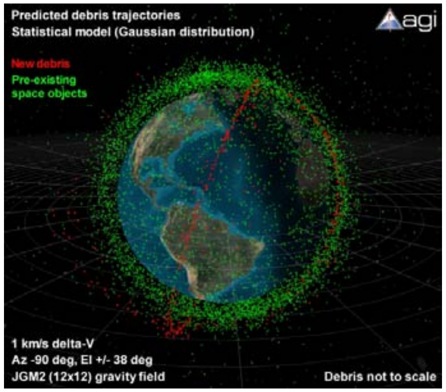
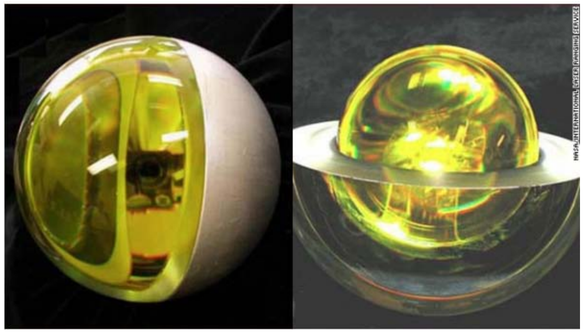
Debris Destroy Satellites!



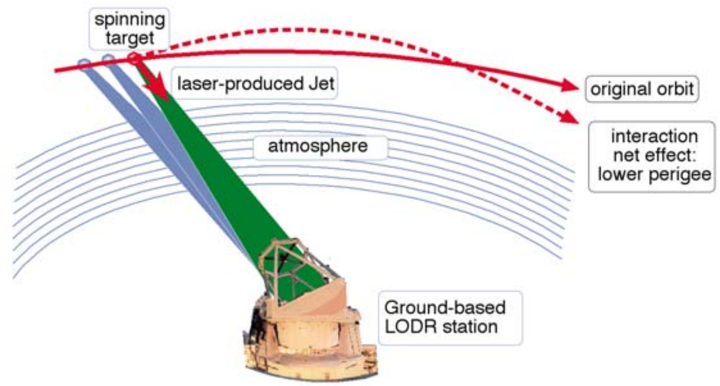
- Collisional cascades = major debris source➔
  - ➢ Multi-ton debris important, but <u>must</u> include <u>small</u> debris threat in plans!
  - ➢ Threat from small debris 45X larger than from large debris
- Causes: 4 known, 35 possible debris-caused
- 4/12/13: Debris destroy Russian BLITS ➔



- Main urgency: mitigate <u>future</u> risks
  - ➢ More than 100, 1360-kg "Tsyklon" 3rd stages in LEO & MEO, waiting to explode
  - ➢ ENVISAT: detonation would jeopardize future use of sun-sync orbits ➔

Solutions

- Large Debris (only)
  - Chasing and grappling, deploying nets
  - Electrodynamic tethers or other deorbiting kit (est. cost 27M$)
  - Clouds of frozen mist, gas or aerogel blocks ("Catcher's mitt")
    - » For aerogel, need 13 x 13 km blocks 50 cm thick (mass 81 kT), a 16 GN thrust booster to orbit, a 75 kN rocket to maintain orbit, 1.6 T$ to launch
    - » For gas/mist idea, need 400, 100-km-diameter balloons also costing 1.6 T$ to orbit, plus manufacturing cost
- For both Large and Small Debris
  - Laser Orbital Debris Removal (LODR)
  - Stay on the ground
  - Least expensive approach for either
    - » About 1M$/1-ton target
    - » A few k$/1kg target



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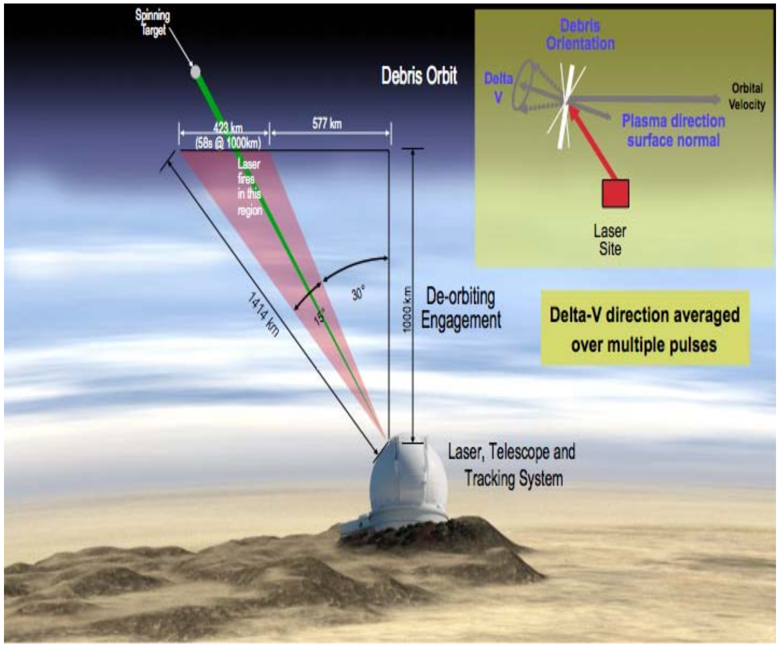
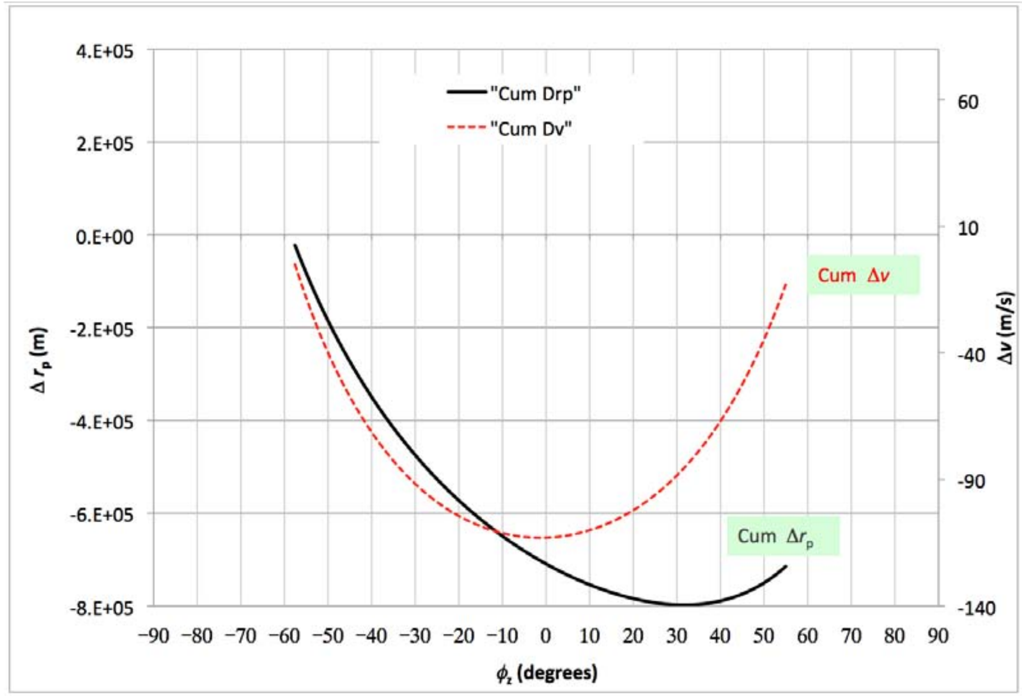
LODR on Small Targets



LODR concept

Laser Orbital Debris Removal (LODR). A focused, repetitively-pulsed laser makes a jet on the debris, slowing it and lowering its perigee, causing re-entry and burnup. A polar station location would give 8 times higher interaction rate for sun-sync orbits.

- Target re-entry achieved in one overhead pass for <u>any</u> debris target smaller than 31 cm at 1000 km range, mass 0.75kg or less
- Pushing "up" lowers perigee as well as pushing "back" against target motion, up until +30° zenith angle in cases of interest



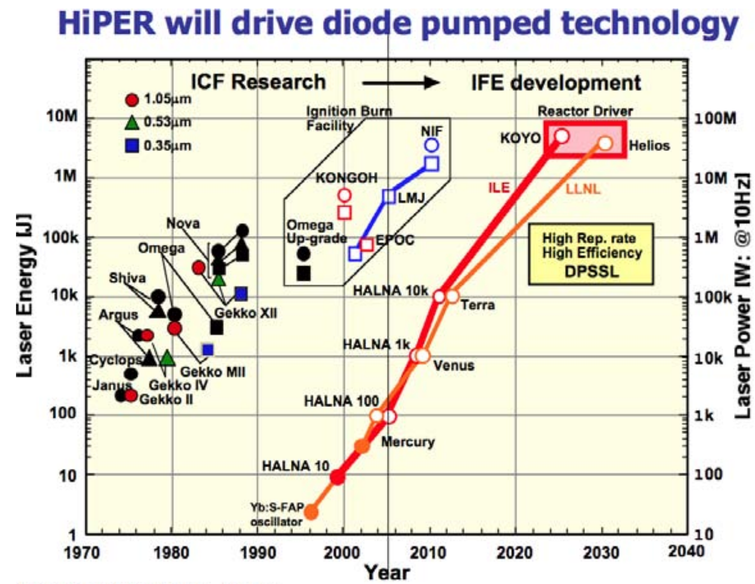
Initial 1000 km perigee located -120 ° geocentric (upstream), 1015 km apogee, C_m=75 µN-s/J, 30% push efficiency, 11 kJ, 5 ns, 1.06µm pulses at 14 Hz, Φ = 75 kJ/m^2 on target, 144 second shine, atmos. T_{eff} =0.8

Multi-ton targets

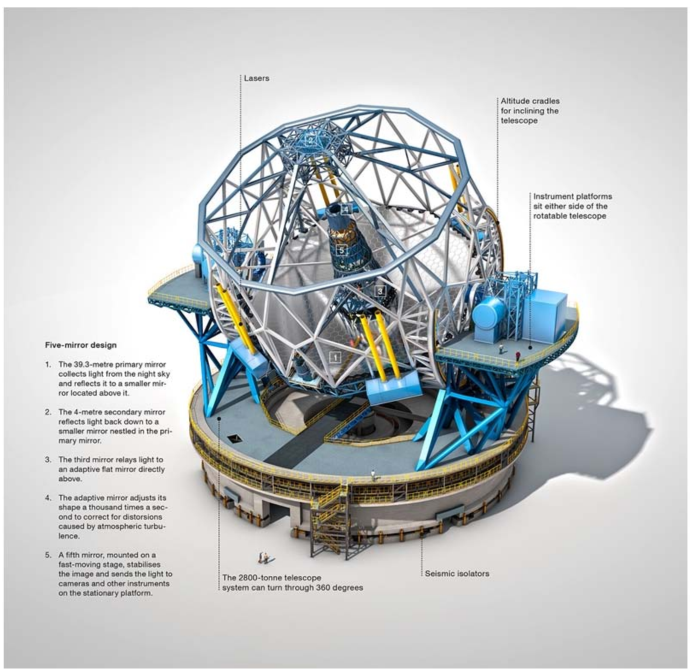
Table 1. LODR System Parameters for Large Targets (Case A = re-entry/CaseB = 40km lowering)			
Target Parameters		**Optical System Parameters**	
Mass [nonspecific target]/ ENVISAT (kg)	1,000/ 8,000	Wavelength λ (μm)	1.06
Perigee (km)	770	Pulse Length τ (ns)	8.0
Apogee (km)	770	Target Spot Size [deliberately defocused] (m)	1.25/ 1.33
Repeat Period [nonspecific orbit] / [ENVISAT] (days)	10/ 35	Pulse Energy (kJ)	125/ 140
Number of Interactions for Re-entry/ or 40km Lowering	68/ 19	Repetition Frequency (Hz)	5/ 10
Time to Re-enter one Target / or to Lower ENVISAT 40km (yrs)	3.7	Push Efficiency η_c	0.30
Primary Mirror Diameter (m)	25	Fluence on Target (kJ/m^2)	75
Average Interaction Duration (s)	250	Beam Quality Factor	2.0

Help for LODR

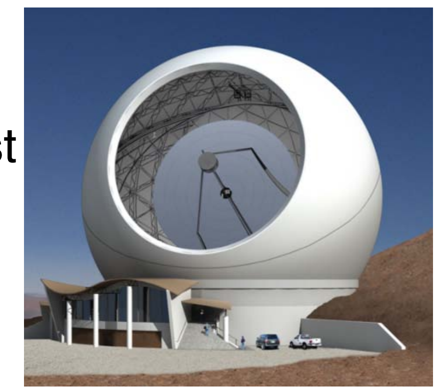
- Lightweight, large mirrors
  - 10-m Keck primary
  - 9.8 x 11-m SALT primary
  - Planned 39-m primary for EELT, very low areal mass density



Graph courtesy of S. Nakai



- LIFE lasers (LLNL)
  - 10kW P_{avg} in 10s burst
- DIPOLE laser (UK)
  - 1kW P_{avg} planned
- HiPER (EU)
  - 200 kJ, 5ns
  - Technology could be adapted to LODR



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International cooperation

- LODR must be built and operated under international protocols
  - Avoids concern that it is a weapon system,
  - Assures safety of all space assets

Multiple benefits

- Improving ephemeris precision for catalogued objects
- Nudging objects to avoid collisions
- Even nudging small asteroids!

Conclusions for LODR

- Only approach that deals with both small and large debris
- Has lowest cost per object removed
- Prefers tumbling objects!
- Access is speed of light, redundant and agile

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