SOSTC

Improving Space Operations Workshop

Spacecraft Collision Avoidance and Co-location

Space Debris Realities and Removal

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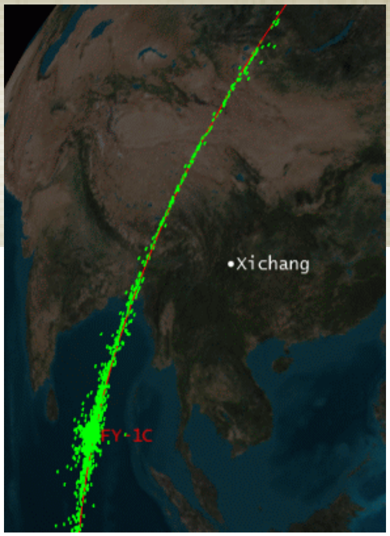
The Problem



➢ Recent events such as
  • Chinese ASAT test in 2007
  • Collision of Iridium 33 & Cosmos 2251 in 2009

have increased the risk of debris collisions with operational satellites in certain zones of low Earth orbits.

➢ These events have created an increased level of urgency in aggressively managing orbiting junk.

➢ There is now a growing consensus that debris population reduction is inevitable if space is to remain freely available for commercial, scientific and security applications.

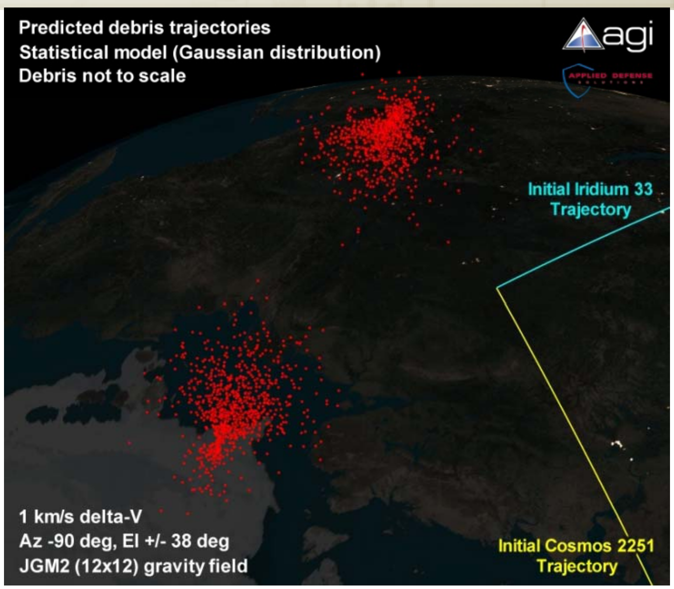
➢ Currently, debris mitigation efforts are limited to minimizing new debris production.

➢ Space-faring nations are beginning to consider intensified mitigation activities, including debris removal programs.

➢ DARPA has initiated a debris removal effort called, “Catcher’s Mitt.”*

*See: http://www.darpa.mil/news/2009/orbitaldebris.pdf

Urgency for a Solution

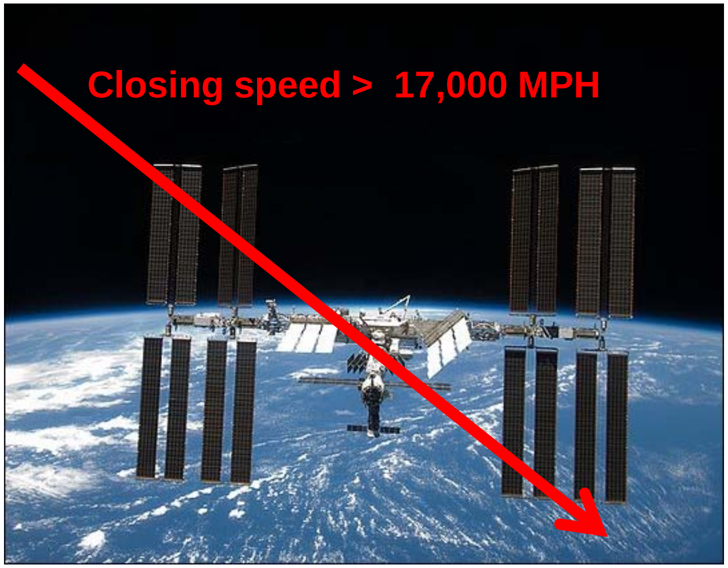


- On Feb 10, 2009, an active Iridium satellite and an expired Russian spacecraft collided, adding some 900+ new debris pieces to the catalog of tracked orbiting objects. This catalog now contains over 20,500 objects that are larger than 10 cm.
- This is the first known satellite-to-satellite collision.
- Debris pieces scattered among the highly populated orbital planes of Iridium (66 satellites + spares) adding additional risk of subsequent collisions, e.g.,
  - Don Kessler (former NASA debris scientist) expects another Iridium type event in about 10 years.
  - TS Kelso (CSSI)* anticipates a high probability of another collision within months.

*Center for Space Standards & Innovation

Close Call for The ISS

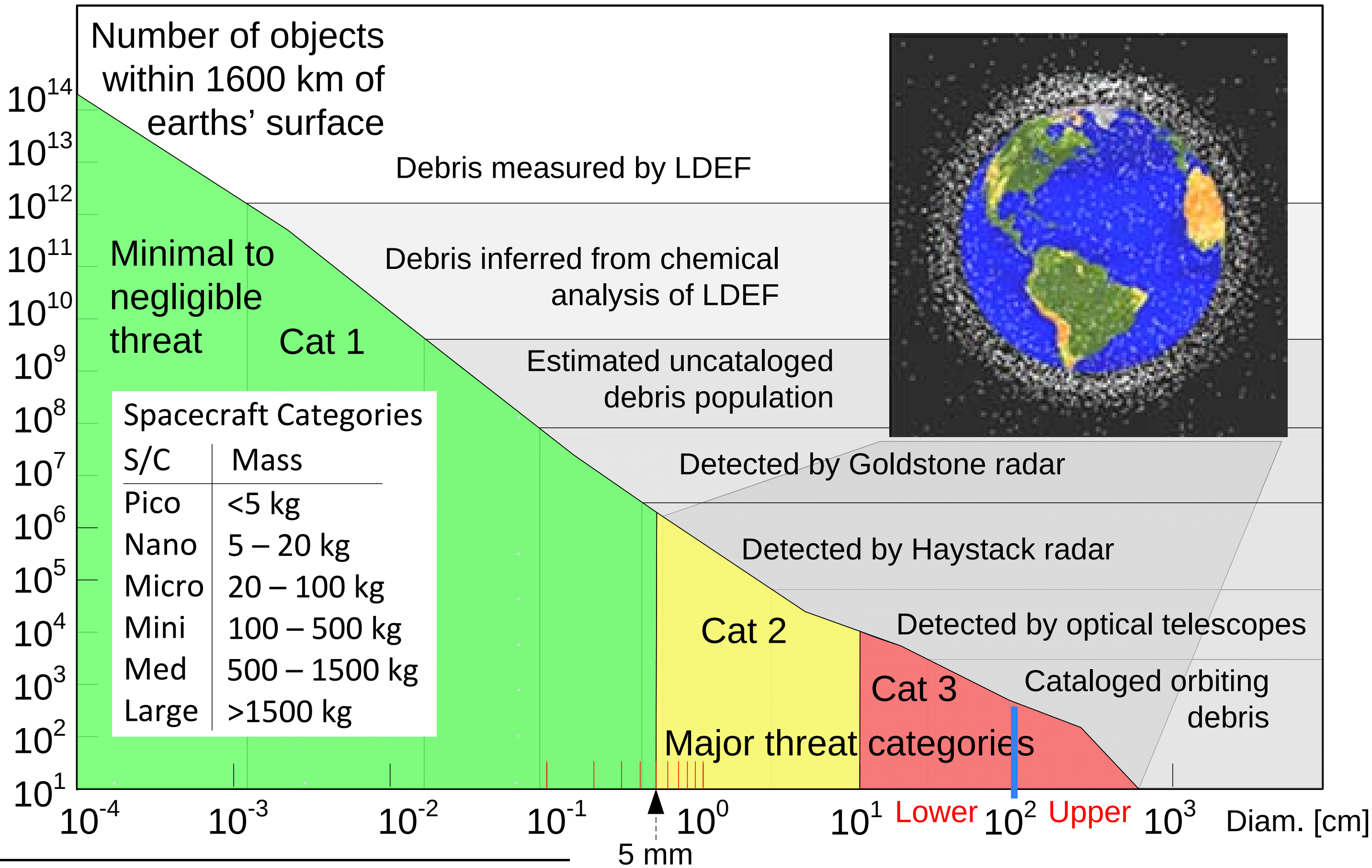
- *Space.com* reported NASA was tracking a piece of metal from an Ariane 5 rocket body* that passed by the ISS on September 4th. This piece of space junk could have collided with the docked ISS/Discovery.
- Fortunately, NASA decided an avoidance maneuver was not necessary.
- This was not the first time and it will not be the last time.



*NASA officials were unsure of the exact dimensions of the debris, but knew it is part of an Ariane launched in August 2006 that sent two communications satellites into GTO. It is relatively massive with about 204 square feet in area, flying in an extremely elliptical orbit with apogee of nearly 20,000 miles, making it hard to track.

Size Classification

LEO Debris Characterization*



*LEO debris represents the greatest threat and will likely require different remediation approaches as opposed to MEO and GEO debris approaches.

Ref: *Orbital Debris: A Technical Assessment*, Committee on Space Debris, National Research Council (1995)

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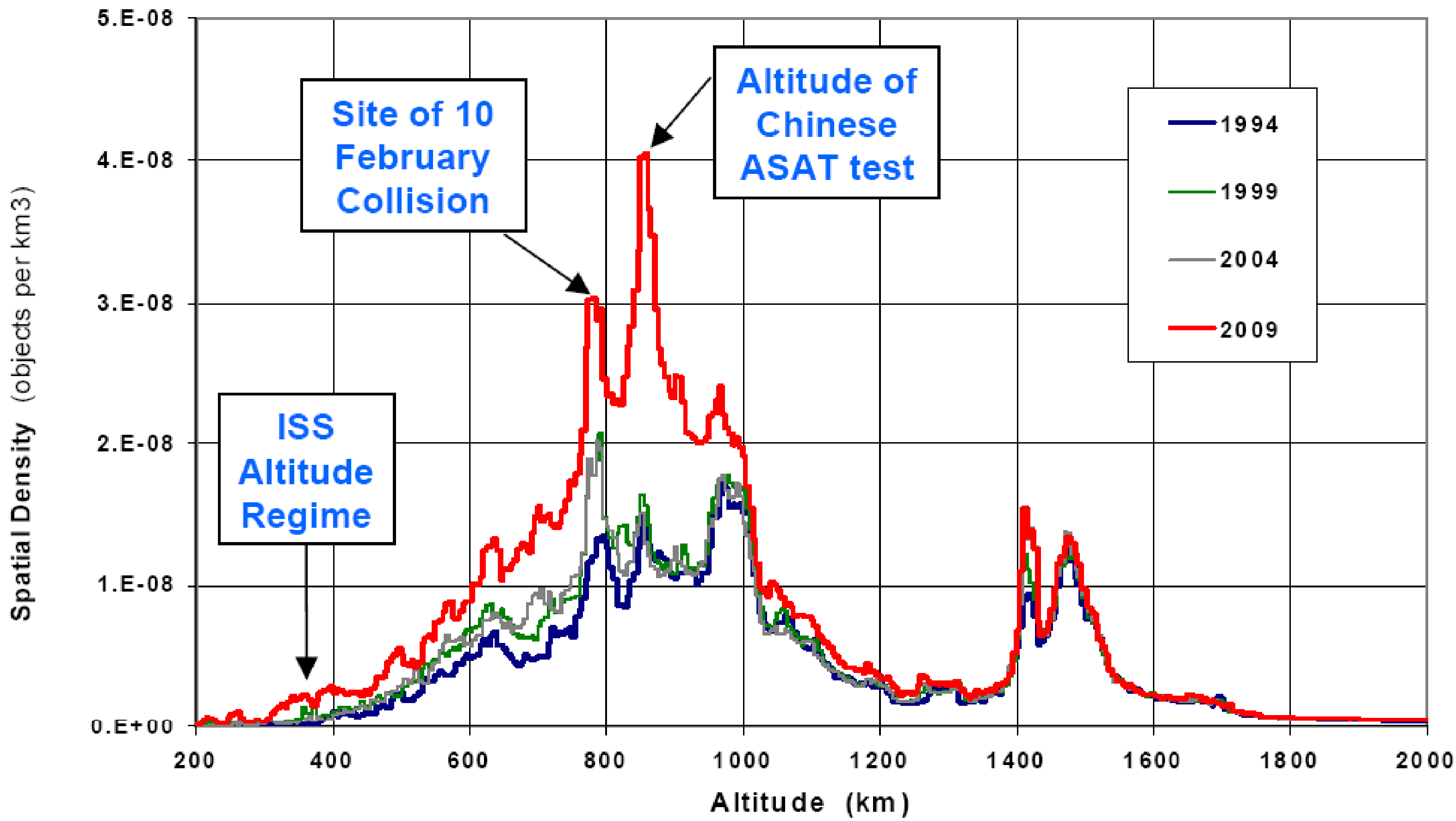
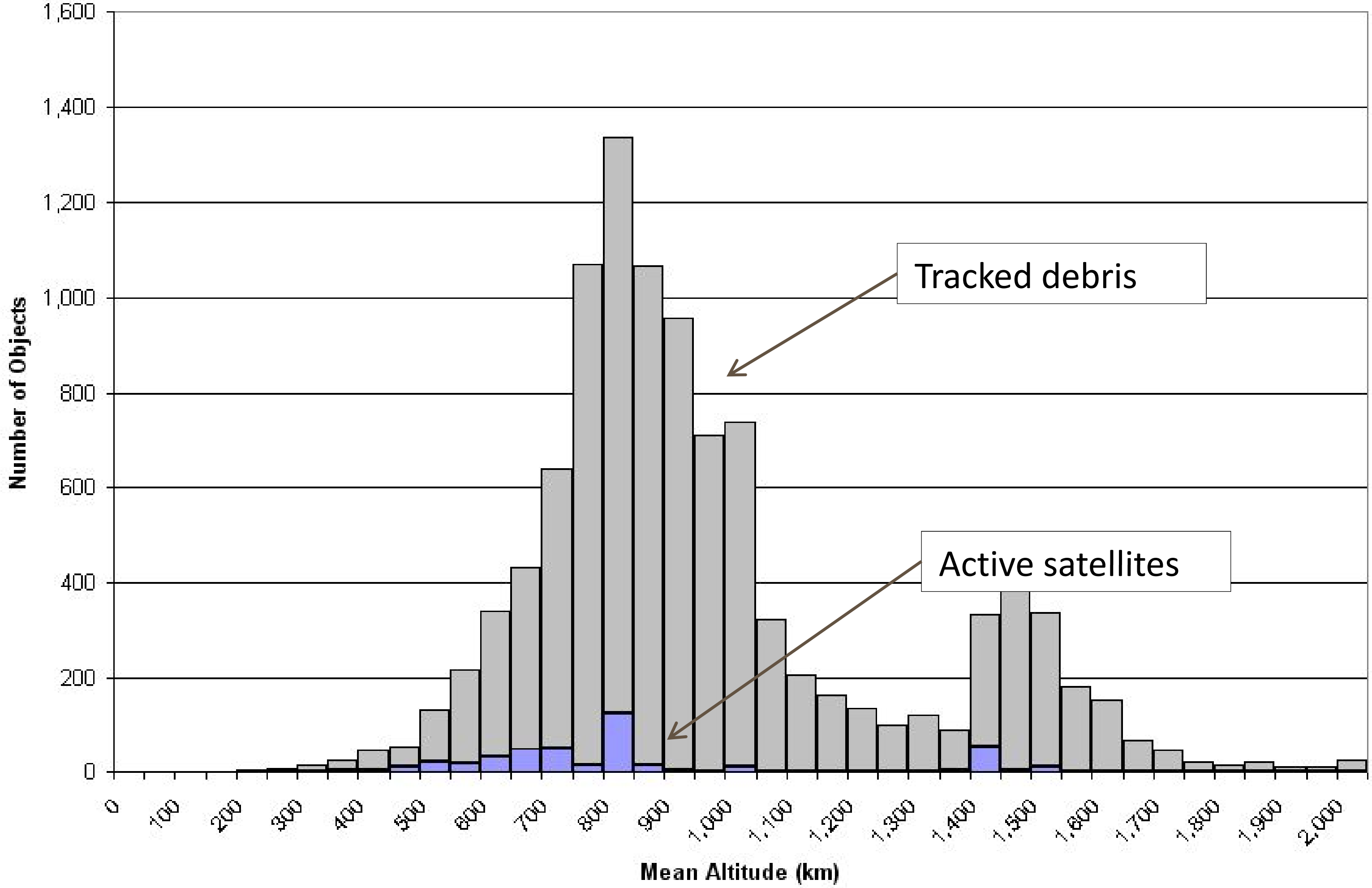
The Nature of the Challenge



Graphic evolution of total trackable low Earth orbit (LEO) object population since 1994

Ref: "Assessment of Space Debris Reduction Methods," M. H. Kaplan, presented at IAC 2009, Daejeon, Republic of Korea, Paper No. IAC-09.A6.4.9, October 12-16, 2009.

The Nature of the Challenge



Histogram of all tracked LEO objects as of July 1, 2009.

Ref: "Assessment of Space Debris Reduction Methods," M. H. Kaplan, presented at IAC 2009, Daejeon, Republic of Korea, Paper No. IAC-09.A6.4.9, October 12-16, 2009.

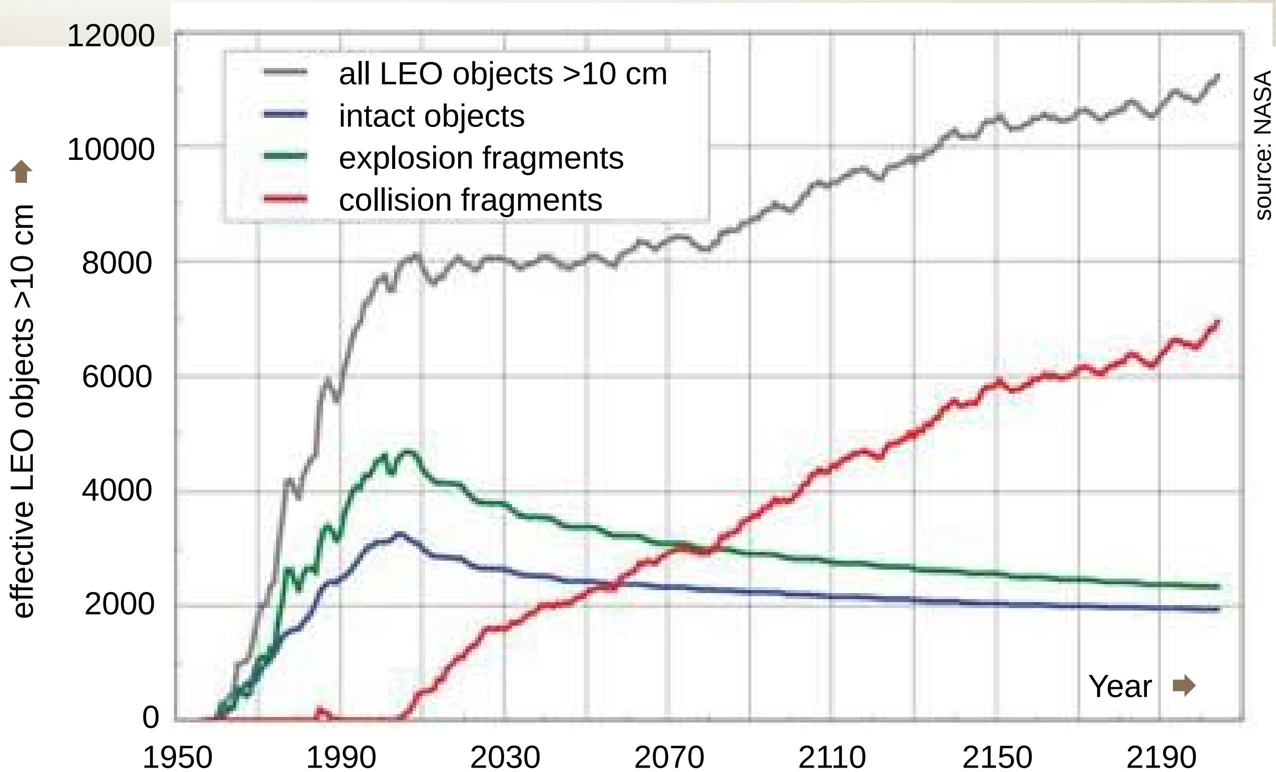
Trends

- Space-faring nations are dependent on space systems, thus space debris is recognized as a growing concern.
- Today, there are currently 900+ active satellites in various orbits around the Earth. About 2/3 of these are in LEO.
- There are over 22,000 tracked objects (> 10 cm) cataloged by the U.S. Space Surveillance Network (SSN).
- All orbits, especially LEO, are subject to highly variable orbit-perturbing conditions - SSN observations are falling behind and conjunction prediction accuracies are not ideal.
- The risk of collision is growing super-linearly and is of great concern to all satellite operators.
- Other than natural processes, there are currently NO measures to reduce existing debris objects.

Approaching a Solution

- Many solutions have been suggested, but few will prove viable in terms of technology limitations and cost issues.
- Additional concerns will contribute to future decisions, such as political and legal issues.
- The initial work done at APL represents a first step in the evolution of a practical solution to one of the most challenging and complex issues facing the future of space flight.
- Insights presented here are intended to be help frame the problem space and formulate realistic options for later decision processes.

Long-Term Debris Environment Forecast

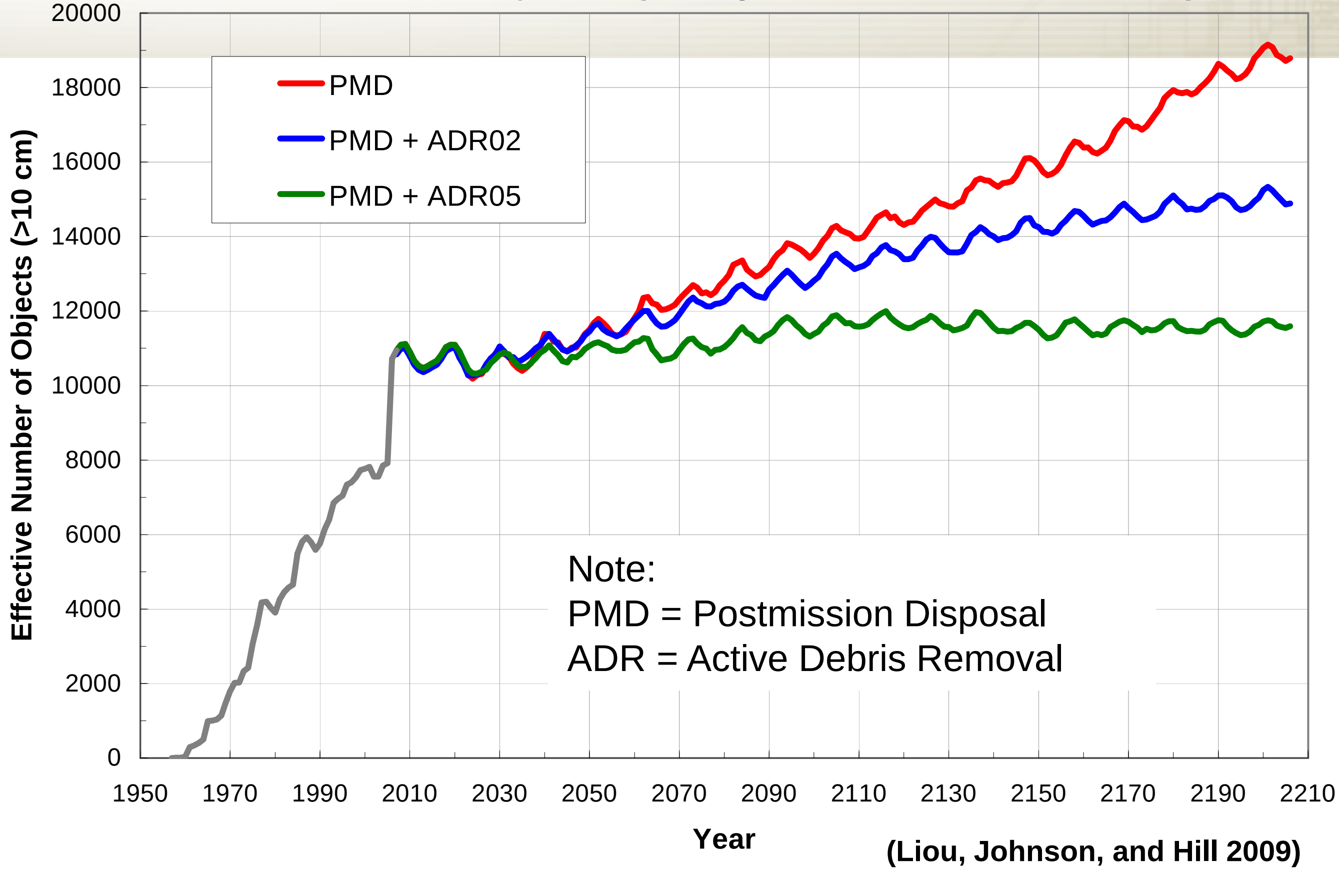


- **assumption: no further launches ➡ "best case" mitigation scenario**
- **result: collisional cascading will start in LEO ("Kessler syndrome")**
  ➡ debris mitigation alone cannot stabilize the environment

Source: Klinkrad and Johnson, "Space Debris Environment Remediation"

LEO Population Control

LEO Environment Projection (averages of 100 LEGEND MC runs)



(Liou, Johnson, and Hill 2009)

- **PMD scenario predicts the LEO populations would increase by ~75% in 200 years**
- **The population growth could be reduced by half with a removal rate of 2 obj/year**
- **LEO environment could be stabilized with a removal rate of 5 obj/year**

Source: Klinkrad and Johnson, "Space Debris Environment Remediation"

Specific Removal Methods

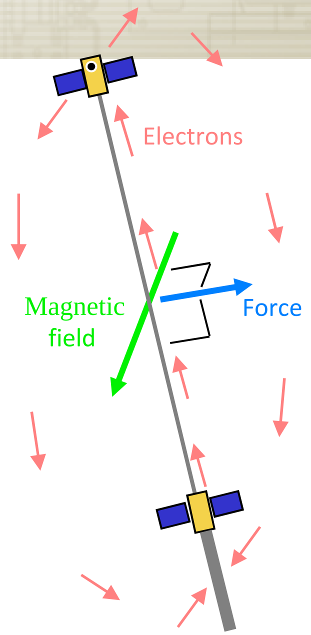
Small Debris Collection

- Less than 0.5 cm - forget it.
- From 0.5 to 10 cm – can't track it and can't collect it, but it is dangerous.

Large Debris Collection

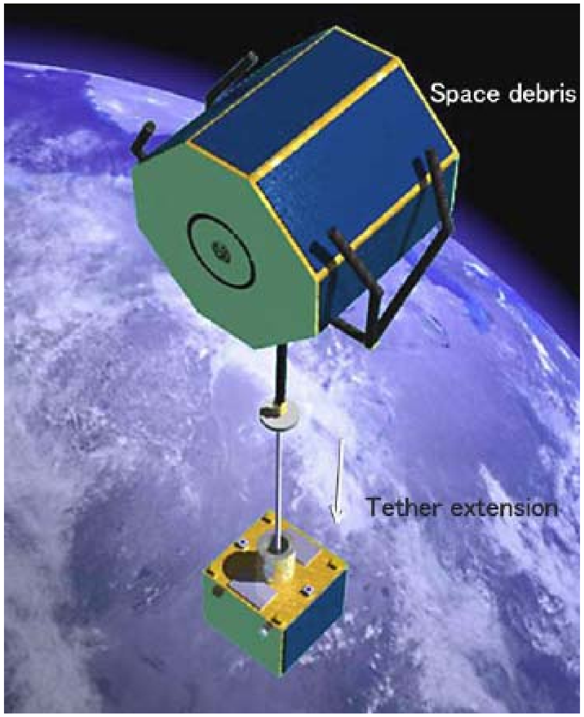
- From 10 cm to 1 m – can track it, but can't collect it and it is very dangerous.
- Larger than 1 m – extremely dangerous. We can track it and we must collect it via:
  - o Trash tenders
  - o Dual-use transfer vehicles
  - o Space tethers
  - o Lasers

Electrodynamic tether tender*



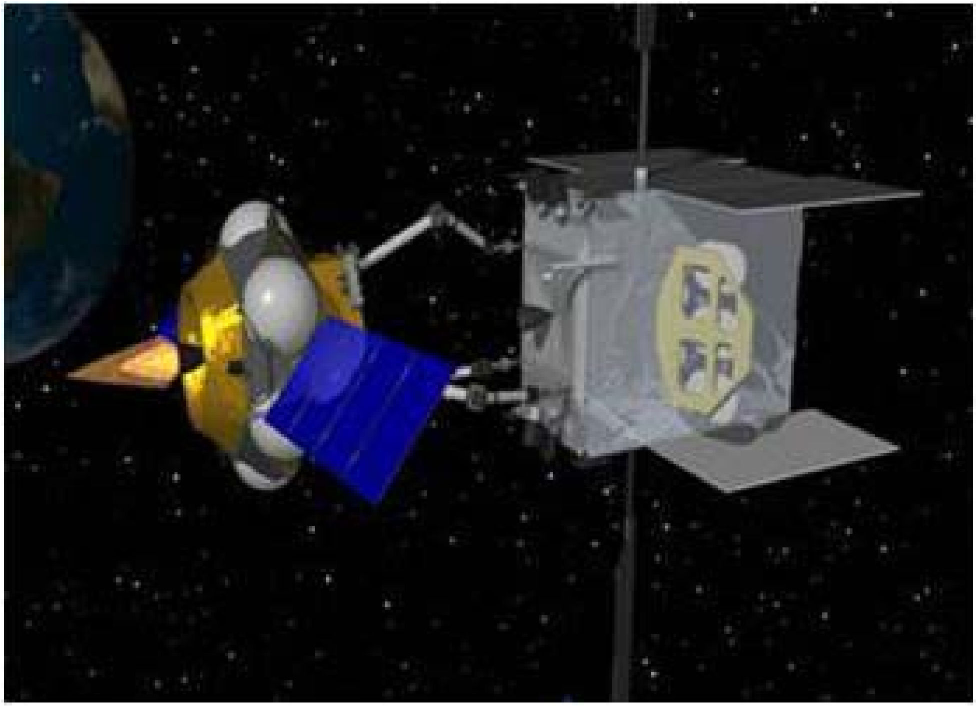
*Ref: Pearson, J., et al., "Overview of the Electrodynamic Delivery Express (EDDE)," 39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibition, Huntsville, AL, 20-23 July 2003.

Capture Techniques: Grappling Examples



Micro Remover tether-extensible gripper with foldable arms, JAXA.

Ref: S. Nishida, S. Kawamoto, Y. Okawa, F. Terui and S. Kitamura, “Space debris removal system using a small satellite,” Acta Astronautica, Vol. 65, 2009, pp. 95–102.



FREND 3-arm system for autonomous unaided grappling.

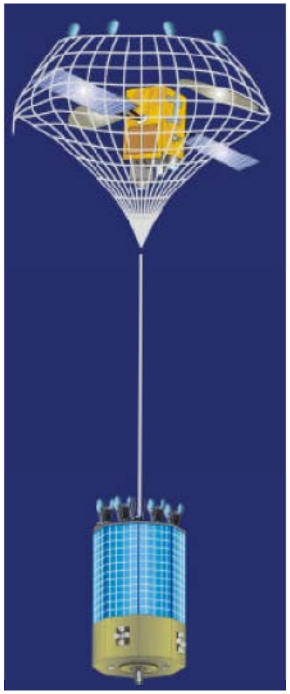
Ref: B. E. Kelm, J. A. Angielski, S. T. Butcher, et al, “FREND: Pushing the Envelope of Space Robotics,” Space Research and Satellite Technology, 2008 NRL REVIEW, pp. 239-241.

Capture Techniques: Grappling Examples

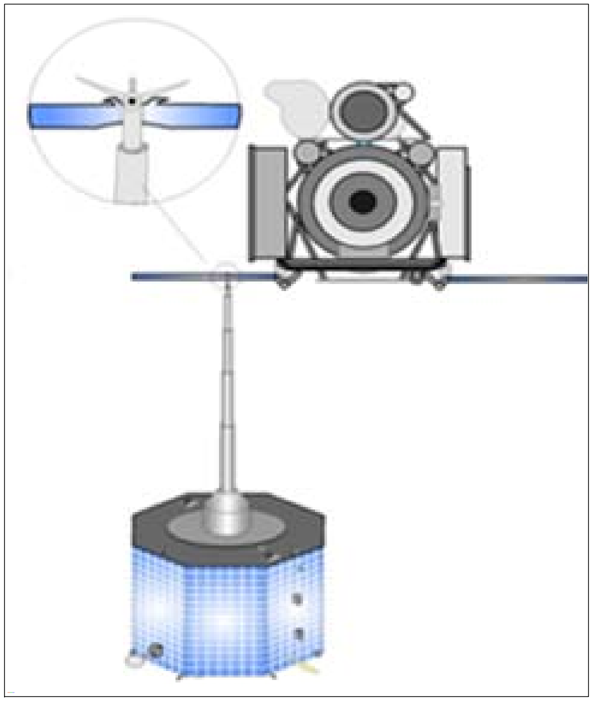
Ranger 8 DOF human-scale grappling arms.
Ref: D. L. Akin, "Robotic and EVA/Robotic Servicing: Past Experiences, Future Promise," presented at the International Workshop on On-Orbit Satellite Servicing, Hosted by NASA Goddard Space Flight Center, Adelphi, MD, March 24-26, 2010, http://servicingstudy.gsfc.nasa.gov/.

OctArm tentacle manipulators.
Ref: D. Trivedi, C. D. Rahn, W. M. Kier and I. D. Walker, “Soft robotics: Biological inspiration, state of the art, and future research,” Applied Bionics and Biomechanics, vol. 3, no. 5, pp. 99-117, September 2008.

Capture Techniques: Grappling Examples



ROGER net-based capture concept, EADS Astrium.

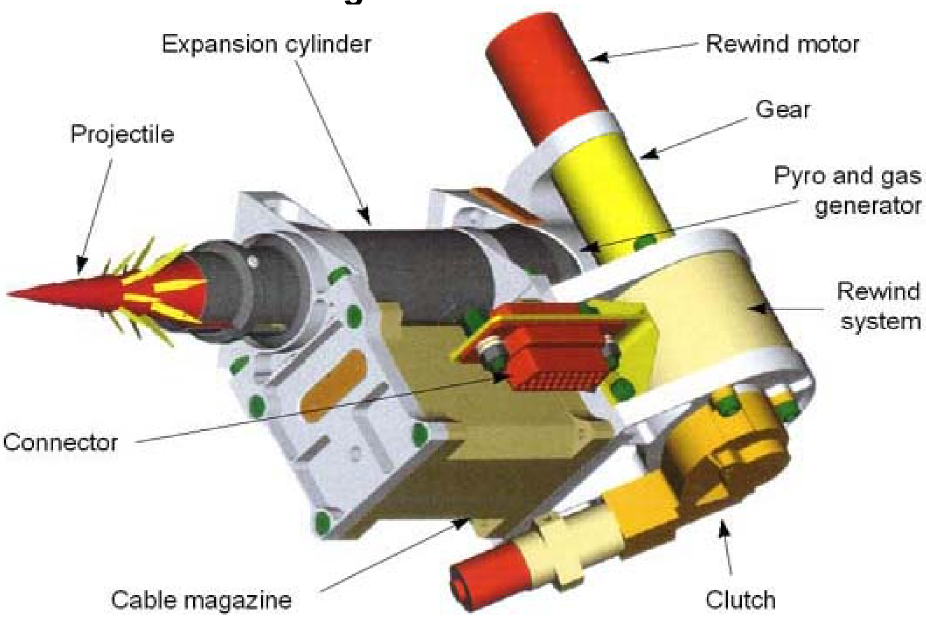


Harpoon capture concept, DLR study.

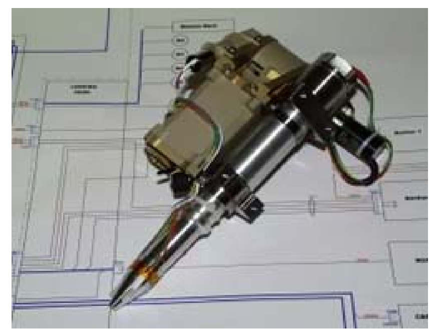
Ref: J. Starke, B. Bischof, W.-P. Foth and H.-J. Guenther, "ROGER: A potential orbital space debris removal system," presented at the NASA/DARPA International Conference on Orbital Debris Removal, Chantilly, VA, Dec. 8-10, 2009.

Capture Techniques: Harpoon Example, Rosetta Lander ANCHOR Subsystem*

- **Anchoring harpoon components:**
  - **Projectile (anchor) designed to anchor safely in a wide range of different comet materials**
  - **An accelerometer and temperature sensor are mounted inside**
  - **Immediately after touchdown projectile is accelerated and shot from a cartridge-driven piston**
  - **Cable magazines are mounted beside cylinder, and anchor cable includes sensor wires**
  - **Rewind system uses a gear motor-driven coil with angular encoder and releasable freewheeling brake**



Qual. model of anchoring harpoon



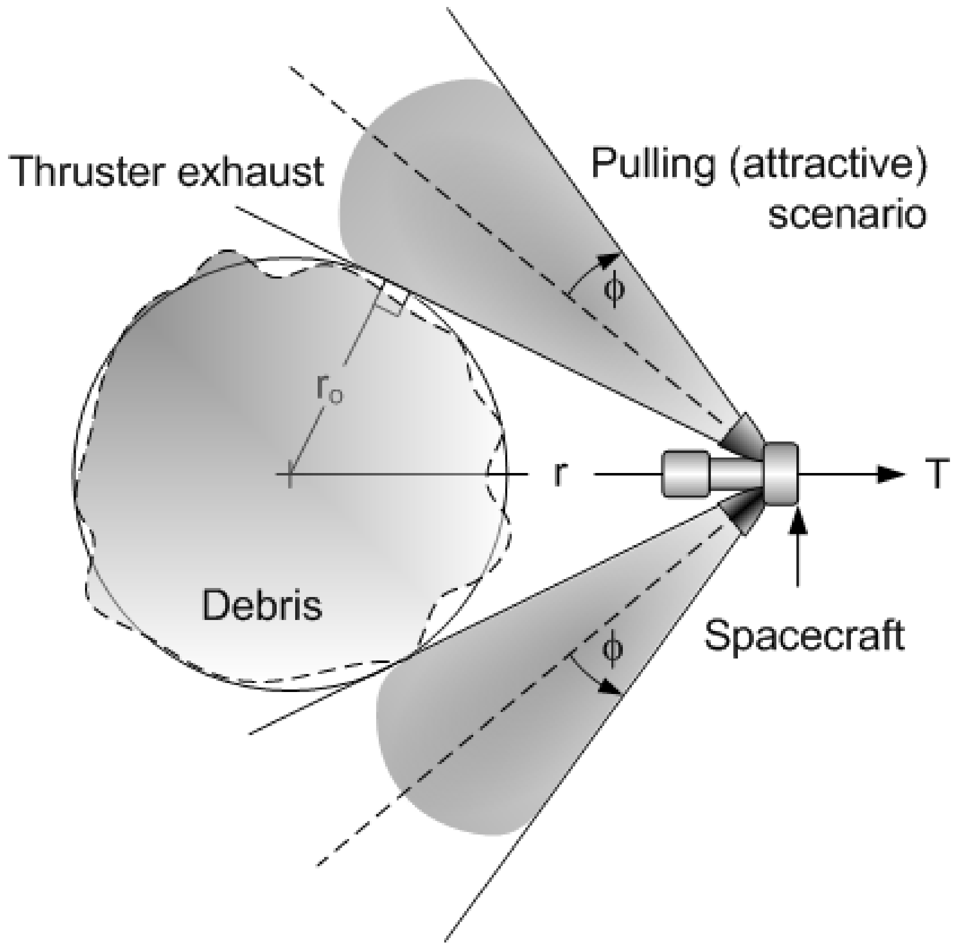
Anchoring system performance parameters

Max gas pressure	250 bar
Anchor velocity at release	60 m/s
Rewind velocity	0.5 m/s
Penetration depth	0.1 ... 2.5 m
Tightening force*	6 ... 36 N
Break force of cable	100 N
* Commandable	

*http://www.magson.de/projects/projects22.html

Electrostatic Forces

- Theoretical application:
  - Using typical spacecraft power a debris object could experience a Coulomb force between tug and debris at standoff distances of several meters.
  - This would lead to an acceleration resulting in an orbital altitude increase or decrease.
  - Decreasing the standoff distance increases the force available to pull the debris.
  - However, close standoff distances are limited by the size, shape and angular motions of the object.



Ref: Electrostatic Tractor for Near Earth Object Deflection," N. Murdoch et al., 59th International Astronautical Congress, Paper IAC-08-A3.I.5.

Conclusions

Fundamental realities about removing space debris

- The debris issue presents near-term and long-term challenges.
- In near term, need to address debris in low-Earth orbits.
- There is no need to eliminate all debris, but to reduce risks to operational spacecraft to levels that are acceptable to space-faring nations.
- This is an international problem and it will likely require an international effort.
- Most space debris objects are resident in orbits below about 1,600 km, with peak densities between 800 km and 1,100 km.
- Tracking is limited to objects that are at least 10 cm in size, but there are indications that there are at least hundreds of thousands of smaller debris pieces that cannot be tracked
- Any debris removal program must divide operations into at least two modes: one for individual large object collection, and one for small debris elimination.

Conclusions

Long-term solution

- In the long term, debris control programs will have to address debris accumulation in almost all orbits, from low to geostationary altitudes.
- There will be permanent debris control and orbit maintenance programs that will require special space systems to patrol and oversee near-Earth space.
- National and international debris advisory committees may evolve into regulatory bodies that will legislate and enforce debris proliferation issues.
- Debris clean up and maintenance operations may be funded through a taxation process, through entrepreneurial innovations or through some international, multi-governmental programs.

Conclusions

Biggest challenges

- The most difficult challenges will be political, legal, economic and cultural. No one in government wants to address debris removal, even though recent events clearly indicate this is an imperative. Human nature and political interests will likely try to put off a solution until catastrophic events increase in frequency. Even then, action may be slow in coming.
- Only a few options and ideas have been included here. There is a myriad of innovations and potentially disruptive technologies just waiting for the moment that incentives are created to excite the many talented individuals and groups around the space world. Hopefully, this opportunity will not be delayed until corrective action becomes a great deal more expensive.