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Orbital Debris Characteristic Analysis and A Small Debris Collection Concept

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Outline

- **Current space situation**
- **Debris characteristics analysis**
- **A small debris collection concept**

  - Focus the discussion on ≤10 cm objects

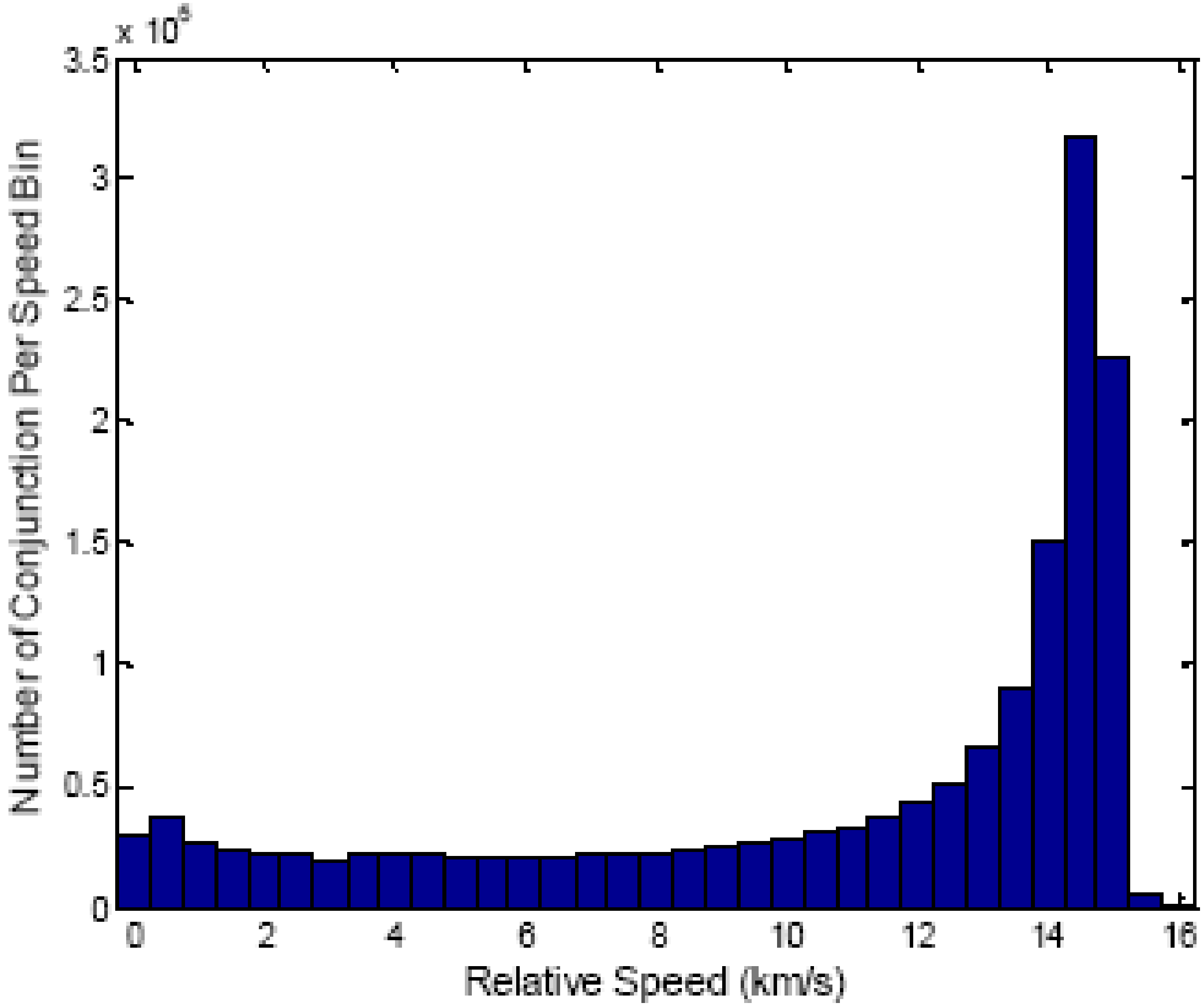
  - Address environment remediation only (will not discuss cost, ownership, legal, liability, and policy issues)

Current space situation

Table 1 Estimated amount of orbital debris, by size

Debris Size	0.1-1cm	1-10cm	>10cm
Total debris at all altitudes	150 million	780,000	23000
Debris in Low-Earth Orbit	20 million	400,000	15000

The table is based on data from European Space Agency MASTER 2005 debris environment, plus estimation of debris from the breakup events from 2006 to 2008.



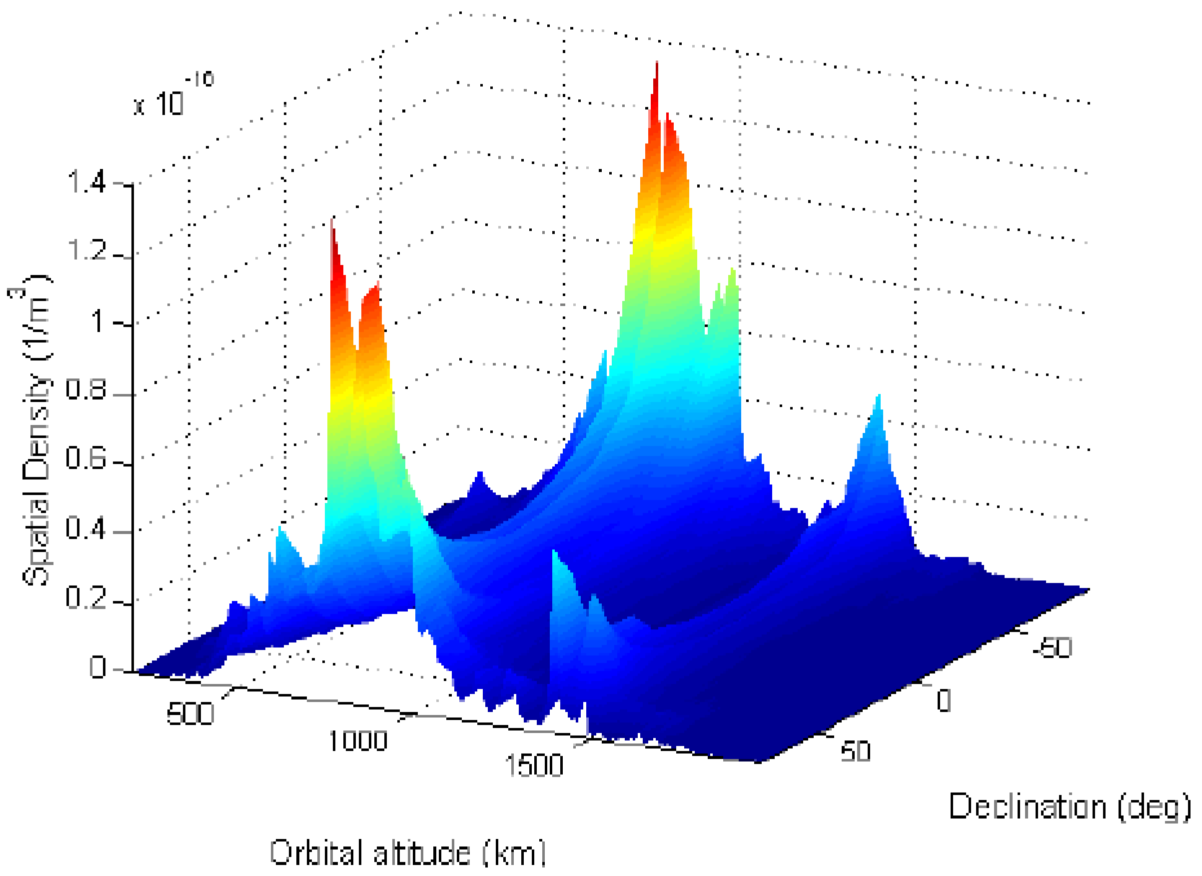
Conjunctions for all cataloged objects, as a function of the approaching speed

If the distance of a fragment and a satellite is smaller than the geometry size of the satellite, a collision will happen. If the distance is smaller than a specific distance (the distance is presumed to be 5km in this presentation) , a conjunction will happen.

Current space situation

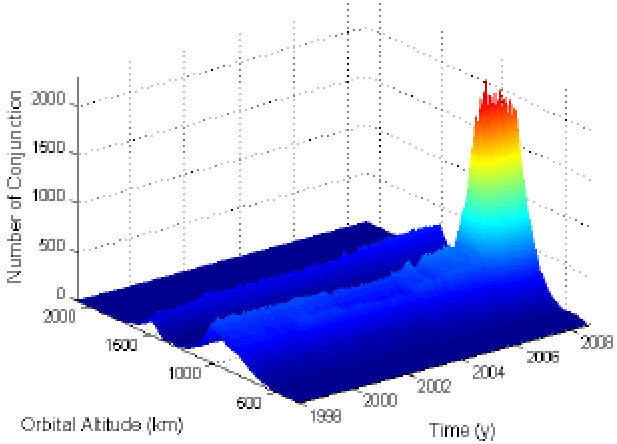
- Debris with size 0.1-1cm： significant damage to vulnerable parts of a satellite . Shielding.
- Debris with size 1-10cm: seriously damage or destroy a satellite in a collision, no effective shielding, too small to be tracked, unlikely to have warning to avoid colliding with such objects.
- The objects with size >10 cm in LEO and objects with size larger than 1 meter in geosynchronous orbit, can be tracked by the US Space Surveillance Network (SSN).

Spatial distribution of Cataloged Objects for low-Earth Orbit

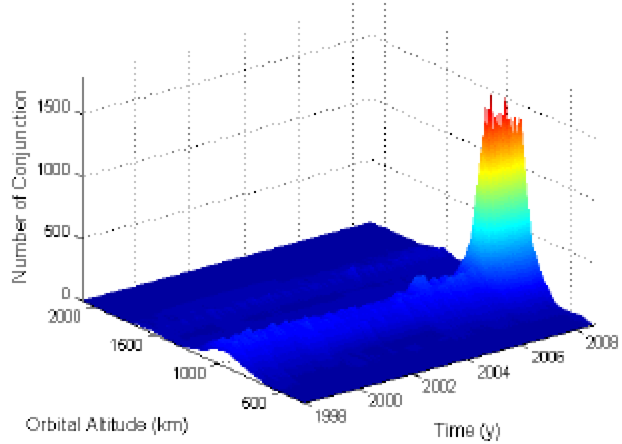


(Data from Space Situation Report of August 25th 2008)

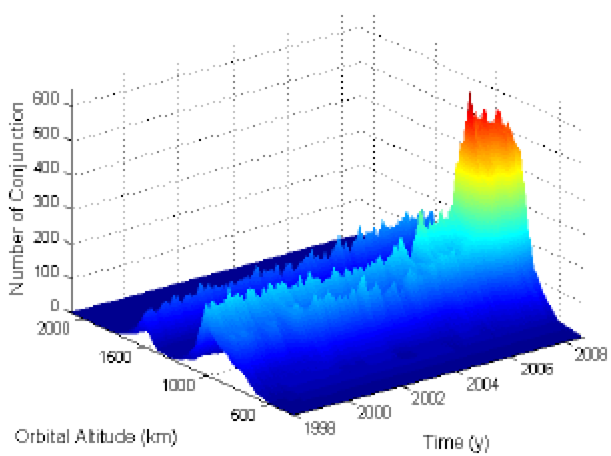
Debris characteristics analysis



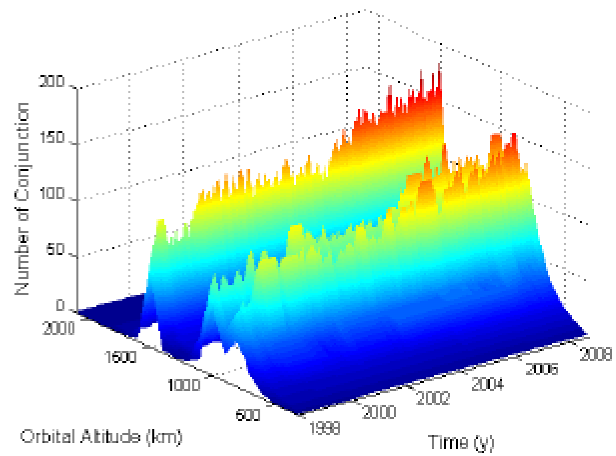
(a) All



(b) Fragment – Fragment



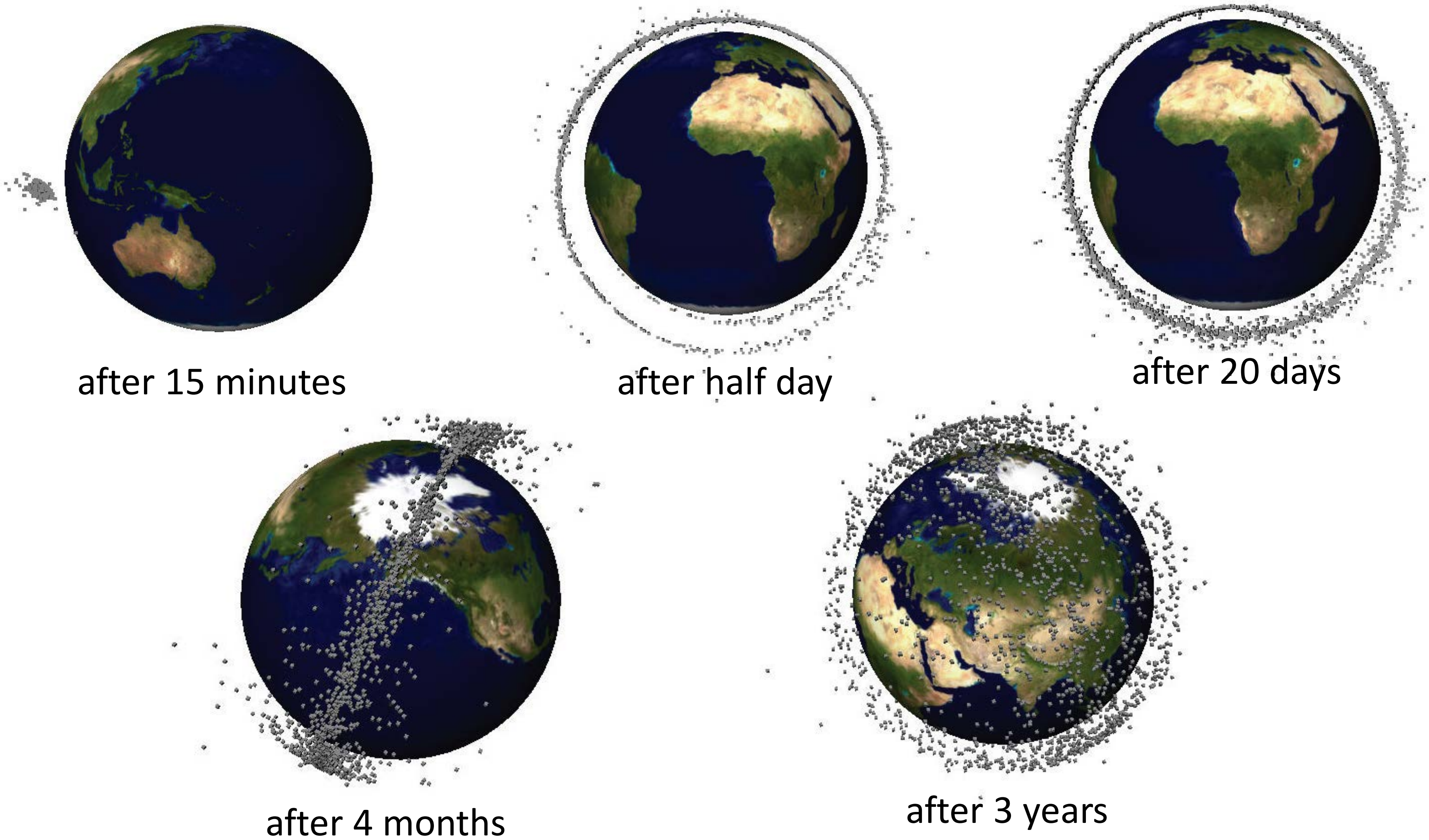
(c) Intact-Fragment



(d) Intact-Intact

Conjunctions Distribution for different categories, as a function of orbital altitude and Time (Jan 1st 1998 – Aug 1st 2008, Class widths: time = 1 day)

Time evolution of a debris cloud generated at LEO

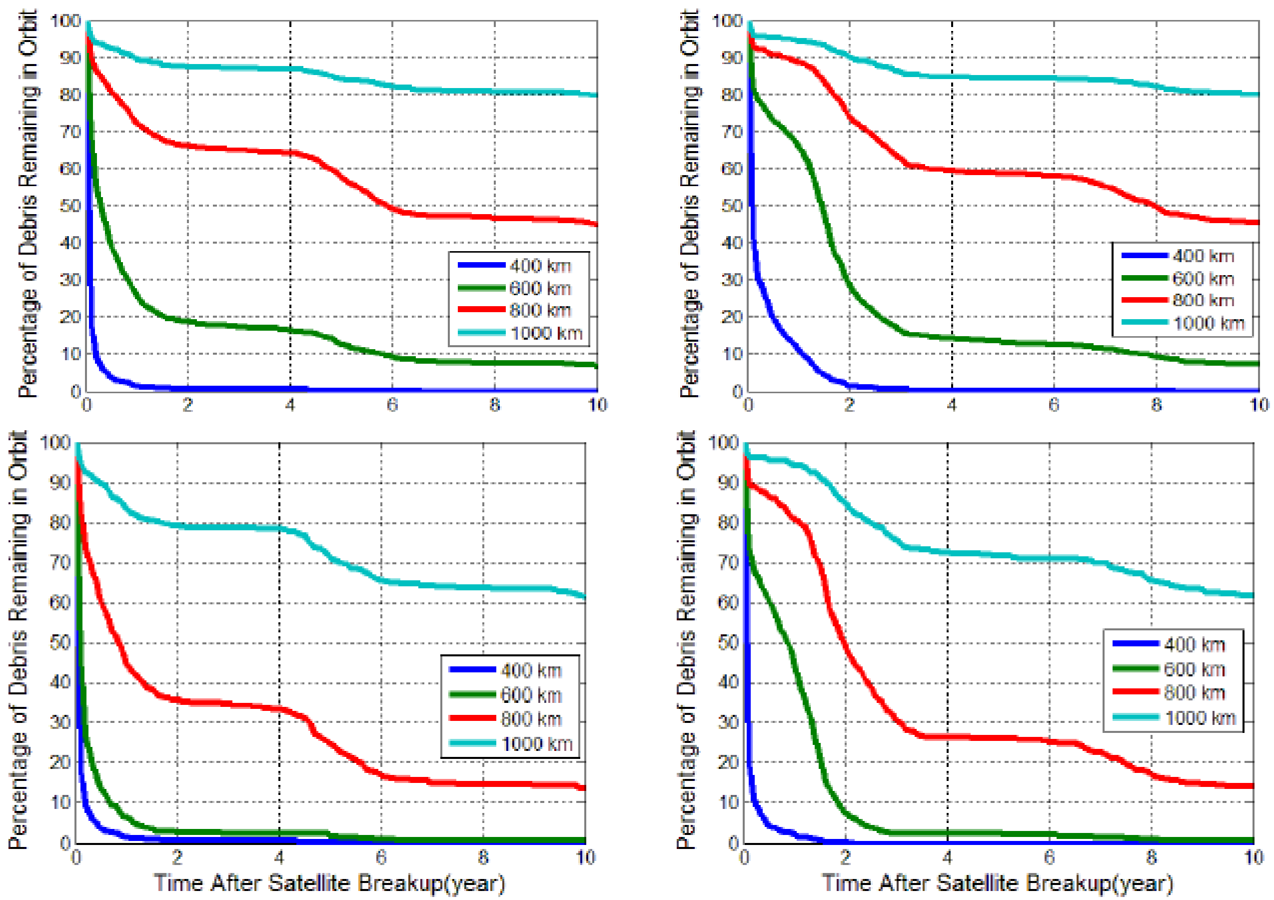


The evolution process of the debris with size greater than 10 cm resulting from a catastrophic collision of a 5-ton satellite, inclination 98.7 deg, Semimajor Axis 7378.135km, eccentricity 0.001.

Lifetime of the Created fragments

greater than 10 cm

greater than 1cm



(a) Breakup during maximum solar activity

(b) Breakup during minimum solar activity

The fraction of debris particles remaining in orbit following the catastrophic breakup of a satellite.

Threats to Satellites

Orbital Altitude (km)	Debris Size		
	>1mm	>1 cm	> 10 cm
500	14	3,500	46,000
600	10	1,300	18,000
700	10.5	930	17,000
800	8	590	10,000
900	8.4	350	9,800
1,000	9.5	780	11,000
1,100	10.9	1,400	31,000
1,200	10.6	1,700	50,000
1,300	11.2	1,760	71,000
1,400	10	920	13,000
1,500	10.5	1,280	19,000
1,600	12.7	1,900	62,000

Mean time for a satellite in various orbital altitudes impacted by a fragment with different sizes (Orbital inclination of spacecraft is 97 deg, cross-section area is 10 m^2, calculation time: Jan 1th, 2007)

Threats to Satellites

- A piece of debris larger than 1 cm was estimated to collide with one of the active satellites in LEO every 2-3 years. (The number is estimated by assuming 390 LEO satellites in LEOs with mean cross-section area of 3 m^2)
- Another measure of the current debris risk is that in the heavily used altitude band around 800-900 km, the chance that any given satellite will be hit by debris larger than 1 cm is approaching 3% over 5 to 10 year lifetime.

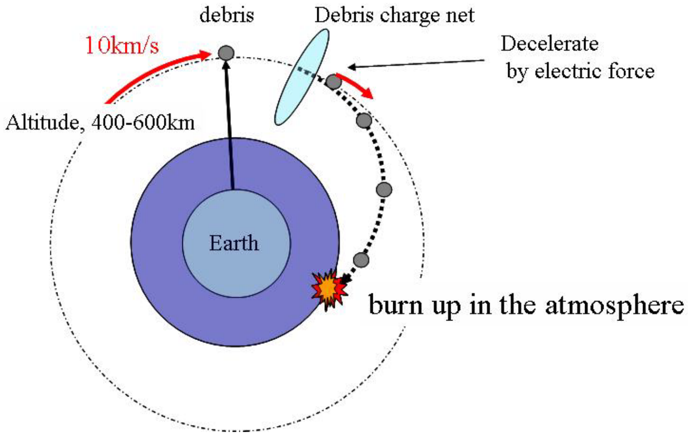
Specific Debris Removal Methods

There are two separate areas of concentration:

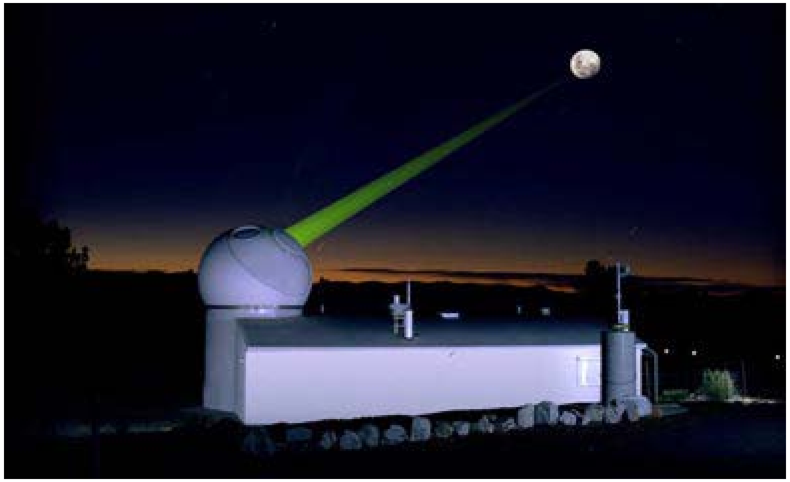
small debris removal and large debris capture.

- Small Debris Collection
- Ground-Based Lasers
- Trash Tenders and Attachable Devices
- Dual-Use Orbit Transfer Vehicles
- Space-Based Lasers
- Space Tethers

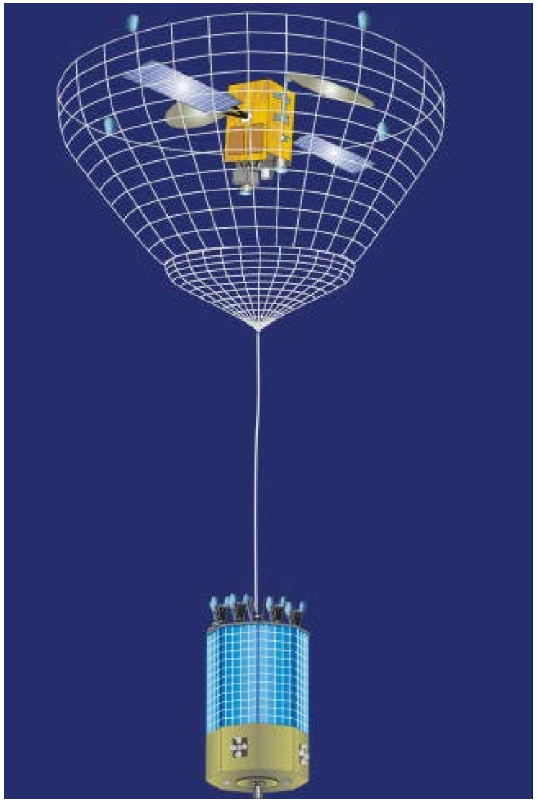
Specific Debris Removal Methods

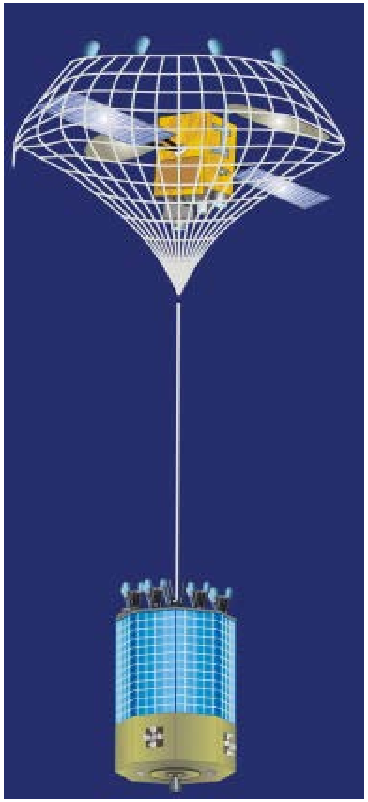


Space debris removal method using electrostatic force in space plasma



debris tracking test





Net Capture Mechanism

Small debris collection

- Due to the large number and small size of the small debris objects (<10 cm), individual capture seems highly unlikely. Orbital maneuvering energies are far too excessive and costs are far too high for one-at-a-time rendezvous and retrieval operations.
- This leaves only one apparent option, i.e., present large collisions cross sectional areas to small debris pieces in those orbital zones where operational satellites are most affected by potential collisions.

Small debris collection

- **There are several materials and shapes that could be considered for debris collisions. For example, an aerogel material could be shaped into a sphere by inflating a folded bag once in orbit.**
- **A spherical shape may be best thought of as an uncontrolled *collision dummy that has no preferred orientation.***

Simulation of a small debris collection concept

An estimate

- Focus on the LEO between the altitudes of 800 km and 1,100 km, the volume of that space is 202 billion cubic kilometers.
- Assume an average orbital speed of 7.4 km/sec and a nominal collector diameter of 100 m. If 100 of these satellites are injected into circular retrograde orbits in the 300 km congested orbital band for 10 years, about 1% of the volume would be swept.

An estimate （cont）

- Considering most debris pieces are in SSO orbits, the effective swept volume would be twice as much. Thus, one can argue that 100 collector satellites can eliminate roughly 2% of the small debris objects every 10 years from this zone of high congestion.
- According to this estimate, a 20% reduction can be done with 1,000 collector satellites of 100-meter diameter, each surviving for 10 years.

Another estimate

$$\lambda = f_c S t$$

f_c **Collision flux, collision number for a satellite with cross-section area 1** ***m^2*** **in one year.**

$$S = \pi d_{mean}^2$$

Another estimate

SSN No.	*f(1/m^2/yr)*
5	1.18e-6
12	1.17e-6
16	9.90e-7
46	4.93e-6

Mean collision number with debris size large than 10cm for a collection satellite with 100m diameter within 10 year

$$\lambda_{>10cm} = 1 * 10^{-6} \cdot \pi \cdot 50^2 \cdot 10 \approx 0.0785$$

Another estimate

Based on the proportion of big debris and small debris, we can estimate the mean collision number with small debris a collection satellite with 100m diameter within 10 year.

Debris Size	<1mm	0.1-1cm	1-10cm	>10cm
Debris in LEO	1billion?	20 million	400,000	15,000
Collision number	>5000	105	2	0.0785

1,000 collector satellites of 100-meter diameter, each surviving for 10 years can do 0.5% reduction.

Questions need to answer

- What is the appropriate size of the sphere?
- How many collection satellites are needed?
- How many small debris could be removed within given period?
- How many new debris will be created if impact happened between the collection satellites and intact objects?
- Which material can be used for the huge sphere?
- How to inflate the sphere?

Thank you!

Q & A

Recent and Future Activities Related to Active Debris Removal

- The International Conference onOrbital Debris Removal (Dec. 2009)
- ISTC Space Debris Mitigation Workshop (April 2010)
- European Workshop on Active Debris Removal
- IAA study on removal technologies, IADC study on the LEO environment, debris removal papers at COSPAR, IAC, etc.
- 2010 Beijing Orbital Debris Mitigation Workshop
- Potential collaboration on ADR demonstration missions