Debris-debris collision avoidance using medium power ground-based lasers

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1) Introduction: approaches to mitigate the Kessler collision cascade

2) Existing laser debris removal proposals

3) A new laser debris-debris collision avoidance scheme

4) Summary

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The Kessler Collision Cascade might be a reality*

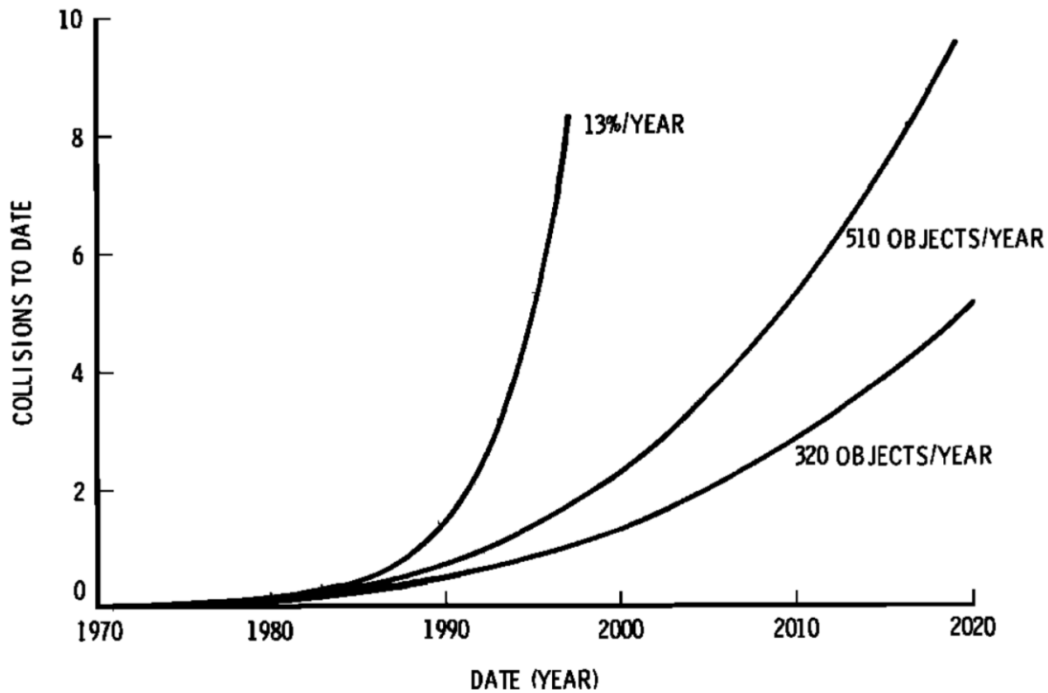


Fig. 4. Total collisions by the given date under various growth assumptions. The first collision is expected between 1989 and 1997.

source: Kessler & Cour-Palais, JGR 83(A6) ***1978***

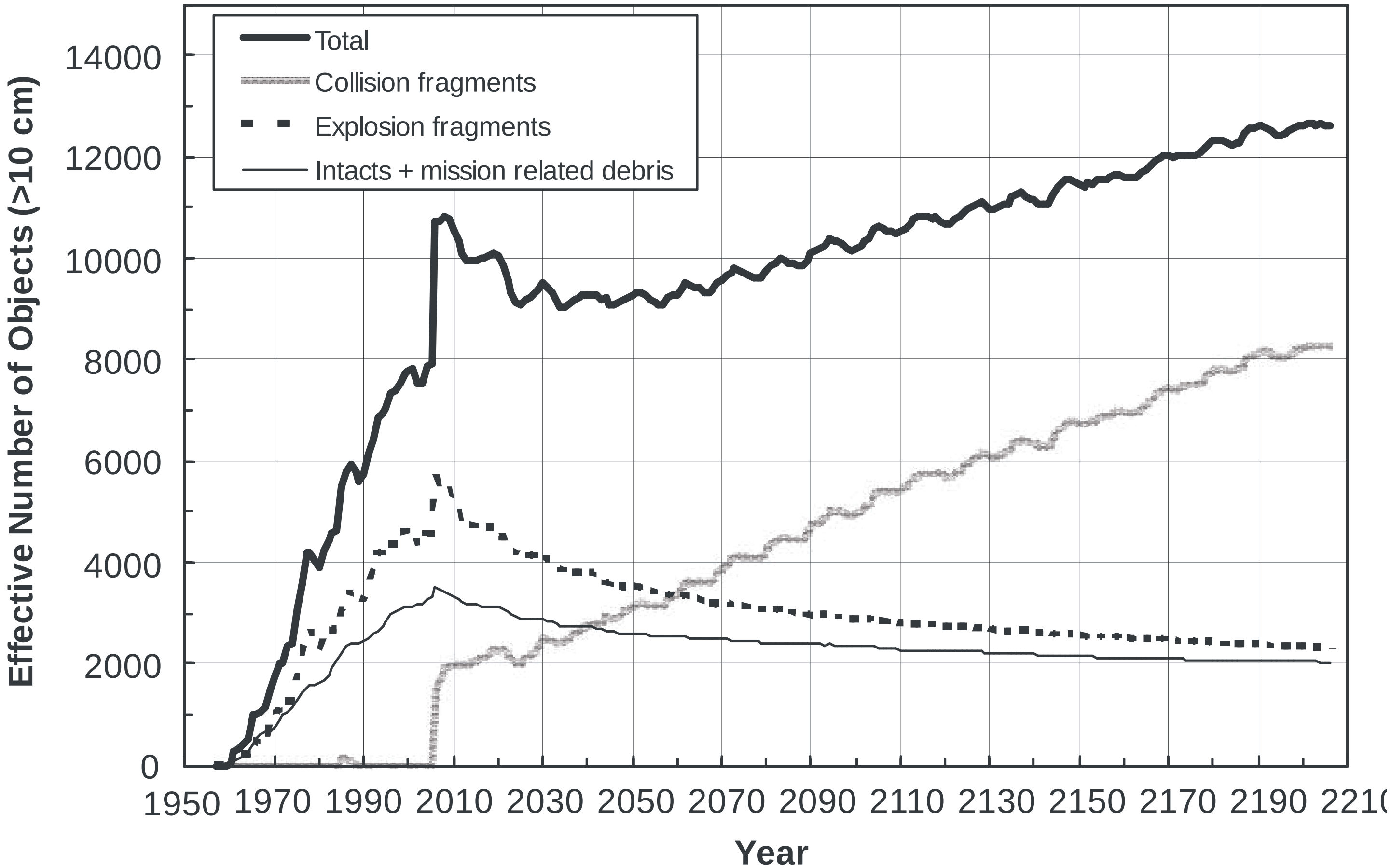
*) J.-C. Liou, N.L. Johnson: *Instability of the present LEO satellite populations,* Advances in Space Research 41 (2008)

Three options to solve the Kessler problem

1. debris mitigation plans (*e.g. IADC guidelines*)
2. debris removal
3. collision avoidance (*active and/or non-active payloads*)

Models indicate that debris mitigation alone will not be enough to prevent a cascading effect

LEO Environment Projection for *No Future Launch Scenario*



source: Liou et al, Acta Astronautica 66:3/4 (2010)

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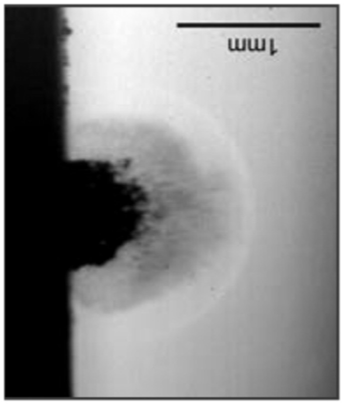
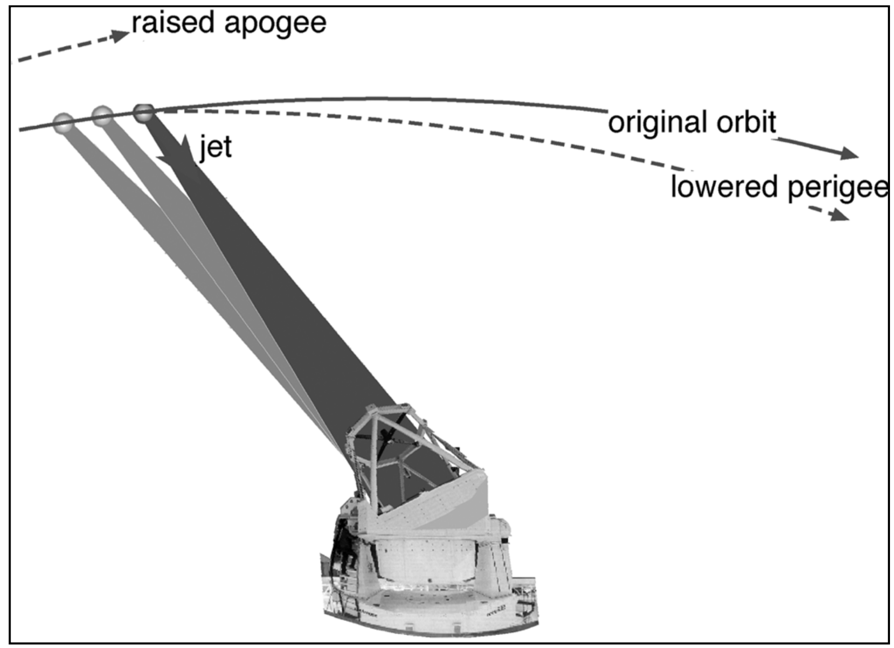
Existing laser debris removal proposals are based on ablation induced recoil

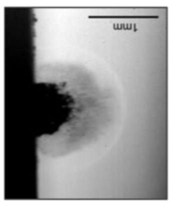


source: Phipps et al., J. Propulsion, 26:4(2010)



adapted from: Phipps et al., J. Propulsion, 26:4(2010)

Ablation requires high *threshold* laser intensities



$$T_{\mathrm{max}} = \sqrt[4]{\frac{A I_{\mathrm{max}}}{\varepsilon_{\mathrm{hg}} \sigma}}$$

A: debris absorption
I: laser intensity
ε: debris emissivity
σ: Stefan-Boltzmann constant

Example:boiling point of Aluminium: 2792 K, if ε=A
→ ***minimum* intensity <u>I=3.4 MW/m²</u>**

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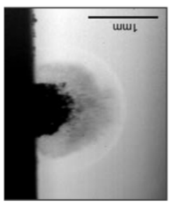

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→ ***minimum* intensity I=3.4 MW/m²**

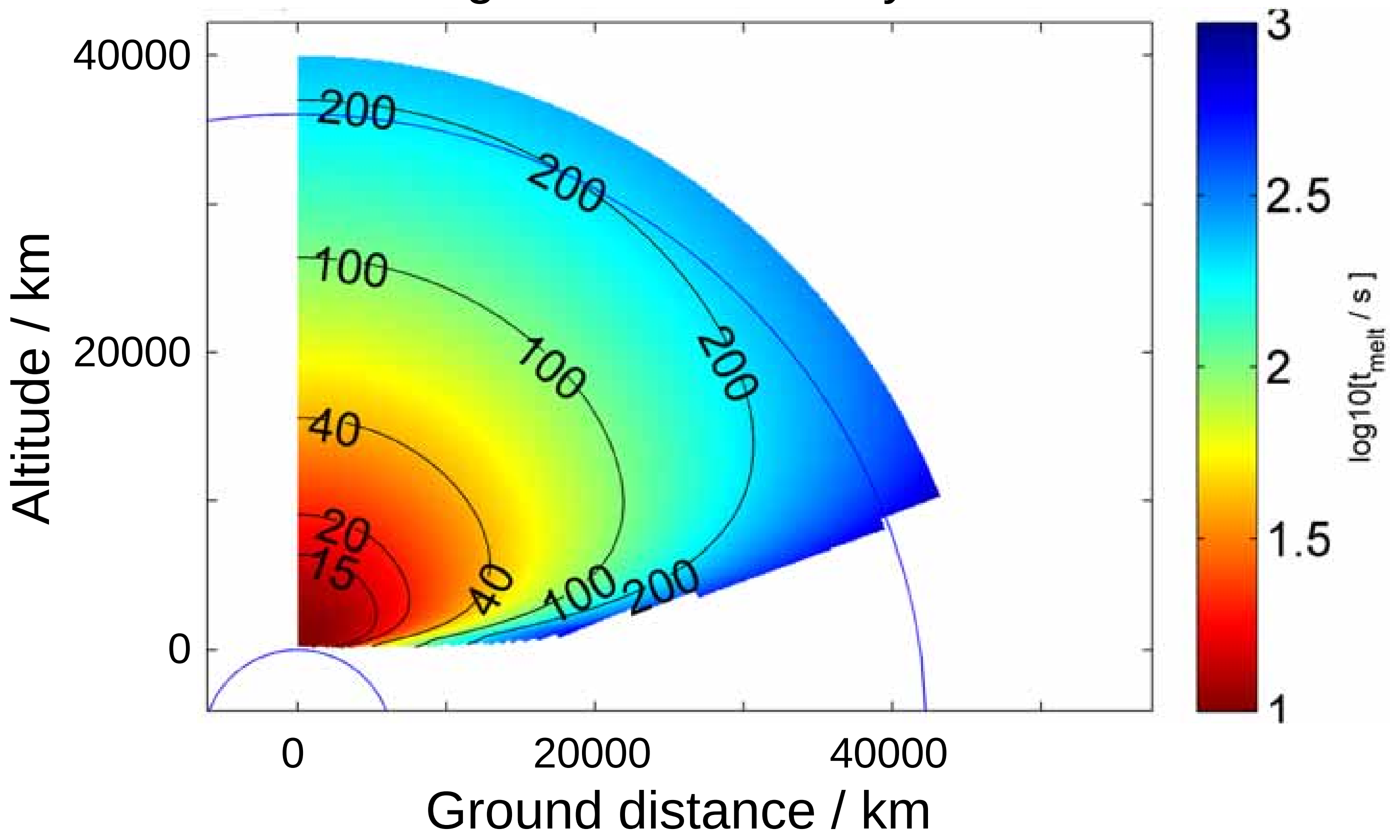
→high laser power **and/or** large telescopes

Proposed systems require lasers which are not commercially available today

proposed by	***based***	***Telescope diameter***	***average optical power***	***Pulse length***	***Pulse energy***	***Fluence***
Monroe 1993	ground	10m	5000kW	N/A continuous	N/A continuous	N/A continuous
Campell 1996 *Project Orion*	ground	3.5m	25kW	5ns	5kJ	5 J/cm^2
Schall 2002	space	2.5m	100kW	100ns	1kJ	10 J/cm^2

Monroe's proposed continuous laser system could be used as a laser ASAT weapon

Time in [s] to heat up a 1mm Al plate to 673 K
using a 10m / 5 MW system



Assumptions: Turbulence according to Hufnagel/Valley 5/7 ,
AO: adaptive optics correction according to ABL ref.

High fluence pulses are potentially dangerous for solar cells, radiators and optics

Estimated threshold for catastrophic laser damage

Components	Impulse and Stress (J cm^{-2})
Sensors	
Glass optics	8 [4] (out of band)
Detectors:[5]	
Si:X	100
InSb or HgCdTe	2
Power	
Solar cells: 30 μm silicon and a 20 μm glass overcoat	8
Thermal Control	
Thermal wrap:[7,8] 10 layers of 0.25 mil aluminized mylar with 2 mil kapton overlayer	-
Radiator: silver on glass 8 mil thickness[7] $\mathcal{A}$=0.07, ϵ=0.8	8
Structural	
Anodized alumininum plate: 1 mm thick[6], $\mathcal{A}$=0.16, ϵ=0.76 with back-surface flat paint, ϵ=0.22 [7]	1.6×10^3

source: Federation of American Scientists, Laser ASAT Test Verification, 1991

1) Introduction: approaches to mitigate the Kessler collision cascade

2) Feasibility of laser debris sweepers

3) A new laser debris-debris collision avoidance scheme

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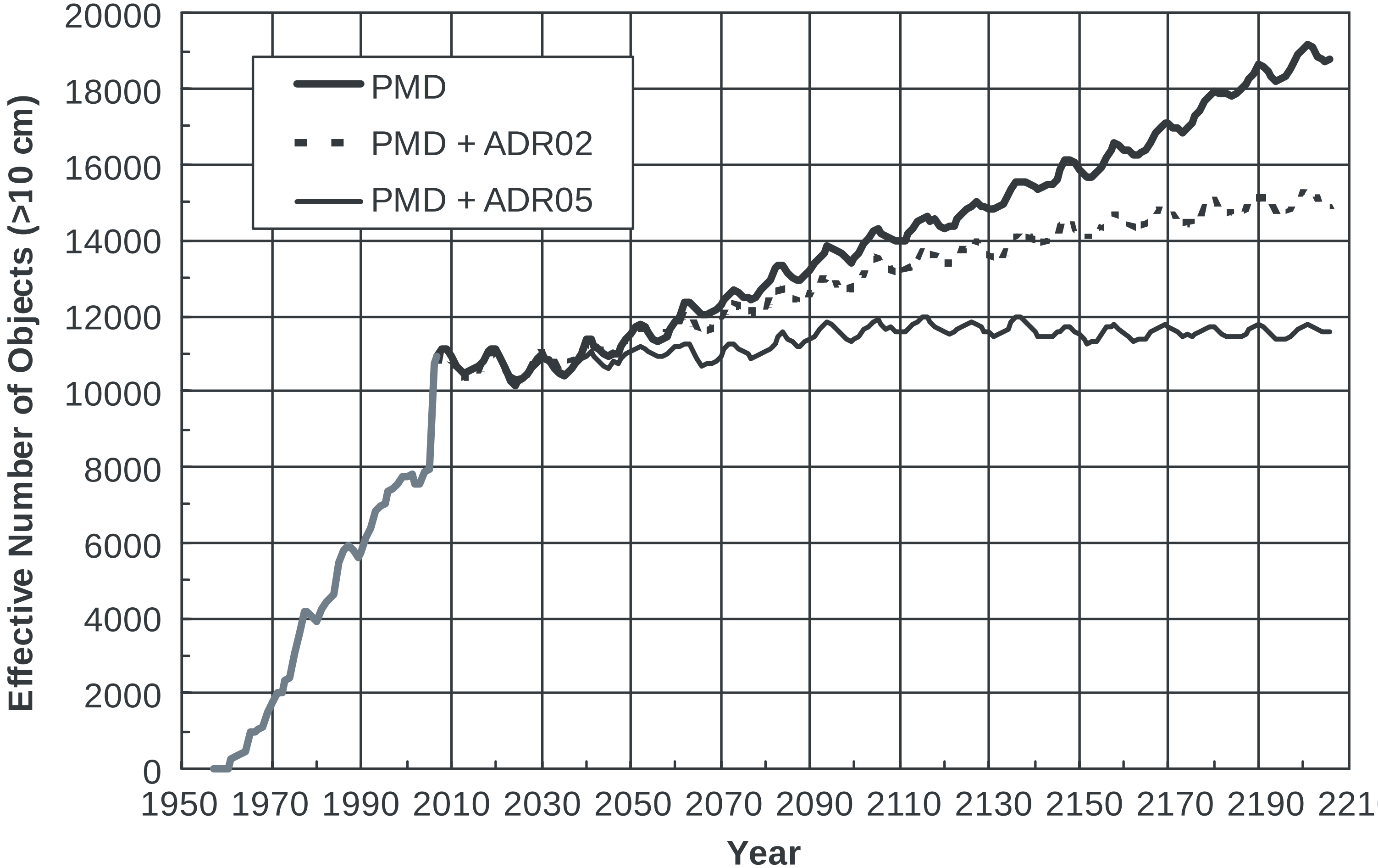
Clearing the entire orbits is not necessary in order to avoid the Kessler cascade

LEO Environment Projection for Postmission Disposal (PMD) and Active Debris Removal (ADR) Scenarios



source: Liou et al, Acta Astronautica 66:3/4 (2010)

Collision avoidance requires high accuracy all-on-all conjunction analysis

High accuracy: -avoids false alarms
-enables small avoidance maneuvers

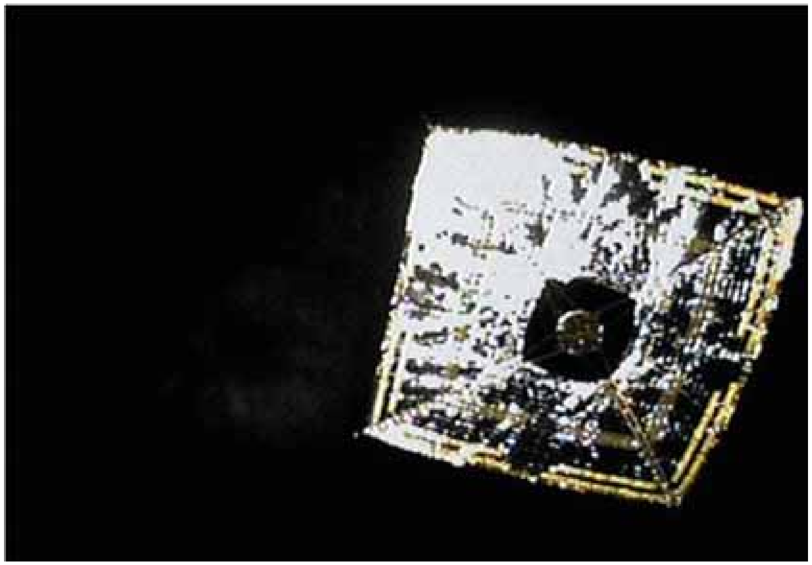
Given high accuracy predictions, medium power lasers might be used to prevent the Kessler syndrome

product	prediction (days)	accuracy (m)	accuracy (m/day)
Laser Ranging (ILRN "truth")	0	0.1	
Fence (raw direction cosines)	0	10	
High Accuracy Catalog + SP	10	500	50
Public Catalog + SGP4	10	5000-25000	1000
Public Catalog + new scheme	10	500-2000	50-200

More info: http://arxiv.org/abs/1002.2277/

→ **Compared to debris removal (~100m/s), for debris collision avoidance a small push is sufficient (~0.01m/s)**

Our approach focuses on radiation pressure, not on ablation



source: JAXA

$$\left|\vec{F}\right| = \frac{h\nu \mathrm{d}N}{c\,\mathrm{d}t} = \frac{IA}{c}$$

A: illuminated debris area
I: laser intensity
h: Planck constant
c: speed of light
dN/dt: photon stream

→ no threshold intensity necessary, but area-to-mass ratio crucial

A first case study assumes use of available equipment to mitigate debris collisions in sun synchronous orbits

source: IPG photonics

+

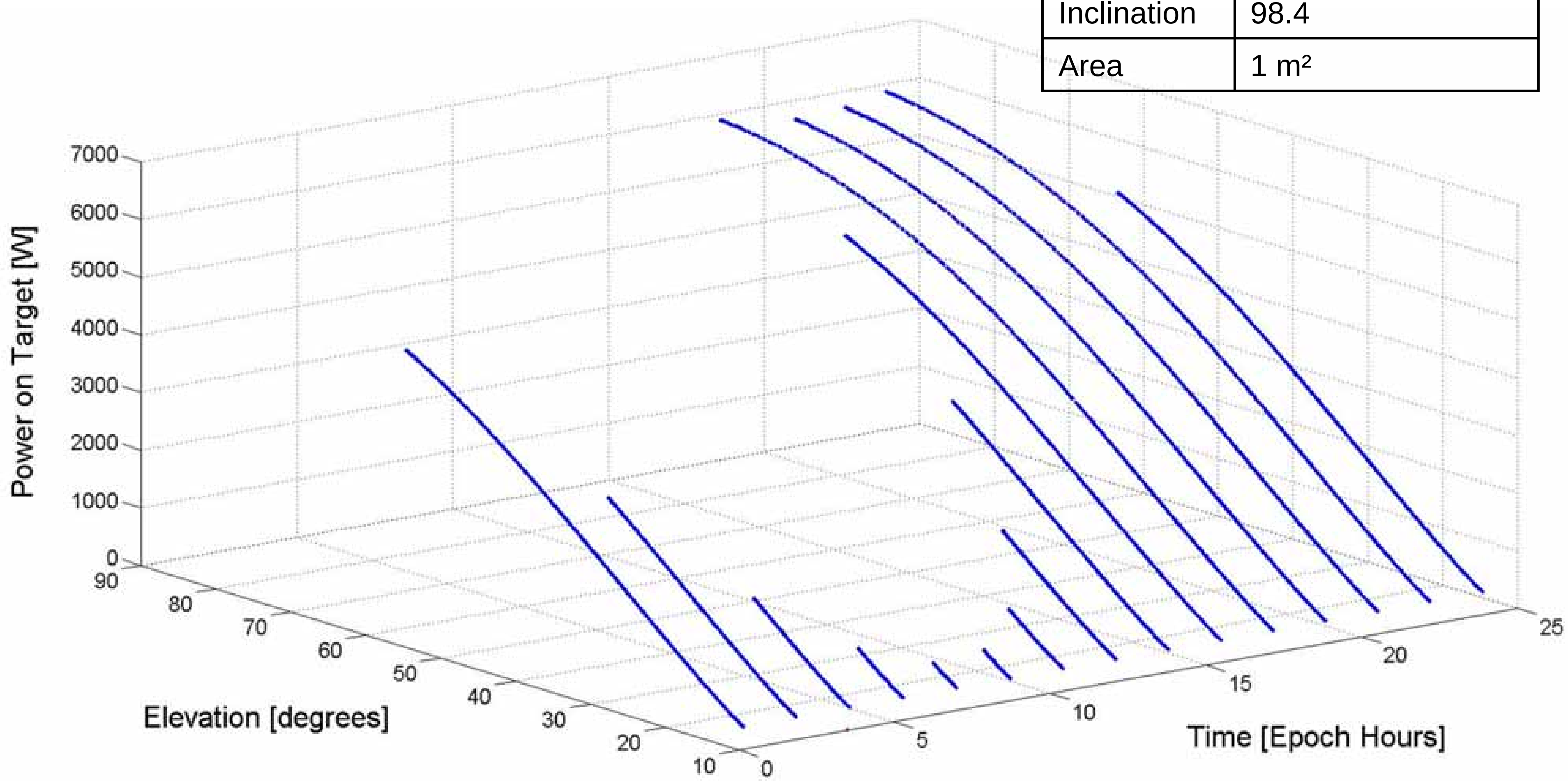
source: L3 communications

Case study: laser system

location	Antarctica (4 km altitude)
power	10 kW continuous
telescope	1.5 m diameter
Adaptive optics	ABL performance + guide star

Resulting intensities depend on satellite orbit and the location of the laser system

Orbit	sun-synchronous
Apogee	875 km
Inclination	98.4
Area	1 m²



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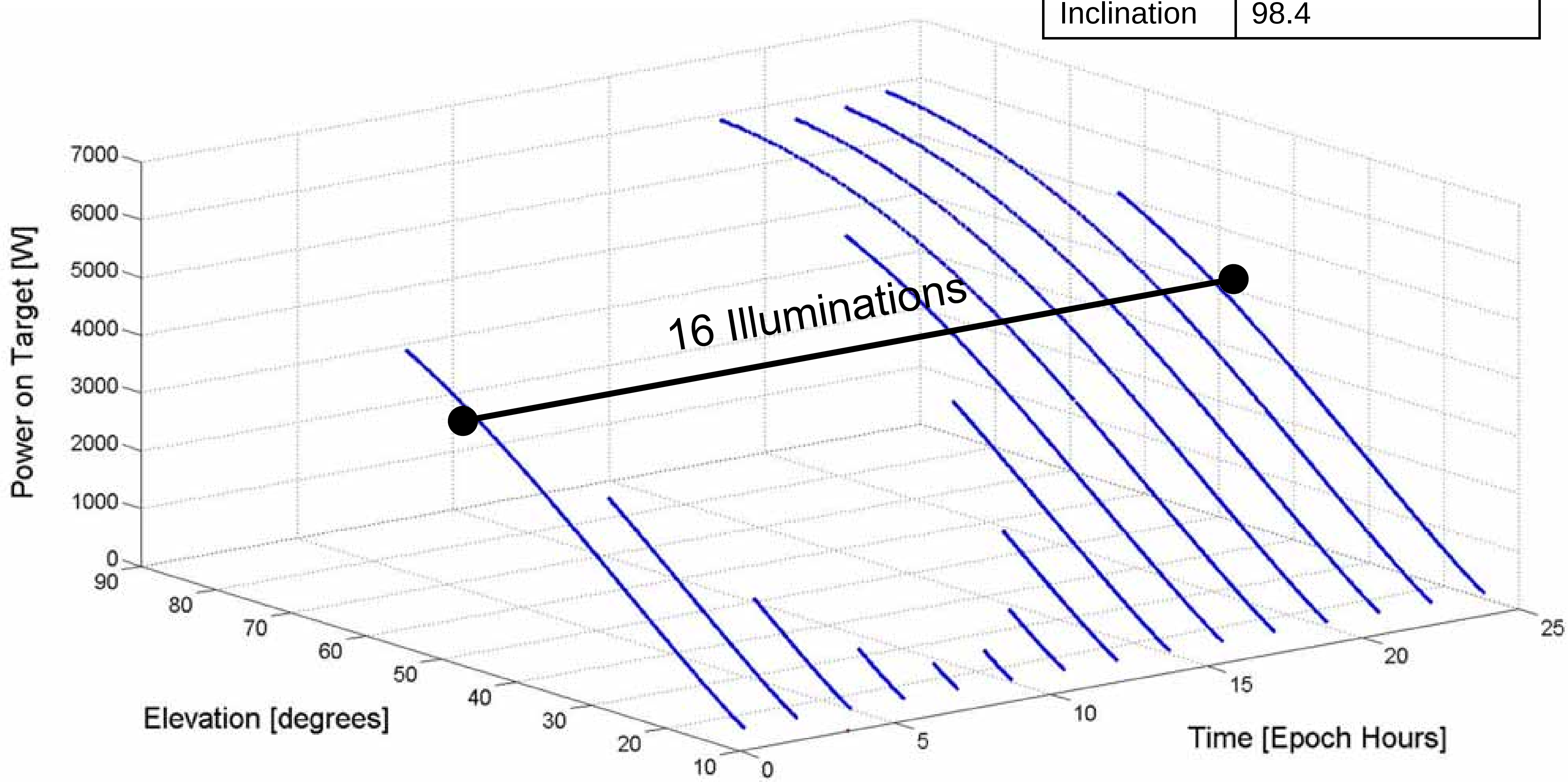
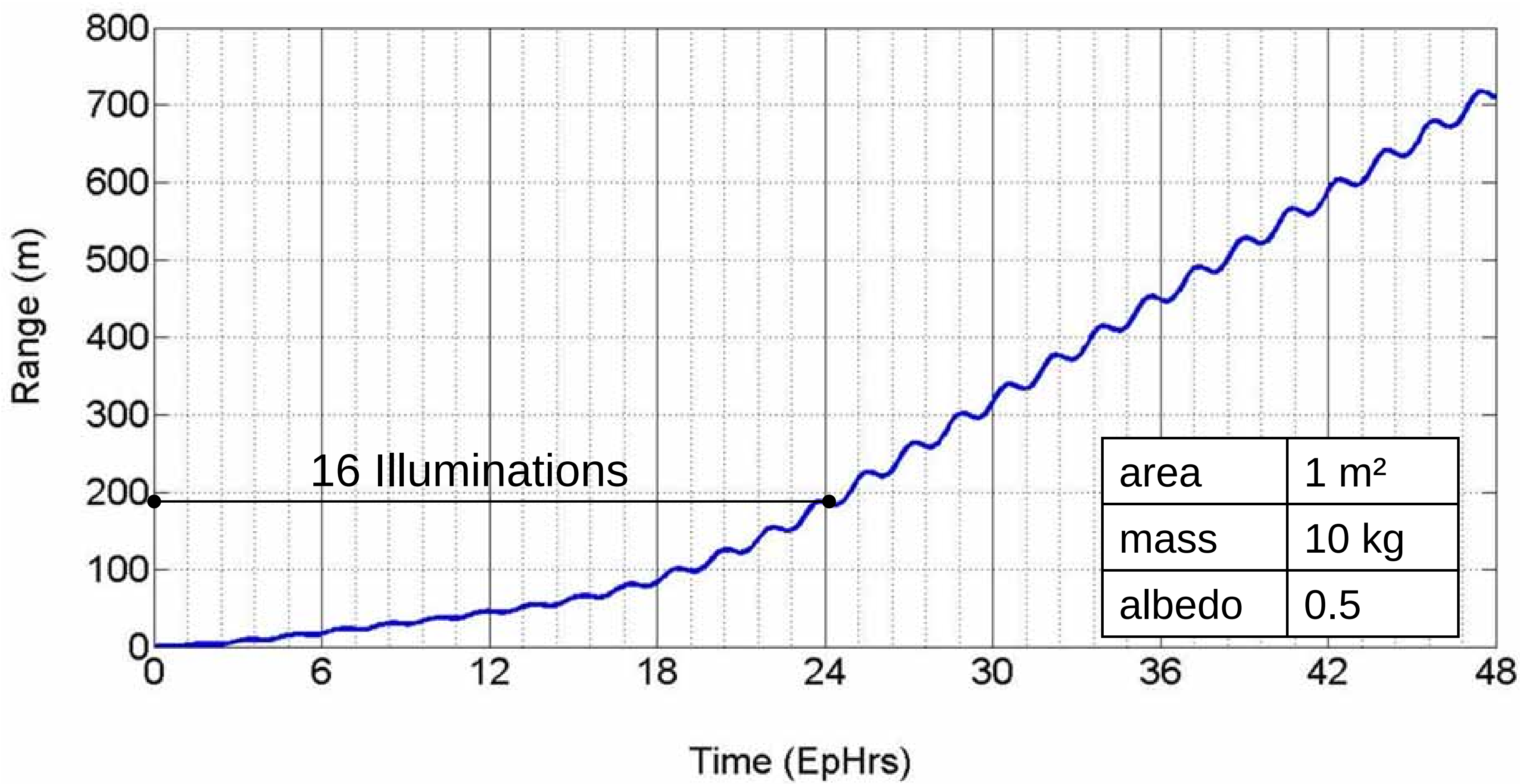


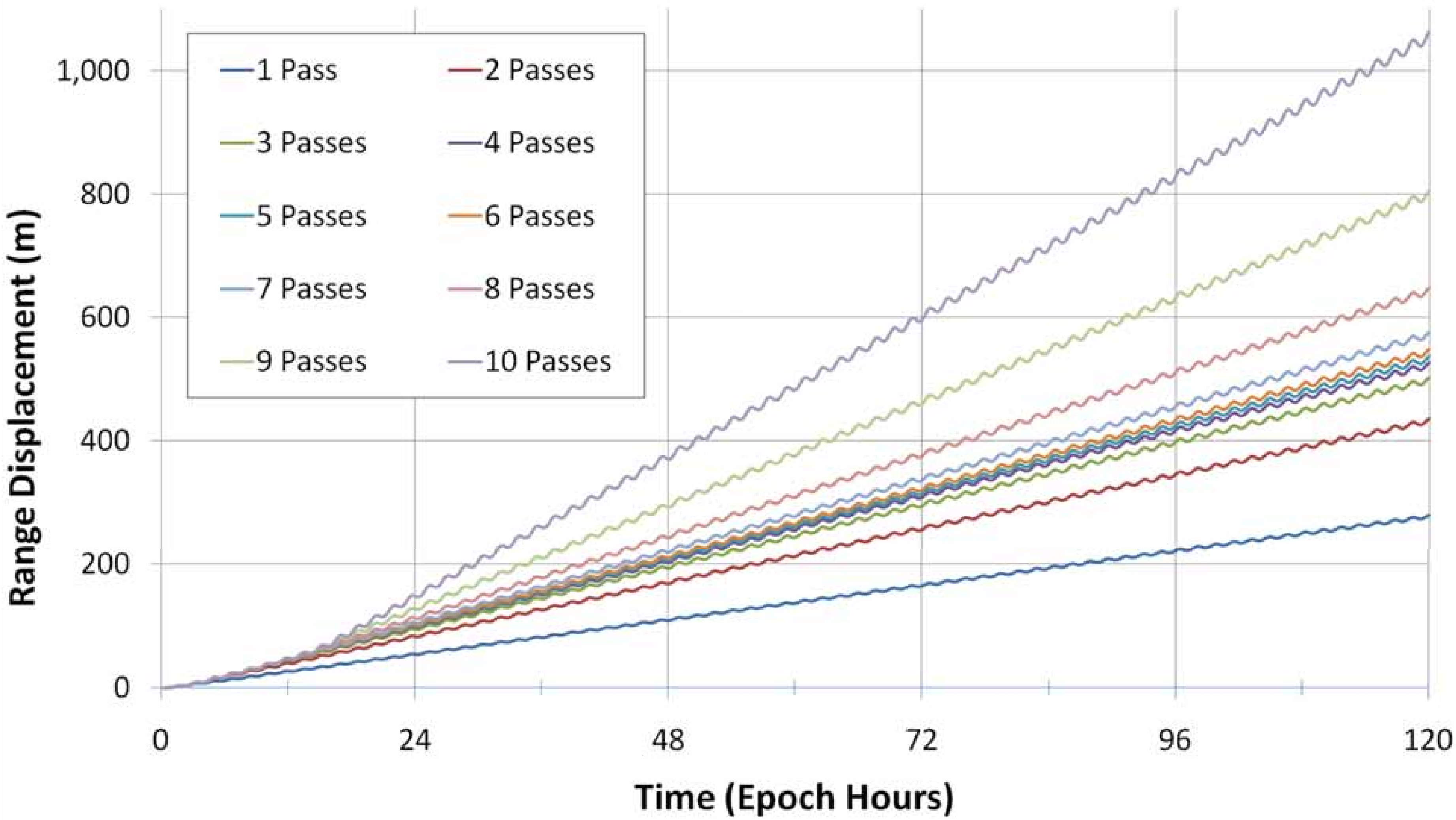
Case study shows promising range displacements

Range displacement illuminating for 1st half of each pass.

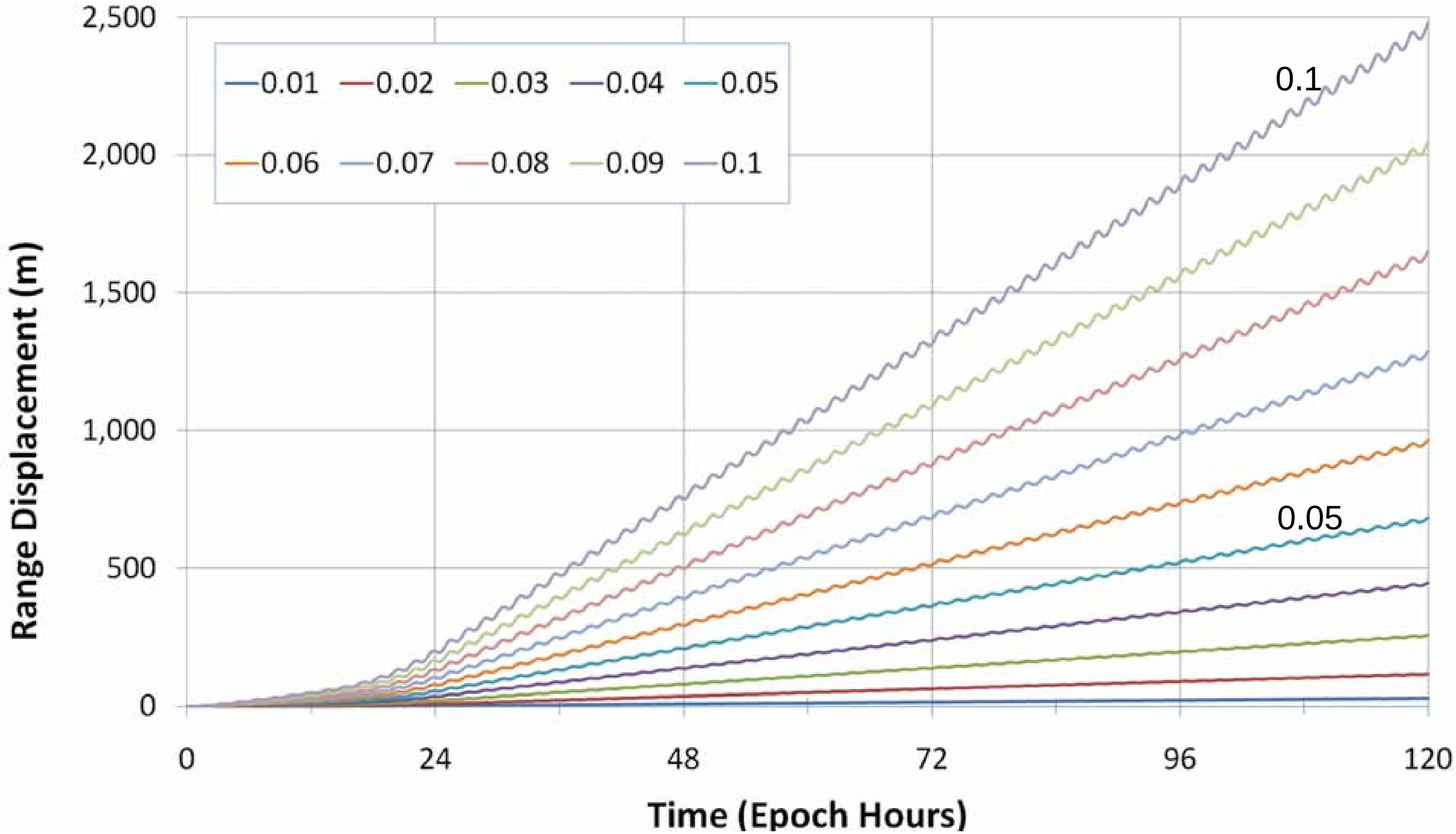


→ **displacement sufficient in the context of accuracy**

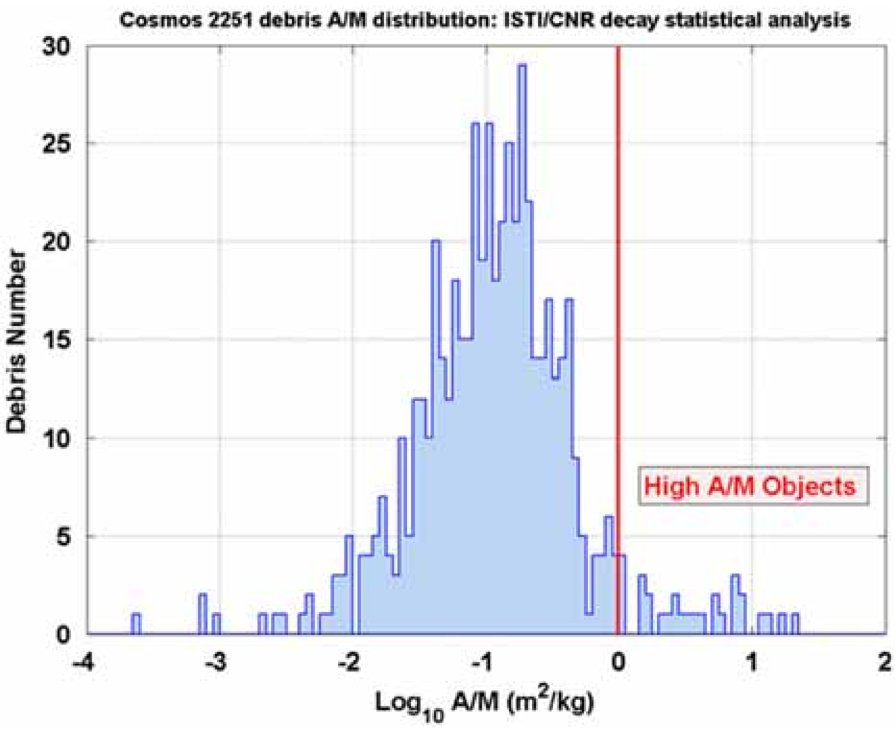
Multiple illuminations increase range displacement

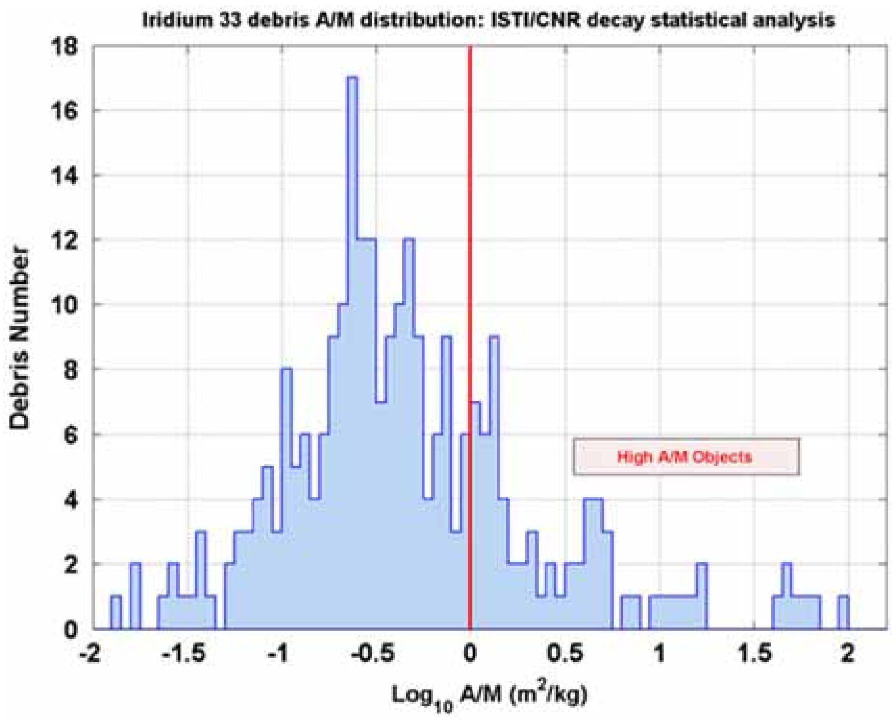


Useful displacements are possible for a range of area-to-mass ratios



A area-to-mass ratio of 0.1 or larger includes a large part of recently released debris





source: Anselmo & Pardini**,** Acta Astronautica 67 (2010)

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Summary

Status:

- Laser ablation debris removal is possible in theory, but still a challenging and costly endeavor, as necessary lasers are not commercially available
- High accuracy conjunction analysis is necessary for collision avoidance, but standard TLE data might be sufficient with modern propagator and fitting
- First case study suggests that laser debris-debris collision avoidance possible with commercially available hardware

To do:

- Look into all aspects of a collision avoidance system, determine optimal setup and location
- Determine effective strategies of use to avoid the Kessler syndrome
- Laser safety via international laser clearinghouse process?

Additonal Information

Laser propagation:

J.Stupl & G.Neuneck: *Assessment of Long Range Laser Weapon Engagements: The Case of the Airborne Laser*, Science & Global Security: 18(1):1-60.

High accuracy conjunction analysis using public TLEs:

C.Levit & W.Marshall: *Improved orbit predictions using two-line elements*, pre-print submitted to Elsevier, http://arxiv.org/pdf/1002.2277

Cascading Debris:

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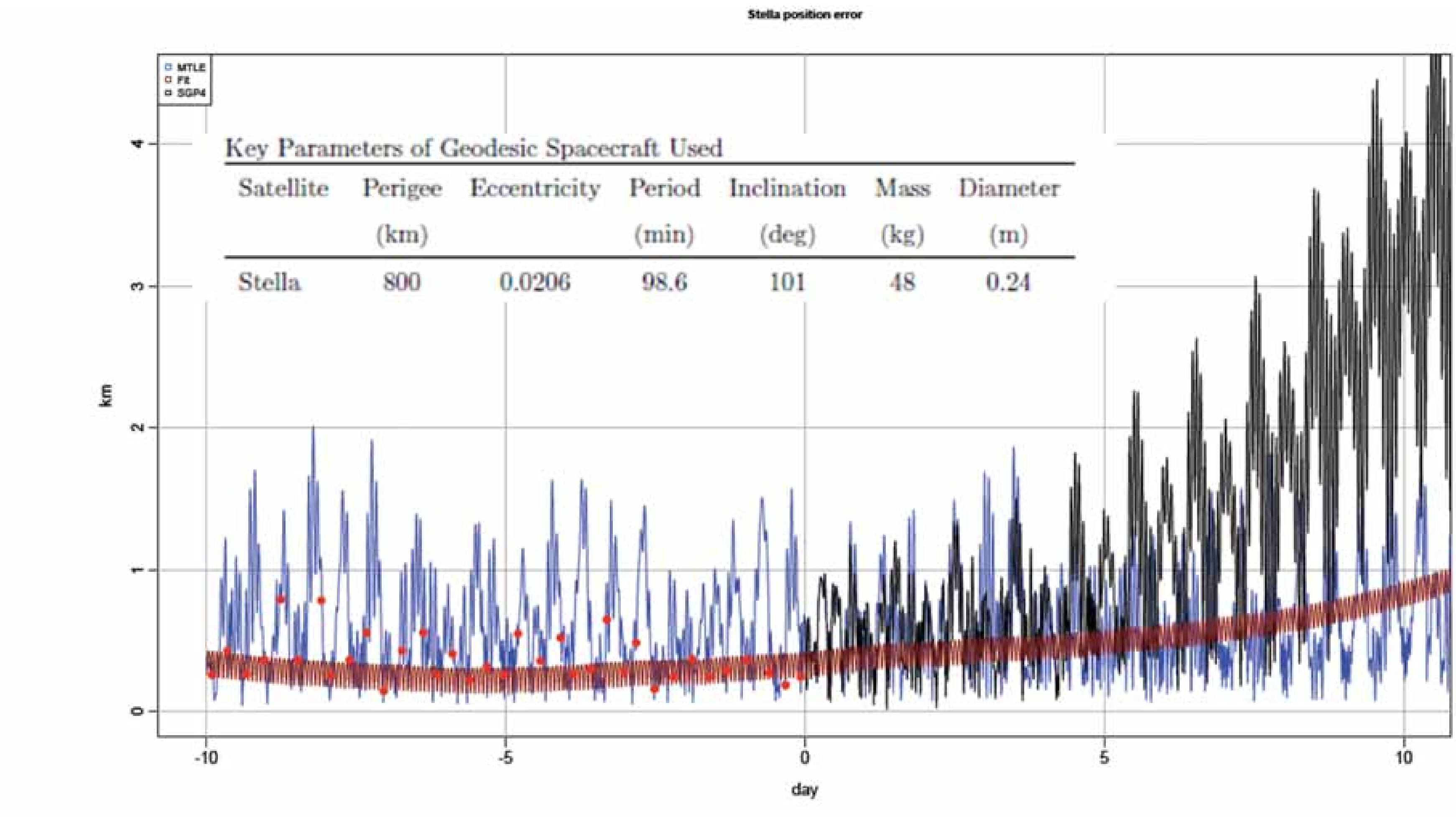
Thank you for your attention!

BACKUP

Fitting a series of TLEs coupled with a modern propagator, higher accuracy predictions are possible

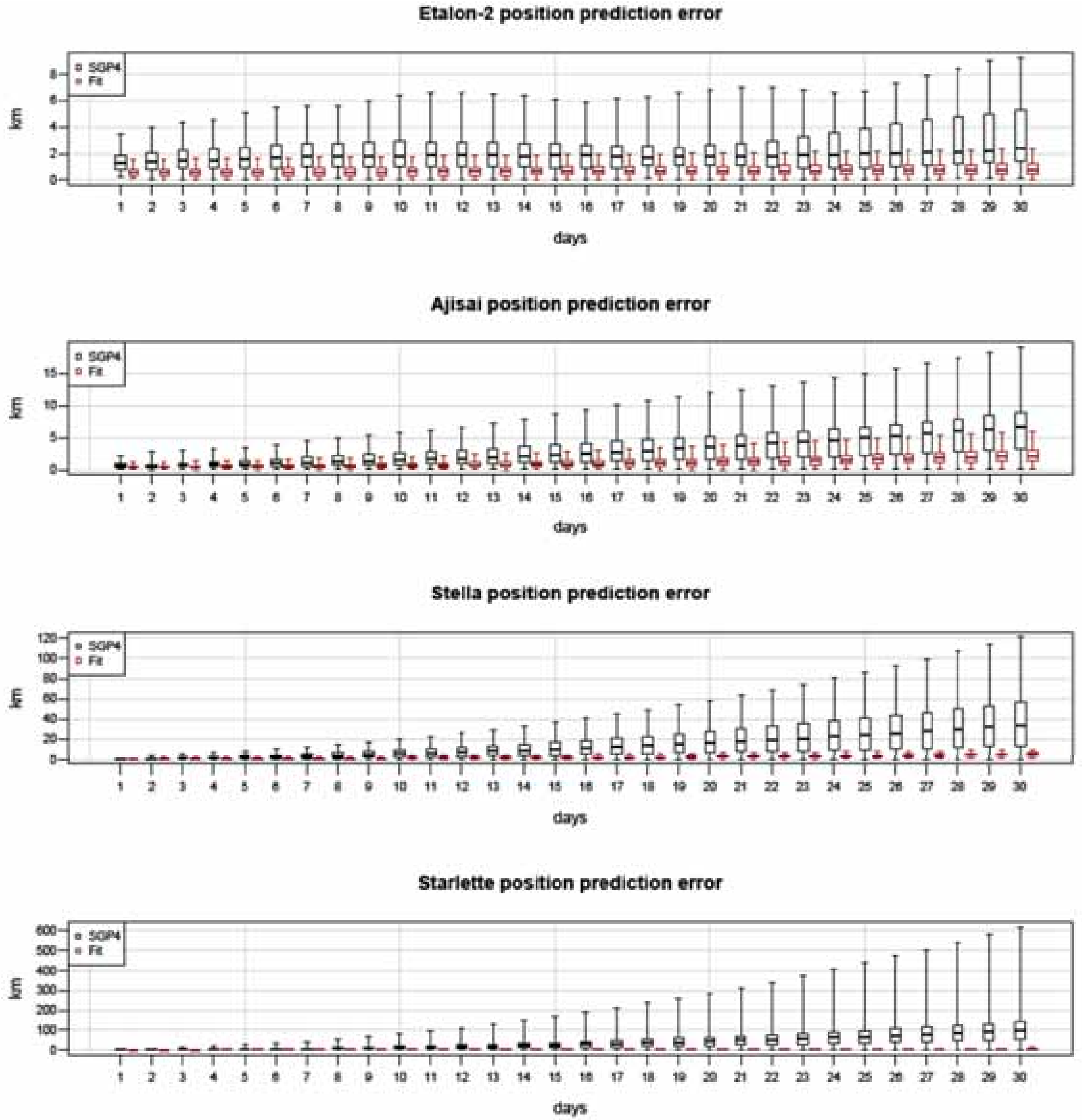


Key Parameters of Geodesic Spacecraft Used

Satellite	Perigee (km)	Eccentricity	Period (min)	Inclination (deg)	Mass (kg)	Diameter (m)
Stella	800	0.0206	98.6	101	48	0.24

Compared to public TLEs + SGP4, new fitting scheme predictions are significantly more accurate

Satellite	Perigee (km)
Stella	800
Starlette	812
Ajisai	1490
Etalon 2	19120



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