Directed Energy Deflection Laboratory Measurements

For DE-STARLITE Planetary Defense System

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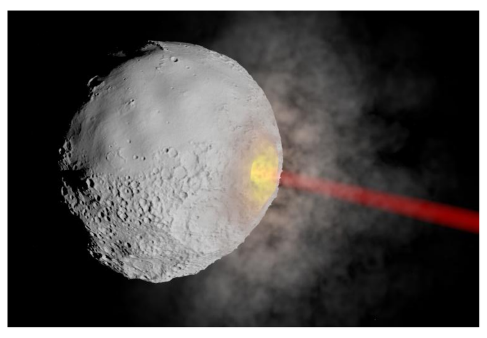
Abstract

We report on laboratory studies of the effectiveness of directed energy planetary defense as a part of the DE-STAR (**D**irected **E**nergy **S**ystem for **T**argeting of **A**steroids and explo**R**ation) program. DE-STAR [1] and DE-STARLITE [2] are directed energy "stand-off" and "stand-on" programs, respectively. These systems consist of a modular array of kilowatt-class lasers powered by photovoltaics, and are capable of heating a spot on the surface of an asteroid to the point of vaporization. Mass ejection, as a plume of evaporated material, creates a reactionary thrust capable of diverting the asteroid's orbit. In a series of papers, we have developed a theoretical basis and described numerical simulations for determining the thrust produced by material evaporating from the surface of an asteroid. [1][2][3][4] In the DE-STAR concept, the asteroid itself is used as the deflection "propellant". We constructed a vacuum chamber to simulate space conditions, and installed a custom torsion balance that holds an "asteroid" sample. The sample is illuminated with a fiber array laser with flux levels up to 60 MW/m^2 which allows us to simulate a mission level flux but on a small scale. We use a separate laser to readout the angular motion and can thus determine the thrust. We compare the measured thrust to the models. Our theoretical models indicate a coupling coefficient well in excess of 100 $\mu N/W_{optical}$, though we assume a more conservative value of 80 $\mu N/W_{optical}$ and then degrade this with a optical "encircled energy" efficiency of 0.75 to 60 $\mu N/W_{optical}$ in our deflection modeling. Ours measurements discussed here yield about 45 $\mu N/W_{absorbed}$ as a reasonable lower limit.

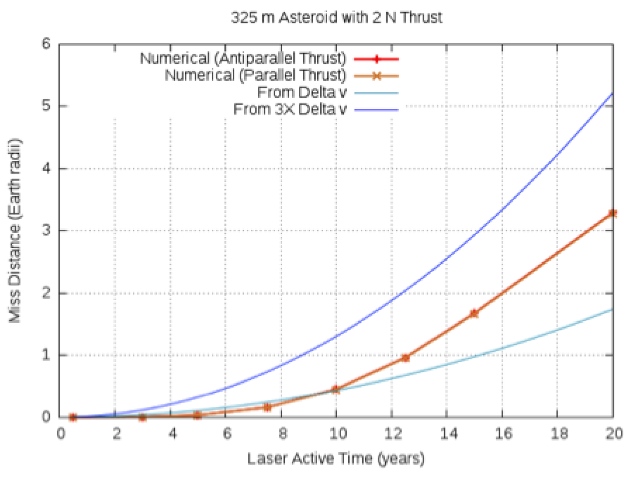
Research Background

The DE-STAR concept is envisioned as an orbiting system consisting of a modular array of phase-locked lasers powered by photovoltaics.

The multi-purpose system is capable of planetary defense against asteroids that are projected to collide with the Earth.

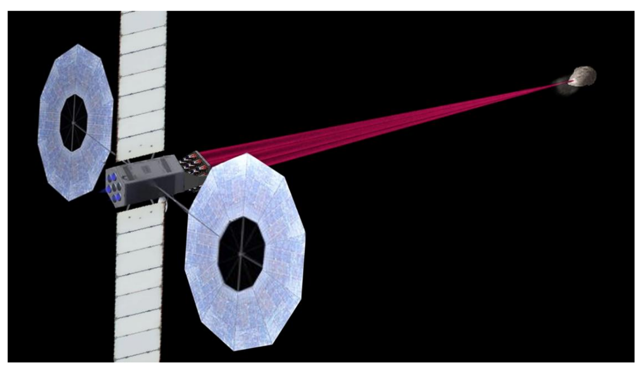


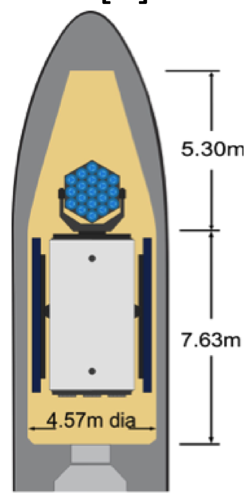
The laser produces a spot on the target that heats the surface at the spot to a temperature great enough to vaporize all known constituent materials. The vaporization consequently creates a reactionary force that diverts the asteroid.



Miss distance vs. laser on time for orbital simulation at 60 $\mu N/W$ absorbed including beam efficiency.

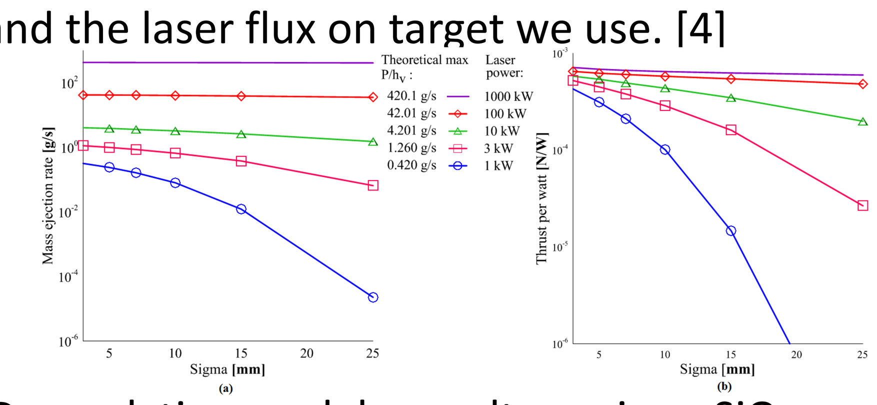
DE-STARLITE is near term feasible and fundable mission. It is a smaller, stand-on version of the larger mission. DE-STARLITE is designed to be sent to the target on an SLS class launcher. [2]





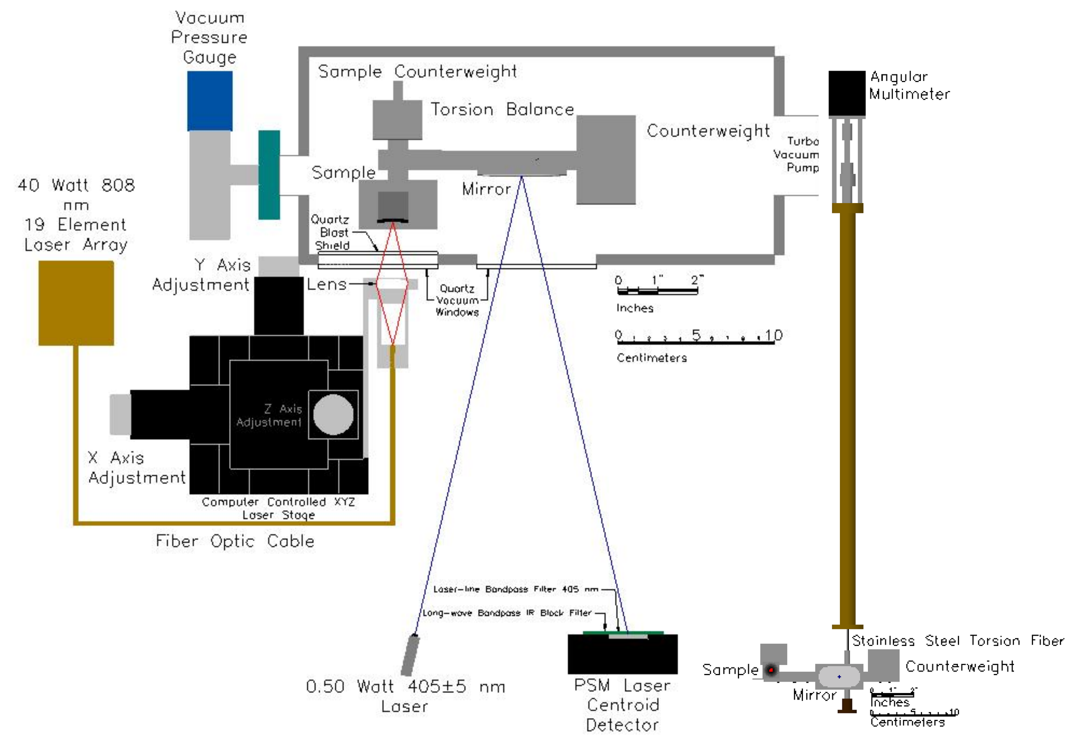
2D Analytic Modeling

Using DE-STARLITE we assume more conservative numbers for system performance, typically 80 $\mu N/W_{optical}$ though our calculations show the coupling to be between 100 and 500 $\mu N/w_{optical}$ depending on the asteroid material composition and the laser flux on target we use. [4]



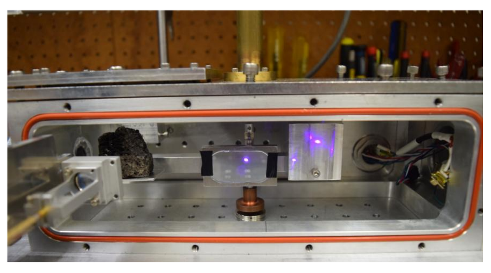
2D analytic model results using SiO_2 as the equivalent material. **(a)** Integrated mass ejection rates vs. sigma case for different powers between 1 kW and 1 MW. **(b)** Similarly, integrated thrust (N) per watt vs. sigma

Experimental Setup



In order to measure thrust we use a custom torsion balance in the vacuum chamber.

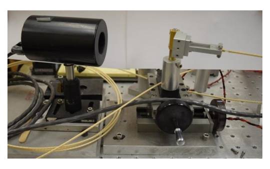
- Stainless steel torsion fiber
- Eddy current dampening
- Adjustable counter weights

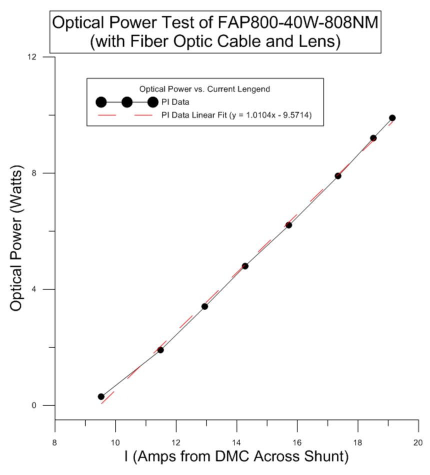


When a thrust is applied to the end of the torsion balance the measurement laser moves along the detector and outputs a voltage proportional to the displacement.

19 element laser array with max power of 40 Watts, operating at 808nm. The beam passes through an outer quartz vacuum window, through an inner quartz blast shield, and strikes the sample, ablating it.

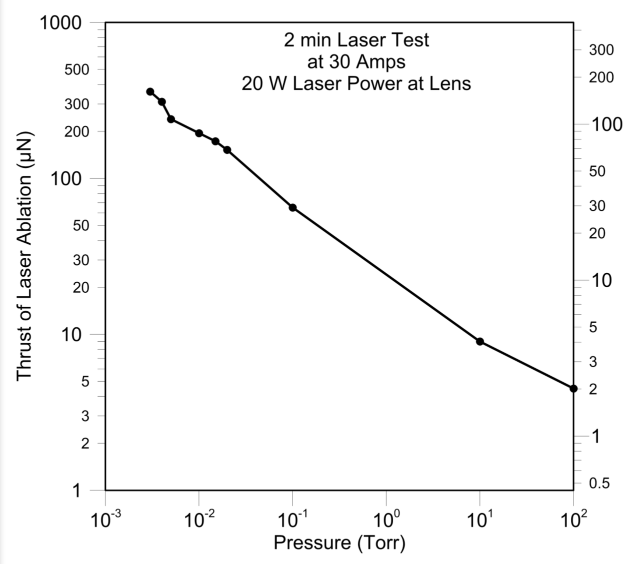
Our laser has a slope efficiency of 1 watt/amp and current threshold is 10 amps. This gives us about 20 watts of optical power at the lens at 30 amps.



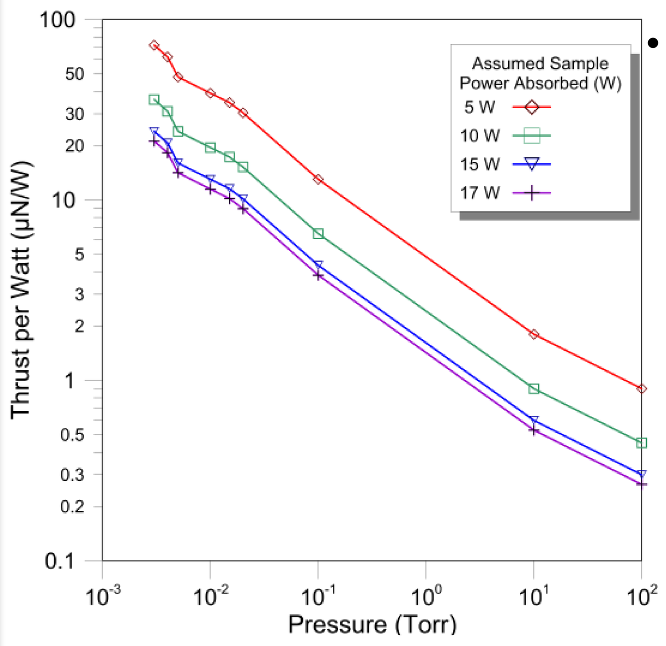


The sample used in the experiment is basalt due to its similar composition to known asteroid material.

Results



- We measured a **thrust of 360 µN** for our lowest pressure to date (1mT).
- 20W of laser power outside the chamber and 17W inside the chamber. We estimate getting about **50%** of this in the critical central spot.

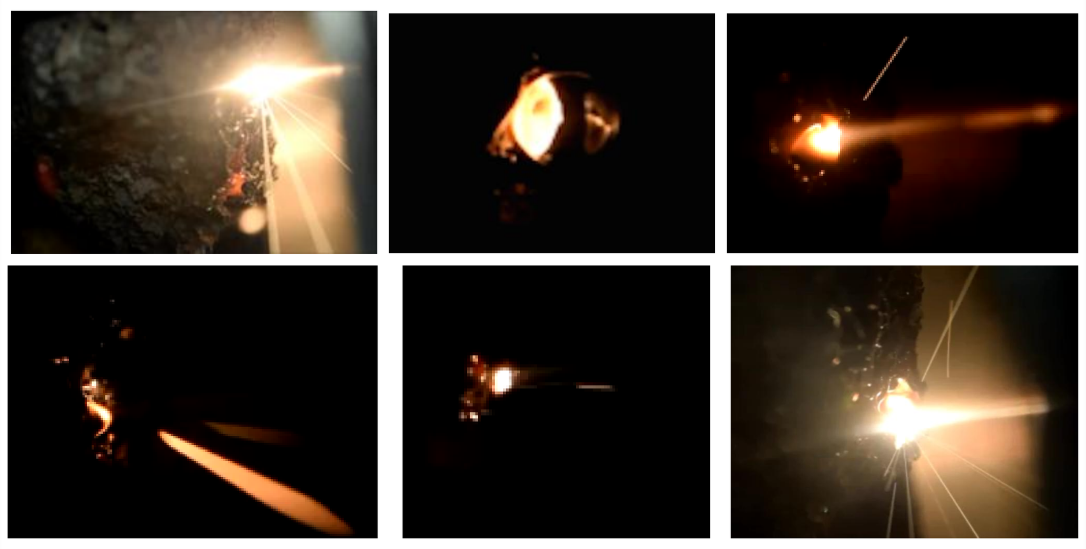


- Approximately **8 watts** absorbed by the sample.
- We then calculate a thrust per watt of **~45 $\mu N/Watt_{absorbed}$.**
- Compared **to 60 $\mu N/W_{optical}$** with optical "encircled energy" efficiency of 0.75. [4]

Our measurements of thrust become a **lower limit** to what will be encountered in a real target. Thus our measurements are **extremely conservative compared to what can be achieved in an optimized system.**

Ablation Photos and Video

Below are a variety of images taken while ablating at low pressure. Pictures show the environment at the surface of the basalt target while ablating. There is bubbling, mass ejecta, sparks, and plume clouds:



Video containing multiple clips of laser ablation is here:
http://www.deepspace.ucsb.edu/projects/directed-energy-planetary-defense

Optical Power Degradation

1. Blast debris quickly builds up on the inner quartz shield. We get a **40% - 70% loss from this effect**.

1. Laser has to pass through two uncoated quartz which results in a 15% overall loss **assuming no blast debris on the inner quartz blast shield window.**
2. As the surface is ablated the actual target location moves into the sample. However, our laser is not focused on this new location leading to loss of flux delivered to the sample.

Conclusion and Future Works

We have shown that directed energy mitigation of asteroids is a feasible method of deflecting threats and that laboratory measurements of this approach is reasonably consistent with our analytic and numerical simulations. Much more work is needed to explore optimizing the system performance. In the future we will increase the chamber size, increase the laser power, optimize the optics to increase the flux and further automate the system. We will also have a real time servo controlled focusing system to optimize the thrust. There are numerous system diagnostics that need to be implemented including ejecta and beam profiling.

Acknowledgments and References

We gratefully acknowledge funding from the NASA California Space Grant NASA NNX10AT93H in support of this research.

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