Concept of Operations (ConOps) Documentation & Camera Pointing Evaluation Tool

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Chris Zheng
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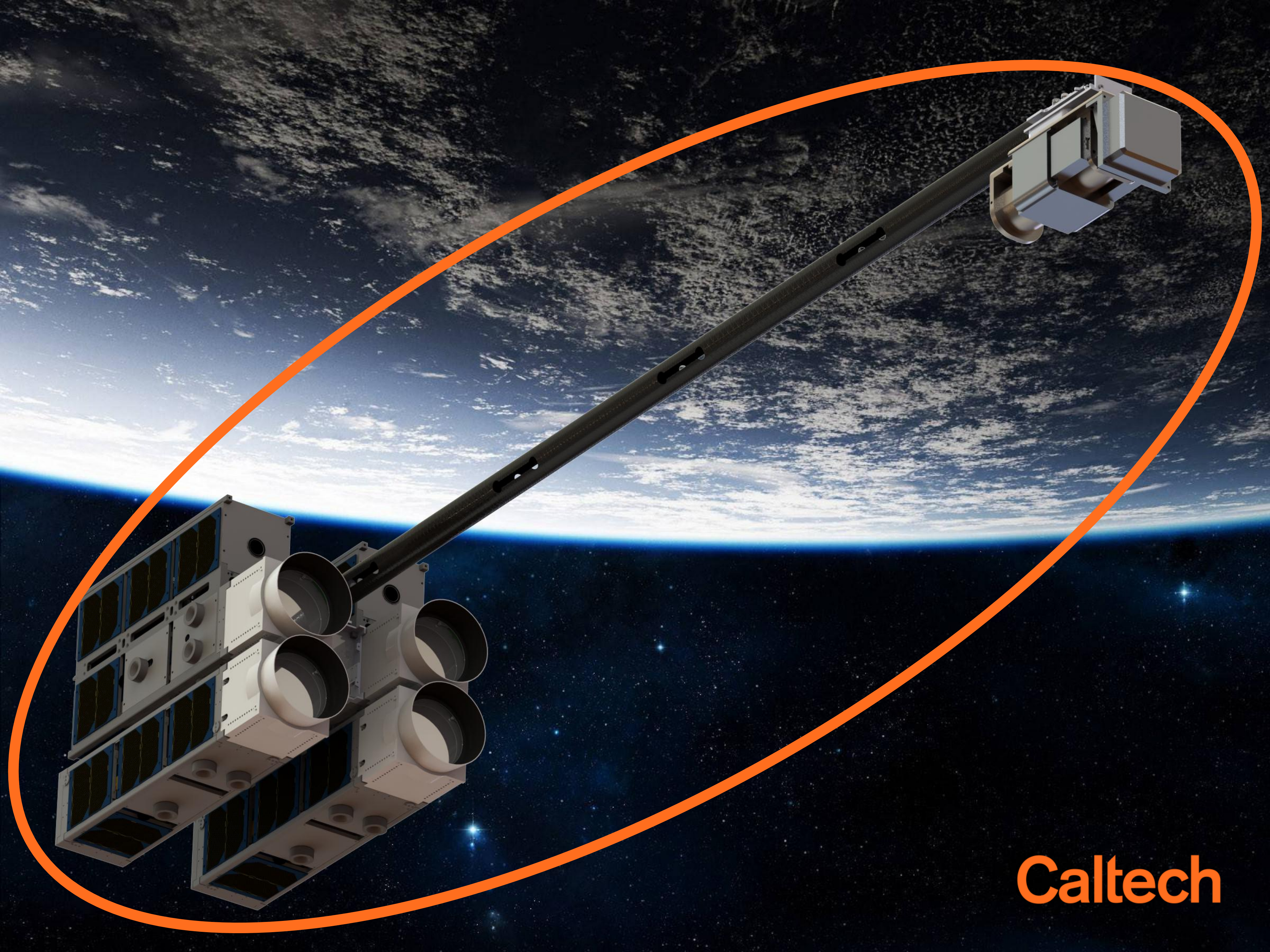
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Concept of Operations (ConOps) Document

- Useful introduction to AAReST for incoming team members
- Centralized reference for current group members
- A way to make sure teams have a consensus on mission and subsystem goals and objectives, while also providing a space to record their progress
- ‘Living’ document to consolidate essential project information
  - Up to date mass and power budget, mission requirements, subsystem requirements, mission plan, etc.

Table of Contents

Risk Table

If	Due to	Then (Consequence)	Likelihood of Occurrence	Pre-Flight Risk Reduction	Software Fix	Hardware Fix	Rescue Likelihood
Preoperational: Boom Deployment							
Restraint strap does not burn	Insufficient power	Boom does not deploy – mission failure	Unlikely	Test power intake		Turn off non-operational/non-essential parts, turn the spacecraft to get more power	Very likely
	Mechanical fault		Unlikely	Test durability			Unlikely
Hinges do not unfold	Insufficient strain	Boom does not deploy or boom does not stay in alignment, thus unable to align with mirrors and take an image – mission failure of some L1 goals (can still reconfigure)	Unlikely	Test durability, do not store in folded configuration for too long		Shock the spacecraft to attempt to shake the boom loose by pulsing thrusters or reaction wheels	Very likely
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	Boom-strap friction too great		Unlikely	Test deployment with strap		Shock the spacecraft	Likely
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Preoperational: Boom Deployment Continued							

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Hinges do not unfold	[illegible]	Boom [illegible] does not stay in alignment, thus unable to align with mirrors and take an image – mission failure of some L1 goals (can still reconfigure)	[illegible]	Test [illegible] in folded configuration for too long		[illegible] to attempt to shake the boom loose by pulsing thrusters or reaction wheels	[illegible] likely
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Phase – ***Preoperational: Boom Deployment***

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“**If**” is the fault

Example: “Hinges do not unfold”

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Preoperational: Boom Deployment Continued							

“**Due to**” is the reason for the fault, can have many per fault

Example:

- Insufficient strain
- Hinges damaged
- Boom-CoreSat friction too great
- Boom-strap friction too great

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Risk Table

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	Hinges not fully deployed		Unlikely	[illegible] under non-ideal conditions		Shock the spacecraft	Unlikely
Preoperational: Boom Deployment Continued							

"**Then**" is the consequence from the fault

Example:
Boom does not deploy or boom does not stay in alignment, thus unable to align with mirrors and take an image – mission failure of L1 goals (cannot image or reconfigure)

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Risk Table

If	Due to	Then (Consequence)	Likelihood of Occurrence
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Restraint strap does not burn	Insufficient power	Boom does not deploy – mission failure	Unlikely
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	Mechanical fault		Unlikely
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	Hinges not fully deployed		Unlikely
		Preoperational: Boom Deploymen	

"**Likelihood**" is the risk Categories: Very likely, Likely, Unlikely

Example:
Hinges having insufficient strain is "Unlikely" because we will have done testing to prove this.

Need to validate "likelihood"

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Risk Table

"**Pre-flight Risk Reduction**" are tests, design changes, etc. to determine likelihood and make the fault less likely

Example:
Hinges should be tested for deployment in nominal cases, and also off nominal cases, such as after heavy launch vibrations

Pre-Flight Risk Reduction	Software Fix	Hardware Fix	Rescue Likelihood
Preoperational: Boom Deployment			
Test power intake		Turn off non-operational/non-essential parts, turn the spacecraft to get more power	Very likely
Test durability			Unlikely
Test durability, do not store in folded configuration for too long		Shock the spacecraft to attempt to shake the boom loose by pulsing thrusters or reaction wheels	Very likely
Test durability (shake tests, etc)		If boom can still stay stiff, attempt to shock the boom to deploy; otherwise no fix	Unlikely
Test deployment with mock CoreSat		Shock the spacecraft	Likely
Test deployment with strap		Shock the spacecraft	Likely
Test power intake		Turn off non-operational/non-essential parts, turn the spacecraft to get more power	Likely
Test durability			Unlikely
Test durability under non-ideal conditions		Shock the spacecraft	Unlikely
Test effectiveness under non-ideal conditions		Shock the spacecraft	Unlikely
Preoperational: Boom Deployment Continued			

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Risk Table

“**Software Fix**” and “**Hardware Fix**” are contingency operations for during the mission

Example:

- If boom does not deploy due to friction, then shock the spacecraft with its thrusters and reaction wheels to force a boom deployment.
- If boom does not deploy due to a crack, then we have not developed a contingency plan.

No contingency plan: red flag!

Software Fix	Hardware Fix
	Turn off non-operational/non-essential parts, turn the spacecraft to get more power
	Shock the spacecraft to attempt to shake the boom loose by pulsing thrusters or reaction wheels
	If boom can still stay stiff, attempt to shock the boom to deploy; otherwise no fix
	Shock the spacecraft
	Shock the spacecraft
	Turn off non-operational/non-essential parts, turn the spacecraft to get more power
	Shock the spacecraft
	Shock the spacecraft

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Risk Table

“**Rescue Likelihood**” is how likely we will recover from the fault

Categories: Very likely, Likely, Unlikely

Rescue Likelihood
Very likely
Unlikely
Very likely
Unlikely
Likely
Likely
Likely
Unlikely
Unlikely
Unlikely

Example:

- If boom does not deploy due to friction, then shocking the spacecraft is a “very likely” fix
- If boom does not deploy due to a crack or mechanical failure, then we are “unlikely” to fix it

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Risk Table

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Preoperational: Boom Deployment Continued							

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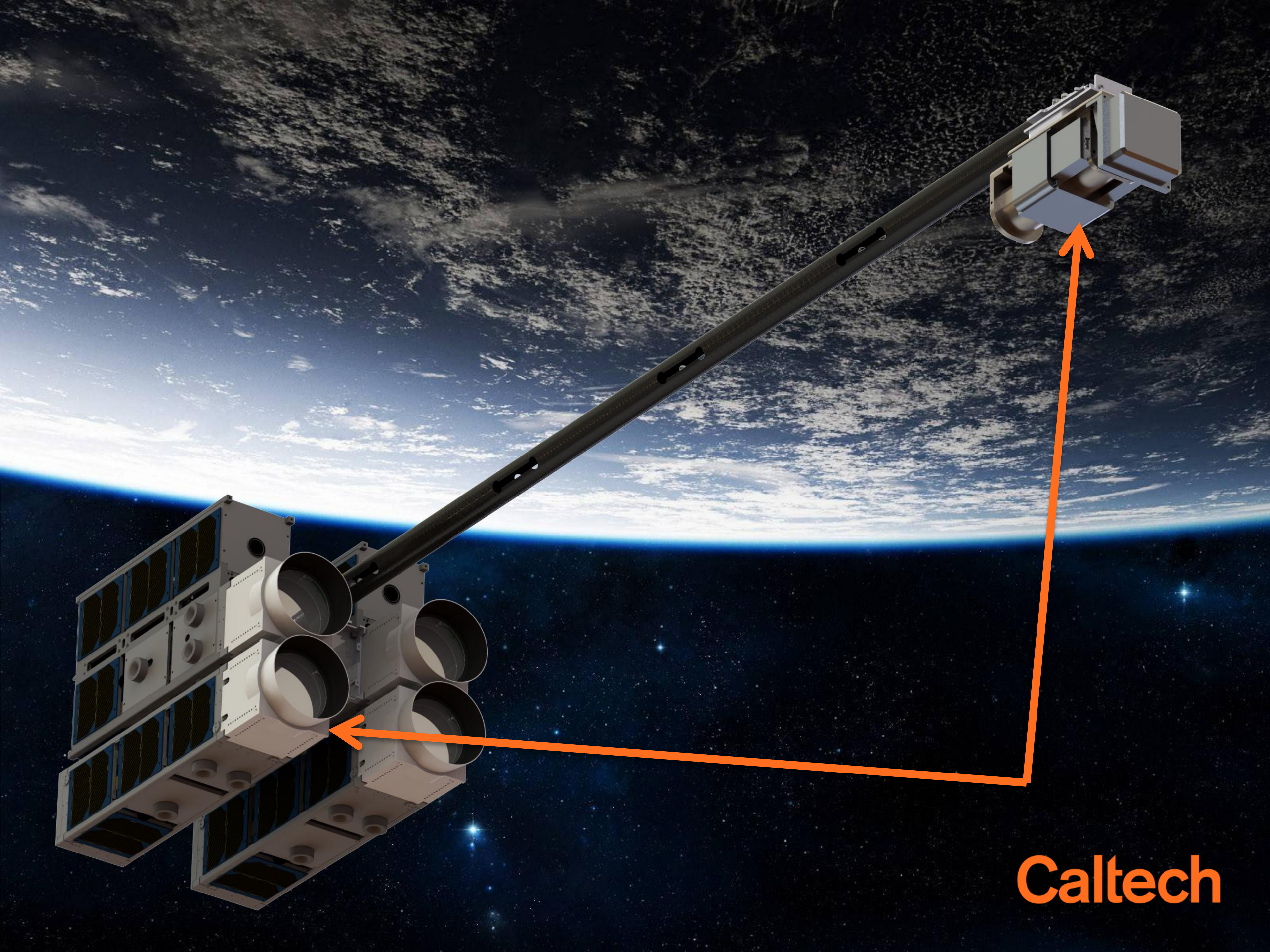
Recommendations

- Continue to identify and reduce risks and incorporate them into the document maintaining a centralized record
  - Reduce number of single point failures
- Prioritize robust launch simulation tests for all hardware in its launch configuration (shake tests)
- Consider utilizing the boom inspection camera to measure the relation between the camera and spacecraft positions over time
- Develop better configuration management to help address the issues of workers separated temporally (year to year turnover) as well as spatially (Pasadena and Surrey)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Camera Pointing Capability Evaluation

- Goal: Develop an evaluation tool to assess camera jitter due to reaction wheels disturbances incorporating the relevant flexible modes of the boom
- Camera Requirements:
  - Jitter: <0.02°/s
  - Pointing accuracy: <0.10°
  - Duration: ≥600s

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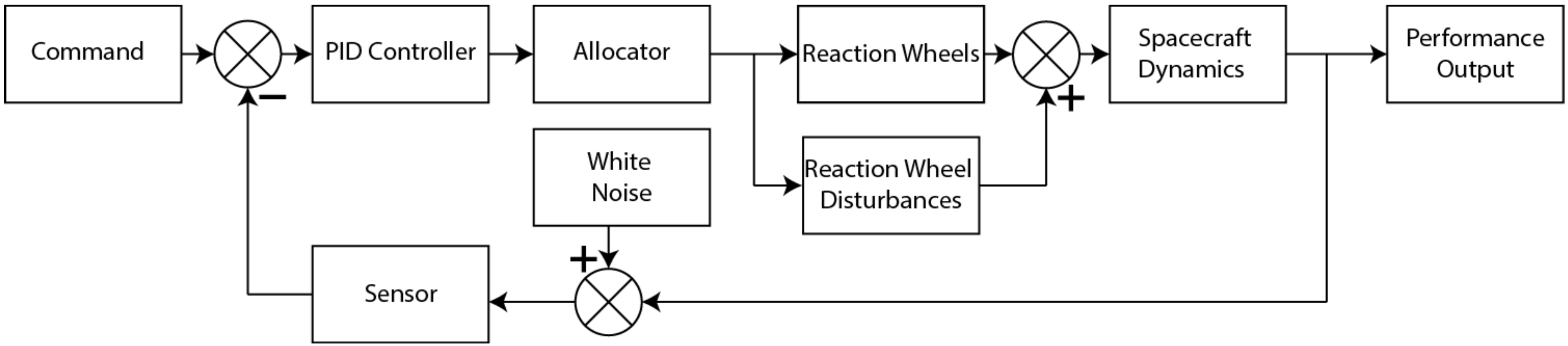
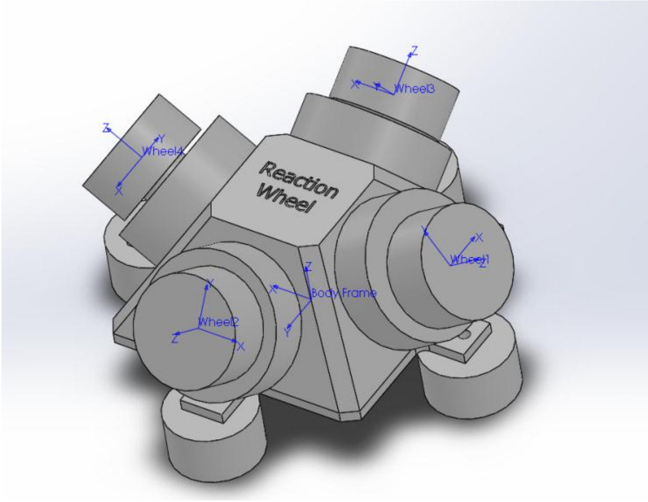
Overview of Tool

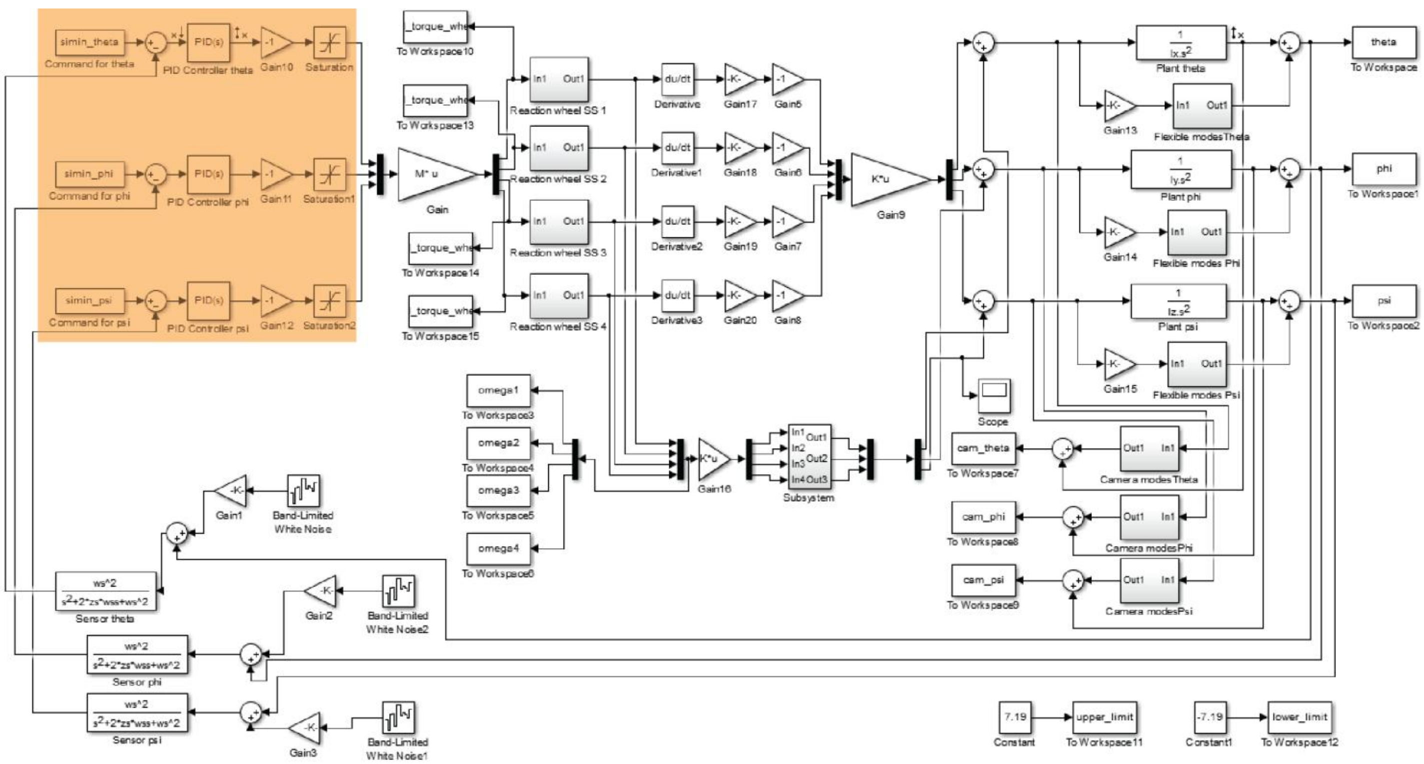
Developed close-looped Simulink model of entire spacecraft



- Allocator using pseudo-inverse
- Comprehensive reaction wheel model
- Reaction wheel disturbance model with variable phasing capability
- Spacecraft dynamics based on simplified FE model
- Jitter determination through performance output
- Second order sensor transfer function



Simulink Model



PID Controller

Allocator

Reaction wheel model

Reaction wheel disturbances

Rigid body plant

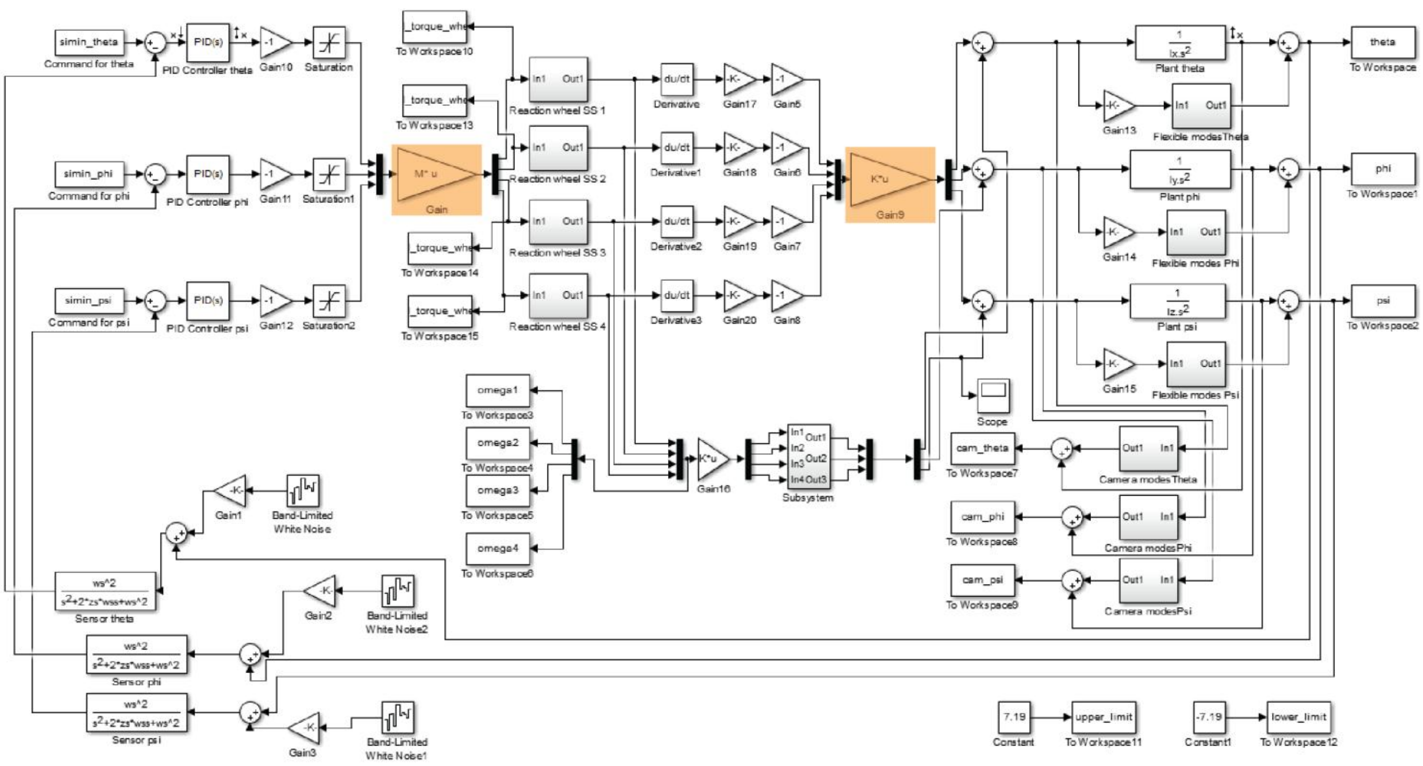
Flexible modes transfer function

Camera jitter evaluation

Sensor Noise

Sensor transfer function

Simulink Model



- PID Controller
- **Allocator**
- Reaction wheel model
- Reaction wheel disturbances
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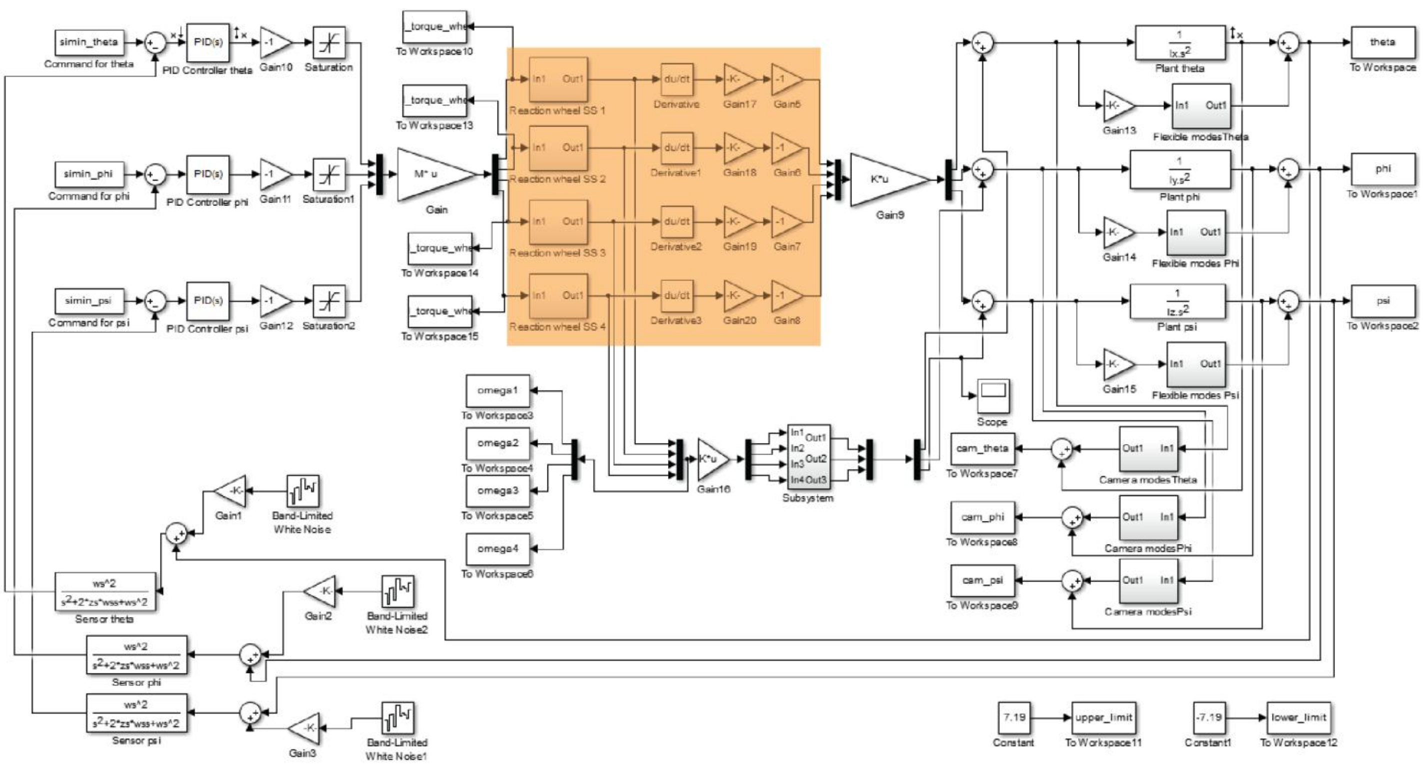
Simulink Model



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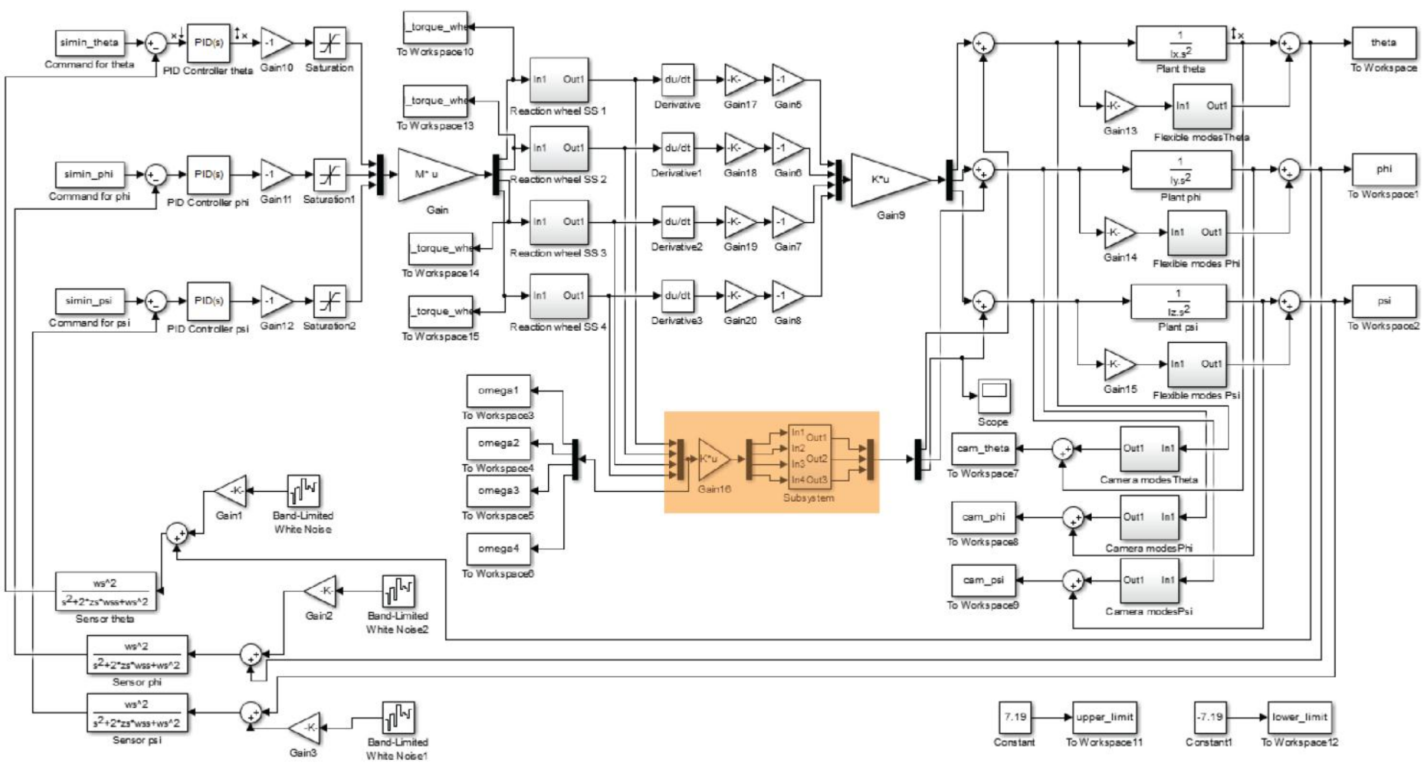

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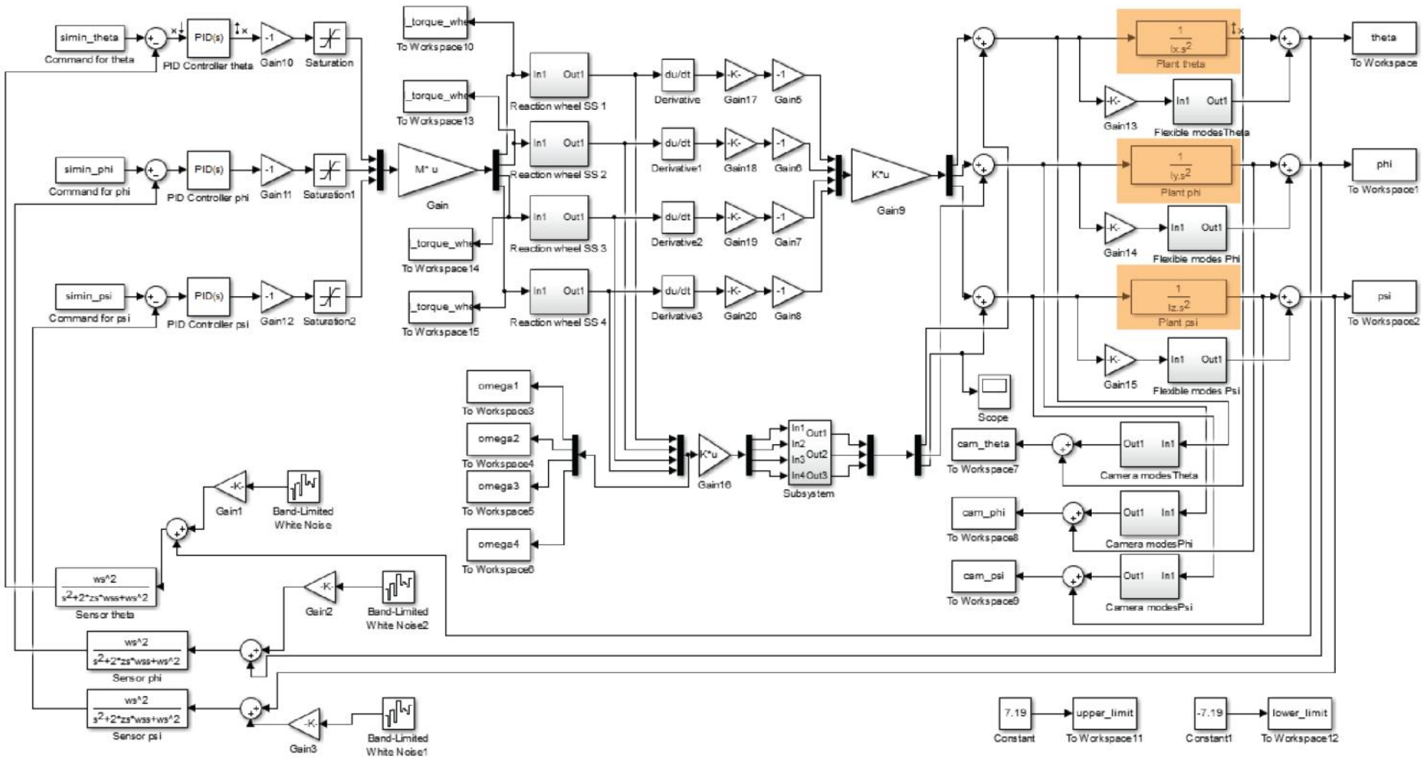

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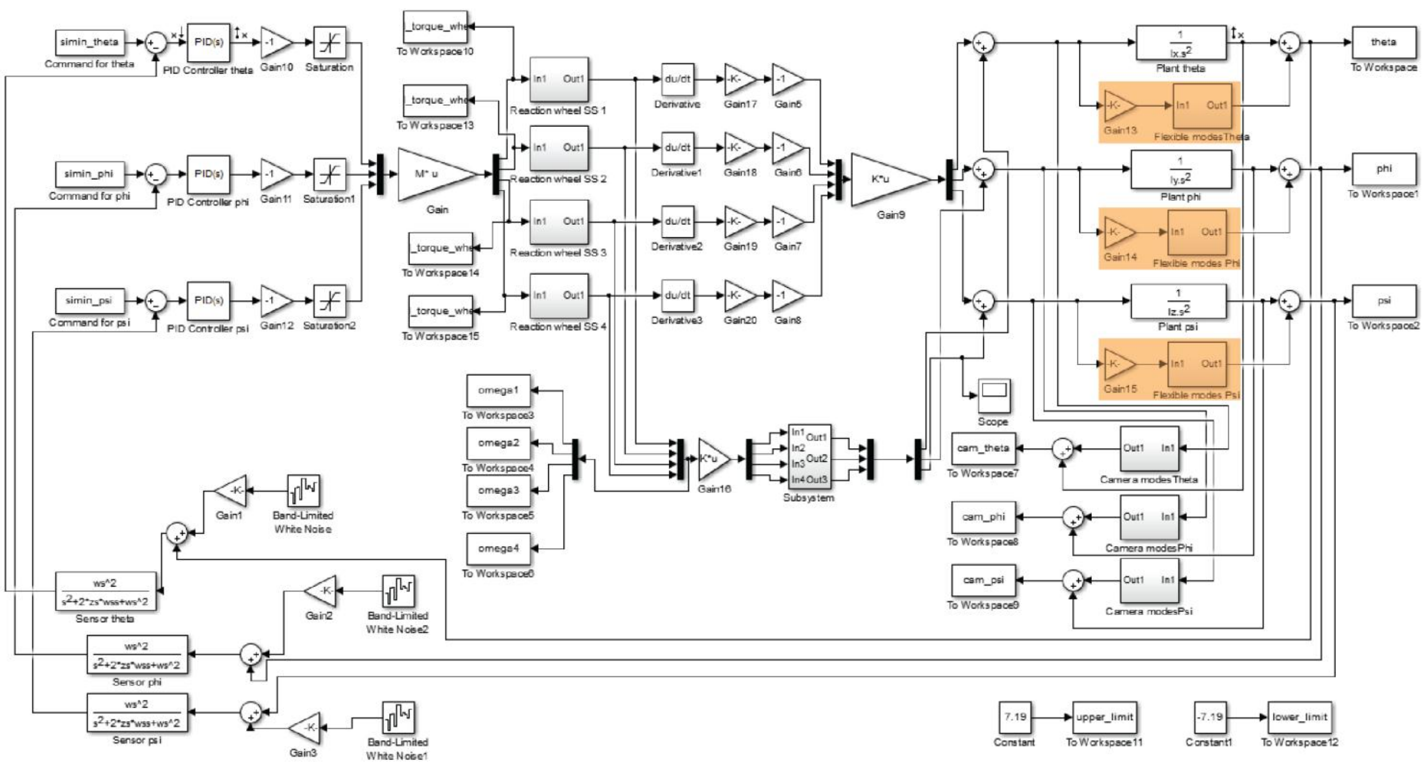

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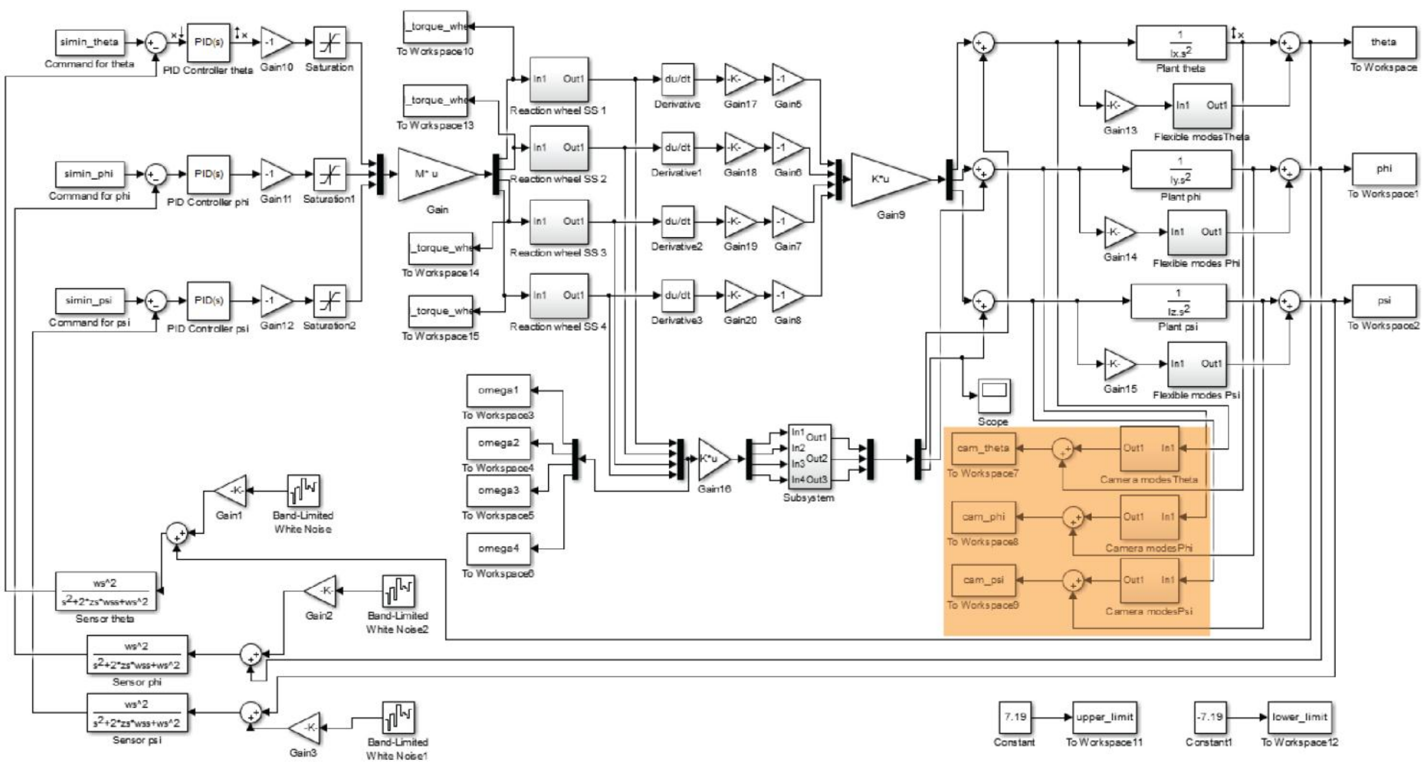

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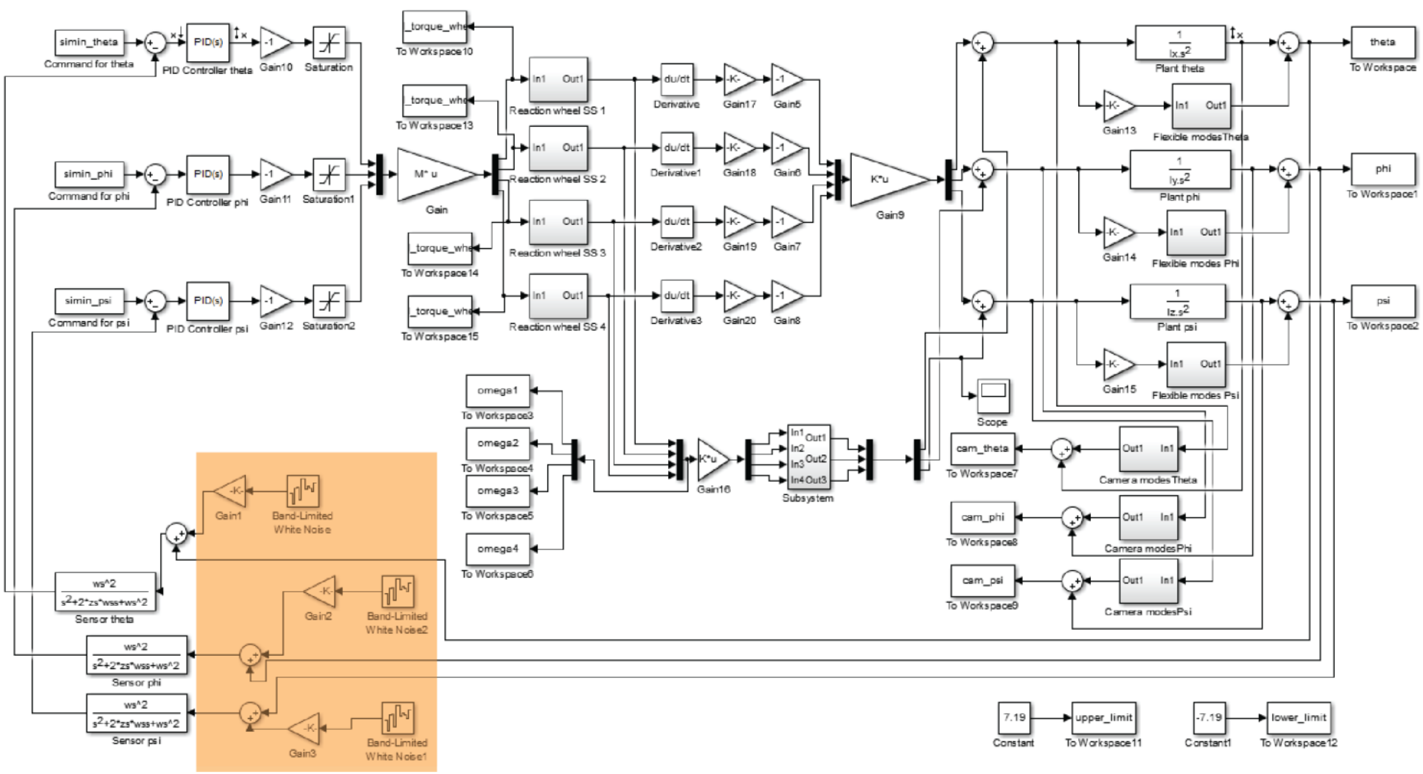

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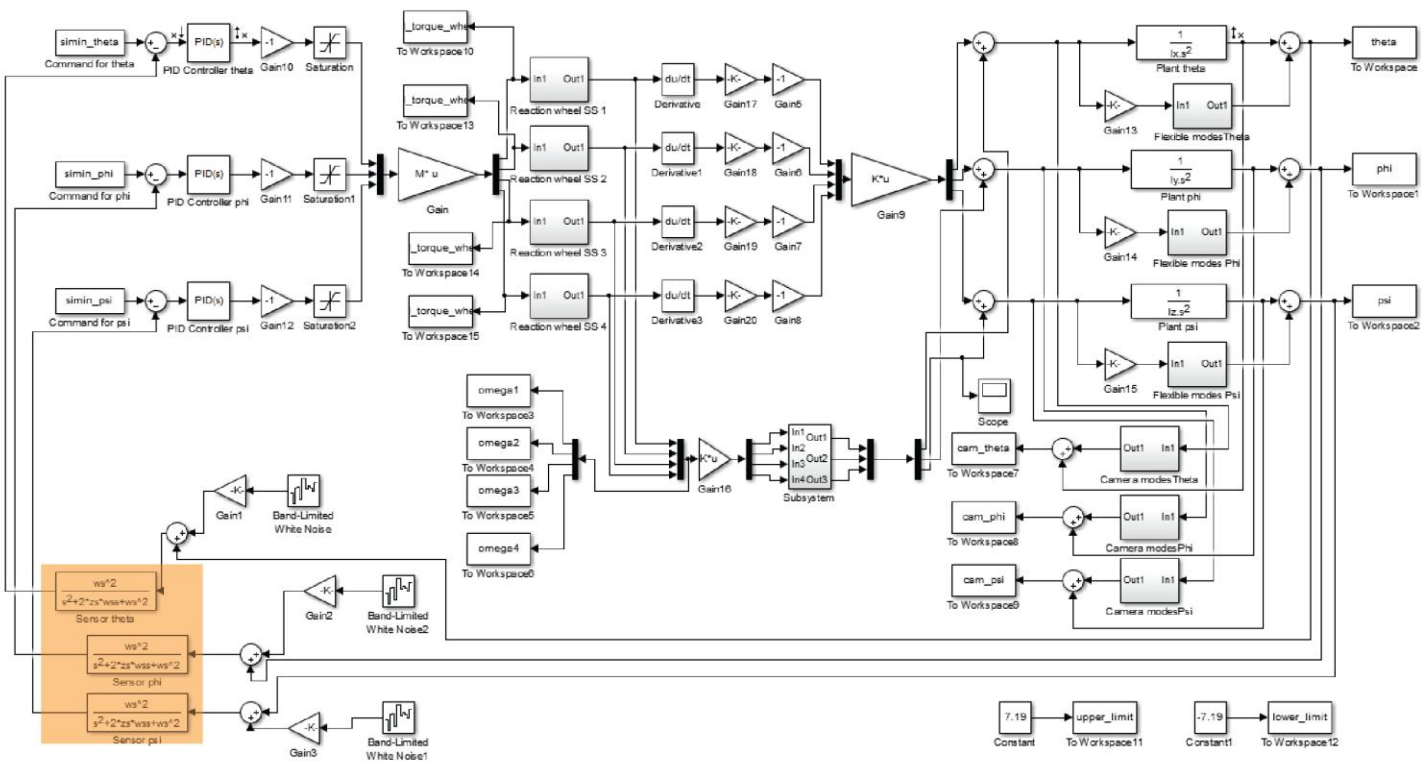

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- **Sensor transfer function**

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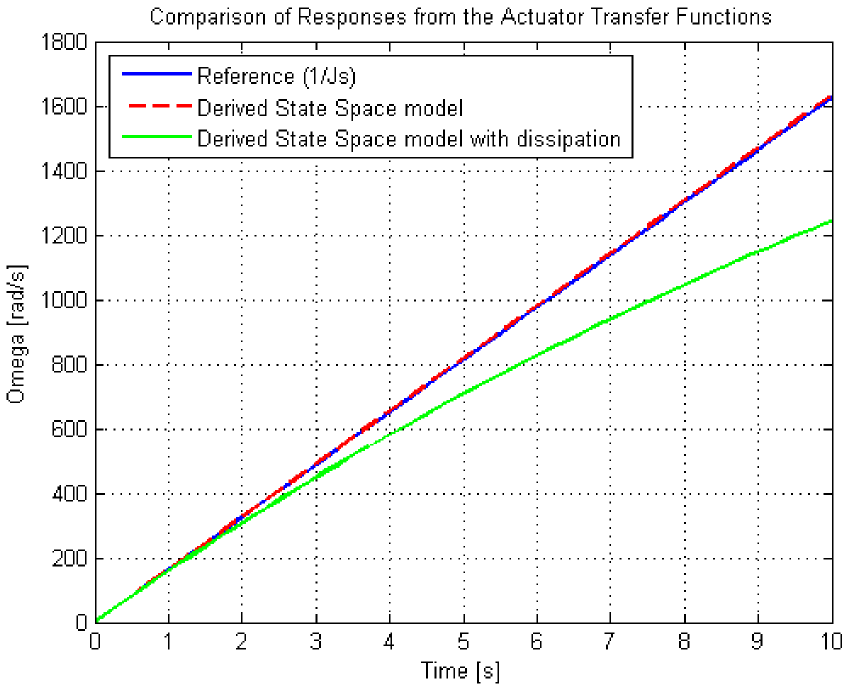
Major Unit Tests Preformed

- Reaction wheel model
- Disturbance model output check
- Sensor transfer function comparison to manufacturer data



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Simulation Verification

Unit test system feed reaction wheel disturbance sinusoid to flexible modes and seek to match analytic predication

$$\sum \mathrm{T}(\omega; t) = \sum A(\omega) \cdot \sin(\omega t + \varphi)$$

↓

Flexible Modes, $G(j\omega)$

↓

$$\psi\,(\omega; t) = B(\omega) \cdot \sin(\omega t + \theta)$$

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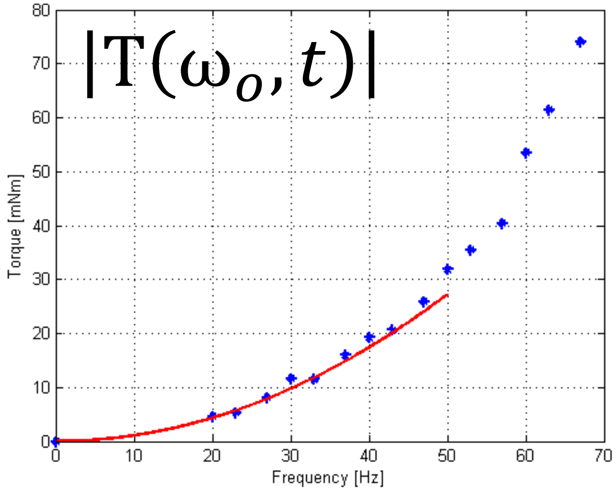
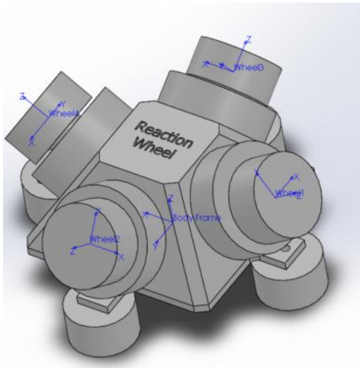
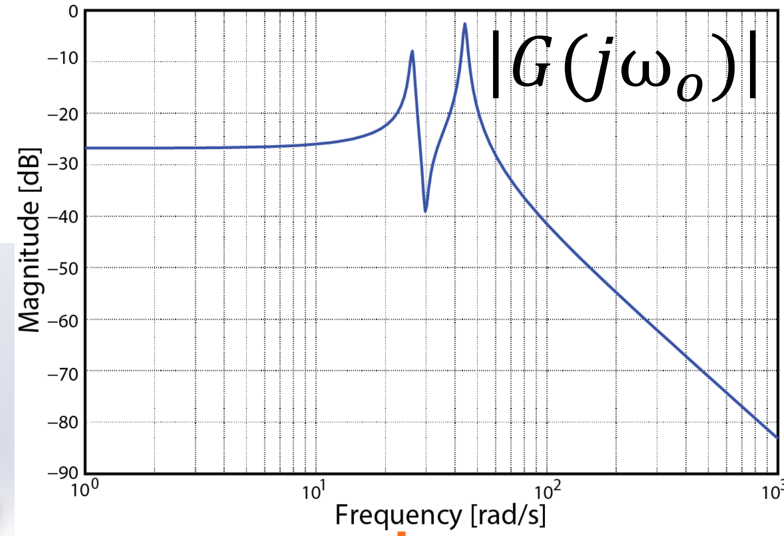
Simulation Verification

Reaction Wheel Disturbance Model





Bode Plot: Flexible Modes, No Rigid Body



$$\mathrm{N} \cdot \sin(\beta)$$

$$|\psi(\omega_o, t)| = \mathrm{N} \cdot |\mathrm{T}(\omega_o, t)| \cdot \sin(\beta) \cdot |G(j\omega_o)|$$

Simulation Verification

$\omega_o = 7.1\text{Hz}$

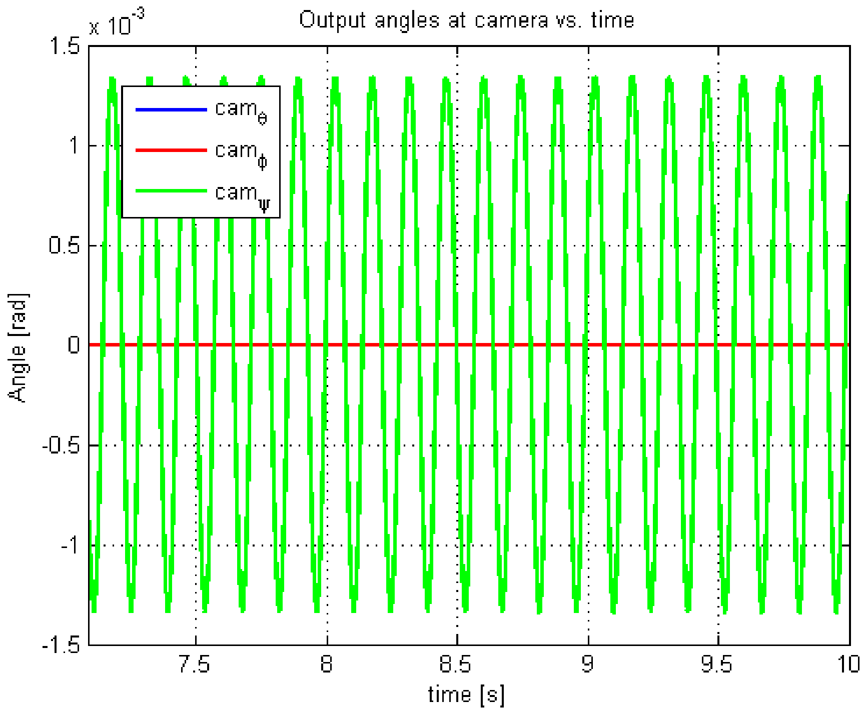
N=4

$|T(\omega_o, t)| = 0.54 \text{ mNm}$

$\beta = 56.31°$

$|G(j\omega)| = -2.55\text{dB}$

$\therefore |\psi(\omega_o, t)| = 1.3 \text{ mrad}$



Results are as expected

$$|\psi(\omega_o, t)| = N \cdot |T(\omega_o, t)| \cdot \sin(\beta) \cdot |G(j\omega_o)|$$

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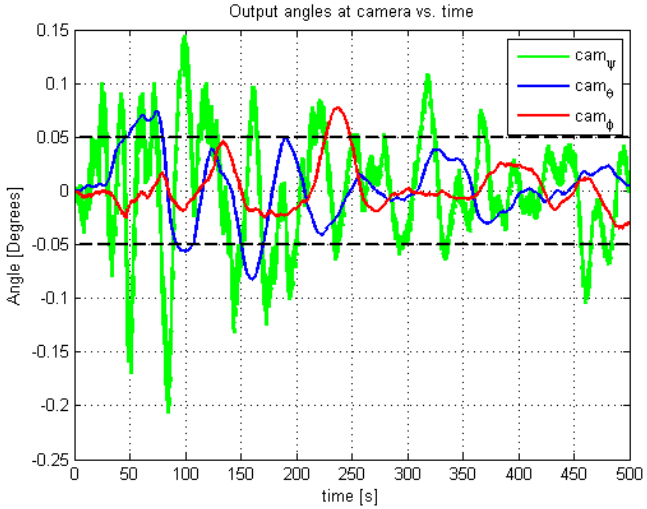
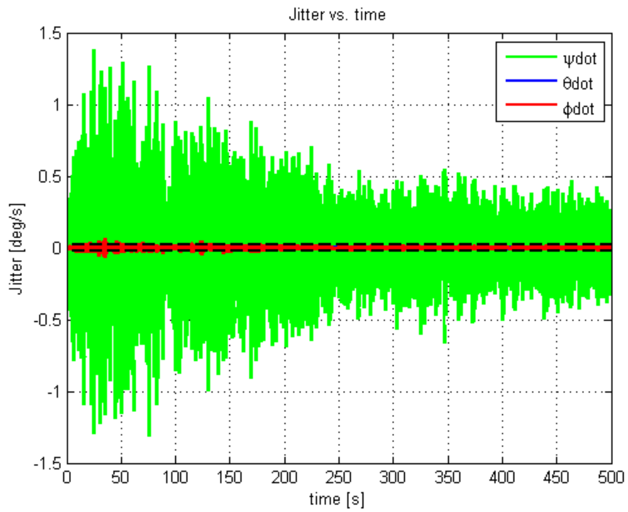
Sample Results





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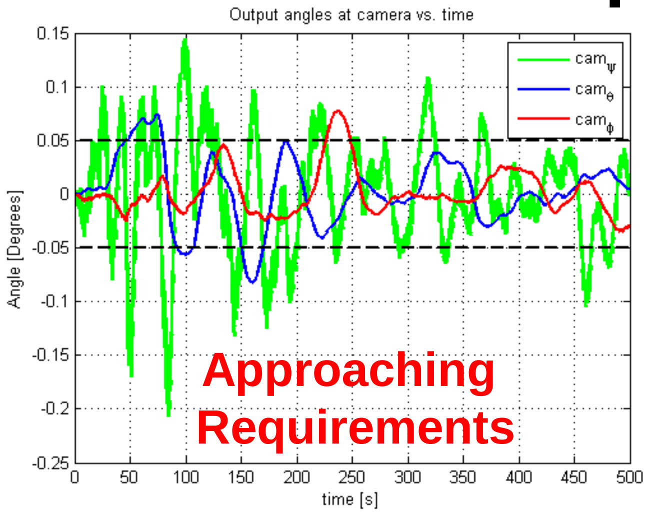
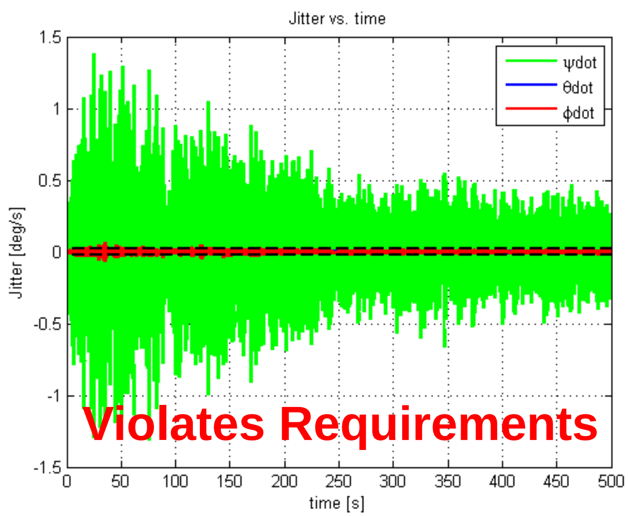
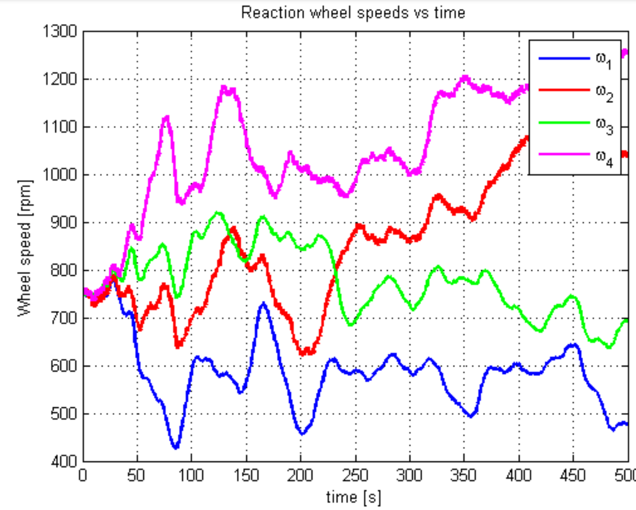
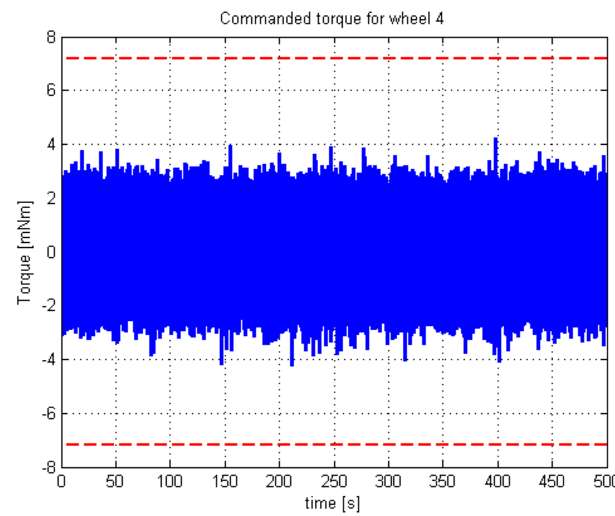
Sample Results









Within Reaction Wheel Specifications

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Moving Forward

- Develop model and implement reaction wheel isolation transfer function
  - Work currently being performed by Surrey
- Obtain and update the reaction wheel disturbance model
  - Current data was taken on a unbalanced wheel
- Deterministic sweep of reaction wheel speeds with random disturbance phasing to determine wheel speeds where camera requirements met

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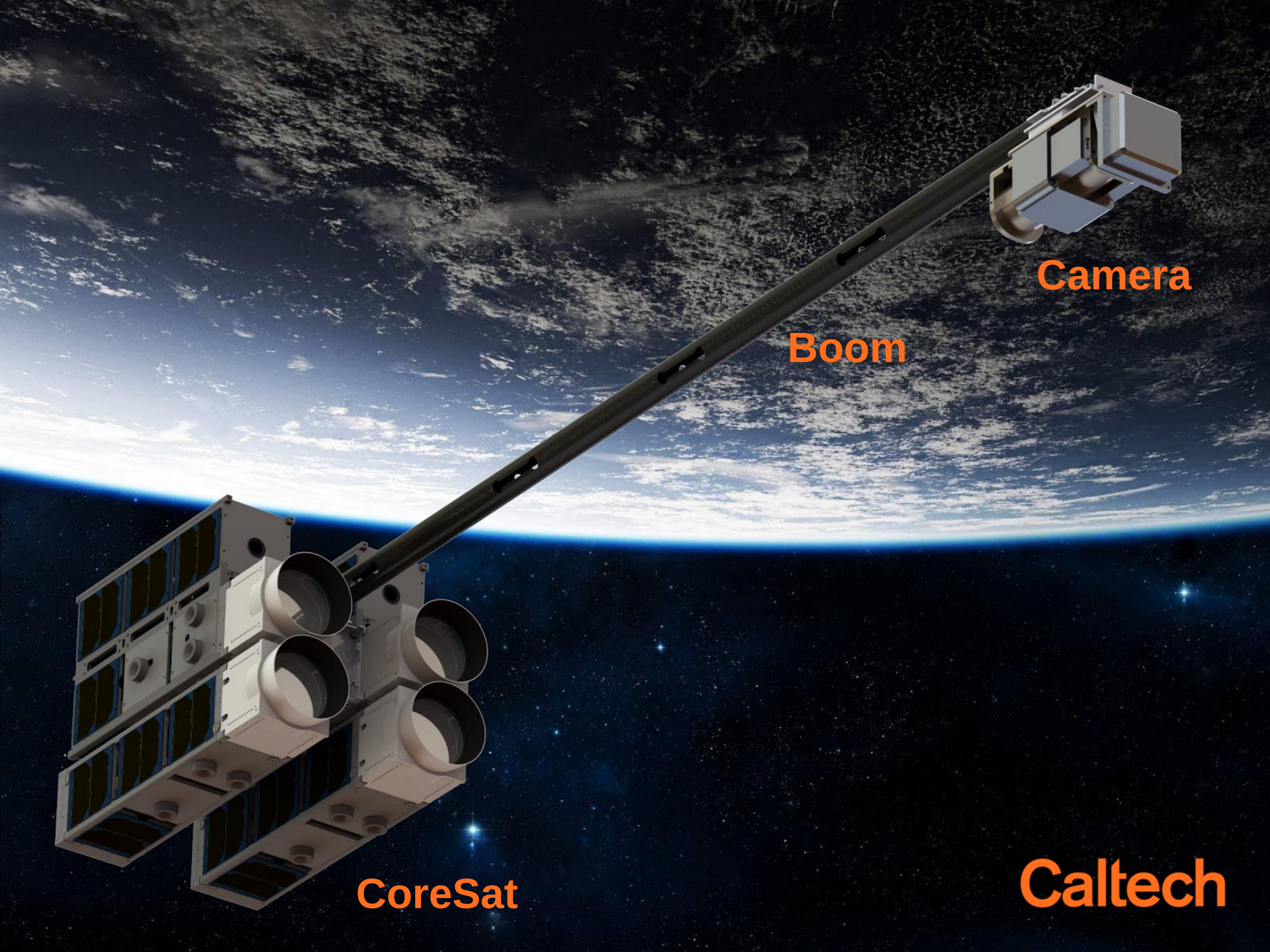
Questions?

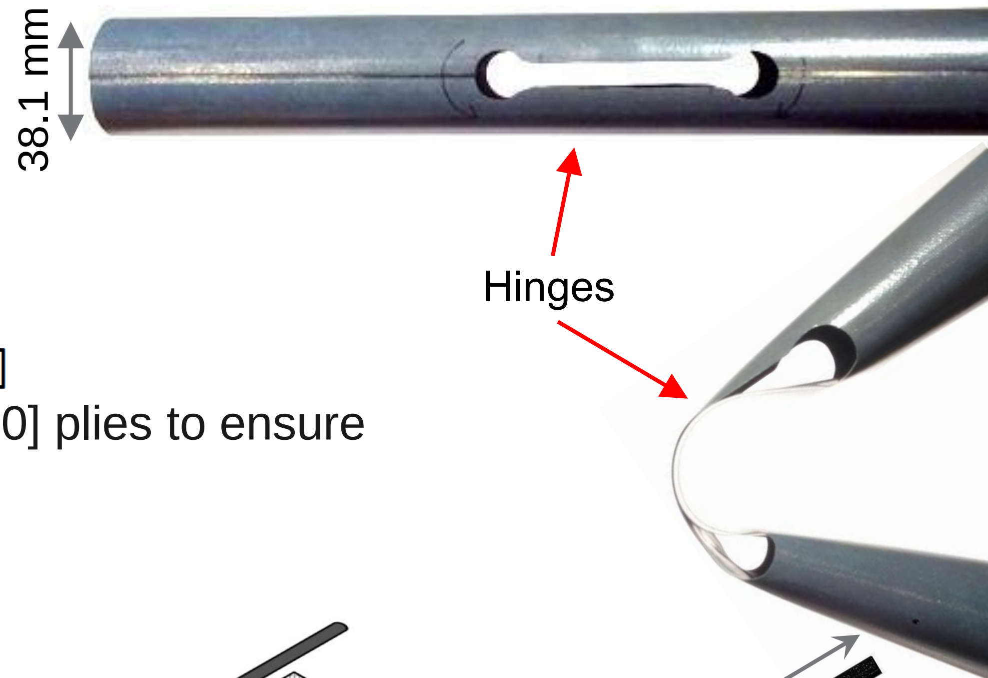
Boom Subsystem

Sandra Fang, Arturo Mateos,
Yuchen Wei, Michael Williamson

Mentor: Lee Wilson

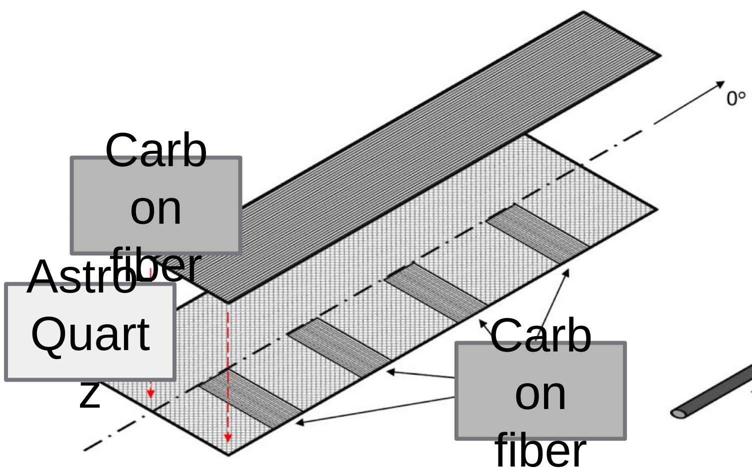

Camera
Boom
CoreSat
Caltech

What is the Boom?

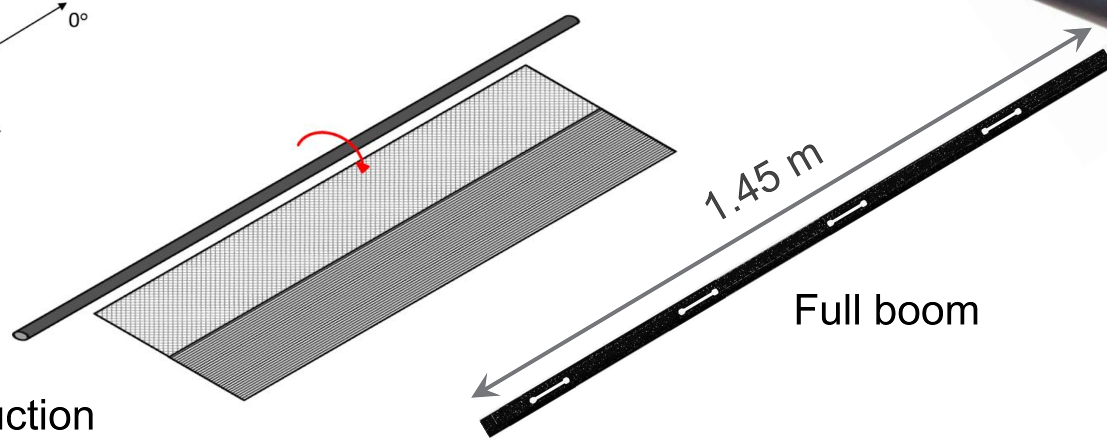


Lay-up consists of
- Plain-weave AstroQuartz
- Unidirectional carbon fiber

Lay-up sequence
- General: [$\pm45_{AQ}$ / $0_{3\ CF}$ / $\pm45_{AQ}$]
- At hinges: [$\pm45_{AQ}$ / $0_{3\ CF}$ / 90_{CF} / $\pm45_{AQ}$]
- Locally reinforced at hinges with [90] plies to ensure proper deployment

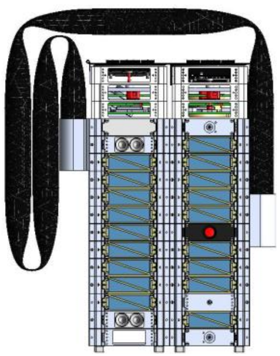


Boom Construction

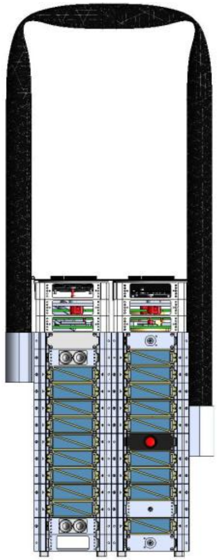


Caltech

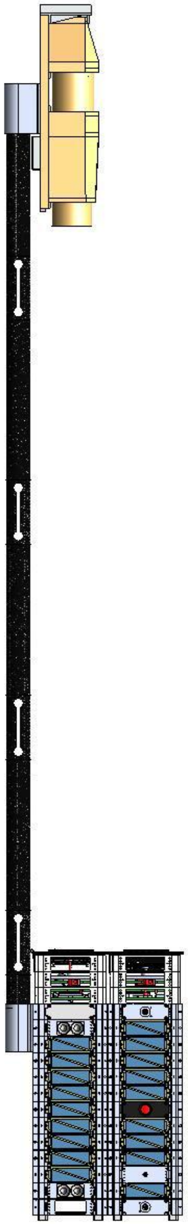
What does it do?



Stage 1 deployment →



Stage 2 deployment →



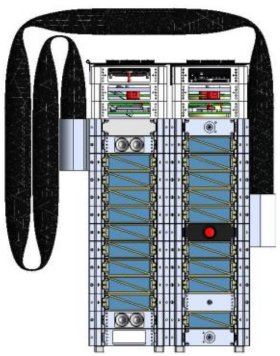
Stowed configuration

Deployed configuration

Caltech

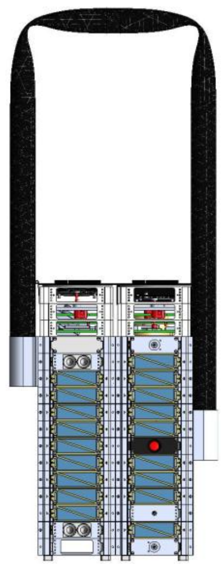
What ~~does it~~ *did we* do?

1. Characterize boom deployment with **experiments** and **simulations**
2. Design **restraints** and **interfaces** (boom/camera/CoreSats)

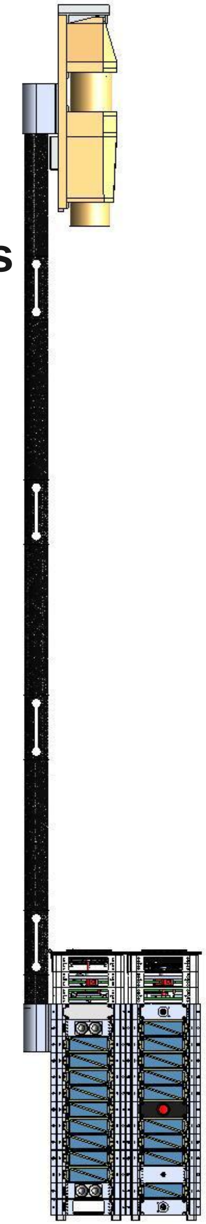


Stowed configuration

Stage 1 deployment →



Stage 2 deployment →

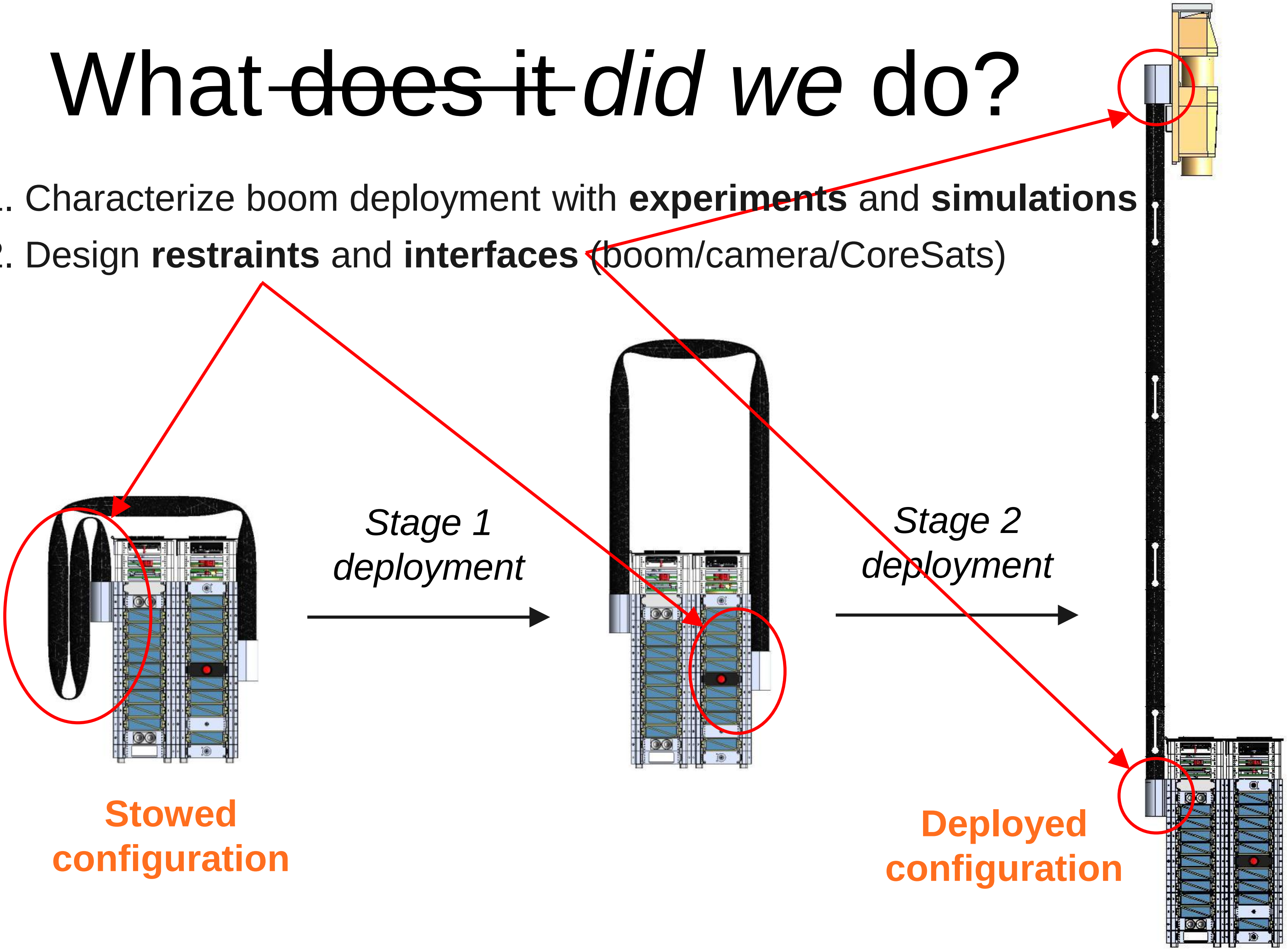


Deployed configuration

Caltech

What ~~does it~~ *did we* do?

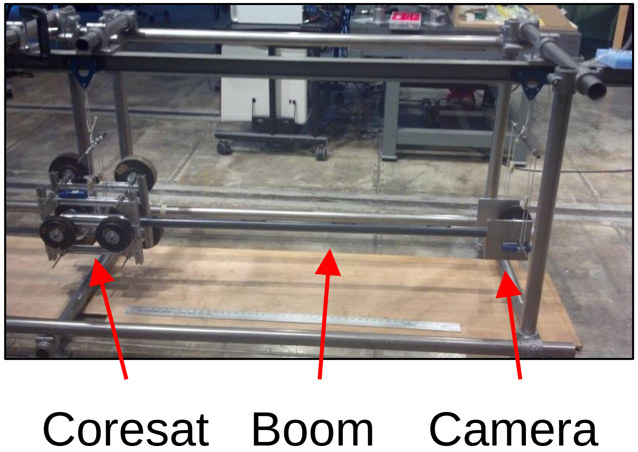
1. Characterize boom deployment with **experiments** and **simulations**
2. Design **restraints** and **interfaces** (boom/camera/CoreSats)



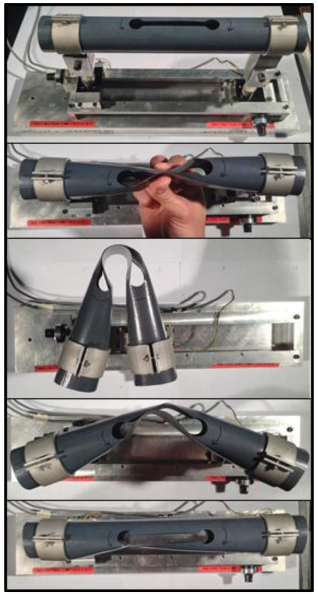
Caltech

Critical Tasks

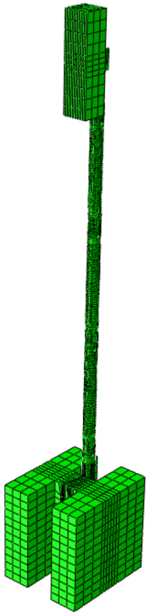
1. Characterize boom deployment with **experiments** and **simulations**
2. Design **restraints** and **interfaces** (boom/camera/CoreSats)



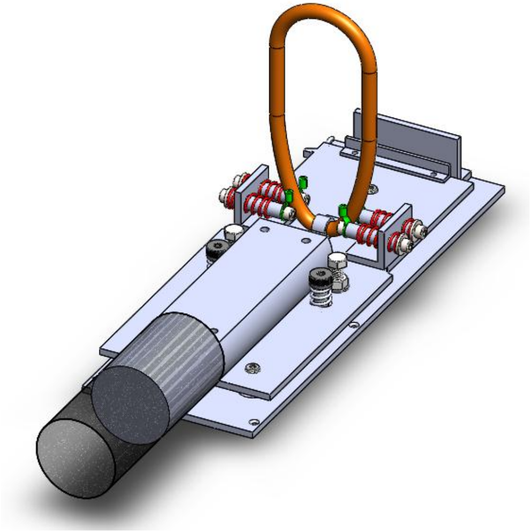
Full-boom deployment tests



Single-hinge characterization tests



FEM Simulation



Restraints and Interfaces

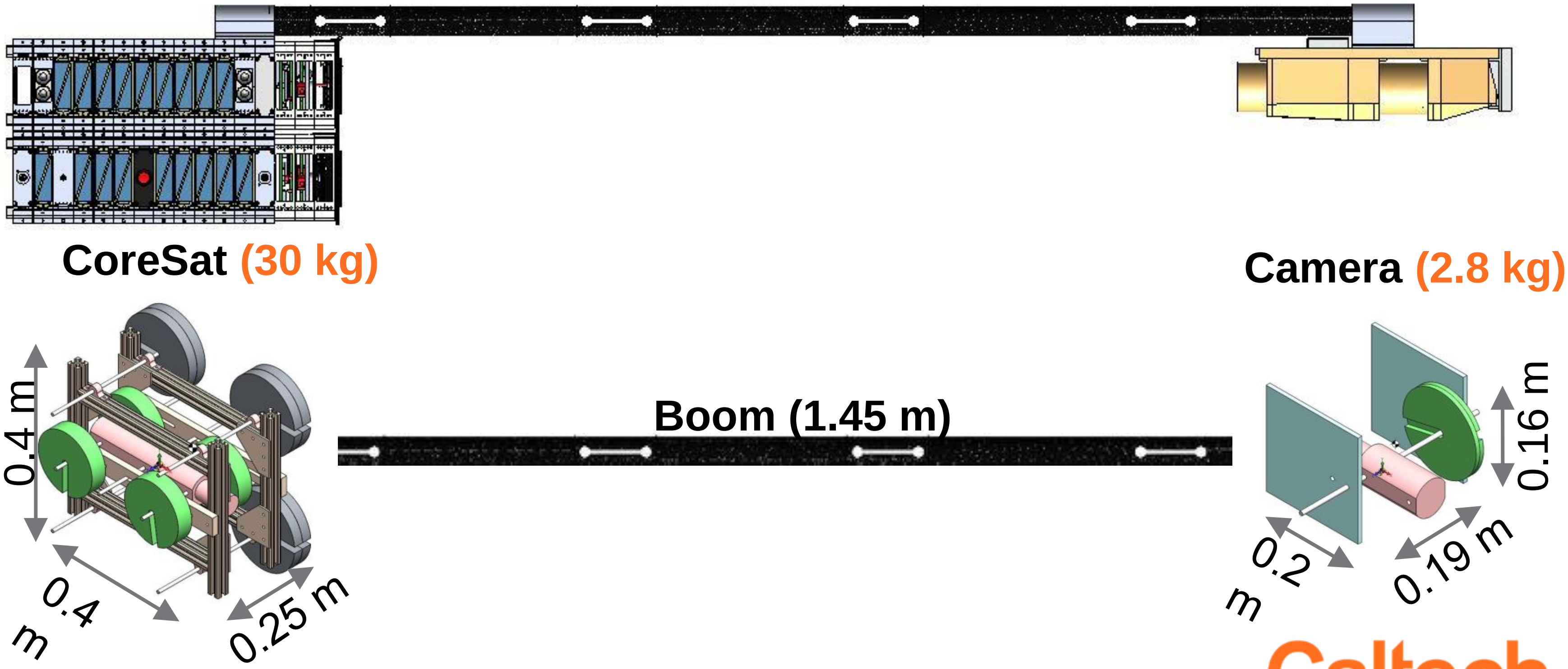
Stage 2 Deployment Test

Objective

- Characterize **large-displacement behavior** of the boom
- Study **accelerations** during boom deployment

Method

- Prepare an experimental setup modeling end masses and inertias
  - Simulate deployment in space via **gravity offload**



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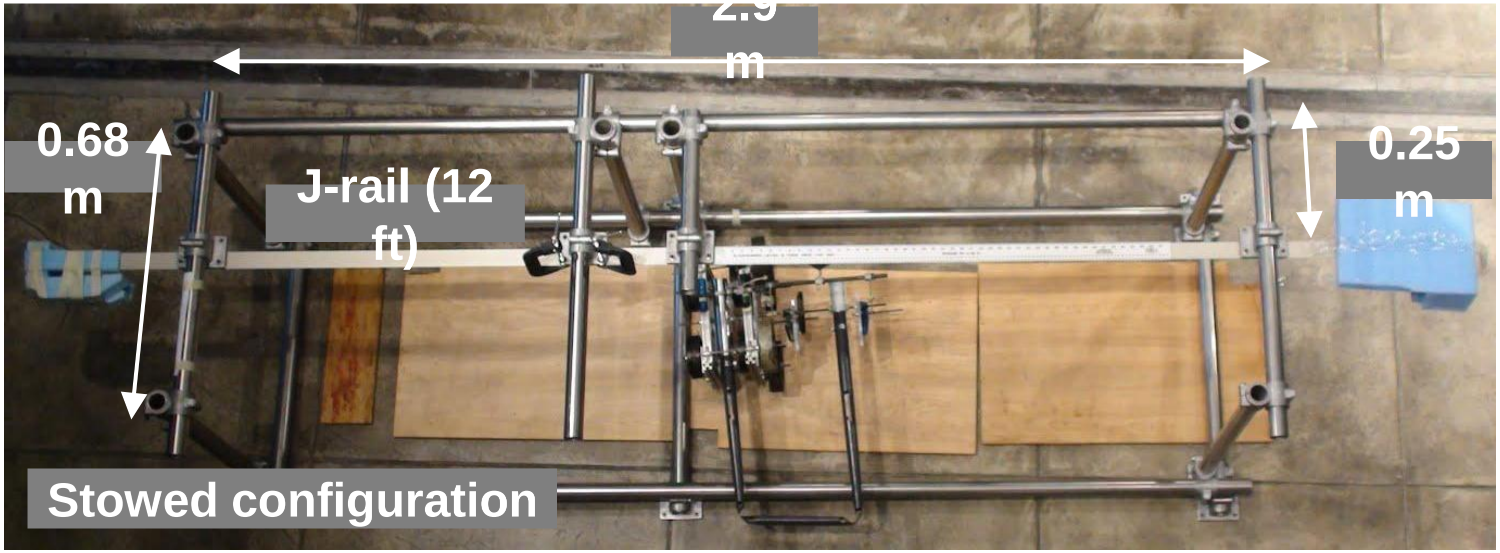
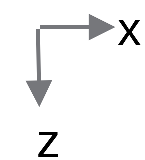
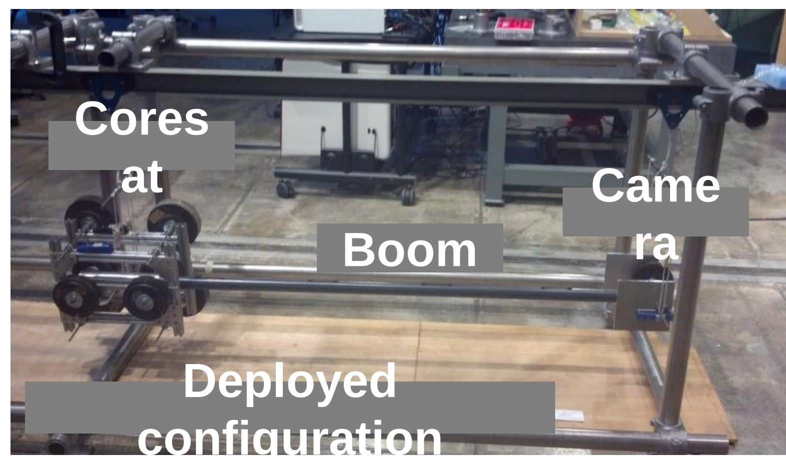
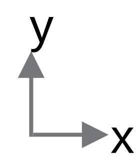
Stage 2 Deployment Test - Setup





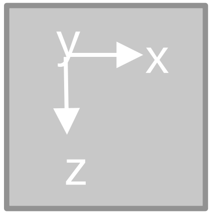
- Gravity offload system suspends boom and end masses from J-rail with rollers
  - Displacement constrained in y-axis
- Boom has manufacturing defects affecting accelerations





Caltech

Stage 2 Deployment Test



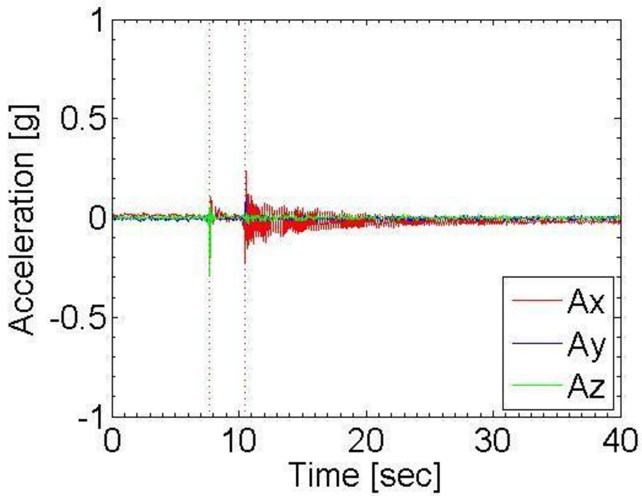
Caltech

Results: low accelerations

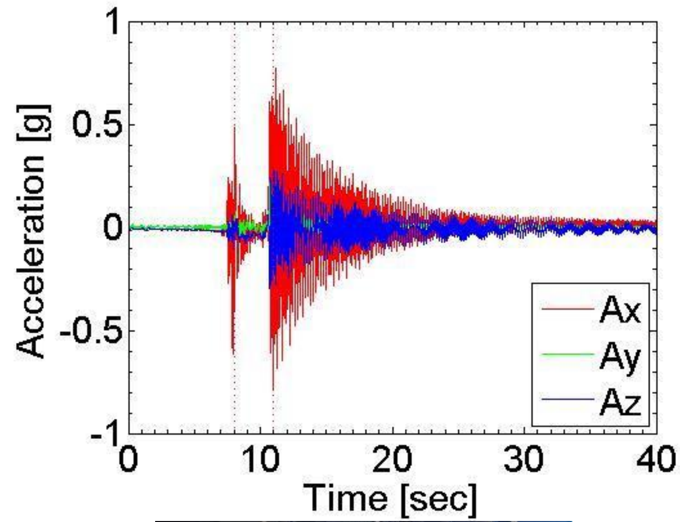
- Low accelerations compared to those experienced during launch. For reference:

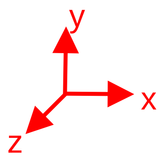
Delta IV rocket
- axial load factors: [-2g, 6g]
- lateral load factors: [-2g, 2g]

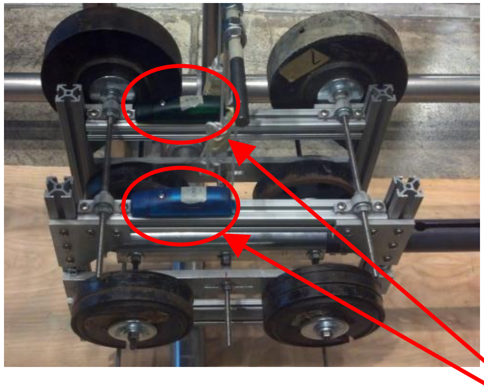
CoreSat

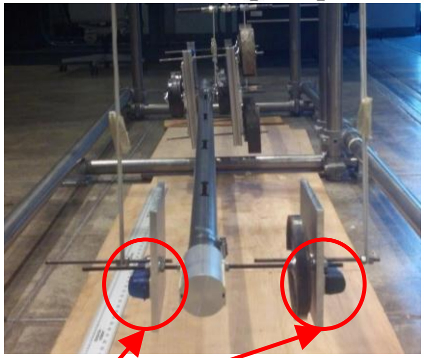


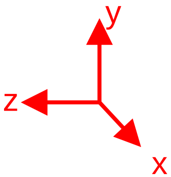
Camera











Accelerometers

Caltech

Stage 2 Deployment Simulation

Motivation

- Limitation of ground testing facility to simulate micro-G environment
- Examine material thermal effects on in-orbit deployment

Objective

- Develop high fidelity **finite element model**
- Capture **whole deployment process** in detail

[1x speed]

Hinge Characterization

Objective: Provide quantitative comparison between **simulations** and **measured** behavior of hinge to validate model

- Perform **quasi-static deployment** experiments
- Develop **finite element model** for single-hinge experiments
- Compare moment-angle profiles

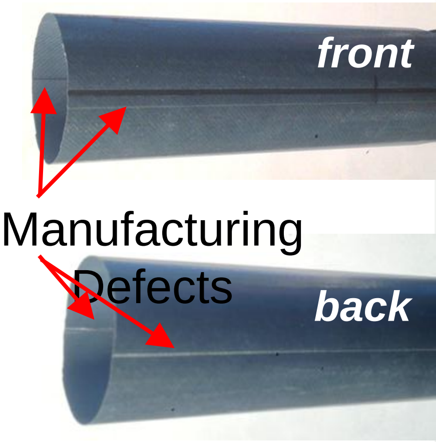
• Design and calibrate new apparatus with better boundary conditions

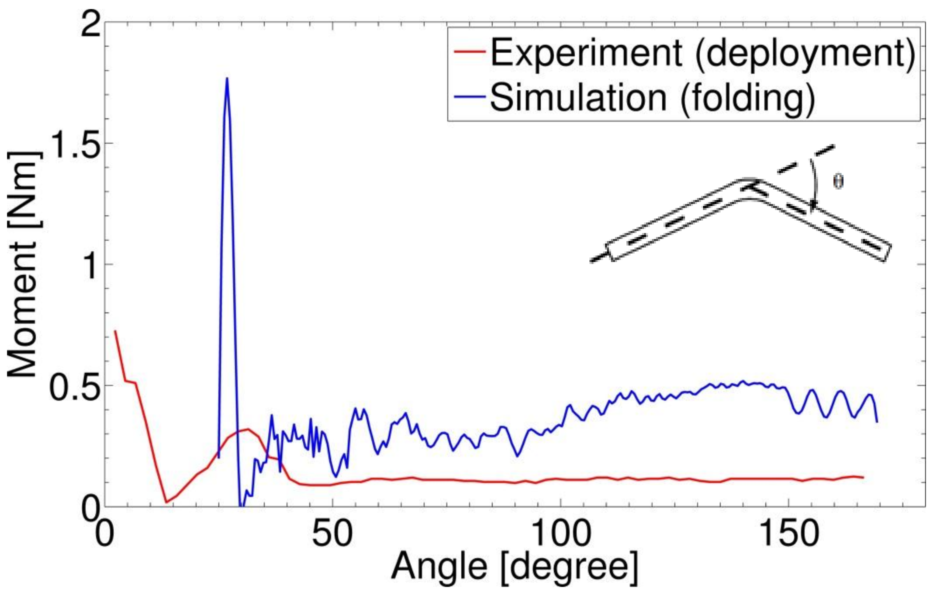
Experiment - deployment
[32x speed]

Simulation - folding
[1x speed]

Hinge Characterization

- **Hinges locked** before reaching deployed configuration
  - Quasi-static + Manufacturing Defects = prevented deployment
  - Manufacturing process has been improved
- Estimated **moment-angle profile** for this boom/hinge design
  - Steady-state moment region (0.1 Nm)
  - High snap-back moment to overcome (~0.7 Nm)
  - Small peak at ~30 degrees (0.3 Nm)
  - When hinge is latched, it is in a highly stable configuration





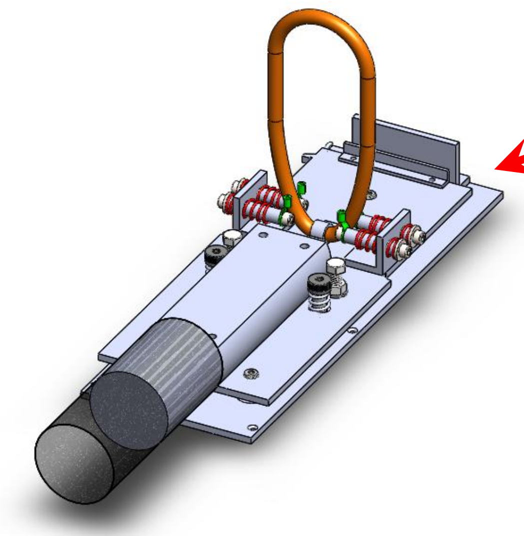
Deployed configuration

Locked configuration

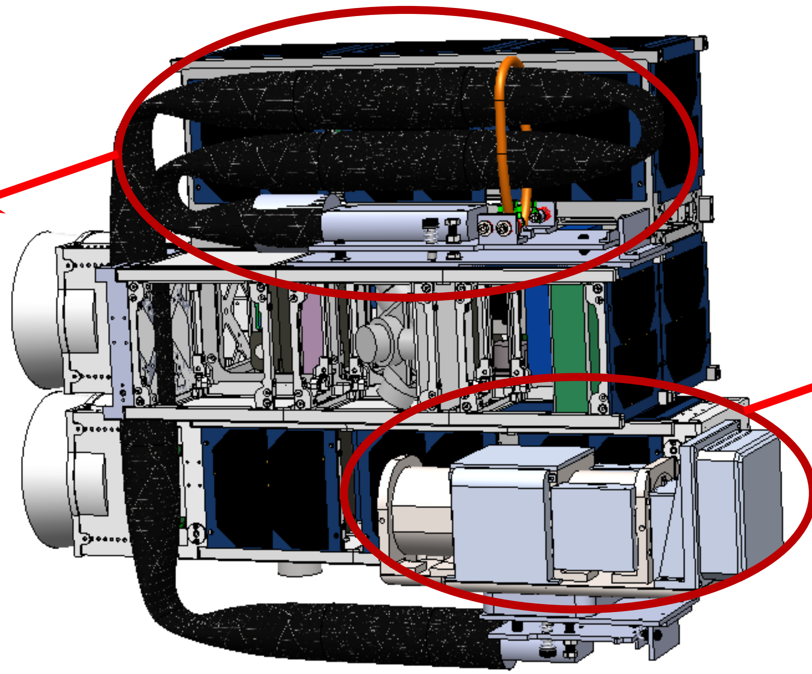
Restraints and Interfaces

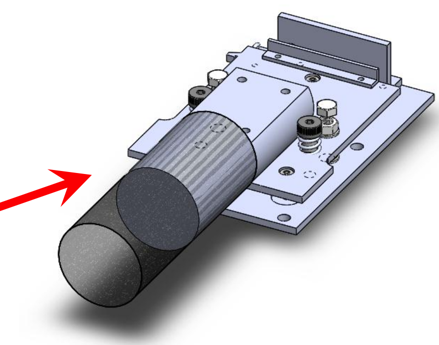
<u>Objective</u>: Secure boom to spacecraft during launch and and in-orbit

- Design **kinematic mounts** to allow for camera adjustment relative to the coresat
  - Corrects for misalignments in the construction satellite
- Design **release mechanism** for Stage 1 deployment



Core Sat kinematic mount
(with restraint strap)

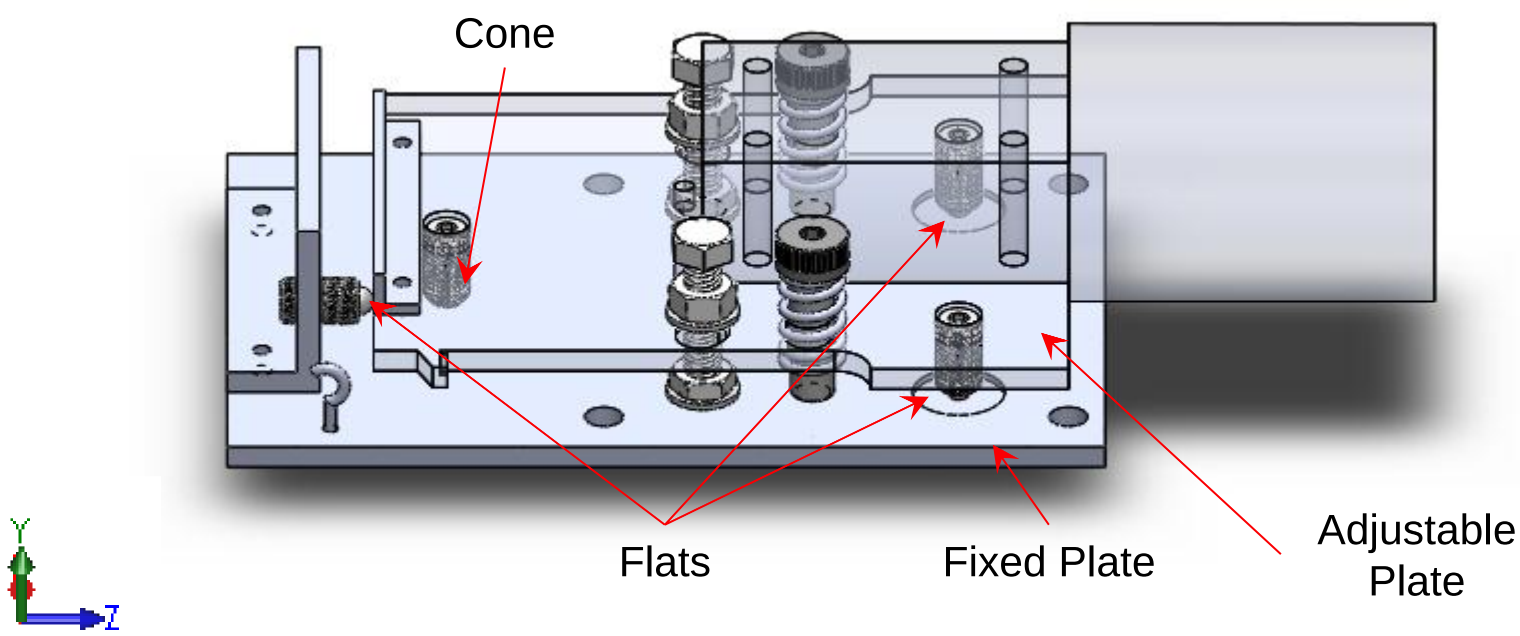




Camera kinematic mount

Kinematic Mount

- Cone and 3 flat configuration
- contact points with four 100 tpi ball tipped screws
  - Allows rotation of the adjustable plate around x, y, and z axes



Camera kinematic mount

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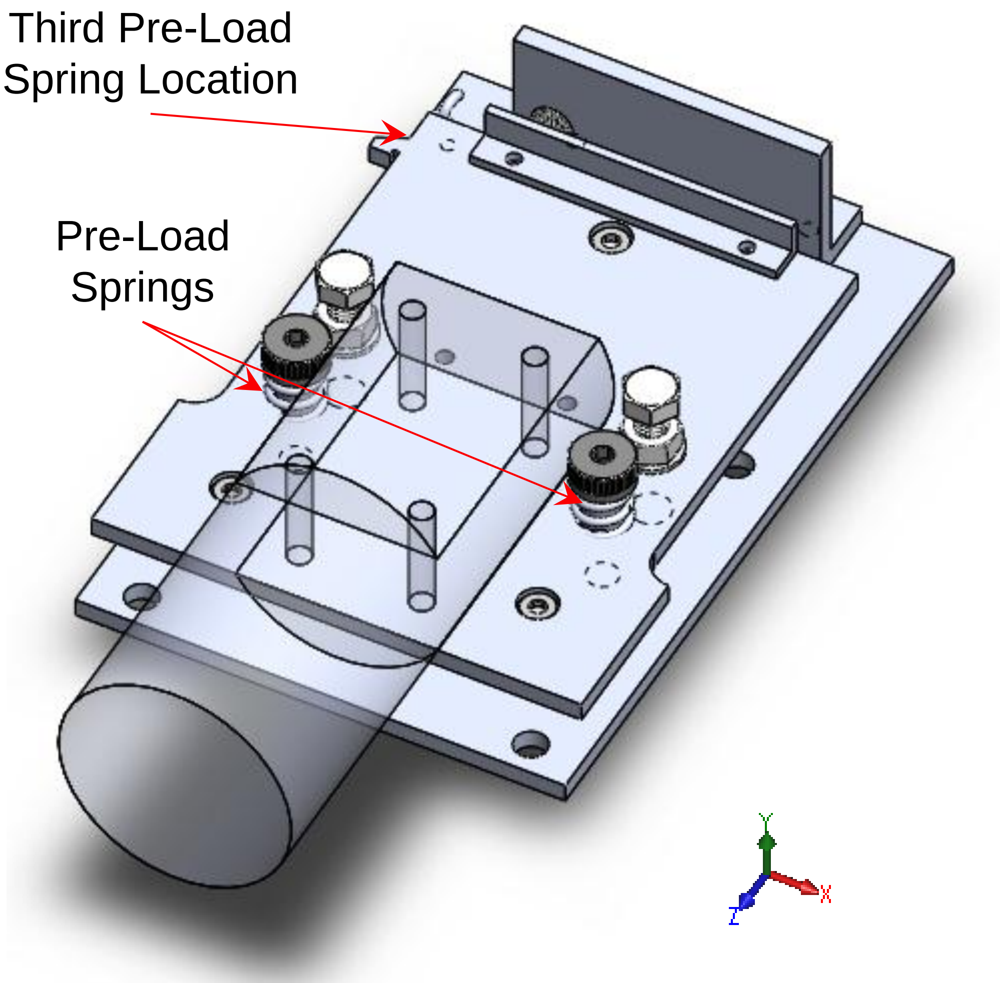
Kinematic Mount

<u>**Key Features**</u>

- **Three pre-load springs maintain contact during adjustment**

- Clamp down nuts provide holding force after adjustment



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Kinematic Mount

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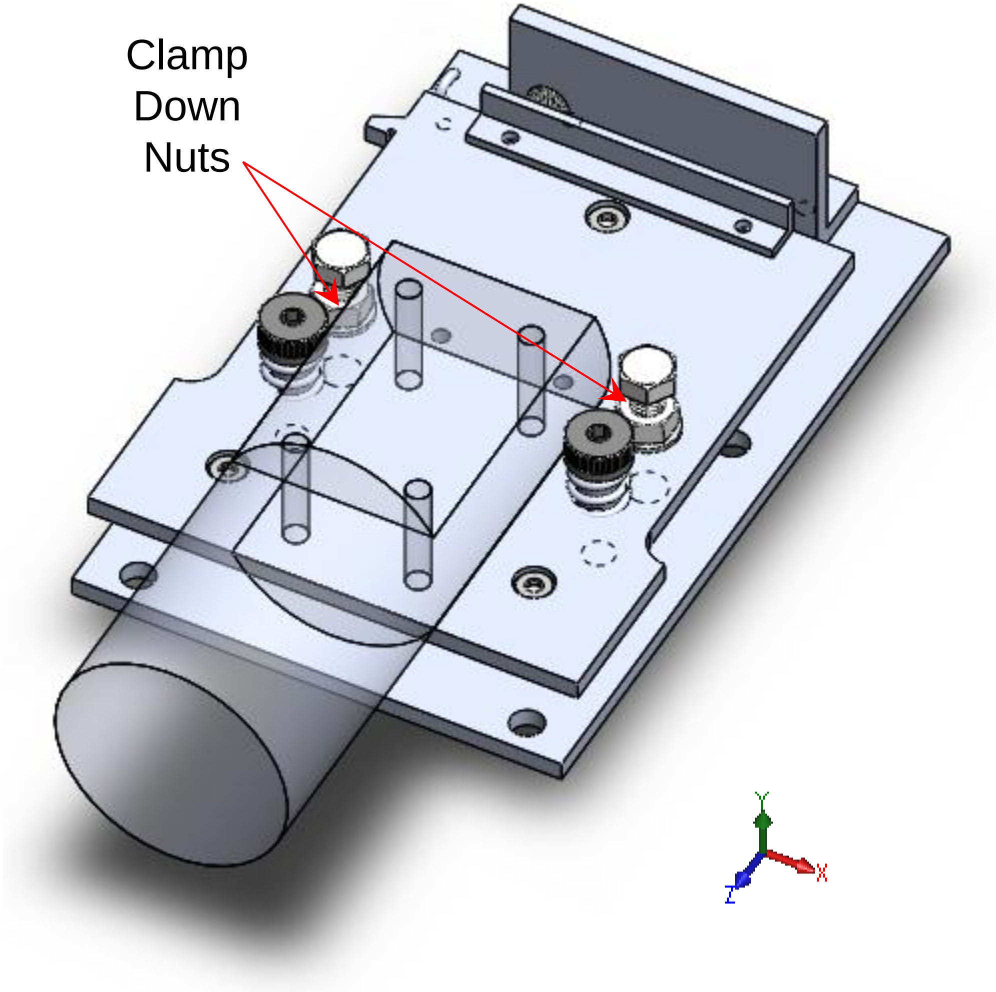
- Three pre-load springs maintain contact during adjustment

- **Clamp down nuts provide holding force after adjustment**



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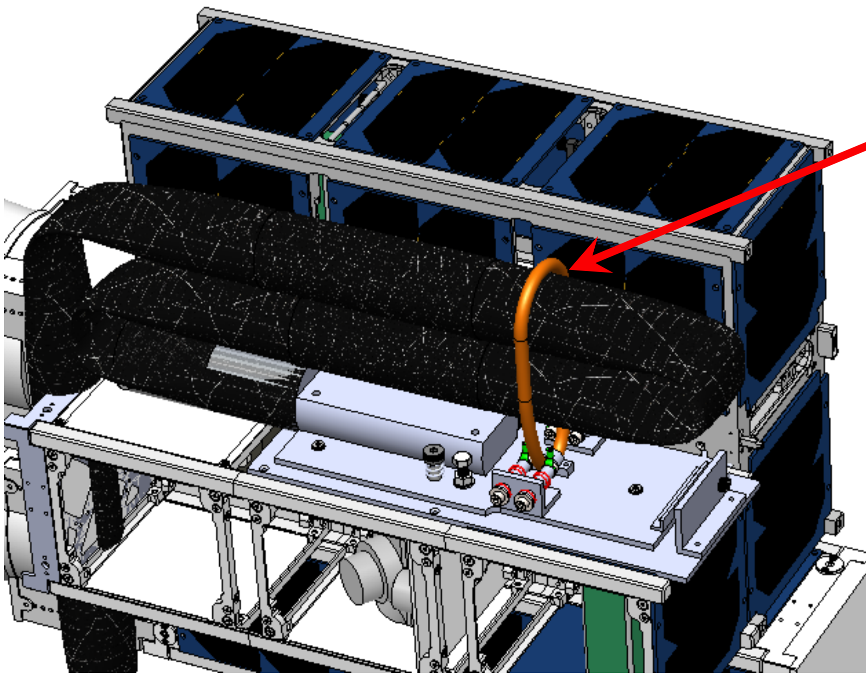
Release Mechanism

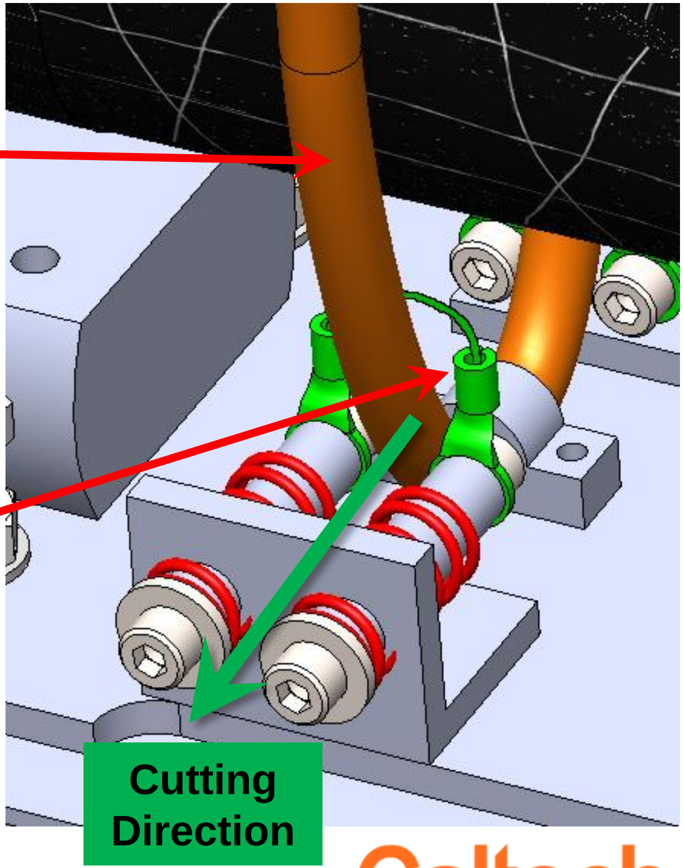
- **Vectran cable** ties down boom in stowed configuration
- **Nichrome wire** looped around tie down cable between pairs of terminals
- When heated, nichrome wire cuts through the vectran cable due to spring preload



Tie down cable

Nichrome wire

Based on design outlined in *A Nichrome Burn Wire Release Mechanism for CubeSats* by Thurn et al.



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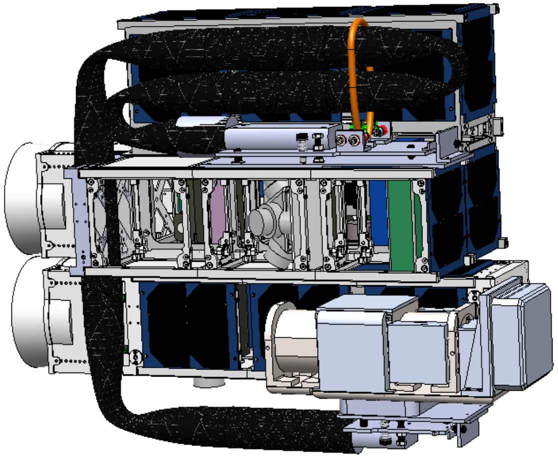
Completed Tasks

Boom deployment tests
- Modeled masses with accurate weights and intertias
- Assembled test rig
- Performed Stage 2 deployment experiment

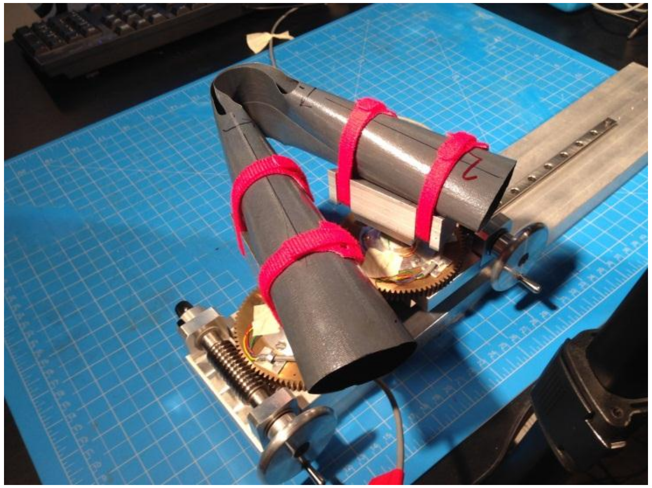
Single-hinge characterization
- Improved experimental set-up with boundary conditions
- Estimated moment-angle profile

FEM Simulation
- Developed full-boom and single-hinge simulations
- Obtained preliminary results for stage-2 deployment

Restraints and Interfaces
- Designed kinematic mounts
- Designed burn wire release mechanism

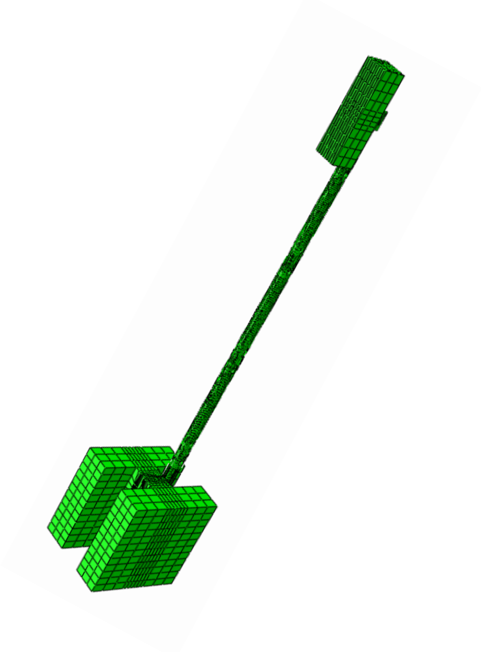


Future Work



Boom deployment tests
- Perform Stage1/Stage2 deployment experiments
- Analyze acceleration for all degrees of freedom

Single-hinge characterization
- Perform multiple-folding experiments
- Perform storage experiments



FEM Simulation
- Expand boom & single-hinge simulation to deployment phase
- Modify FEM model according to experimental results
- Incorporate thermal properties of material into model

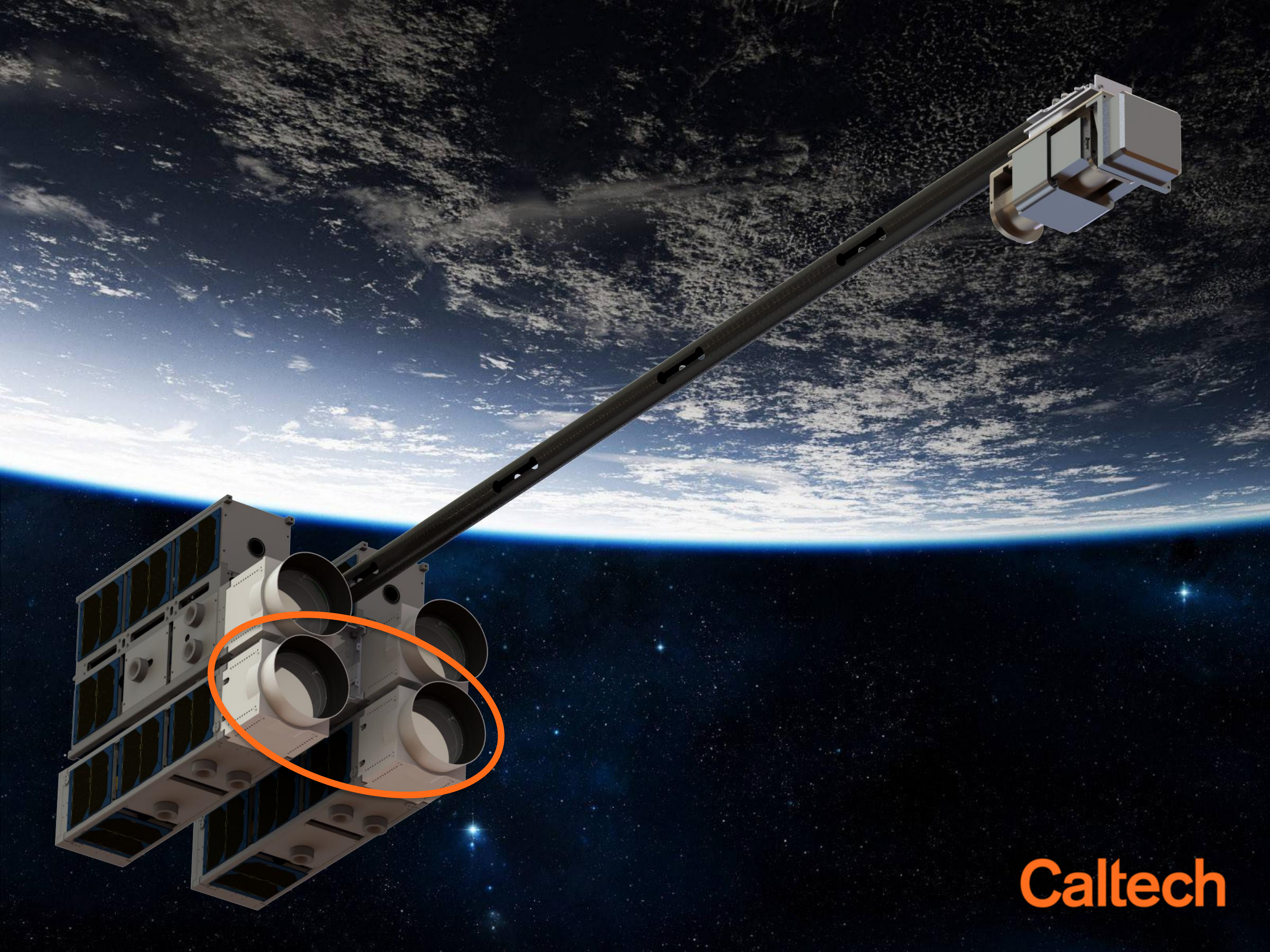
Restraints and Interfaces
- Prototype kinematic mounts and burn wire release mechanism
- Integrate prototypes into deployment tests

Questions?

Mirror Team: Vibrational and Thermal Testing

Erin Evans, Christian Kettenbeil, Akshay Sridhar, Yuchen Wei

Mentor: John Steeves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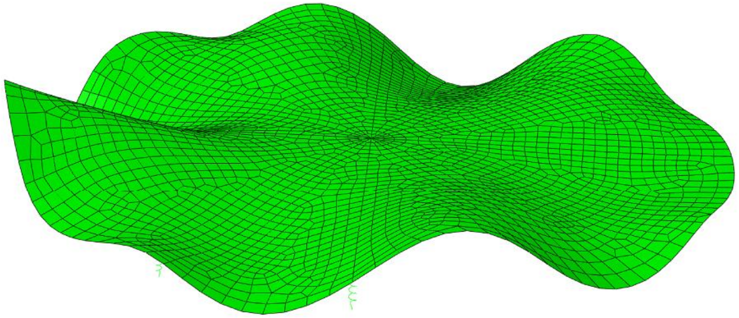
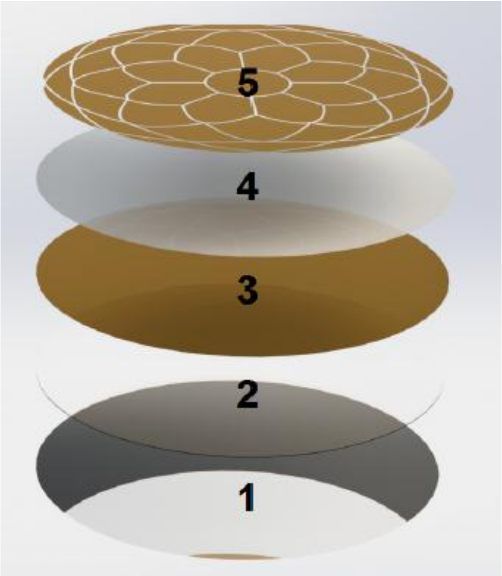
Motivation

Lightweight, Deformable Mirrors





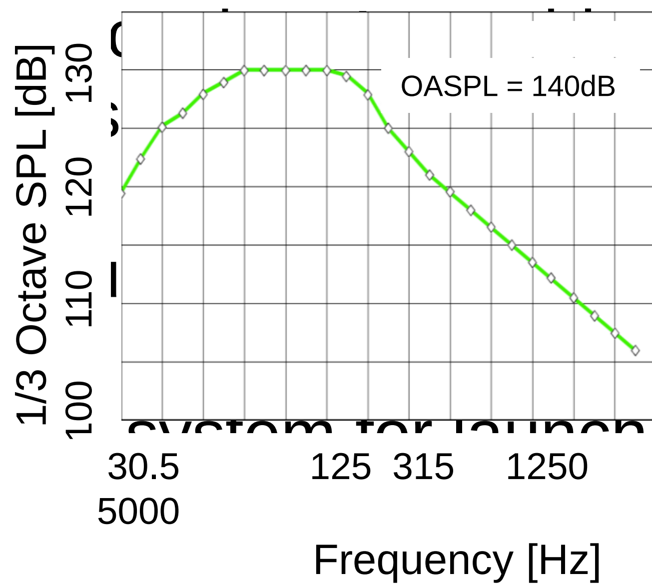
Acoustic / Vibration

Thermal

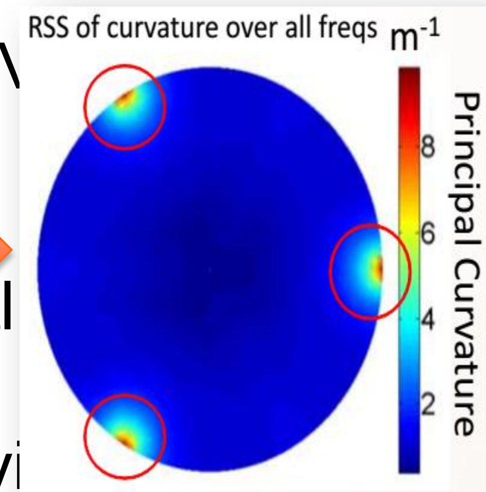
Acoustics

- Analysis showed that launch survivability is a concern with current configuration

Delta IV Rocket
(Potential Carrier)



Delta IV Sound Pressure Curve



Mirror Subjected to
Acoustic Loading

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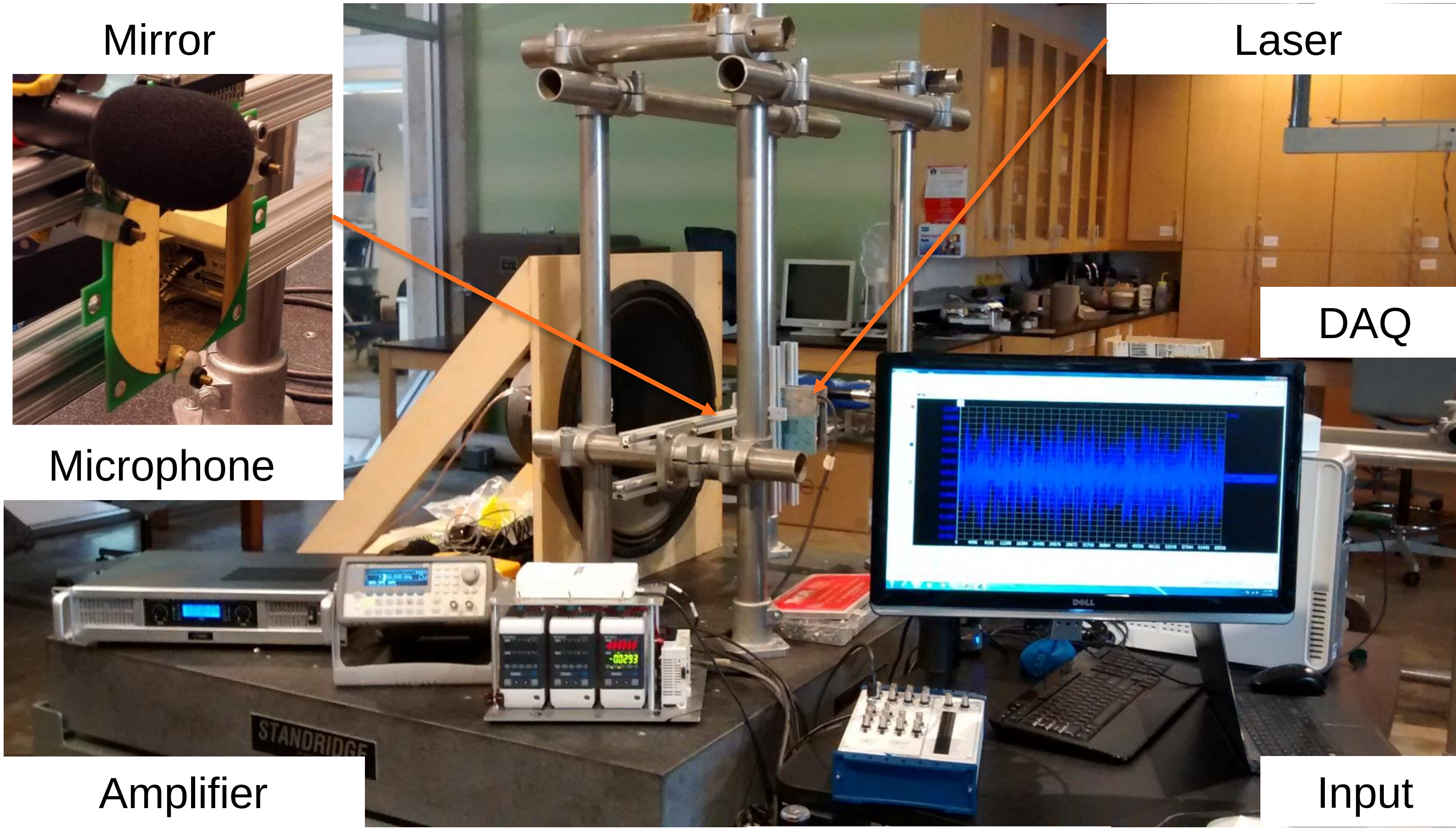
Acoustic Experiments



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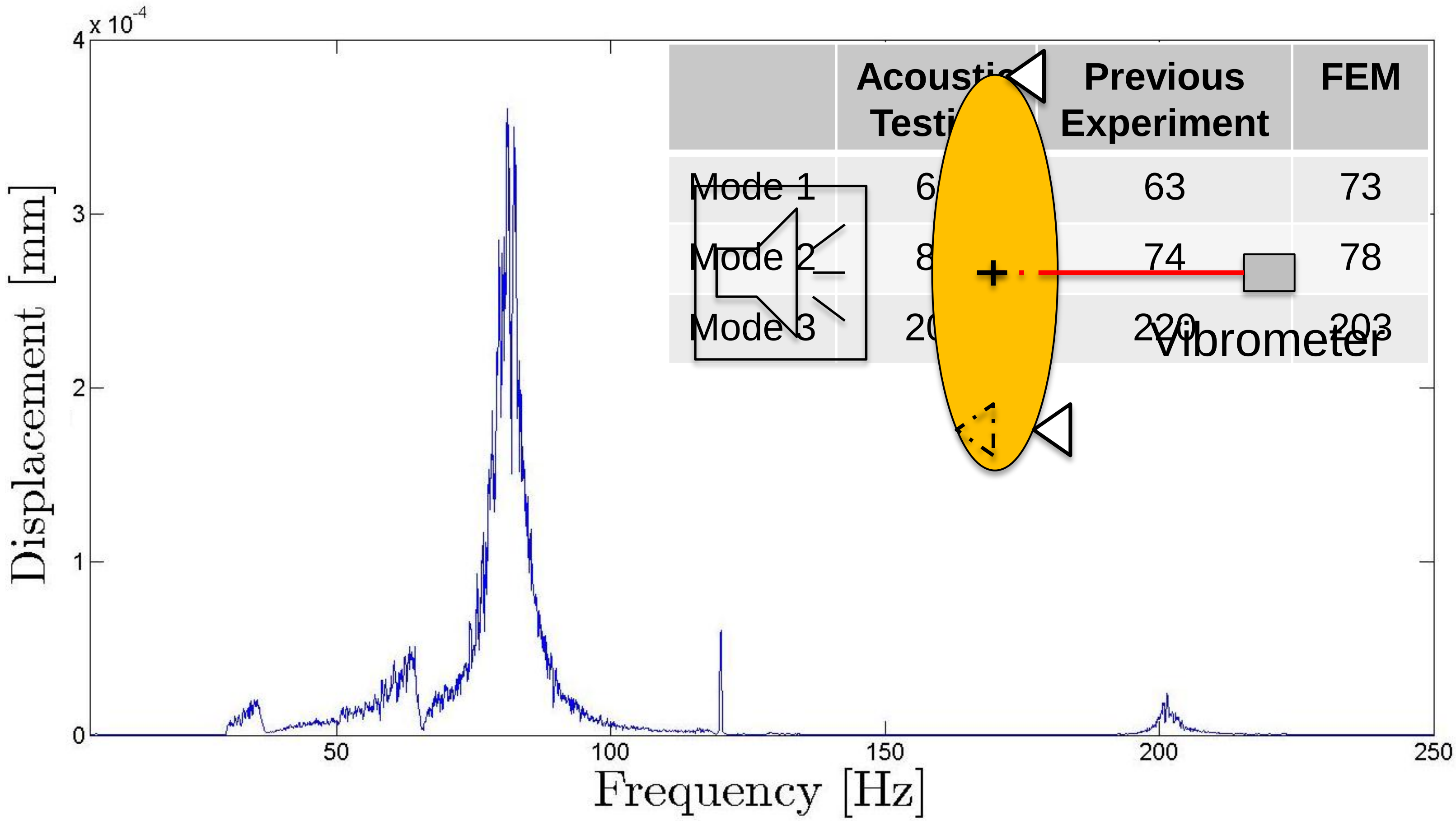
Test-Bed Validation



	Acousti[illegible] Testi[illegible]	Previous Experiment	FEM
Mode 1	6[illegible]	63	73
Mode 2	8[illegible]	74	78
Mode 3	20[illegible]	220	203

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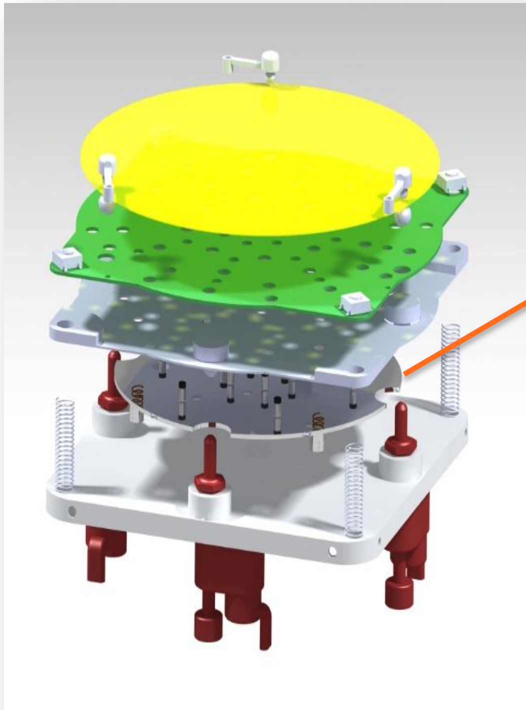
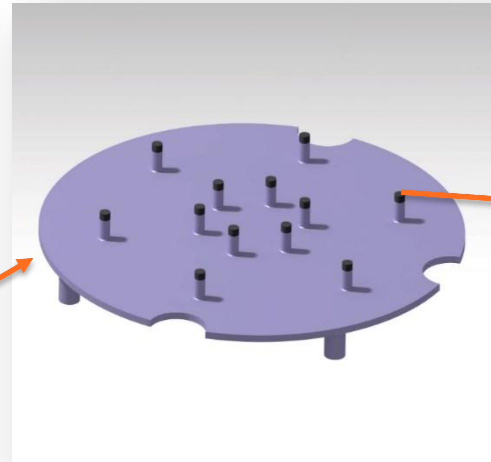
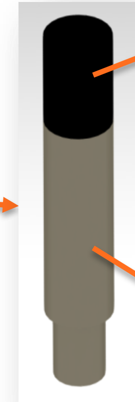
Mirror Restraint System – Concept



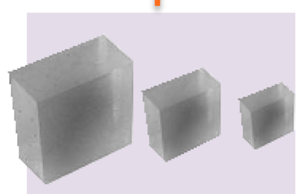
- *Deformable Mirror Package*



- *Restraint Plate*



- *Restraint Peg*



- *Silicone Rubber*

- *Silicone Foam*

- *Styrene*

- Break the Symmetric Mode of the Mirror
- Pillars act as damping element in restraint system

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Mirror Restraint System – Analysis & Design

Analysis

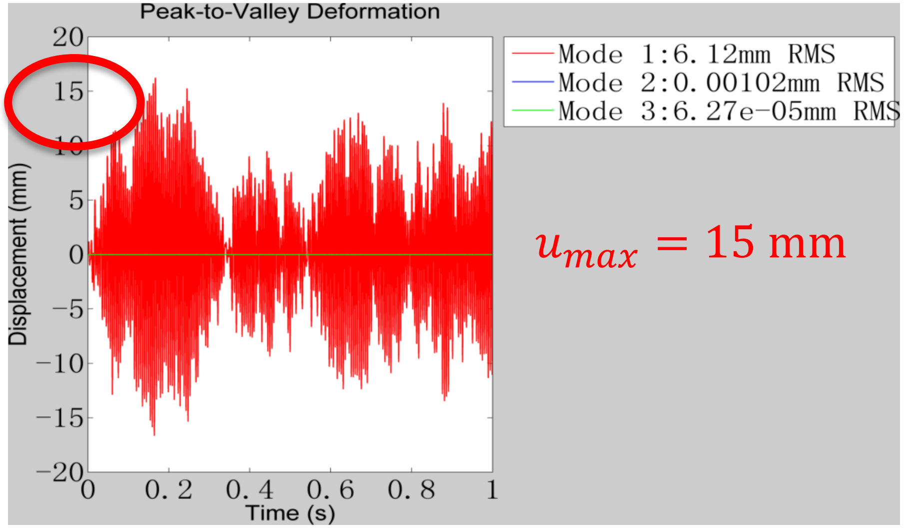
- Analysis has predicted that restraint system can inhibit the acoustic vibration greatly (reduce 90% of the peak deflection magnitude)

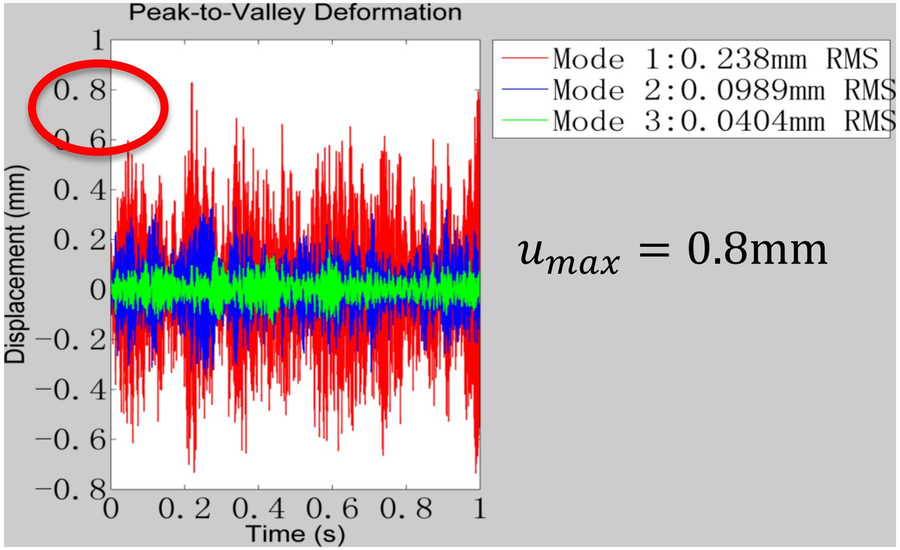
Design

- Developed (with Mirror Test Team) mirror package prototype & test bed with restraint system

Implementation

- Performed mirror acoustic loading experiment with restraint system





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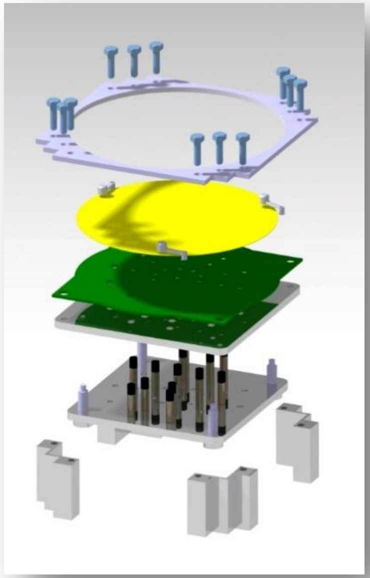
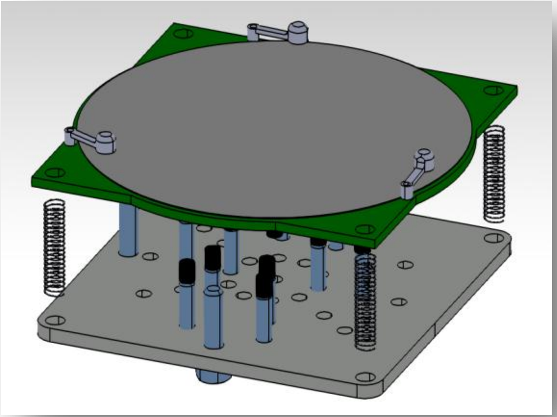


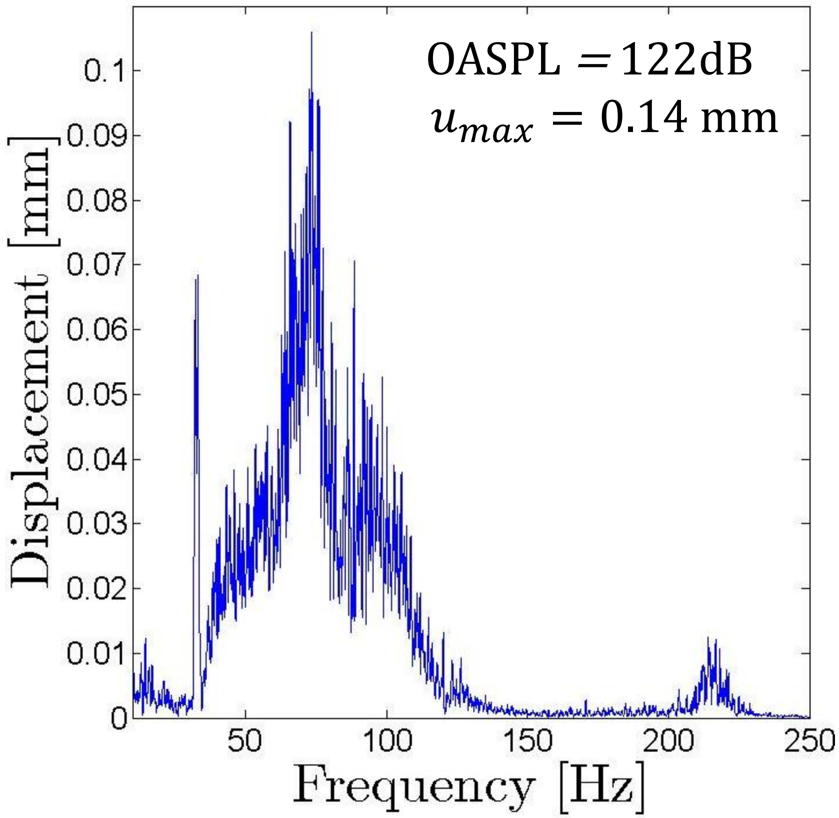
- *Mirror Test Bed*



- *Restraint System Test Bed*

Restraint System Test

W/O Restraint



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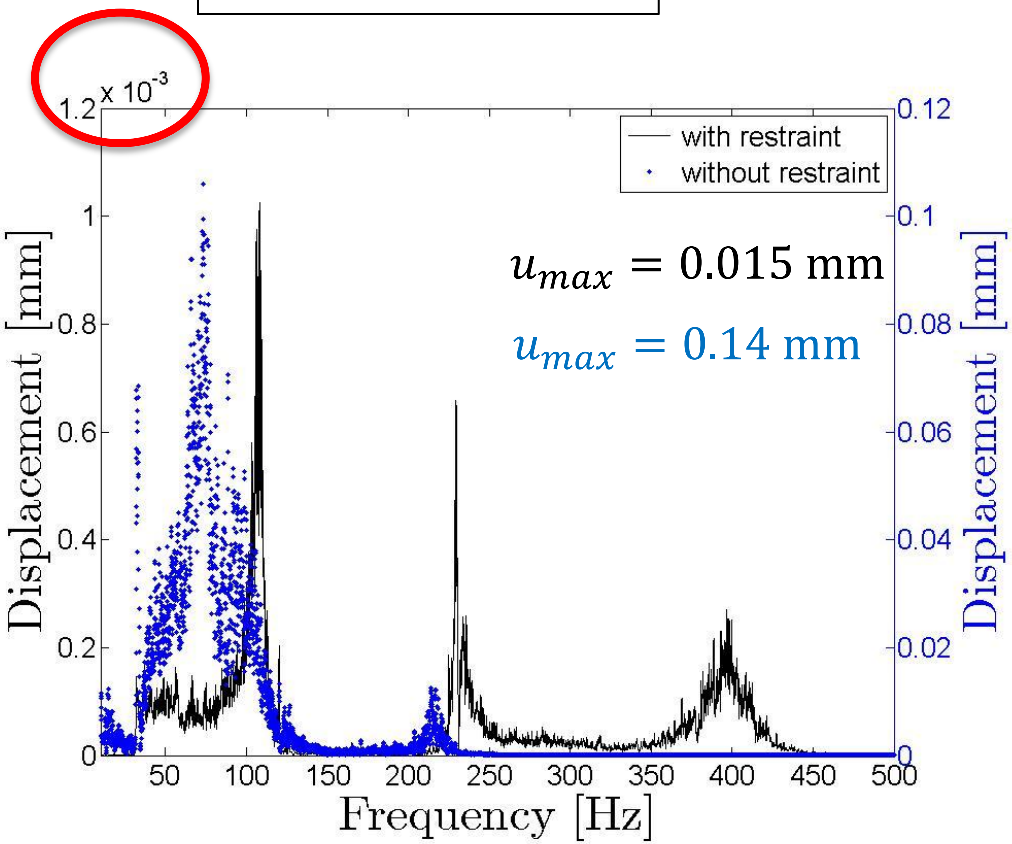
Restraint System Test

Restraint



$u_{max} = 0.015$ mm

$u_{max} = 0.14$ mm

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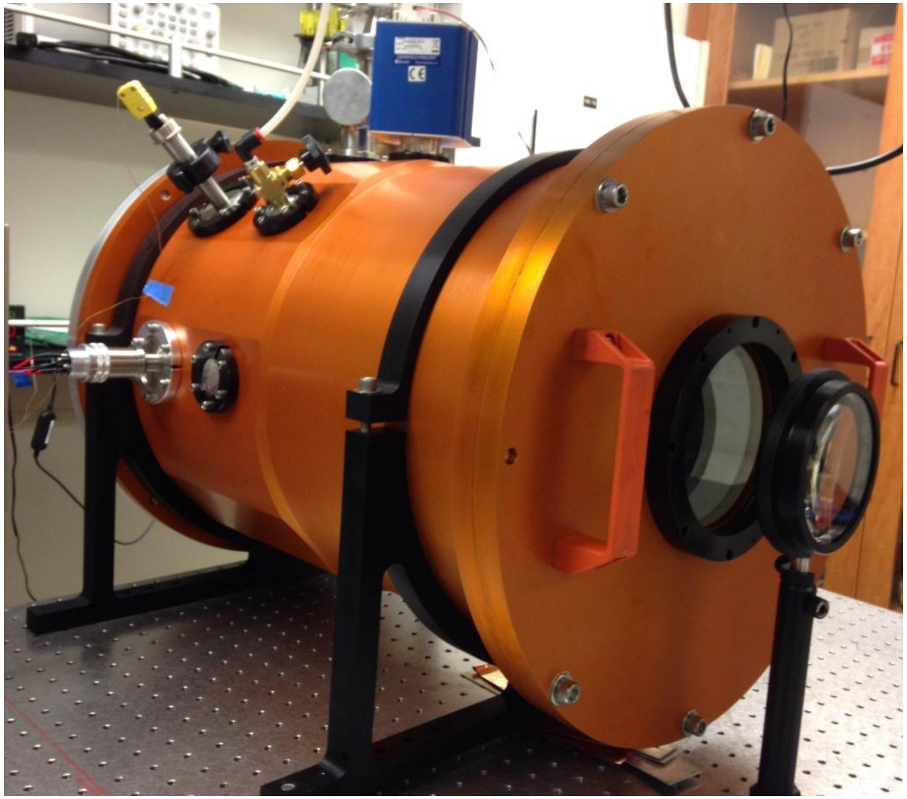
Summary & Future Work

- Design, Manufacturing, Assembly and Validation of an acoustic test-bed
- Observed high deflections in current configuration
- Designed a restraint system that reduces the deflections by <u>an order of magnitude</u>

- Measurement of surface curvatures for different restraint configurations using optical techniques
- Increase SPL capability by use of an enclosure

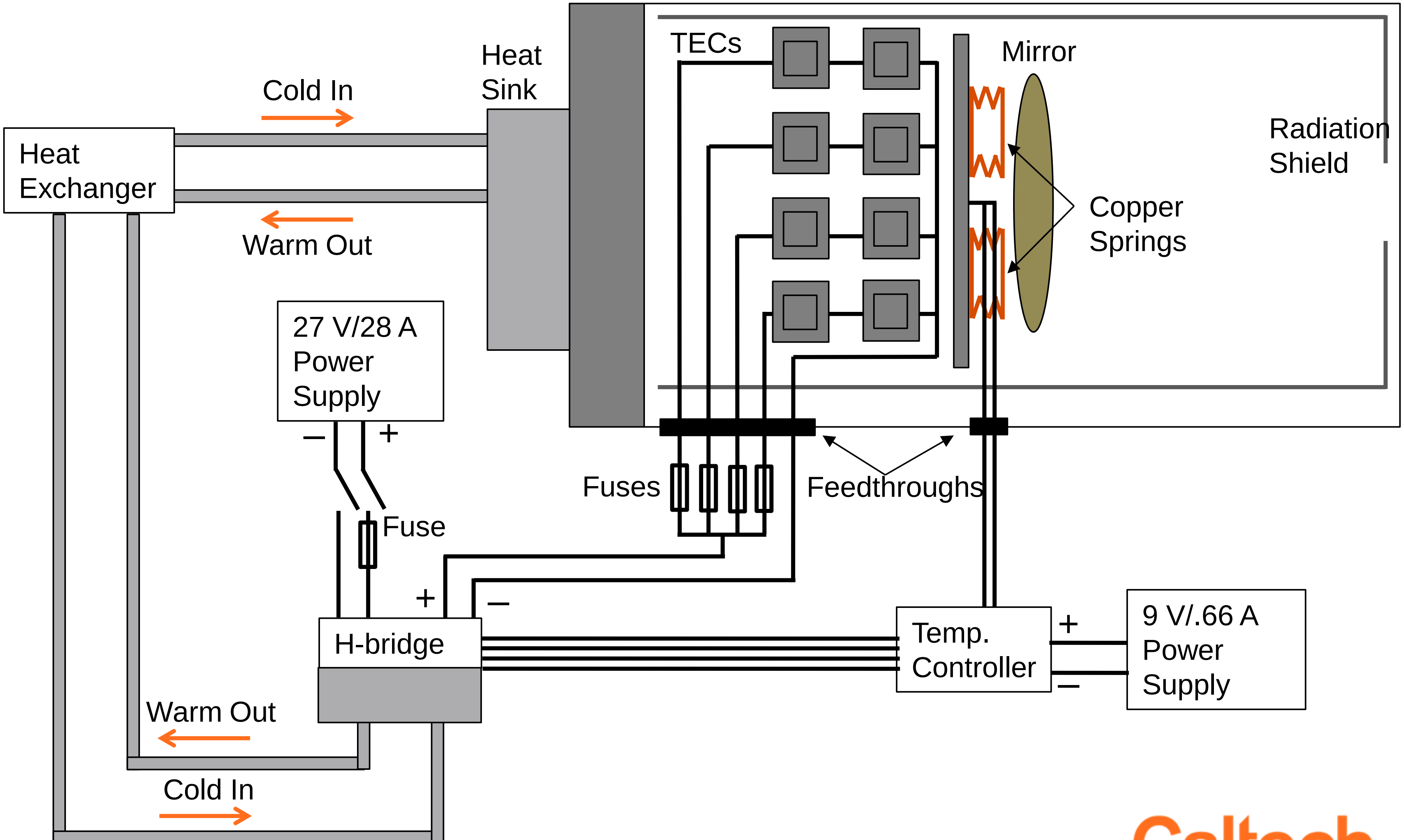
Mirror Thermal Stability Testing

- **Problem**: Mirror deformation sensitive to temperature changes
- **Goal:** Build test platform that can operate at -50˚C and 10^{-5} torr
- **Method:** Set up vacuum chamber, build mirror cooling circuit, set up optical array for data collection



Caltech

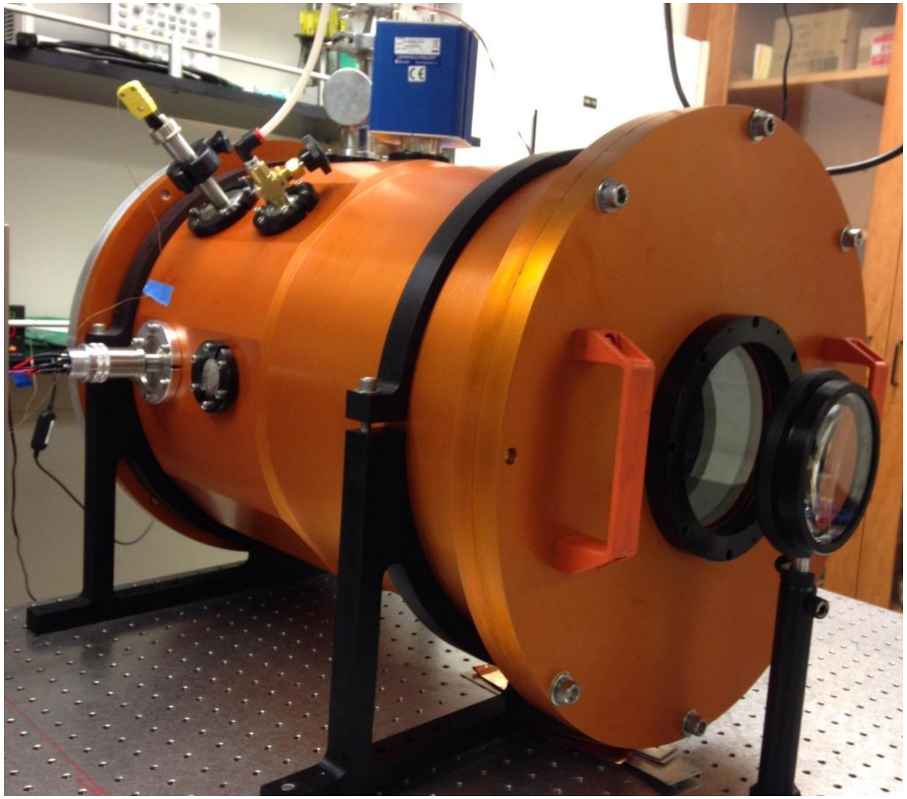
Cooling System Layout



Caltech

Cooling System Performance

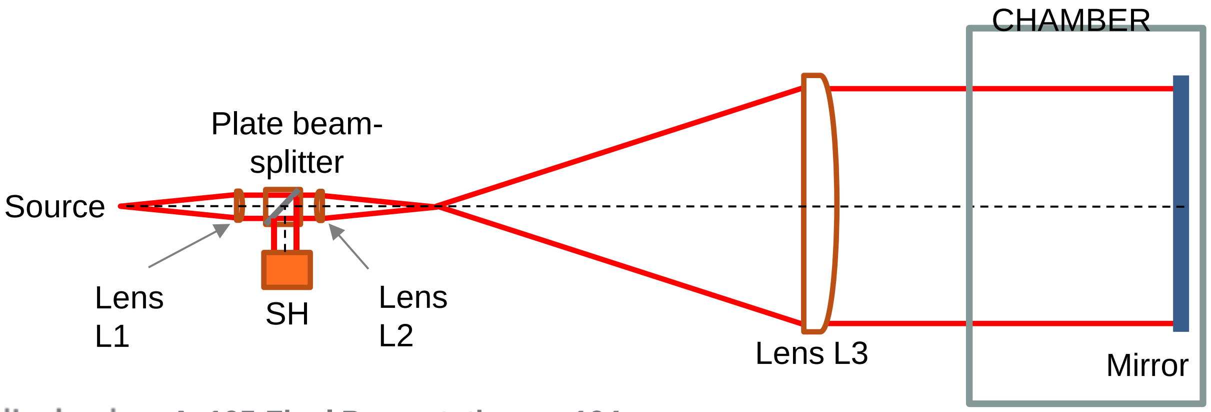
- Vacuum: 10^{-5} torr in 3.5 hours.
- Water cooled heat sink can reach 10˚C.
- Cooling plate temp of -20˚C in 20 min.
- Reached 0˚C on mirror surface with TEC temp of -20˚C.

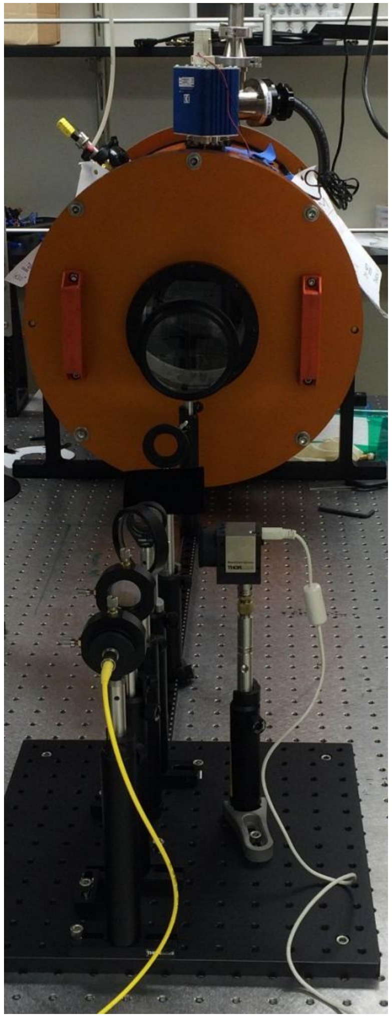


Caltech

Data Acquisition

- Need to characterize mirror deformation as function of temperature
- Lens array set up to use point source to illuminate mirror
- Reflected waveform captured using Shack Hartmann wavefront sensor





Caltech

Preliminary Results

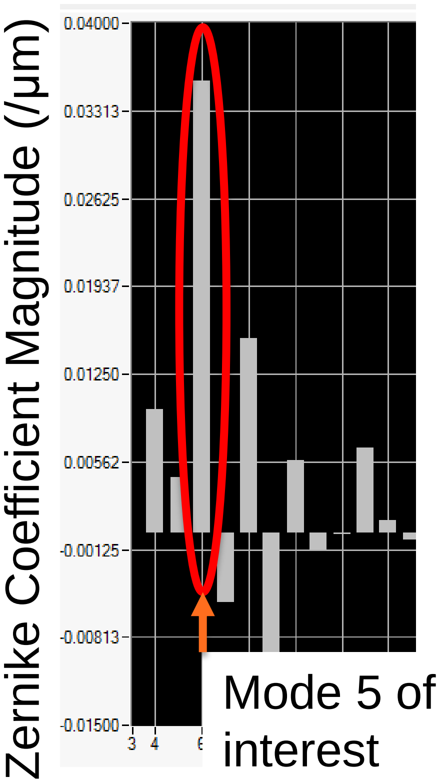
Wavefront Error Plot

Y-Coordinate [mm]

Measured Wavefront Error (µm)

X-Coordinate [mm]

Wavefront error: Comparison of mirror shape with that of a flat surface (processed into curvatures)



Zernike Coefficient – De-focus Metric

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Summary and Future Work

- ✓ Designed, commissioned experimental setup to test deformable mirrors at -20˚C and 10-5 torr.
- ✓ Confirmed ability to capture mirror deformations with temperature
- ○ Concept - secondary radiation shield to improve mirror temperature profile if necessary
- ○ Characterise mirror deformation as a function of temperature
- ○ Compare different mirror designs – layer thickness specifications

Caltech

Questions?

AAReST Camera Design

Spencer Freeman, Maria Sakovsky
Mentor: Manan Arya

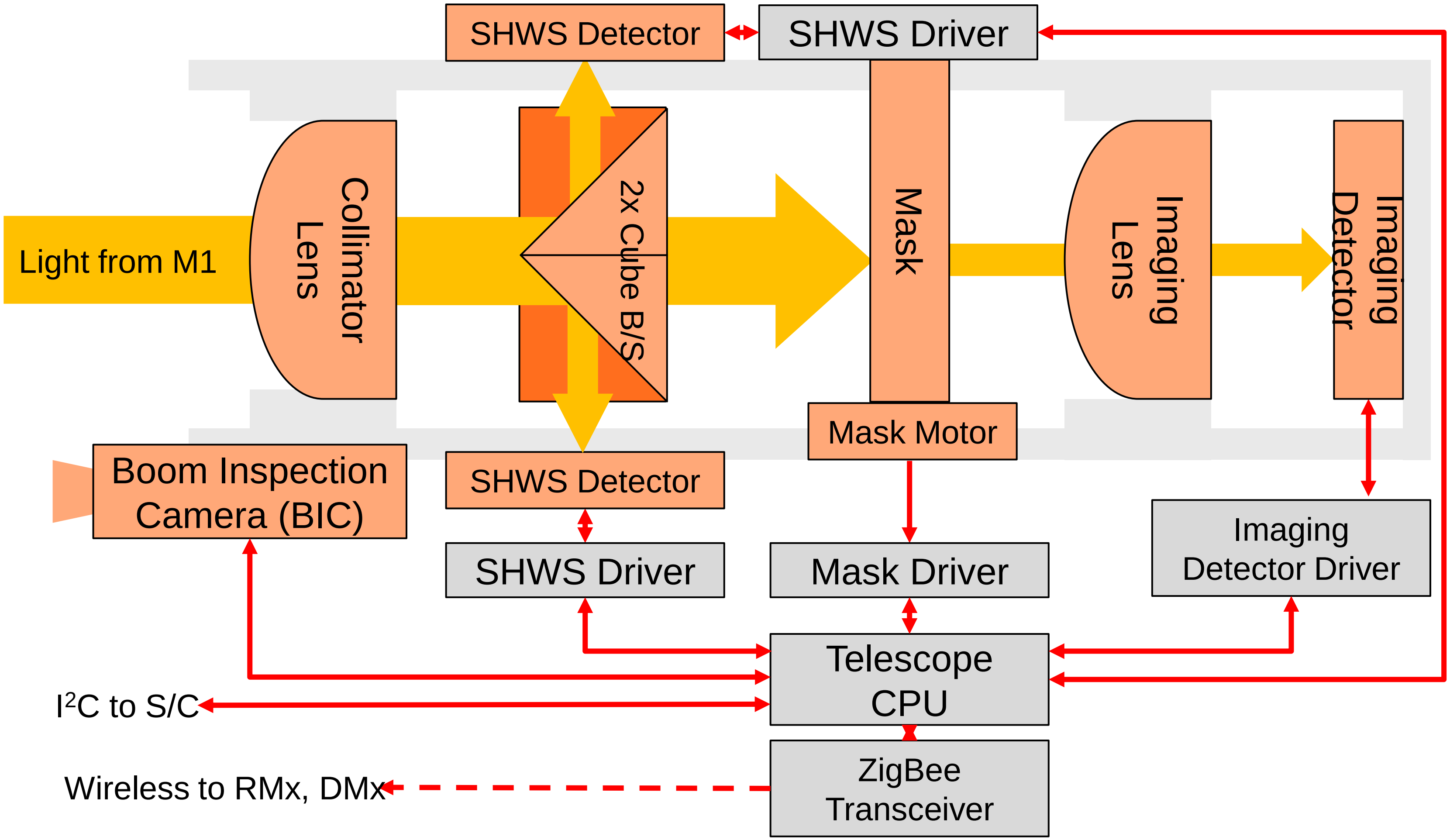
Caltech


Camera
Caltech

Overview

1. System Definition
2. Requirements
3. Prototype
4. Flight Camera Design
5. Future Work

System Definition



Caltech

Task Overview

- Camera Prototype
  - SHWS mount prototype
  - SHWS alignment
  - Imaging and collimator groups

- Flight camera design
  - Mount optics
  - Package camera hardware and electronics

Requirements

Functional
- Work with reconfigurable primary mirror
- Provide feedback during primary mirror calibration
- Science imaging

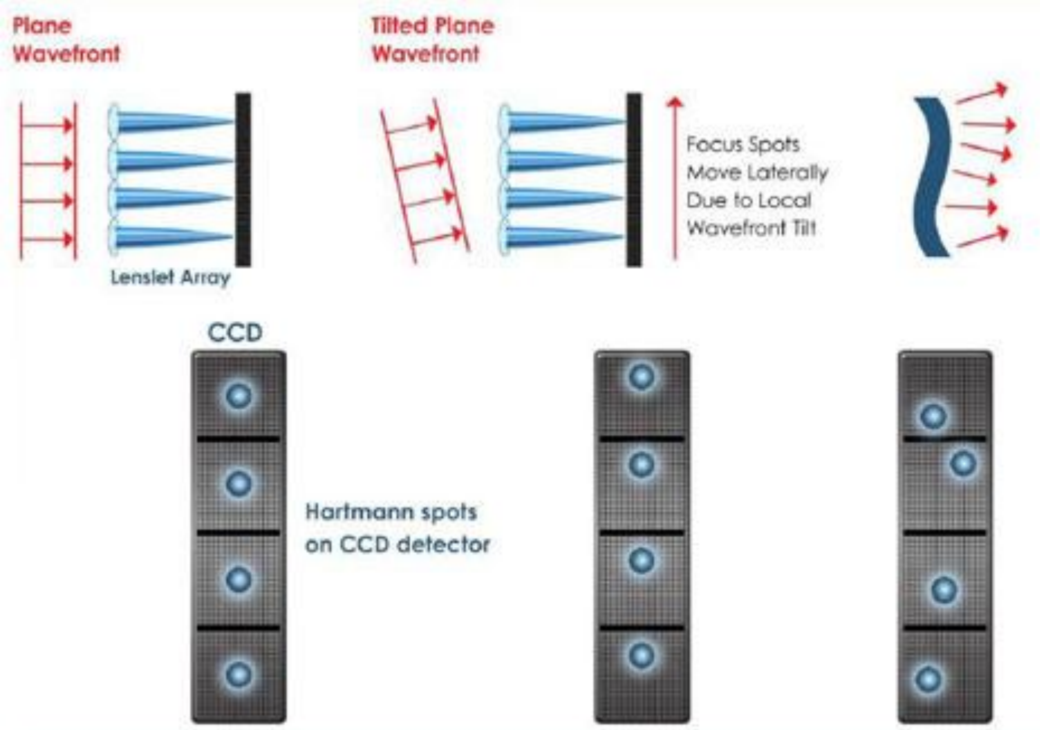
Performance
- 80% encircled energy radius < 90% diffraction-limited EE radius
- 0.3° full field-of-view
- Bandwidth: 465 – 615 nm
- SNR > 100

Constraints
- Mass < 4kg
- Volume (excluding boom interface) < 10cm × 10cm × 35cm
- Power < 5W

Caltech

Prototype: SHWS

- Consists of a microlens array (MLA) and CMOS detector
- Objective: Develop procedure for aligning MLA and detector (tip, tilt, piston)

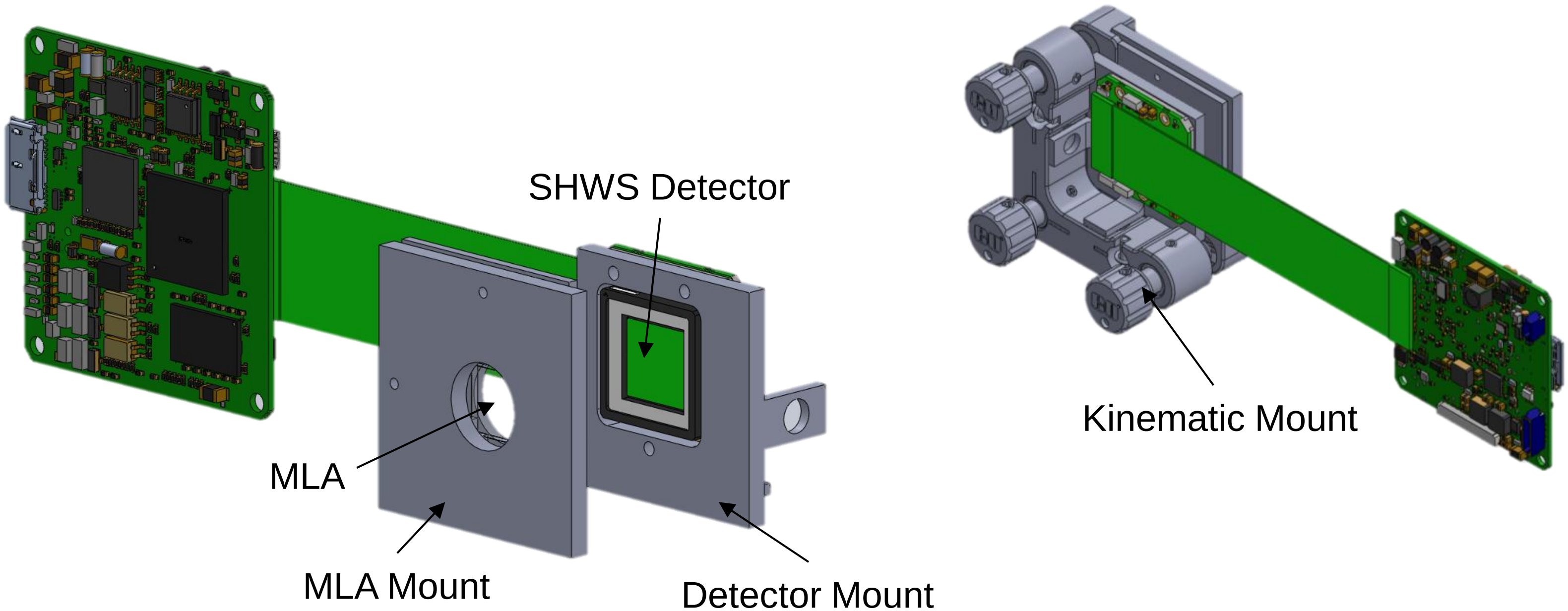


Boston Micromachines Corporation. (2013). Wavefront Sensor and Control System, Deformable Mirrors [Online]. Available: http://www.bostonmicromachines.com/wavefront-sensor.htm

Caltech

Prototype: SHWS Mount

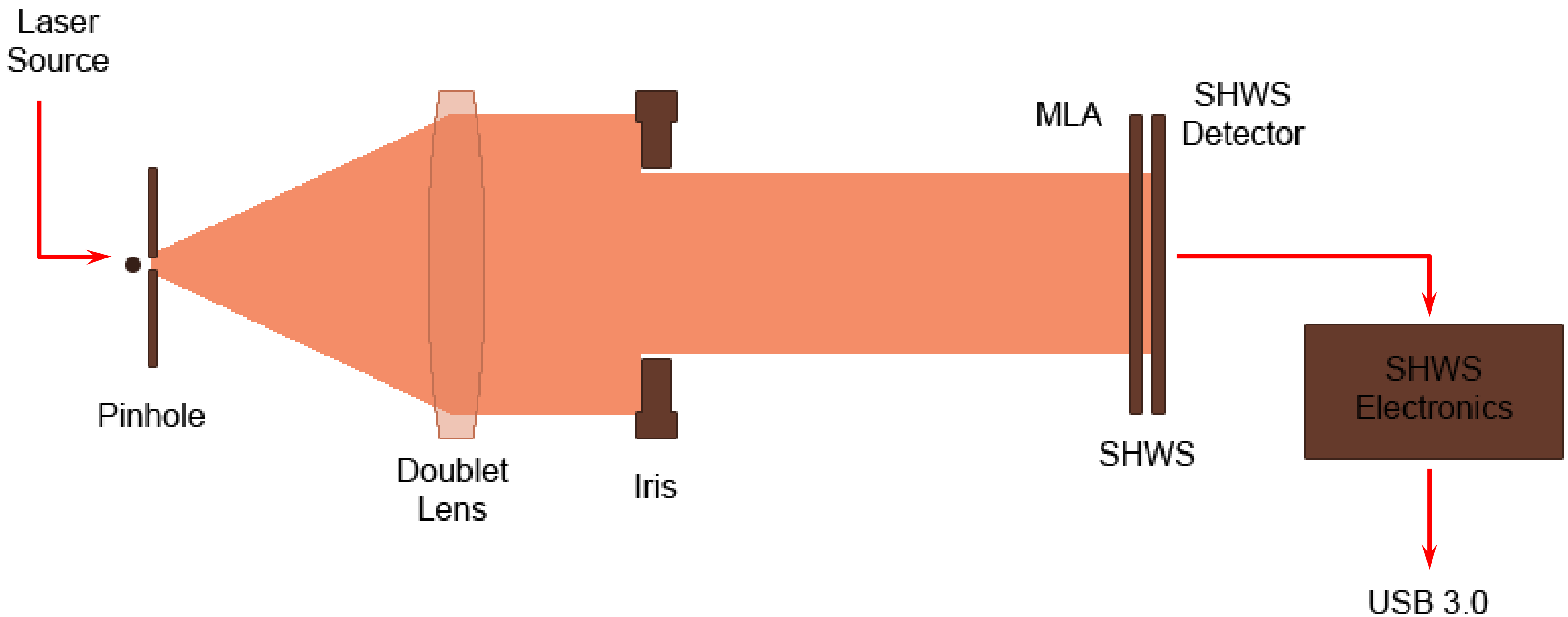
- Solution: Off the shelf kinematic mount + design modifications to hold 2 components rigidly in place



Caltech

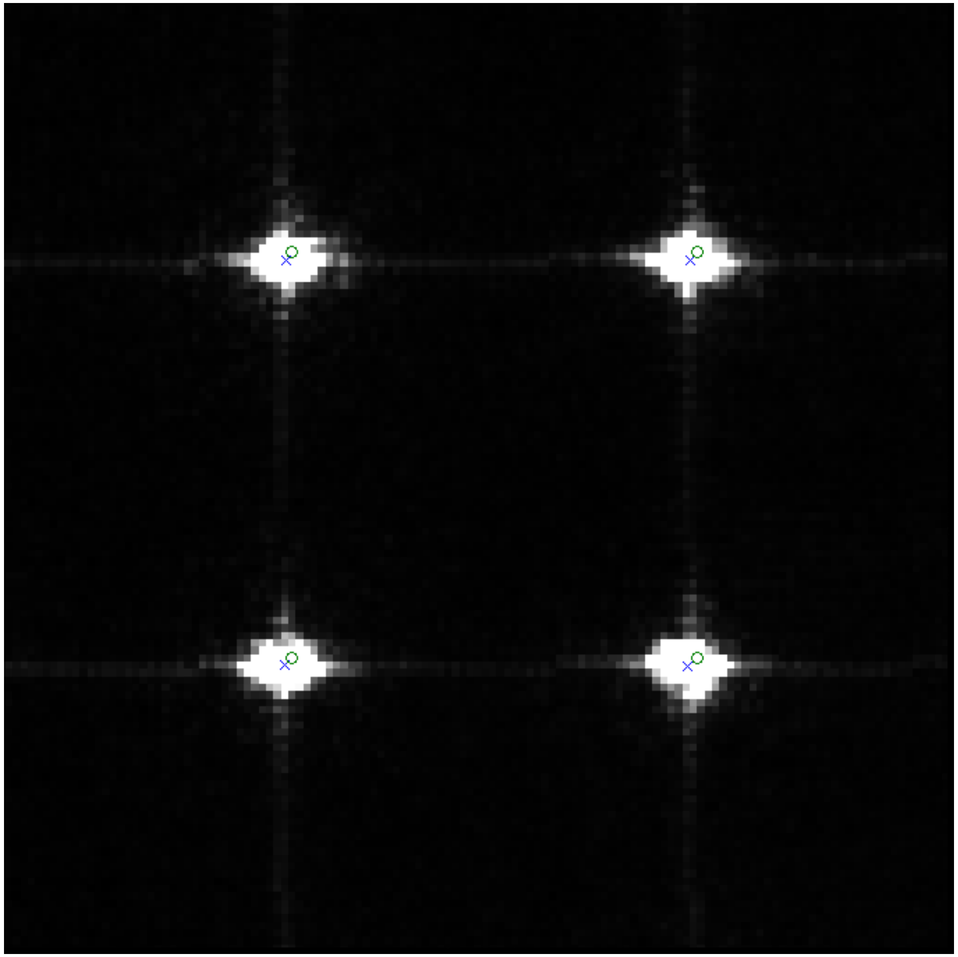
Prototype: SHWS Alignment

- Point source and collimating lens to generate plane wavefront for alignment
- Alignment verified with off-the-shelf SHWS



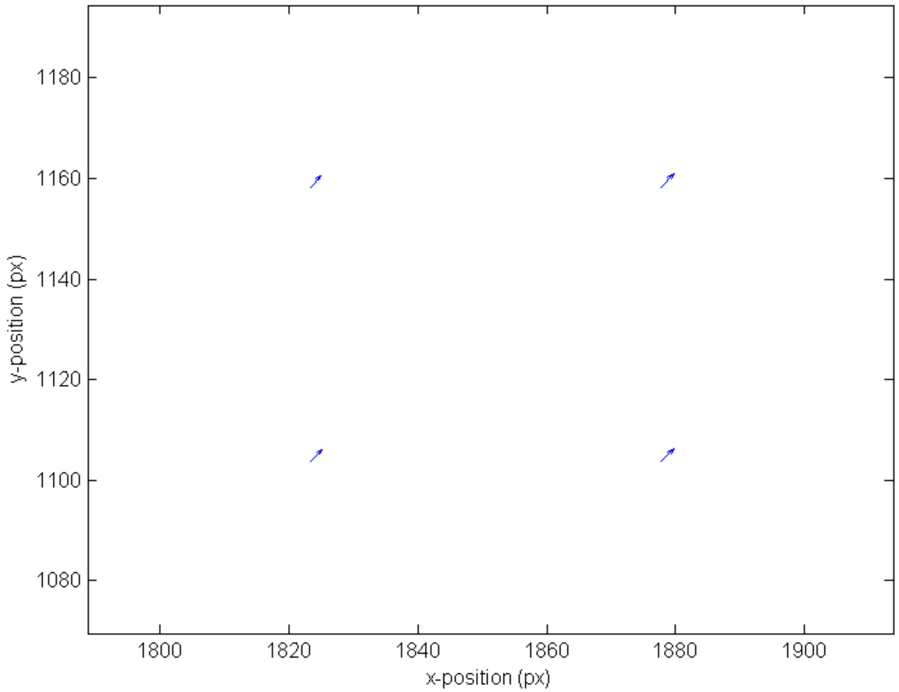
Prototype: SHWS Alignment

1. Threshold and clean up image
2. Extract spot locations (x)
3. Compute location of reference grid (o)
4. Wavefront slope is the difference between the two locations
5. Plot slopes to correct misalignment

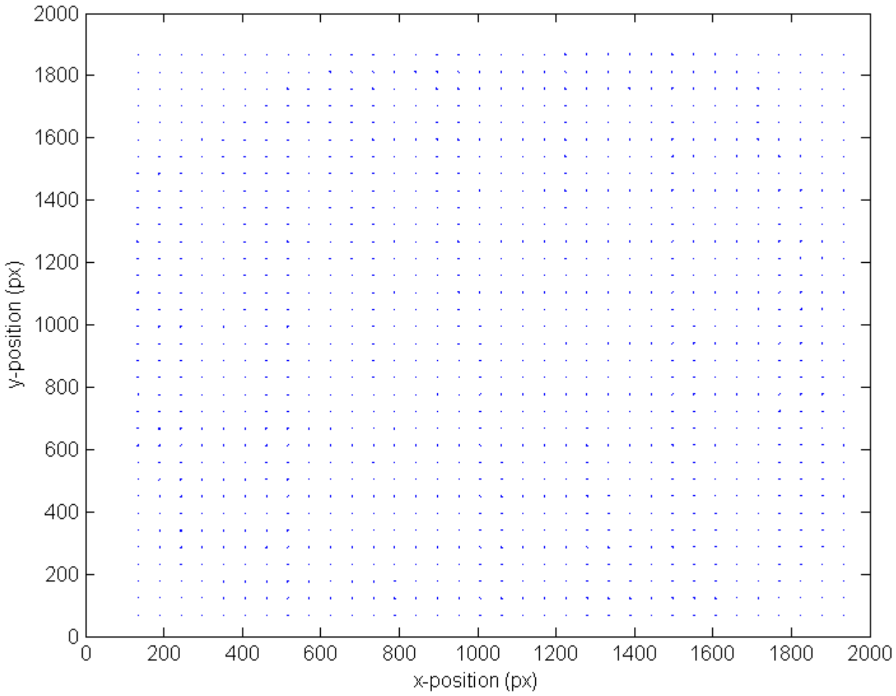


Caltech

Prototype: SHWS Alignment



Misaligned



Adjusted for tip and tilt

Caltech

Prototype: SHWS Conclusion

1. Alignment process developed (know effects of tip, tilt, piston)
2. SHWS currently coarsely aligned
3. Interferometer needed for fine alignment

Prototype: Power Budget

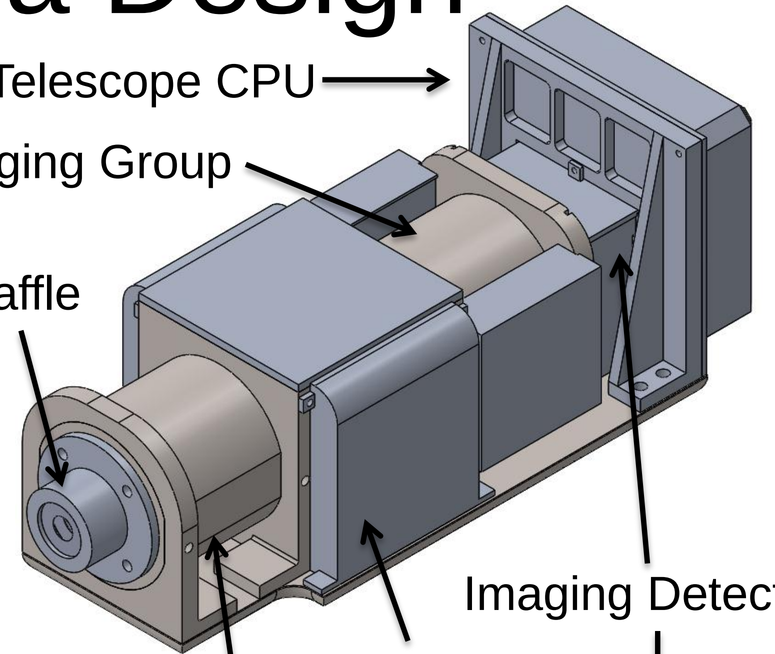
Part	Peak (W)	Nominal (W)	MODE 1	MODE 2	MODE 3
Telescope CPU	0.600	0.450	0.600	0.600	0.600
Imaging Detector	0.735	0.300	0	0.735	0
SHWS	2.400 x 2	1.800 x 2	2.400 + 1.800	0	0
Boom inspection camera	0.218	0.150	0	0	0
Wireless module	0.144	~0	0.144	0.144	0.144
Mask	0.600	0.600	0	0	0.600
Total	**7.097**	**5.100**	**4.944**	**1.479**	**1.344**

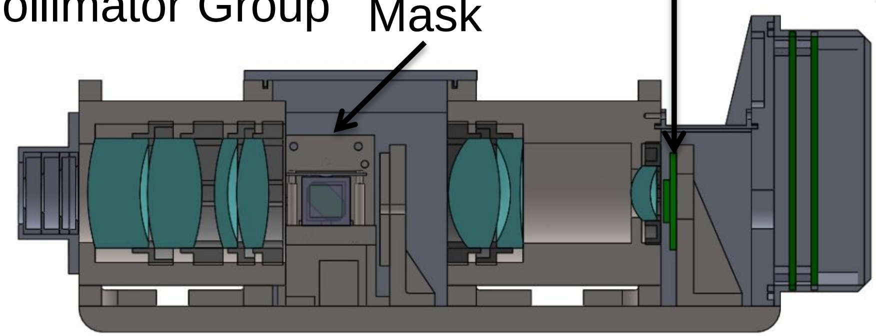
- Mode 1: Wavefront sensing
- Mode 2: Imaging
- Mode 3: Mirror reconfiguration

Caltech

Flight Camera Design

- Optical redesign required new mechanical design
- Physical Requirements
  - Mass: 4 kg
  - Envelope: 10x10x30 cm
- Current best estimate:
  - Mass: 2.94 kg
  - Envelope:9.8x9.5x26.5 cm

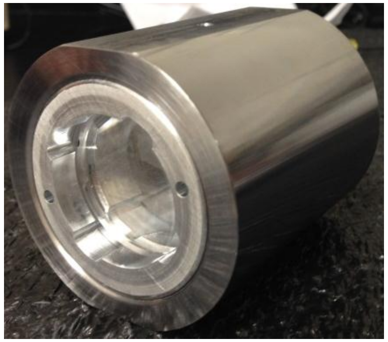


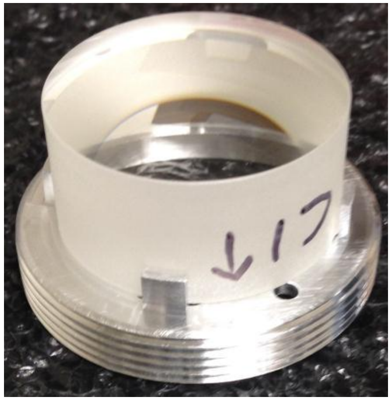


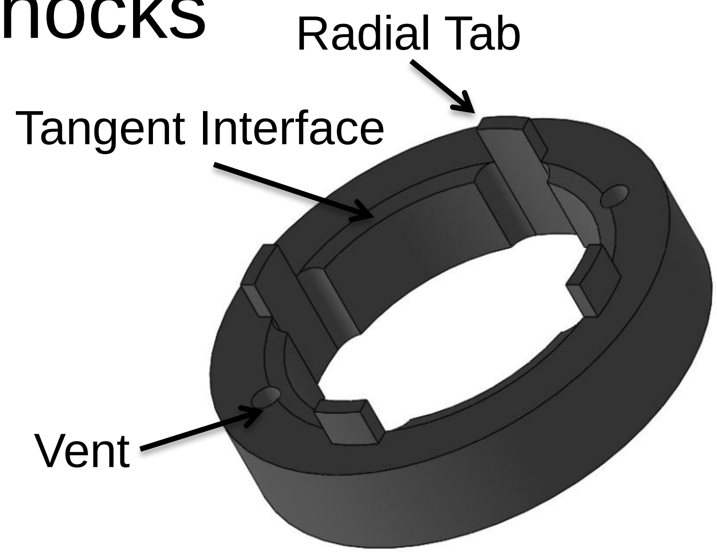
Caltech

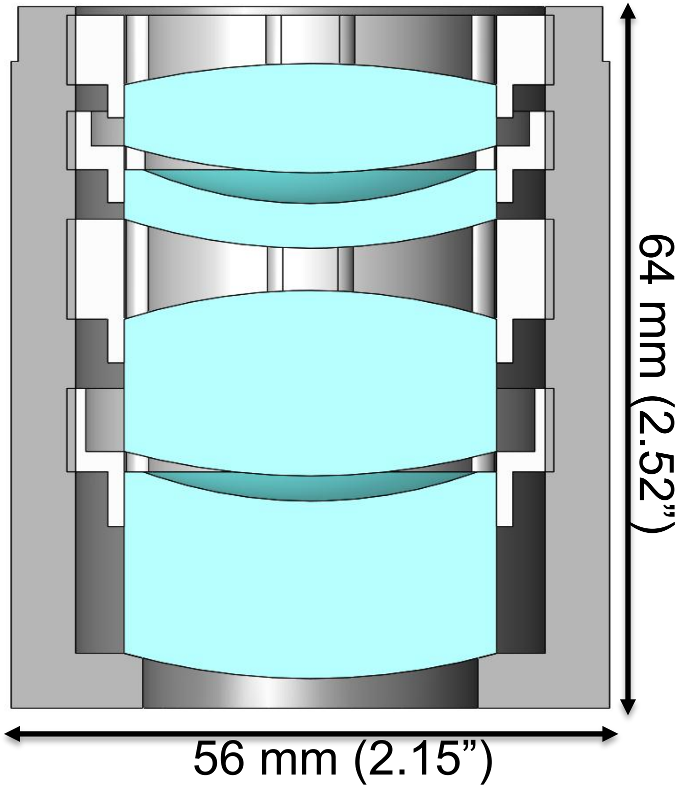
Lens Groups

- Designed tangential interfaces
  - Minimize stress concentrations
  - Radially self-centering
- Radial tabs prevent decenter due to shocks





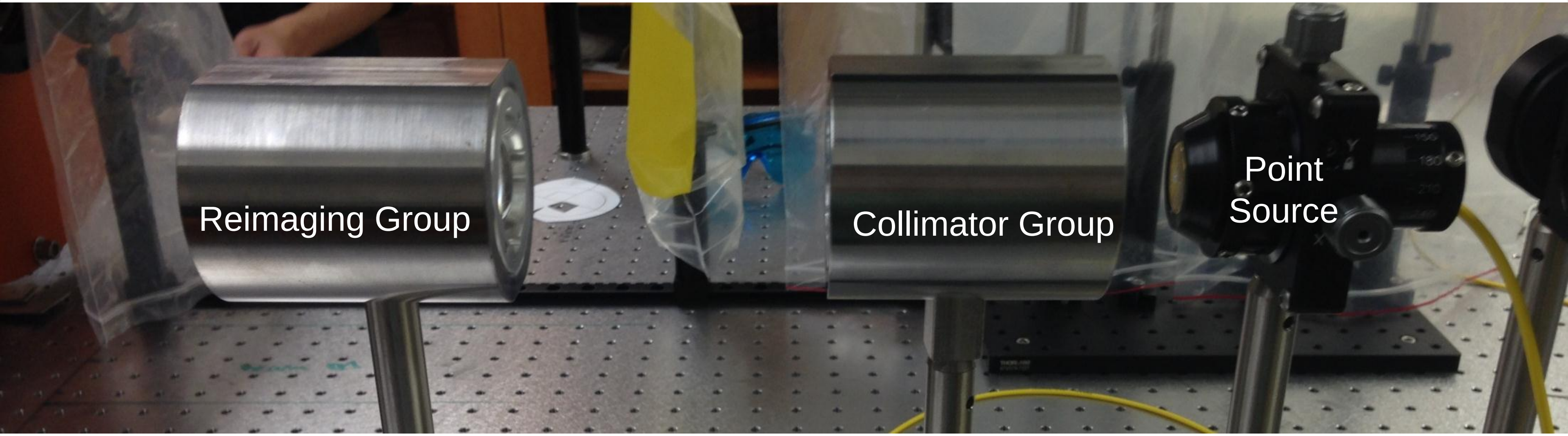




Caltech

Prototype: Lens Groups

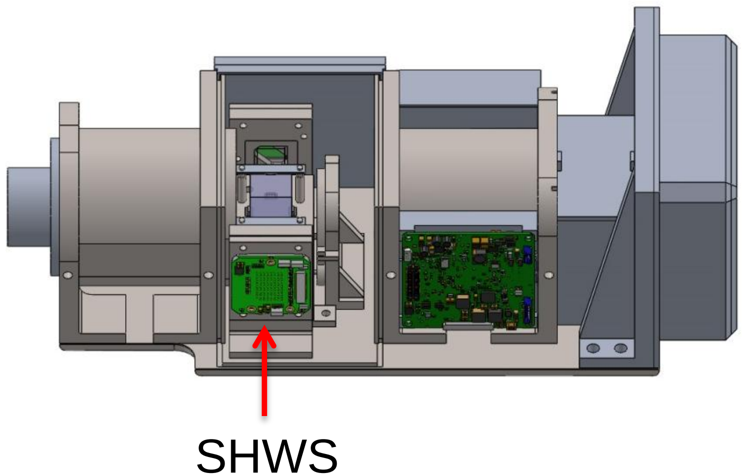
- Collimator and imaging groups assembled
- Point source at the prime focus of the collimator used for alignment
- See small spot at the end of the imaging lens as expected

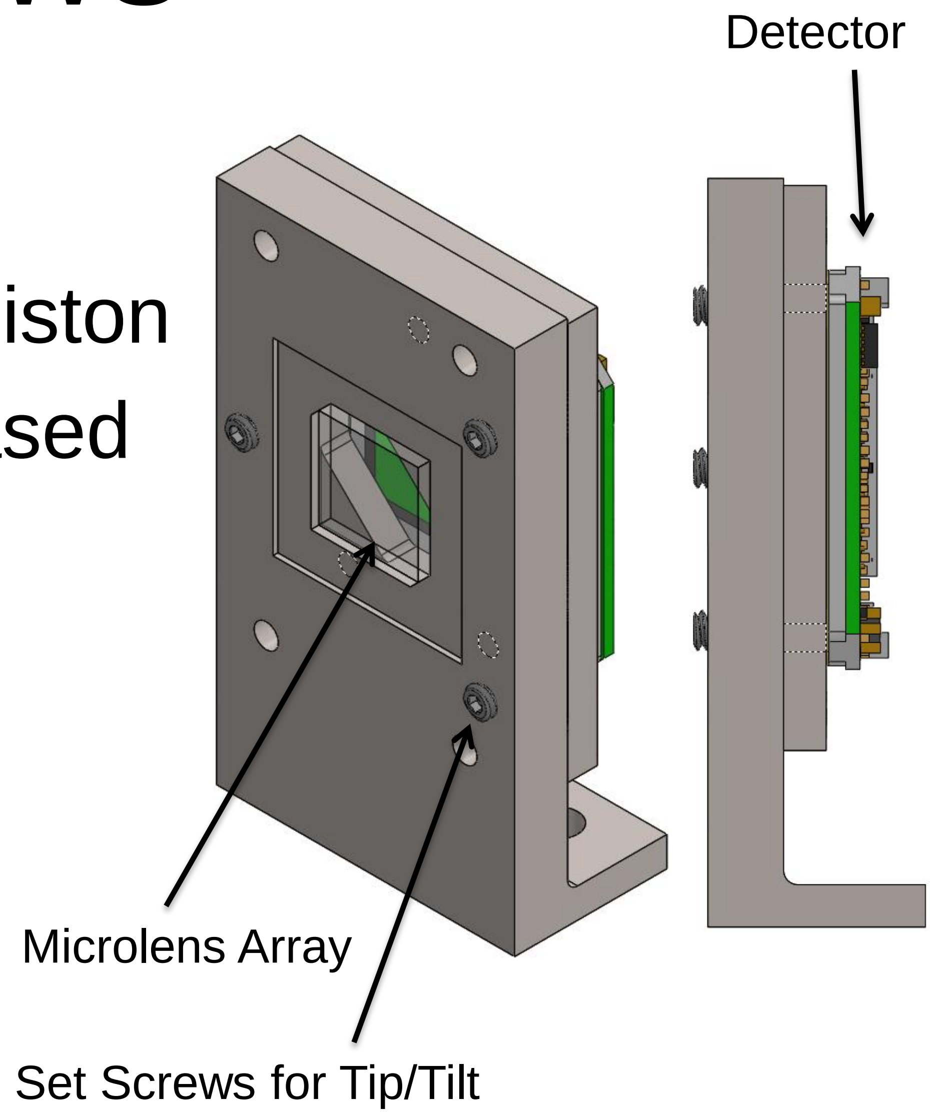


Caltech

SHWS

- MLA fixed, detector adjusts in tip/tilt and piston
- Alignment process based on prototype SHWS





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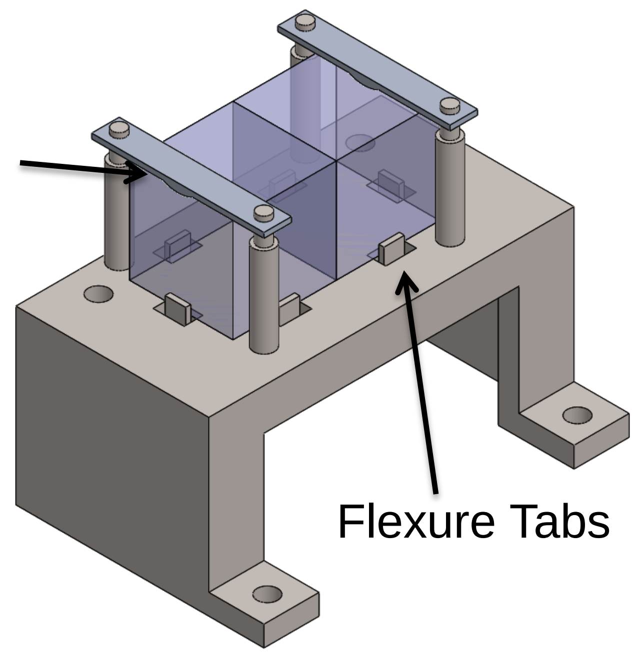
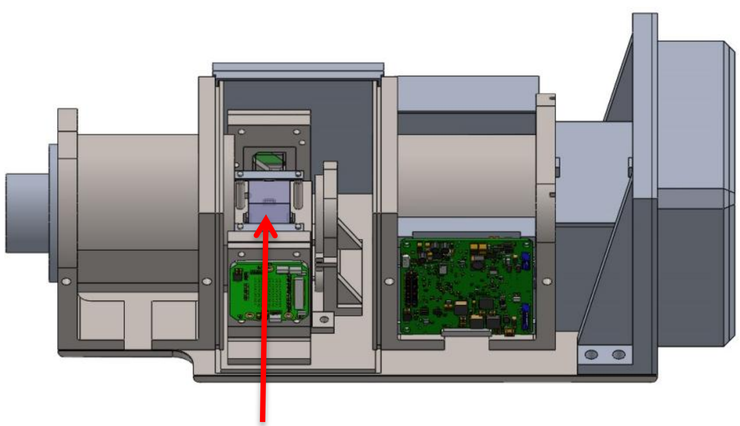
Beam Splitters

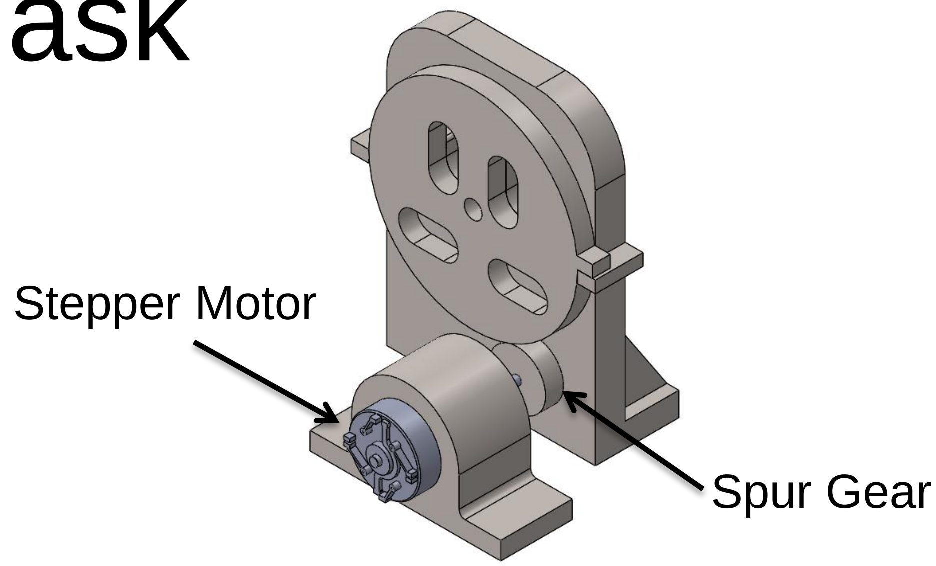
- 6 DoF constrained by flexures
  - Cannot bond due to CTE mismatch over large surface area

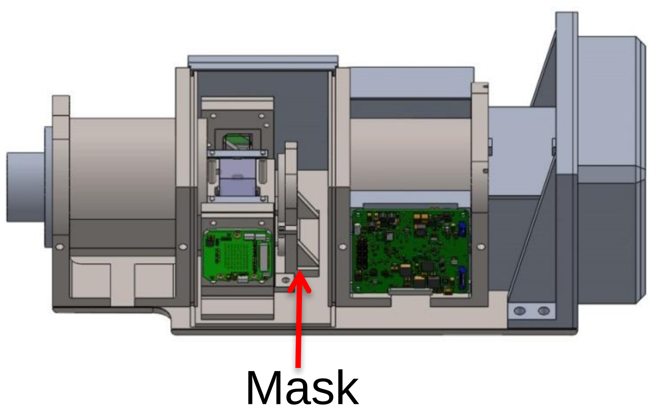


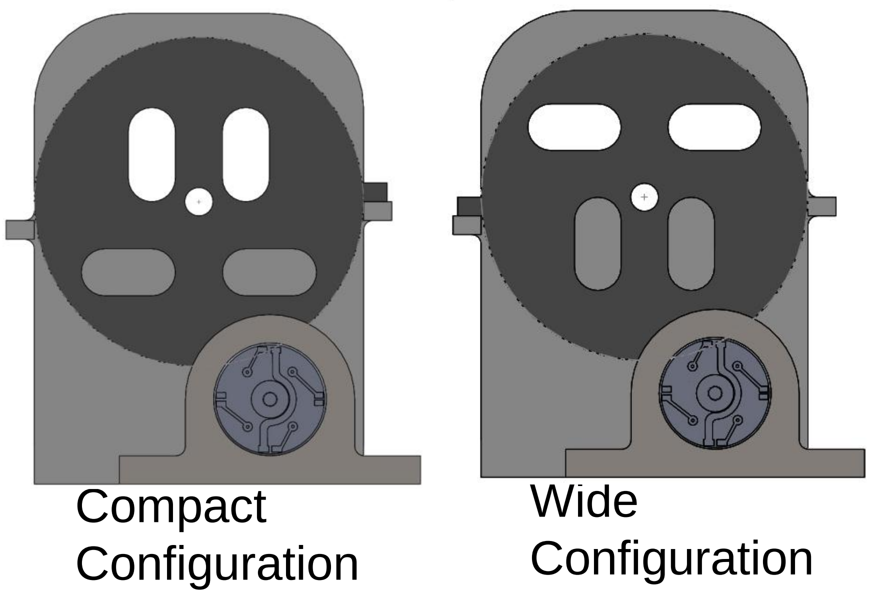


Mask

- Two positions for Compact and Wide Configurations
- Actuated by off-axis motor and spur gear
- Controlled by limit switch and hard-stop







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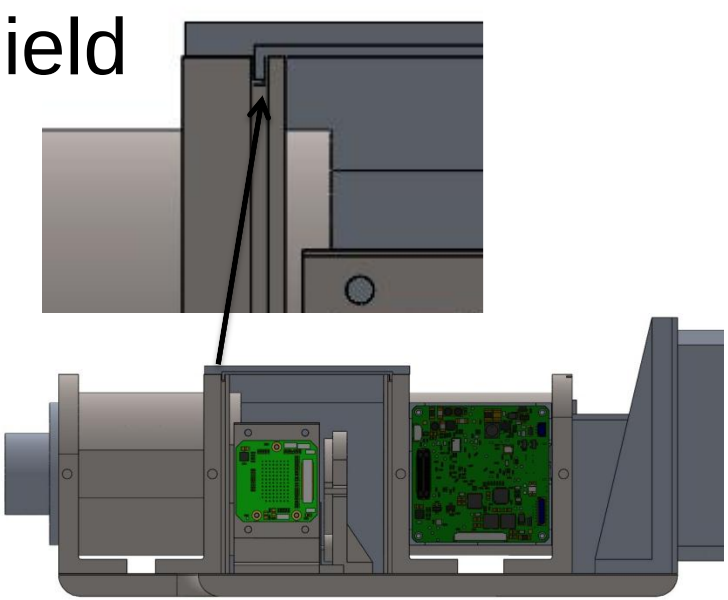
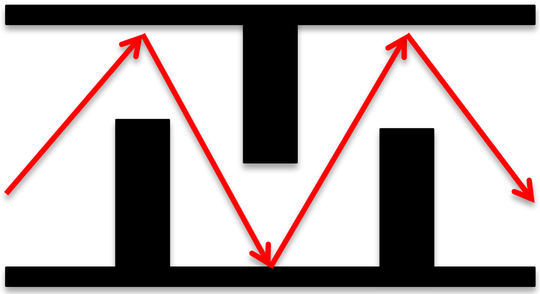
Stray Light/Electronics Shield

- Makes use of triple-bounce interface for stray light blocking
- Minimum 1 mm thick Aluminum radiation shield





Caltech

Requirements

Functional
- Work with reconfigurable primary mirror – **Dynamic Mask**
- Provide feedback during primary mirror calibration - **SHWS**
- Science imaging – **Entire Subsystem**

Performance
- 80% encircled energy radius < 90% diffraction-limited EE radius
- 0.3° full field-of-view
- Bandwidth: 465 – 615 nm
- SNR > 100

Constraints
- Mass < 4kg – **CBE < 3kg**
- Volume (excluding boom interface) < 10cm × 10cm × 35cm - **Met**
- Power < 5W – **CBE ~ 4.9 W maximum**

Caltech

Future Work

- Prototype
  - Fine SHWS alignment
  - Integration with testbed

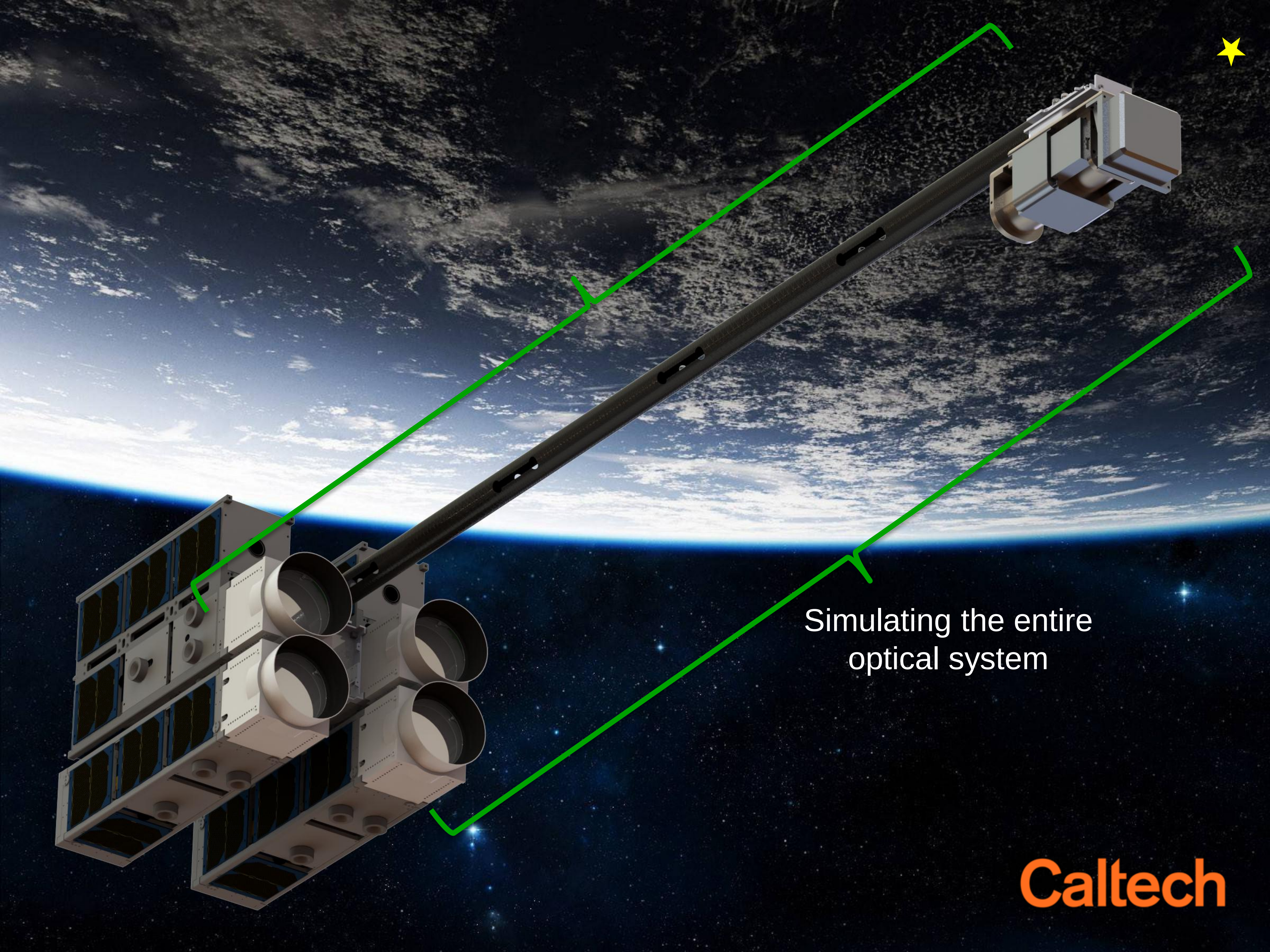
- Flight Camera Design
  - Thermal analysis
  - Boom inspection camera
  - Design for manufacturability

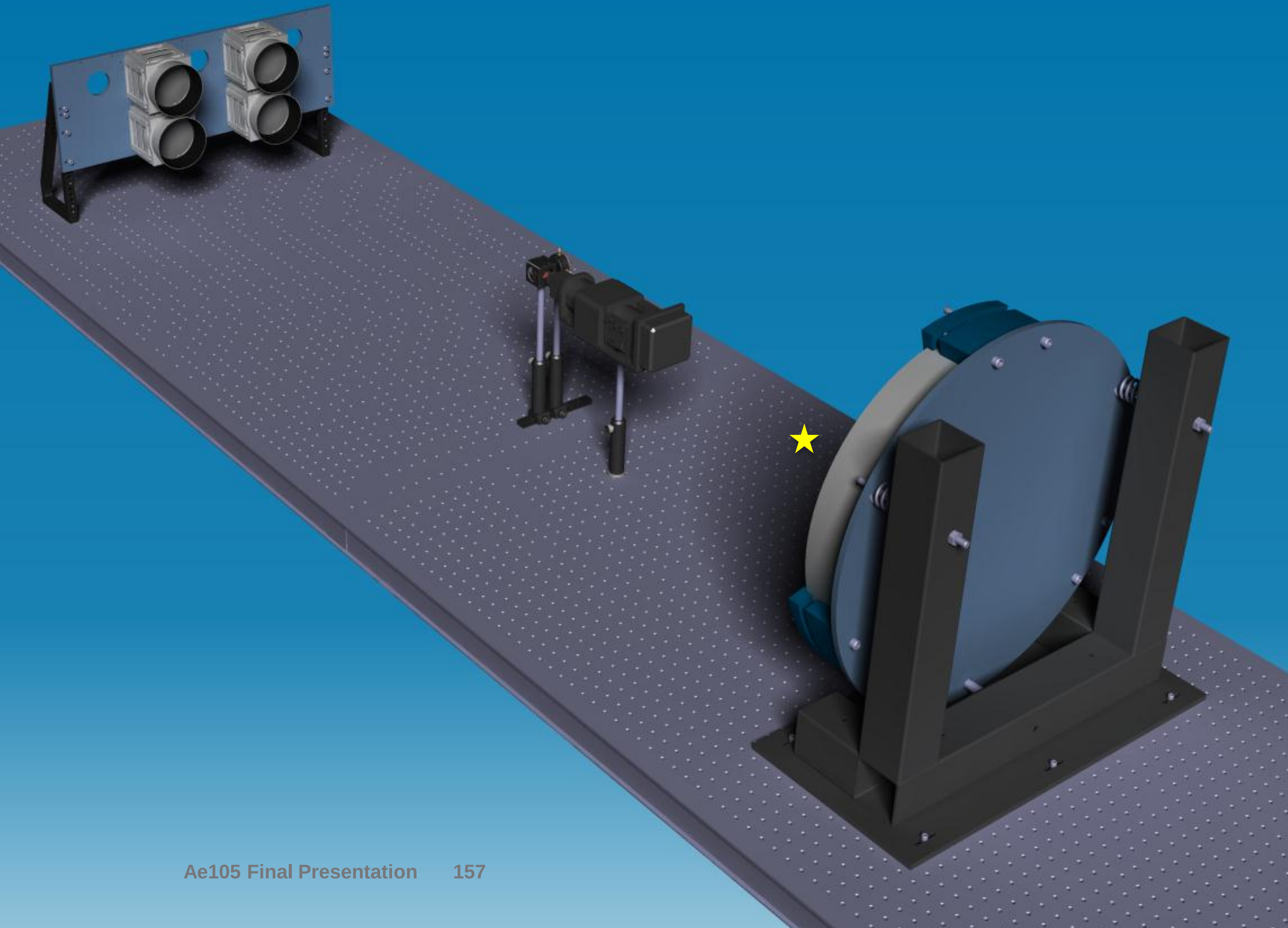
Questions?

Optical Testbed

Garima Gupta, Manuel Martinez
Mentor: Marie Laslandes

Caltech


Simulating the entire
optical system
Caltech



Overview

- Primary Goal
  - To provide a setup in which the different components of the telescope could be tested as a whole
- Objectives
  - To model the optical components of the spacecraft
  - To simulate the observation of a distant star

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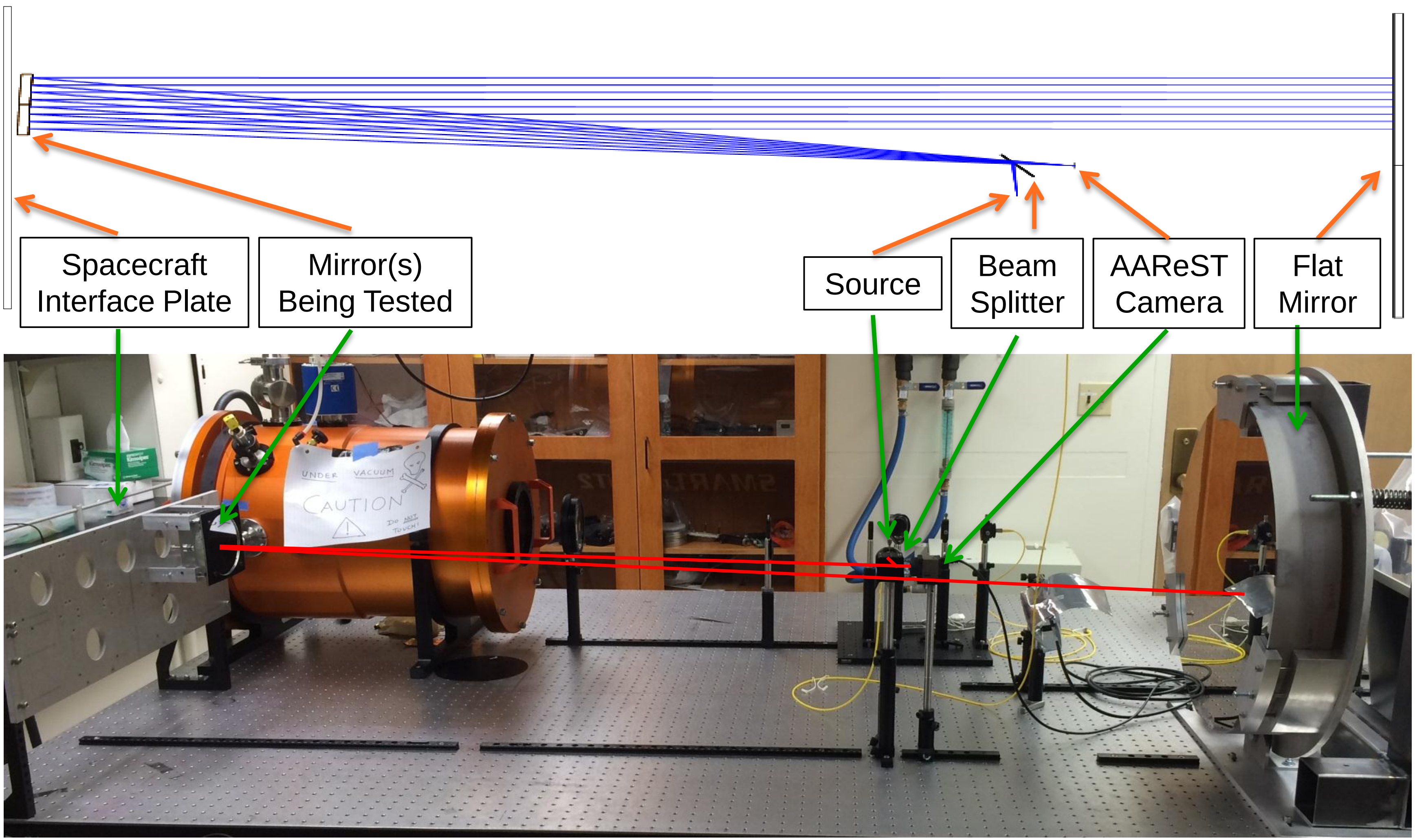
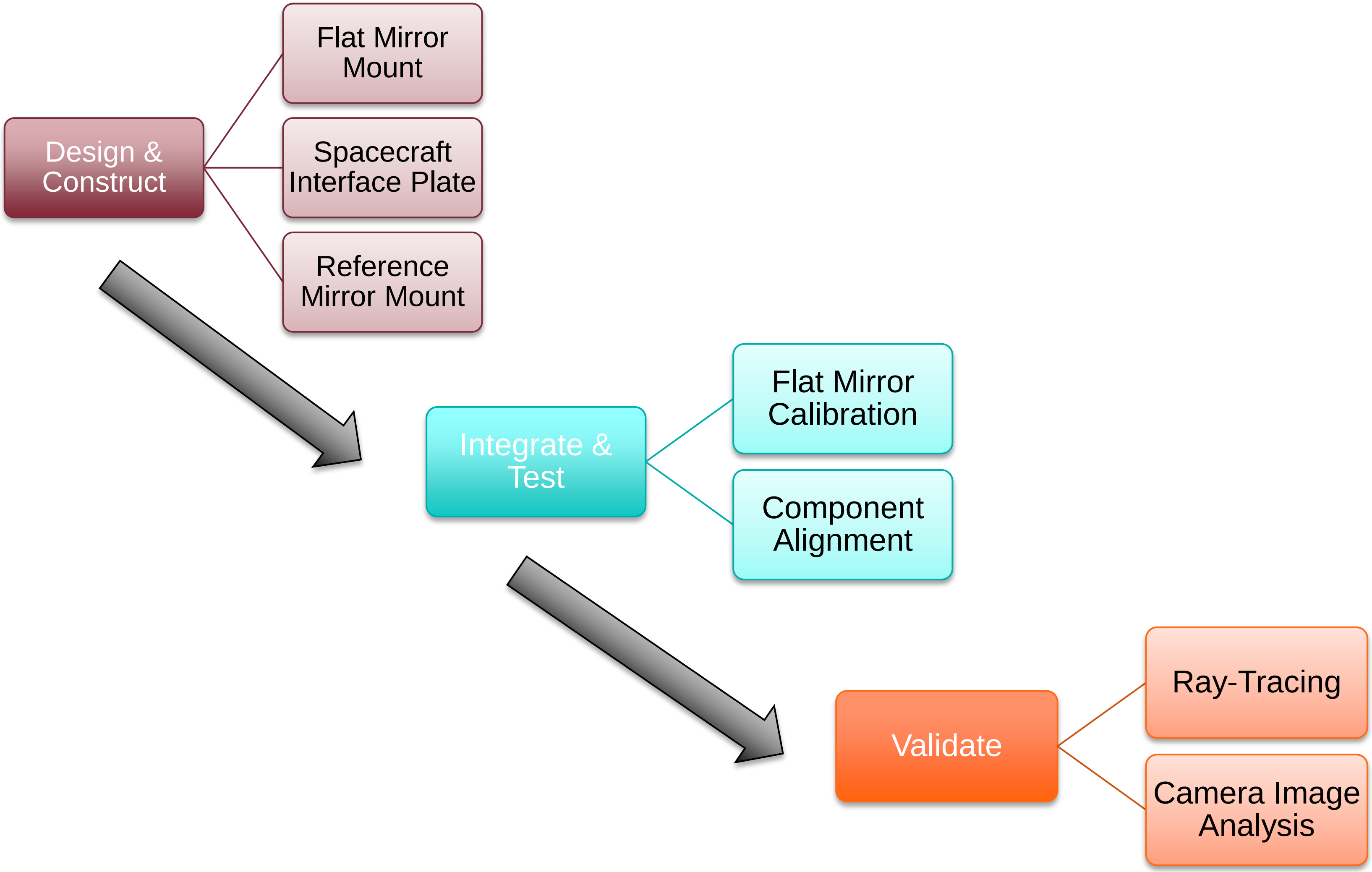
Basic Setup

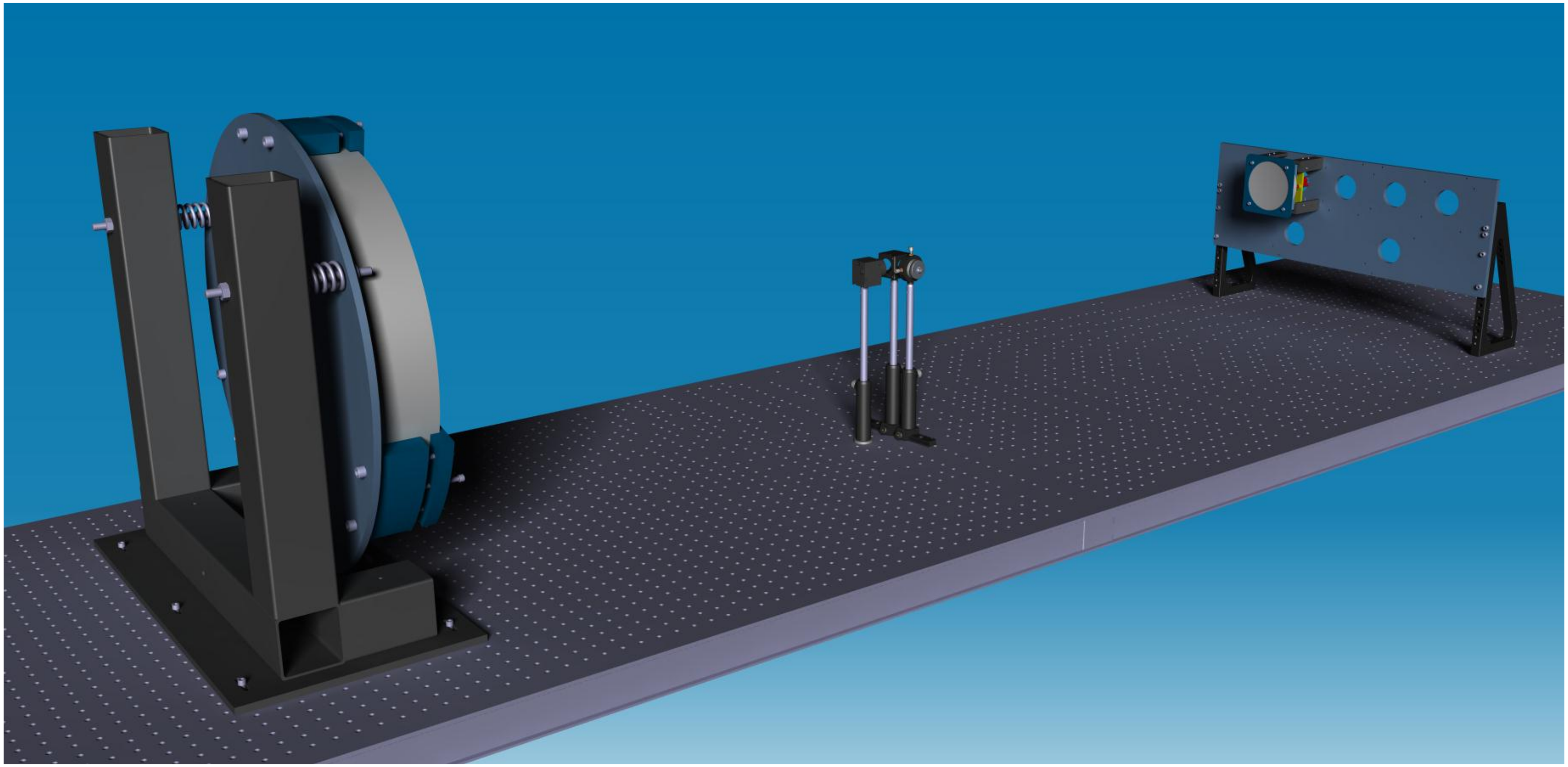


Spacecraft Interface Plate
Mirror(s) Being Tested
Source
Beam Splitter
AAReST Camera
Flat Mirror
UNDER VACUUM
CAUTION

Tasks

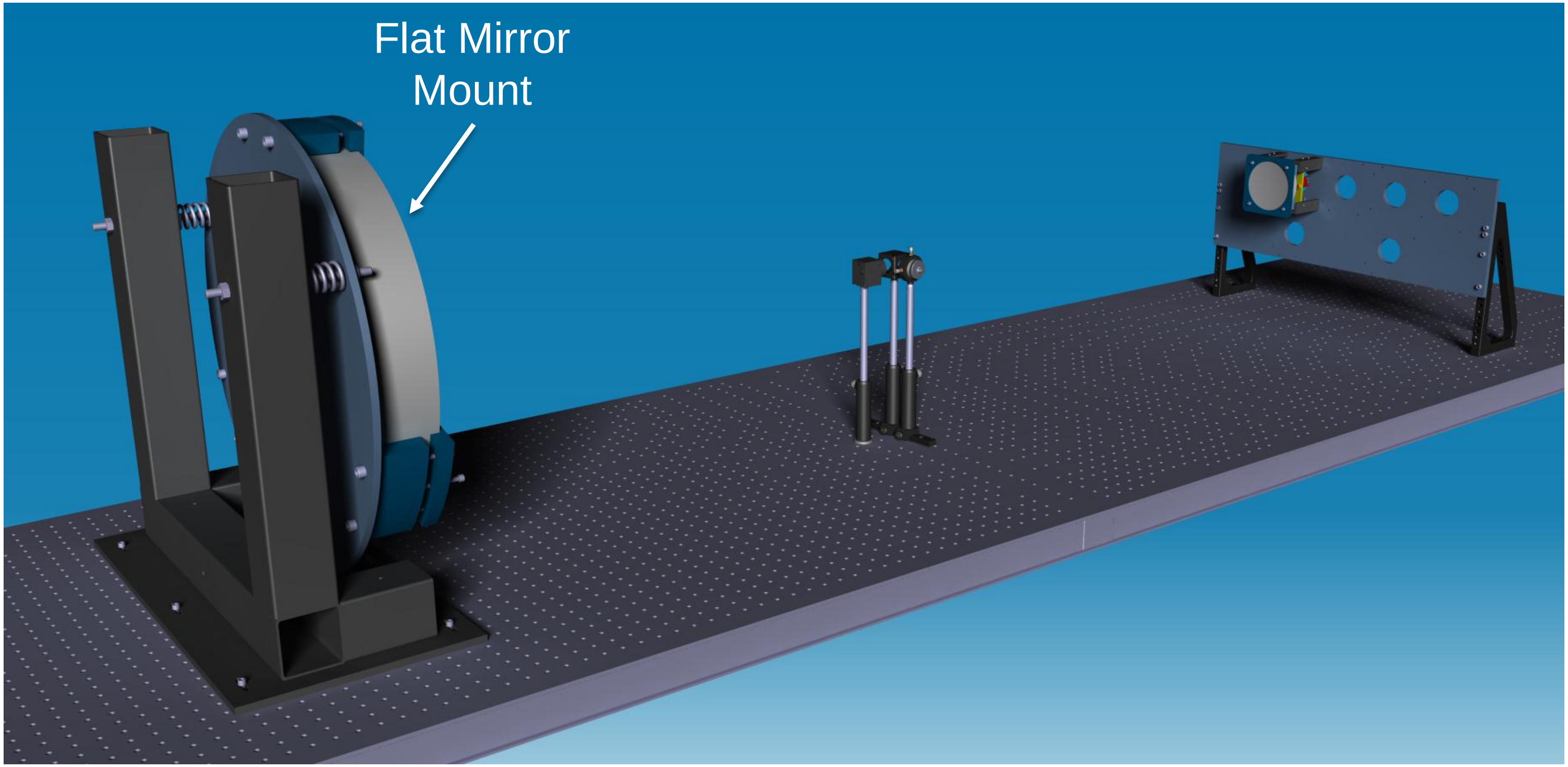

Design & Construct
Flat Mirror Mount
Spacecraft Interface Plate
Reference Mirror Mount
Integrate & Test
Flat Mirror Calibration
Component Alignment
Validate
Ray-Tracing
Camera Image Analysis

Design & Construct



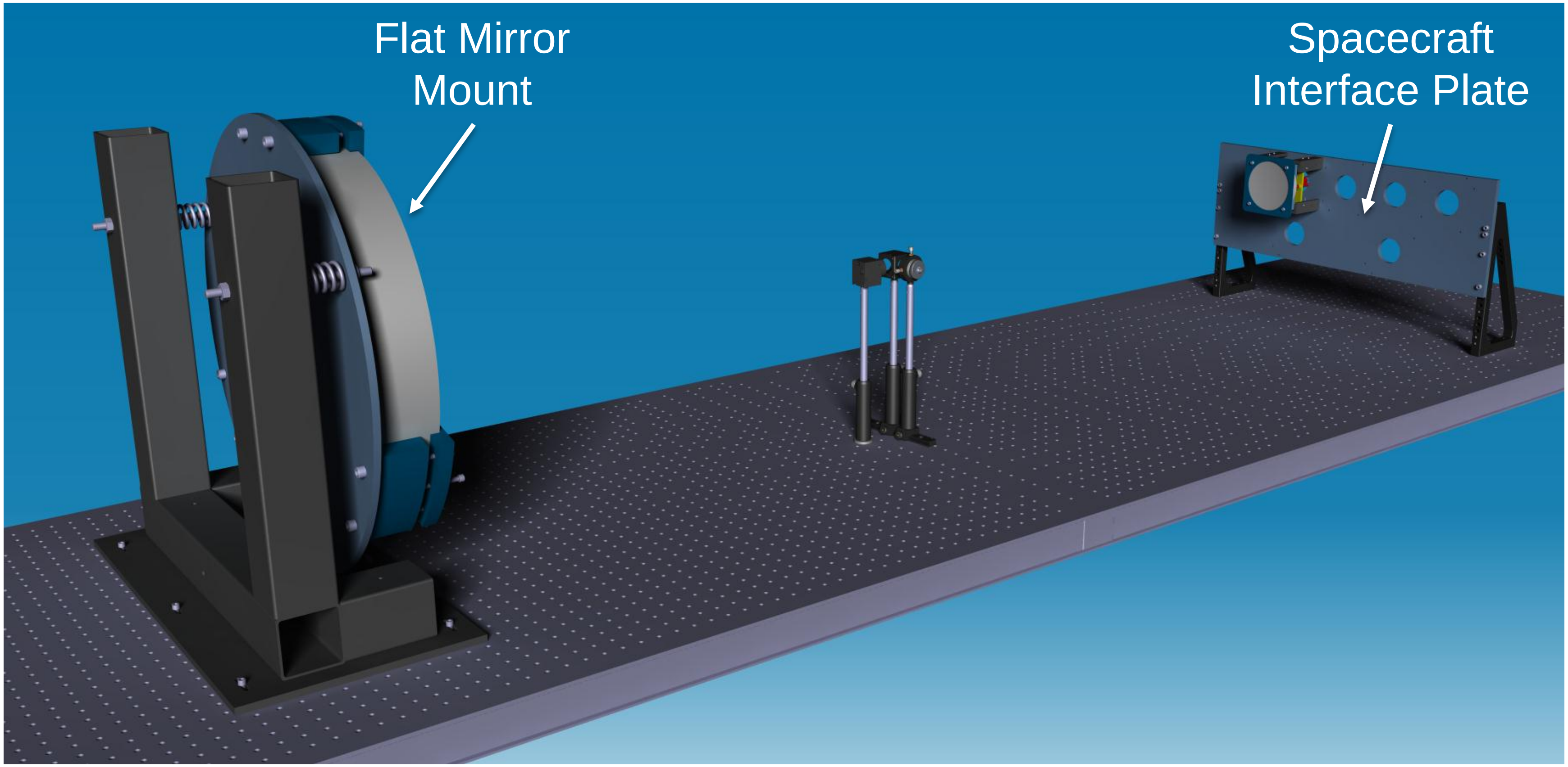
Caltech

Design & Construct



Caltech

Design & Construct



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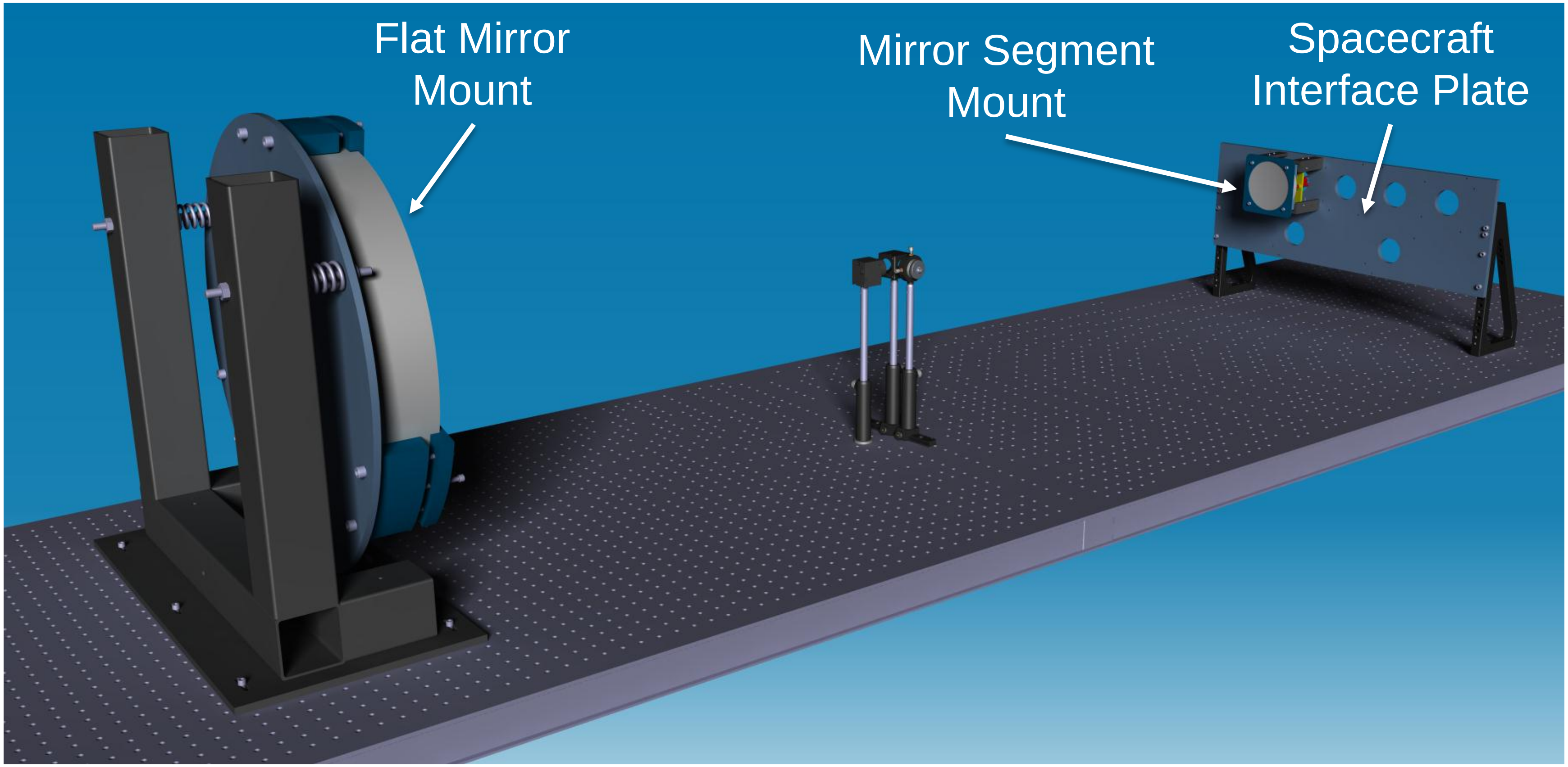
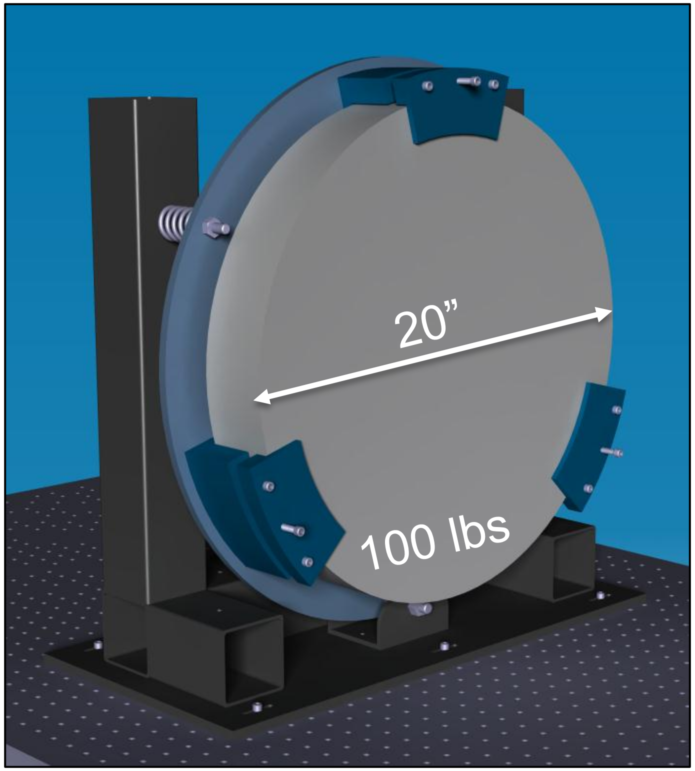
Design & Construct

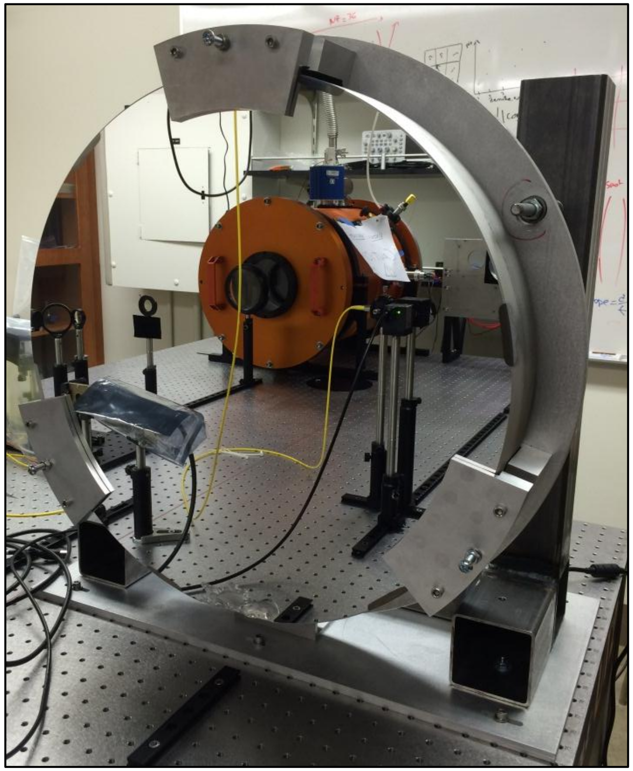


Caltech

Design & Construct

Flat Mirror Mount





Purpose: to mount the large flat mirror (acquired from JPL) used for auto-collimation

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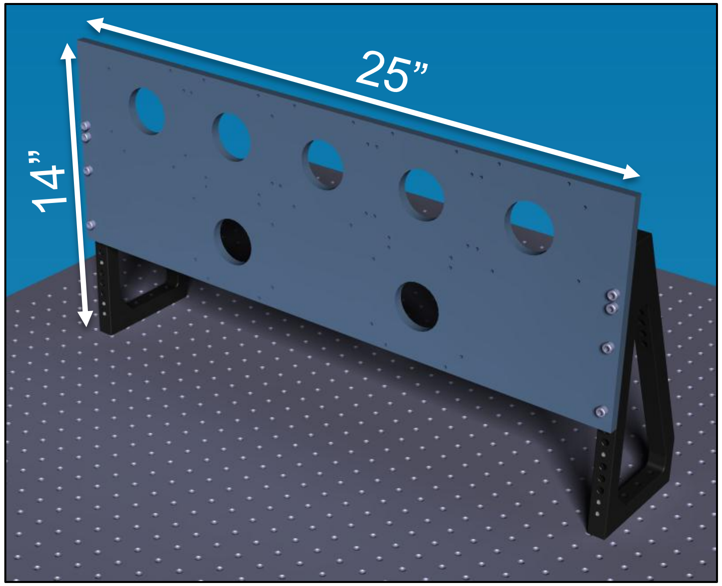
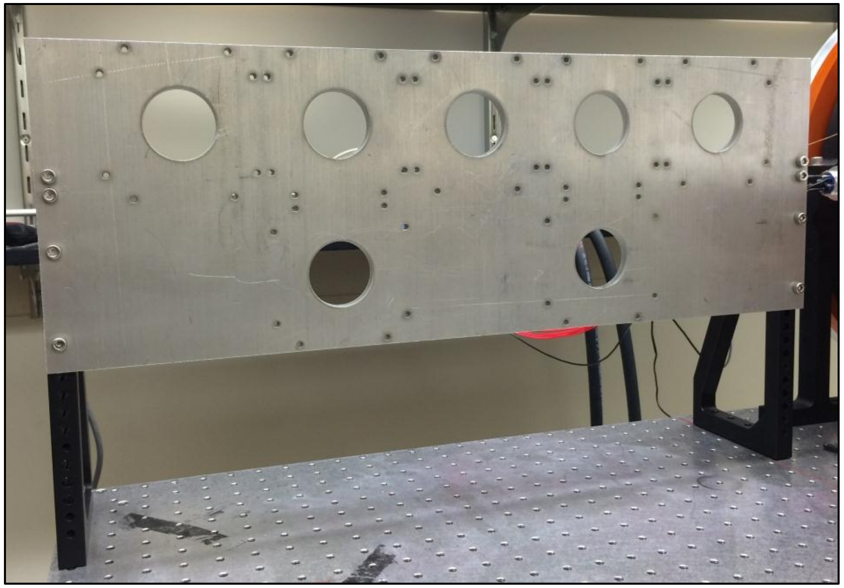
Design & Construct

Spacecraft Interface Plate



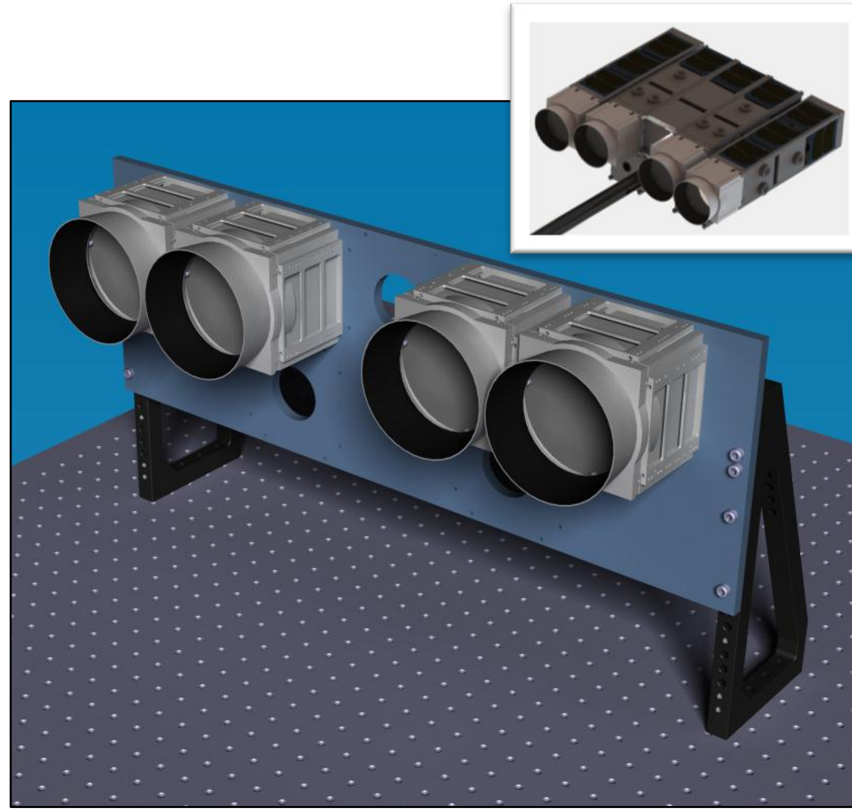


Purpose: to simulate the mechanical interface with the spacecraft

Caltech

Design & Construct
Spacecraft Interface Plate

Narrow Configuration



Wide Configuration

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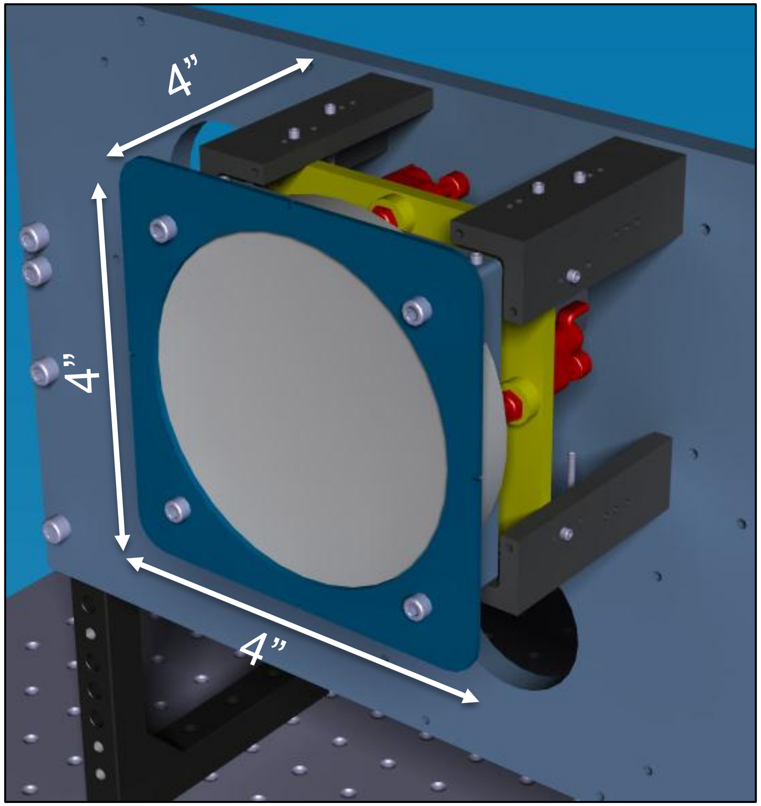
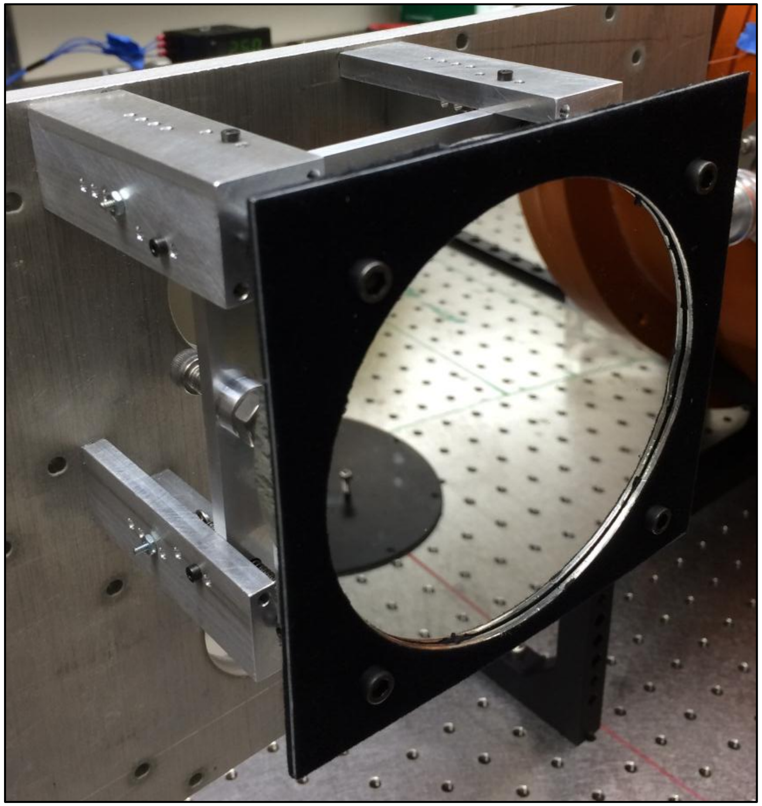
Design & Construct
Mirror Segment Mount





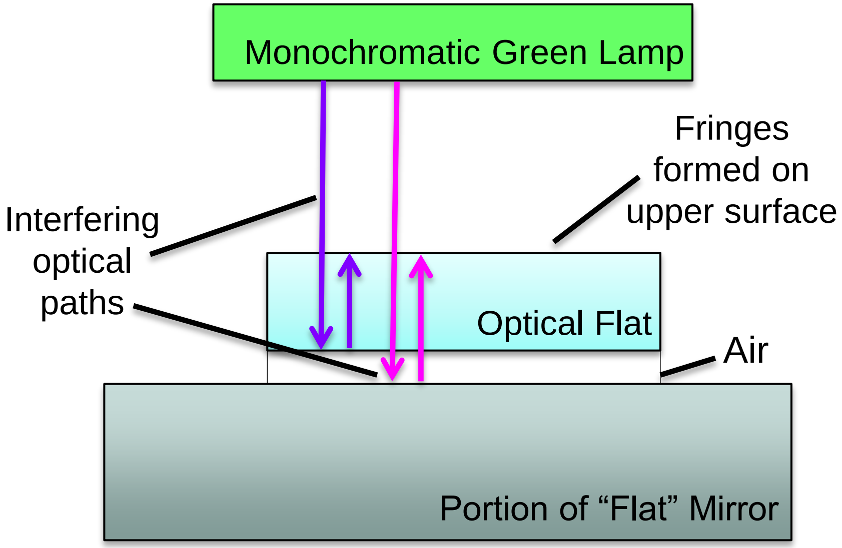
Purpose: to mount the reference and deformable mirrors to the spacecraft interface plate (with the ability to tip and tilt)

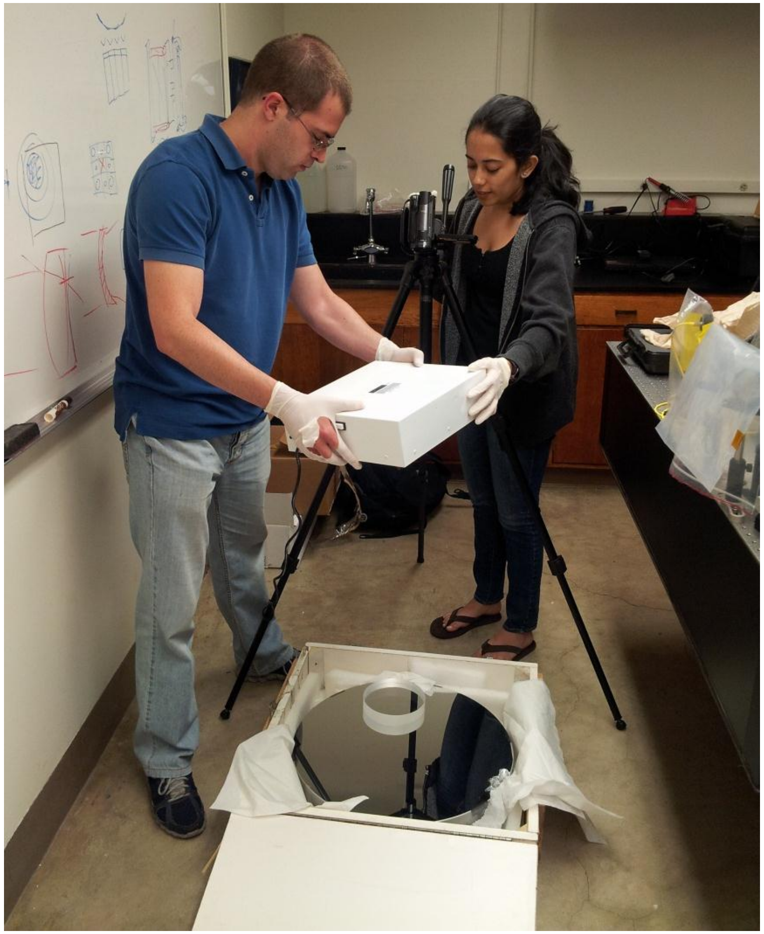
Caltech

Integrate & Test

Flat Mirror Calibration

- Setup
  - Newton Fringes
  - Images taken at different positions on mirror

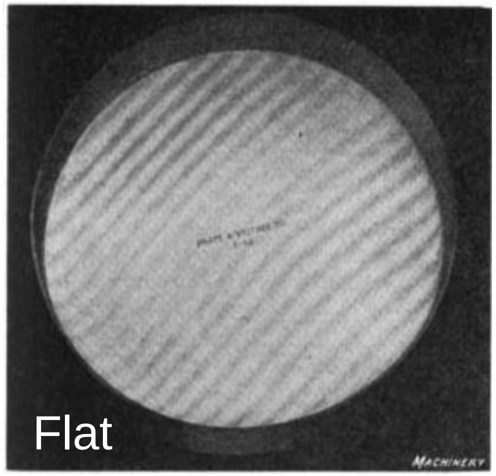


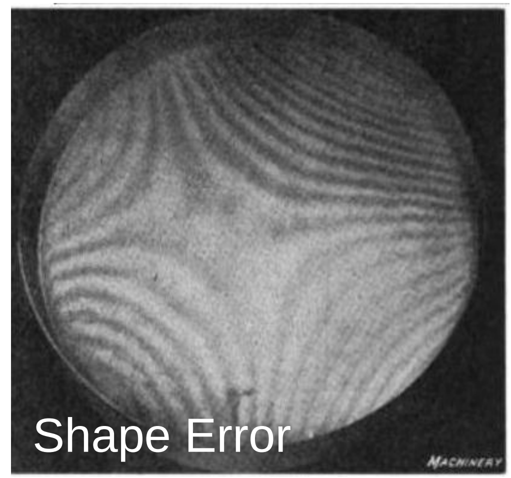


Caltech

Integrate & Test
Flat Mirror Calibration

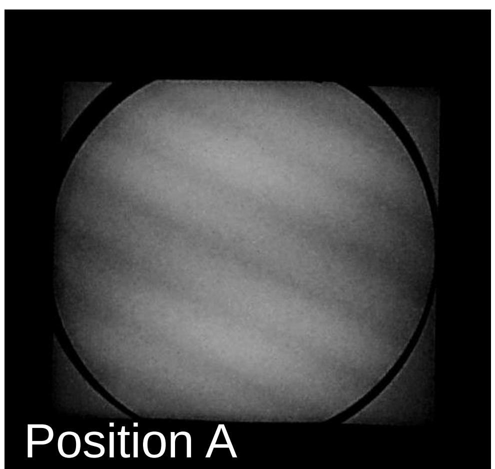
Example Measurements

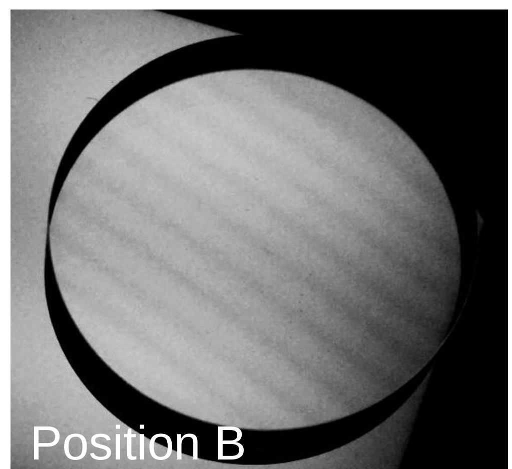




http://en.wikipedia.org/wiki/File:Optical_flat_interference_fringes.jpg

Measurements on Studied Mirror



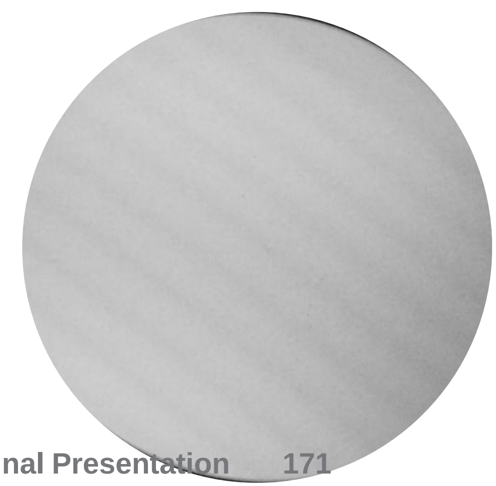


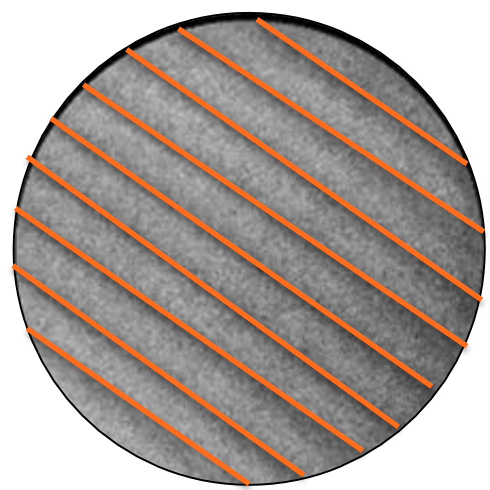
Caltech

Integrate & Test
Flat Mirror Calibration

- Image Processing
  - Qualitative: All fringes look straight by eye
  - Quantitative
    - Detect edges, fit lines, measure deviation between edges and lines
    - Problem: Low contrast
    - Exploring Spatial Fourier Transform Approach

Original Image





Processed Image

Caltech

Integrate & Test
Component Alignment

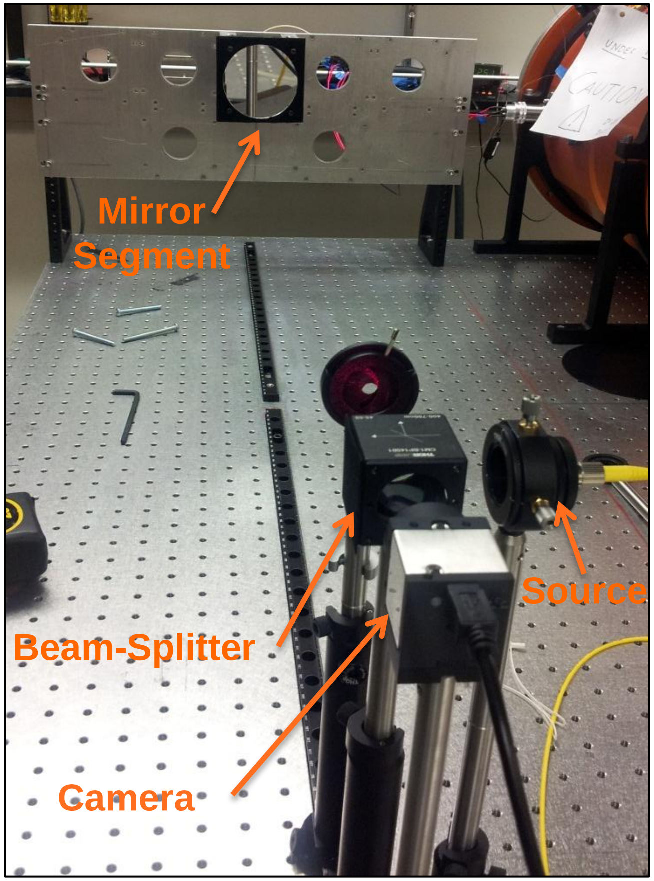
- Goal: Align the different breadboard elements
  - Numerous coupled degrees of freedom
  - Need to define protocol for an efficient and effective alignment

- Two different situations (protocols):
  1. Breadboard alignment with on-axis mirror
     - Define the optical axis
  2. Integrate segments in AAReST configuration

Caltech

Integrate & Test
Component Alignment – Protocol 1

- Source & Beam Splitter
  - Illuminate the interface plate
- Mirror Segment & Flat Mirror
  - Adjust Piston/Tip/Tilt to have return spot focusing on initial source
- Camera
  - Position on the optical axis, at the focal plane



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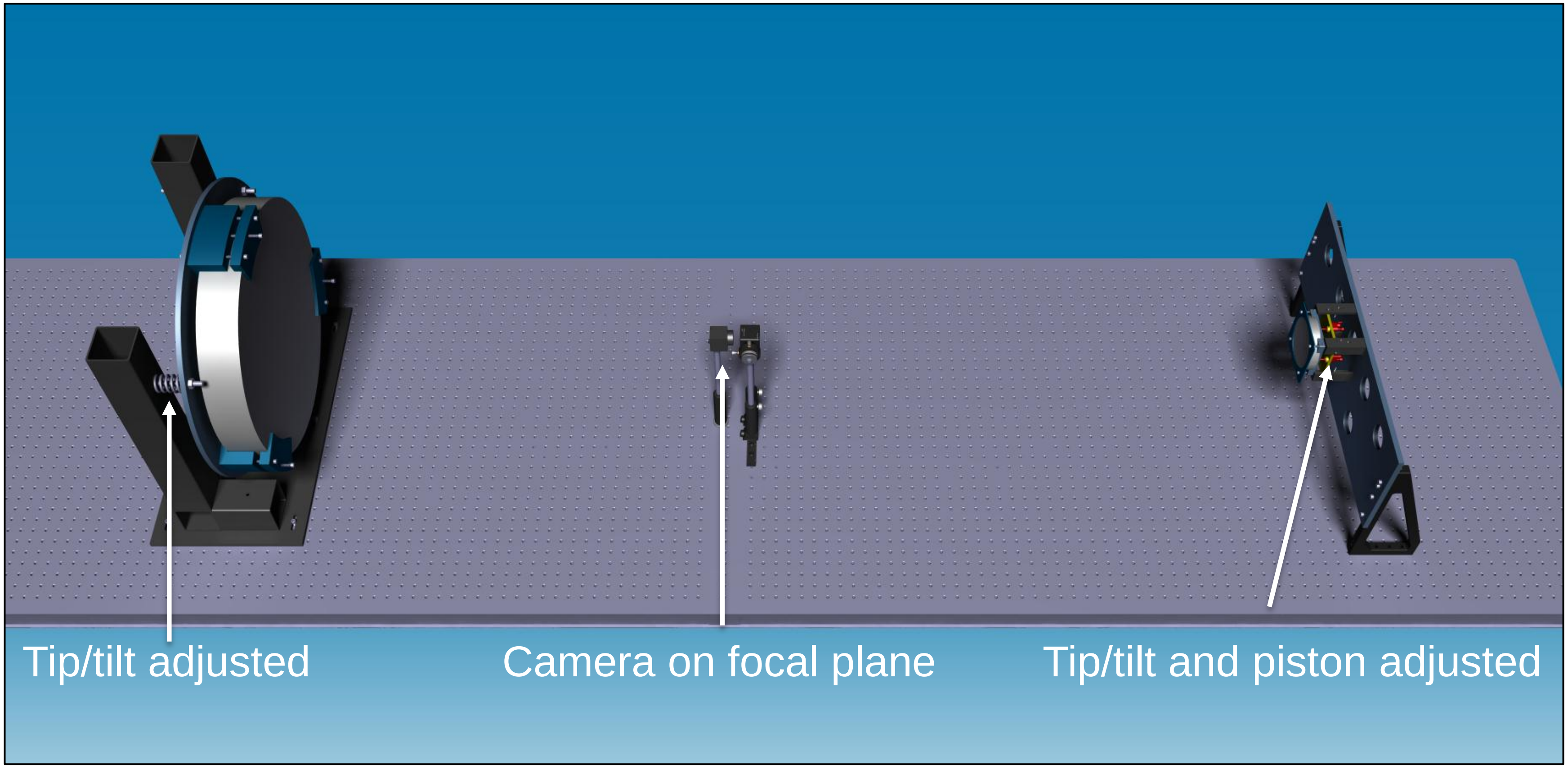
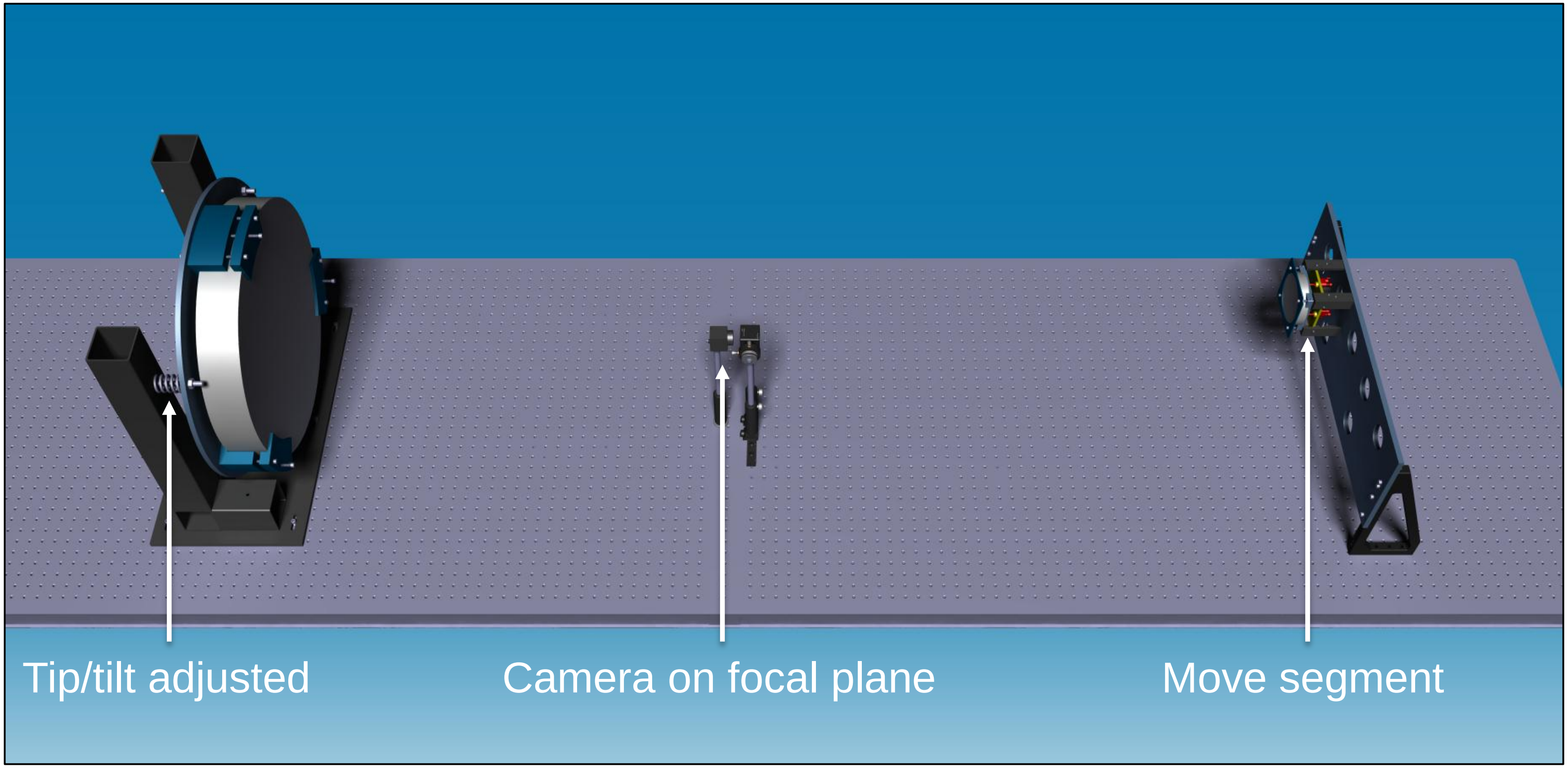
Integrate & Test

Component Alignment – Protocol 1



Caltech

Integrate & Test
Component Alignment – Protocol 2



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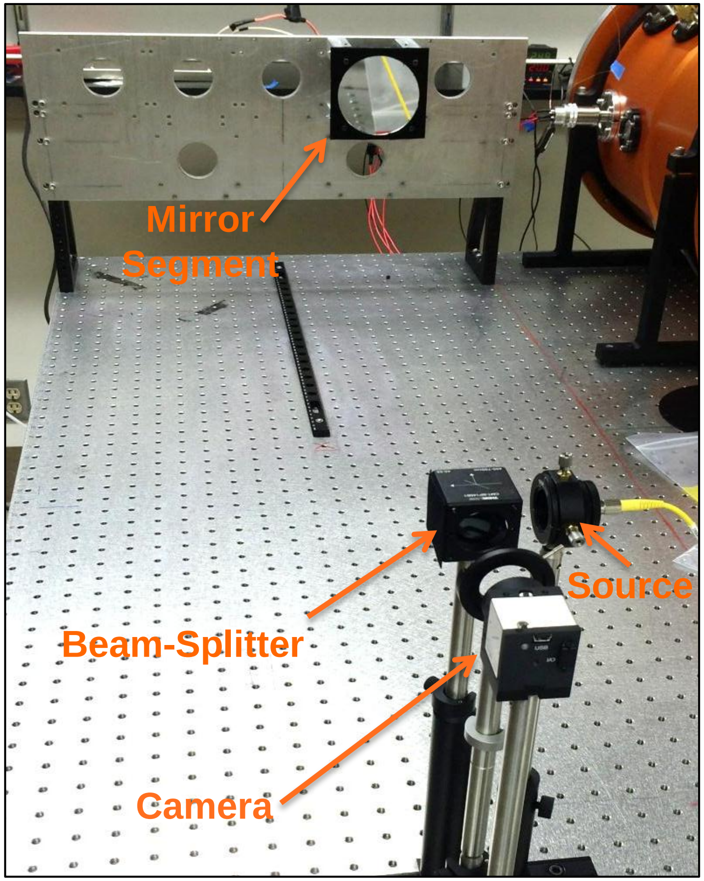
Integrate & Test

Component Alignment – Protocol 2

- After protocol 1
  - optical axis is defined
- Move mirror segment to a particular AAReST configuration
  - The other components previously aligned *must not* be moved
  - Adjust piston, tip & tilt to position the spot on the camera



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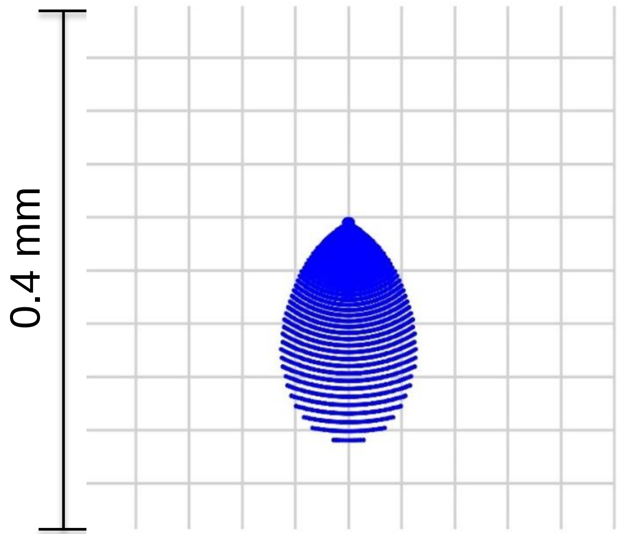
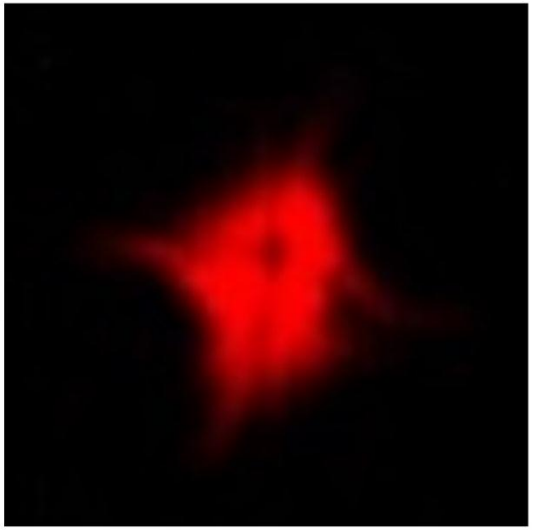
Validate

- Ray-tracing software gives expected image based on mirror configuration
- Comparing the actual image to the expected image is used to validate configuration and alignment



Simulated spot obtained for a single reference mirror



Measured spot after alignment of the reference mirror

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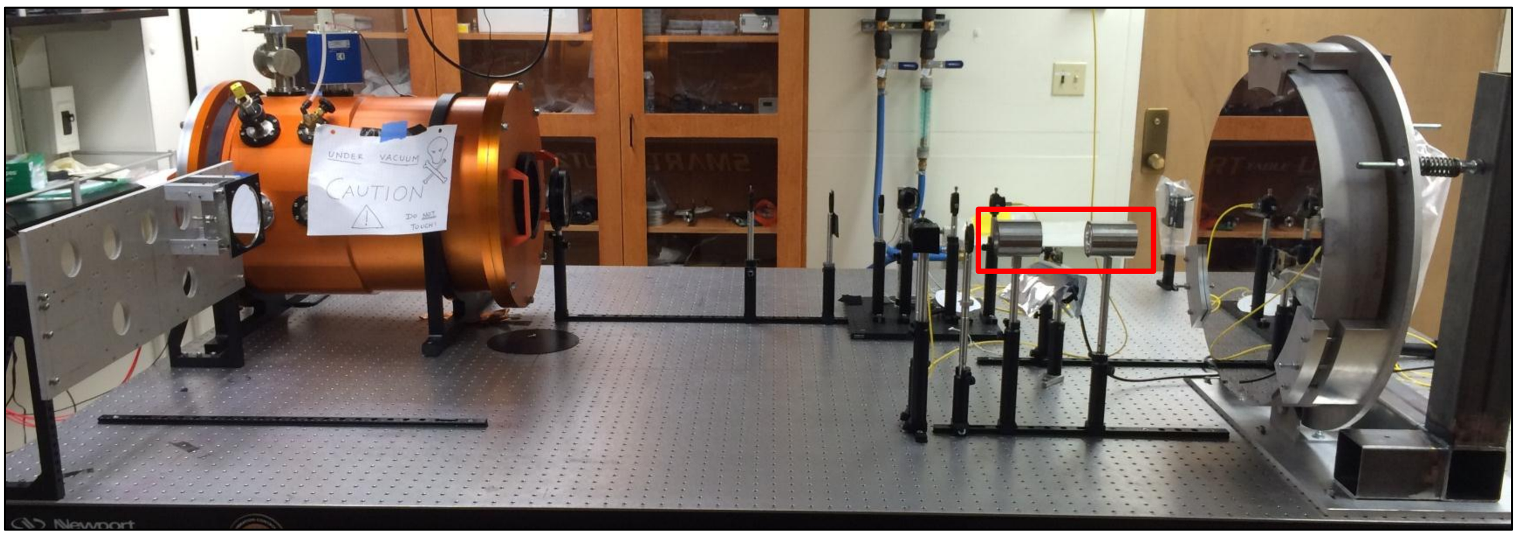
Conclusion

- All components needed to perform tests on the in-flight subsystems: manufactured and tested
- Alignment protocols have been developed
- Therefore, the testbed is ready to accommodate the different subsystems to analyze the overall behavior of the telescope
  - More precise alignment needed for the camera to be integrated



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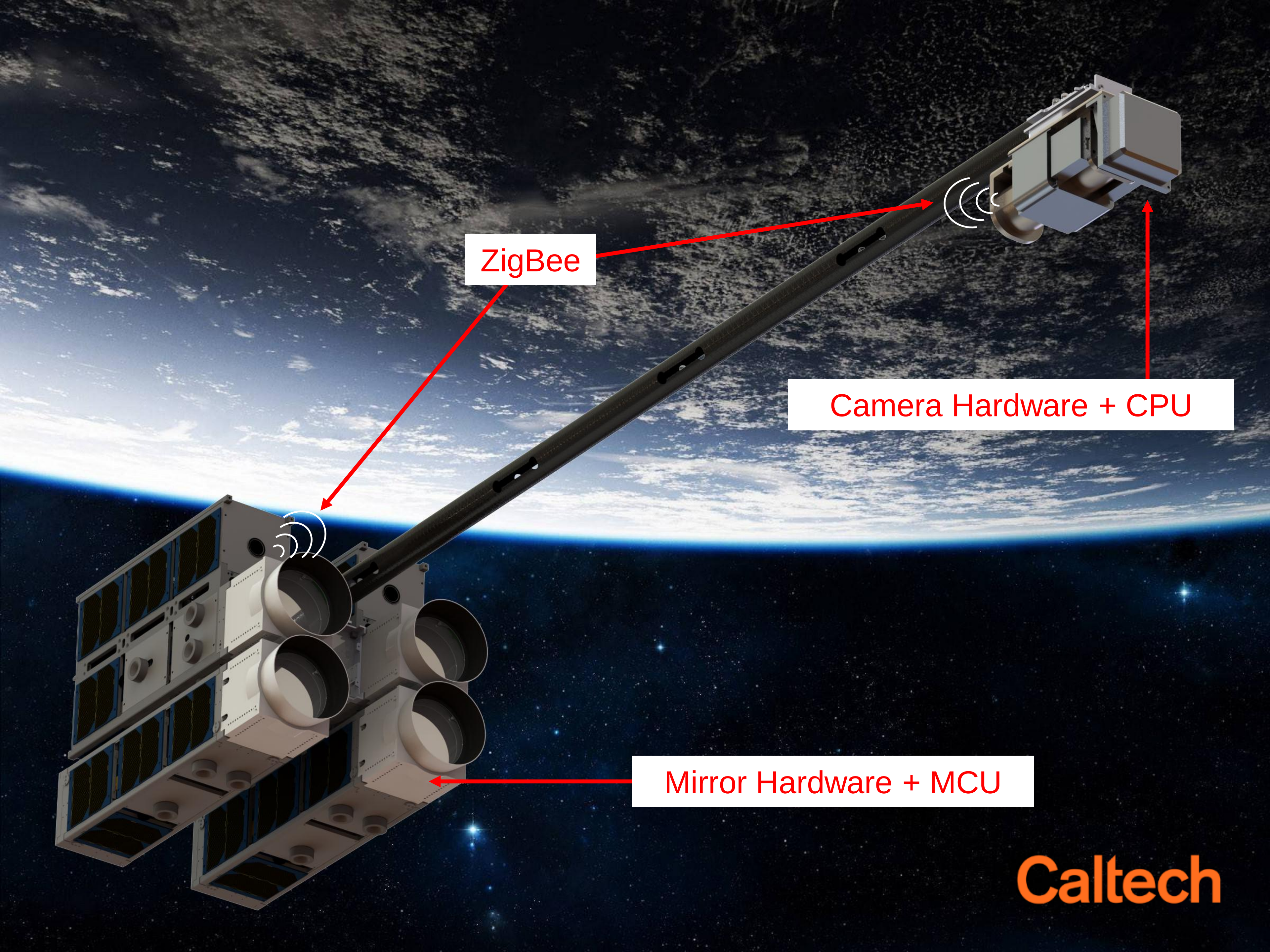
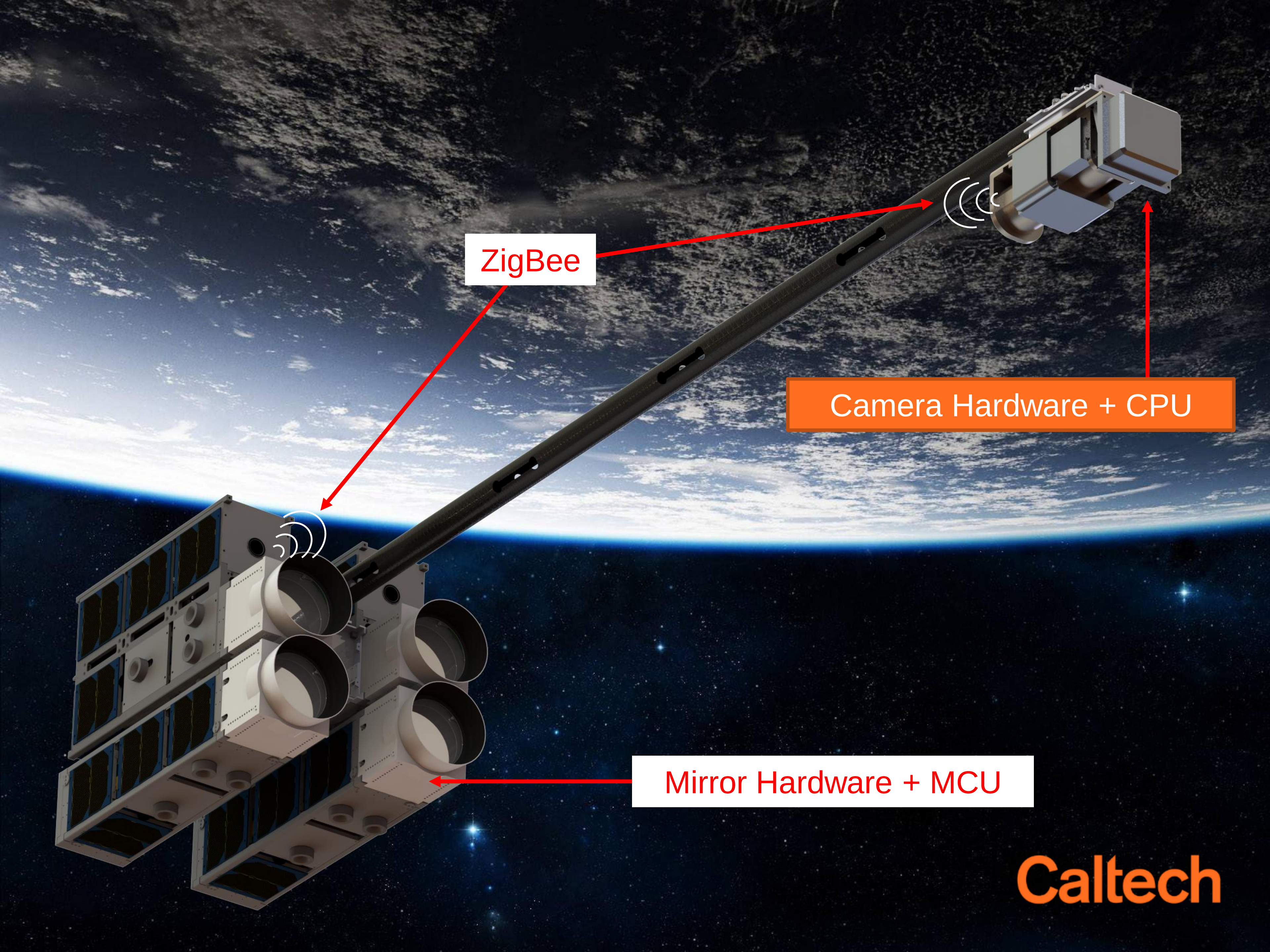
Questions?

Camera & Mirrors
Hardware and Software

Ilana Gat, Casey Handmer,
Yamuna Phal, Thibaud Talon

Mentors: Mélanie Delapierre,
Heather Duckworth


ZigBee
Camera Hardware + CPU
Mirror Hardware + MCU
Caltech


ZigBee
Camera Hardware + CPU
Mirror Hardware + MCU
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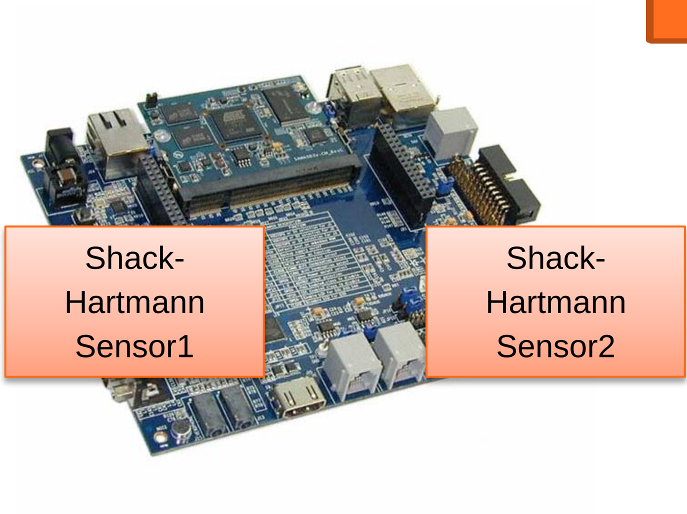
Camera Hardware

Camera CPU



- Purchased off-the-shelf Evaluation board for in-lab setup
  - Good for testing and writing software
  - Too large y unused connections for in-flight
- Will try to use the CPU board for in-flight
- Will design new main board for in-flight setup

Image Detector

I^2C

S/C CPU

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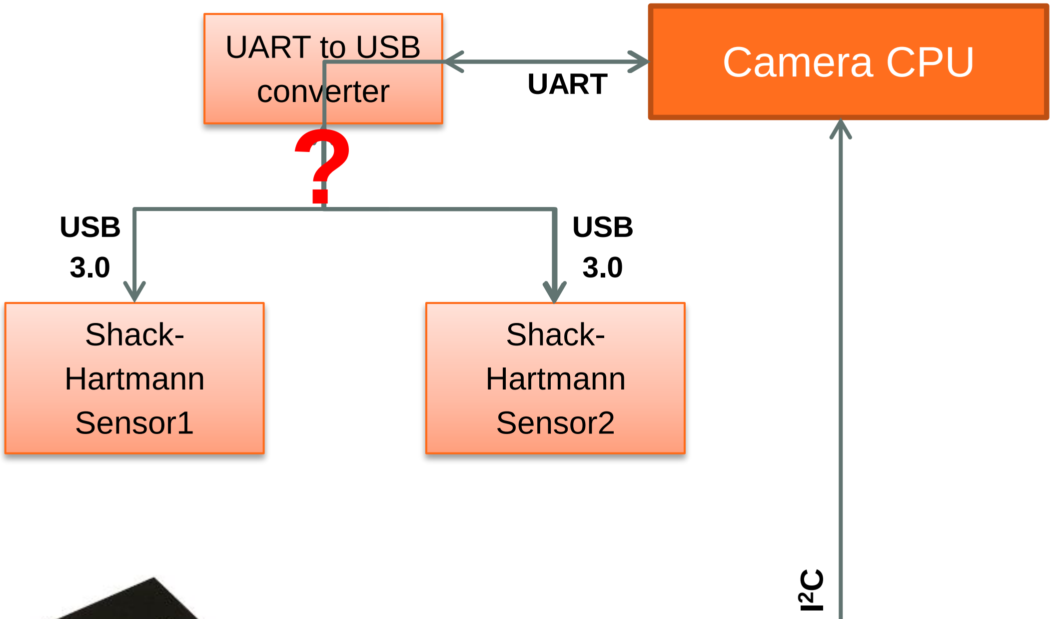
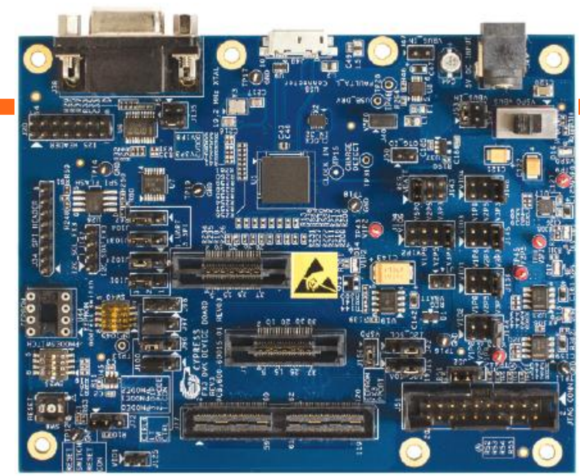
Camera Hardware



- Purchased off-the-shelf UART to USB 3.0 Converter
  - Good for in-lab testing
  - Too bulky and requires too much power for in-flight
- Will use main converter chip + crystal oscillator for in-flight setup



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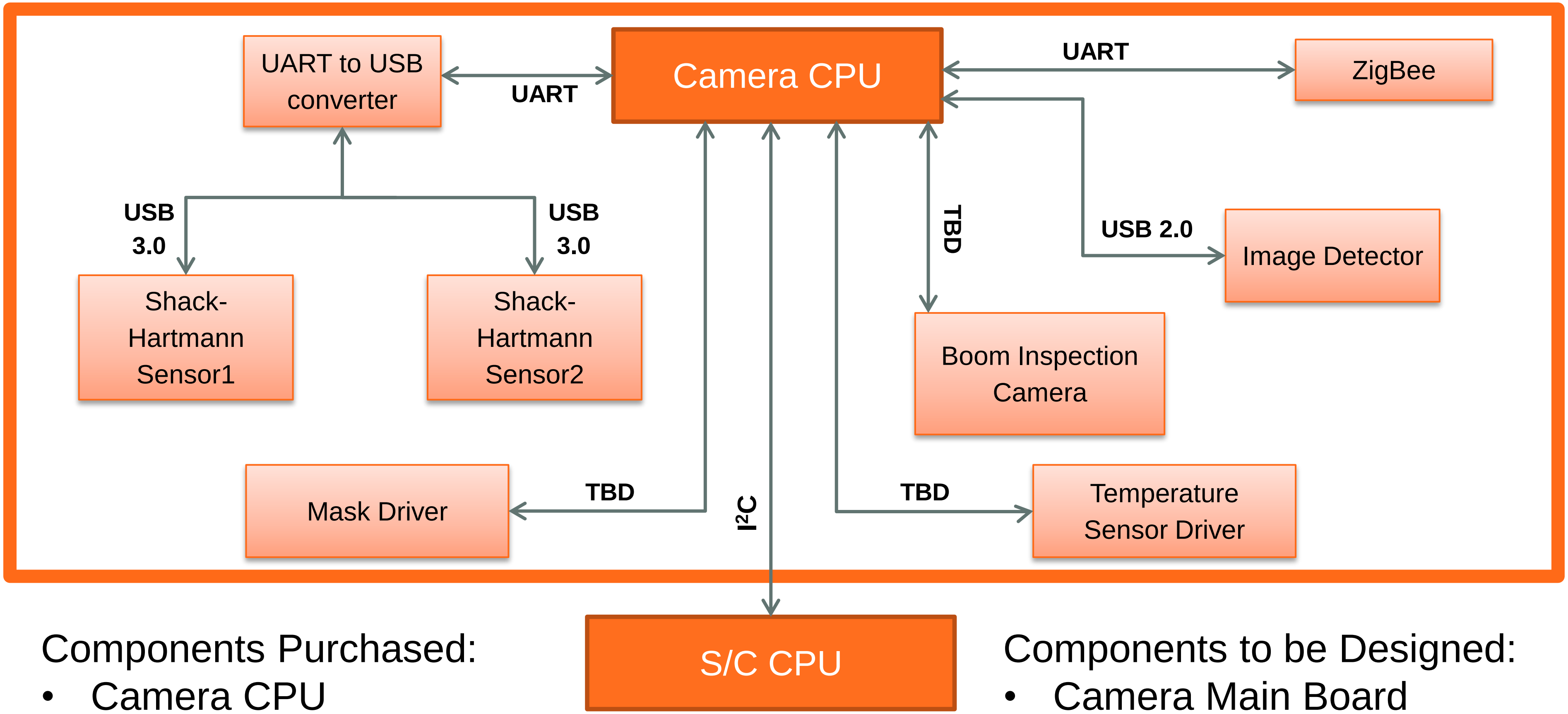
Camera Hardware



Components Purchased:
- Camera CPU
- UART to USB Converter
- 2 x ZigBee

Components to be Designed:
- Camera Main Board
- UART to USB Converter with crystal oscillator

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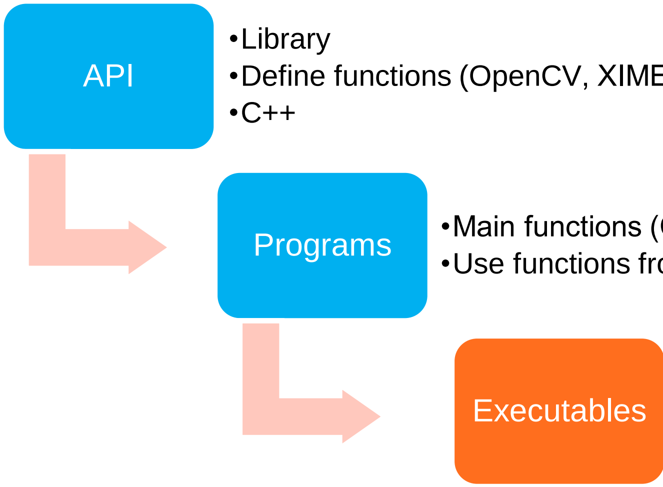
Camera Software

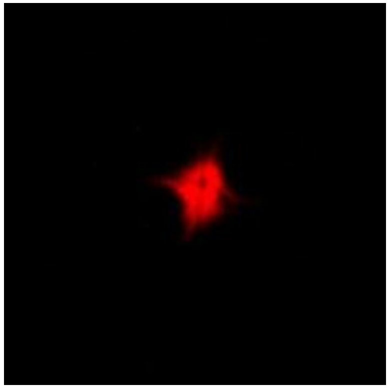
Q/ How do we go from an image to corrective commands to the mirrors?

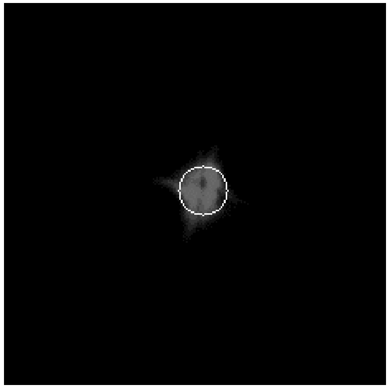


- Library
- Define functions (OpenCV, XIMEA API, …)
- C++

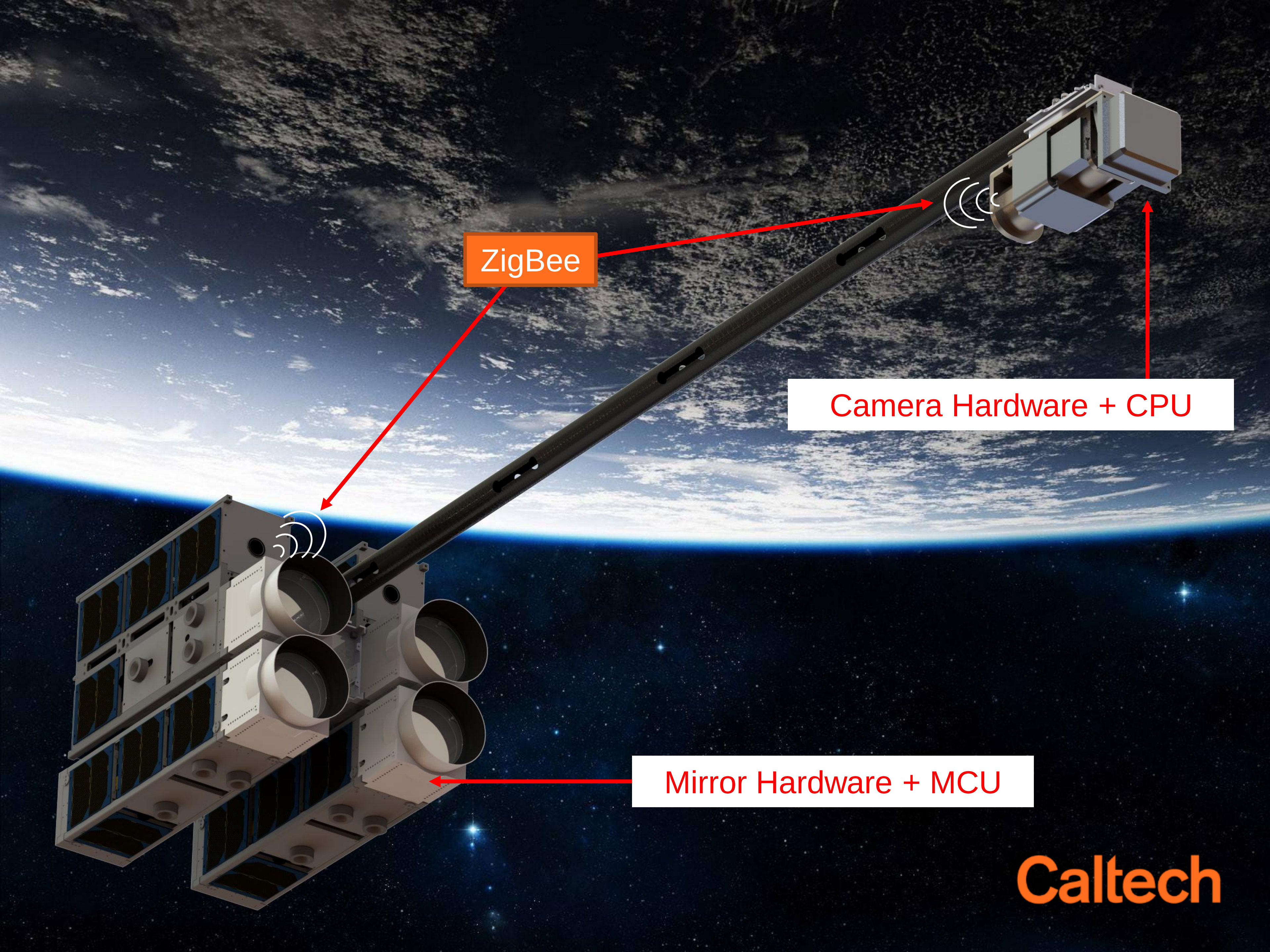
- Main functions (Corrective loops, …)
- Use functions from API

- Compiled programs


Raw image


Analyzed image

- Started with image processing for the image detector
- Compiled and works for a computer
- Compiled and works for the Camera CPU !!!


ZigBee
Camera Hardware + CPU
Mirror Hardware + MCU
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ZigBee Hardware

Requirements:

- Easy to use out of the box
  - Minimal programming needed
  - Minimal hardware to be designed for in-flight
- Used previously in space
- Performs well with radiation
- Low cost
- Low power

XBee satisfies all of these!!

XBee = hardware
ZigBee = network protocol

Antenna Options:

- Chip: Bad because XBee inside metal box
- Wire Whip: Bad because attached to XBee inside metal box
- U.FL Connector: Fragile
- RPSMA: Just right!

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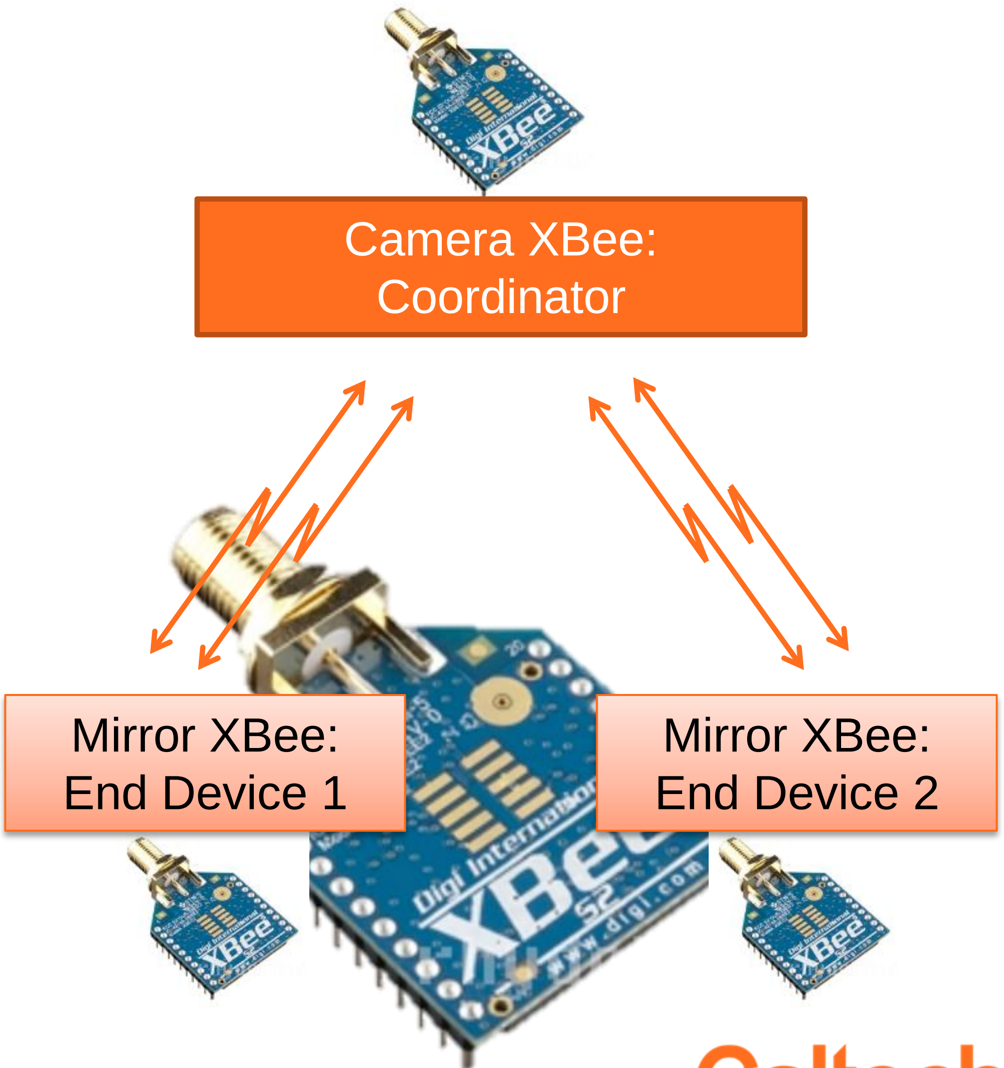
ZigBee Communication

Requirements:

- Easy to use out of the box
    - Minimal programming needed
    - Minimal hardware to be designed for in-flight
- Used previously in space
- Performs well with radiation
- Low cost
- Low power

XBee satisfies all of these!!

XBee = hardware
ZigBee = network protocol



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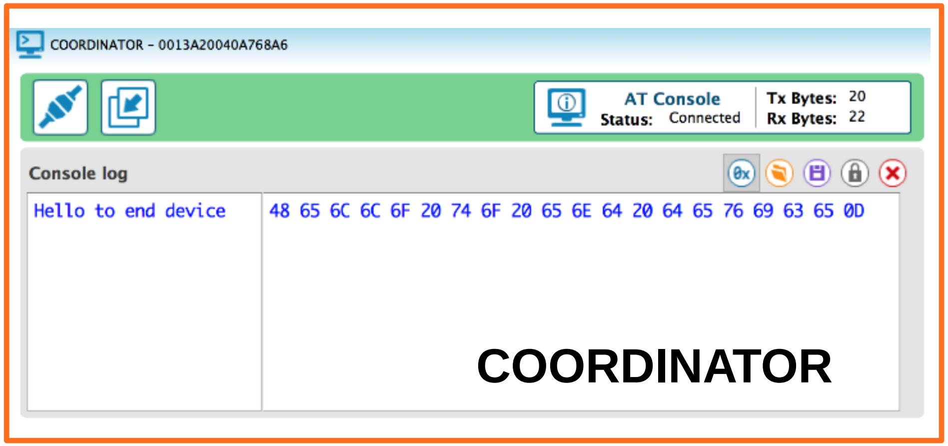
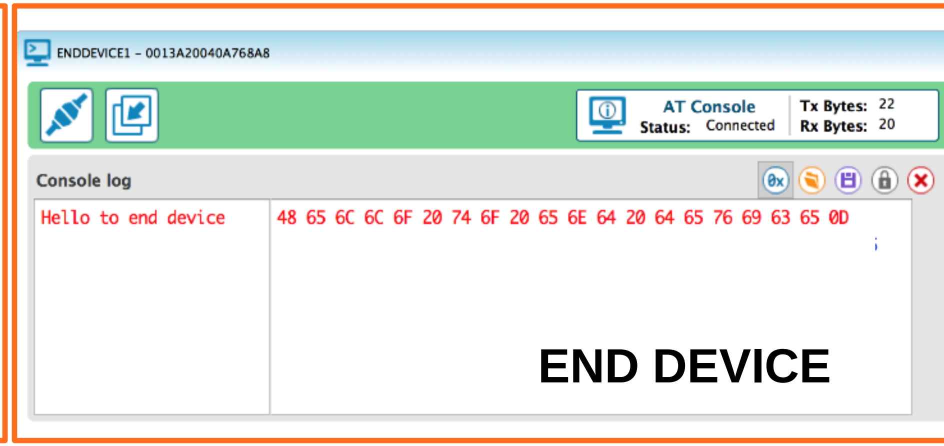
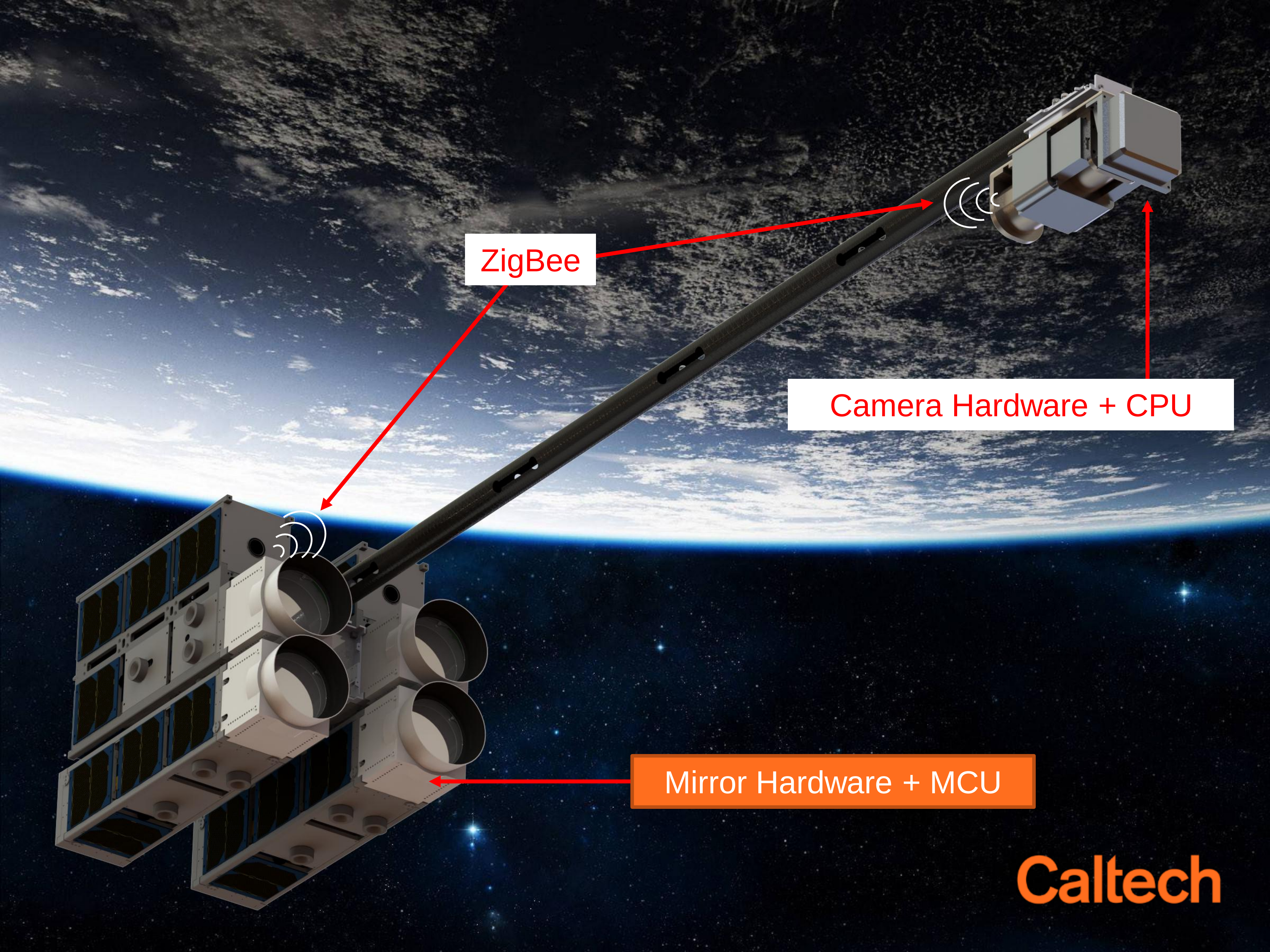
XBee Communication: IT WORKS!!!





- XBees currently talk with both connected to computer
- Next step:
  - Connect End Device to mirror CPU
  - Connect Coordinator to Camera CPU
  - Program ZigBee network for in-flight


ZigBee
Camera Hardware + CPU
Mirror Hardware + MCU
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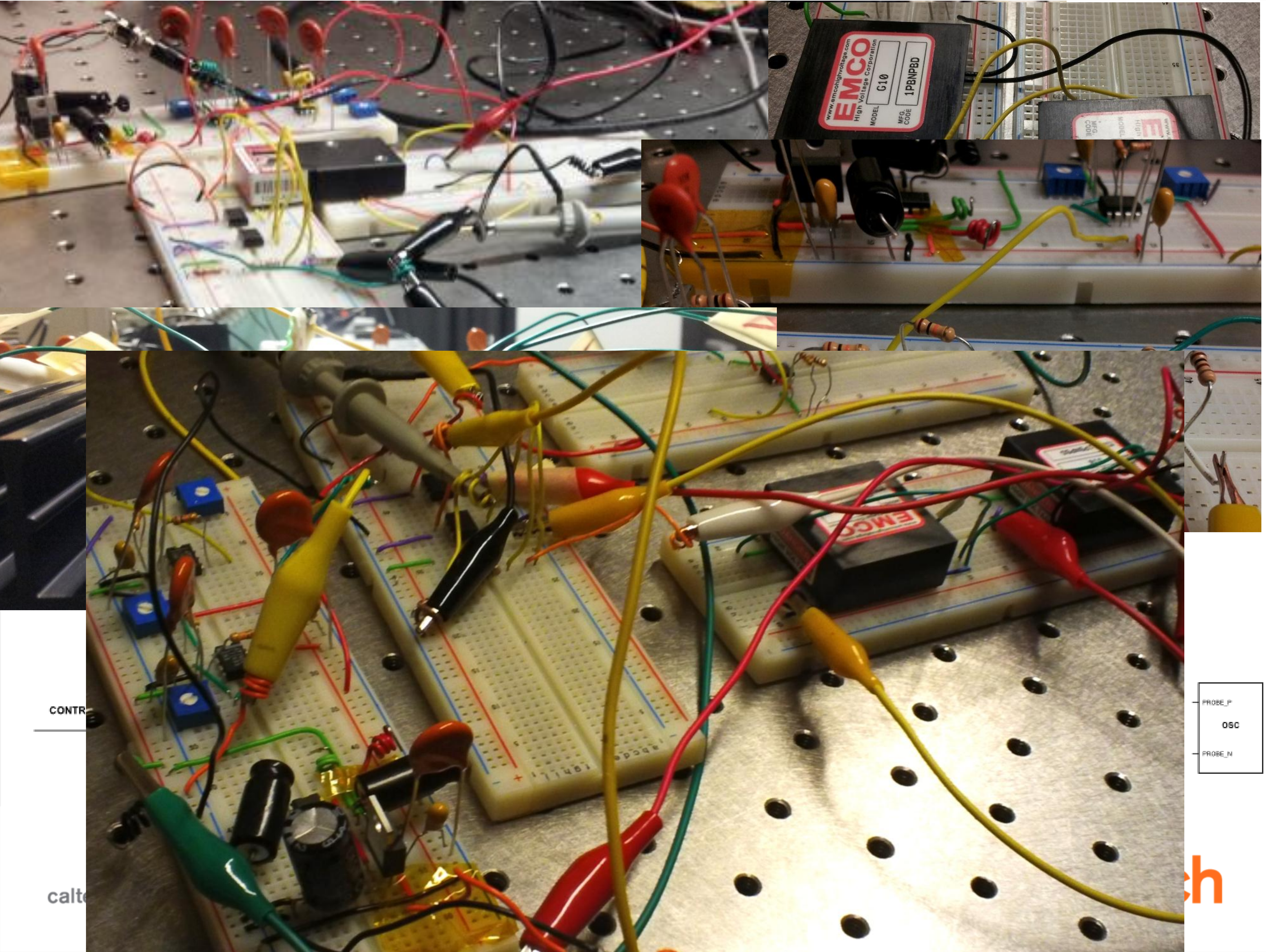
www.emcohighvoltage.com
EMCO
High Voltage Corporation
MODEL G10
MFG. CODE 1PBNPBD
CONTR
PROBE_P
OSC
PROBE_N
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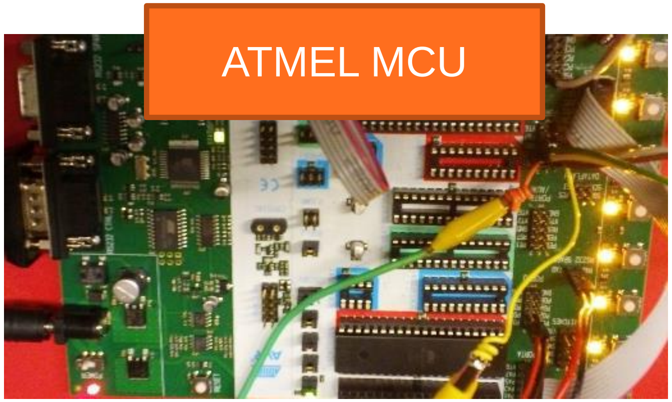
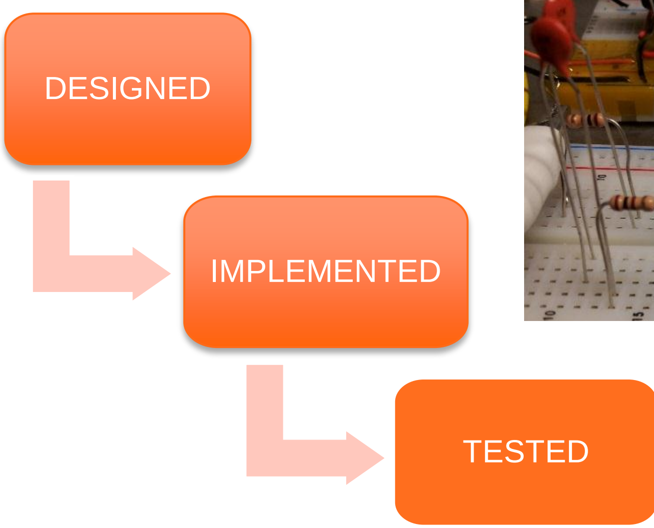
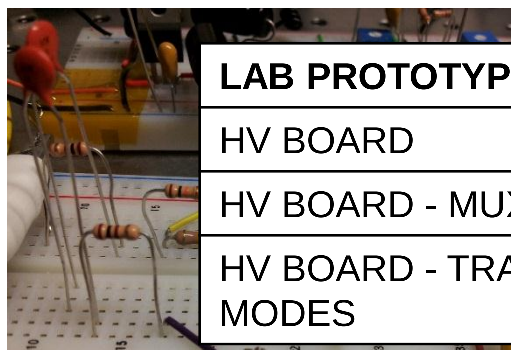
Mirror - HV board

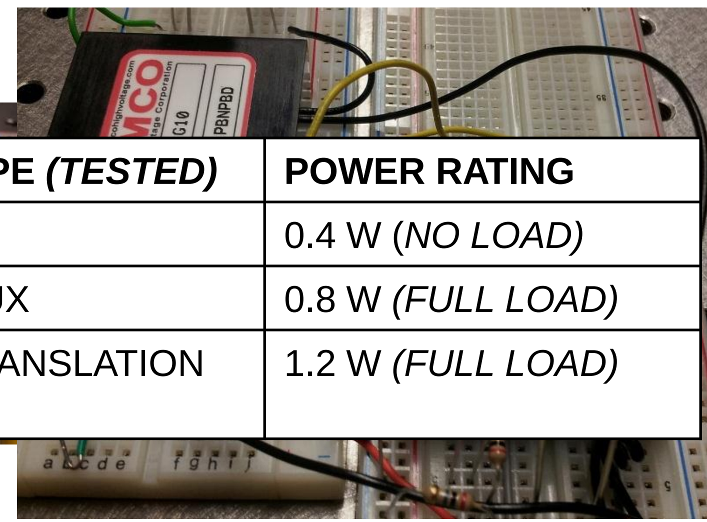
How do you design a HV board which is NOT 14.9 kg and 680 W?



- ATMEL stamp from *INSPIRE* mission
- SPI-I^{2}C-UART interfaces
- Digital output only – *DAC needed*







LAB PROTOTYPE *(TESTED)*	POWER RATING
HV BOARD	0.4 W (*NO LOAD)*
HV BOARD - MUX	0.8 W *(FULL LOAD)*
HV BOARD - TRANSLATION MODES	1.2 W *(FULL LOAD)*

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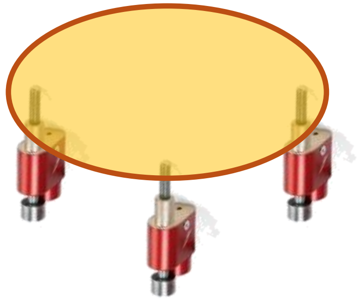
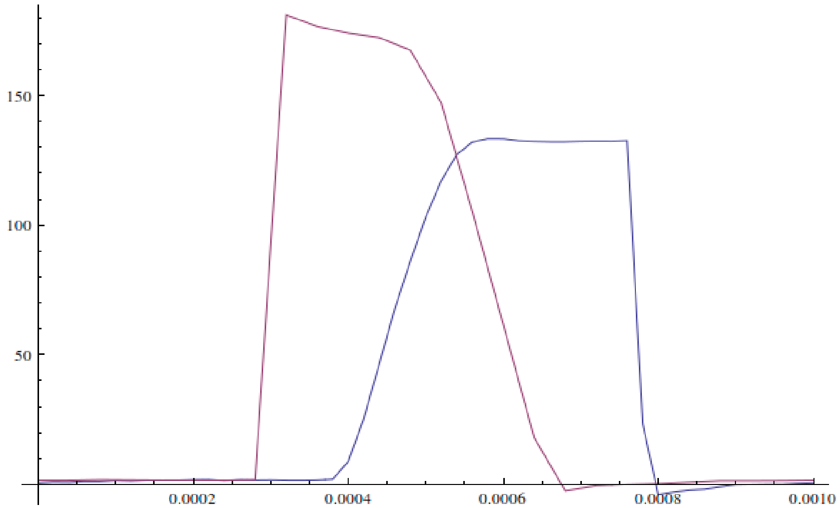
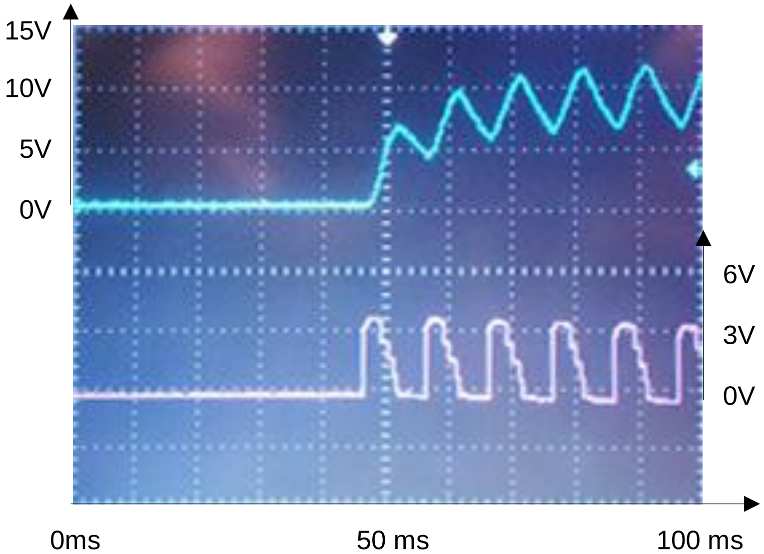
Mirror Picomotors

- Anticipate 'set and forget' usage
- Require 1kHz waveform at ~120V
- Attempt to leverage existing HVB architecture failed
- HVB latency/response time too slow under load
- Need picomotor-specific signal generator







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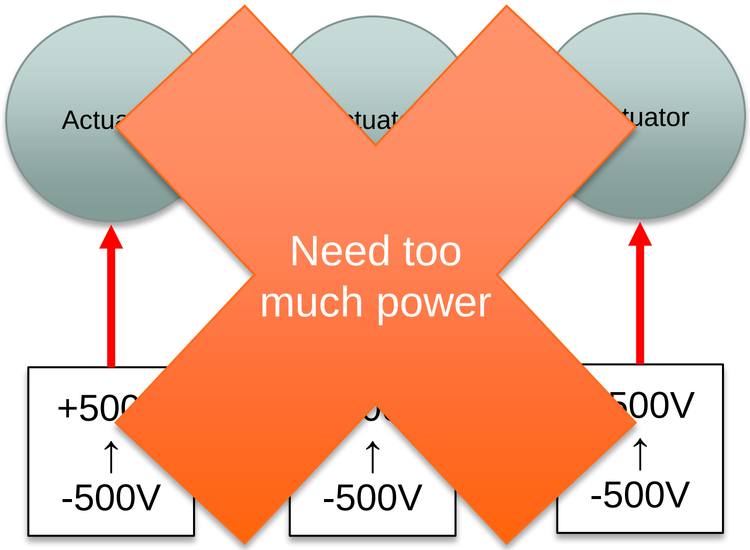
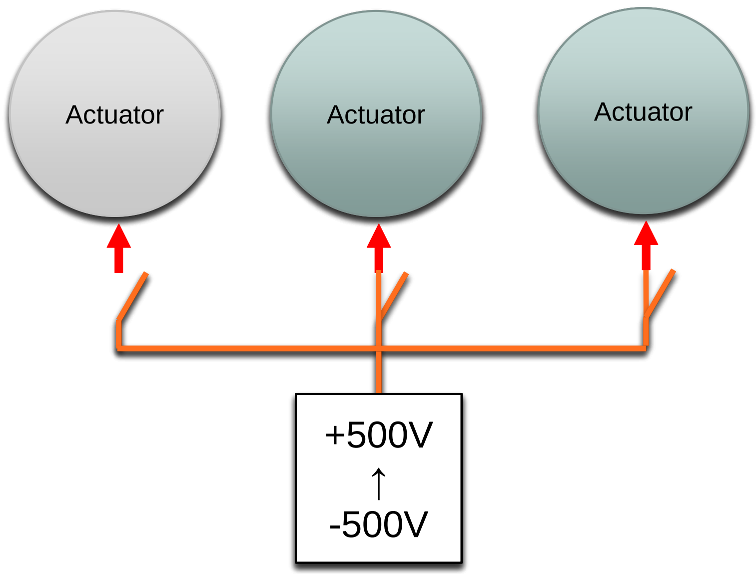
Mirror Multiplexer

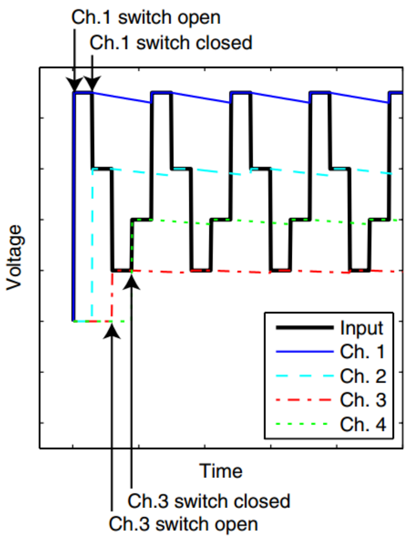
- Multiplexing concept



Mirror Multiplexer

- How does it work? Actuators behave as capacitors





Loop over all 41 channels in 1s (24 ms / channel)

Set Voltage	On	Wait	Off
8 ms	2.5 ms	1-10 ms	2.5 ms

Patterson, K., and Pellegrino, S. (2013). Ultra-lightweight deformable mirrors. Applied Optics 52(22): 5327-5341.

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Mirror software

- Translated the former code
- Created low level functions to transfer data through I^2C and SPI
- Developed feedback for testing
- Integrated and tested for all 41 channels with the HV board

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Mirror

Summary

Camera

- In-lab CPU purchased
- Shack-Hartmann USB 3.0 compatibility implemented
- First image analysis programs designed - tested

ZigBee

- XBee hardware selected
- Communication established

Mirror

- HV board - lab breadboard complete
- Lab prototype designed - implemented - tested

Future Work

Camera

– In-flight main-board design
– Continue writing software package for in-flight use

ZigBee

– Connect XBees to in-lab mirror and camera CPUs
– Program XBees to communicate with in-lab setup

Mirror

– HV driving picomotors
– Finalize in-flight design

Questions?