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Space debris mitigation & remediation: a general update

Christophe Bonnal (CNES)

The strong increase in time of the number and mass of orbital objects imposes to have appropriate answers if one wishes to guarantee a long term sustainable operation of Earth orbits.
The first step is to develop and apply general debris mitigation rules, declined in standards, codes of conduct, laws, guidelines… shared by all and clearly identified.
Collision Avoidance, when possible, may prove to be efficient to avoid collision on a maneuverable satellite. The driving line of such process, known as Space Traffic Management, requires progress in Space Surveillance and Tracking means, feeding the Space Situational Awareness.
As this prevention may not be enough, it may be necessary to remove the major sources of debris from orbits, in order to avoid collisions among large objects, sources of countless new debris. Numerous proposals for such Active Debris Removal have been made and often tested in orbit.
Some recent works have also proposed ways to avoid collisions thanks to the slight modification of the orbit of a potentially dangerous debris. This Just-in-time Collision Avoidance process appears very promising, provided the orbital accuracy of the debris is drastically increased compared to today.
The use of a small orbital laser could provide both the required orbital accuracy and the control of the position of large debris, following concepts known as Large Debris Traffic Management.
The presentation will briefly describe these various steps, fundamental to guarantee our future in space.

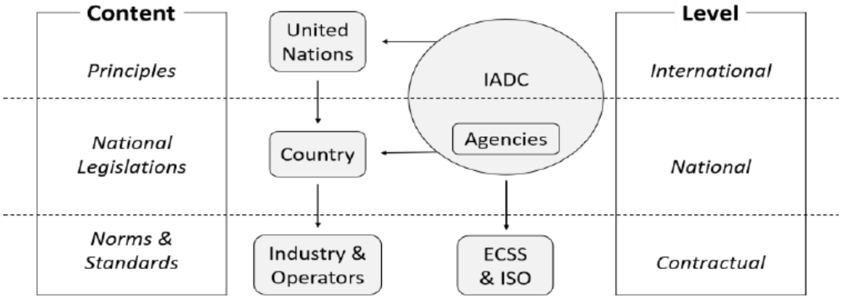


Figure: Structure of the Orbital Debris Mitigation rules

Biography

Christophe Bonnal

Christophe Bonnal started his career in 1983 in Aerospatiale, now Arianegroup, working on Ariane 4 technical topics, before dealing with future launchers and the development of Ariane 5.
He joined CNES in 1992 as responsible of the Ariane 5 development system tests. Christophe then headed the Future Launchers department for 8 years, before becoming the System Senior Expert of the Launcher Directorate.
In parallel, Christophe is in charge of the Space Debris topic since 1987. He is now chairman of the IAA and IAC Space Debris Committees, and is French delegate to IADC, ECSS and ISO.

Space debris mitigation & remediation: a general update

8th JAXA Space Debris Workshop, Chofu, 3 Dec. 2018

Christophe BONNAL

CNES, Launcher Directorate, Paris, France

Chairman – IAA Space Debris Committee – French delegate to IADC, ECSS, ISO

Mitigation & Remediation: an update

OUTLINE

1. Introduction
2. Mitigation rules
3. Collision Avoidance
4. Remediation
   - Small debris sweeping
   - Active Debris Removal
   - Just-in-time Collision Avoidance
   - Large Debris Traffic Management
5. Conclusion

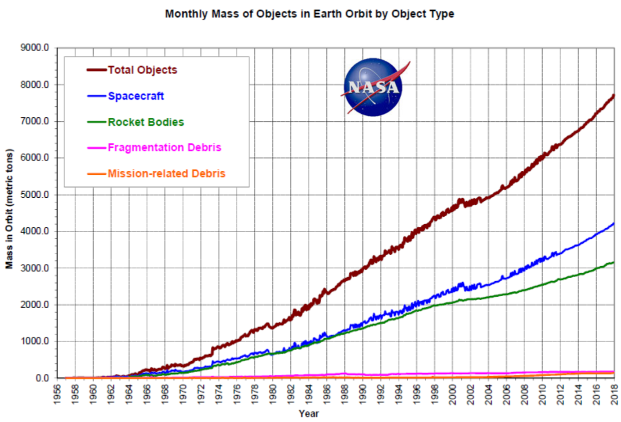
Mitigation & Remediation: an update

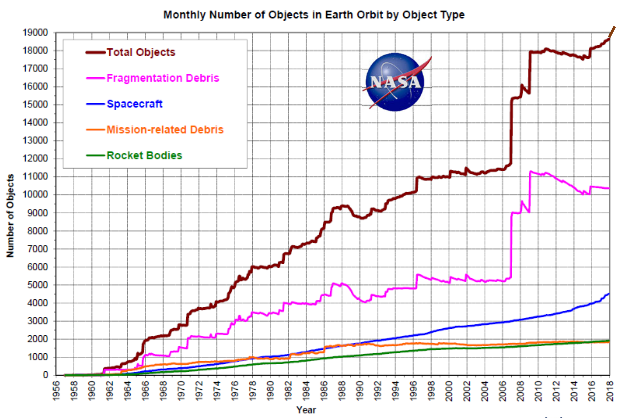
1. Introduction

Ever increasing orbital population

Since 1957, number and mass of space objects raise continuously:

- Despite reduction of launch rate compared to 60-80's
- Despite decades of debris mitigation rules





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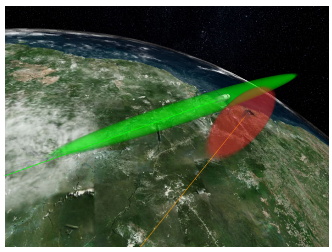
1. Introduction

Two major risks

- **Casualty risk at reentry**
- **Collision risk in orbit**



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Four families of required actions

- **Mitigation rules**
- **Shielding *(not addressed here)***
- **Collision avoidance and Space Traffic Management**
- **Remediation**
  - Small debris sweeping
  - Active Debris Removal
  - Just-in-time Collision Avoidance
  - Large Debris Traffic Management LDTM

Mitigation & Remediation: an update

2. Mitigation rules: An ever-lasting process…

- **First concerns in early 70s', mainly in Japan and at NASA level**
  - First collision models
  - First debris propagation models
  - First orbital density models
  - Comparison with micro-meteoroids
  - Initial development of evolution tools
- **First recommendations in 1978 by D. Kessler and B. Cour-Palais**
  - To "deorbit" at end of mission,
  - To avoid explosions and collisions
  - ↳ Identification of the potential cascading effect
- **Dissemination of the information at international level in early 80s'**
  - General description of Space Debris environment
  - Modelling
  - First recommendations for Space Station

Mitigation & Remediation: an update

2. Mitigation rules: An ever-lasting process…

- **First standard, published in Europe in 1988, PSS (now ECSS)**
  - ESA-PSS-01-40 Issue 2, September 1988
  - Not devoted to Space Debris, but includes numerous associated requirements
  - Controlled reentry for hazardous space systems, deorbiting
  - Proper mastering of collision risks, passivation
  - Probably too theoretical and not applicable
- **NASA Standard (1995): Guidelines and assessment procedures for limiting orbital debris**
  - Depleting on-board energy sources after completion of mission
  - Limiting orbit lifetime after mission completion to 25 years or maneuvering to a disposal orbit
  - Limiting the generation of debris associated with normal space operations
  - Limiting the consequences of impact with existing orbital debris or meteoroids
  - Limiting the risk from space system components surviving reentry as a result of postmission disposal

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2. Mitigation rules: An ever-lasting process…

- **NASDA Standard (1996) NASDA-STD-18**
- **CNES Standard (1998) RNC-Q-40-512,** (now French Space Operations Act 2008)
- **ECSS-Q-40-A (1996):** Evolution of the PSS-01-40 applicable to ESA (April 1996)

Decision to prepare International standards

Since then at National standard level:

- **UKSA:** Mainly devoted to spacecraft registration
- **DLR RF-0S-001:** Latest issue: (7) August 2012
- **Russian GOST –P - 52925-2008:** General Requirements on Space Systems for the Mitigation of Human-Produced near-Earth Space Pollution (2009)
- **South-Korea:** under preparation
- **Relatively good coherence of standards at national level**

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2. Mitigation rules: An ever-lasting process…

- **IADC (Inter-Agency Space Debris Coordination Committee)**
  - Initial meetings starting in 1987 between NASA and ESA
  - Officially 1st IADC meeting in Moscow 1993
  - 36 meetings so far; now once per year
  - 13 countries (including ESA) today
  - 4 Working Groups + Steering Group
    - *WG1: Measurements*
    - *WG2: Environment and Data Base*
    - *WG3: Protection*
    - *WG4: Mitigation*
  - IADC Space Debris Mitigation Guidelines
    5 years convergence
    Unanimously approved in **2002**, revised in 2007

- **UN Guidelines**
  - Elaborated by UNCOPUOS on the basis of IADC Guidelines
  - Published in 2007
  - No mention of 25-year rule

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2. Mitigation rules: An ever-lasting process…

- **European Space Debris Mitigation Standard EDMS (1998)**
  - 5 years work to prepare EDMS
  - Vol.1 = Standard
  - Vol.2 = Explanations and Guidelines for implementation
  - Edition 1.7 ready for approval on 1st July 2002
    ↳ but, not allowed to write standards!

- **European Code of Conduct ECoC (2003)**
  - From Sept. 2003 to June 2004
  - Replacement of all "shall" by "should"
  - Major 3 days workshop with Industrials in December 2003
  - Approval ASI-BNSC-CNES-DLR-ESA on 26 July 2004
  - Issue 2 in August 2005
  - Volume 2 "Support to Implementation of ECoC"

↳ **Used as initial text for ISO 24113**

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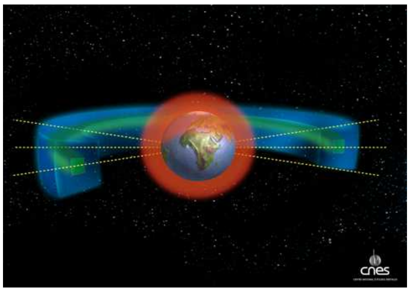
2. Mitigation rules: An ever-lasting process…

Mitigation rules are logical and easily understandable

1. **Short term:**
   - Minimization of operational debris; no voluntary break-ups,
   - Systematic passivation to prevent accidental break-ups,
   - Two protected zones (LEO, GEO): 25 years rule,
   - Avoid collisions when possible,
   - Minimize casualty risk at reentry.

2. **Long term**
   - Systematic deorbitation or escape.



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2. Mitigation rules: An ever-lasting process…

- **ISO-24113 = High level standard**
  - Lengthy process from 2005 to formal issue in February **2010**
  - Family of “second level” standards
  - Currently under revision: quantification of the requirements
  - ↳ Major evolution to include all “second level” standards

- **ISO adopted by ESA through**
  - ESA/ADMIN/IPOL(2008)2 dated 1 April 2008
    Space Debris Mitigation for Agency Projects
  - Updated as ESA/ADMIN/IPOL(2014)2 dated 28 March **2014**
  - ECSS-U-AS-10C 10 February 2012 Adoption Notice of ISO 24113
  - Evolution following current update of ISO-24113

- **ISO also adopted by CNSA (China) since 2012**

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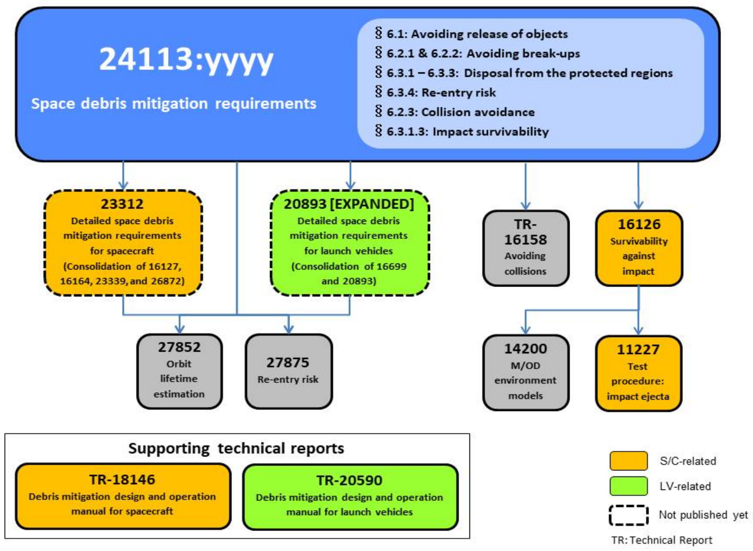
2. Mitigation rules: An ever-lasting process…

ISO standards: current framework



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2. Mitigation rules: An ever-lasting process…

New comer: Charter from Global Viasat Forum GVF

- *"GVF space industry-led endorsement of best practices for sustainable space Activities"*
- Adoption of IADC, UN and ISO rules,
- Additional best-practices, mostly "Space Traffic Management" related
  - Probability of successful disposal of 95%
  - Dispose of satellites within 5 years of end-of-mission
  - …
- Good progress towards efficient STM among large constellations, despite use of "should" instead of "shall" ⇨ Non binding document
- Directly relevant to Long-Term Sustainability (LTS) consensus guidelines
- Still draft, not yet distributable. Some 40 operators involved; more than half have already signed. May be approved before end of **2018**

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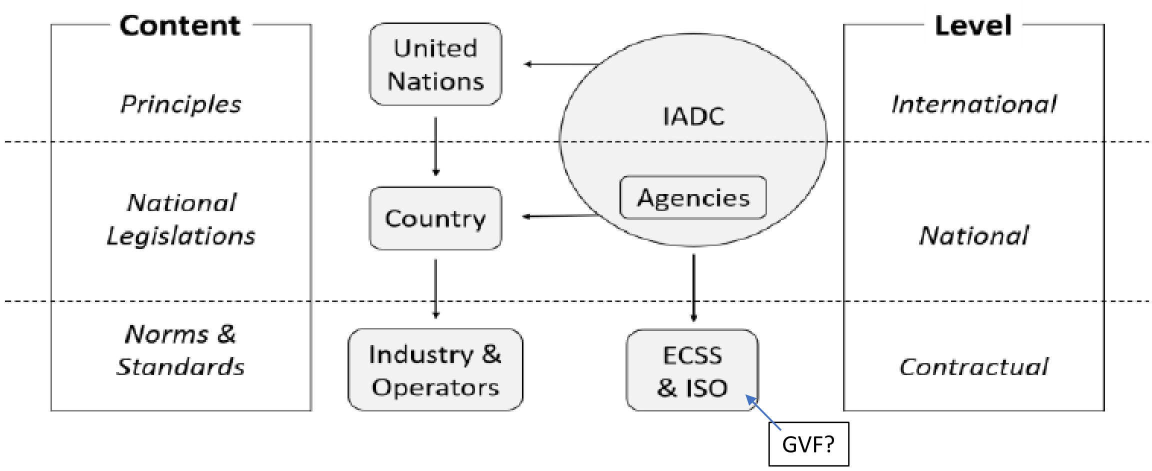
2. Mitigation rules: An ever-lasting process…

Structure of the current debris related documents



+ Numerous support documents such as IAA Situation Reports

This document is provided by JAXA.

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2. Mitigation rules: An ever-lasting process…

Current status of the debris related documents

- **Mostly non binding requirements**
  - Guidelines, Codes of conduct, Recommendations, Best practices… (only one Law)
  - Significant difficulties to have documents approved
- **Current level of compliance is very low**
  - Only **20%** when considering "large" objects above 600 km
  - Simulations show a continuous increase in orbital population when compliance < 90%
  - Very low progress in LEO
    - ↳ Continuously increasing number and mass of debris in orbit since 1957
    - ↳ Significant collisions and fragmentations still observed in orbit
- **Potentially troubled waters ahead…**
  - Increasing number of satellites announced for the coming decades
  - Increased number of catalogued objects thanks to new radars

↳ **Mitigation rules alone are possibly not sufficient**

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3. Collision avoidance: Space Traffic Management

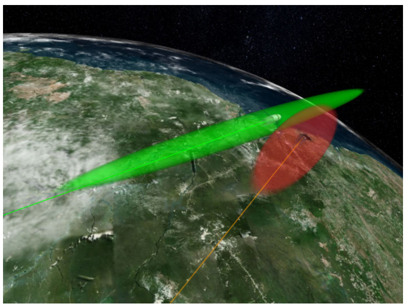
Between catalogued, maneuvering objects (COLA)

⇨ Orbital propagation of catalogued objects

Identification of close encounter risks
Alert messages from JSpOC (USA) or self-generated
Maneuver when risk > threshold

↳ Efficient for operational satellites, <u>but</u>

No protection against untracked debris
No action on collision between large debris
Essentially false alarms due to poor orbital accuracies



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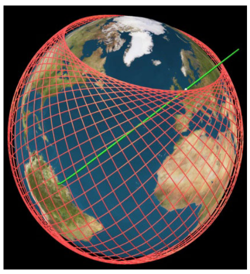

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Also, Collision risk assessment at launch (CORAL)

Examples in 2017

. Roughly 1 maneuver every 3 days
. NASA: 21 maneuvers, (ISS: 25 maneuvers since 1999)
. ESA: 16 maneuvers for 23 satellites; JAXA 3 maneuvers;
. CNES: 13 maneuvers for 27 satellites monitored
60.000 conjunctions (2.7 million messages) in 2017 (≅ 1 every 9 minutes…)

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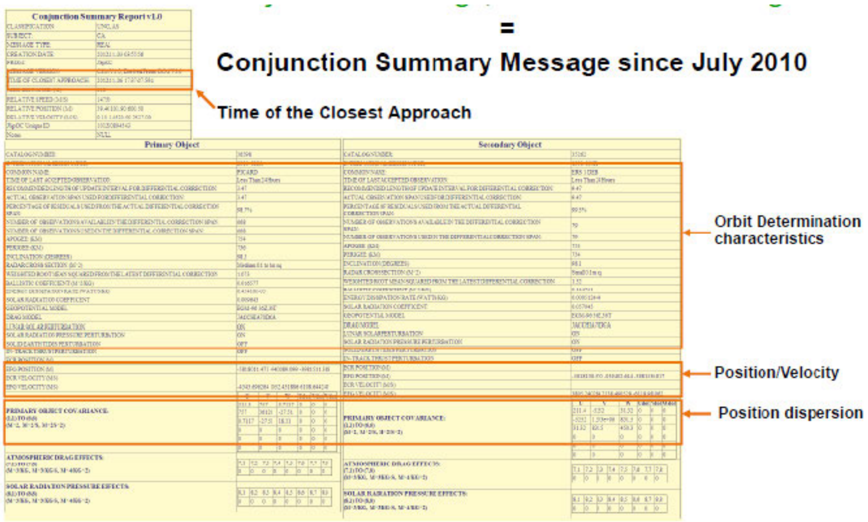
3. Collision avoidance: Space Traffic Management

Conjunction Data Messages



⇨ Lack of accuracy ⇨ Numerous false alarms

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3. Collision avoidance: Space Traffic Management

International actions on Space Traffic Management STM

1st step: Space Surveillance and Tracking SST

Improvement of the knowledge of the orbital population

Need for additional observation means SST

Figure 4.25: Sensors in the ComSpOC® Observing Network [4.7, 4.8]

- Space Fence
- Private US networks: Comspoc®, LeoLabs®, …
- On-going in Europe with EU-SST, improvements (GRAVES) and new systems (GSTRA)
- Significant work throughout the world (Example of Japan)
- Russian radar network (no information)
- Russian ISON® network

2nd step: Space Situational Awareness SSA

- Tools necessary to use this information
- Catalogs
- Exchange processes: unsuccessful UN LTS guidelines

Figure 4.21: Kamasaibara Space Guard Center KSGC

↳ Numerous on-going actions internationally

Mitigation & Remediation: an update

4. Remediation: small debris sweeping in LEO

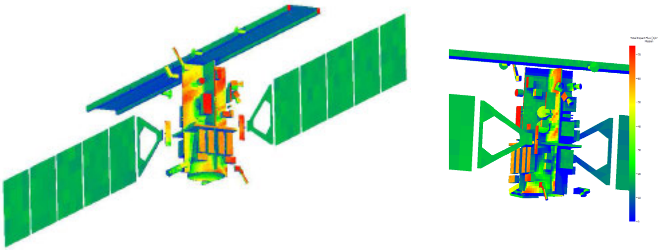
Small debris are invisible satellite killers

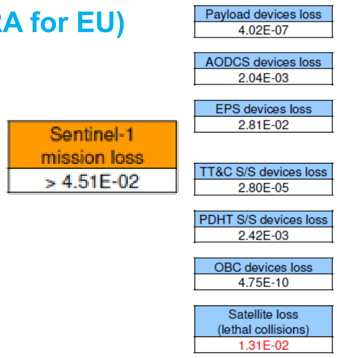
Hypervelocity impacts with high energies

- 1 mm debris ≅ 1 kJ ≅ Bowling ball @ 100 km/h
- 1 cm debris ≅ 1 MJ ≅ Large car @130 km/h
- 10 cm debris ≅ 1 GJ ≅ 25 kg TNT

Numerous studies show probability of loss of mission due to debris ≈ 5%

Example of the P²ROTECT Study (TAS-I ONERA for EU)
Similar results: REVUS (Airbus DS) ANRICO (CNES)





P²ROTECT FP7-SPACE-262820
Prediction, Protection & Reduction of Orbital Exposure to Collision Threats

© L.Grassi (TAS-I) et al.

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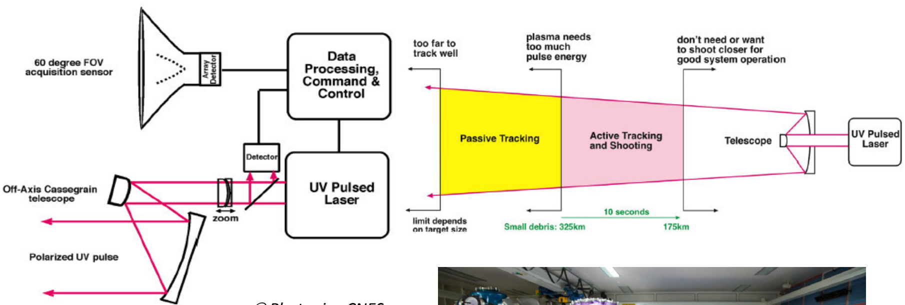
4. Remediation: small debris sweeping in LEO

Remediation is difficult due to non-trackability of small debris

Most promising solutions are based on lasers



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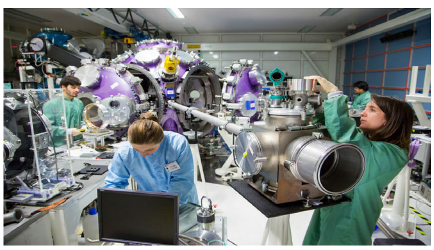

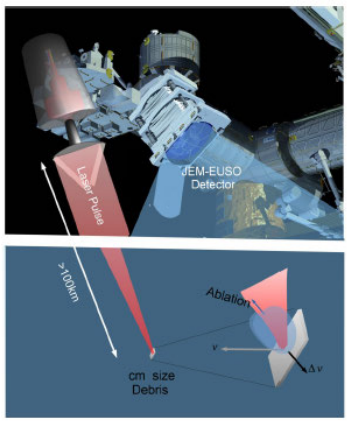

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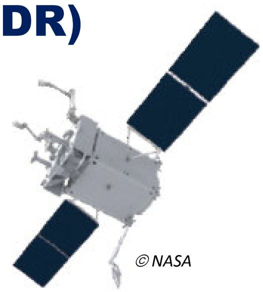
4. Remediation: Active Debris Removal (ADR)

GEO satellite reorbiting

Globally credible: Low ΔV and positive Business Plan

- Space Tug mission
- Electrostatic leash (GLIDER)
- Ion Beam Shepherd
- Laser reorbiting



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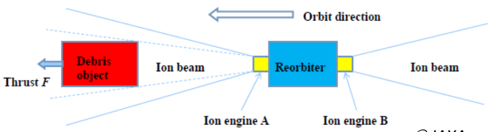

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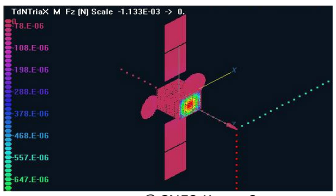

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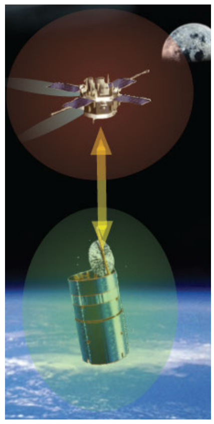

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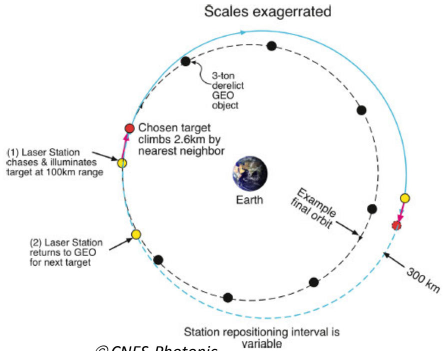

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4. Remediation: Active Debris Removal (ADR)

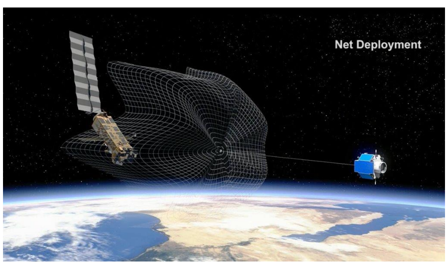
Removal of large debris in LEO to retrieve sources of future debris

Technically feasible

- Close to a Space Tug mission
- Numerous variants, passive or active, with or without prior stabilization of Debris, with or without controlled reentry (robotic arm, harpoon, net, grapple, EDT, drag sail, airbag,…): **no best solution so far**

↳ Good progress on ground demonstrations

↳ Few in-orbit demonstrations developed or flown yet *(JAXA KITE, SSTL Remove-Debris, D-Orbit D-SAT, Astroscale ELSA, EPFL CSO)*



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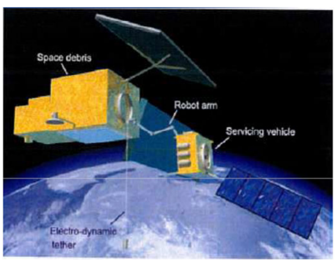

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4. Remediation: Active Debris Removal (ADR)

Active Debris Removal (ADR) in LEO

Questionable Business Plan: expensive operations

Global efficiency is questionable: 35-45 retrievals to avoid one collision?

↳ Who wants to pay to retrieve such debris? (potentially 15-20 M€ each)

Four ways identified as per today

- International environmental conscience, mission under the aegis of UN (COPUOS), first "global" space program, cost sharing ⇨ probably naïve…
- Missions targeted as function of their economical interest, paying service for concerned operators ⇨ promising for constellations *(cf Cycler from Airbus DS)* and GEO
- Eco-tax towards every operator not complying correctly with the international regulation
  ⇨ "police" role to be defined, potentially insurers: new international organism
- Operational satellites turn-over gain by lowering probability of collision
  ⇨ Precise calculation and Business Plan still to be done

Still strong hurdles ahead: legal, military, insurance…

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4. Just-in-time Collision Avoidance (JCA) in LEO

Prevent an avoidable collision between 2 large debris

- Tactical action to avoid a predicted collision
- Nudging: slight modification of the trajectory of one of the debris
- Some promising solutions today
  - Artificial atmosphere (gas and/or particles) in front of the debris
  - Laser
- Open problem: impart a 4 mm/s ΔV to a large orbital debris

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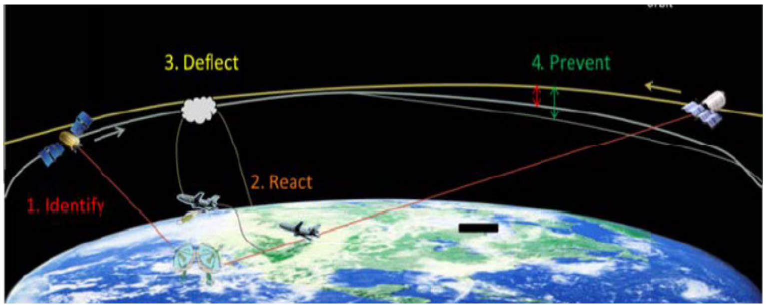

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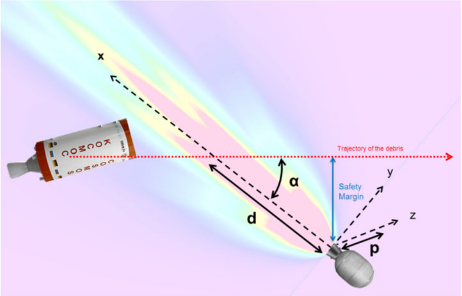

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4. Large Debris Traffic Management LDTM

Manage the collision risk within debris population at minimal cost

- **Evolution of the JCA idea: prevention before increase in collision probability**
- **Analogy with a shepherd dog reacting to bring back a sheep before danger**
- **Potentially: orbital pulsed laser in 700-900 km SSO, 6h00-18h00 RAAN**
- **Dual use:**
  - Drastic improvement of orbital parameters accuracy (laser ranging)
  - Trajectory correction with short energetic laser pulses
    Increase in warning time: 3 days instead of 1
    ⇨ Decrease in ΔV: 1.5 mm/s instead of 4
  - Typical laser: NdYAG 3rd harmonic, 80 ps pulses, pulse energy 100 mJ (ranging) 1 kJ (Nudging)
  - Potentially small satellite: 500 – 800 kg
- **No real study yet**
  - Preliminary evaluations at University level ongoing (Polytechnique, Mines Paris)

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5. Conclusions

Numerous points of concern…

Space Debris Mitigation rules are not yet correctly respected

Roughly 55% of the missions are compliant
Still numerous fragmentations in orbit

Potential problems ahead

Large number of Cubesats
Mega-constellations arriving
New Space fence radar arriving in US

No serious remediation development yet

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Priorities:

- Improve drastically compliance to mitigation rules (> 90%)
- Coordinate actions at STM (SST-SSA) level
- Prepare for ADR, first constellations and GEO
- Prepare for JCA to prevent avoidable debris collisions, mainly within large clusters
- Identify solutions for LDTM in complement to STM
  ↳ All at international cooperative level

Thank you for your attention

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To know more:

IAA Situation Report on Space Debris – 2016

Downloadable from IAA website: http://iaaweb.org/content/view/487/655/