigation and spacecraft design



https://iaaspace.org/wp-content/uploads/iaa/Scientific%20Activity/sg423finalreport.pdf

JSpOC Recommendations for Optimal CubeSat Operations

The Joint Space Operations Center (JSpOC) offers the following recommendations for CubeSat launch entities and Owner/Operators to consider as they conduct CubeSat planning.

- Satellite identification is extremely difficult to determine without initiative taken by the launch entity and/or Owner/Operator.
- Satellites should have some maneuver capability to facilitate conjunction avoidance on-orbit.
- Satellites should be built to allow controlled reentry or expedited uncontrolled reentry to minimize the threat of individual CubeSats beyond the satellite's mission life.

JSpOC Recommendations for Optimal CubeSat Operations

1 JFCC SPACE and the JSpOC

The Joint Functional Component Command for SPACE (JFCC SPACE) is responsible for identifying, cataloging and tracking over 23,000 man-made objects achieving orbit. JFCC SPACE executes this mission using data collected by the U.S. Space Surveillance Network (SSN) and through the expertise of its personnel at the Joint Space Operations Center (JSpOC), located at Vandenberg Air Force Base, in California. The proliferation of CubeSats (10cm x 10cm x 10cm satellites) and associated technology, have posed unique tracking and identification challenges. In light of this evolving situation, JFCC SPACE would like to share information on the current challenges it faces and propose recommendations on how to optimize operations in coordination with the JSpOC, to support the growing government, commercial, and academic CubeSat communities of interest.

2 Current Challenges

In late 2013, two launches presented an unprecedented challenge for JSpOC personnel. The ORS-3 mission launched STPSAT 3 and 27 CubeSats, closely followed by a DNEPR rocket hosting 31 CubeSats. Both launches involved multiple owner/operators (O/Os) from all facets of the space community; U.S. and foreign governments, academia, and commercial entities, all of whom depend on the JSpOC to a varying degree for support functions to ensure mission success. These two independent multi-payload deployment missions presented known challenges to JSpOC processes. After-action reviews completed after the launches revealed that the JSpOC and O/Os require higher levels of collaboration in order to provide optimal pre- and post-launch support. Notable points included:

- The JSpOC uses information provided by the launch entity and/or O/O as the truth-source. Without launch information from the launch entity and/or O/O, the JSpOC has limited data to inform tracking and cataloging, which delays delivery of information to satellite stakeholders.
- The JSpOC does not command and control satellites, communicate with satellites (passive or active), or provide telemetry of satellites. Many O/Os are unaware of this fact. The JSpOC relies on O/Os to perform this role and provide telemetry information that may assist with identification.
- The JSpOC depends on O/Os to provide detailed information on launch plans and payload deployment to ensure individual payload(s) are quickly identified upon separation or release from the payload deployer. Without this information and coordination, the JSpOC may have difficulty tracking and differentiating CubeSats. As a result, the JSpOC may be required to categorize the objects as unknown "analyst satellites" until more data can be collected. Analyst satellites are not publicly releasable, which makes it difficult for O/Os to conduct their missions, and inhibits collaborative identification efforts between the JSpOC and the O/O.

August 4, 2015

https://www.space-track.org/documents/Recommendations_Optimal_Cubesat_Operations_V2.pdf

7. Summary

7. Summary

The current LEO debris population is expected to increase even with no new launches and explosions.

Even with a good implementation of the commonly-adopted mitigation measures, the LEO debris population is still expected to increase.

Environmental remediation is required to prevent an increase in the LEO debris population.

We must understand the above situation and comply with the space debris mitigation guidelines to ensure the sustainability of outer space activities.

Thank you very much.

[Disclaimer]
The views and opinions expressed in this presentation are those of the authors and do not necessarily reflect those of the United Nations.