Optimizing the Orbital Trajectory of Laser-Propelled Spacecraft for All Launching Times

UC SANTA BARBARA SUMMER SESSIONS Research Mentorship Program

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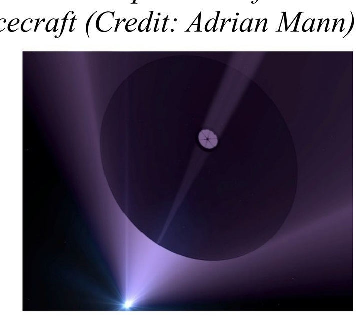
Abstract

In the DE-STAR lab, we propose to **use phased-laser array with photon propellant** in order to achieve higher speed for the spacecraft. During the simulation, the laser is sometimes turned off to avoid cancellation of force. Yet, if we shut off the laser accurately, the duration rises and drops sharply even when the launch time is altered slightly, which makes the real implementation difficult. We optimize the algorithm, modifying the craft's orbit to maximize the propelling force. We also attempt to stabilize the chaotic results and minimize the time of transit for the craft to reach a target in space.

DE-STAR Lab

Context

- DE-STAR: **D**irected **E**nergy **S**olar **T**argeting **A**steroid and explo**R**ation



Artistic Expression of Sail on Spacecraft (Credit: Adrian Mann)

Computer simulation results for DE-STAR 4 — one with 10km square array and 70GW power[1]:

Craft Mass (kg)	1	10	10^2	10^3	10^4
Days to 1 AU	0.3	1	3	10	30
Speed Compare to c	4%	1.2%	0.4%	0.15%	0.05%

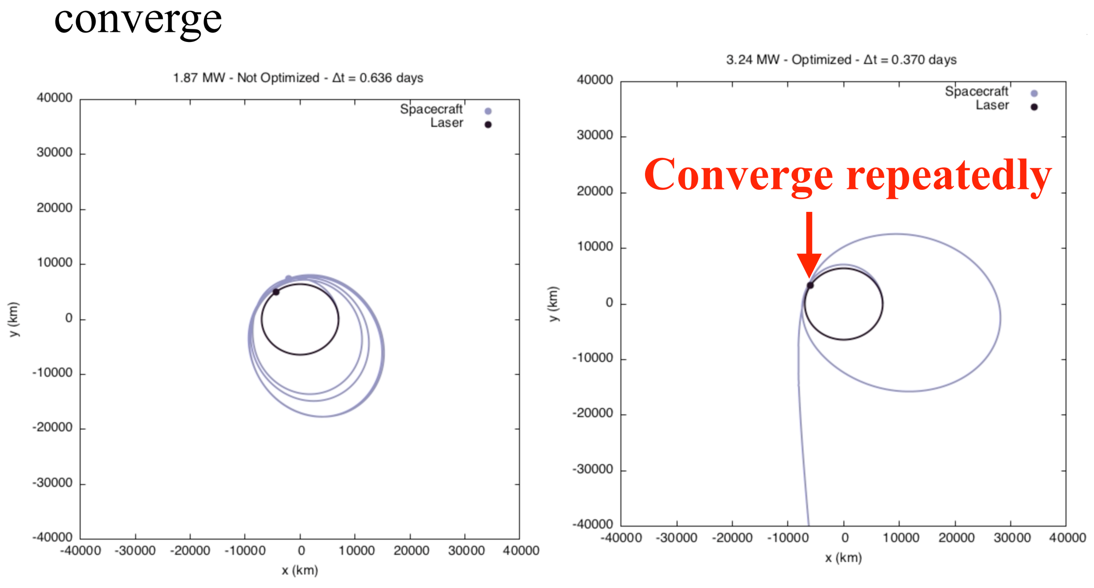
Data on the Voyager 1, the farthest we have gone in space[2]: **c = speed of light*

Launch Time	Out of Solar System	Speed	Compare to c
1977	2012	17km/s	0.006%

- Laser provides a **higher speed** than conventional fuel for space travel

Goal

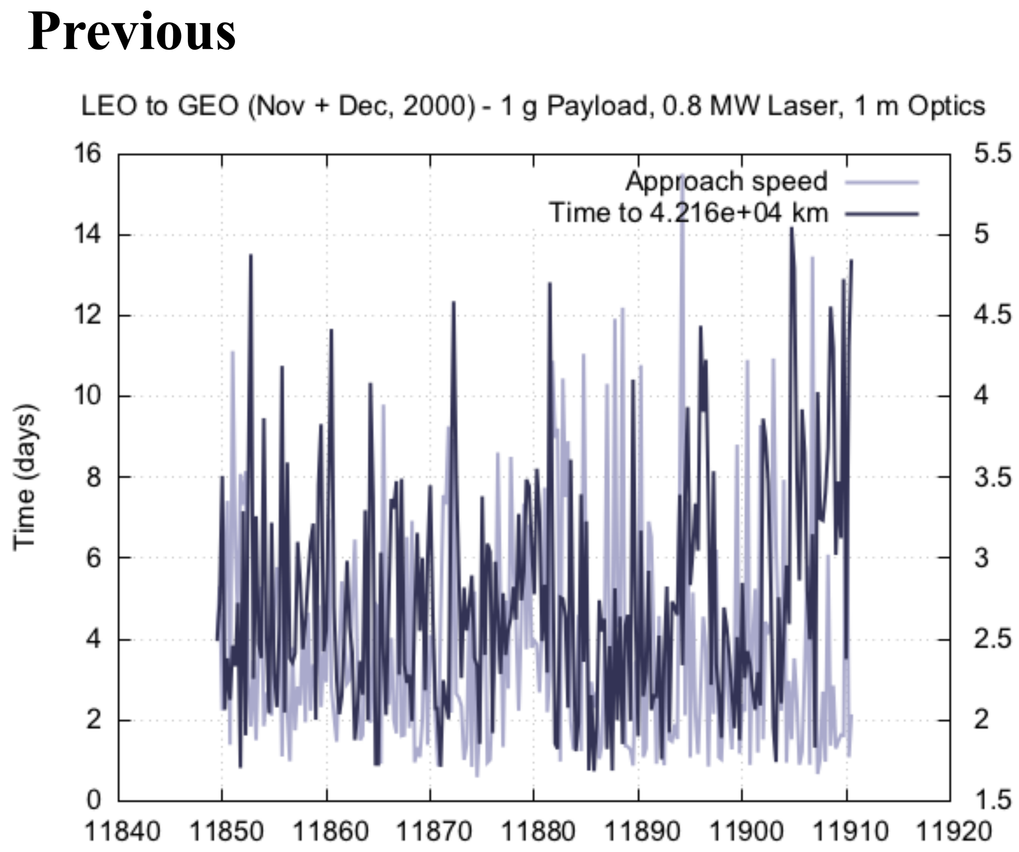
- To make the craft and laser **converge repeatedly** at craft perigee
- Maximum propelling force can be given when converge



Not converged *Converged*

- **Converge: the craft and the laser arrive at the point where they are closest to each other**

Previous



Results given by previous algorithm. Time of transit and speed with respect to the change of launching time is overly sensitive that makes real-time implementation difficult.

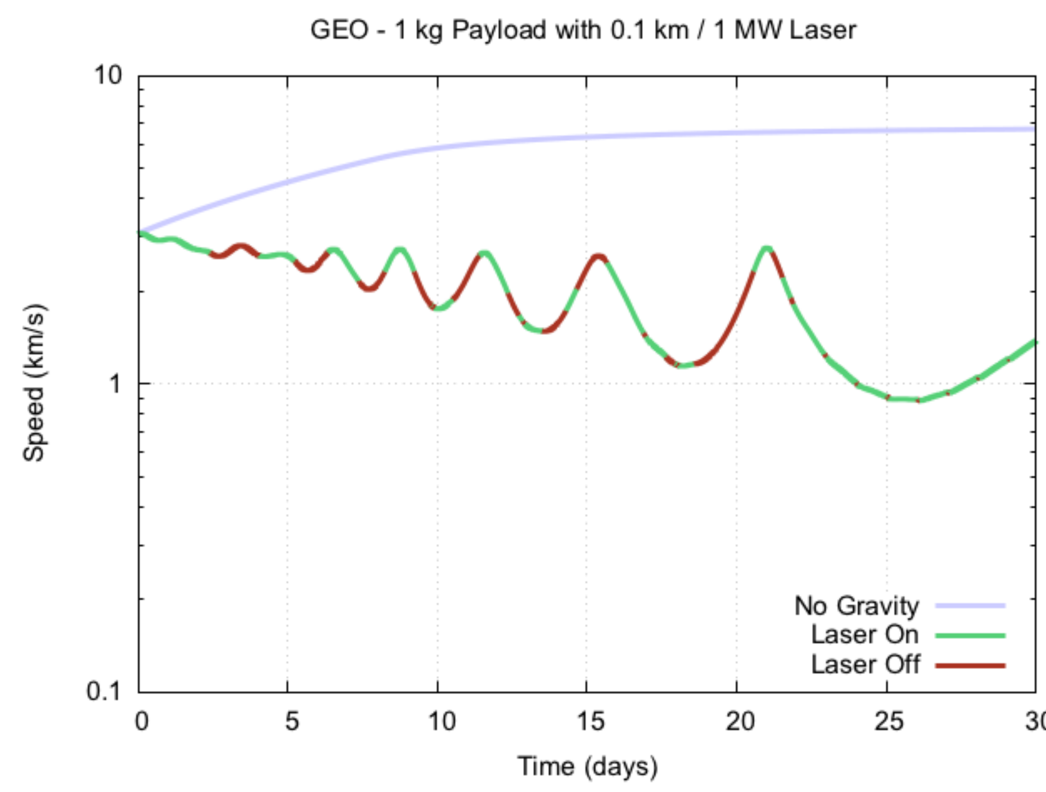
- Duration and approach speed sensitive to launch time
- Real implementation difficult
- **No perceivable trend**

Significance

- Use laser to improve speed in space travel
- **Make the system more efficient**

Algorithm

- Previously: laser off when have negative effect
- Now: **turn it off earlier so craft speed can be changed according to our needs**
- **O**ur needs: want convergence to happen repeatedly



Red rising part = laser turned off because it is in front of the craft, thus directing energy against the craft direction (negative effects)

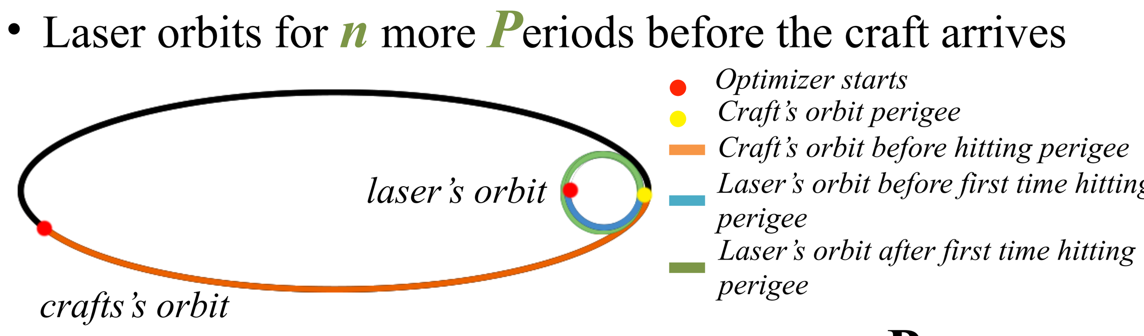
The Optimizer

Equation (1): $\Delta T_{craft} = nP + \Delta T_{laser}$

Left side: Time needed for craft to arrive at its perigee

Right side: Time needed for laser to arrive at craft's orbit perigee

- The craft orbit is longer than the laser
- Laser takes time ***Delta T*** to reach craft's orbit perigee while craft is still far away
- Laser orbits for n more **P**eriods before the craft arrives



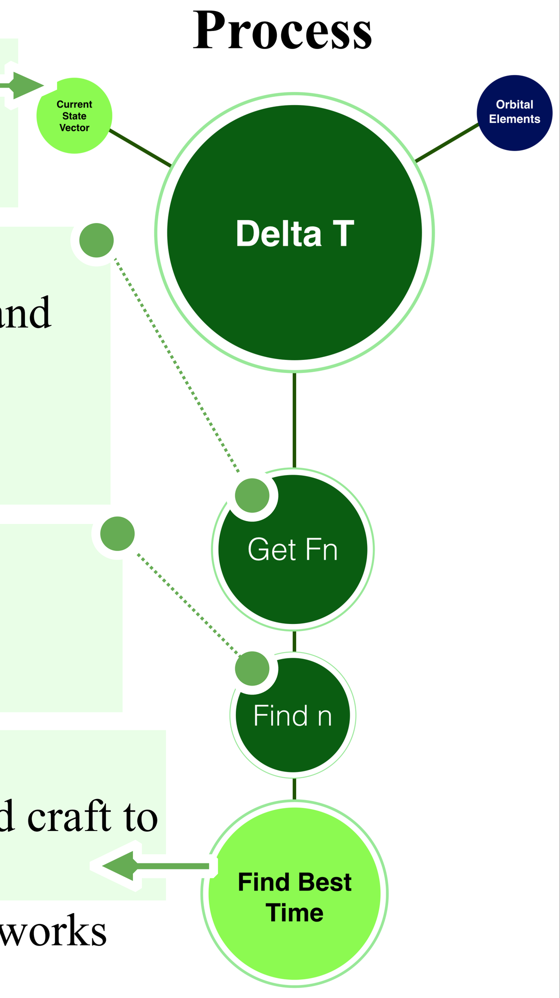
Process

Input:
- Current position and velocity of the laser and the craft

Fn:
- Time difference between laser's and craft's arrival at craft's perigee = Equation(1) left side - Equation(1)right side

n:
- n is the one from **Equation (1)**
- Test a list of n to find best

Output:
- Best time that allows the laser and craft to converge

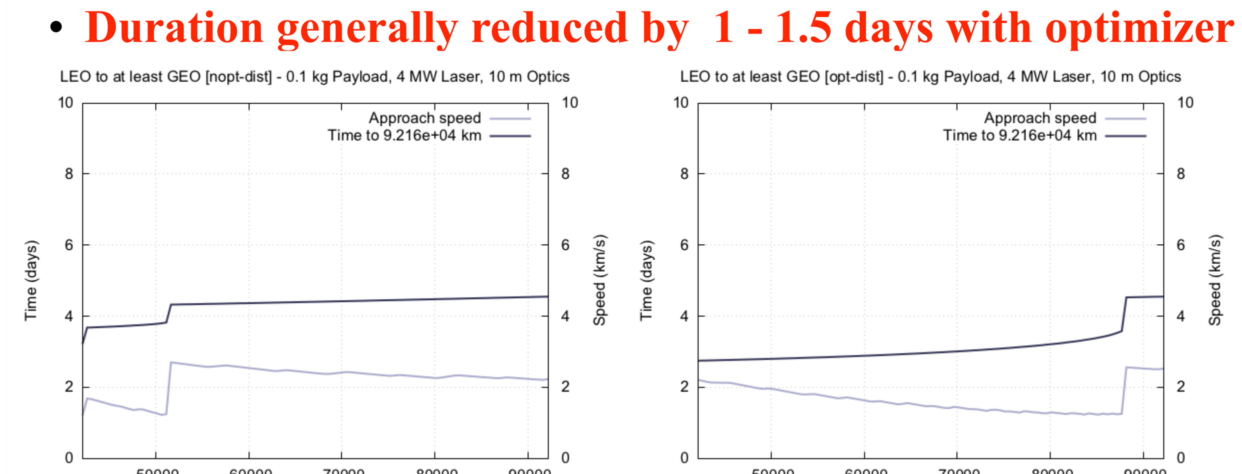


Other inputs that help the optimizer works better:

minimum eccentricity	maximum eccentricity	threshold	jump	shift	cost

Orbital Simulations

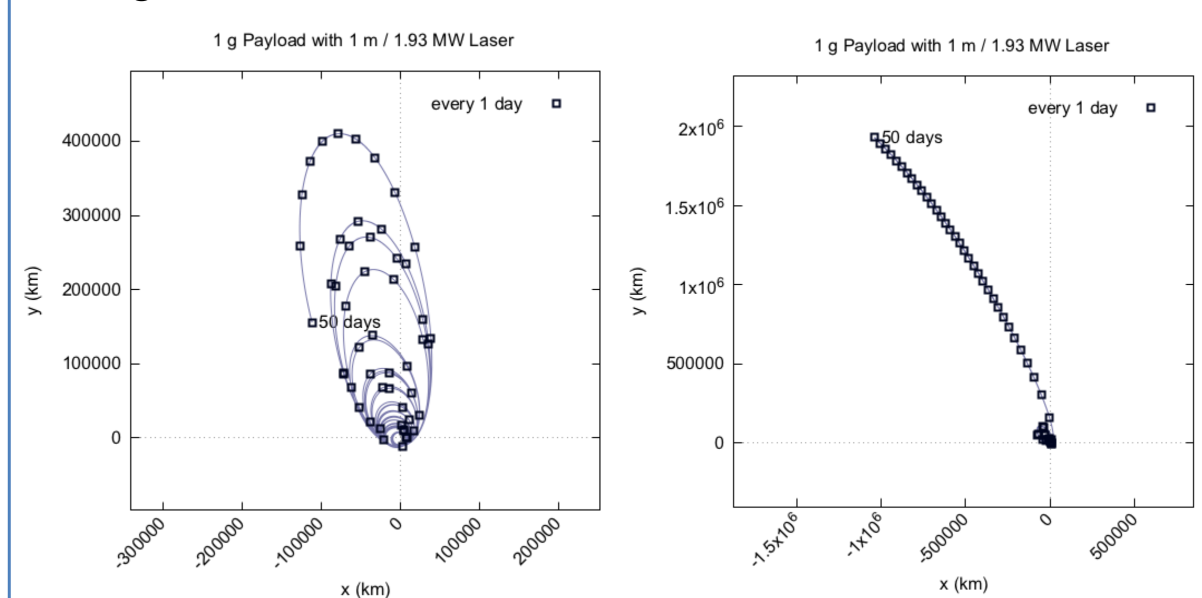
EX. 1
- 0.1kg craft, 4MW laser with 10m diameter
- Increasing target distance
- **Duration generally reduced by 1 - 1.5 days with optimizer**



Duration and Approaching speed of the spacecraft. Left: without optimizer. Right: with optimizer.

Orbital Simulations

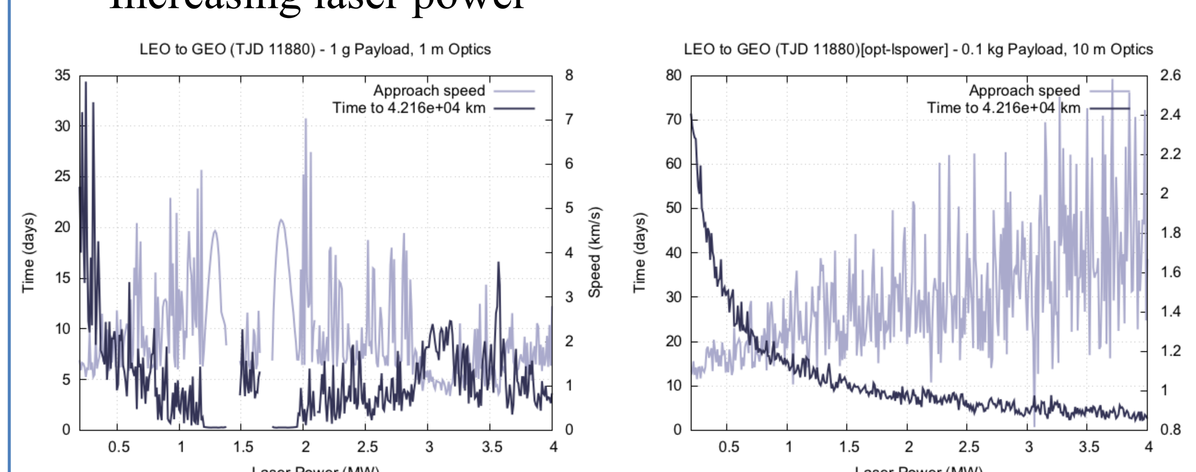
- **EX. 2**
- Arbitrarily picked initial values
- 1g craft, 1.93MW laser with 1m diameter



Simulation for orbital trajectories with duration of 50 days. Left: unoptimized. Right: optimized.

- Significant improvements emerge
- In 50 days, craft with optimizer goes roughly 20 times further

- **EX. 3**
- Arbitrarily picked initial values
- 1g craft, laser with 1m diameter, distance LEO to GEO
- Increasing laser power

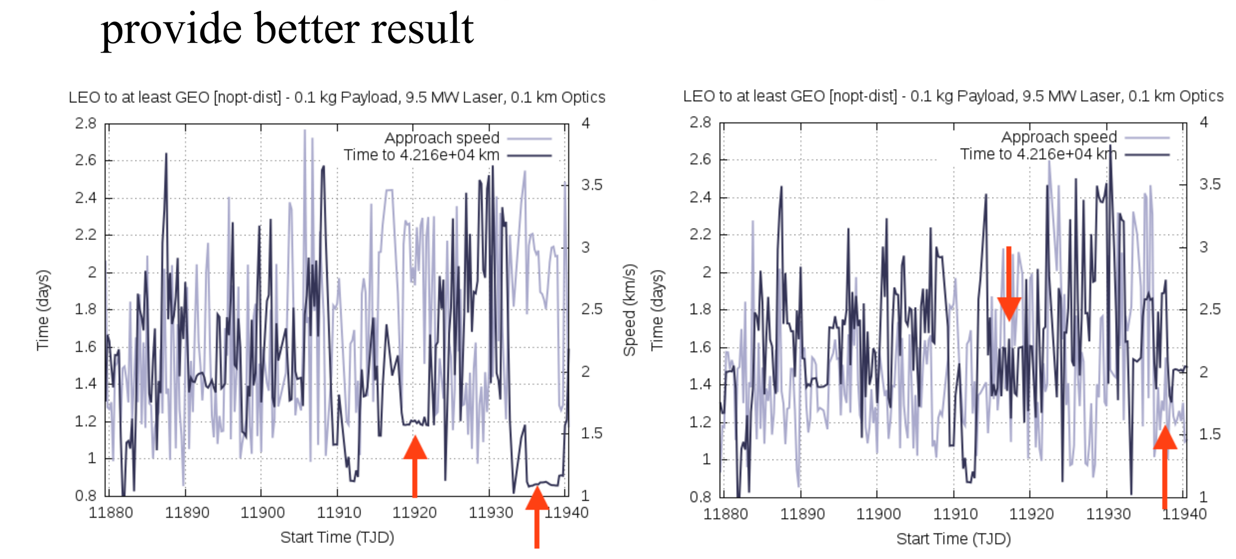


Effects of increasing laser power on duration and approaching speed. (Left: Non optimized. Right: Optimized)

- The resulting trend is stabilized with optimizer
- **New graph shows distinct trend**

Discussion

- confident level not high enough that the optimizer will provide better result



Effects of various starting time on duration and approaching speed. (Left: Non optimized. Right: Optimized)

- Red arrows: where optimizer creates more chaos and increases duration
- Possible reason of ineffectiveness: use optimizer too many times (**too many adjustments backfires**)
- In some cases, not using optimizer is actually better

Future developments:

- To perfect our system further, possibly will consider more situations with the optimizer
- **Add more inputs** to make the optimizer work better
- Determine level of confidence that the optimizer will improve results
- **Find out how much more efficient is the system with optimizer** by statistical analysis

References

[1] Lubin, P. M., et al., "Directed Energy for Relativistic Propulsion and Interstellar Communication," Physics Dept., UC Santa Barbara, Santa Barbara, CA, 2014.
[2] UCSB Experimental Cosmology Group. *A Roadmap to Interstellar Flight.* [Online]. Available: http://www.deepspace.ucsb.edu/projects/directed-energy-interstellar-precursors

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