A06

New Space and the Continued Need for Space Debris Mitigation

○Stijn Lemmens (ESA)

The on-going revolution in the way the space environment is used, with ever smaller and more versatile platforms and the deployment of large constellation, is creating not only opportunities but also concerns when it comes to assuring the long term sustainability of outer space for operations.
Space debris mitigation, and remediation, requires to use the data being produced by space situational awareness systems to design technologies to be implemented on space missions, based on a solid scientific understanding of the environment. At the European Space Agency's (ESA) last ministerial council in 2019, its member states endorsed the creation of a Space Safety programme to, among others, address some of the challenge which are coming up. This includes the development of surveillance sensors and new data products such as attitude motion, a platform for automated collisions avoidance operations, technologies to aid safe disposal and re-entry, and a mission to demonstrate the viability of active debris removal by removing an ESA owned object from orbit. This is complemented with a research component in ESA's Space Debris Office, looking into, among others, uncertainty quantification and metrics to assess the orbital use of the environment.
This lecture will give an overview of how the changes in the space environment has driven the need for the new developments in technologies which are taking place at ESA. The focus will be on how the new space situational awareness capabilities are needed for evolutions in space debris mitigation, such as the development of rating schemes, and enablers for active debris removal.

Biography

Stijn Lemmens
Senior Space Debris Mitigation Analyst
Space Debris Office, European Space Agency

Stijn Lemmens graduated from the Catholic University of Leuven, Belgium, with a degree in Mathematics in 2009. He started his career at the European Space Agency two years later, at the space debris office in Darmstadt, Germany, after discovering the technical and legal problems associated with active debris removal. After working on software engineering and various scientific investigation related to space debris, his current duties involve running and coordinating activities on the boundaries between technology development, modelling, and observations to the advancement of space debris mitigation and remediation. He is actively involved in international bodies dedicated to standardisation and advancement of the field, currently chairing the Inter-Agency Space Debris Coordination Committee's working group on mitigation, and taking the next steps towards sustainable space operations in an ever more congested space environment.


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New Space and the continued
Need for Space Debris Mitigation
Stijn Lemmens
Space Debris Office, European Space Agency
9th JAXA Space Debris Workshop, 2021-02-24
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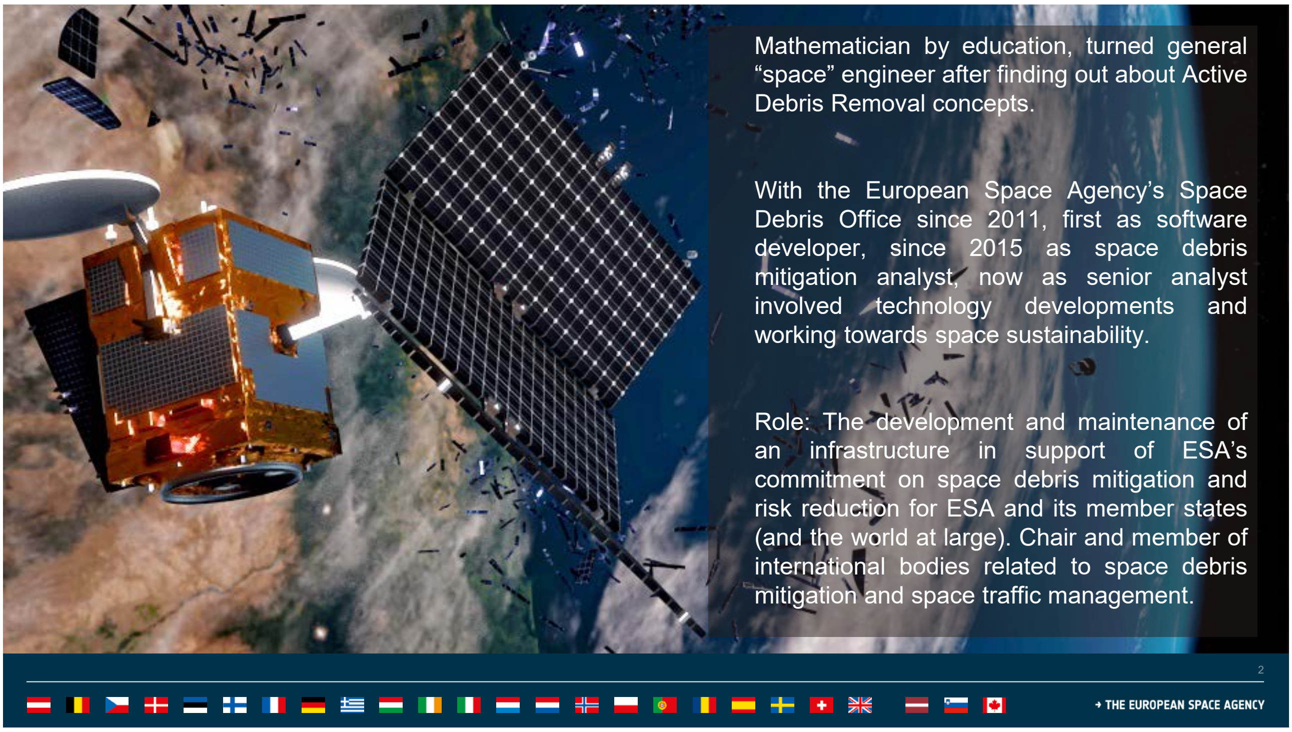
Mathematician by education, turned general "space" engineer after finding out about Active Debris Removal concepts.
With the European Space Agency's Space Debris Office since 2011, first as software developer, since 2015 as space debris mitigation analyst, now as senior analyst involved technology developments and working towards space sustainability.
Role: The development and maintenance of an infrastructure in support of ESA's commitment on space debris mitigation and risk reduction for ESA and its member states (and the world at large). Chair and member of international bodies related to space debris mitigation and space traffic management.
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Abstract

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The on-going revolution in the way the space environment is used, with ever smaller and more versatile platforms and the deployment of large constellation, is creating not only opportunities but also concerns when it comes to assuring the long term sustainability of outer space for operations.

Space debris mitigation, and remediation, requires to use the data being produced by space situational awareness systems to design technologies to be implemented on space missions, based on a solid scientific understanding of the environment. At the European Space Agency's (ESA) last ministerial council in 2019, its member states endorsed the creation of a Space Safety programme to, among others, address some of the challenge which are coming up. This includes the development of surveillance sensors and new data products such as attitude motion, a platform for automated collisions avoidance operations, technologies to aid safe disposal and re-entry, and a mission to demonstrate the viability of active debris removal by removing an ESA owned object from orbit. This is complemented with a research component in ESA's Space Debris Office, looking into, among others, uncertainty quantification and metrics to assess the orbital use of the environment.

This lecture will give an overview of how the changes in the space environment has driven the need for the new developments in technologies which are taking place at ESA. The focus will be on how the new space situational awareness capabilities are needed for evolutions in space debris mitigation, such as the development of rating schemes, and enablers for active debris removal.

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Overview

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1. New Space, the ongoing evolution of how we use the near Earth environment and its implications.
2. European Space Agency's Space Safety programme. Focus points for debris mitigation and research.
3. What is next? From changing environment to new technologies and active debris removal (, back to measuring the impact).

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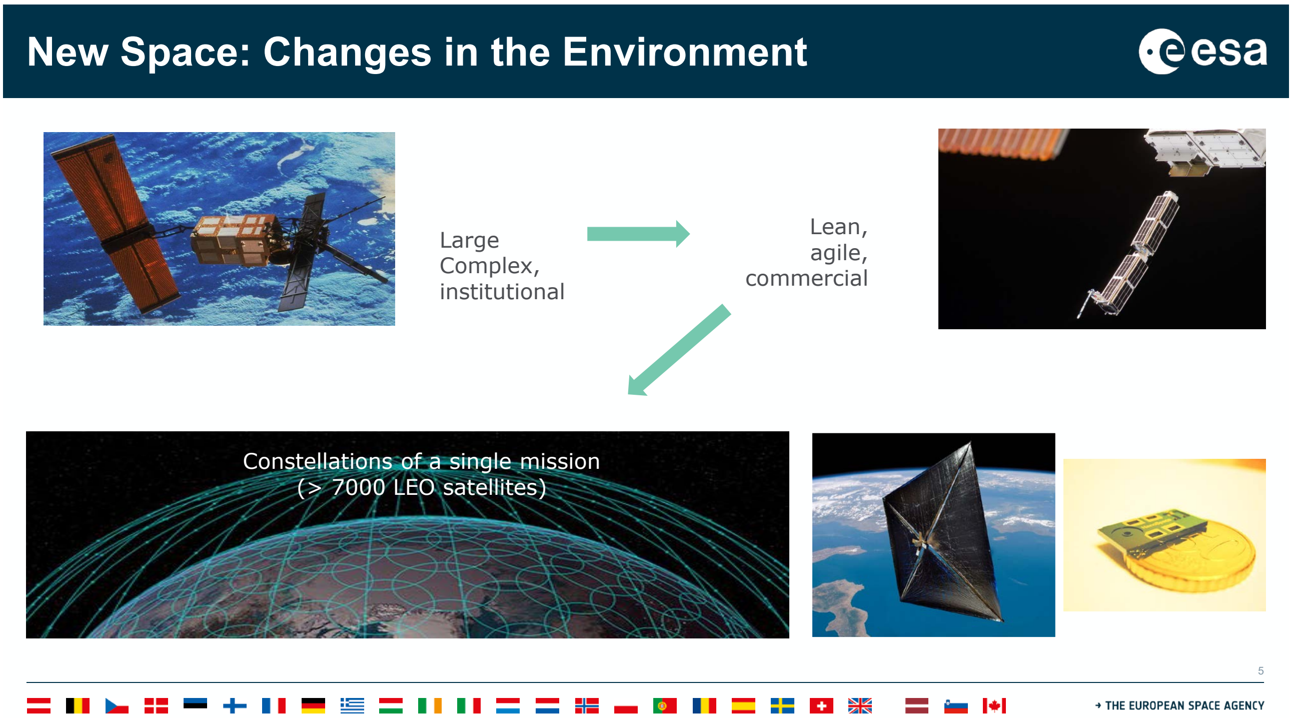
New Space: Changes in the Environment
esa
Large
Complex,
institutional
Lean,
agile,
commercial
Constellations of a single mission
(> 7000 LEO satellites)
5
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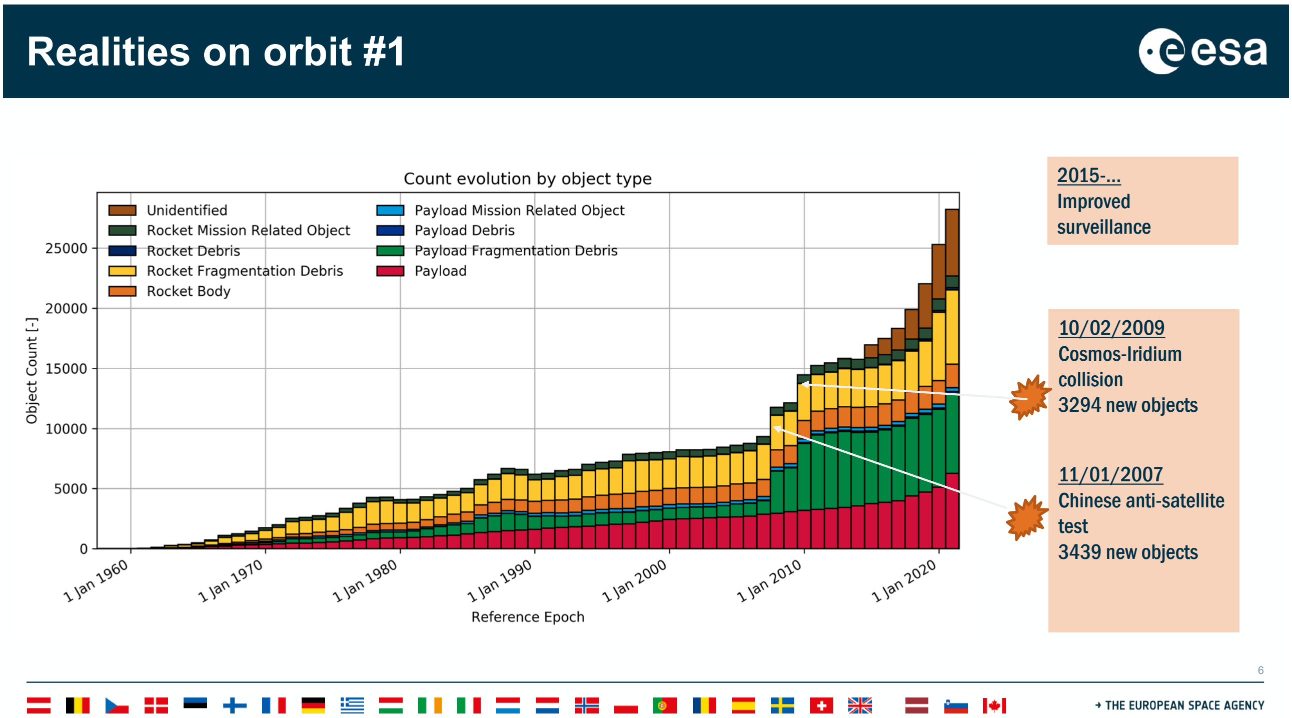
Realities on orbit #1
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Count evolution by object type
Unidentified
Rocket Mission Related Object
Rocket Debris
Rocket Fragmentation Debris
Rocket Body
Payload Mission Related Object
Payload Debris
Payload Fragmentation Debris
Payload
Object Count [-]
25000
20000
15000
10000
5000
0
1 Jan 1960
1 Jan 1970
1 Jan 1980
1 Jan 1990
1 Jan 2000
1 Jan 2010
1 Jan 2020
Reference Epoch
2015-...
Improved
surveillance
10/02/2009
Cosmos-Iridium
collision
3294 new objects
11/01/2007
Chinese anti-satellite
test
3439 new objects
6
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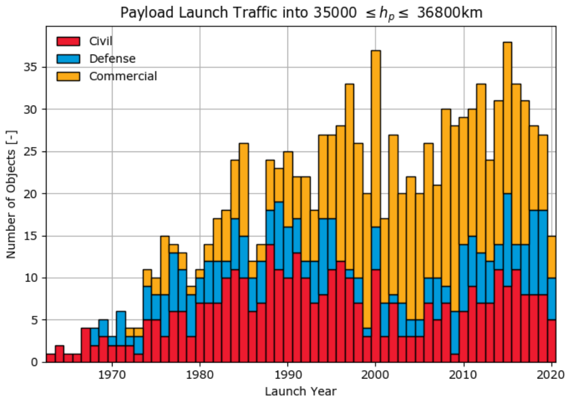
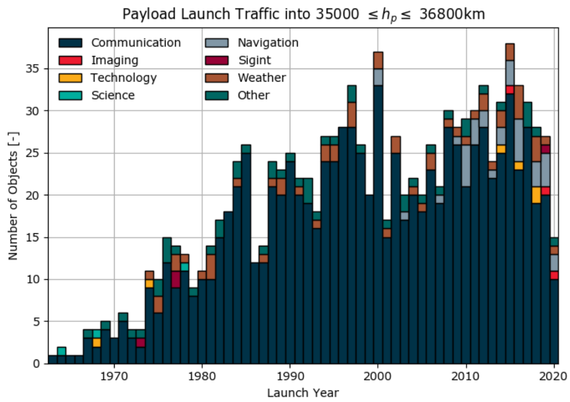
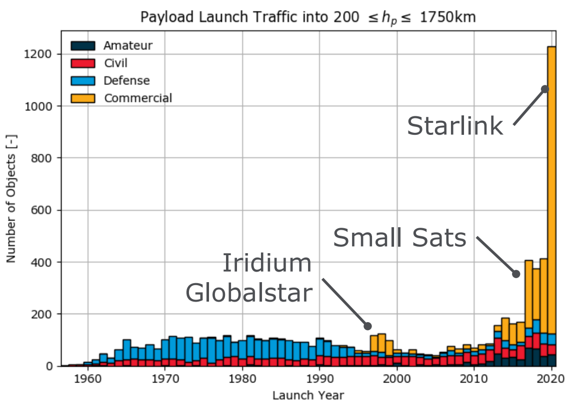
Realities on orbit #2: Stable GEO usage trends

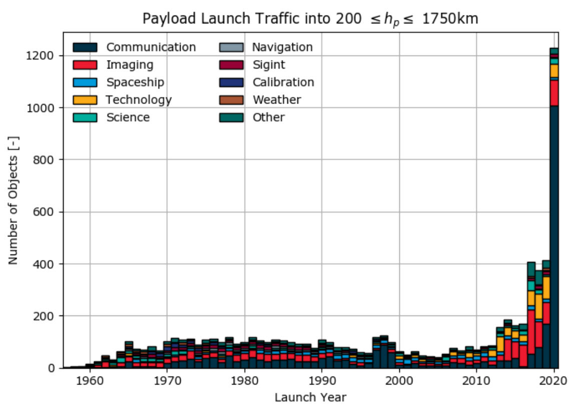




h_p: perigee altitude

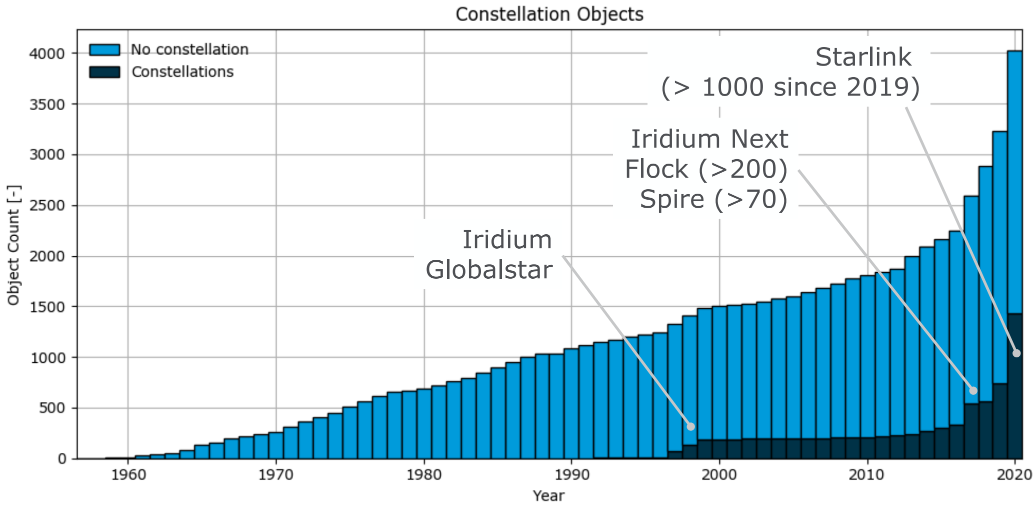
Realities on orbit #3: changing LEO usage trends





h_p: perigee altitude

Realities on orbit #4: Use of constellations



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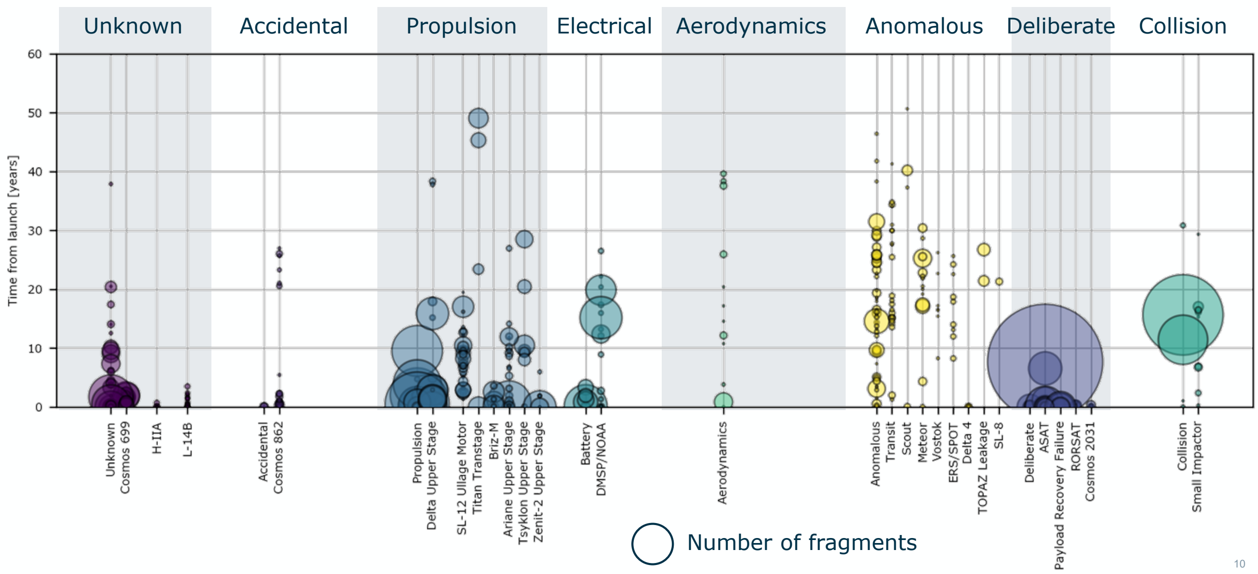
Realities on orbit #6: Fragmentation trends



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Realities on orbit #6: Collision avoidance in LEO

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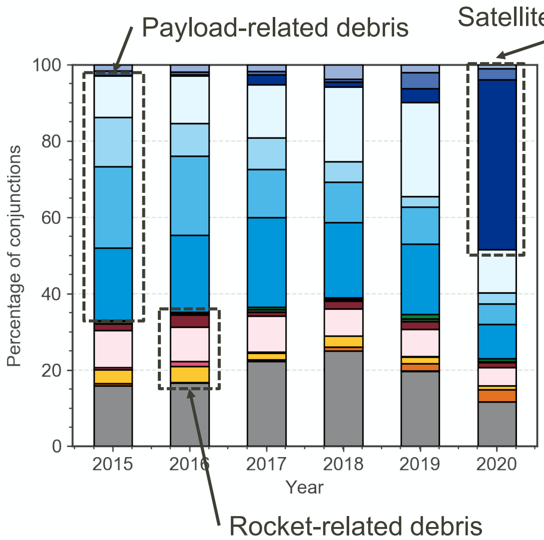

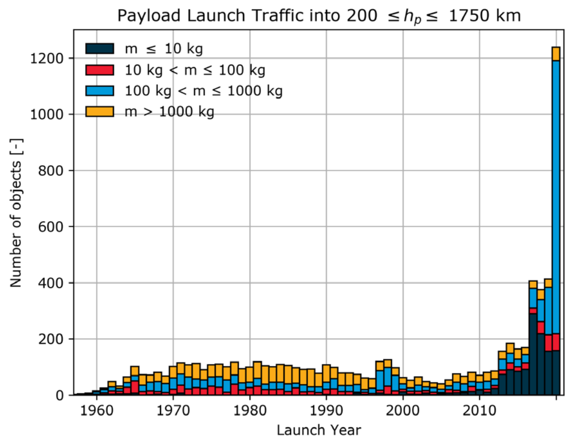

Space Debris Mitigation Objectives: Sustainability

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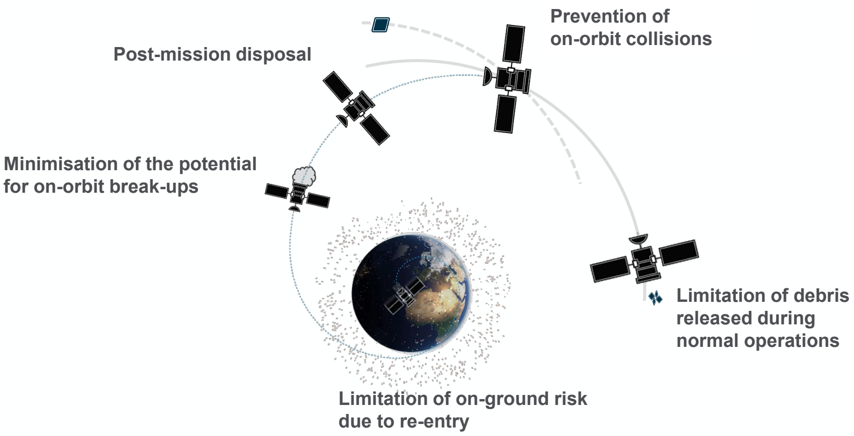


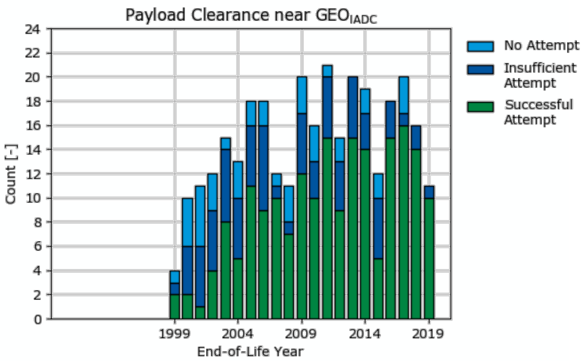

INTERNATIONAL STANDARD

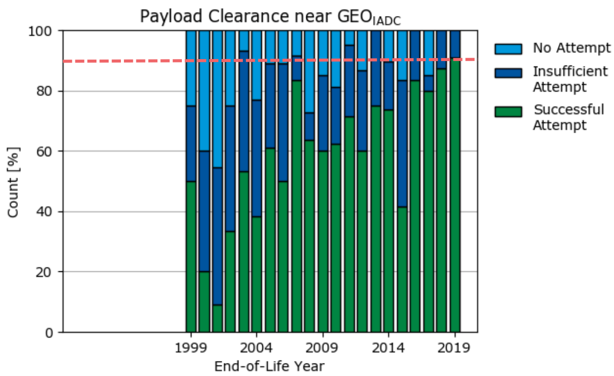
ISO 24113

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

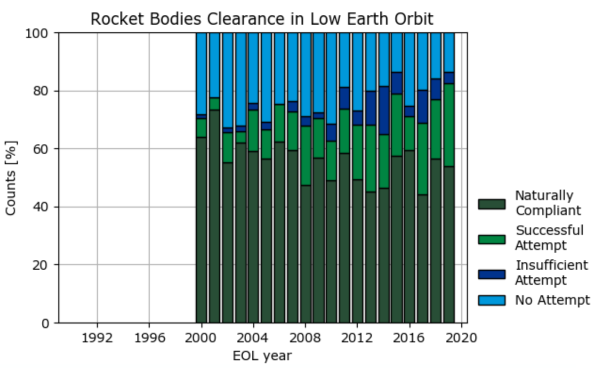
Post mission disposal: GEO Payloads

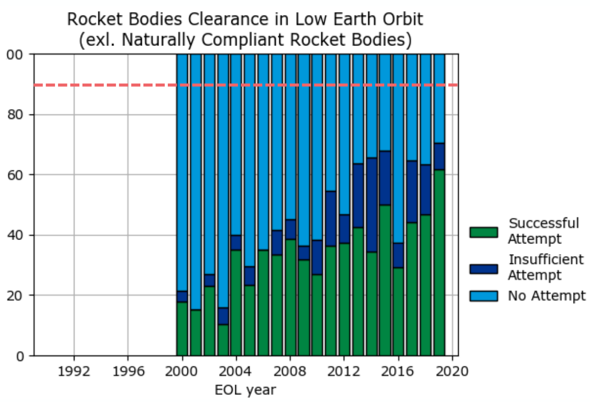




---------------- 90% success rate requirement

Post mission disposal: LEO Rocket Bodies





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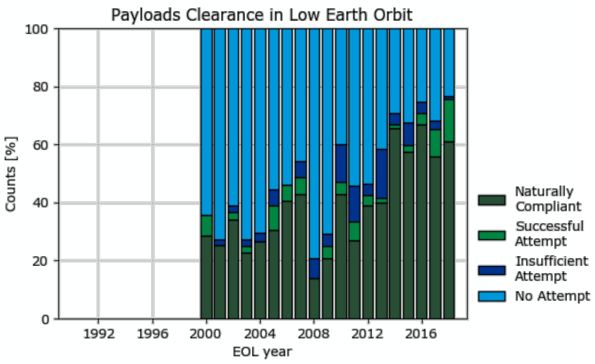
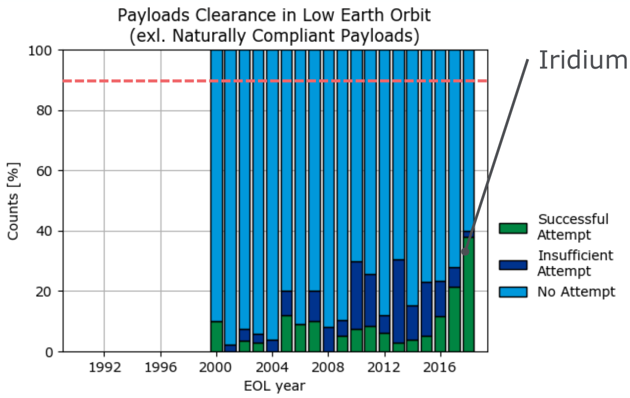
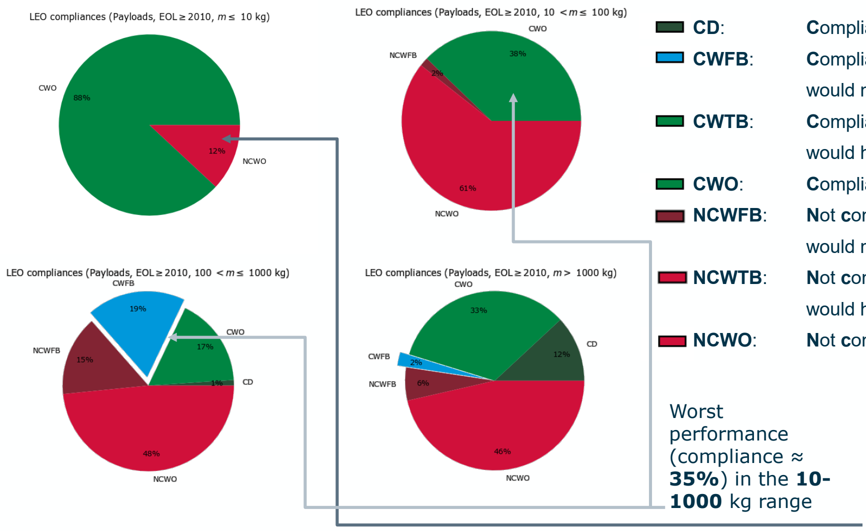
Post mission disposal: LEO Payloads





----------------- 90% success rate requirement

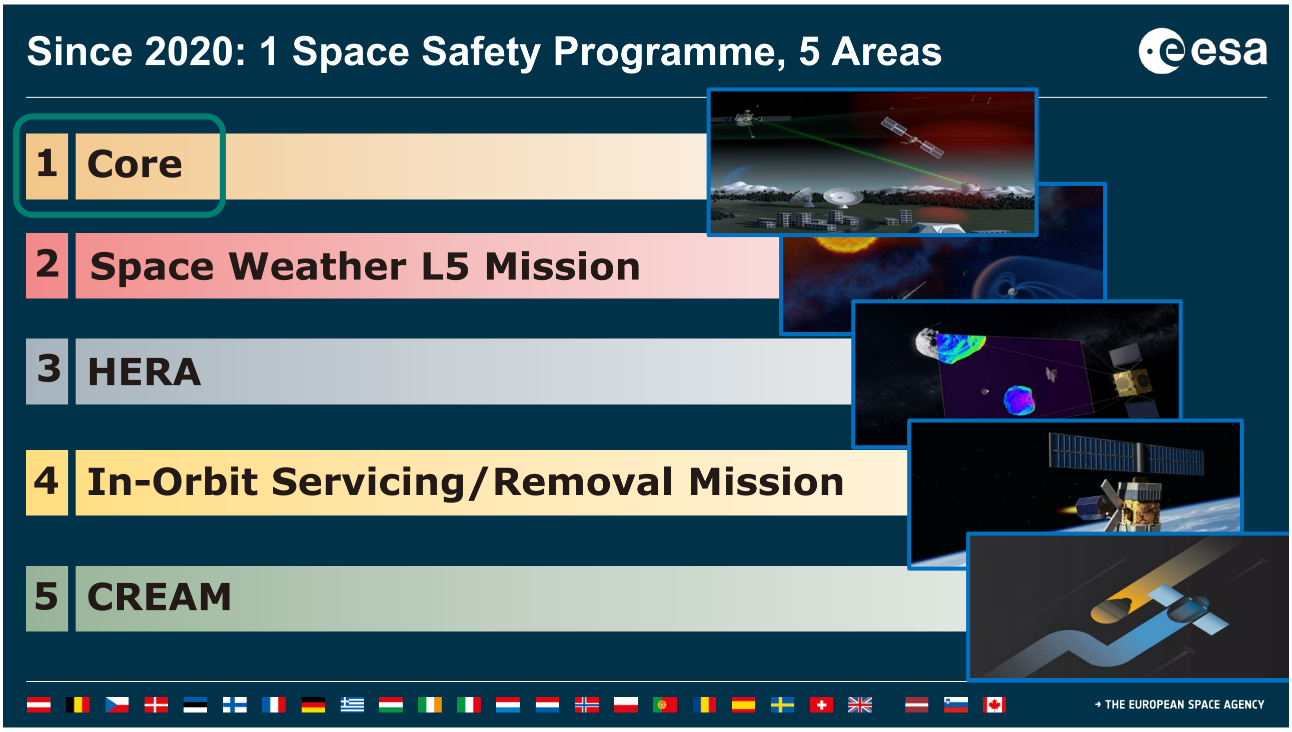
Post mission disposal: LEO Payloads



- **CD**: Compliant with direct re-entry
- **CWFB**: Compliant with attempt where the destination orbit would not have been compliant (with False Before)
- **CWTB**: Compliant with attempt where the destination orbit would have been compliant (with True Before)
- **CWO**: Compliant without an attempt
- **NCWFB**: Not compliant with attempt where the destination orbit would not have been compliant (with False Before)
- **NCWTB**: Not compliant with attempt where the destination orbit would have been compliant (with True Before)
- **NCWO**: Not compliant without an attempt.

Worst performance (compliance ≈ **35%**) in the **10-1000** kg range

12% small objects left in long-life orbits with no manoeuvre capability



Since 2020: 1 Space Safety Programme, 5 Areas
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1 Core
2 Space Weather L5 Mission
3 HERA
4 In-Orbit Servicing/Removal Mission
5 CREAM
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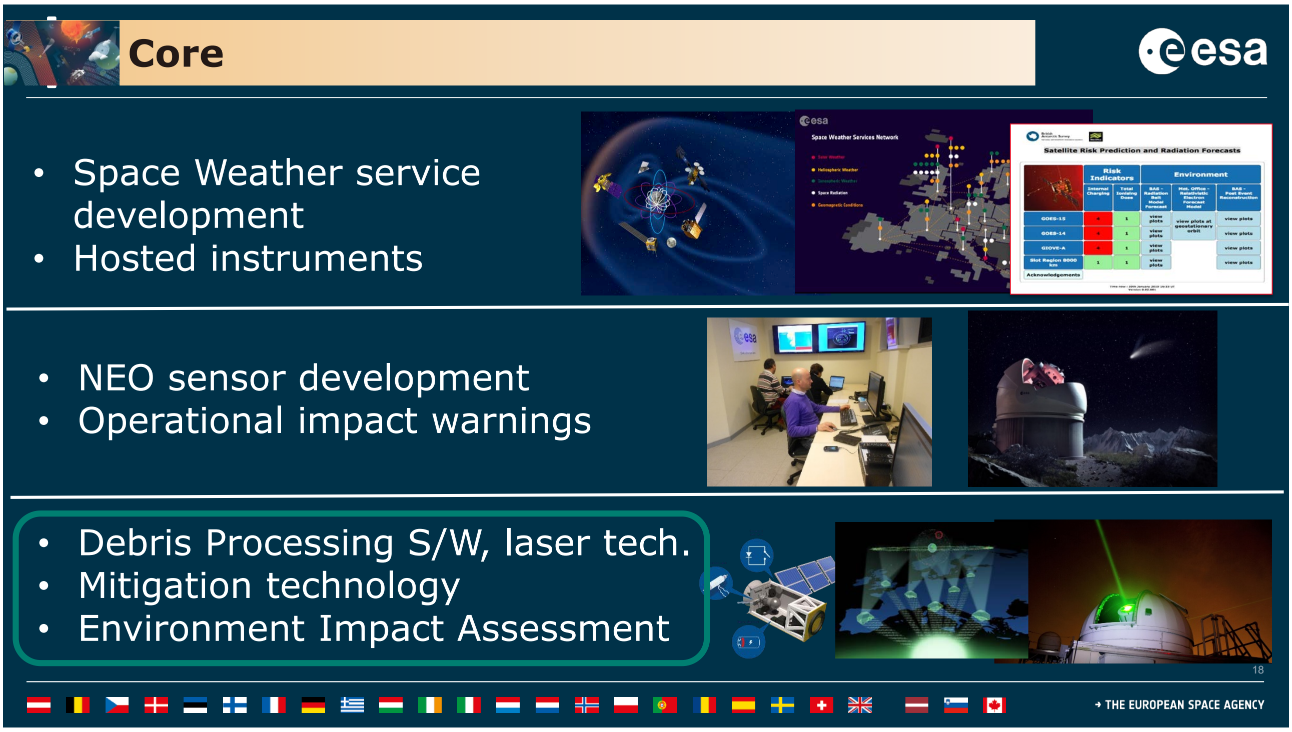

Core
esa
• Space Weather service development
• Hosted instruments
• NEO sensor development
• Operational impact warnings
• Debris Processing S/W, laser tech.
• Mitigation technology
• Environment Impact Assessment
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S2P Core – Debris Technologies

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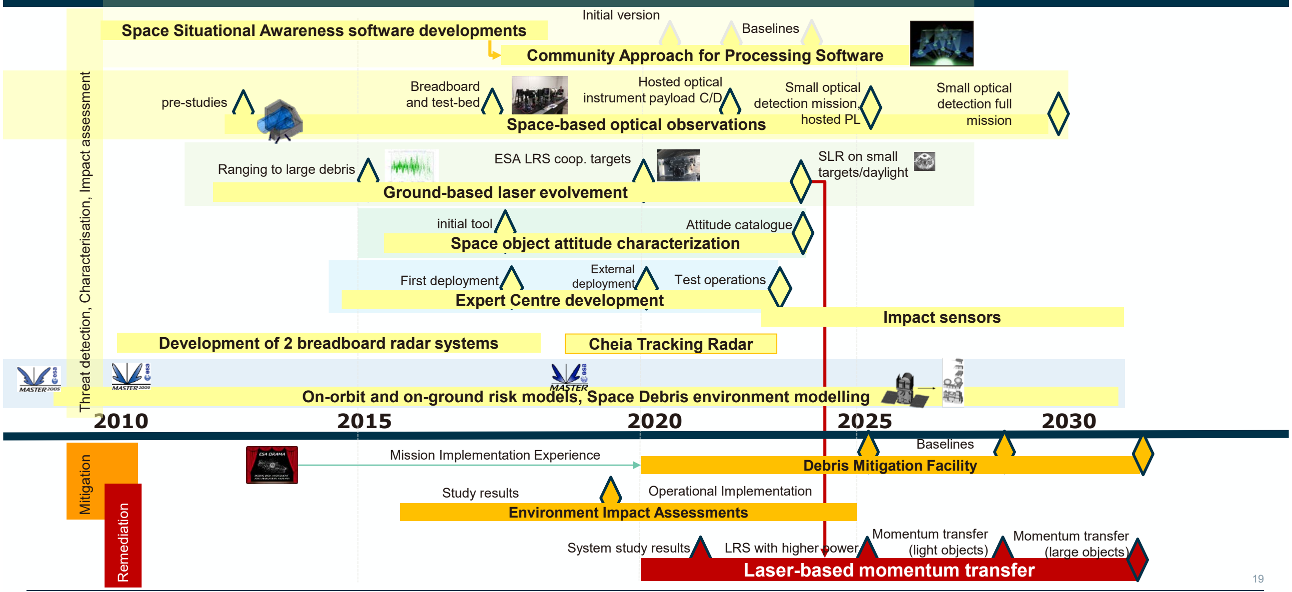

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S2P Core – Space Debris

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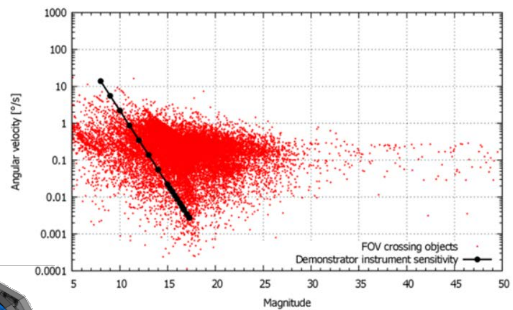
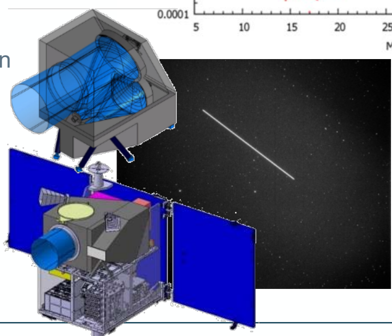
Space-based Optical Component

Small-sized space debris characterisation from a LEO mission (hosted & demo mission)

- Current TRL / Heritage
  - Pre-studies (2005)
  - Detection algorithm prototyping (mm-sized)
  - Phase A mission design (2015)
  - Breadboard, test-bed, algorithm risk reduction
- In the pipeline:
  - Engineering model, ground segment, qualification (“instrument C/D”)
  - Flight opportunities for hosted payload to demonstrate ~2024
  - **Full mission** ~2030





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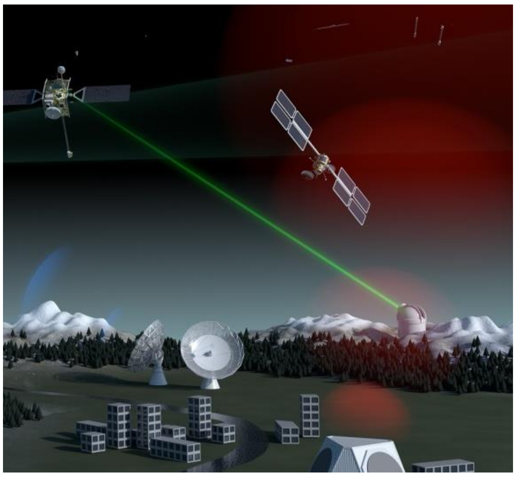
S2P Core – Space Debris

Laser Ranging to non-cooperative Targets

- Satellite Laser Ranging for non-cooperative targets for independent detection and tracking of un-known non-cooperative targets for space object cataloguing
- Successful first demonstration experiments are promising
  - Need for networking, "stare and chase"
  - Laser ranging demonstrated during daytime
- Support to European technology development
- ESA build laser ranging station (LRS) on Canaries



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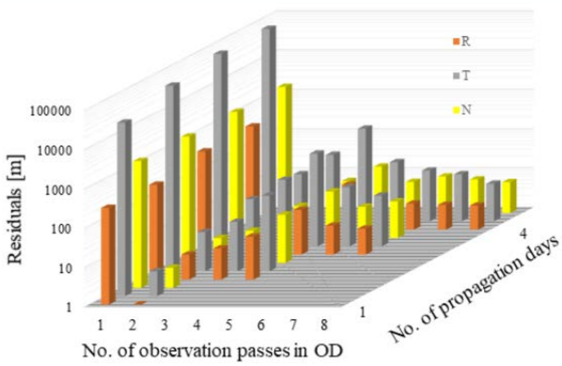
S2P Core – Space Debris

Laser Ranging to non-cooperative Targets

https://conference.sdo.esoc.esa.int/proceedings/neosst1/paper/116/NEOSST1-paper116.pdf



Covariance matrix with	
$20m \times 150m \times 30m$ at TCA	$10m \times 10m \times 10m$ at TCA
An action threshold of 10^{-4} would have to be applied to reduce the collision risk by $>$ 90%	For the same risk reduction of $>$ 90% an action threshold of 10^{-2} will be sufficient
This leads to about 2 annual manoeuvres per spacecraft on average	This leads to 0.025 annual manoeuvres per spacecraft on average
The false alert rate is at 99.9%	The false alert rate is at 10%

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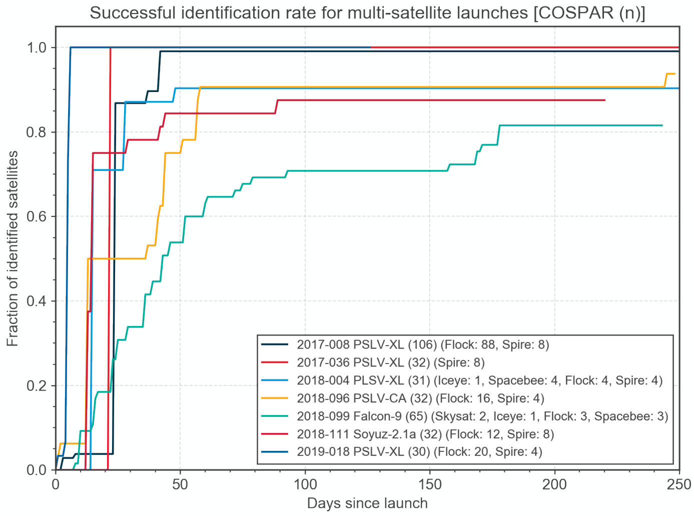
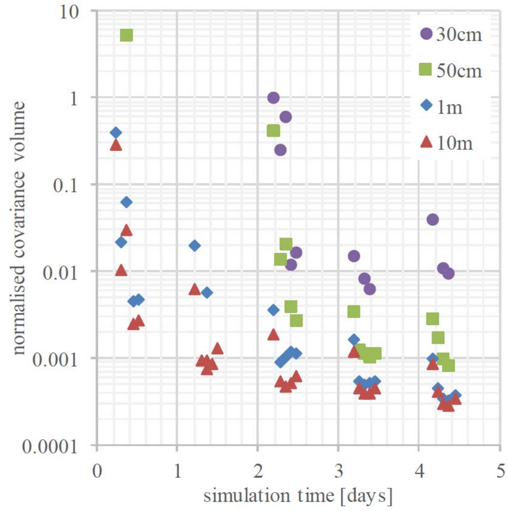
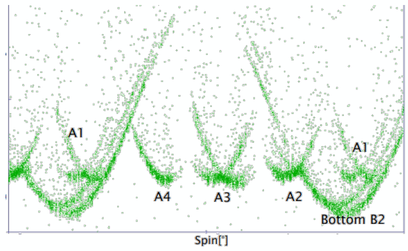
Emerging trends: small satellites & trackability issues



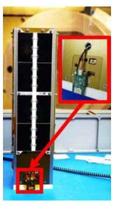


Trackability, Attitude, and Identification solutions

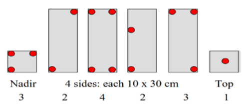
1. Radar Passive Electrical Dipole
2. Active Radar Repeater
3. Inverse Synthetic Aperture Radar
4. Passive Optical Tracking
5. **Passive Laser Retro-reflector**
6. Modulated LED
7. Coloured LED
8. Modulated Laser
9. **Space Transponder**
10. **Radio Beacons**

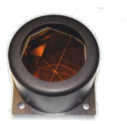


https://cddis.nasa.gov/lw21/docs/2018/presentations/Session6_Wang_presentation.pdf



https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4451&context=smallsat





https://www.thorlabs.com/navigation.cfm?guide_id=2539

S2P Core – Space Debris

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Re-entry & Impact Safety

Significant knowledge and implementation gaps, and routes to address them, have been established but not brought to full maturity.

Shape-effect modelling for risk evaluation

- Leverage computational and test facilities to close known gaps.

Creation of material and component databases for high risk objects

- Demonstration a process based risk methodology aiming to significantly reduce licencing/verification work by creating databases (MBSE).

Baseline for a generic re-entry break-up instrument

- low-cost & generic flight sensors to hook on missions with controlled re-entry or short orbital lifetimes

Mitigation Technologies: Clean Space

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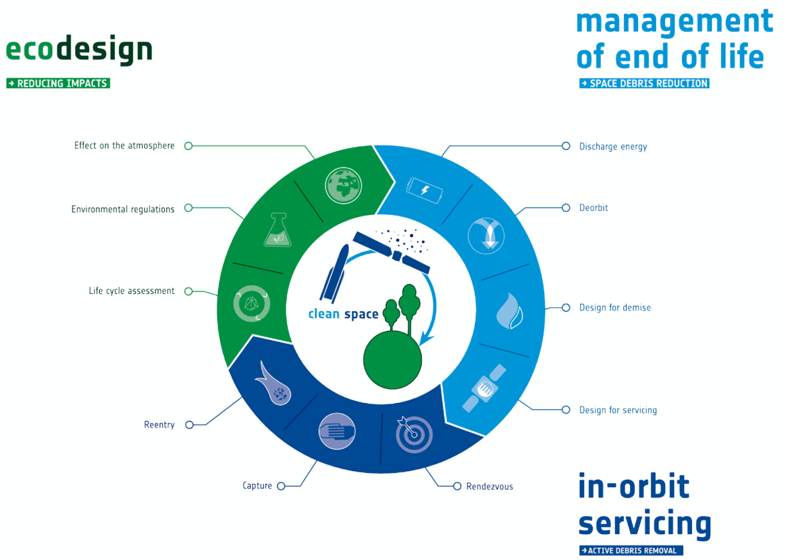
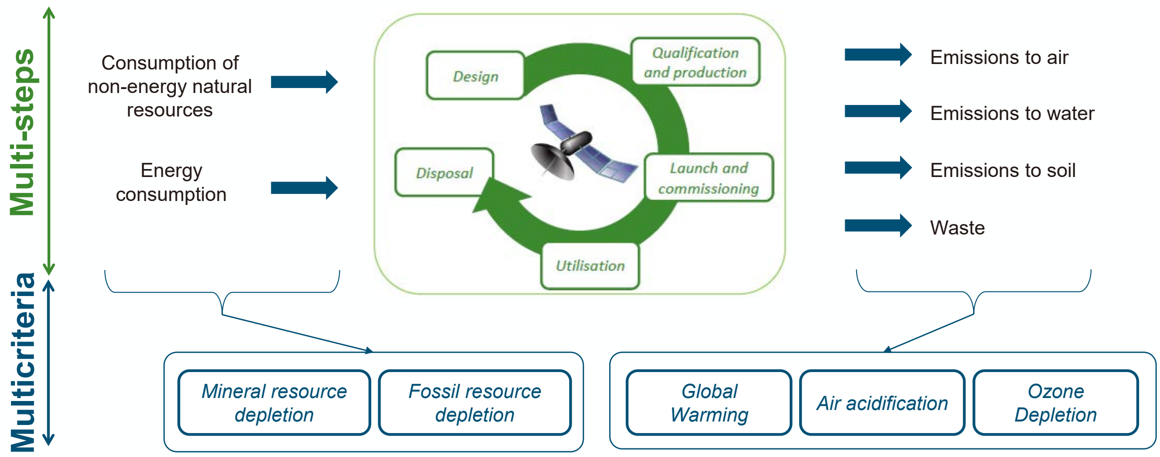
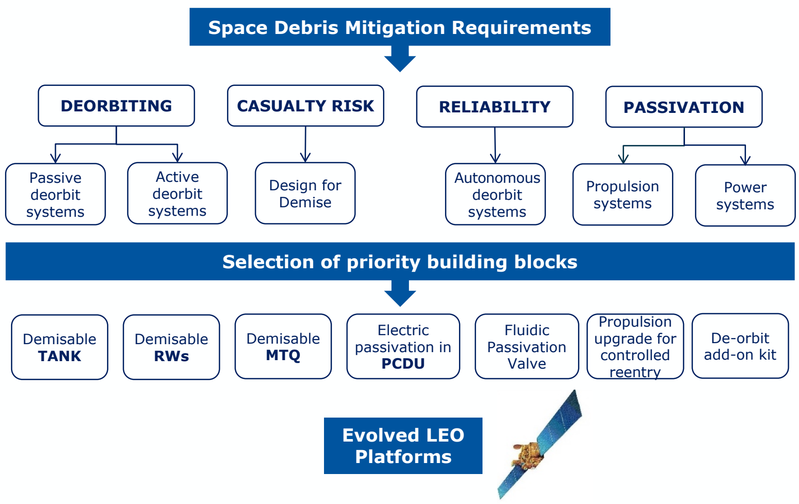


Mitigation Technologies: Life Cycle Assessment

To quantitatively assess the potential environmental impacts of a product or service



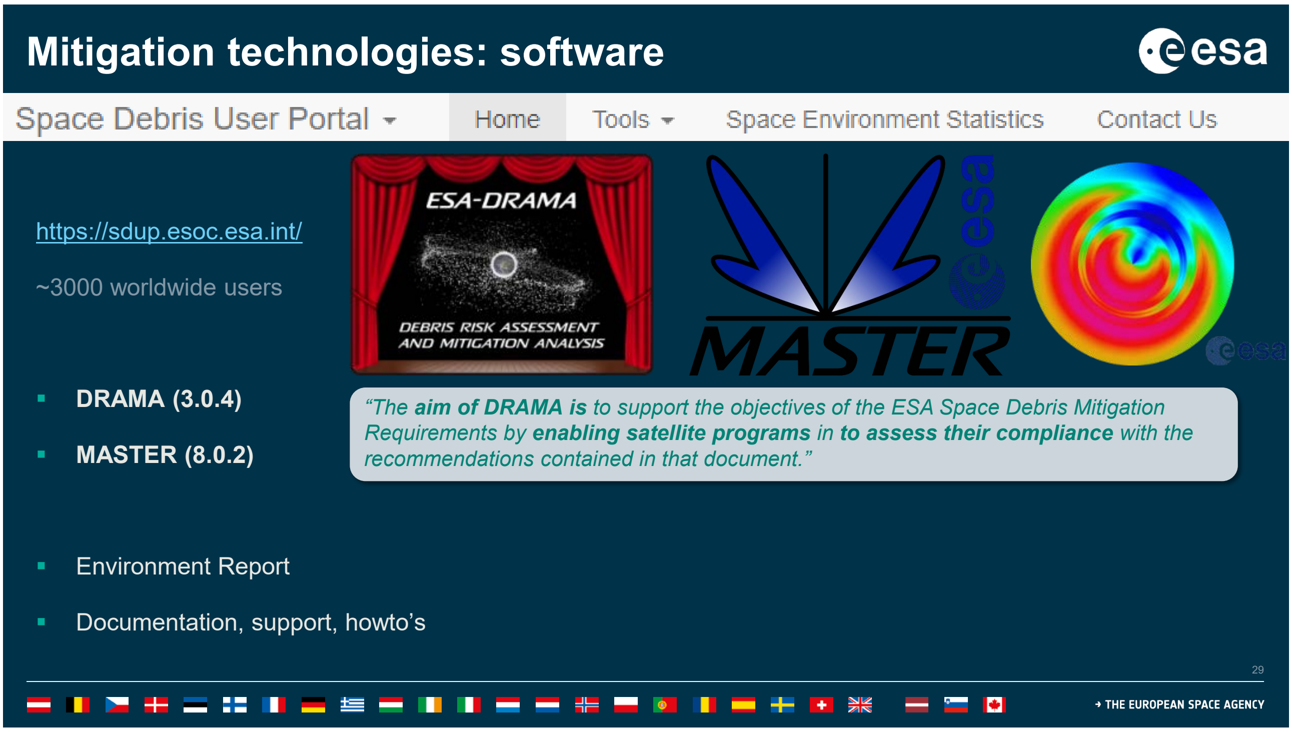
Mitigation Technologies: CleanSat



RW: Reaction Wheel

MTQ: Magnetorquer

PCDU: Power Conditioning and Distribution Unit


Mitigation technologies: software
esa
Space Debris User Portal
Home
Tools
Space Environment Statistics
Contact Us
https://sdup.esoc.esa.int/
~3000 worldwide users
ESA-DRAMA
DEBRIS RISK ASSESSMENT AND MITIGATION ANALYSIS
MASTER
DRAMA (3.0.4)
MASTER (8.0.2)
"The aim of DRAMA is to support the objectives of the ESA Space Debris Mitigation Requirements by enabling satellite programs in to assess their compliance with the recommendations contained in that document."
Environment Report
Documentation, support, howto's
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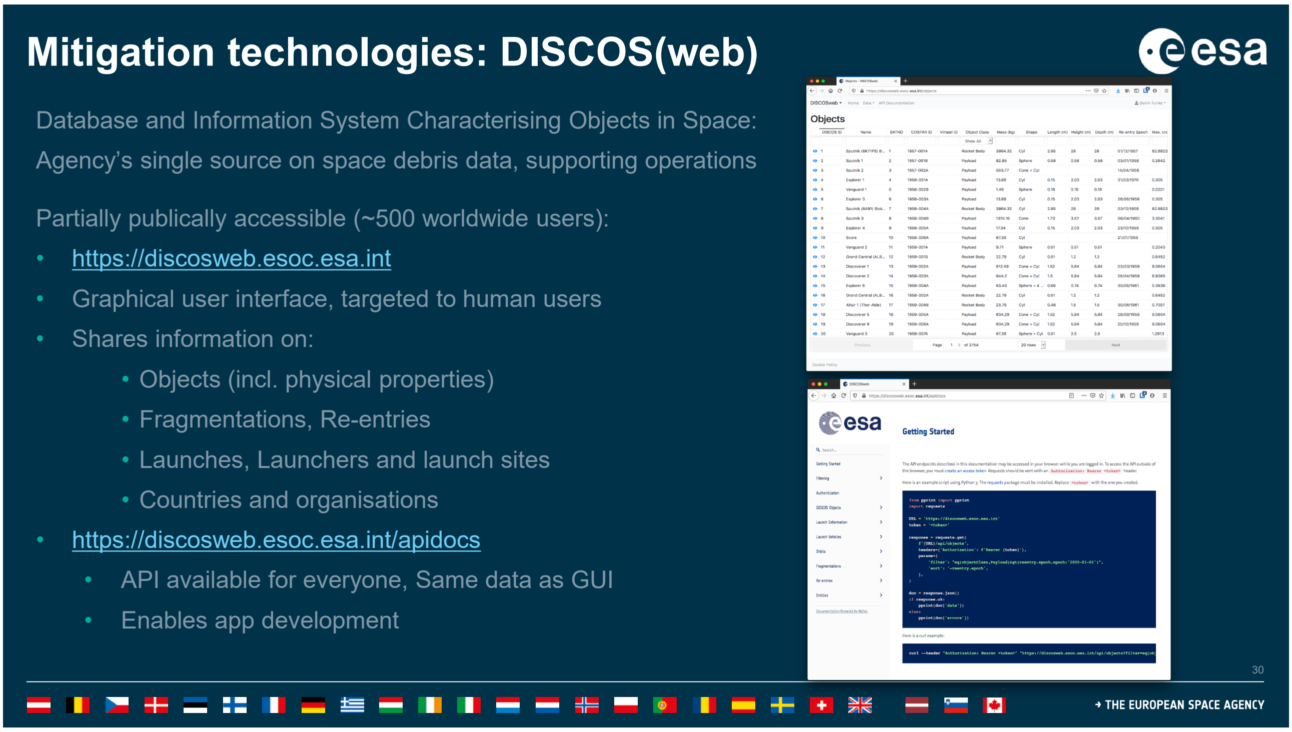
Mitigation technologies: DISCOS(web)
esa
Database and Information System Characterising Objects in Space: Agency's single source on space debris data, supporting operations
Partially publically accessible (~500 worldwide users):
https://discosweb.esoc.esa.int
Graphical user interface, targeted to human users
Shares information on:
Objects (incl. physical properties)
Fragmentations, Re-entries
Launches, Launchers and launch sites
Countries and organisations
https://discosweb.esoc.esa.int/apidocs
API available for everyone, Same data as GUI
Enables app development
Objects
Getting Started
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Since 2020: 1 Space Safety Programme, 5 Areas

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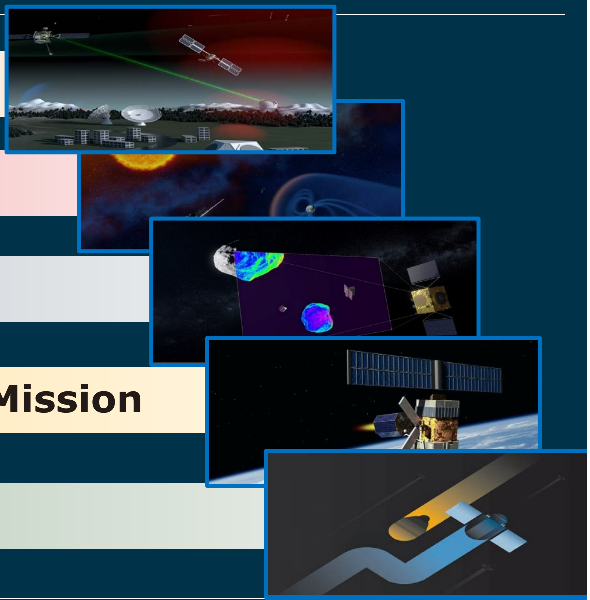

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Towards automated collision avoidance systems

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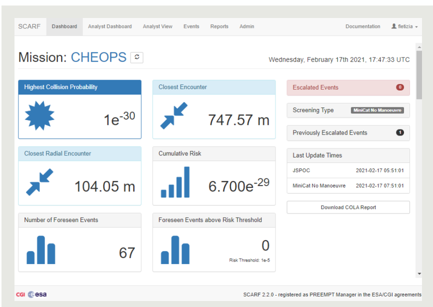
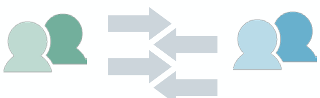
Current approach





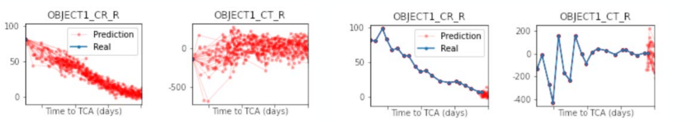
Known risks and opportunities

Expected increase in conjunction alerts (improved **sensors** & **constellations**)

On-going research of techniques such as **machine learning** to predict the likely evolution of an event.

On-going research of techniques such as **uncertainty quantification** allows to get a better grip on the situation.

ESA released a **dataset** with collected conjunction alerts for researchers to test their algorithms.
https://kelvins.esa.int/collision-avoidance-challenge/data



F. Pinto et al, NeurIPS, 2020

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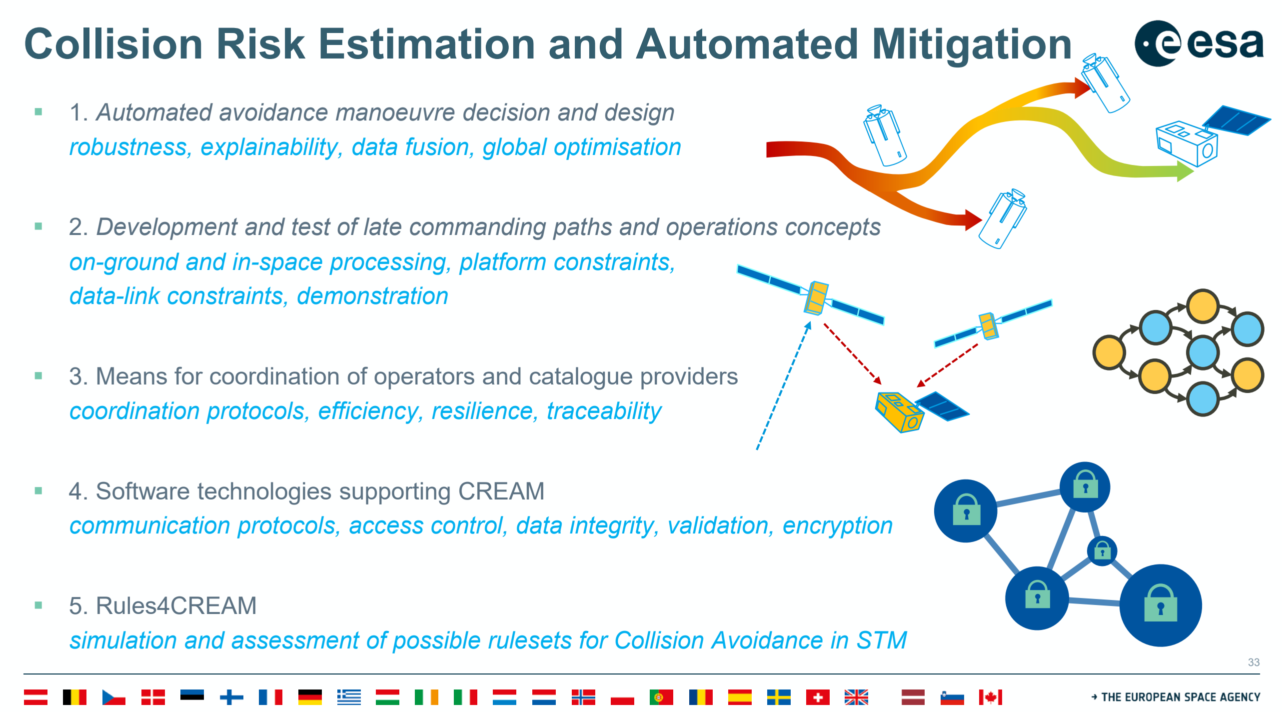
Collision Risk Estimation and Automated Mitigation
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1. Automated avoidance manoeuvre decision and design
robustness, explainability, data fusion, global optimisation
2. Development and test of late commanding paths and operations concepts
on-ground and in-space processing, platform constraints, data-link constraints, demonstration
3. Means for coordination of operators and catalogue providers
coordination protocols, efficiency, resilience, traceability
4. Software technologies supporting CREAM
communication protocols, access control, data integrity, validation, encryption
5. Rules4CREAM
simulation and assessment of possible rulesets for Collision Avoidance in STM
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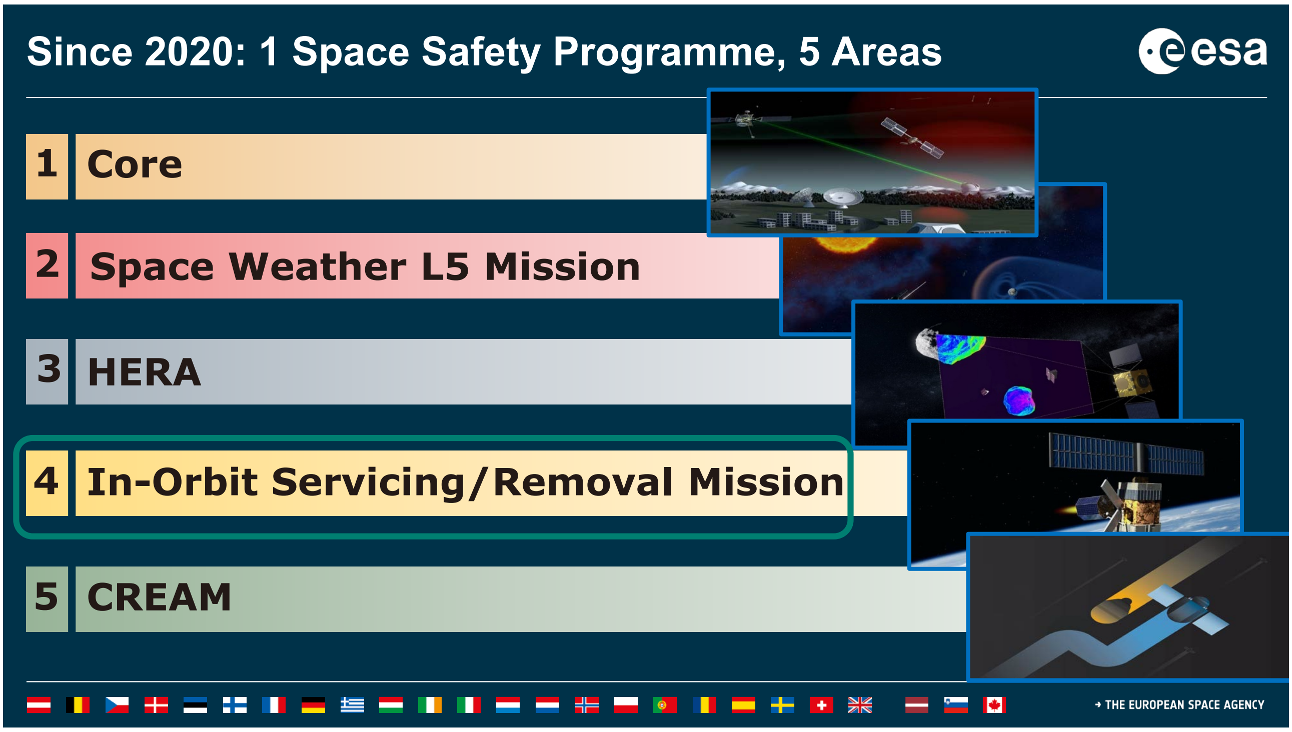
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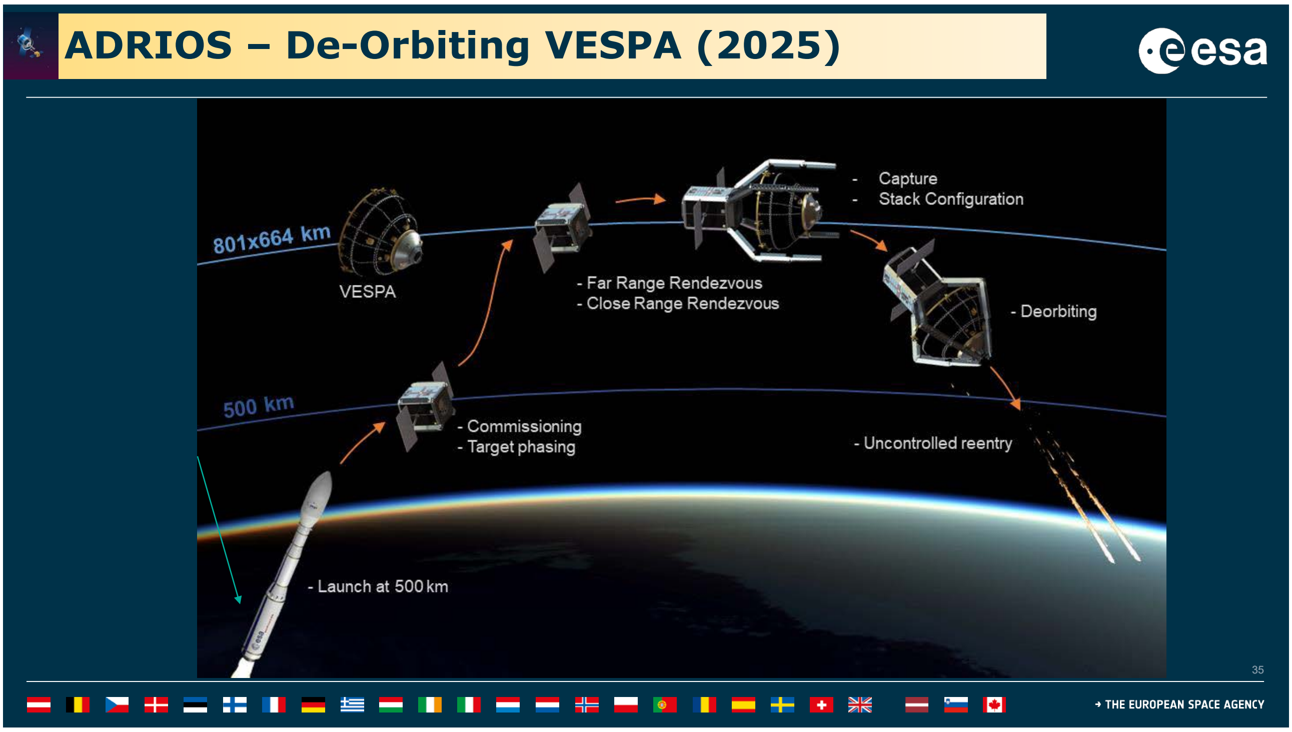
4 In-Orbit Servicing/Removal Mission
5 CREAM
→ THE EUROPEAN SPACE AGENCY


ADRIOS – De-Orbiting VESPA (2025)
esa
801x664 km
VESPA
- Capture
- Stack Configuration
- Far Range Rendezvous
- Close Range Rendezvous
- Deorbiting
500 km
- Commissioning
- Target phasing
- Uncontrolled reentry
- Launch at 500 km
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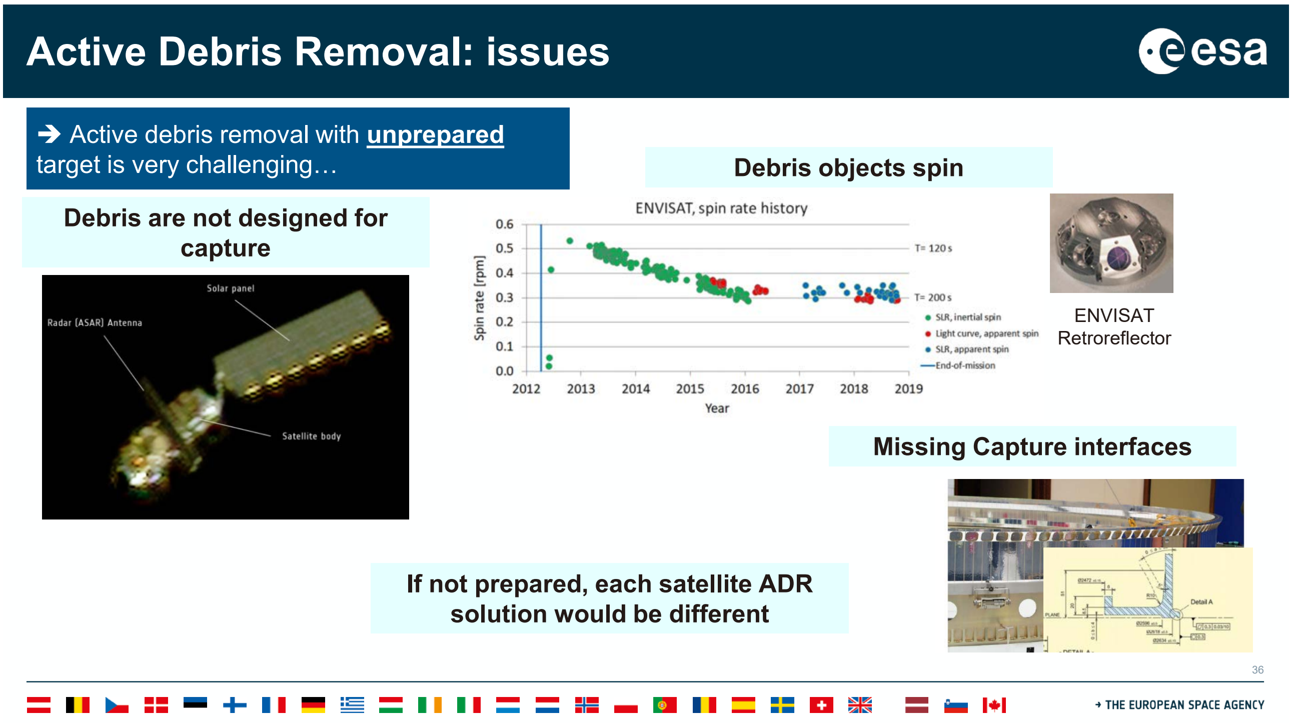
Active Debris Removal: issues
esa
➔ Active debris removal with unprepared target is very challenging…
Debris objects spin
Debris are not designed for capture
ENVISAT, spin rate history
Spin rate [rpm]
Year
T= 120 s
T= 200 s
SLR, inertial spin
Light curve, apparent spin
SLR, apparent spin
End-of-mission
Solar panel
Radar (ASAR) Antenna
Satellite body
ENVISAT Retroreflector
Missing Capture interfaces
If not prepared, each satellite ADR solution would be different
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Active Debris Removal: issues

ENVISAT Tumbling Motion

- Synchronised motion with high rates

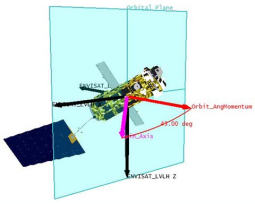
→ RCS thrusters sizing

- Large uncertainty box

→ Long robotic arm needed

- Sizing for torques of robotic interface
- Complex trajectory planning to avoid appendages
- Complex CAM planning
- RdV cameras + scanning LIDAR

→ No-markers for relative navigation



Design for Removal

- **Markers to Support Navigation** (MSN)

2D markers and 3D markers to help relative navigation (attitude, distance, velocity, etc.)

- **Mechanical Interface for Capture (MICE)**

Passive interface on satellite for capture

For cooperative & uncooperative

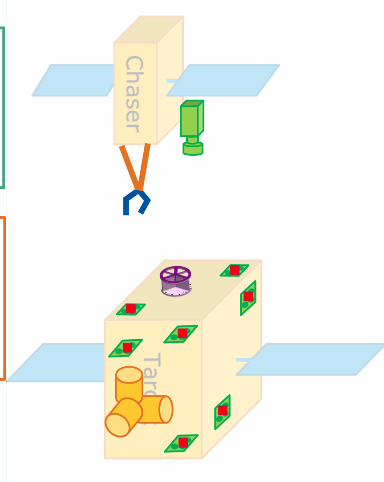
- **Stabilisation of tumbling motion (FOME)**

Short-circuit magnetorquers to detumble at EoL

- **Passive Identification System (PAIS)**

LRR embedded in 2D Markers to enhance ground based attitude reconstruction

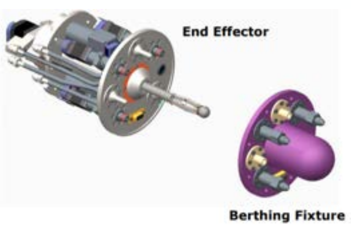
Only for uncooperative



In-Orbit Servicing: Enablers

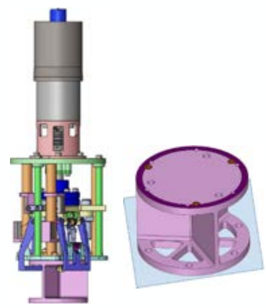
Enabling satellites in LEO/GEO for servicing through standardized interfaces / technologies e.g.:

- Design for removal for Copernicus/LEO
- Design for servicing for GEO satellites



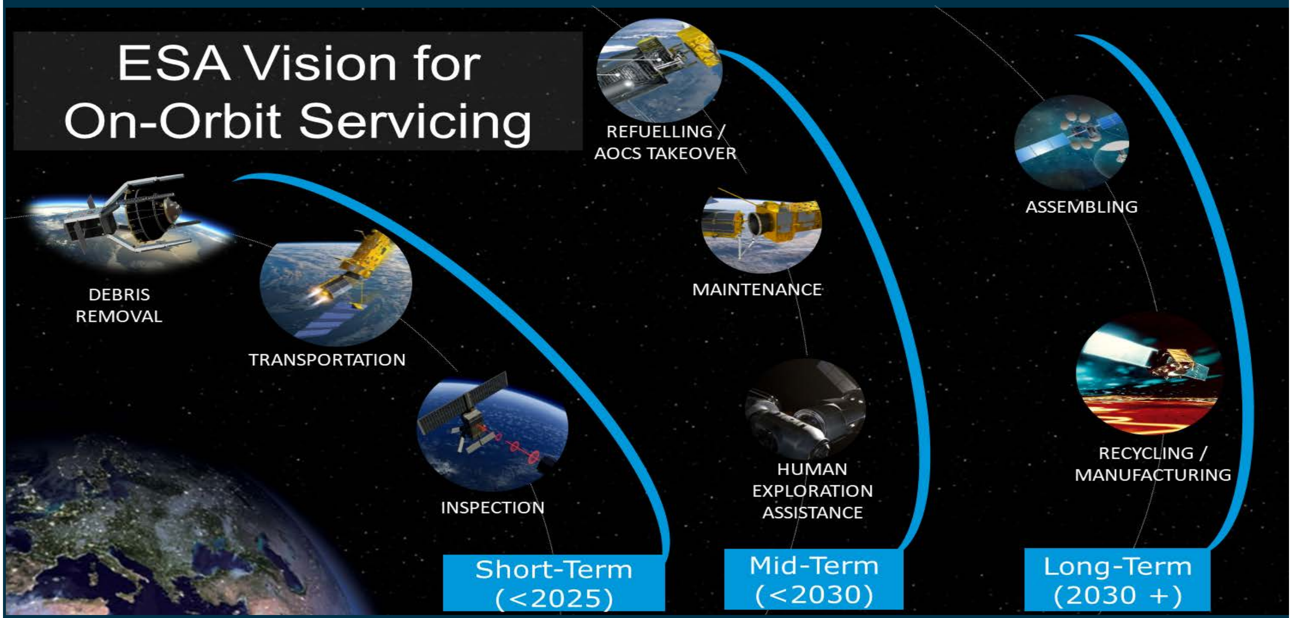
ASSIST – Standardised Refuelling Interface
Credits: GMV

Rendezvous markers for close proximity Operations / Laser ranging
Credits: NTUA/TAS-F, GMV/AVS



Gripper (left) and passive standardized interface for capture (right)
Credits: GMV/AVS

ADRIOS – Mission



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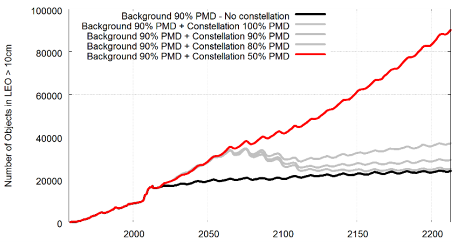
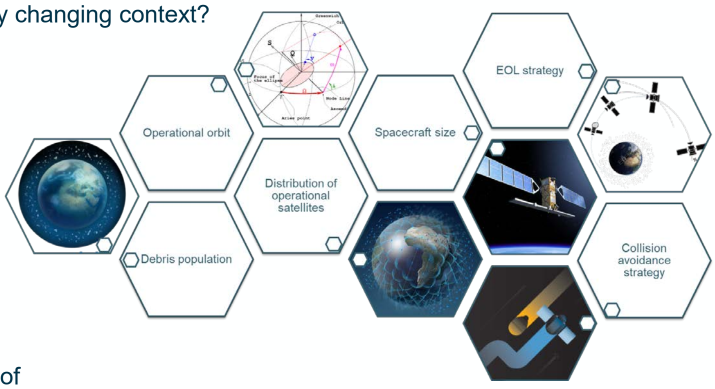
What is next? Towards environmental impact assessments

Mission types -> Changed , **Technologies used** -> Changed, **The environment** -> Changed

How to effectively mitigate space debris in an every changing context?





Can one measure for each mission or group there-of

- How detrimental is it to its **orbital neighbours**? (short-term, collision avoidance is now a fact of life)
- How does it contribute to the **Kessler syndrome**? (long-term, the raison d'etre for debris mitigation)

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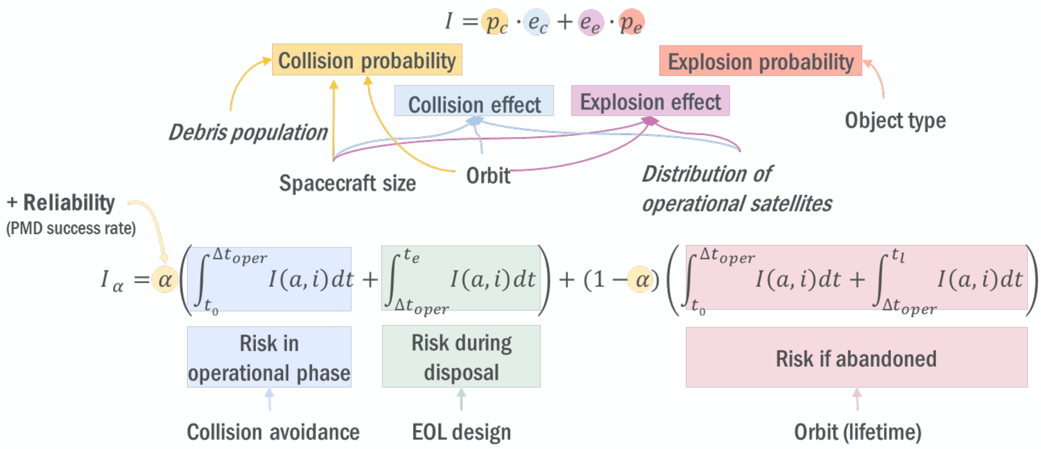
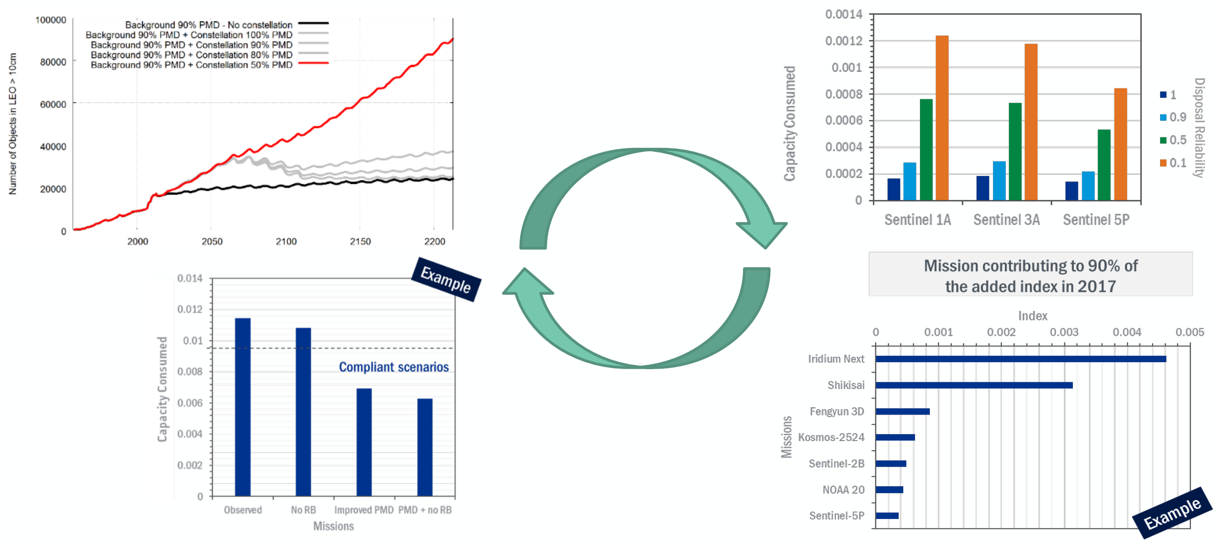
What is next? Object impact assessment (interference)

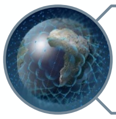


Letizia et al, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/417/SDC7-paper417.pdf
Letizia et al, https://www.sciencedirect.com/science/article/pii/S009457651930222X

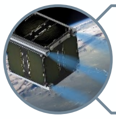
What is next? From object to environment capacity



What is next? Towards environmental impact assessments

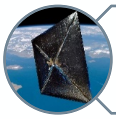


Which is the impact of operating at different altitude from the space debris point of view?
(e.g. for large constellations)

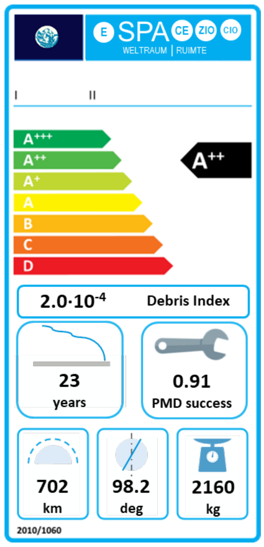


Which is the impact of having/not having propulsion capabilities?

Which is the impact of implementing a mission with a single large satellite vs a fleet of smaller ones?



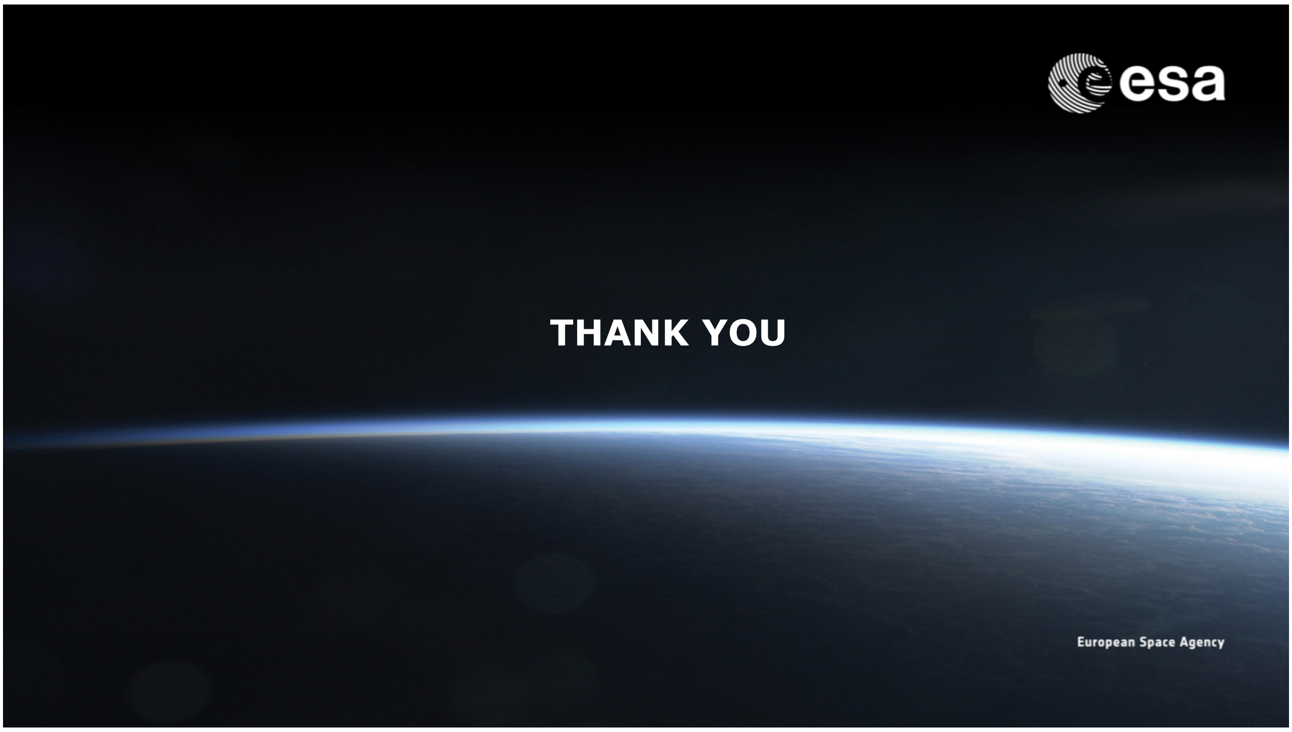
Which is the impact of using passive disposal systems?



Concluding remarks

New Space, the ongoing evolution of how we use the near Earth environment has implications:

1. Increased focus on operating in a congested environment: improved/additional sensors such as laser ranging and automated collision avoidance.
2. Adoption of space debris mitigation requirements are still too low: Investment into technologies to improve compliances for all.
3. The environment changes faster than the mitigation counter-measures: need to become adaptive, rather than reactive, by quantifying impact and interference.


esa
THANK YOU
European Space Agency