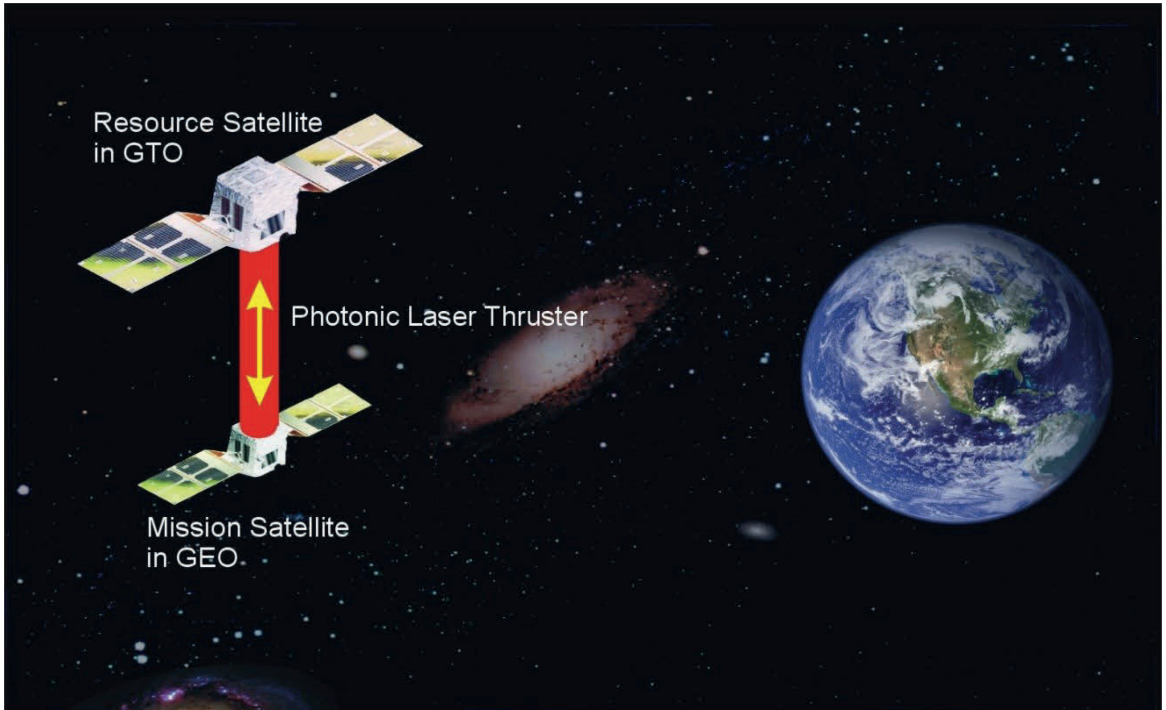
Propellantless Spacecraft Formation-Flying and Maneuvering with Photonic Laser Thrusters



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

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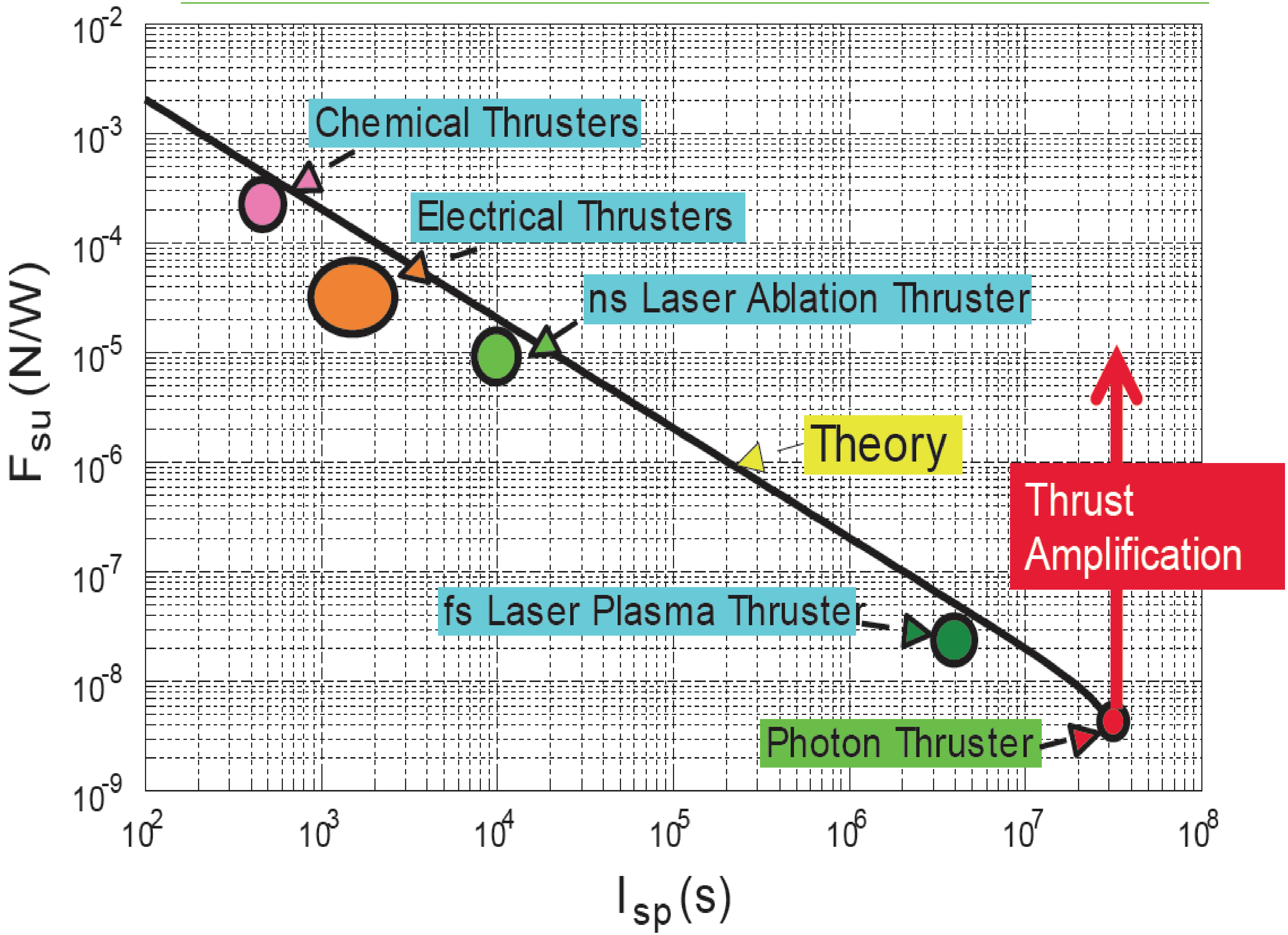
High Power Laser Expert

The Vision

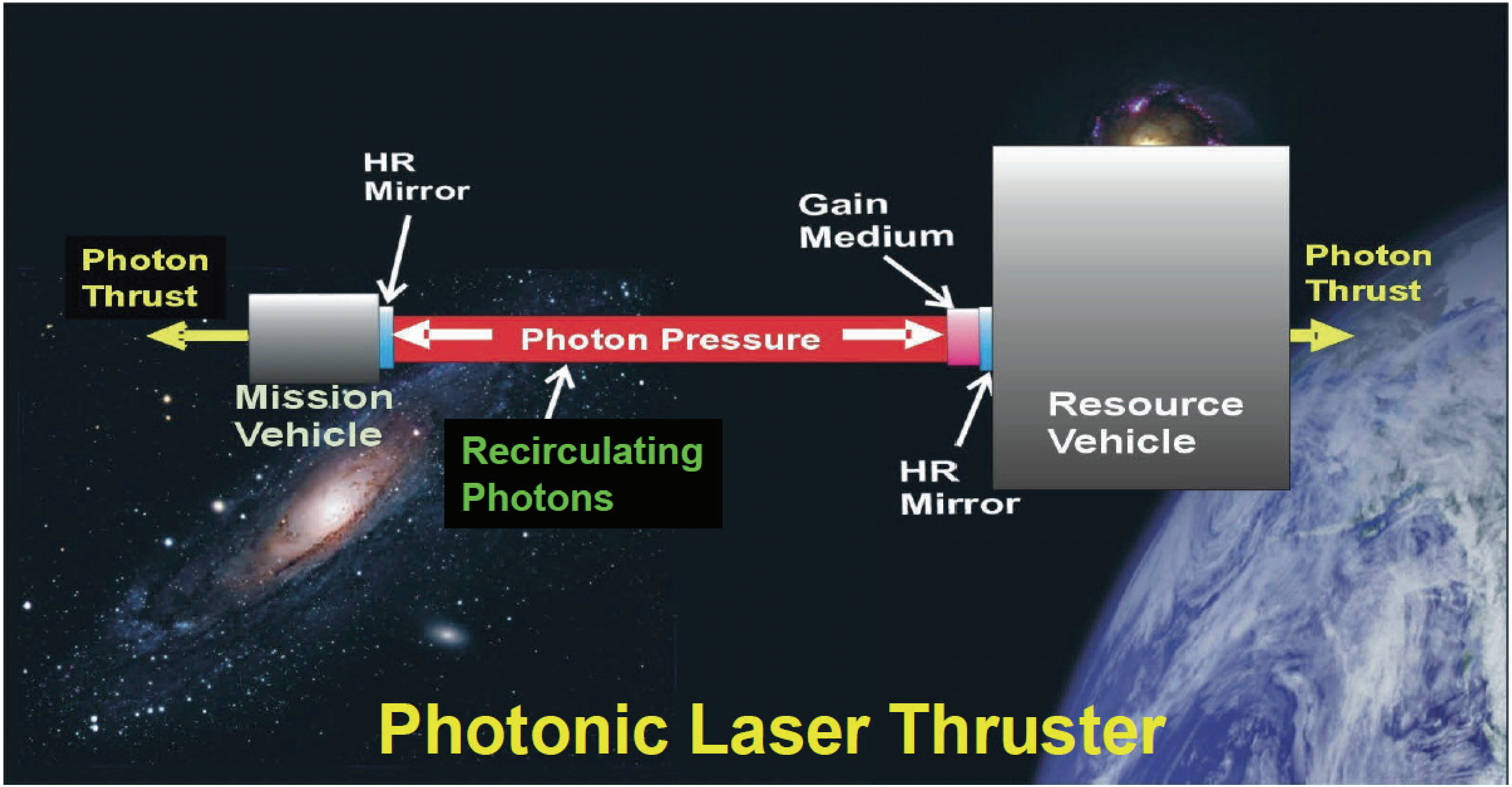
Mastering photon propulsion is envision to be the key to overcoming the limit of the current in-space propulsion technology based on conventional rocketry and potentially opening a new space era.

The Goal

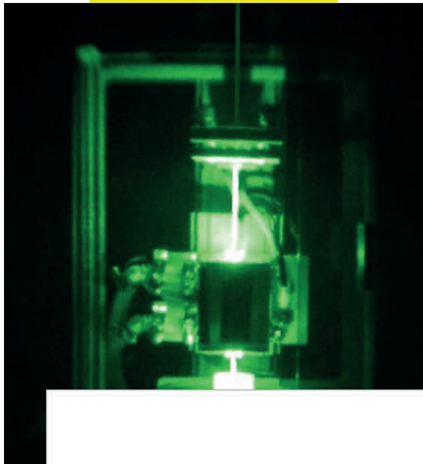
Systematic advancement of photon propulsion starting from near-earth endeavors towards interplanetary and interstellar endeavors with the use of the photon thrust amplification technology.


Chemical Thrusters
Electrical Thrusters
ns Laser Ablation Thruster
Theory
Thrust Amplification
fs Laser Plasma Thruster
Photon Thruster
F_{su} (N/W)
I_{sp} (s)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}

Photon thrust can be amplified and beamed via recirculating photons between space platforms with the use of high power laser and optics technologies.

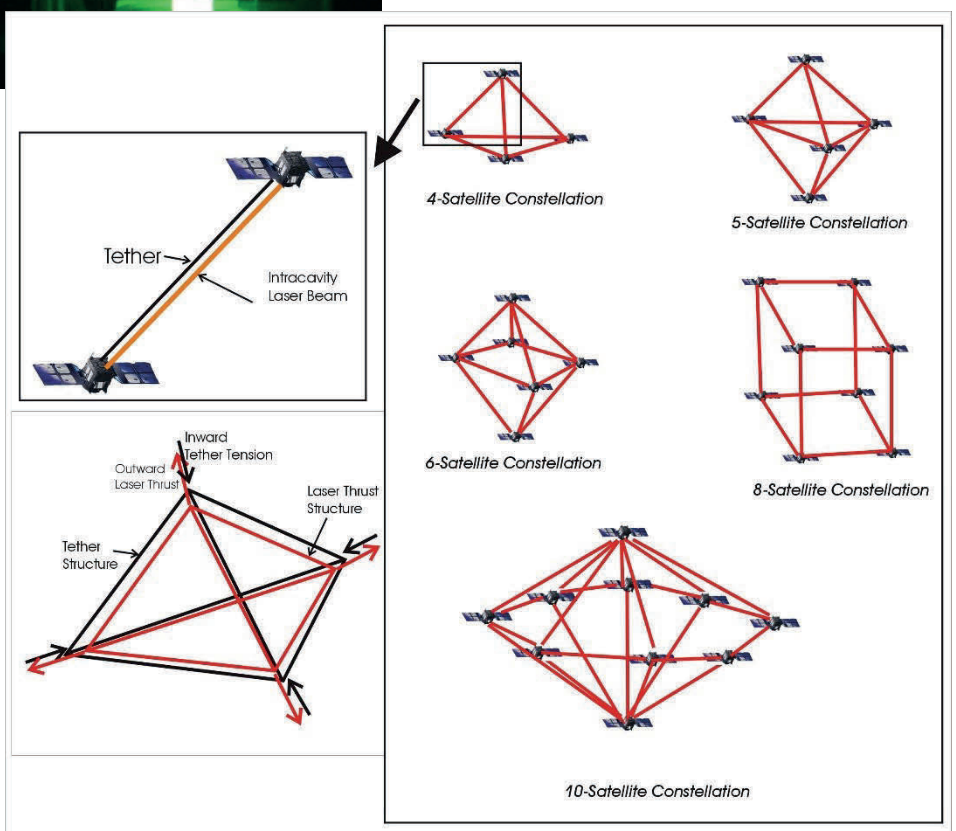


PLT Demo



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:

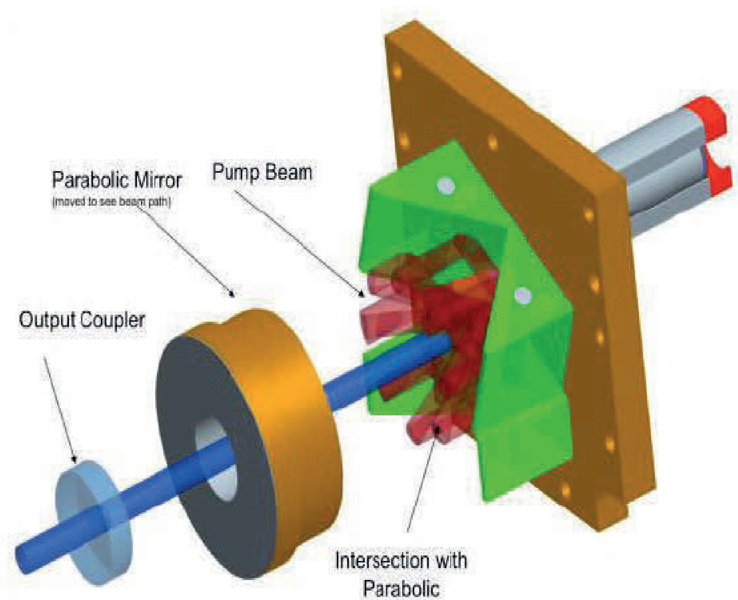
--- Thin Disk Laser

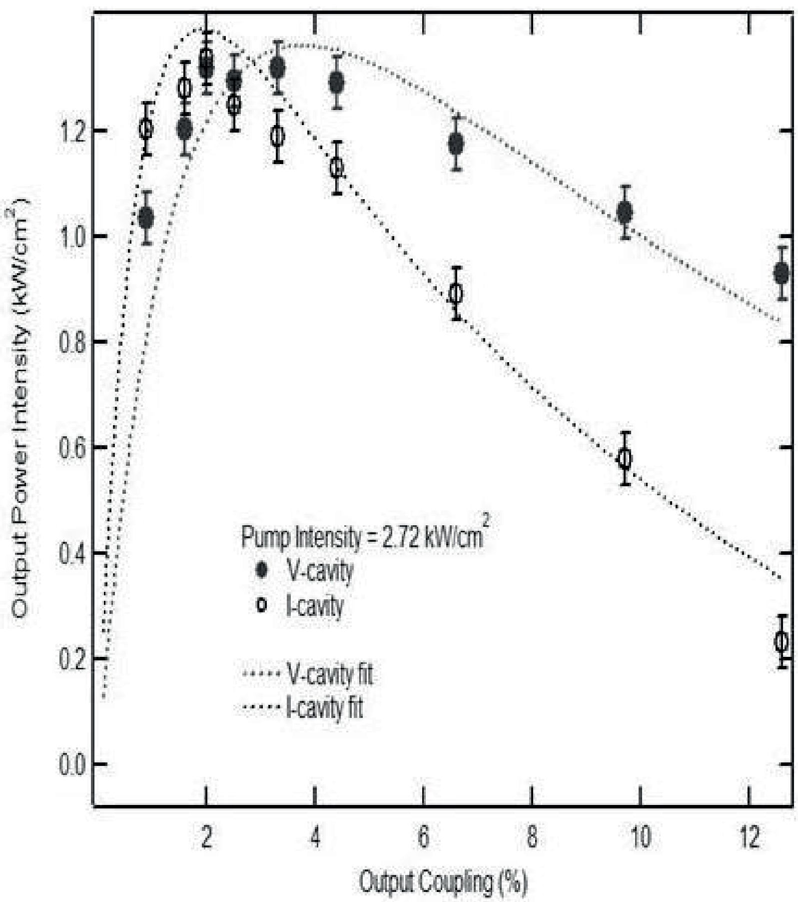
- Extremely thin gain media enhances high photon recirculation
- Excellent in thermal management

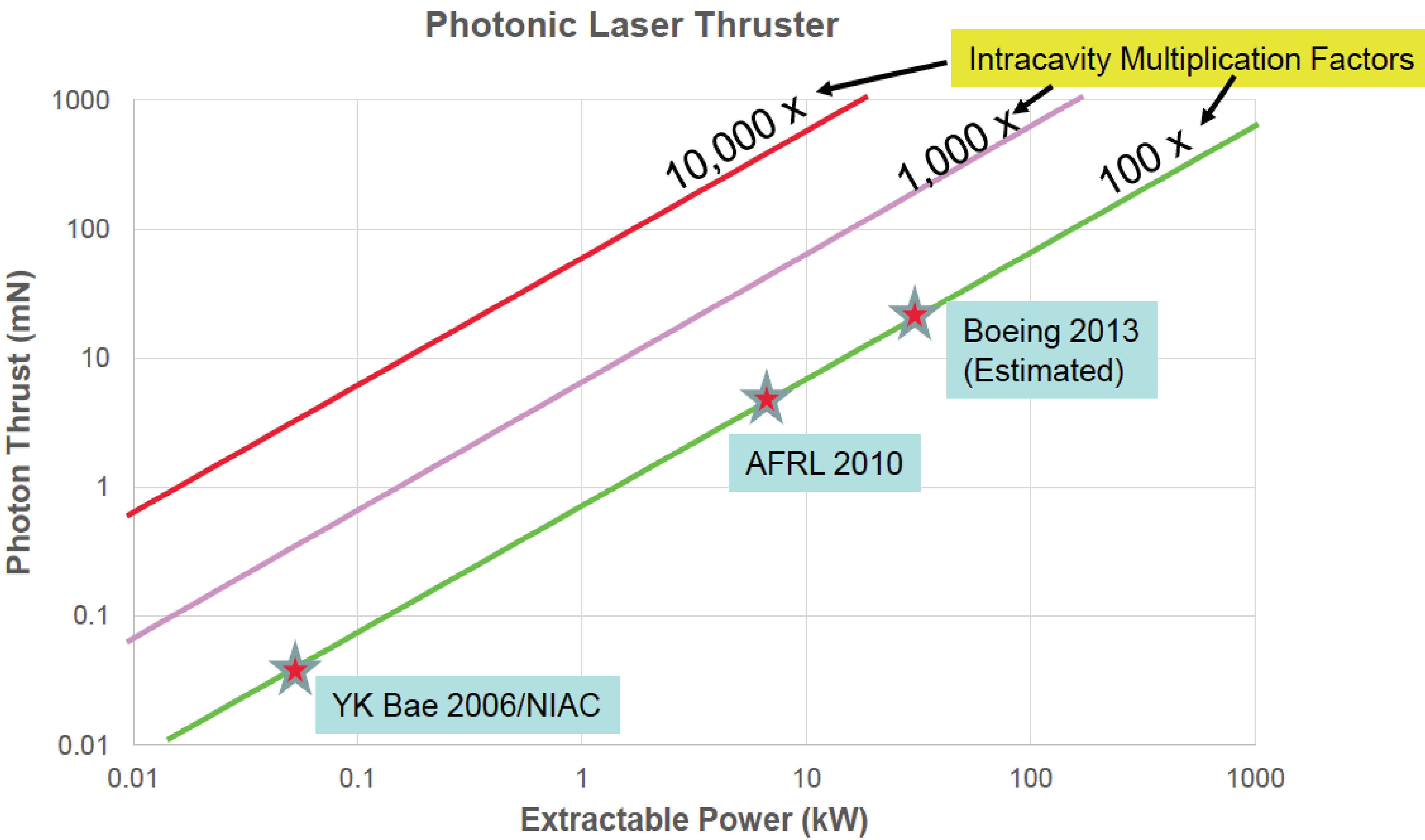
(Unintentional) PLT Scaling Up Demonstration in 2010

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 Powe
Thrust: 4.3 mN






Photonic Laser Thruster
Intracavity Multiplication Factors
10,000 x
1,000 x
100 x
Boeing 2013 (Estimated)
AFRL 2010
YK Bae 2006/NIAC
Photon Thrust (mN)
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
Extractable Power (kW)

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

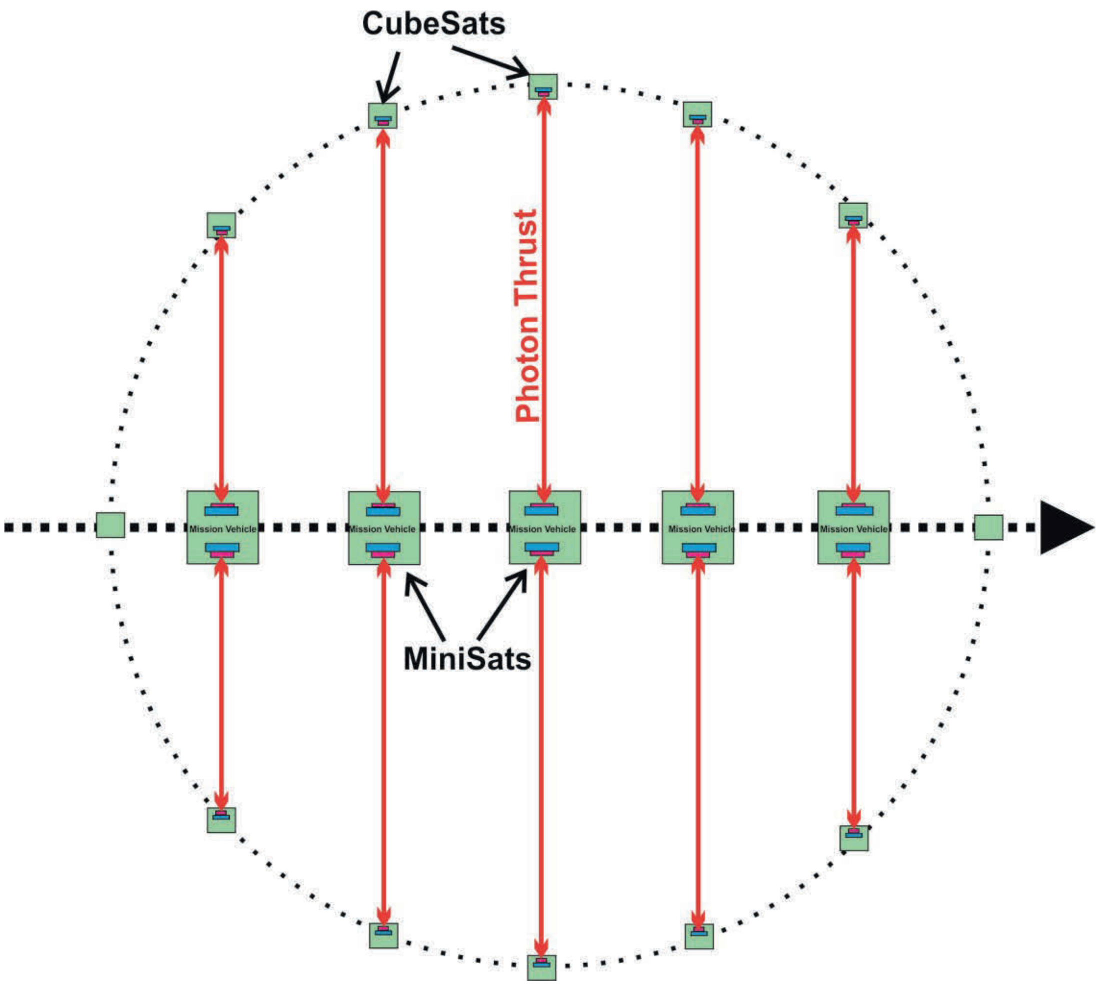
Force Balance:

PLT Thrust (Red)
+
Gravity Gradient

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

μ = the mass of the target spacecraft
r_c = the orbit radius of the chief
m = Earth's gravitational constant
L = Radius of the Aperture

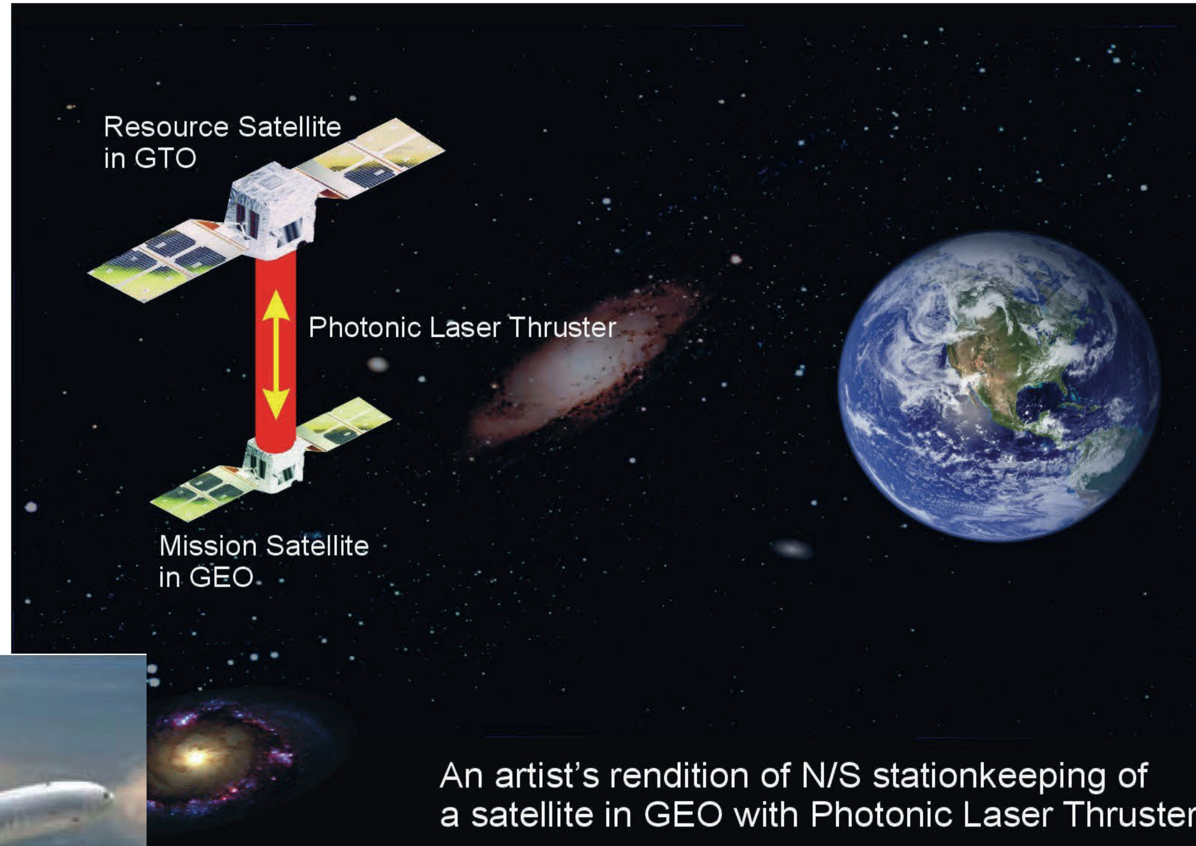
Persistent Annulus Formation Concept (Gyroscopic Attitude Control)



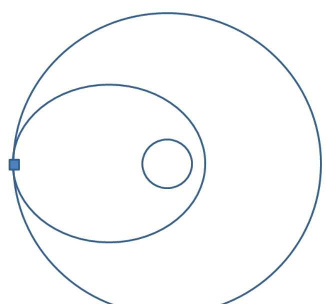
Maximum PLT thrust required for maintaining persistent apertures with various diameters

	Altitude	Aperture Diameter	Satellite Weight Misssion	Maximum Required PLT Thrust
LEO	1,000 km	100 m	10 kg	~ 0.5 mN
LEO	1,000 km	1.0 km	10 kg	~ 5 mN
GEO	37,000 km	100 m	1 Ton	~ 0.25 mN
GEO	37,000 km	1.0 km	1 Ton	~ 2.5 mN
GEO	37,000 km	10 km	1 Ton	~ 25 mN

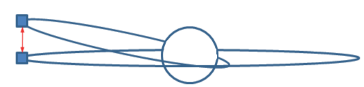
N/S Stationkeeping with PLT in GEO



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



Top-Down View



Side View

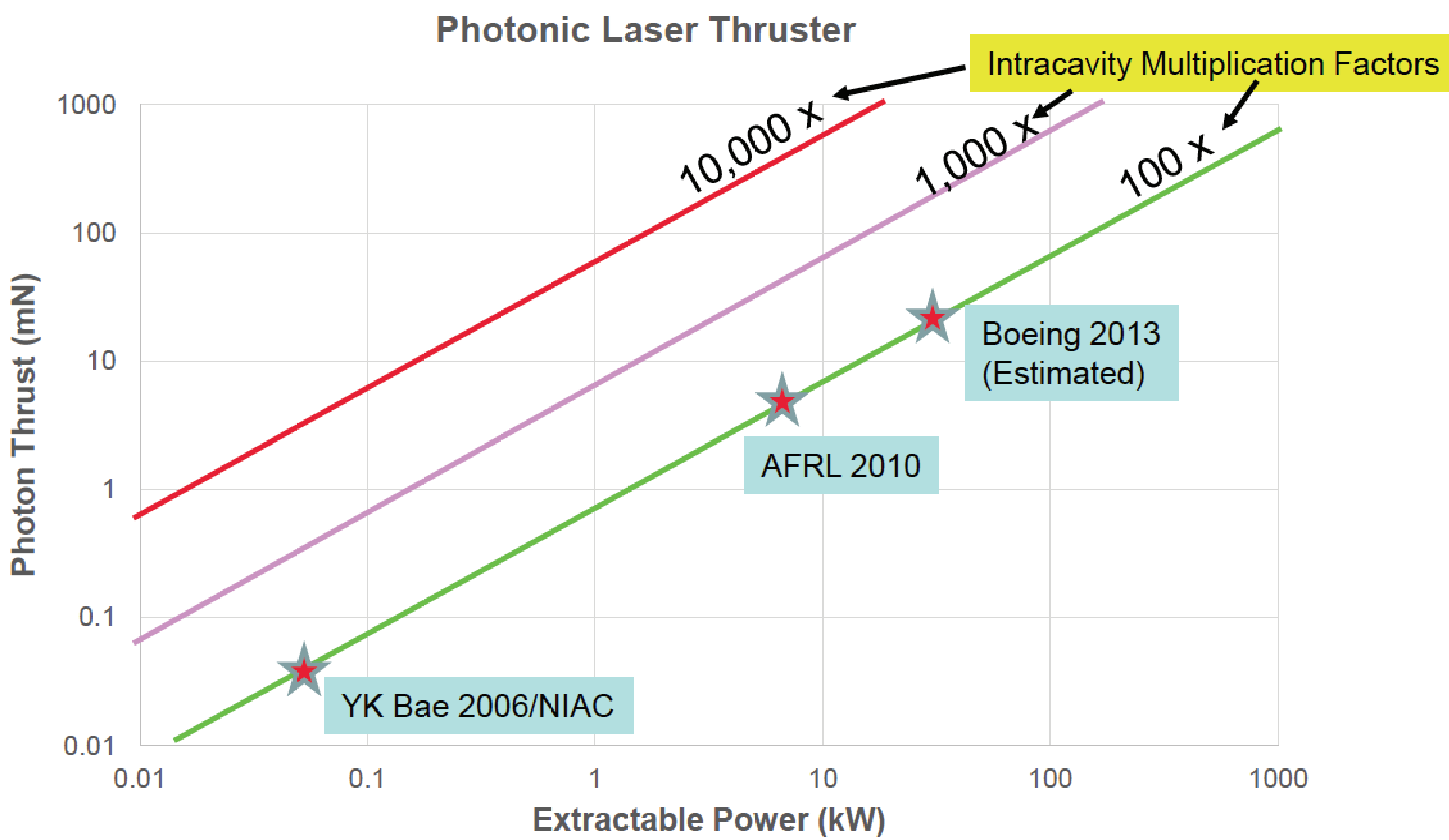
This work was provided by Dr. Mason Peck.

Phase II Progress since Oct. 2013

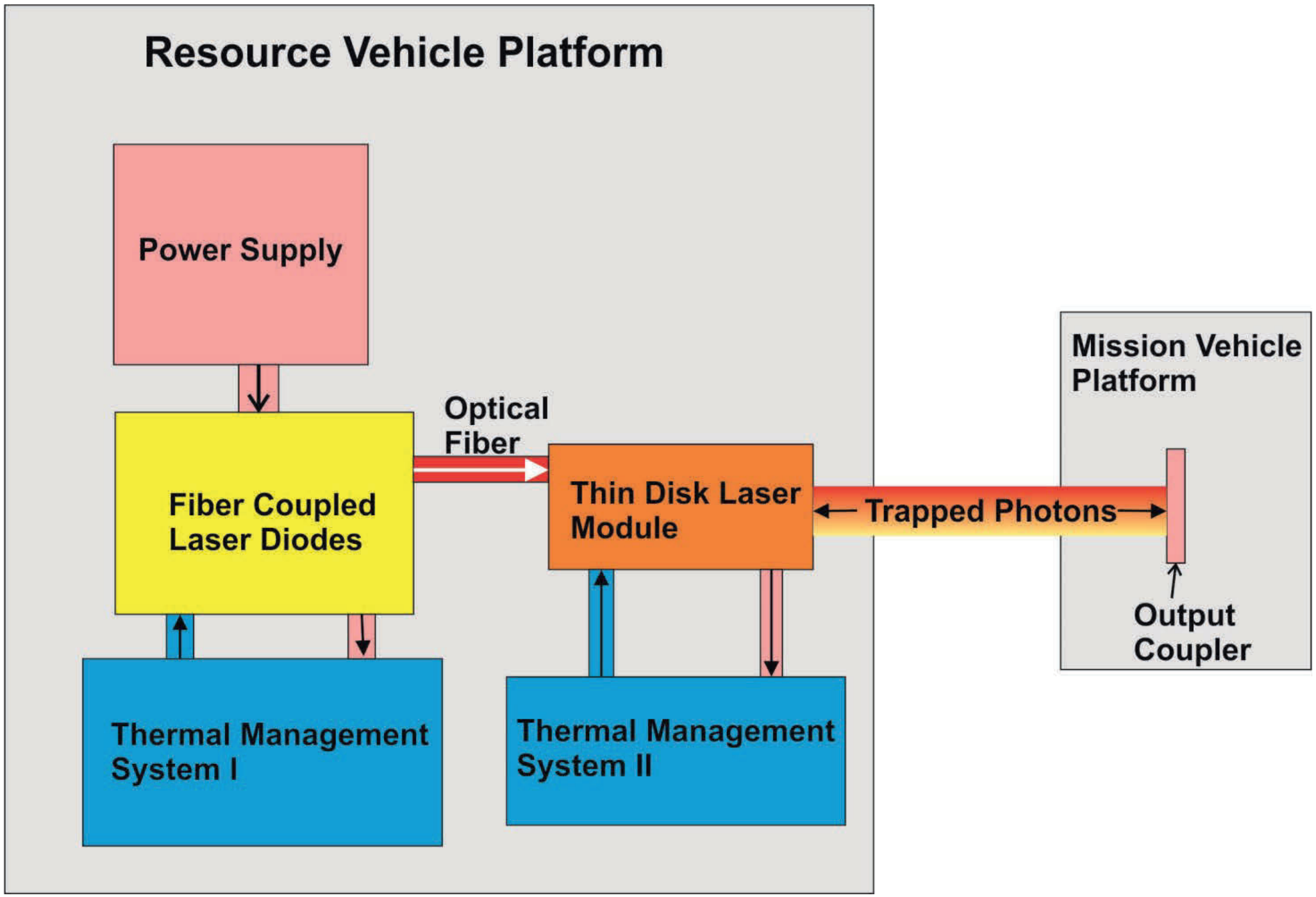
Survey and Comparison of Currently Available Various High Power Lasers at ~ 1 kW Power Level for PLT (Dr. Injeyan)

Gain Medium Architecture	Source	Extracted Power (kW)	Max Circulation Enhancement	Needed Power (kW) for 1.6 mN Thrust
Thin Disk	D+G	1.0	244	1.0
Rod	CEO/NG	0.6	16	15.2
Zig-Zag Slab	NG	4.0	21	11.6
Thin-Zag slab	Textron	1.2	17	14.5
Thick Disk (Heat capacity)	LLNL	5.0	95	2.6
Thick Disk (He cooled)	LLNL	1.2	65	3.8
Thick Disk (liquid back cooled)	China	1.2	105	2.3

Thrust/Power Scaling-up Demonstration



PLT Laboratory Demonstration Block Diagram



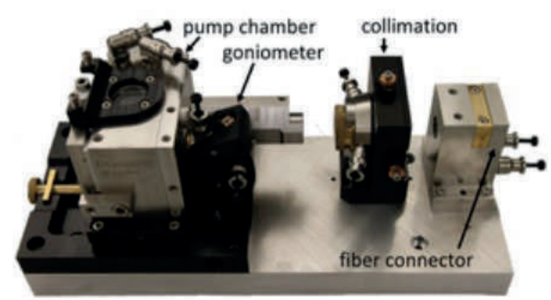
1 kW Class Photonic Laser Thruster Demo Construction

(With the help of Dr. Injeyan, a high power laser expert.)

Y.K. Bae Corp PLT Lab

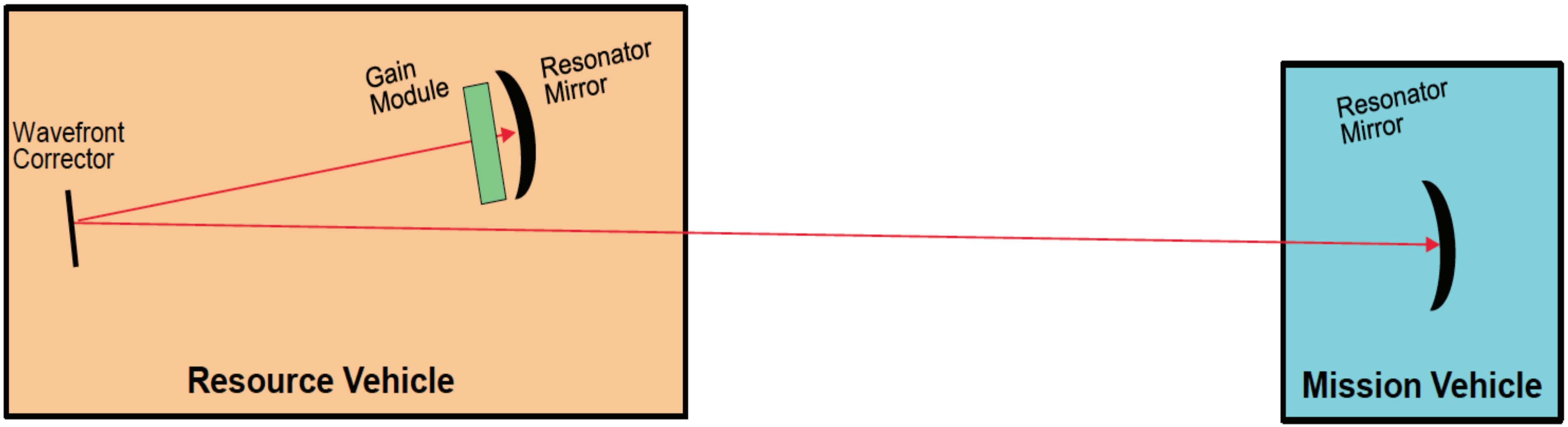
In Ordering Process

Fiber Coupled Diode Laser



1 kW Thin Disk Laser Module

Distance Scaling-up Investigation



- 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?