Plasmonic Force Propulsion Revolutionizes Nano/PicoSat Propulsion

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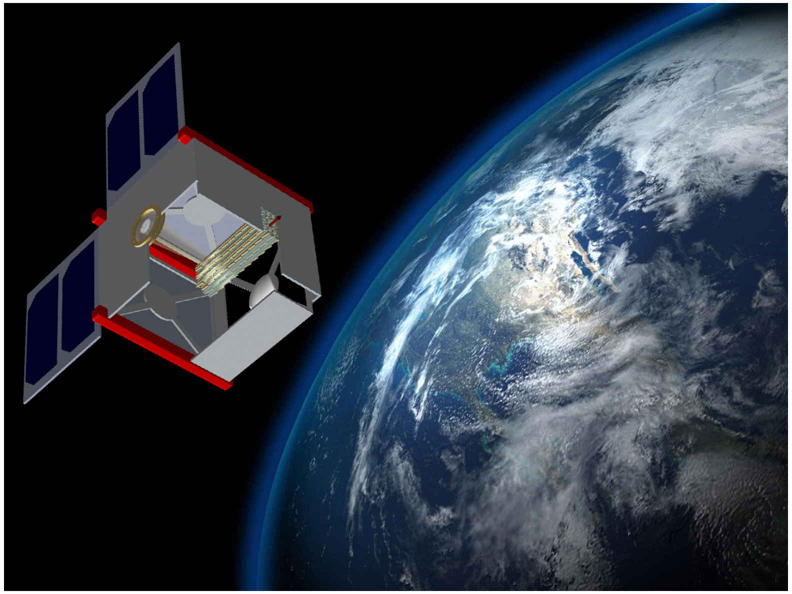
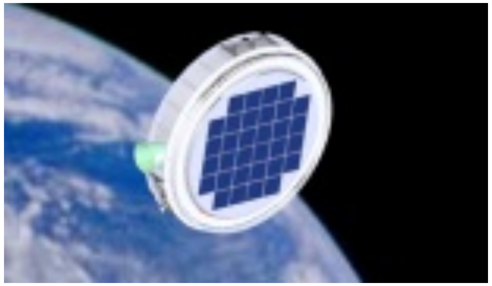
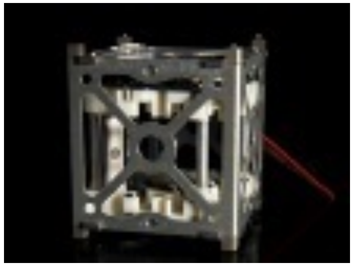


Motivation

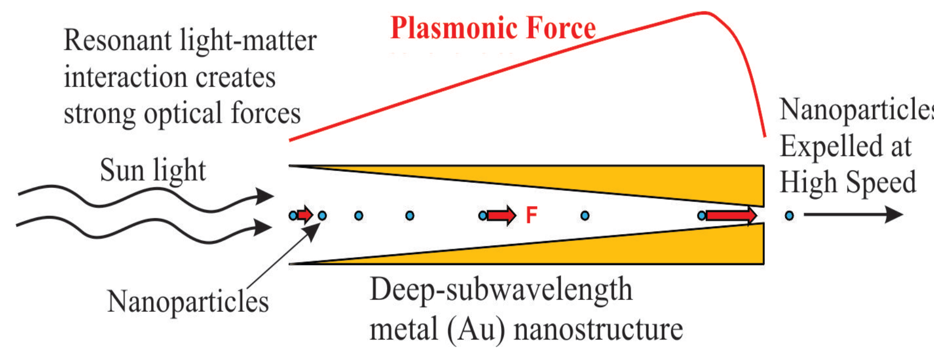
- Motivation
  - Small sat manuevability
  - Mass, volume, power challenges with Smallsat
- Benefits
  - No Spacecraft Power!
  - Direct Energy Conversion Solar-to-Propulsive Thrust
  - Minimal Mass/Volume Requirement: ~1% of Cubesat

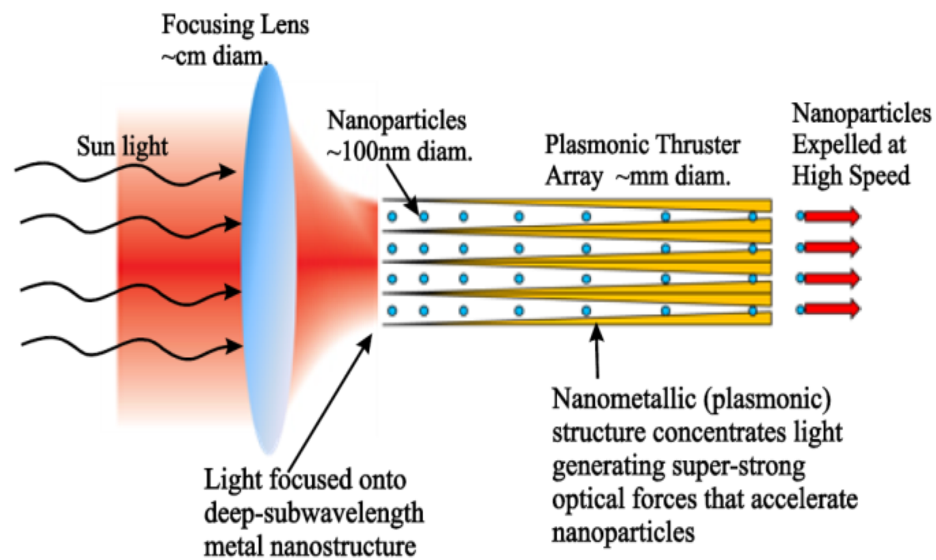




The Concept

- Plasmonic Force Propulsion
  1. Sun light is focused onto deep-subwavelength metallic nanostructures through a lens
  2. Resonant interaction and coupling of light with the nanostructure excites surface plasmon polaritons that generate a strong gradient optical force field
  3. Nanoparticles (e.g., glass beads) are accelerated by the gradient force field and expelled at high speeds





Project Overview

- **Main Question:** Is plasmonic propulsion feasible/ beneficial for nano/picosatellite applications?
- **Objective:** Evaluate position and pointing control resolution for a cubesat
- **Approach**

Plasmonic Force Field Predictions
-Uses our existing plasmonics model
-Studies:
  -Gradient geometry
  -Gradient angle
  -Solar light effects
  -Nanoparticle mass effects

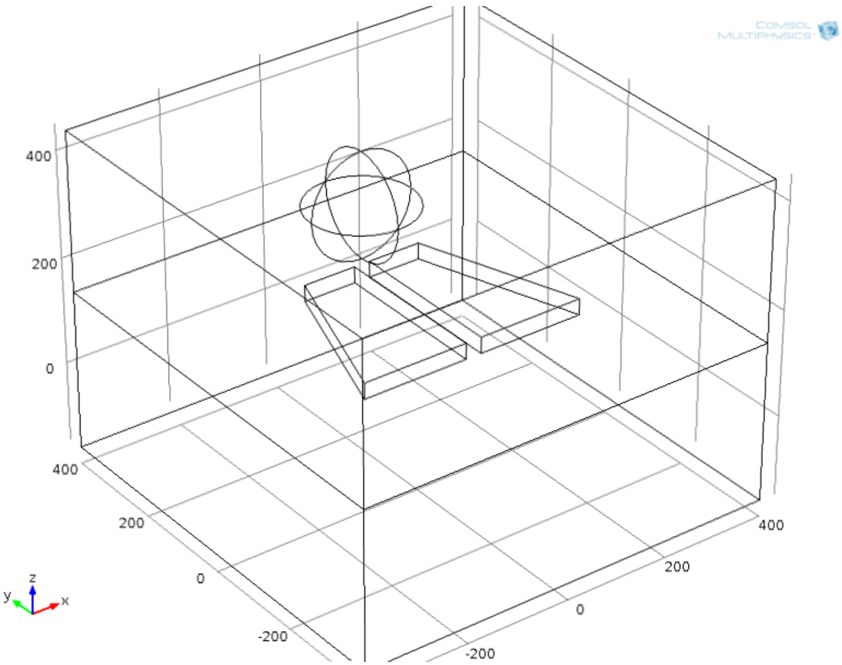
Used In →

Propulsion Performance Predictions
-First order principles
-Predicts thrust, Isp
-Incorporates:
  -Nonlinear force profile
  -Nanoparticle mass
  -Variable acceleration distance
  -Nanoparticle expulsion rate

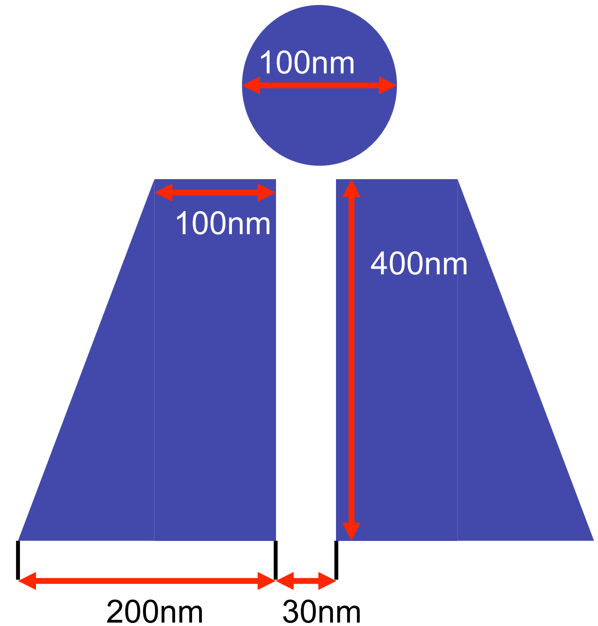
Used In →

Mission Context Assessment
-Precision pointing control system context
-Predicts control resolution and pointing precision
-Based on similar analyses for LISA, GOCE, and ExoPlanetSat
-Comparison with SoA reaction wheels, colloid EP

Force Field Studies



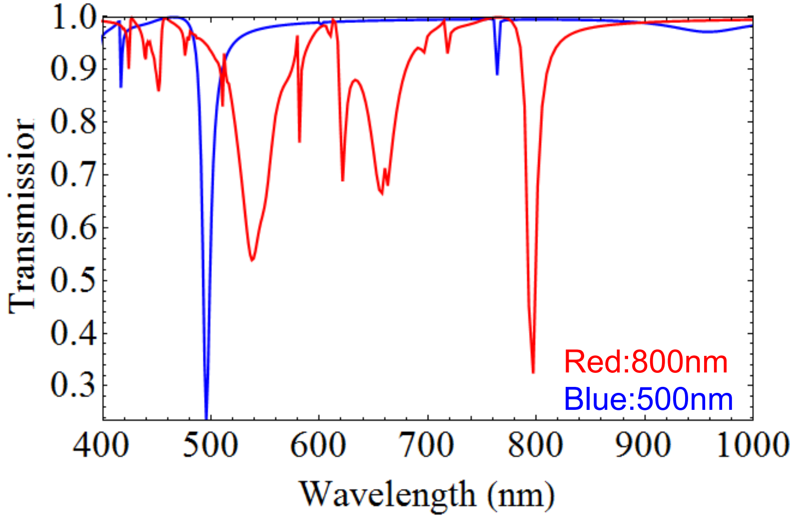
3D-Schematic of Nanostructure Sim Volume

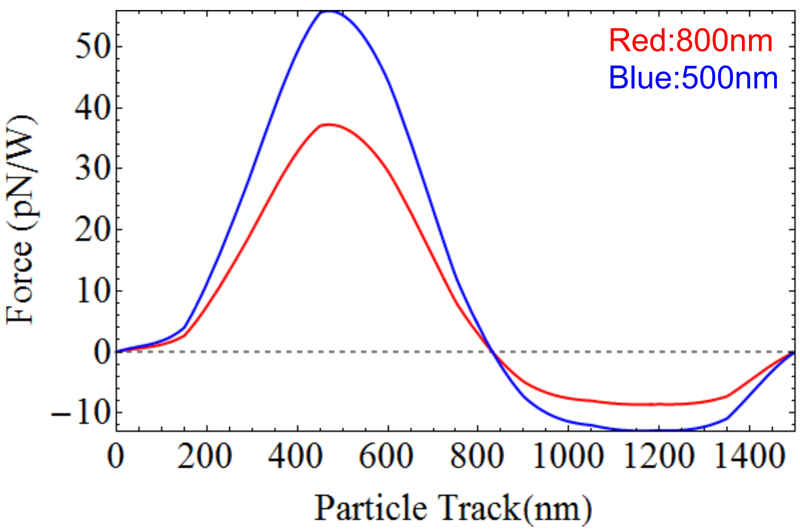


2D-Schematic of Nanostructure

Asymmetric nanostructures have been designed to achieve the strongest resonance in solar light varied wavelength to obtain the gradient electric field and generate the strong optical force in order to propel nanoparticles

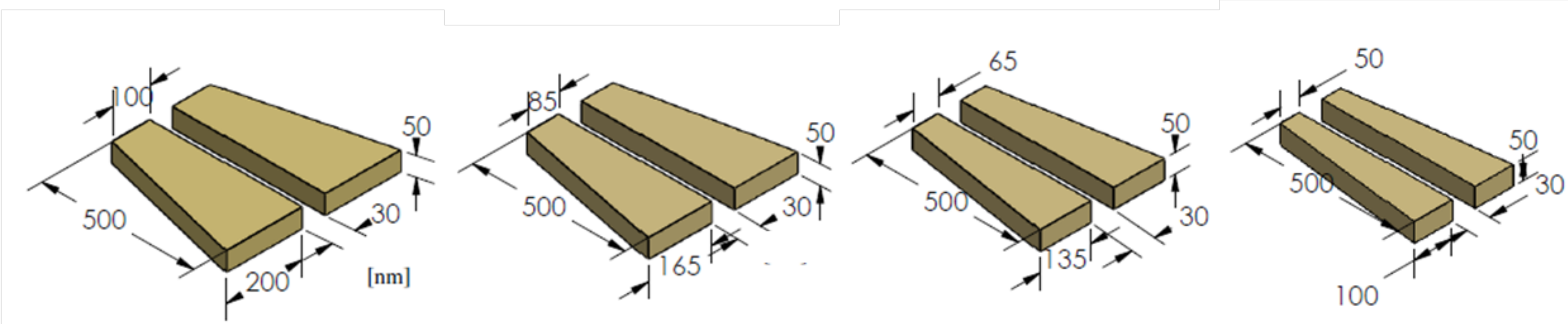
Force Field Studies



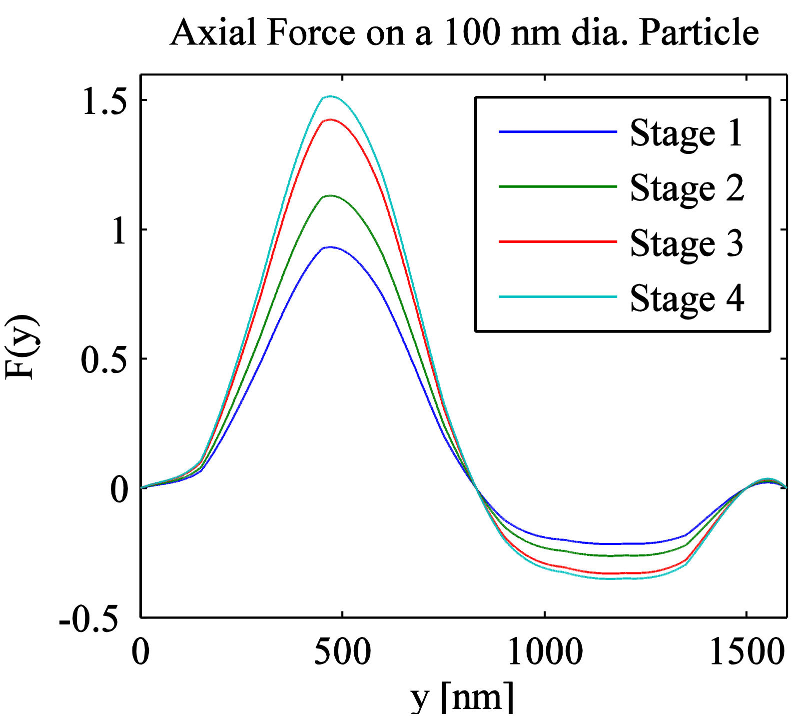


- Transmission spectra show strong coupling resonance at the solar light wavelengths
- Nanostructures that accelerate and expel nanoparticles:
  - Decreasing the width of trapezoid leads to resonance at shorter wave
  - 500nm (Width: 50nm)
  - 800nm (Width:100nm)

Designed Structures

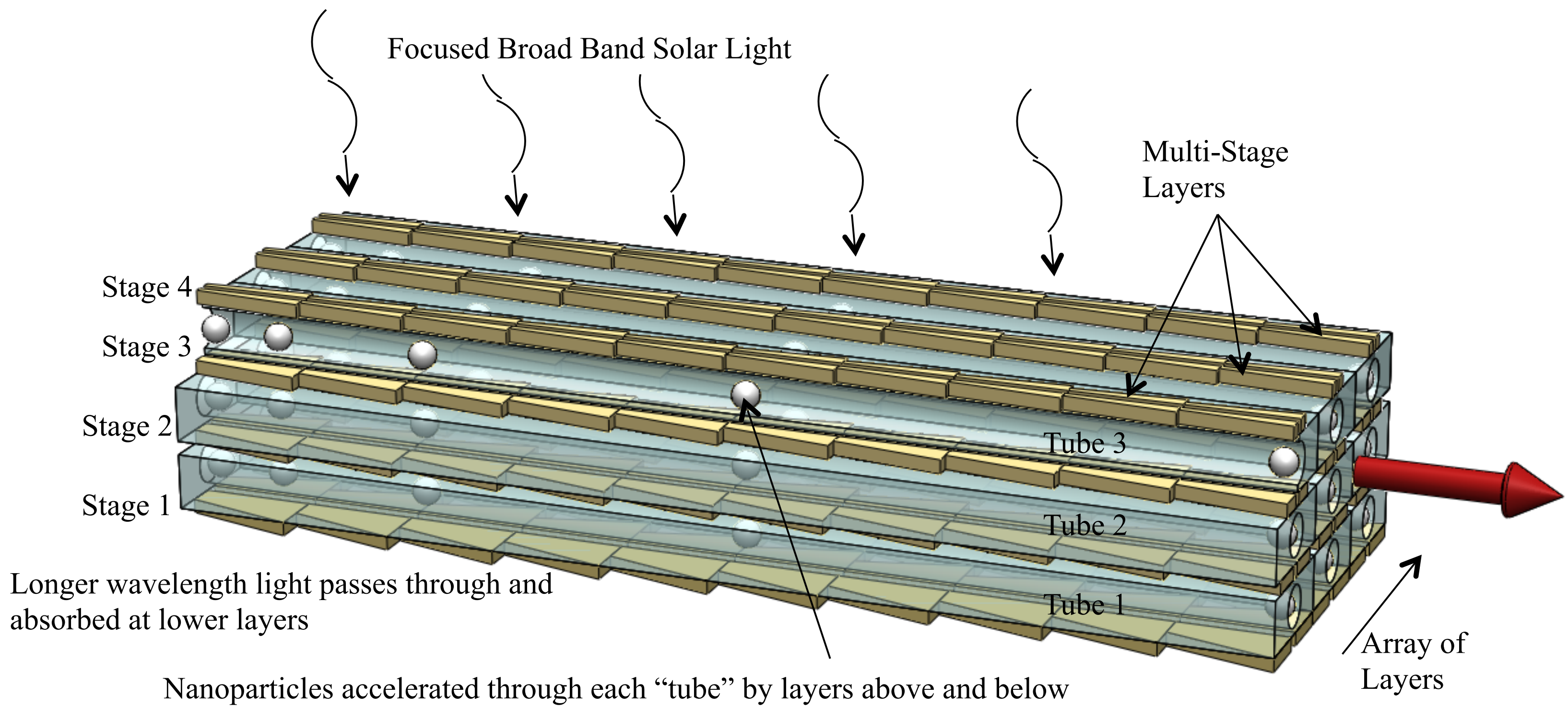


Stage 1, ~800 nm | Stage 2, ~700 nm | Stage 3, ~600 nm | Stage 4, ~500 nm



- Unique Nanostructures
  - Resonate with desired wavelengths in broadband
  - Force profile magnitudes altered by solar intensity
  - Utilizes most intense band of solar emission spectra

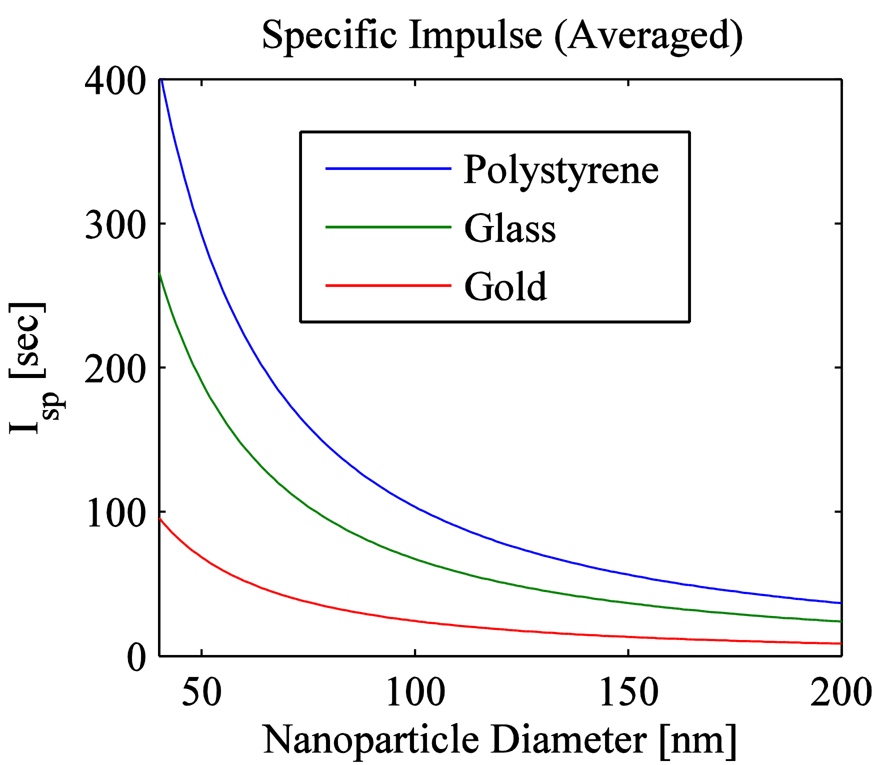
Thruster Design

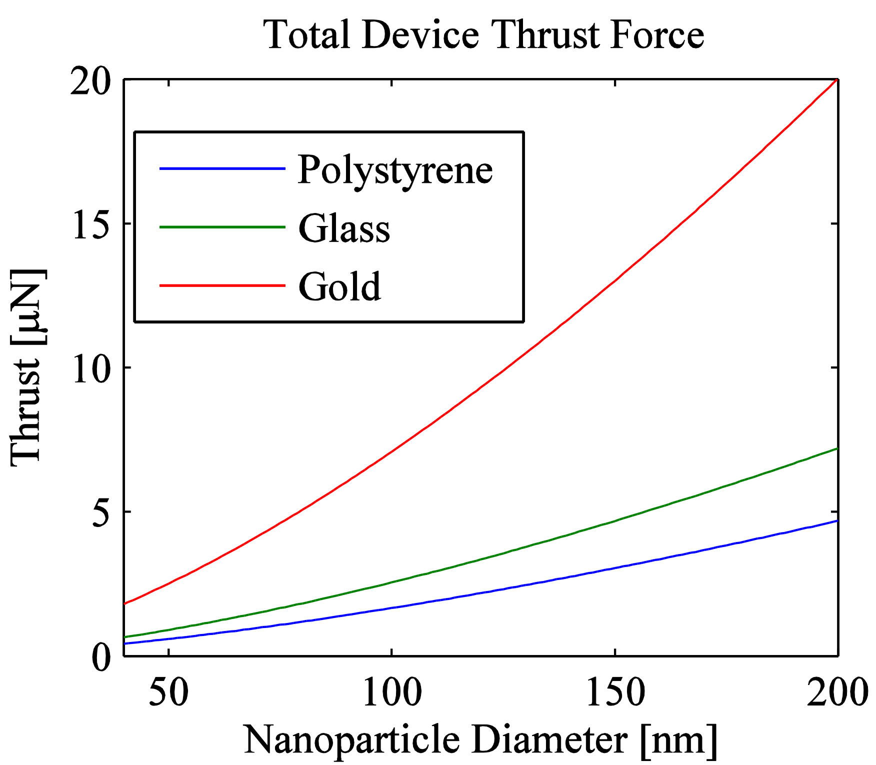


- Plasmonic Force Thruster Device
  - Three layers of ~1000 'tubes' to support and channel
  - Nanoparticles feel forces from above and below each tube

Propulsion Predictions

$$\frac{v^2}{2} = \int_0^L \frac{F(y)}{m} dy \qquad T = \frac{d}{dt}(mv) = \dot{m}v = Nmfv \qquad I_{sp} = \frac{v}{g_0}$$

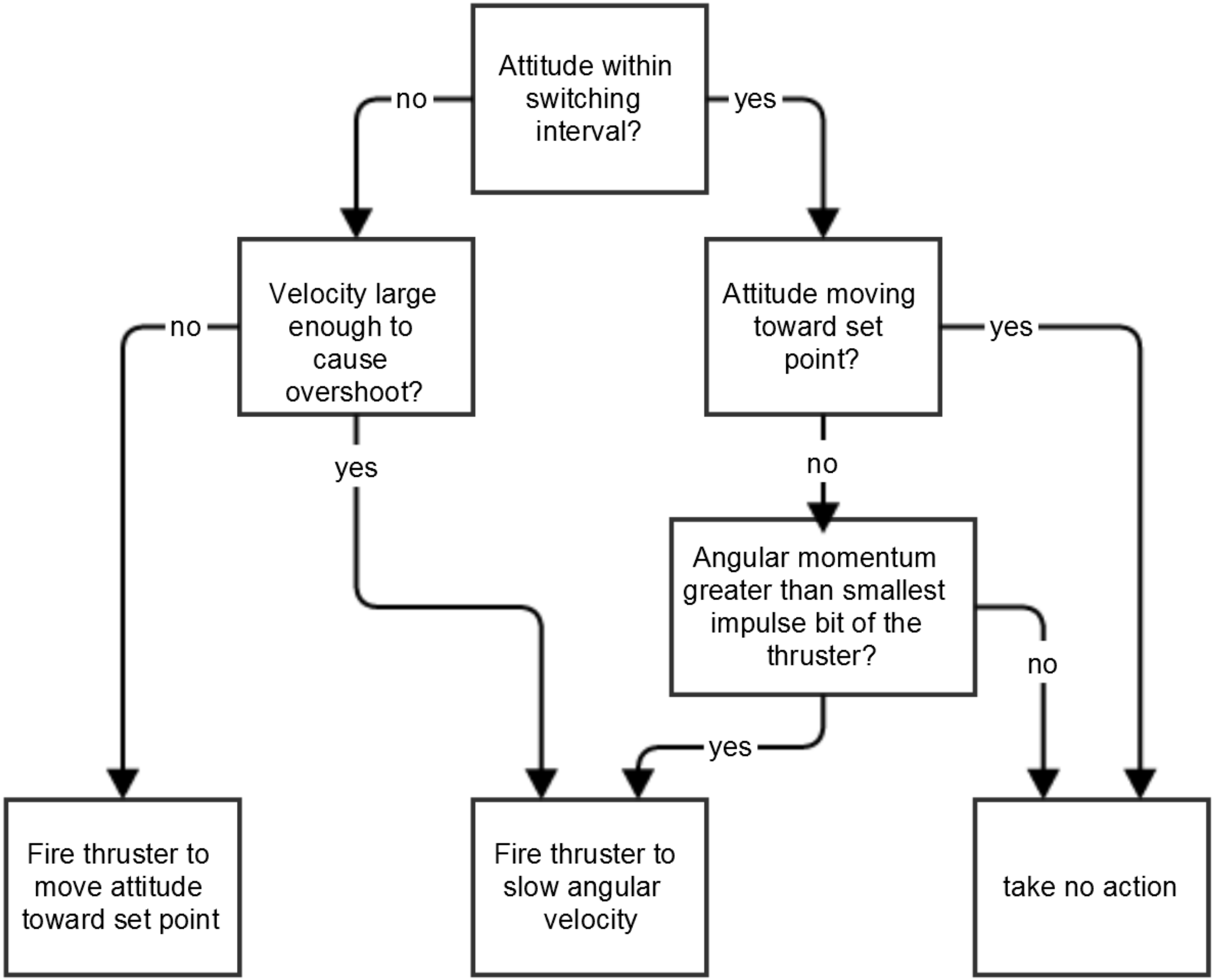




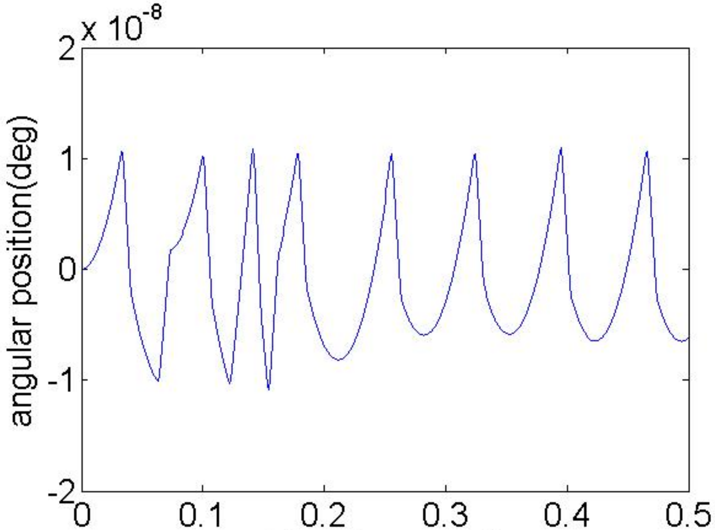
Mission Context Assessment

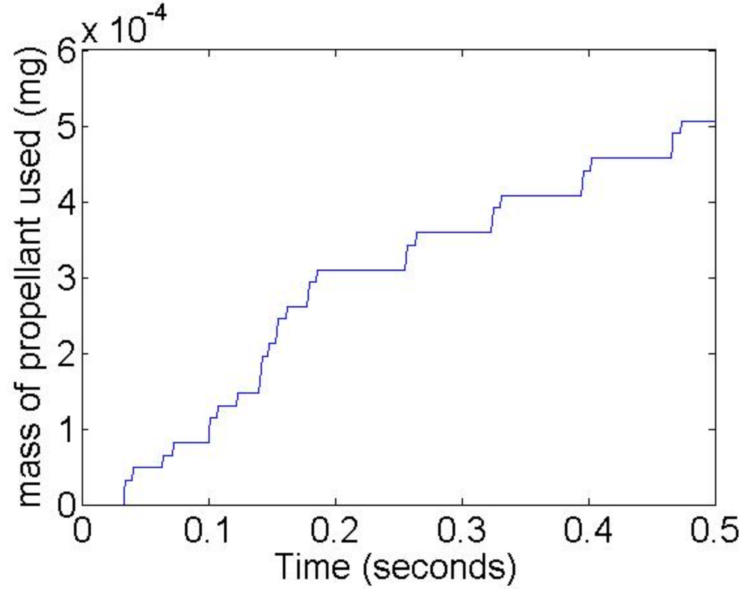
- On-Off ACS Model
  - Simple First-Principles Analysis
  - Quickly Compare SoA Thrusters/Torquers Control Authority
  - Pointing and Positioning Accuracy
- Cubesat RCSs compared using following assumptions
  - Attitude constantly known with zero error
  - Minimum impulse bit for each thruster has no variation.
  - Solar radiation pressure is only disturbance
  - Solid 1U cube sat with 2 kg mass

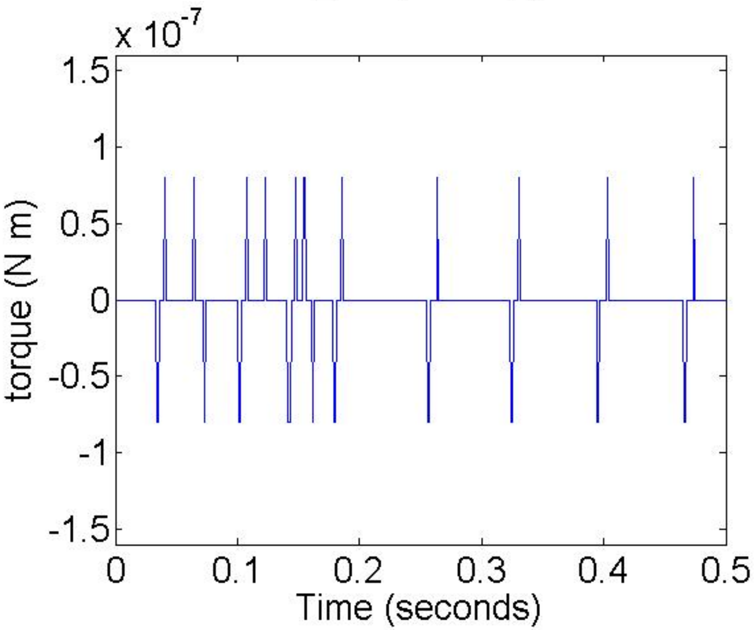
On-Off ACS Algorithm



Sample Output of ACS Simulation







-CubeSat with plasmonic thrusters holding 10^{-8} degree pointing accuracy

-With 50g of propellant this accuracy could be held for ~500 days

Thruster Comparison

Thruster Type	Plasmonic Propulsion	μCAT	Electrospray
Thrust (N)	$1.6x10^{-6}$	$1x10^{-4}$	$1x10^{-4}$
Isp (s)	100	3000	2500-5000
Switching time(ms)	1	10	1
Pointing accuracy (deg)	$1x10^{-8}$	$1x10^{-4}$	$1x10^{-6}$
Position accuracy (m)	$1x10^{-11}$	$6x10^{-8}$	$6x10^{-10}$
System mass (g)	~50	200	~300
Power (W)	~0	0.1-6	10

Other Activities

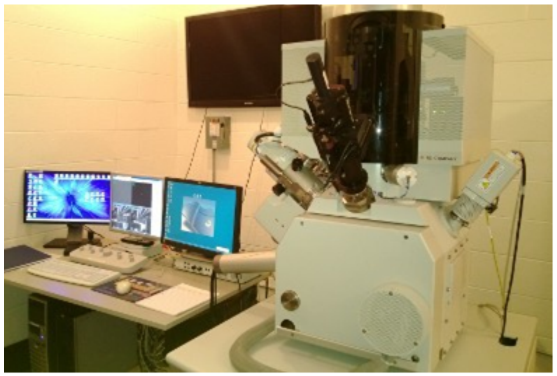
- NASA Interaction
  - Ames: Lead for Small Spacecraft
  - Mission Design Division
    - Division Chief: Dr. Chad Frost
    - Chief Technologist: Dr. Elwood Agasid
    - Conduct early-stage concept development and technology maturation supporting the Center's space mission proposals
    - Facilities and software for rapid mission development and analysis. Experts covering the domains required to fully develop successful spacecraft mission concepts

Phase II Plans

- Raise TRL 2 to 3
- Experimentally Demonstrate Nanoparticle Propulsion
  - Fabricate single, multi-stage asymmetric nanostructures
  - Characterize transmission spectra, characterize nanoparticle motion
  - Compare experiment with model predictions
  - Update propulsion predictions, Smallsat controllability predictions

Phase II – Capability

- Device fabrication facilities



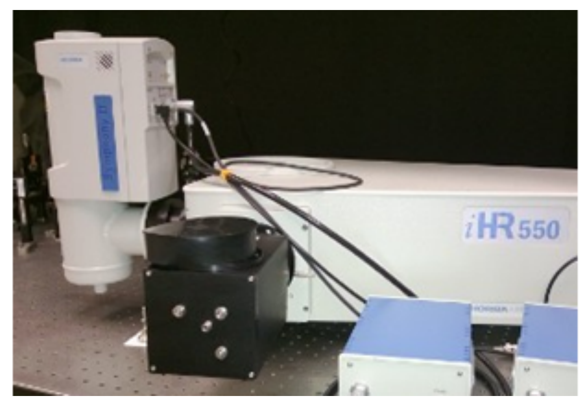
FIB

SEM

- Optical characterization equipment

Lasers

Microscope



Spectrometer

Major Conclusions to Date

- **Main Question:** Is plasmonic propulsion feasible for nano/picosatellite applications?
  – Still to be finalized, but appears promising
- Nanostructures that produce fields for expelling nanostructures are possible
  – Can also be designed with narrow band in solar spectrum, i.e., 40nm FWHM for 500nm resonance
- Optimum Use of Solar Light and Useable Thrust Requires Multi-stage, Layered, Arrays
- NASA Ames wants to work with us
- Phase II – we have the capability to Raise TRL 2 to 3
  – Facilities, equipment to fabricate, test nanostructures

Questions?