Directed Energy Planetary Defense

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Experimental Cosmology at UCSB

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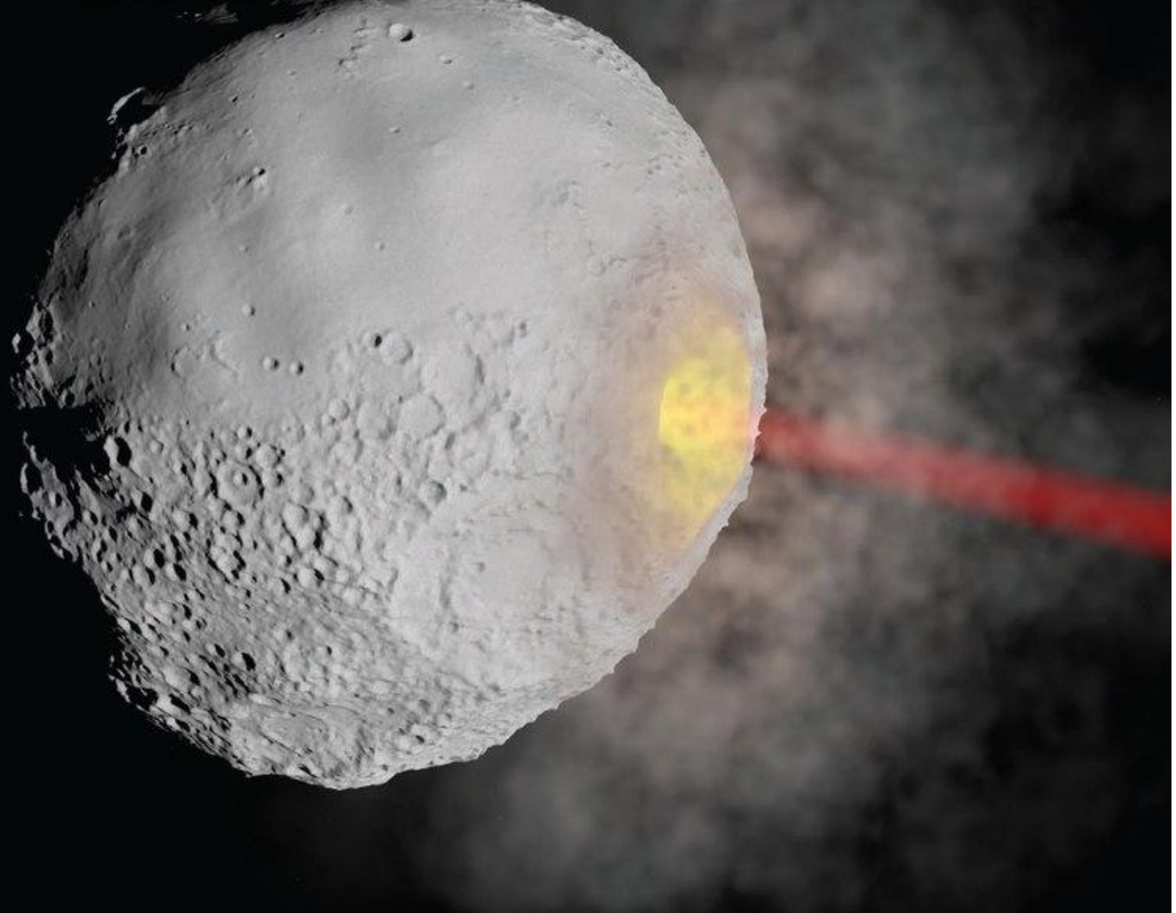
PHOTONICS spectra

Space Lasers
Poised to Protect Earth, Transmit Data



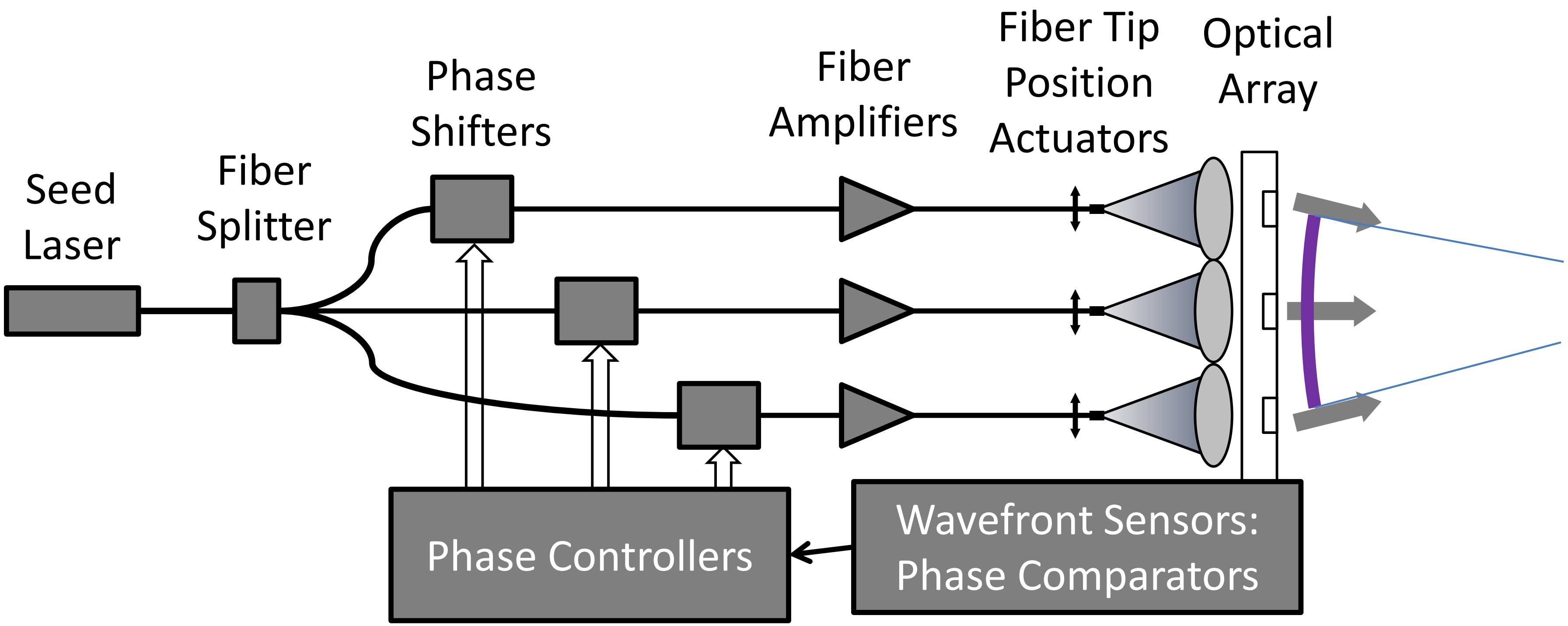
PHOTONICS MEDIA
LAURIN PUBLISHING

1. **Introduction**
2. **DE-STAR: D**irected **E**nergy **S**ystem for **T**argeting of **A**steroids and exploR**a**tion
3. **DE-STARLITE Mission**
4. **Orbital Deflection Capabilities**
5. **Impactor Comparison**
6. **Ion Beam Deflection Comparison**
7. **Conclusions**

References

Acknowledgements

DE-STAR and DE-STARLITE Phased Array



DE-STAR Architecture

Described in Lubin *et al*. (2014), Hughes *et al*. (2013) and others

Phased array of fiber amplifiers, based on work by Vorontsov *et al*. (2009).

Phase Control provides mechanism for:

(1) **Beam Formation**

(2) **Beam Steering**

Optical Simulations

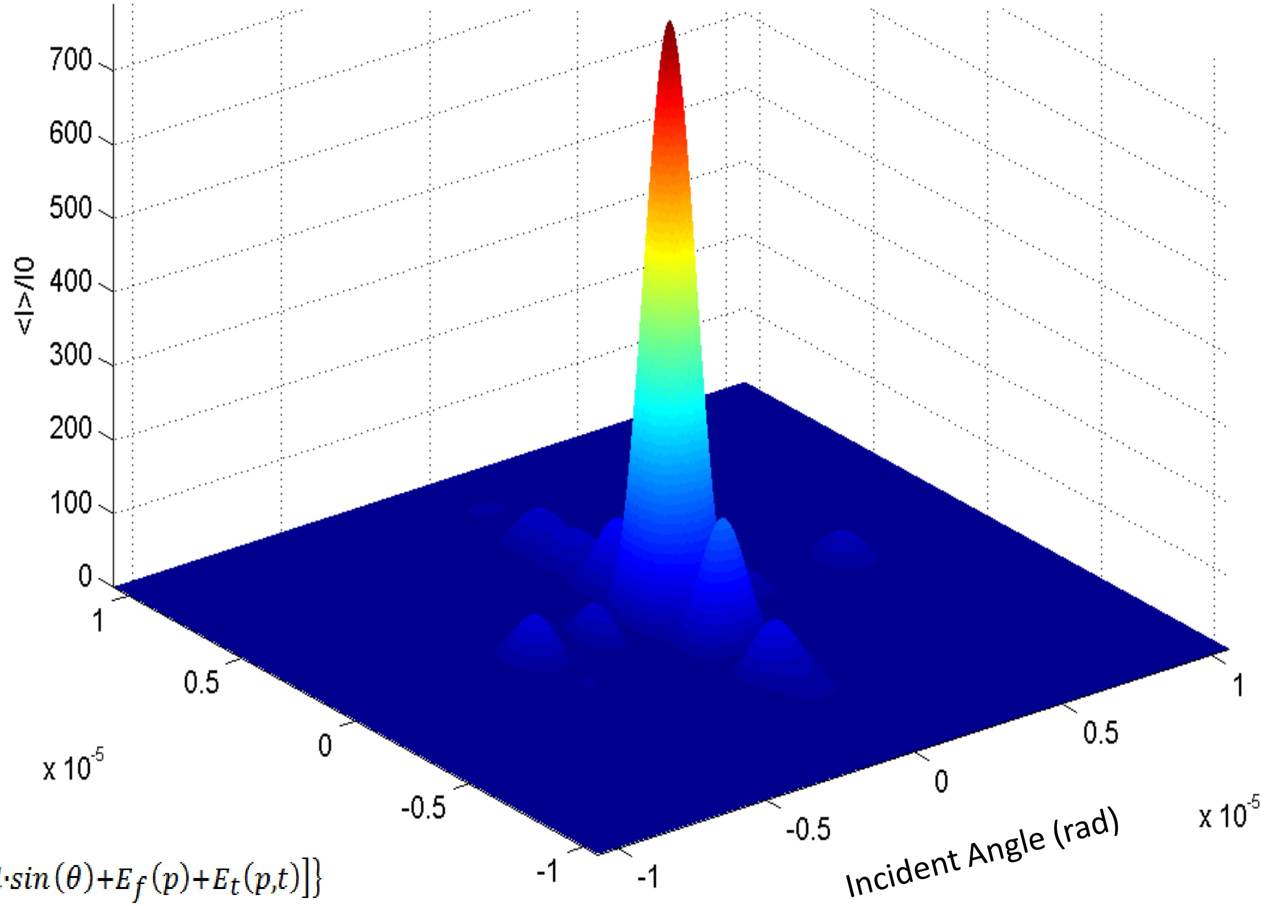
Optical simulations of the far-field beam pattern

Hughes *et al*. (2014)
Lubin *et al*. (2014)

Simulation of 6 by 6 array
Square elements, with close-packed spacing of 10 cm
Laser fiber amplifiers, $\lambda = 1.06\ \mu m$
Static phase perturbations of $\lambda/10$ (1σ rms)

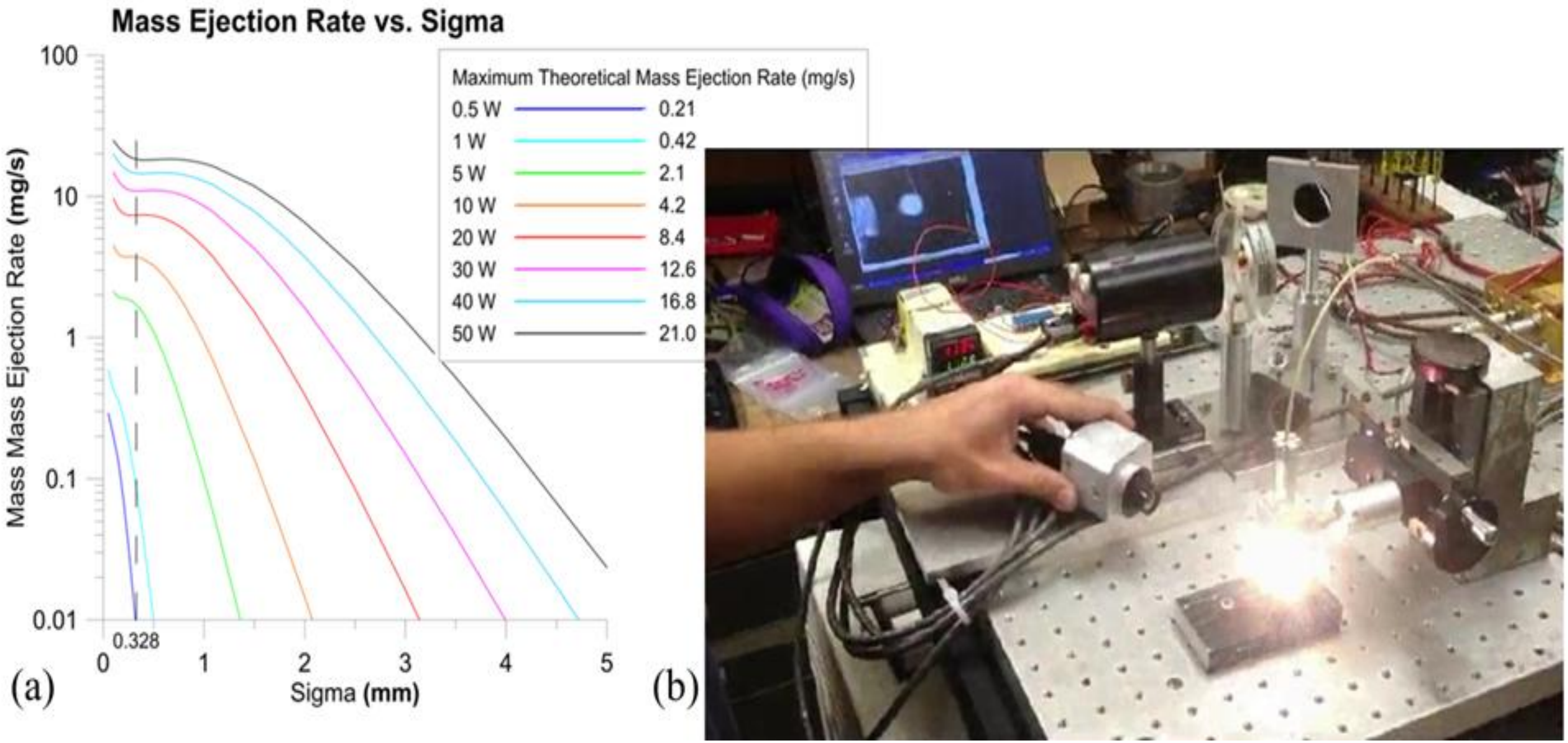
Phase perturbations between emitters:

(1) cause power leakage from the main lobe into adjacent directions
(2) Create pointing jitter of the main lobe



$$E(\theta,t) = \frac{e^{[i\cdot k\cdot a\cdot sin(\theta)]} - 1}{i\cdot k\cdot sin(\theta)} \cdot \sum_{p=0}^{N-1} e^{\{i\cdot[k\cdot p\cdot d\cdot sin(\theta)+E_f(p)+E_t(p,t)]\}}$$

Laboratory Testing



Laboratory Experiments for Heating, Mass Ejection

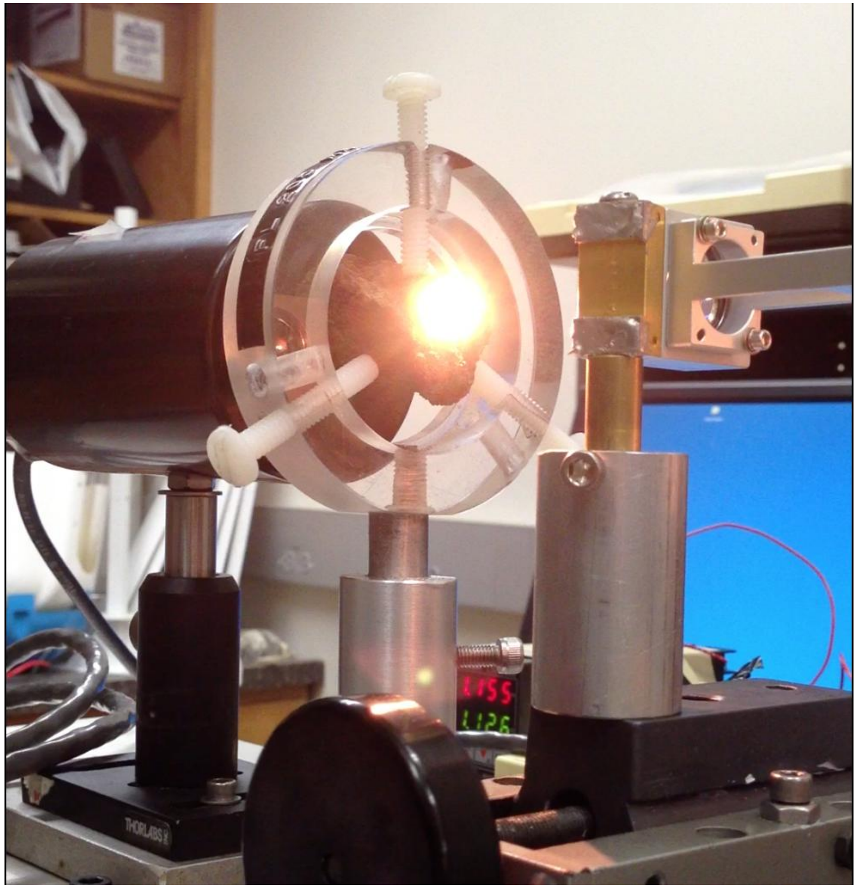
(a) 2D simulation of expected mass ejection vs. sigma (Gaussian beam) for various power levels, from Lubin *et al*. (2014).

(b) Laboratory test system. Small camera is an 8-12 µm FLIR IR micro-bolometer unit. Pictured sample is sand. The sand was melted and vaporized.

http://www.deepspace.ucsb.edu/projects/directed-energy-planetary-defense

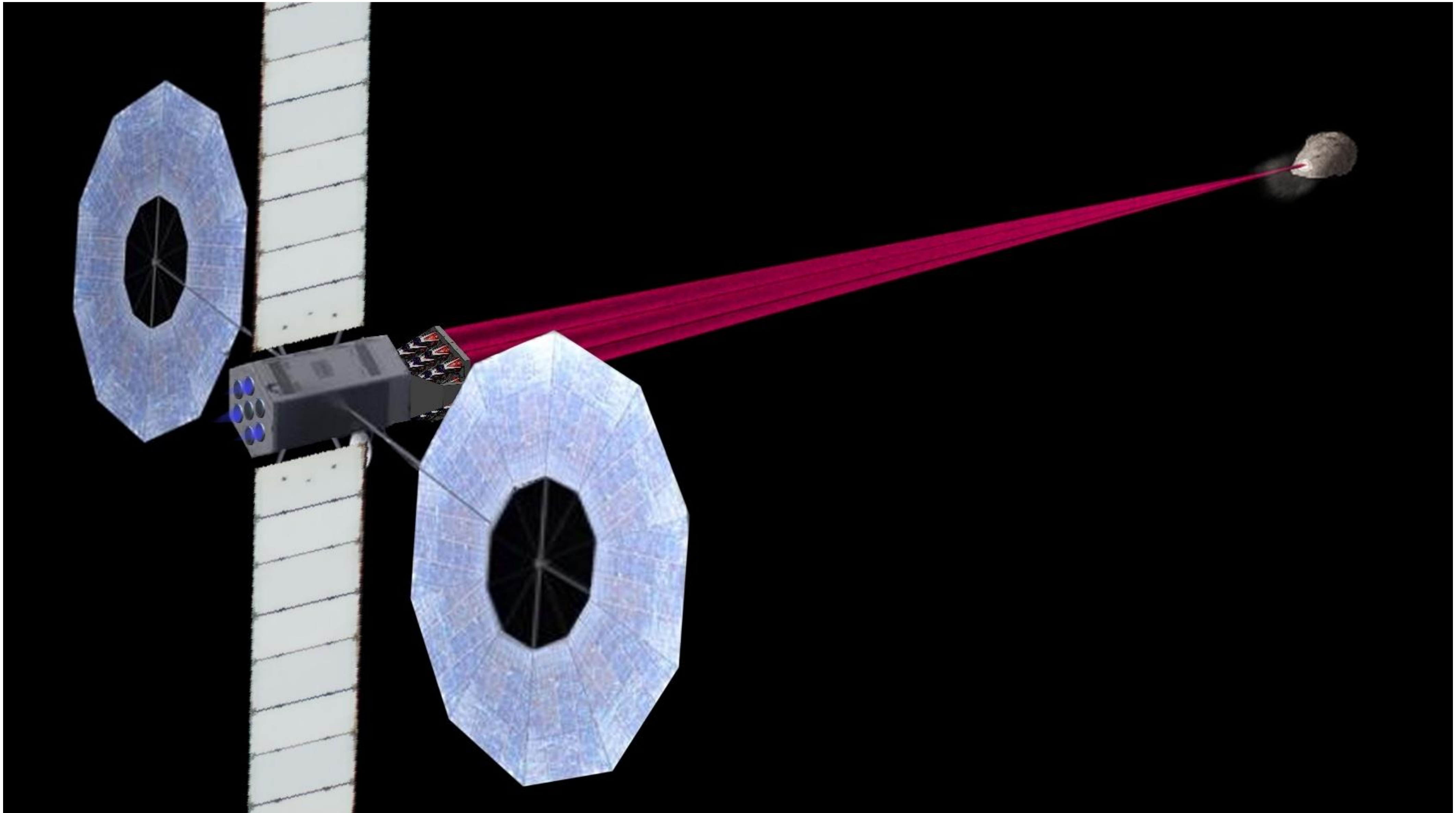
Does it work?

- DE-STAR is designed to deliver ~ 50 MW/m^2 @ 1 AU
- We have built a laboratory test unit that delivers
  - Up to 60 MW/m^2 (not at 1 AU!) ~ **flux at surface of Sun**
  - It works EXTREMELY well!
  - Start vaporizing ~ 2-5 MW/m^2

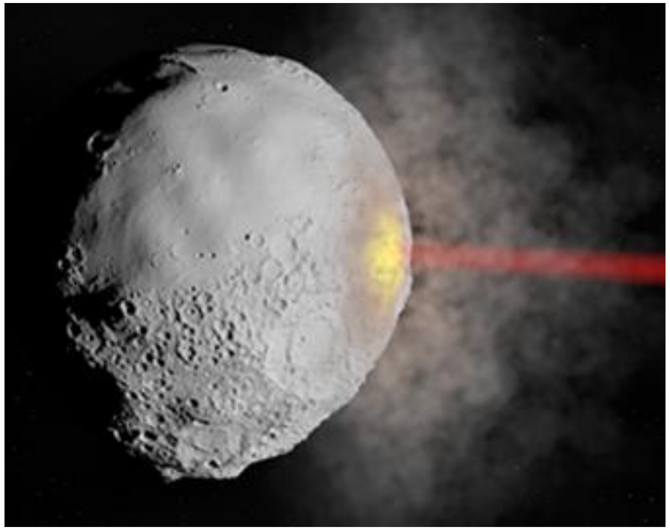


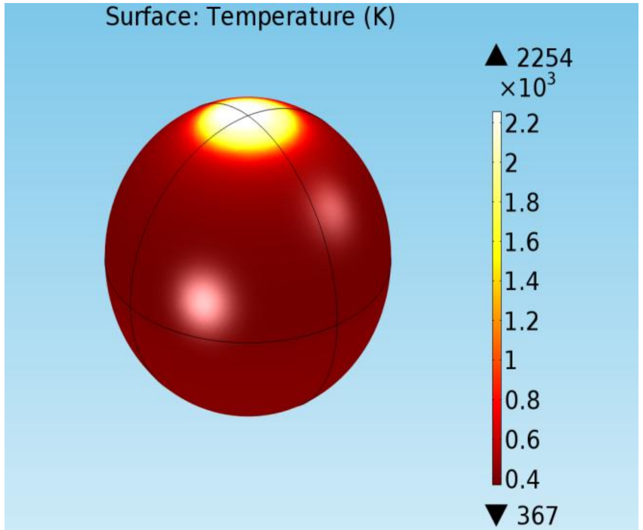
DE-STARLITE

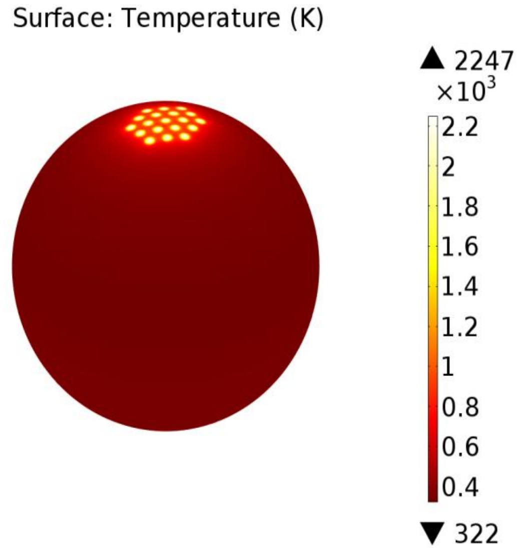
Launch in single SLS Block 1 to LEO Uses Ion Engines to rendezvous

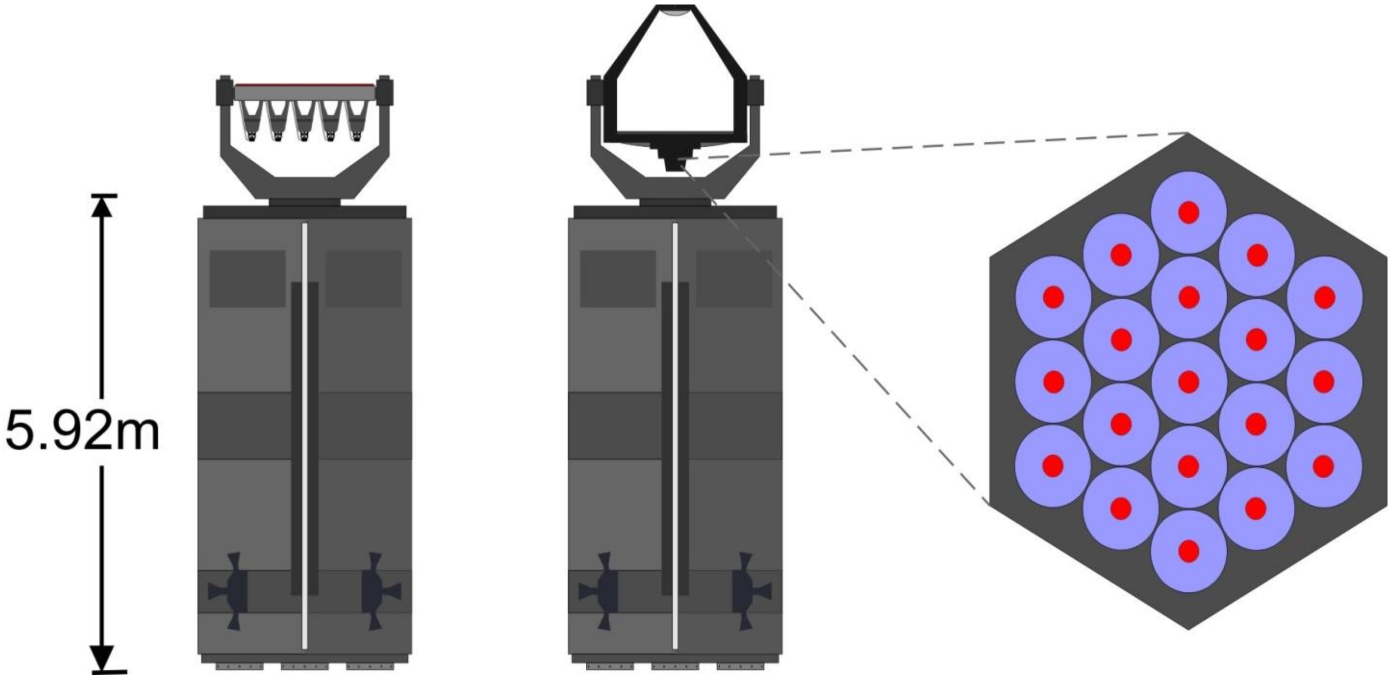


Phased Array vs Fiber Array

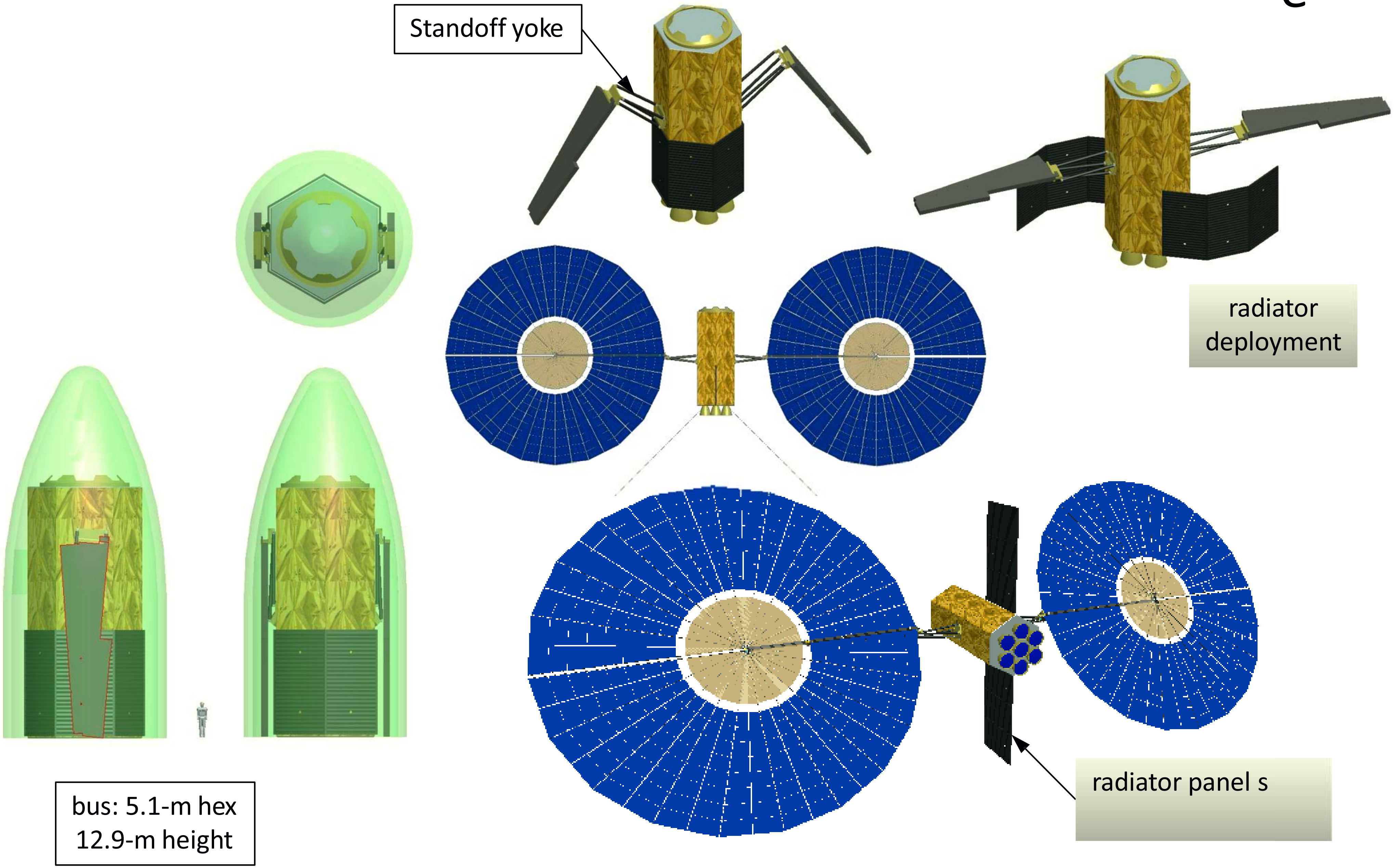




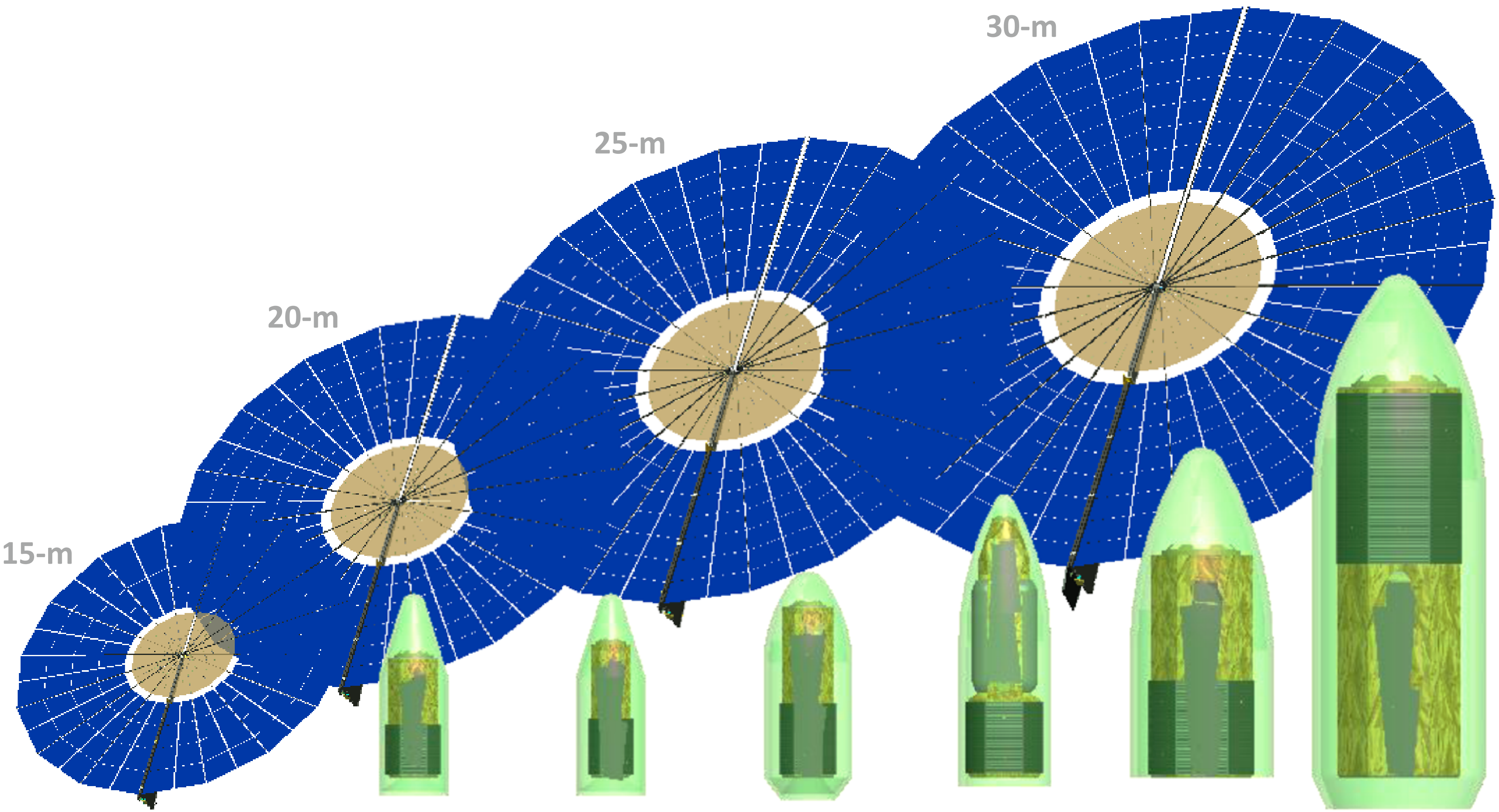




SLS Block 1 Deployment – 450 kw$_e$

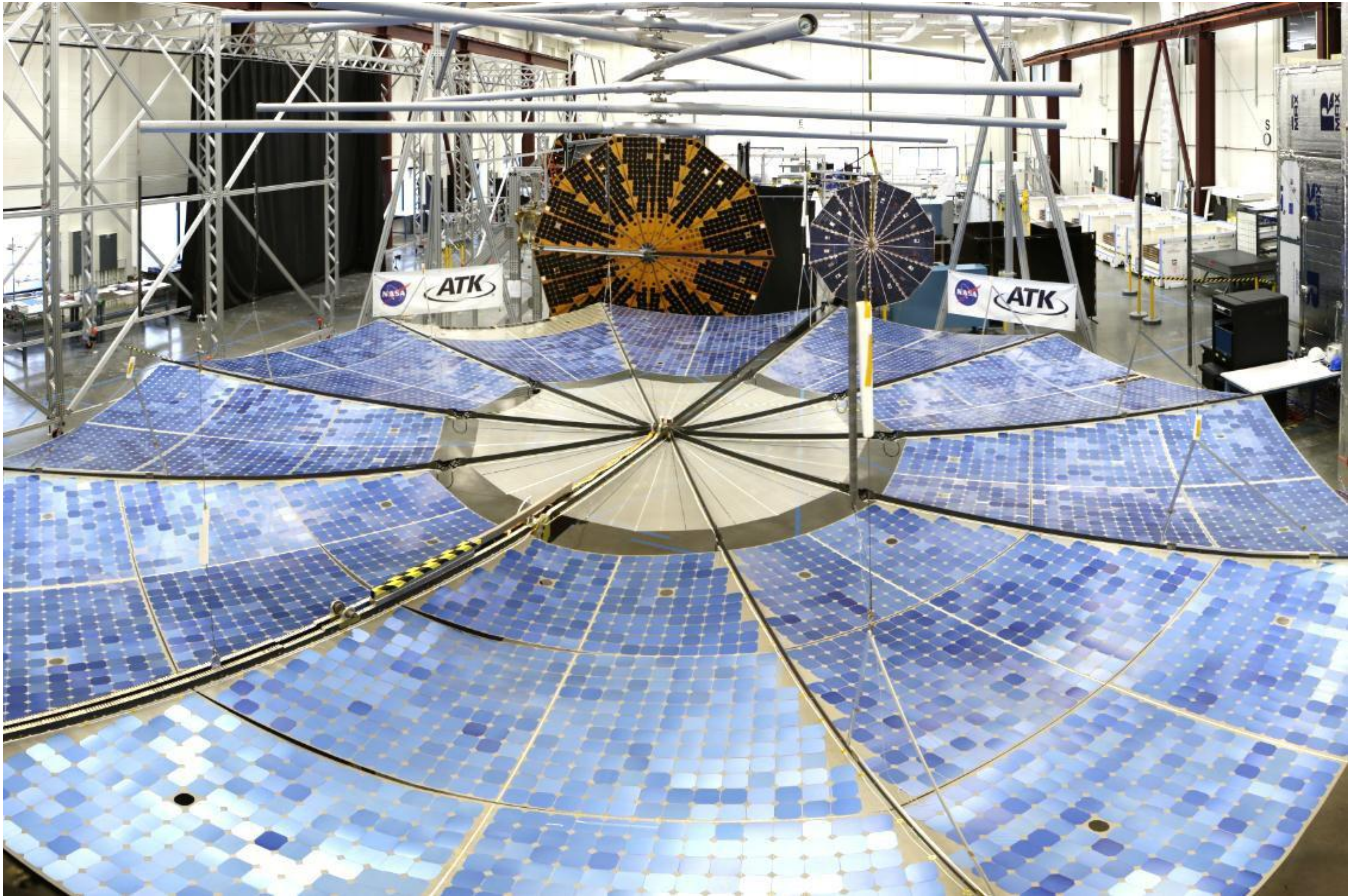


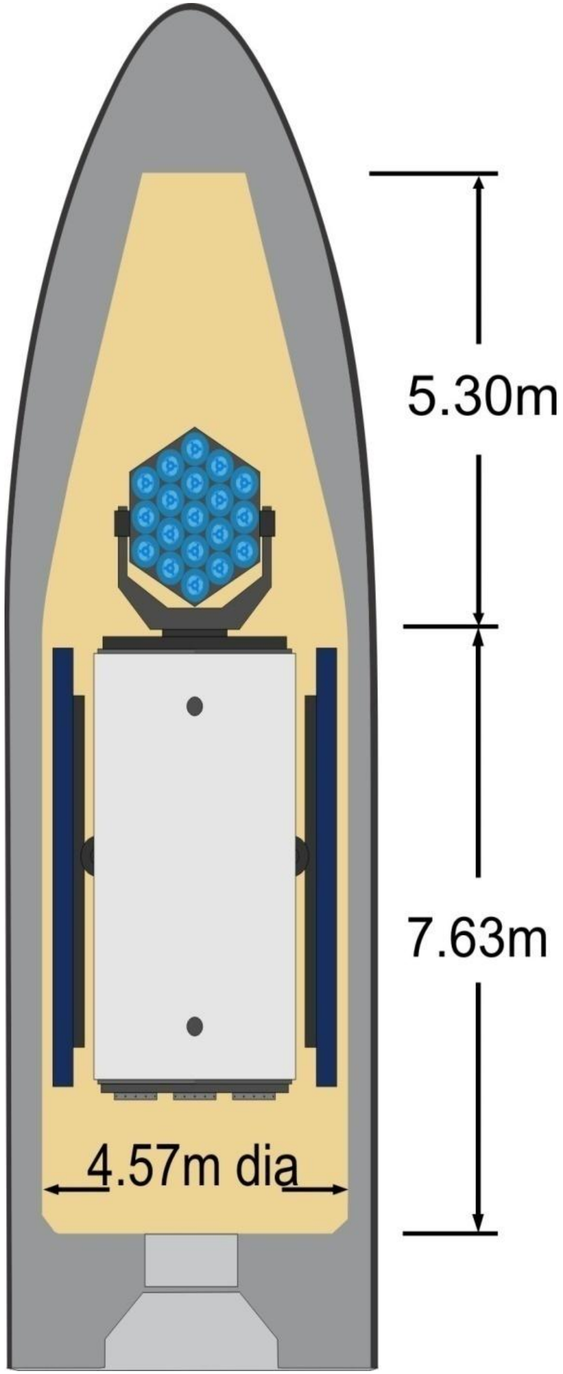
Launcher Options



Fairing Class Fairing Diameter	Delta IV 4-m	Delta IV 4-m	Falcon 9 5.2-m	Ariane5 5.4-m	SLS PF1B 8.4-m	SLS PF2 10-m
Wing Diameter (m)	15	20	25	25	30	30
Array Power Class (kW, IMM)	105	190	300	300	450	450

ATK Megaflex – 10m diam – Near UCSB

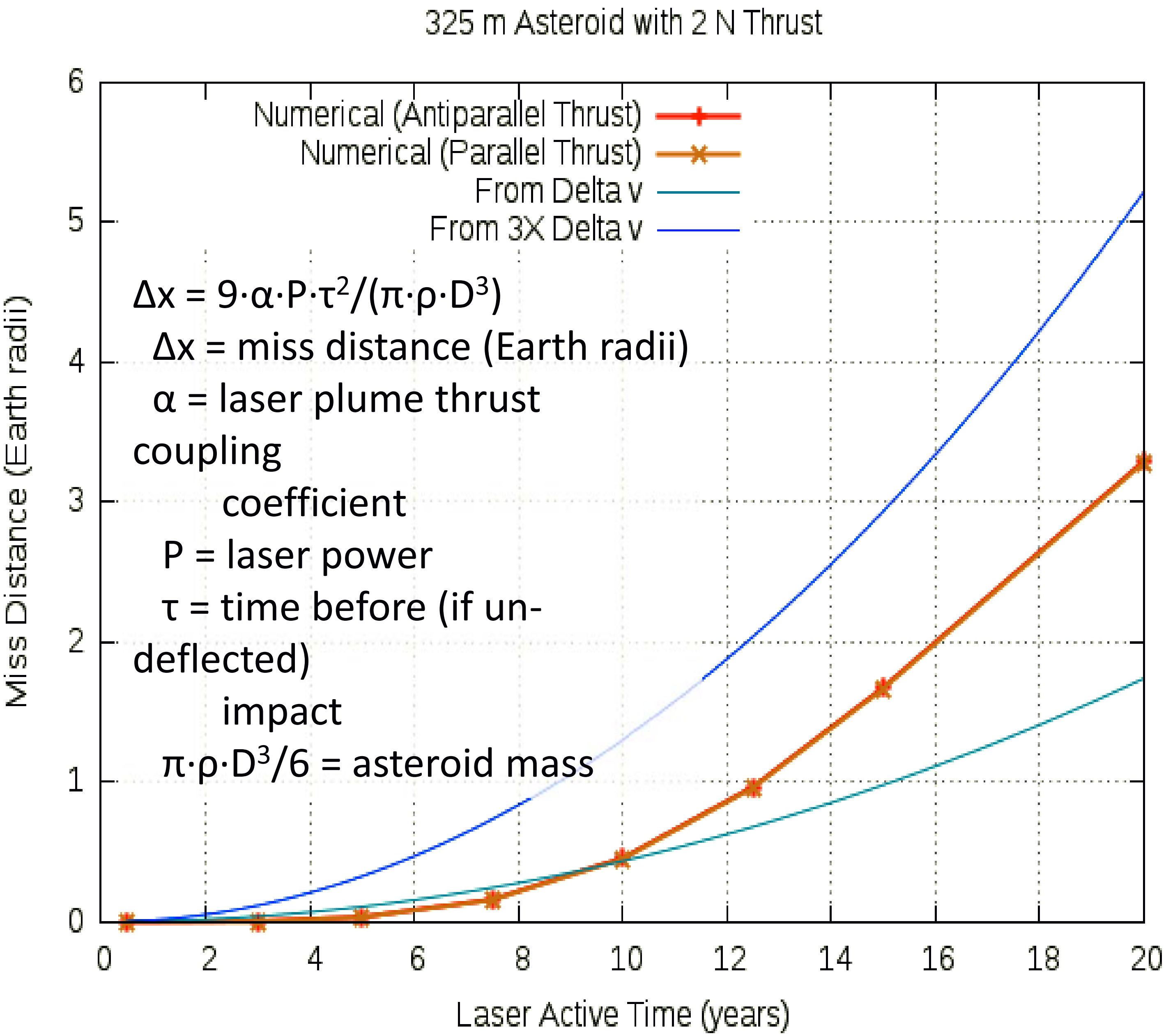




Parameters of various launch vehicles in consideration for DE-STARLITE.

Parameter	Atlas V 551	SLS Block 1	Falcon Heavy	Delta IV Heavy
Payload Mass to LEO (kg)	18,500	70,000	53,000	28,790
Cost per unit mass to LEO	\$13 k/kg	\$19 k/kg	\$1.9 k/kg	\$13 k/kg
Fairing Diameter (m)	5.4	8.4	5.2	5
Status	Flight proven	Expected 2017	Expected 2015	Flight proven

Orbital Deflection Capabilities



$\Delta x = 9 \cdot \alpha \cdot P \cdot \tau^2 / (\pi \cdot \rho \cdot D^3)$

Δx = miss distance (Earth radii)

α = laser plume thrust coupling coefficient

P = laser power

τ = time before (if un-deflected) impact

$\pi \cdot \rho \cdot D^3/6$ = asteroid mass

Miss distance vs. laser active time for full numerical 3 body orbital simulations

Comparison with Δv and $3\Delta v$ approximations

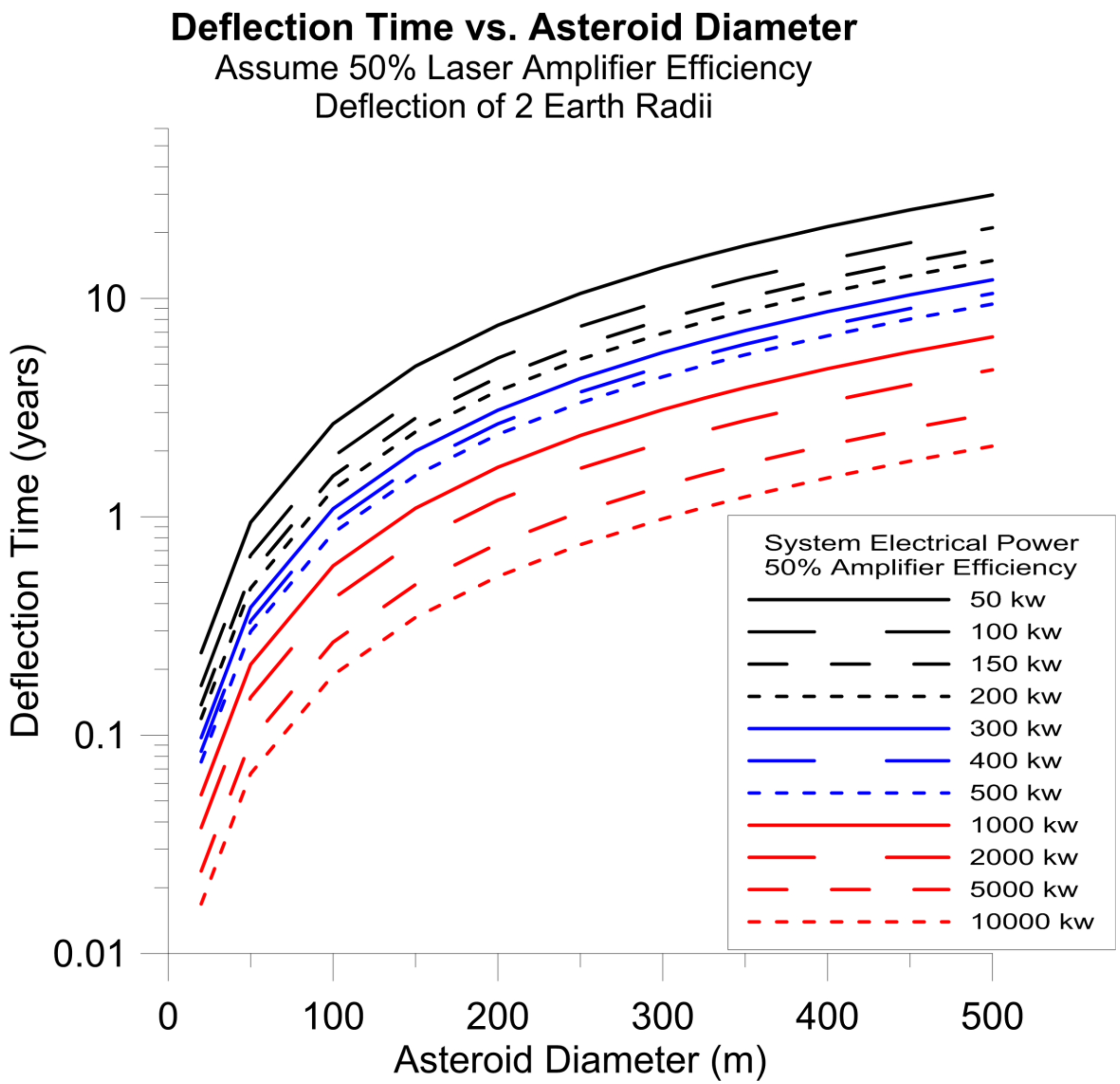
Nominal 2 N thrust, produced by ~30 kW laser

A modest case for a DE-STARLITE mission

More thrust available with larger arrays.

Orbital Deflection Capabilities

Mission Planning



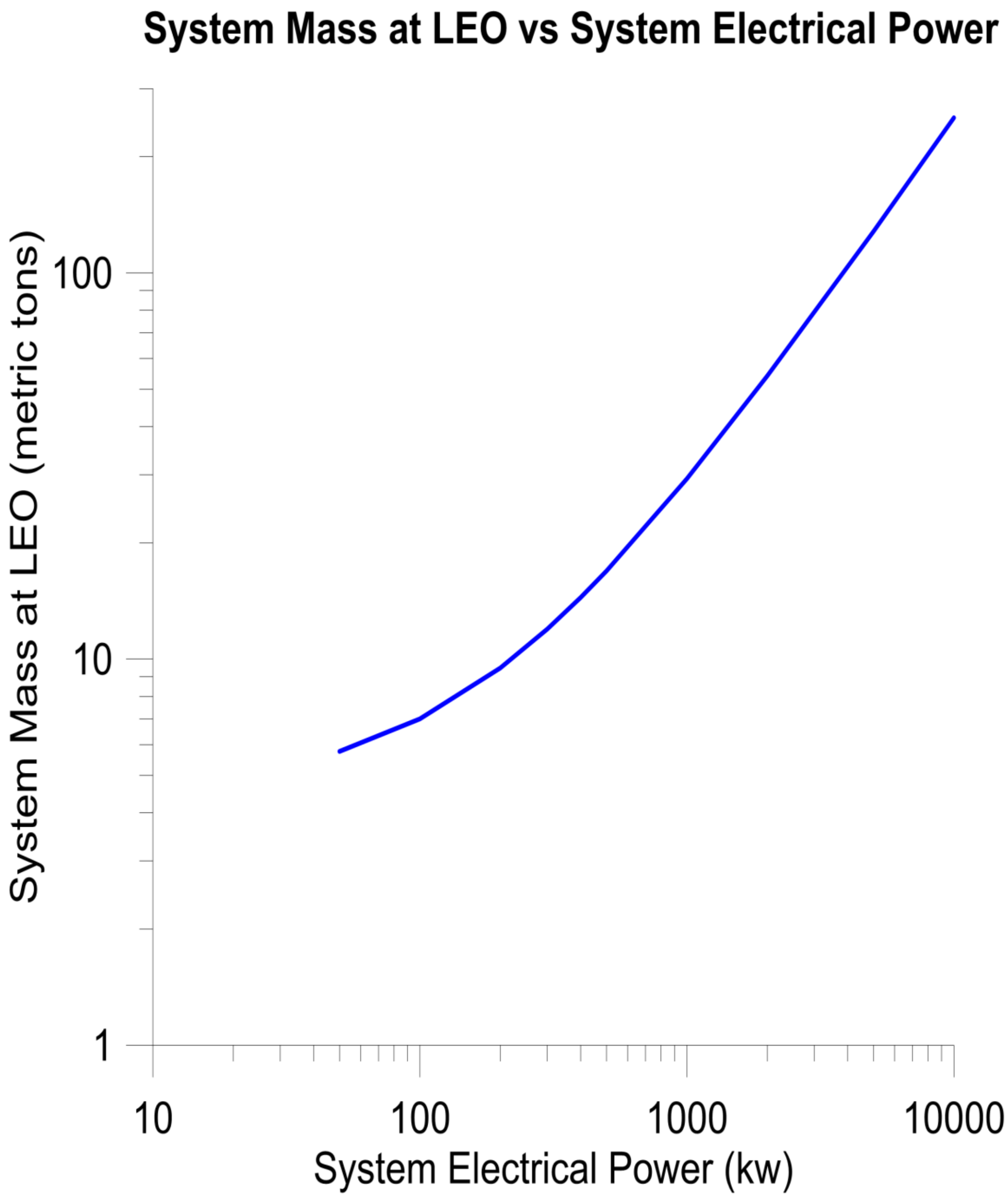
Estimated deflection time vs. target diameter and DE-STARLITE electrical power input from PV

True mission planning requires detailed knowledge of the target orbit and the detailed interdiction scenario.

A **200 m** diameter asteroid could be **deflected in ~1 year** using a MW class laser; larger asteroids require more time.

Assuming a 3Δv approximation often over estimates the deflection (miss) distance.

Impactor Comparison



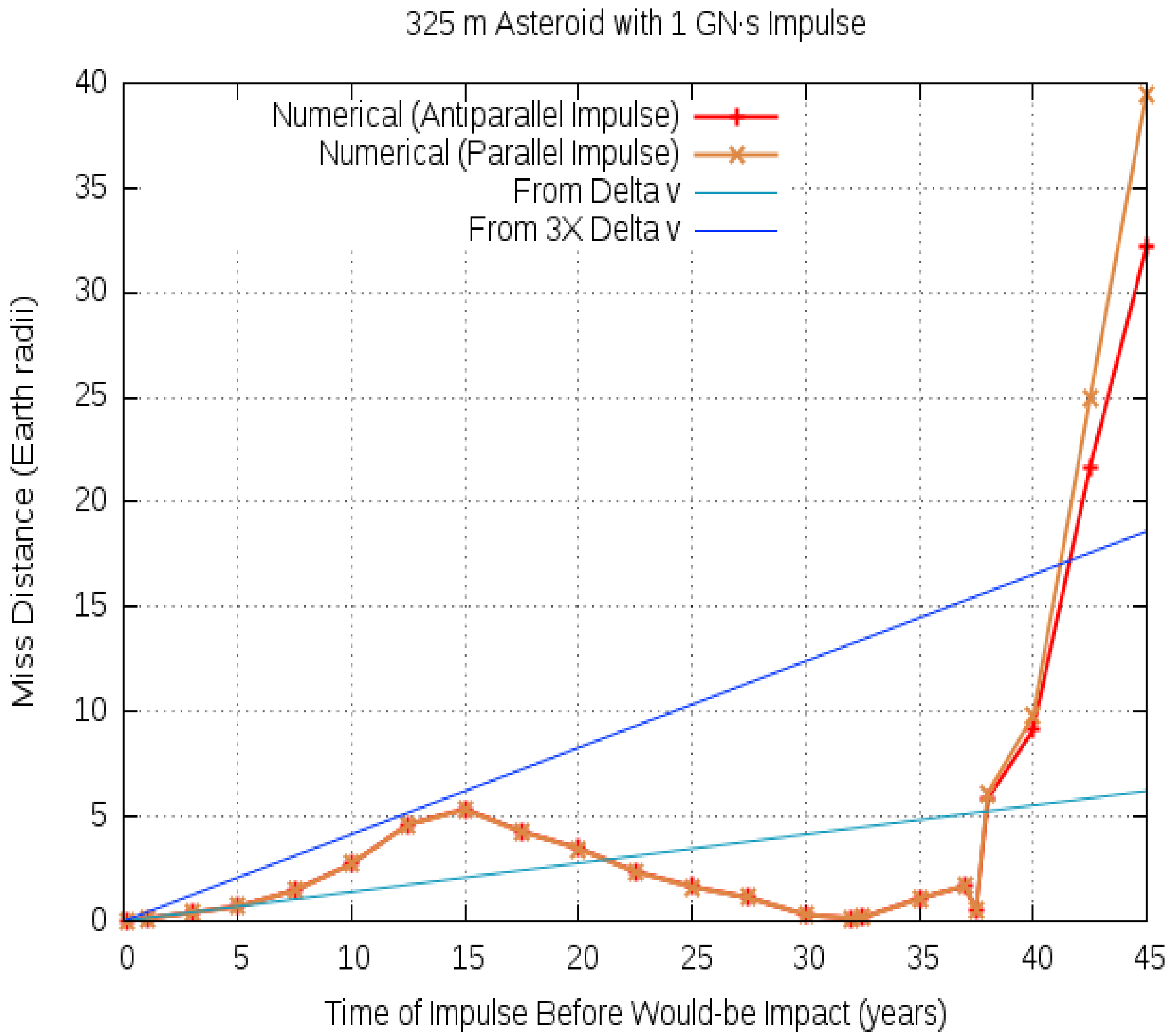
Mission mass at LEO vs. electrical power available from PV

Assuming:

- Nominal 50% laser amplifier efficiency
- Current ATM MegaFlex capability
- I_{sp} = 6,000 s ion engines
- Radiator panels of 25 kg/kW radiated

SLS Block 1 launch of 70 metric tons to LEO corresponds roughly to 2-3 MW electrical or roughly 1 MW laser power.

Impactor Comparison



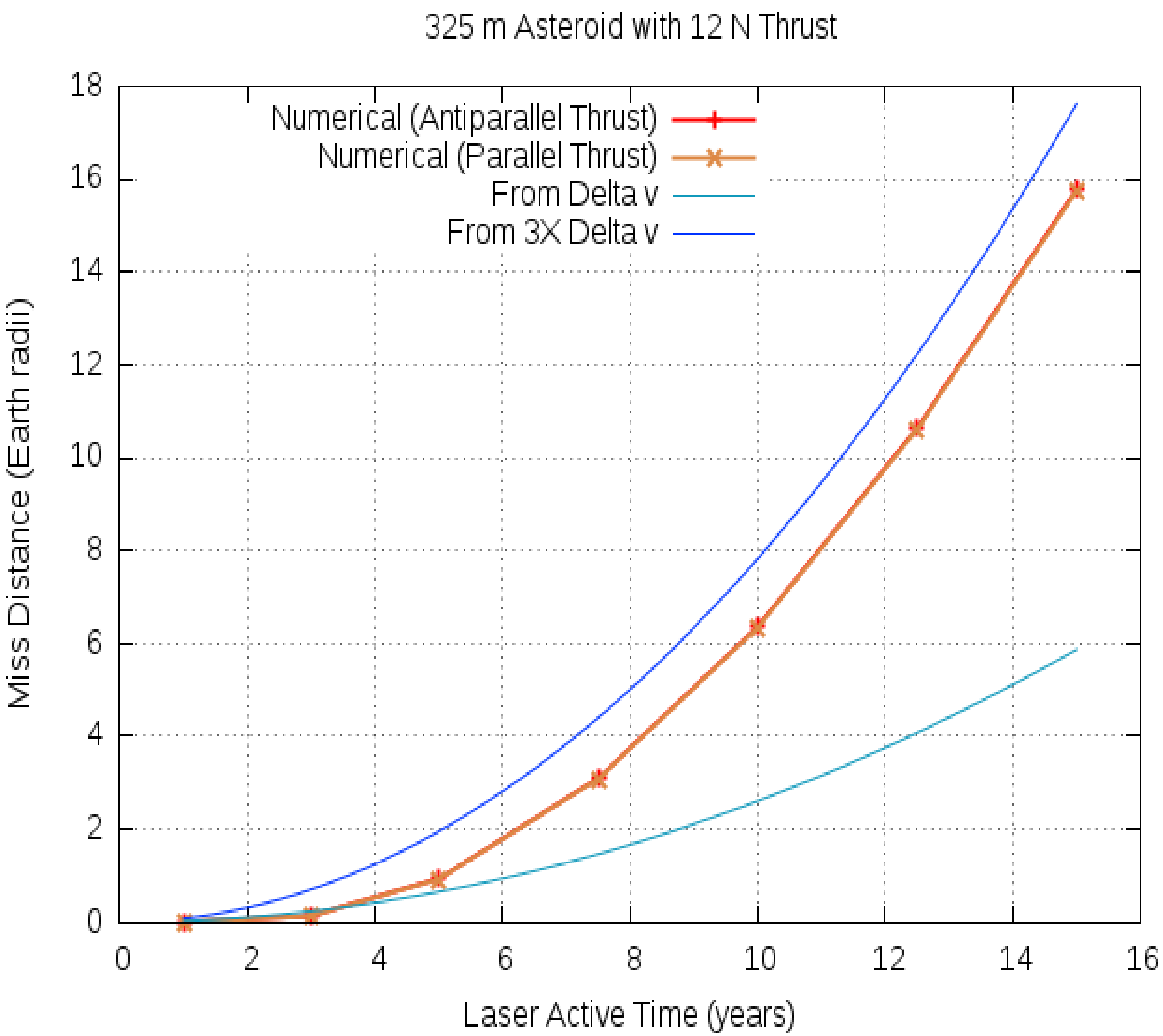
It is clear that the 3Δv approximation is not always accurate, and can be very misleading in some cases.

Miss distance vs. impulse delivery time before impact for 1 GN s impulse 100 ton$_m$ @ 10 km/s (325 m asteroid)

Larger than SLS Block 1 (70 tons LEO Closer to SLS Block 2 (130 tons to LEO)

A miss distance of 2 Earth radii would require interdiction about 10 years before impact

The seemingly unusual behavior from the full simulation is due to resonance effects from the multiple orbits



Miss distance vs. laser exposure time for 12 N thrust on a 325 m diameter asteroid

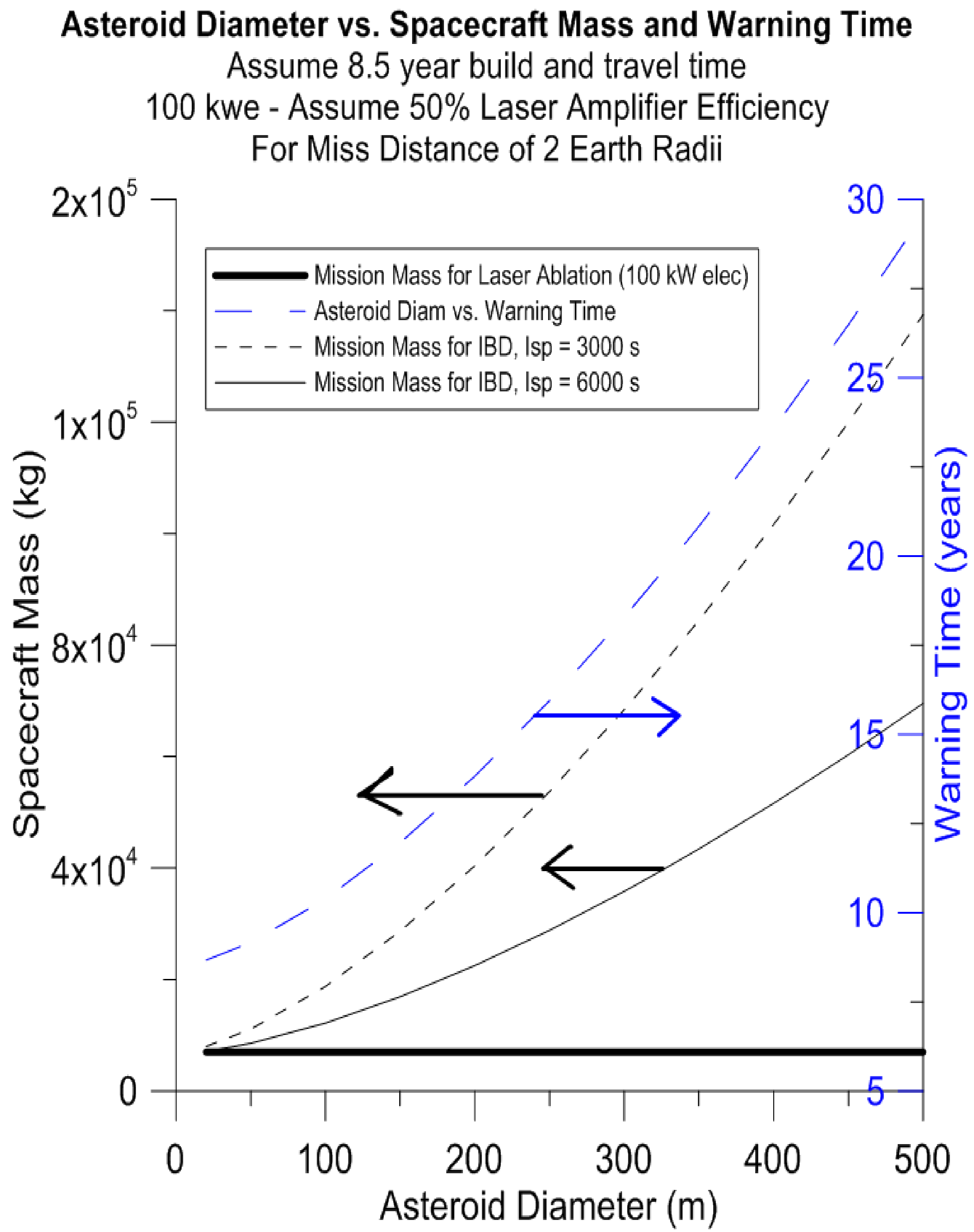
Parallel and anti-parallel cases are coincident in the plot

A 2 Earth radii miss requires ~6 years of exposure

An SLS Block 1 could deliver ~5x this thrust → ~ 1 year

Ion Beam Deflection Comparison

Impact Momentum Transfer vs. Continual Thrust



Asteroid diameter vs. spacecraft mass at LEO

Left Axis: IBD case

Assumes magnetically shielded Hall effect thrusters w/ I_{sp} of 3000 s, and gridded ion thrusters w/ I_{sp} of 6000 s

Right Axis: Laser Ablation Case

Asteroid diameter vs. the required warning time for a modest laser ablation system with 100 kW electrical power

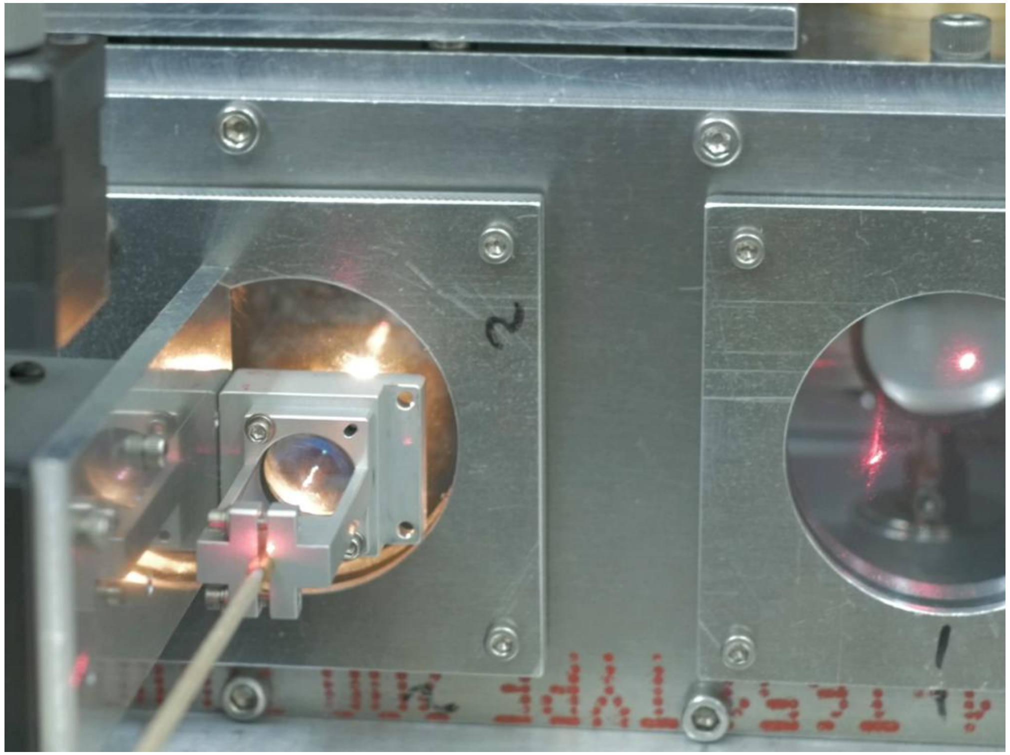
Space Simulated Laboratory Test Transition To:

Travis Brashears

UCSB Physics Department

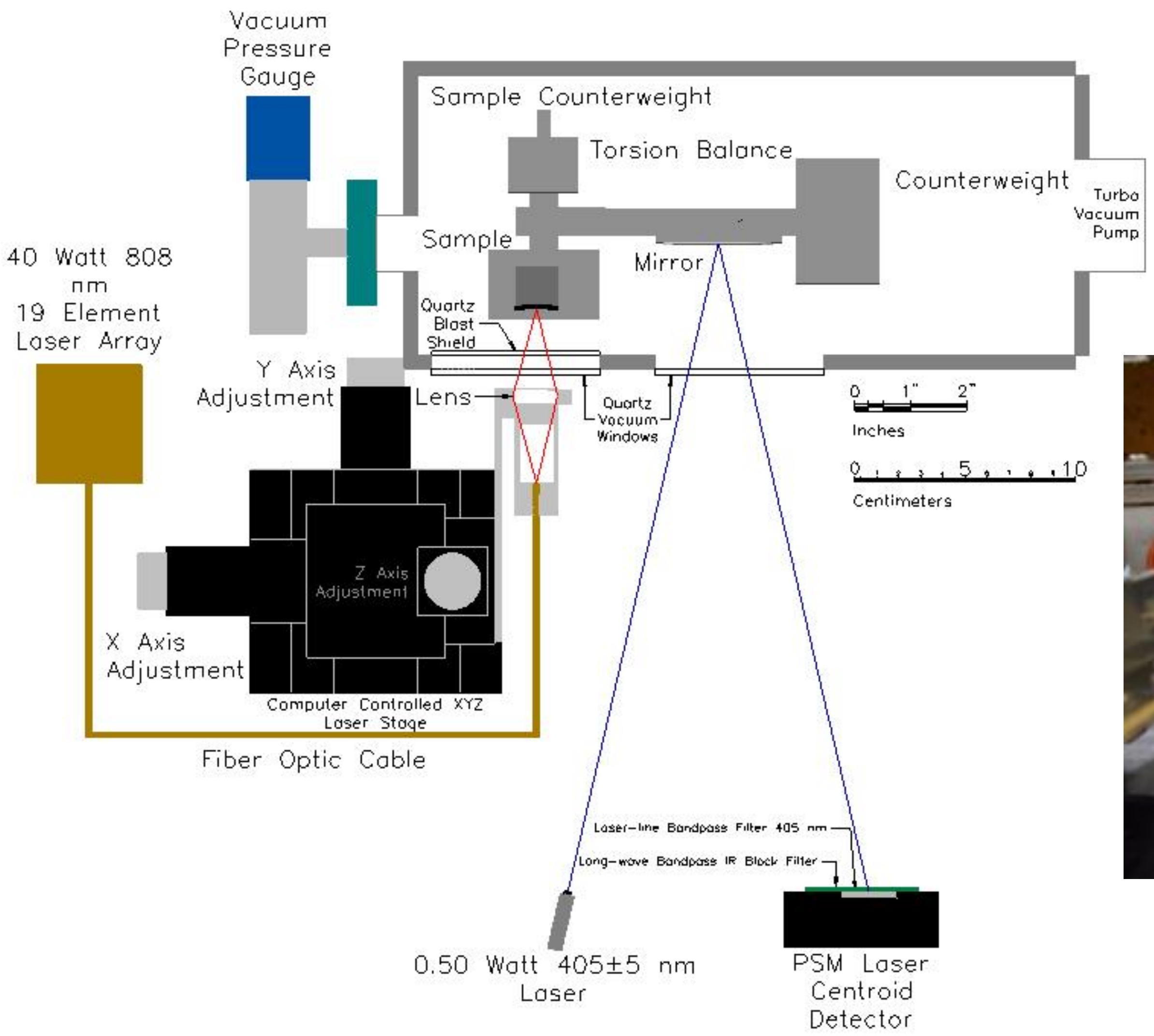
How Does DE-STAR Use Thrust?

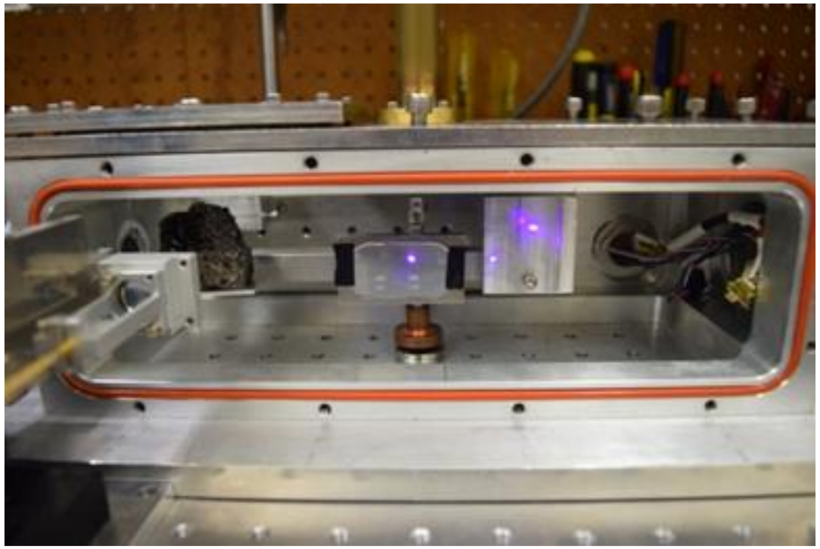
- Mass ejection via laser ablation
- 40 Watt Laser
- Asteroid type material: Basalt



Experimental Design

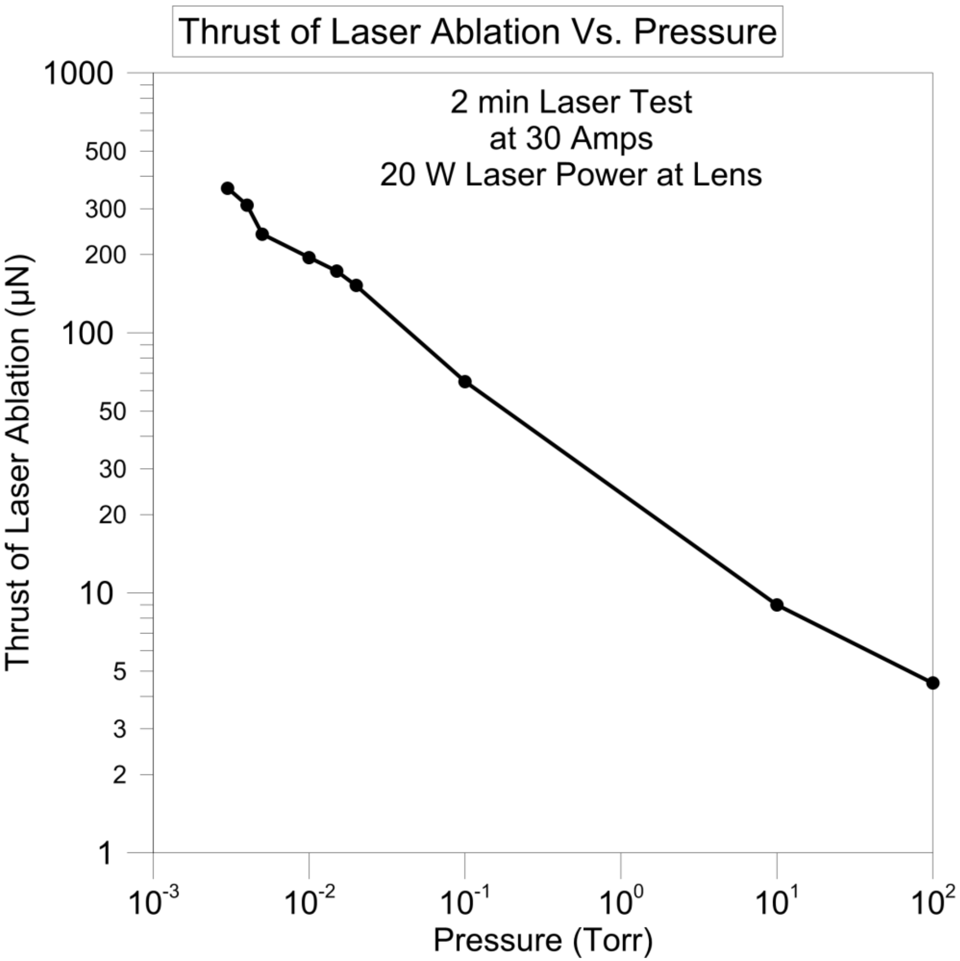
- Cad Drawing and real picture

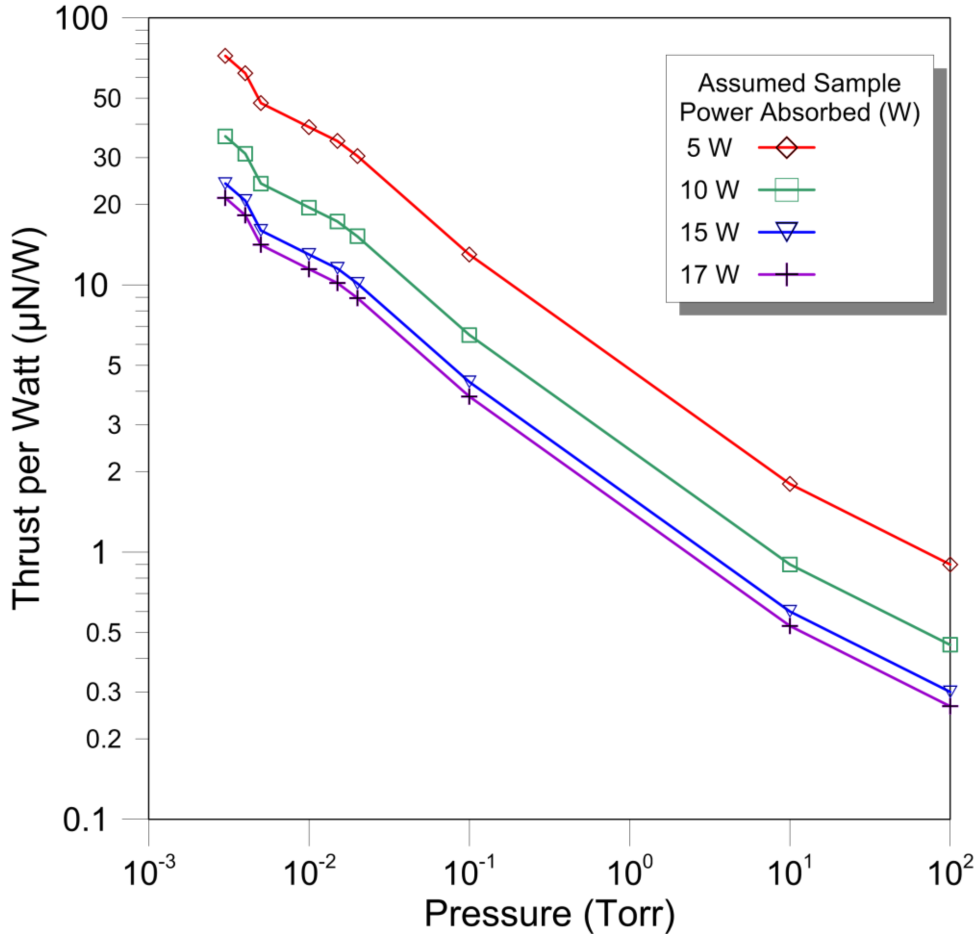




Thrust of Laser Ablation

- Thrust varying with pressure (left)
- Assumed power absorbed by the sample (right)
  - Further study to determine experimental power absorbed



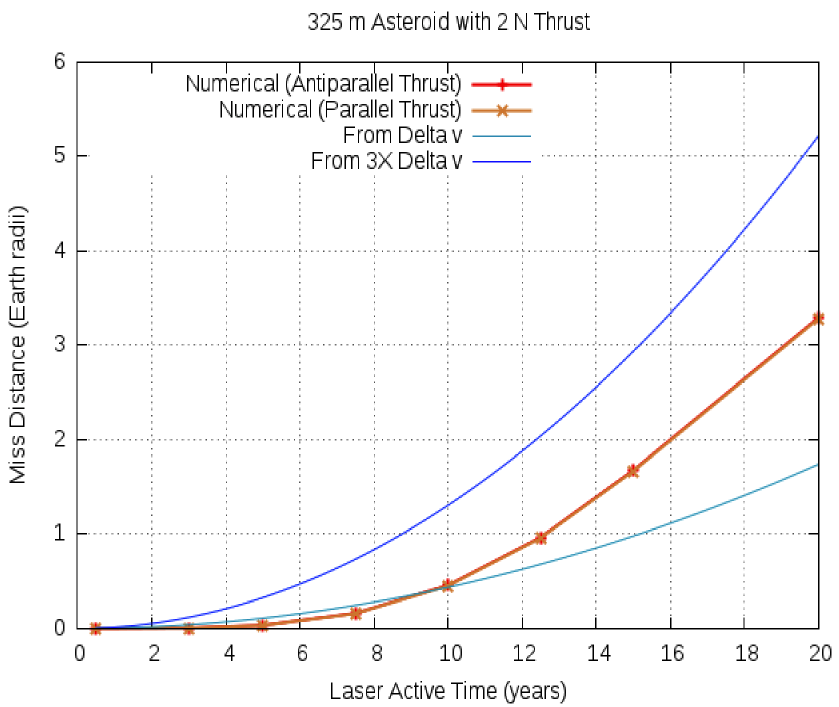


Space Simulation Chamber Mass Ejection Test Videos

Asteroids Are Coming!

- ~600,000 Asteroids and Coments
- Apophis (3.2Gton TNT) – 325m in Diameter
- Even small laser feasible for mitigation
- 30 kW Laser-16 yr-2R_E

"20 coin tosses all coming up Tails."



Conclusions

- **Planetary Defense is feasible with directed energy**
  - DE-STAR Complements Existing Planetary Defense Strategies
  - DE defense is extremely capable and scalable
  - Able to deflect virtually all known threats
  - Response time is key
- **Emerging Technologies make DE Defense Feasible and Desirable**
  - Laser Fiber Amplifiers: →1 kW/kg in near future
  - Phased Array Design for Beam Combining over Great Distances
  - Sufficient Flux is Generated for Surface Evaporation → Orbit Deflection
- **Optical Simulations are Promising**
  - Phase Control Required for Beam Formation is Achievable
- **Pre deployment of planetary defense asset is key to response**
  - No terrestrial defense system would be **built after** enemy launch
  - Could use for orbital debris removal as well
- **Long term program with long term consequences**
- ***Contact us if you are interested – www.deepspace.ucsb.edu***

www.deepspace.ucsb.edu/projects/directed-energy-planetary-defense

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Mechanical Design for Laser Array Directed Energy Systems, Oneill et al SPIE 2014IP

Directed Energy Active Illumination for near Earth Object Detection, Riley et al SPIE 2014

Discovery Channel – Man vs Universe - Fall 2014

"A Roadmap to Interstellar Flight" – Lubin 2015 – JBIS in progress

8 additional papers coming in 2015 SPIE, IAU etc

Acknowledgements

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