Propellantless Spacecraft Formation-Flying and Maneuvering with Photonic Laser Thrusters

An artist’s rendition of N/S stationkeeping of a satellite in GEO with Photonic Laser Thruster.

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Mastering photon propulsion is envisioned to be the key to overcoming the limit of the current in-space propulsion technology based on conventional rocketry and potentially opening a new space era.

Systematic advancement of photon propulsion starting from near-earth endeavors towards interplanetary and interstellar endeavors with the use of the photon thrust amplification technology.
Photon thrust can be amplified and beamed via recirculating photons between space platforms with the use of high power laser and optics technologies.
Phase I and ½ II Objectives

Feasibility Demonstration of Photonic Laser Thrusters (PLT) with tethers for propellantless formation flight

Main Results

PLT laboratory demonstration of photon recirculation feasibility and 35 µN thrust.

Discovery: PLT is much more stable against mirror motions.  --

Usage for dynamic platforms in addition to static platforms?
Further Developments

Theoretical investigations of the use of PLT for:

- Tether-free formation flying and maneuvering
- Propellantless rendezvous/docking
- In-space main-propulsion
  - Interstellar flight?

High power lasers ideal for PLT have been rapidly developed:

--- Thin Disk Laser
- Extremely thin gain media enhances high photon recirculation
- Excellent in thermal management
(Unintentional) PLT Scaling Up Demonstration in 2010

6.5 kW Thin Ceramic Disk Laser Demonstration by William P. Latham (b), Ahmed Lobad (a), Tim C. Newell (b), and Don Stalnaker (a) at (a) Boeing LTS and (b) AFRL Kirtland

650 kW Intracavity Power
Thrust: 4.3 mN
Phase II Objectives

- Feasibility Assessment of the use of Photonic Laser Thrusters (PLT) for static and dynamic platforms

- Scaling-up Demonstration of PLT
  - Thrust/Power
  - Distance
  - Thermal Management Capability

- Development of strategy and design of PLT flight-demonstration in 3-5 years after the completion of the present Phase II
Photonic Laser Thruster
Innovative Spacecraft Maneuvering

- Formation Flying
- Precision Propellantless Orbit Changing & Rendezvous/Docking
- Propellantless Orbit-Drag Compensation
- Propellantless Stationkeeping
Precision Formation Flying For Large Sparse Aperture Telescopes and Radars

**Force Balance:**

\[ \delta F_u \sim - m \frac{\mu}{r_c^3} L \]

- \( \mu \) = the mass of the target spacecraft
- \( r_c \) = the orbit radius of the chief
- \( m \) = Earth’s gravitational constant
- \( L \) = Radius of the Aperture
Maximum PLT thrust required for maintaining persistent apertures with various diameters

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Aperture Diameter</th>
<th>Satellite Weight Mission</th>
<th>Maximum Required PLT Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>1,000 km</td>
<td>100 m</td>
<td>~ 0.5 mN</td>
</tr>
<tr>
<td>LEO</td>
<td>1,000 km</td>
<td>1.0 km</td>
<td>~ 5 mN</td>
</tr>
<tr>
<td>GEO</td>
<td>37,000 km</td>
<td>100 m</td>
<td>~ 0.25 mN</td>
</tr>
<tr>
<td>GEO</td>
<td>37,000 km</td>
<td>1.0 km</td>
<td>~ 2.5 mN</td>
</tr>
<tr>
<td>GEO</td>
<td>37,000 km</td>
<td>10 km</td>
<td>~ 25 mN</td>
</tr>
</tbody>
</table>
N/S Stationkeeping with PLT in GEO

This work was provided by Dr. Mason Peck.
Phase II Progress since Oct. 2013
<table>
<thead>
<tr>
<th>Gain Medium Architecture</th>
<th>Source</th>
<th>Extracted Power (kW)</th>
<th>Max Circulation Enhancement</th>
<th>Needed Power (kW) for 1.6 mN Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Disk</td>
<td>D+G</td>
<td>1.0</td>
<td>244</td>
<td>1.0</td>
</tr>
<tr>
<td>Rod</td>
<td>CEO/NG</td>
<td>0.6</td>
<td>16</td>
<td>15.2</td>
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<tr>
<td>Zig-Zag Slab</td>
<td>NG</td>
<td>4.0</td>
<td>21</td>
<td>11.6</td>
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<tr>
<td>Thin-Zag slab</td>
<td>Textron</td>
<td>1.2</td>
<td>17</td>
<td>14.5</td>
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<tr>
<td>Thick Disk (Heat capacity)</td>
<td>LLNL</td>
<td>5.0</td>
<td>95</td>
<td>2.6</td>
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<tr>
<td>Thick Disk (He cooled)</td>
<td>LLNL</td>
<td>1.2</td>
<td>65</td>
<td>3.8</td>
</tr>
<tr>
<td>Thick Disk (liquid back cooled)</td>
<td>China</td>
<td>1.2</td>
<td>105</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Thrust/Power Scaling-up Demonstration

Photonic Laser Thruster

- Intracavity Multiplication Factors
- Boeing 2013 (Estimated)
- AFRL 2010
- YK Bae 2006/NIAC

Graph showing thrust (mN) versus extractable power (kW) with scaling factors.
PLT Laboratory Demonstration Block Diagram

Resource Vehicle Platform

Power Supply

Fiber Coupled Laser Diodes

Thermal Management System I

Thin Disk Laser Module

Thermal Management System II

Mission Vehicle Platform

Output Coupler

Optical Fiber

Trapped Photons
1 kW Class Photonic Laser Thruster Demo Construction
(With the help of Dr. Injeyan, a high power laser expert.)

Fiber Coupled Diode Laser

1 kW Thin Disk Laser Module

Y.K. Bae Corp PLT Lab
• PLT resonators can be multimode; the wavefront corrector ensures that the gain module aberrations do not destabilize the long resonator.

• Adaptive optics is used for the wavefront correction, its use in high power laser beam delivery has been successfully demonstrated over hundreds of km.
Upcoming Tasks

• Space-qualifiable PLT development: Minimize the size and weight.

• PLT efficiency improvement -- Maximize recirculating power – Intracavity loss mitigation

• Thermal management innovation – Liquid metal:
  • Letter of Interest from Northrop Grumman

• PLT spacecraft maneuvering orbit dynamics

• Concept development and design of PLT flight-demonstration

• Methods to overcome the diffraction limit:
  • Need more fundamental physics on photons: Bose-Einstein condensation of photons?