Photon Tether Formation Flight (PTFF)

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Participants

- **Joseph Carroll, Tether Applications Inc.**
  -- General Tether Aspects and Hardware

- **Claude Phipps, Ph.D., Photonics Associates**
  -- Nano-Newton Thruster Stand

- **Eugene Levin, Ph.D., STARS, Inc.**
  -- Dynamics of Tethers and Formation Flying

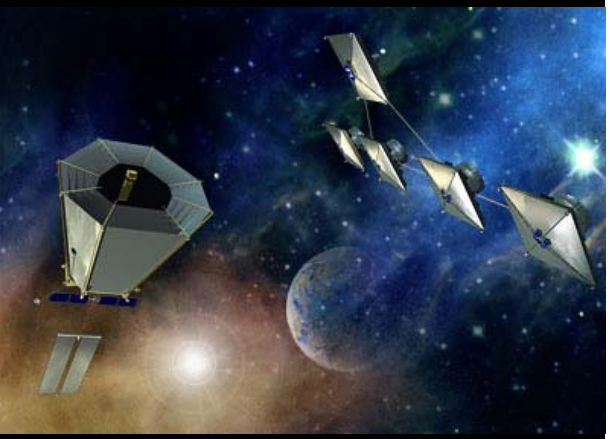
- **Bob Scaringe, AVG Communications**
  -- Business Development

Examples of Revolutionary/Disruptive Technologies

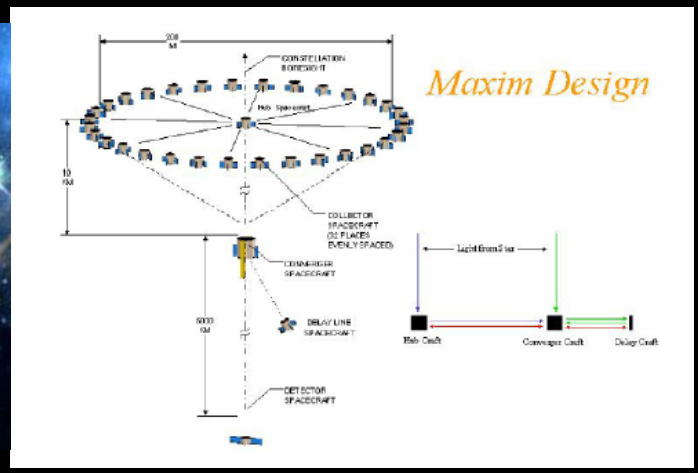
Key Enabling Factor:
Orders of Magnitude Enhancement in Critical Parameters

- **Subatomic Dimension -- Particle Accelerators**
  Critical Parameter: Particle Energy
- **Atomic Dimension – STM/AFM**
  Critical Parameter: Scanning Ability/Noise Reduction
- **Molecular to Daily Life Dimension -- Lasers**
  Critical Parameter: Coherence of Photons
- **Astronomical Dimension – Precision Formation Flying (?)**
  Critical Parameter: Control Accuracy (?)

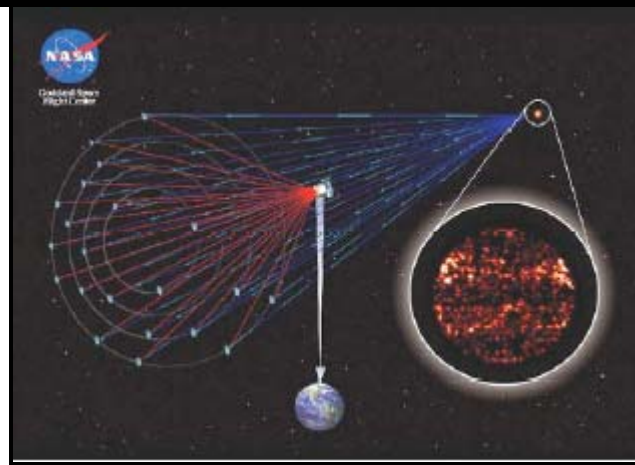
Examples of Precision Formation Flying Concepts



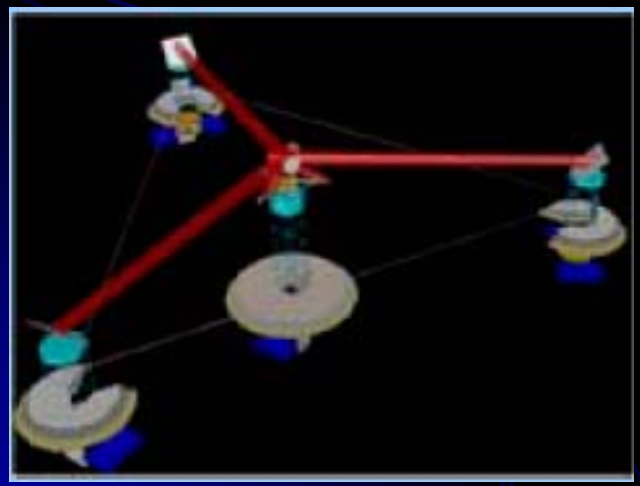
TPF



MAXIM

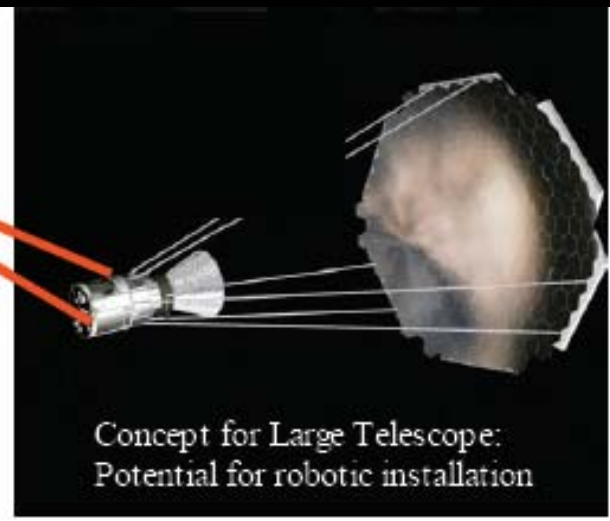


SI Mission

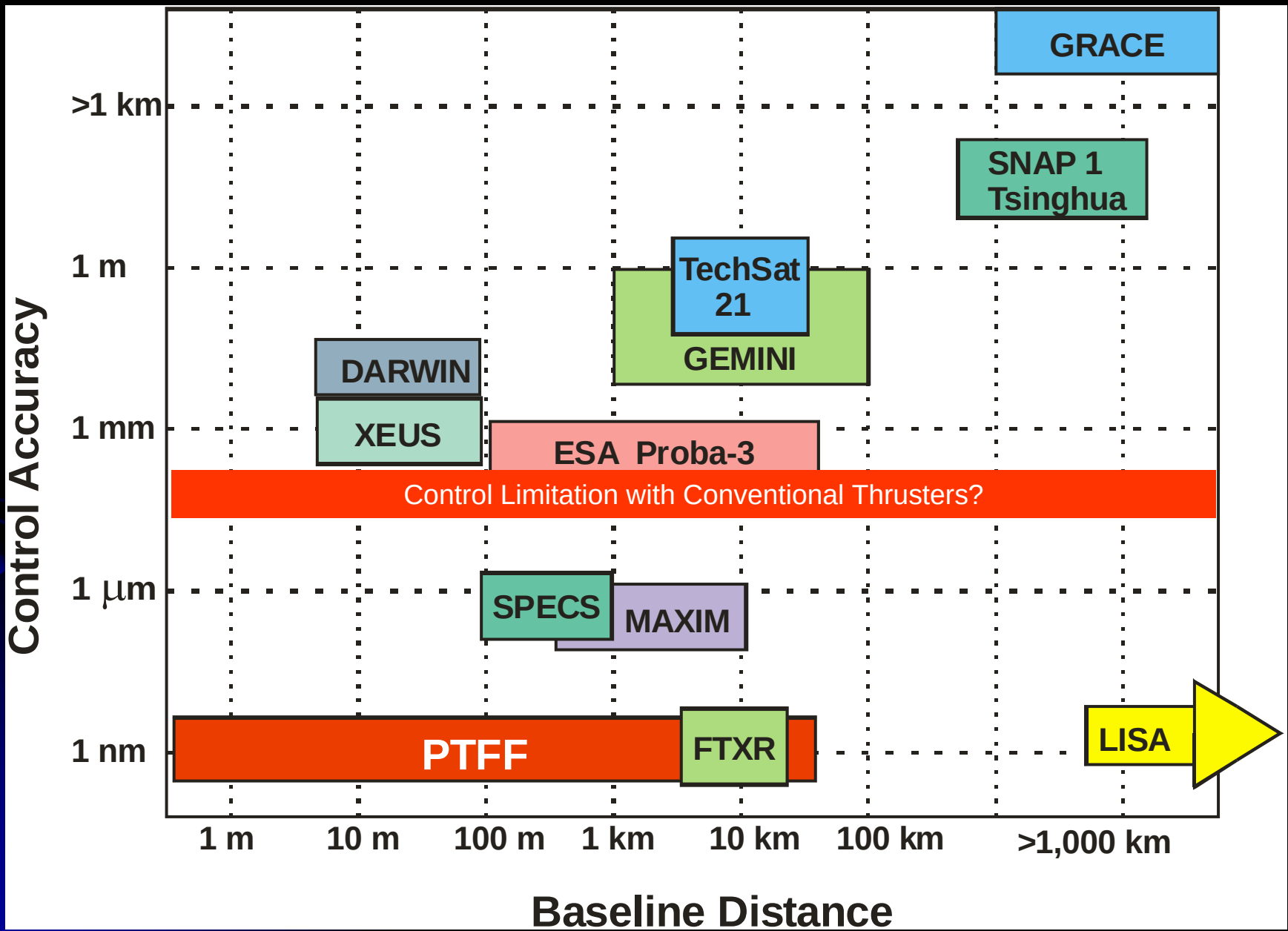


SPECS

Planet Imager



Selected Formation Flying Missions



Nano-Meter Precision Spacecraft Formation Flying:

-- is able to cover most of critical missions planned

-- enables many other new missions

- Thus, it is Potentially a Revolutionary/Disruptive Technology of the 21st Century in Astronomical Dimension.
- So far, its Enabling Technology has been illusive.
- We believe that PTFF could be the Enabling Technology, if successfully demonstrated.
- The Primary Goal of this NIAC Phase II is to demonstrate a sub-scale prototype PTFF engine.

Photon Tether Formation Flight (PTFF)

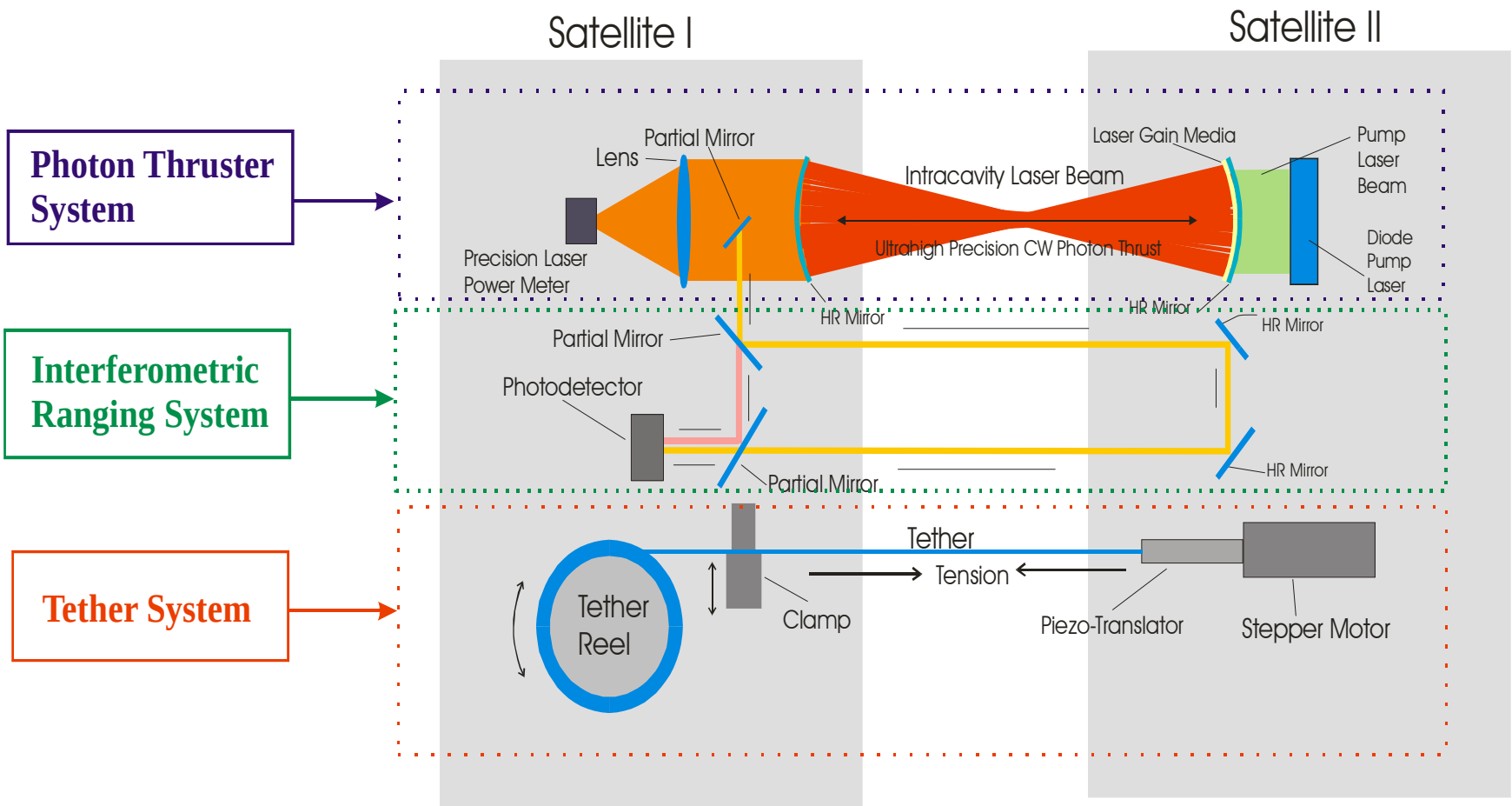
- Force Structure: Counter Balance of Two Forces:
  - Contracting Force: Tether Tension
  - Extending Force: Photon Thrust
    - Intracavity Arrangement
  - Thrust Multiplied by Tens of Thousand Times by Bouncing Photons between Spacecraft
- Geometrical Structure: Crystalline Structure
- Interspacecraft Distance Accuracy: better than nm
- Maximum Operation Range: Tens of kms (Limited by Laser Mirror Size)
- Can be Used for both Static and Dynamic Applications

Major Advantages of PTFF

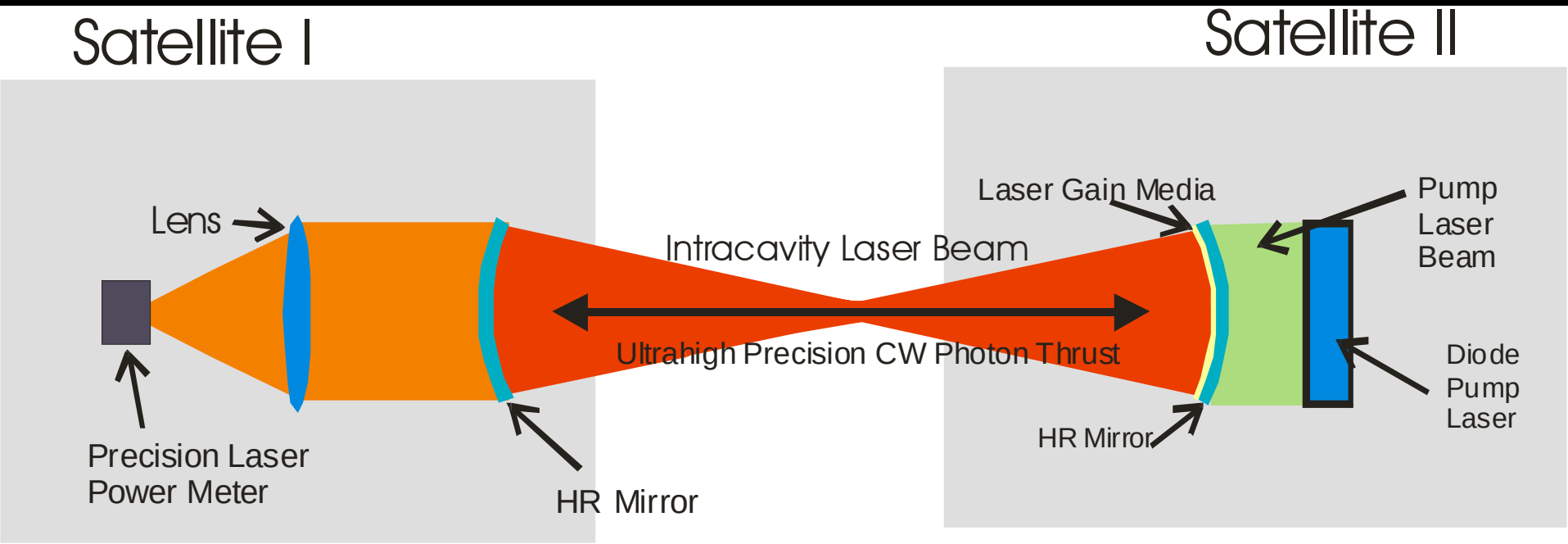
- **Ultra-High Baseline and Pointing Accuracy**
  - -- Baseline Accuracy: better than 1 Nano-Meter
  - -- Pointing Accuracy: better than 0.1 micro-arcsec for 1 km baseline system
  - – Enabling Wide Ranges of Imaging Missions
- **Propellantless**
  - -- System Mass Savings, Contamination Free, Long Mission Lifetime
- **Low Power Consumption**
- **Low Construction Cost**
- **Dual Usage of Photon Thruster Laser for Interferometric Ranging System**
  - -- Simplified System Architecture and Control, Low System Weight
- **Readily Downscalable to Nano- and Pico- Satellites Usage**
  - -- Ideal for Sophisticated Fractionated Spacecraft or Space Structures

PTFF System Architecture

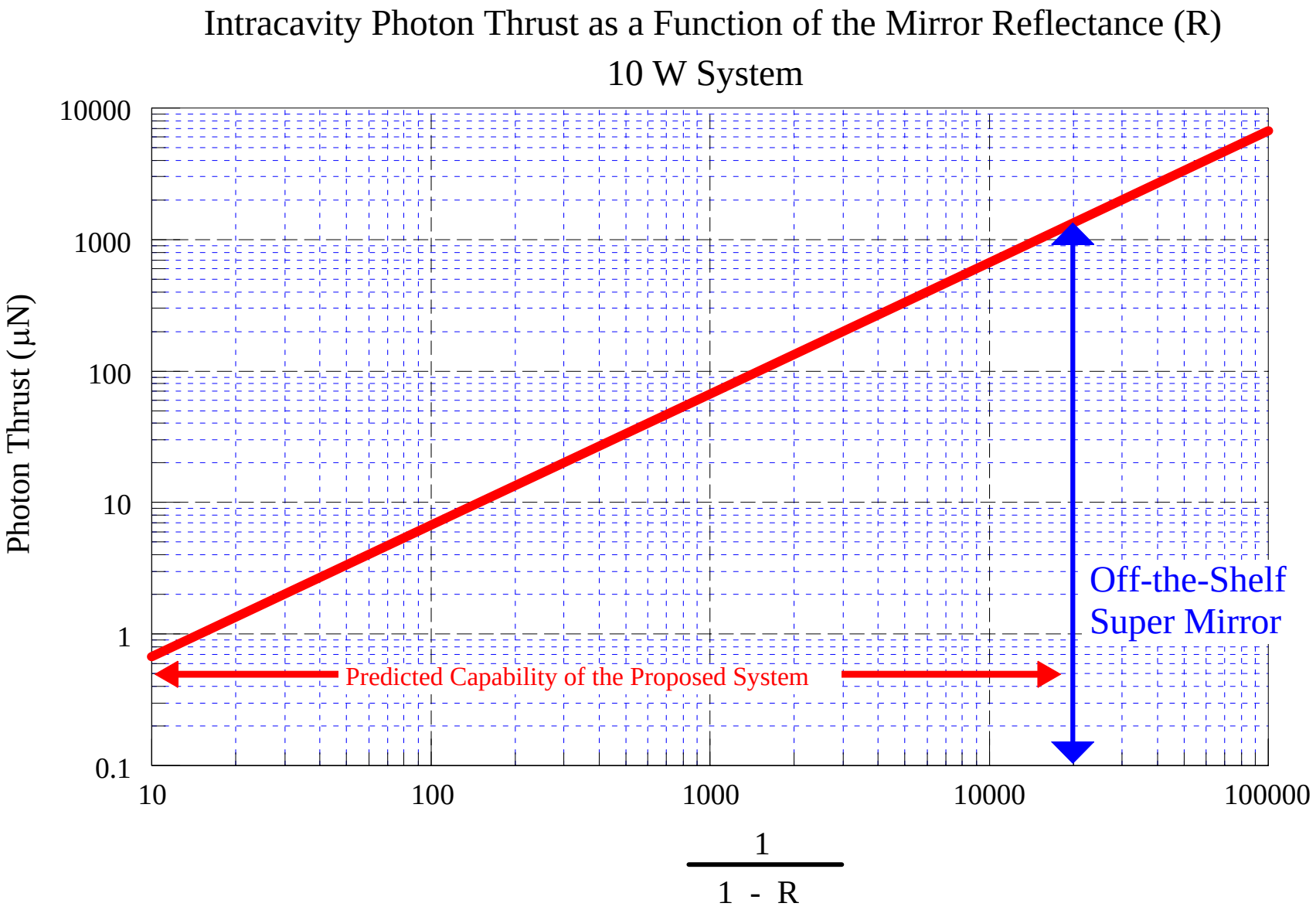
Nano-Precision Formation Flying System Architecture



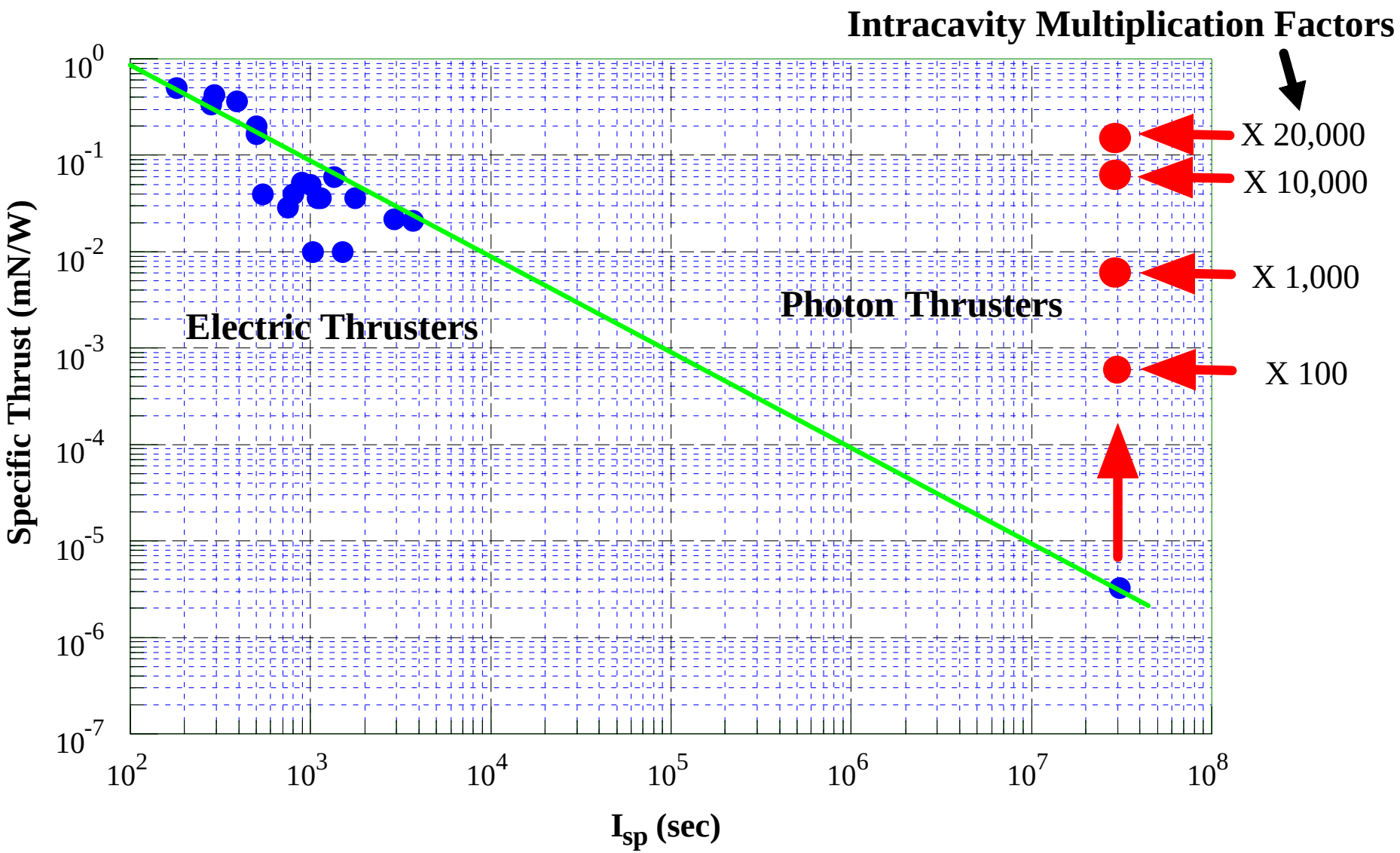
Photon Thruster System: TRL 3

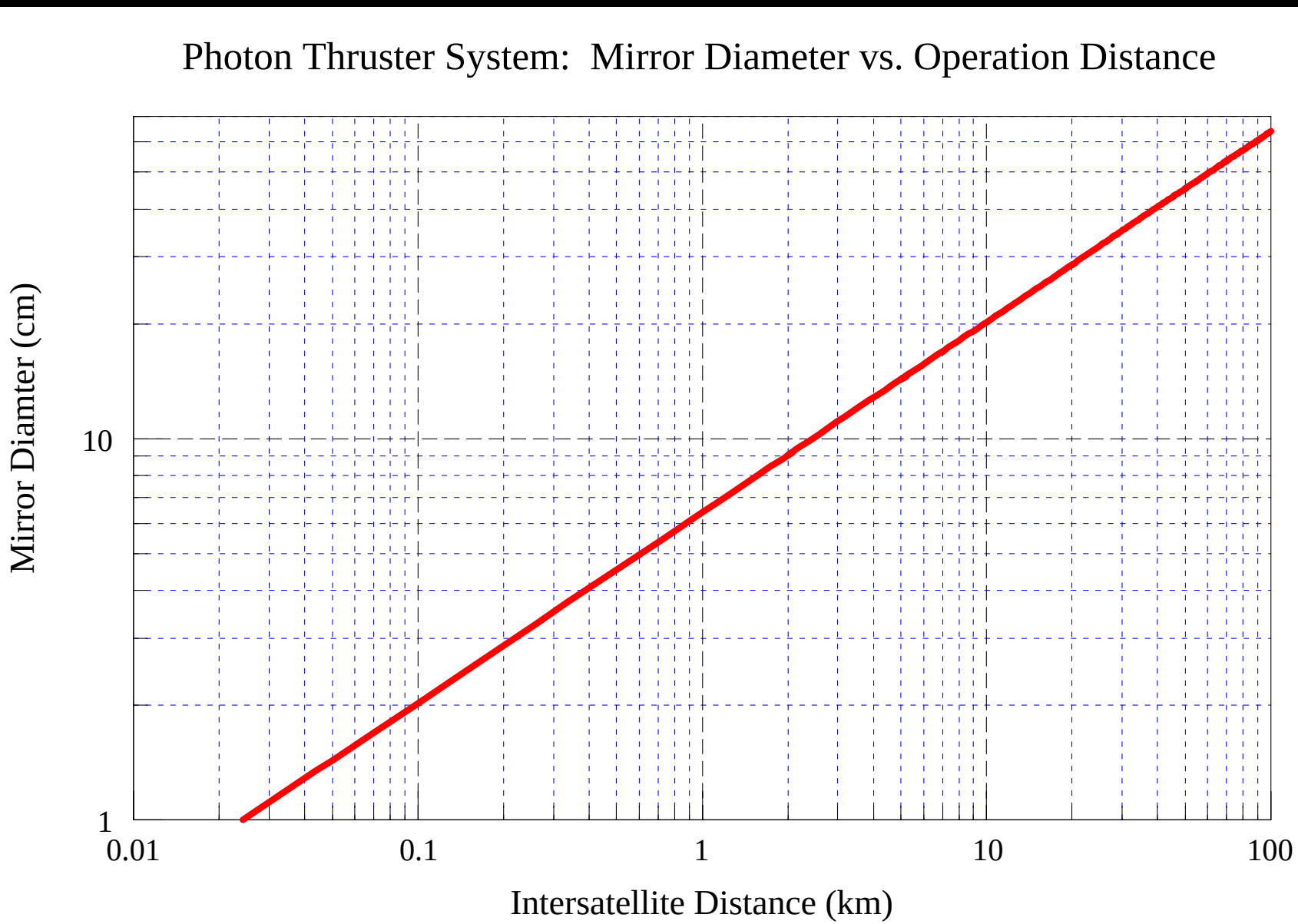


- **Laser System**
  - **-- Diode Pumped Intracavity Laser**
  - **-- Lifetime of Diodes**
    - **1 Year for Continuous Operation**
- **Pump Diode Carousel Design – Tens of Years**

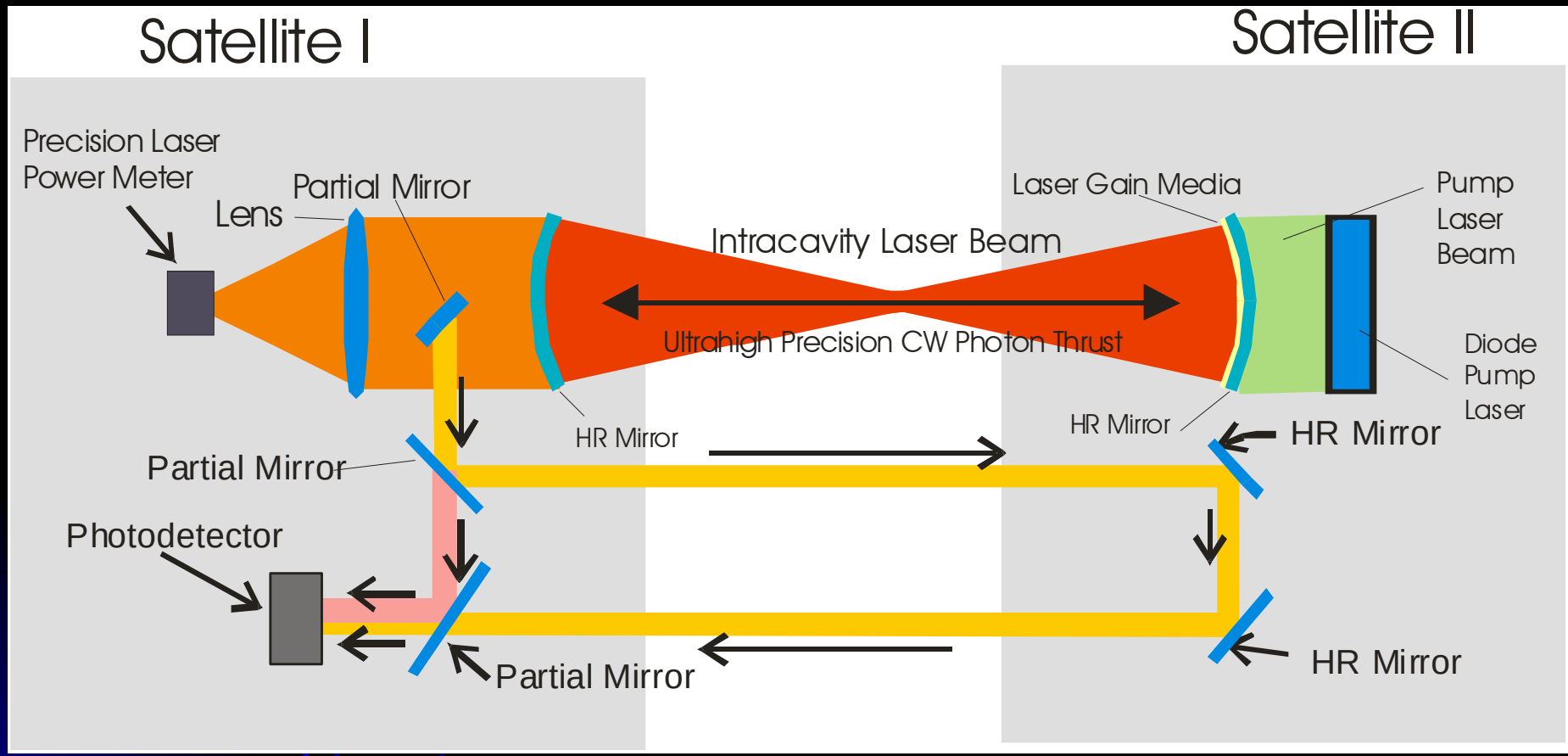

Intracavity Photon Thrust as a Function of the Mirror Reflectance (R)
10 W System
Photon Thrust (μN)
10000
1000
100
10
1
0.1
10
100
1000
10000
100000
1
1 - R
Off-the-Shelf
Super Mirror
Predicted Capability of the Proposed System

Specific thrusts as functions of I_{sp} of various conventional and photon thrusters.



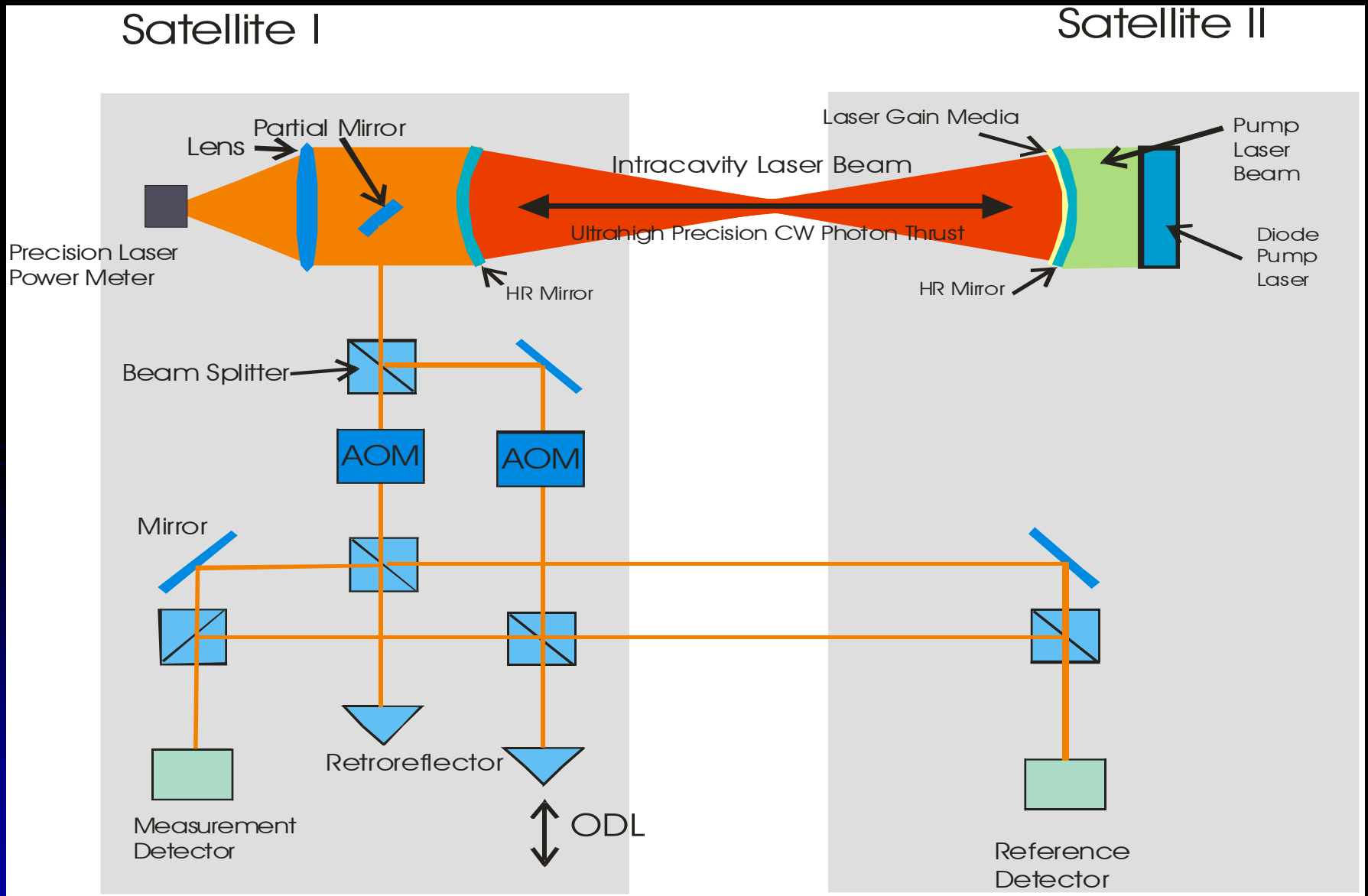

Photon Thruster System: Mirror Diameter vs. Operation Distance
Mirror Diamter (cm)
10
1
0.01
0.1
1
10
100
Intersatellite Distance (km)

Interferometric Ranging System: TRL 5

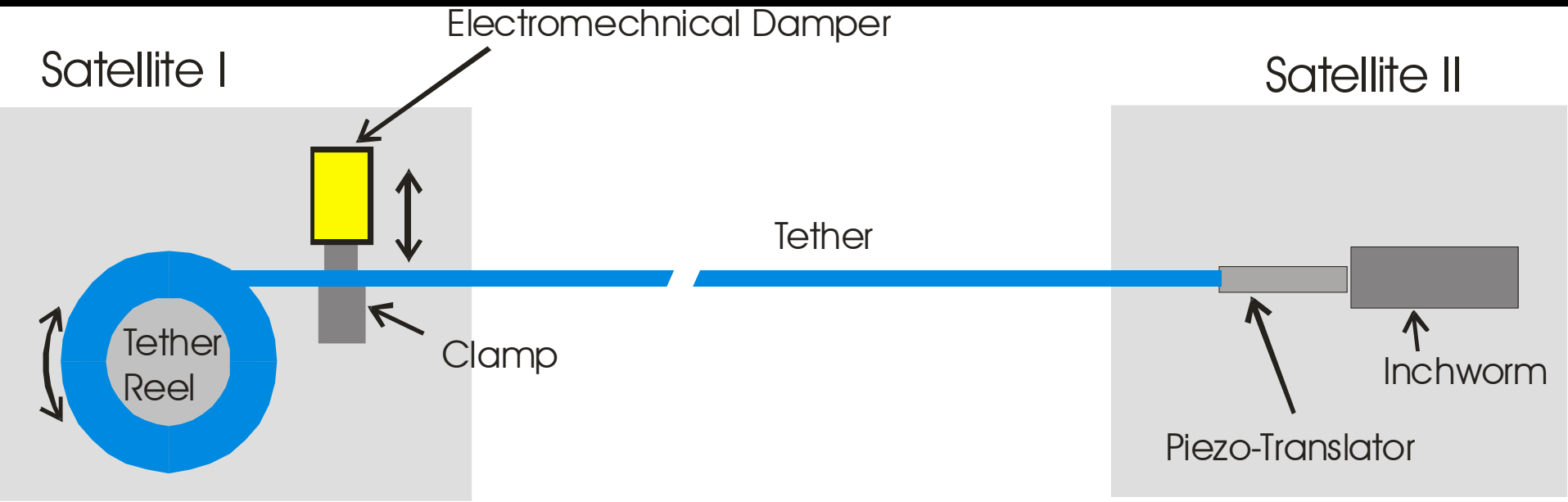


- Dual Usage of Photon Thruster Laser for Interferometric Ranging System Source Laser
  - -- System Architecture Simplification
  - -- System Mass Reduction

Heterodyne Interferometric Ranging System Integrated with Photon Thruster System



Tether System: TRL 5

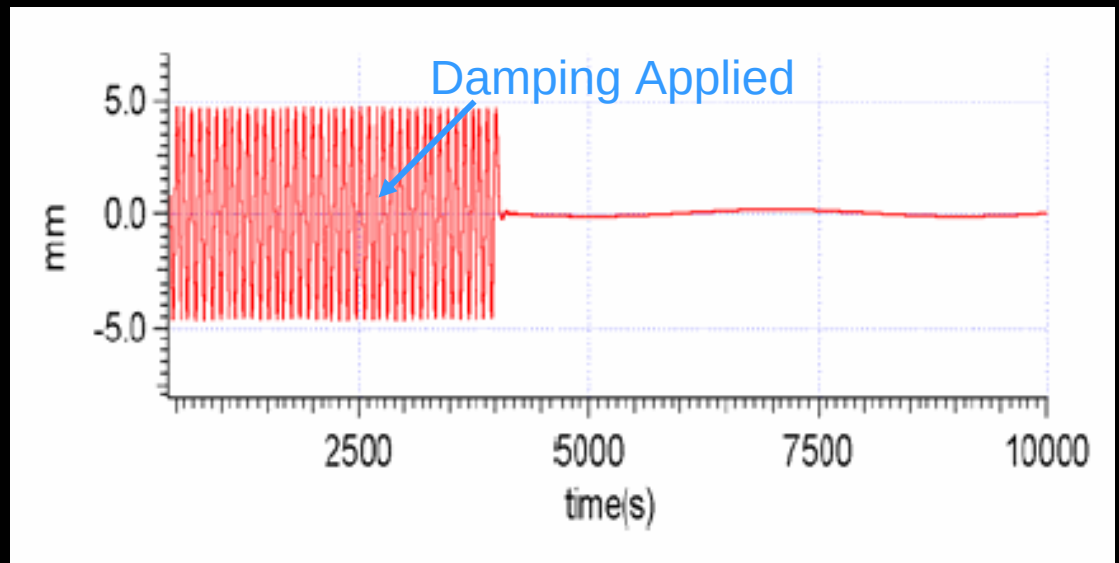


- Coarse Control: Reel System-- mm Accuracy
- Fine Control: Inchworm or Stepper Motor-- μm Accuracy
- Ultrafine Control: Piezo-Translator (off-the-shelf) -- 0.1 nm Accuracy

Method of Tether Vibration Suppression

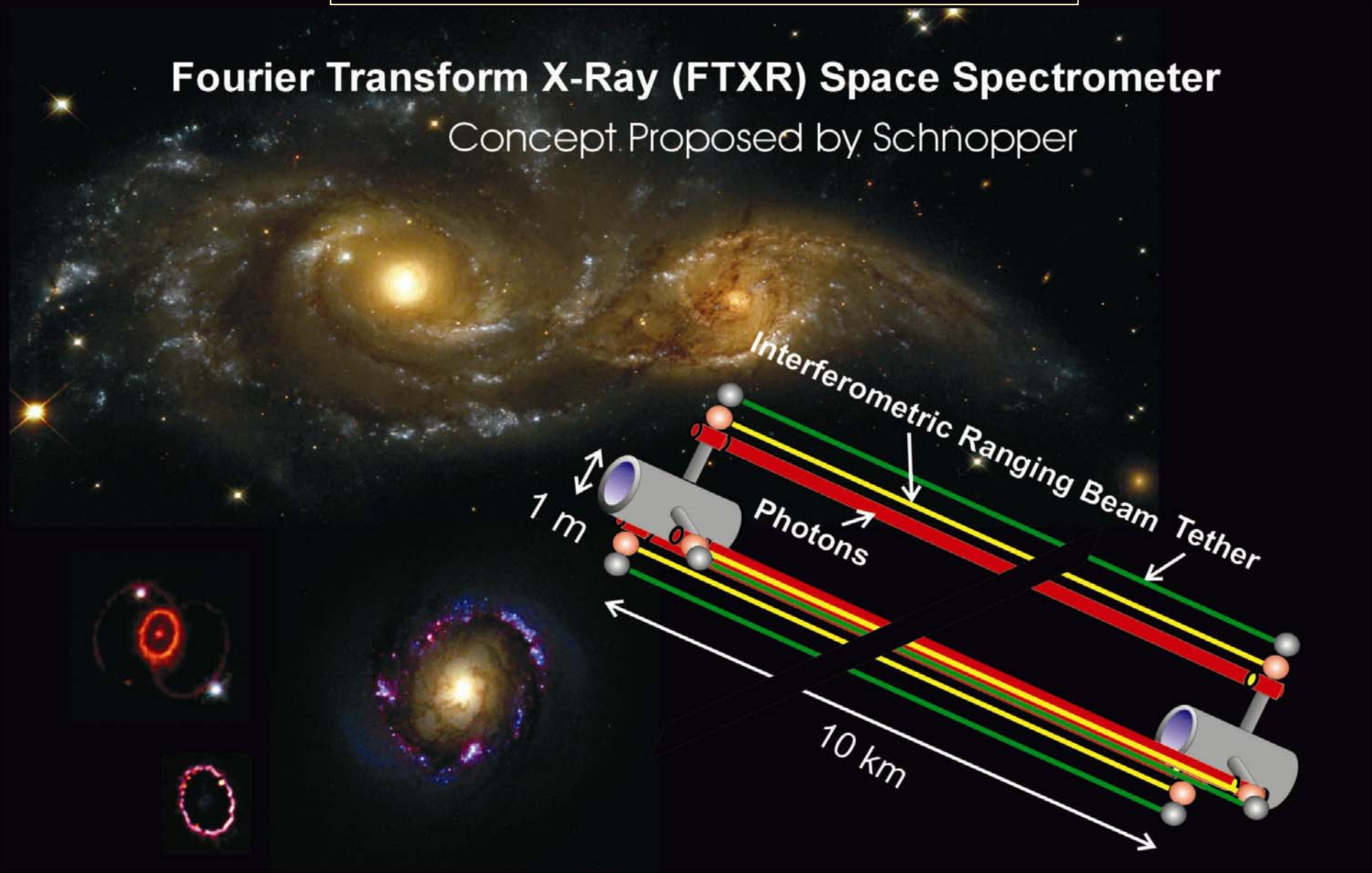
- Major Tether Vibrations will Result from Reorientation of the Whole Formation Structure, and other Sudden Environmental Perturbations, such as Meteoroid Impacts.

- Longitudinal Tether Wave Damping
  Tether Material Friction/ Modulation of Photon Thruster Power
- Transverse Tether Wave Damping
  Electromechanical Damper with Impedance Matching

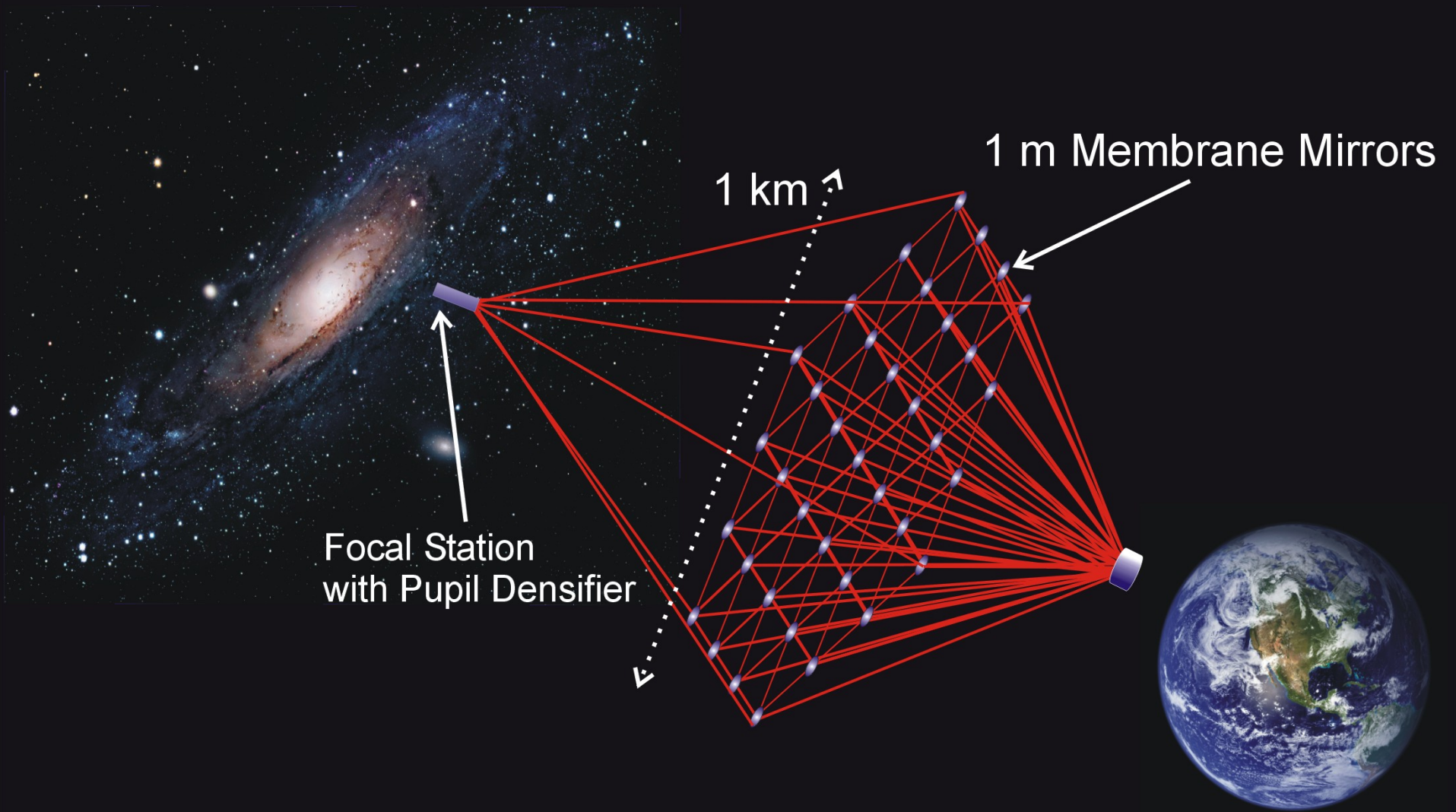


Electromechanical Damping Simulation by Lorenzini et al. For 1 km Baseline System

Example I: 10 km 1-D PTFF at L2



Example II: 1 km PTFF Telescope at L2



1 km PTFF Telescope:
Enables New World Imager Freeway Mission

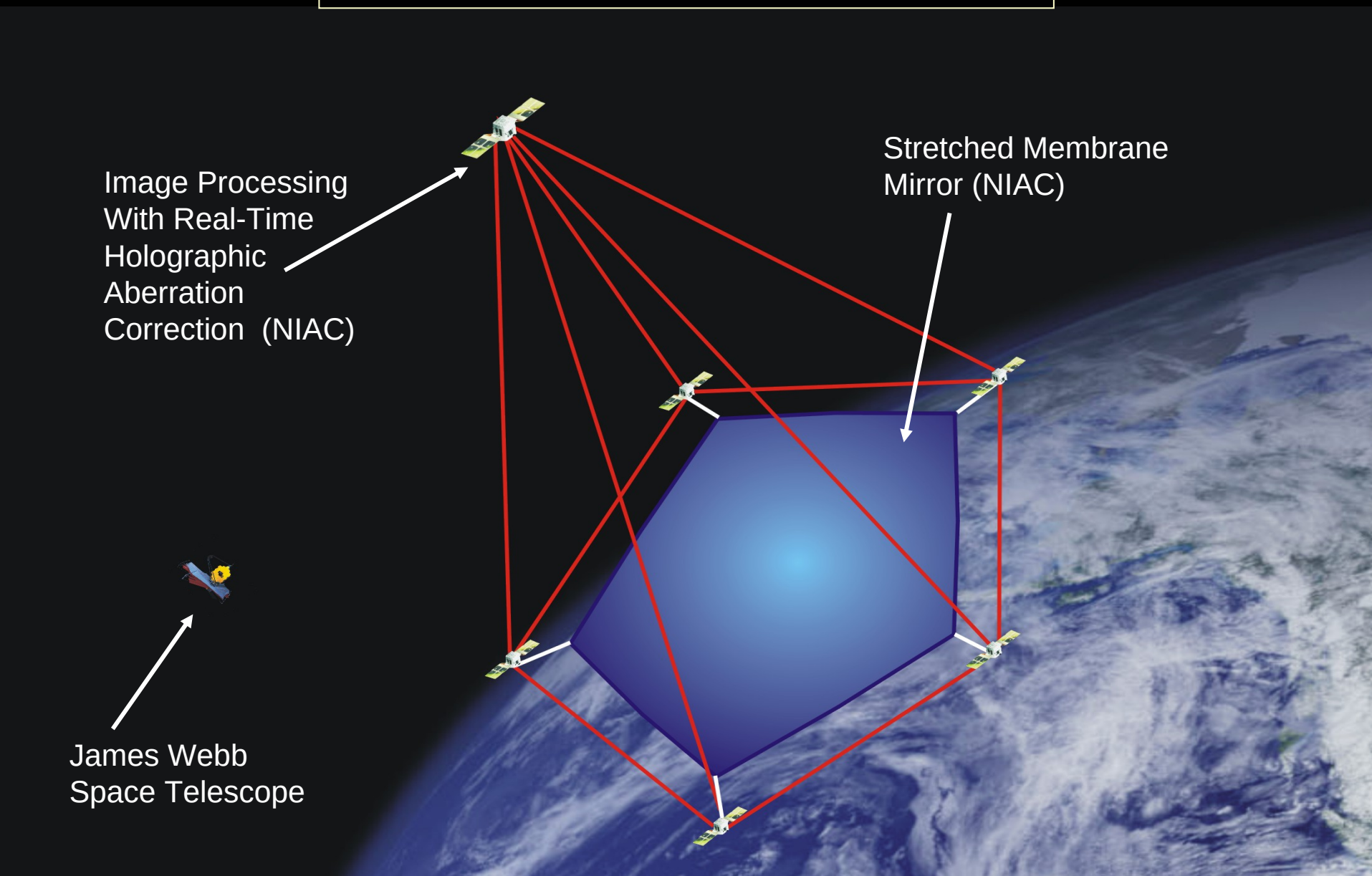
By Prof. W. Cash – 2005 NIAC Fellow Meeting

-- Searching for Advanced Civilization in Exo-Planets

- 300 m resolution at 10 parsecs = 0.02 nano-arcseconds
- 500,000 km based line distance between Collectors
- ***Huge collecting area – one square kilometer***

From the movie Contact.
Dr Arroway gets a brief glimpse of this alien landscape.

More Advanced PTFF Telescope



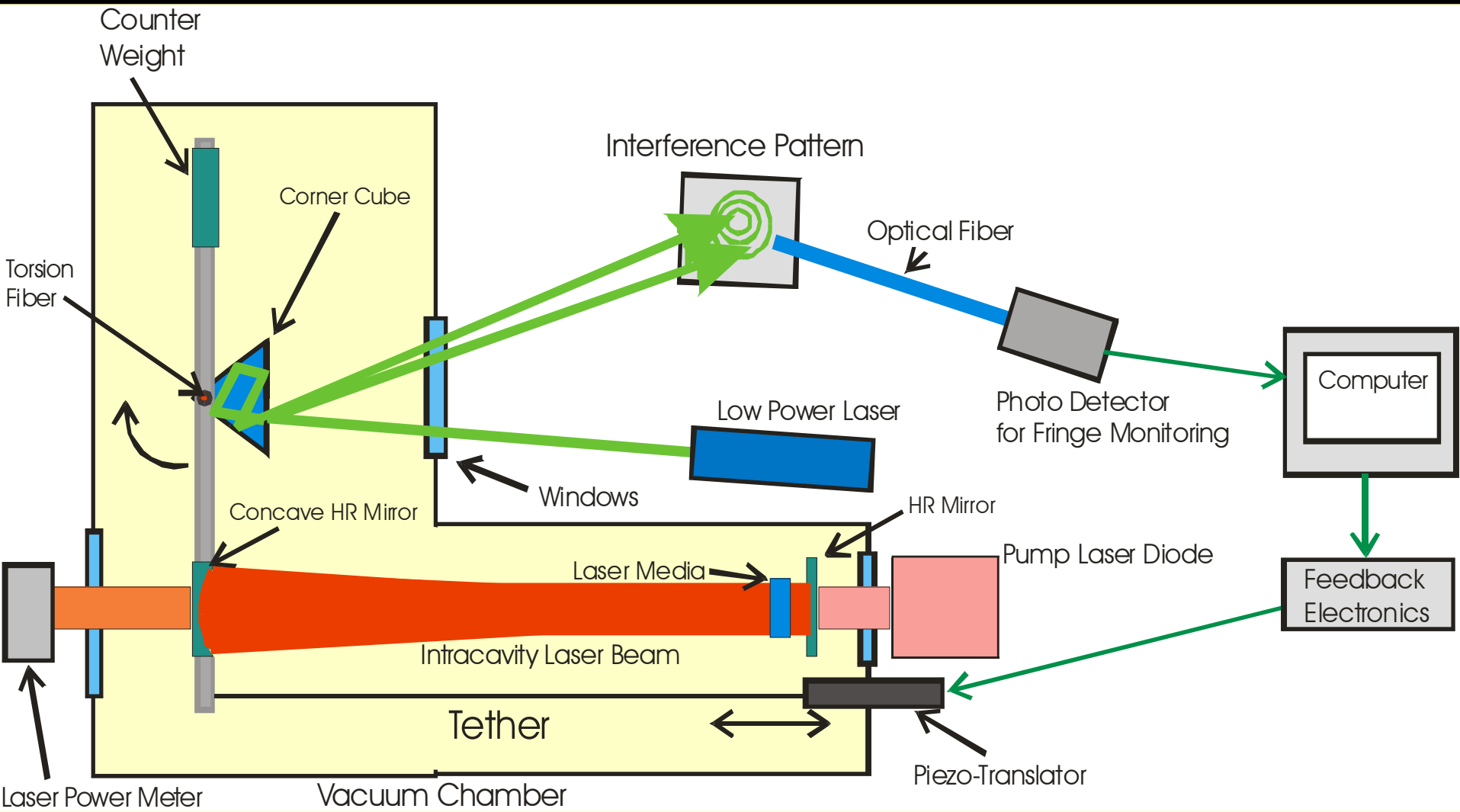
Technology Readiness Assessment Summary

- Photon Thrusters: TRL 3
- Interferometric Ranging System: TRL 5
- Tether System: TRL 5
- System Integration and Control: TRL 2
- R&D^3: II - III (moderate -high) (Degree of Difficulty)
  -- Requires to optimize photon thrust design based on the current laboratory system and system integration, and to develop control system.

Phase II Work Started Since Sept. 1st 2006

- Proof-of-Concept Demonstration of Photon Thruster
  - Construction of a Thrust Stand with nN Accuracy
- Overall System Stability and Control
  - Tether Vibration Dynamics
  - Environment Perturbation
  - 3-D Simulation
- Design of Prototype Interferometric Ranging System
- Design of Prototype Tether System
- Detailed Study of Specific Applications
  - In-Depth Revisits of Existing Concepts -- SPECS and MAXIM
  - Ultralarge Membrane Space Telescopes
  - Ultralarge Sparse Aperture Space Telescopes
  - Others

Prototype Sub-scale PTFF Engine Demonstration



Conclusions I

- If successful, PTFF technology will be revolutionary/disruptive technology of 21st Century in Astronomical Dimension.

- If successful, PTFF technology will open new innovative (revolutionary) ways to implementing new and existing mission concepts at very affordable costs. -- Many applications can be implemented at fractional costs of HST.

- Preliminary Studies concluded that PTFF system can be implemented with off-the-shelf technologies – This will be tried to be proved during this study.

Conclusions II

- **Mission Specific Applications**

  - PTFF Simplifies the Architecture and Reduces the Weight in
    Space Interferometery Missions -- TPF, DARWIN, MAXIM,
    SPECS, FTXR etc.

  - Ultra-large PTFF Space Telescopes
    -- For New World Imager (300 m Resolution – Freeway Mission with km Mirror)
    -- Earth imaging/Monitoring/Surveillance (10 cm Resolution
    Monitoring at GEO with 200 m Mirror)

The Support by NIAC and NASA for this project is greatly appreciated.

“I believe in intuitions and inspirations.
I sometimes feel that I am right.
I do not know that I am.”

by Albert Einstein