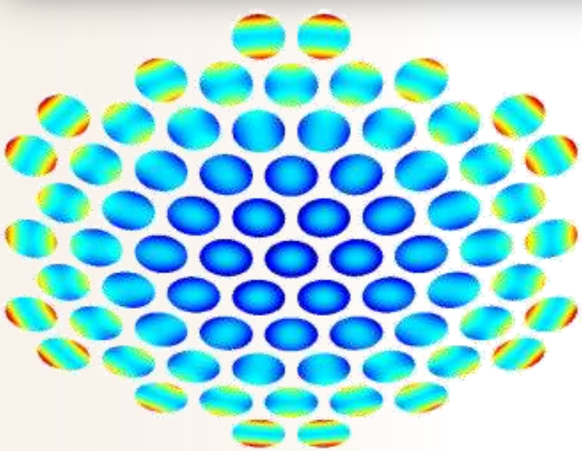
AAReST Mission Overview

John Baker

Future Large Space Telescopes



- How to build aperture > 10 meters?
  - Segmented primary mirror
  - Many segments
  - Multiple launches
  - On-orbit autonomous assembly
- Mirror segments
  - Lightweight
  - Identical (nominally spherical)
    - Lower cost
    - Redundancy
    - Ease of manufacture and test
    - BUT: Curvature errors across array
  - Deformable capability

Team Responsibilities

UNIVERSITY OF SURREY

- NanoSat and MirrorCraft
- Docking system
- Integrated spacecraft & mission ops

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

- Deformable mirrors
- Telescope system
- Optical focus algorithm

TBD

- Launch

UNIVERSITY OF SURREY

- System integration & Testing
- Mission operations

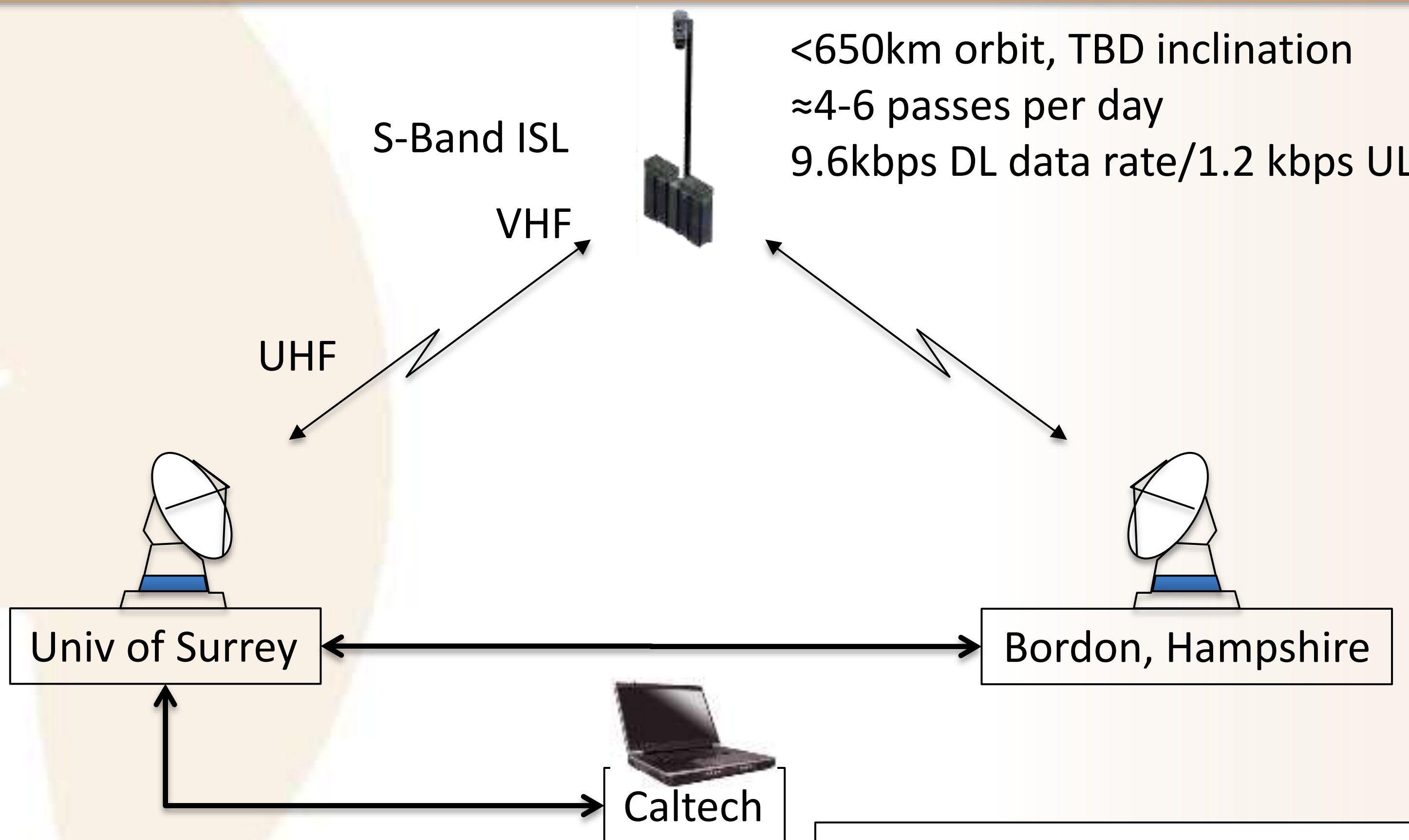
JPL

- Class Instructors
- Mirror Manufacturing Facility

AAReST Mission Objectives

- Accomplish two key experiments in LEO by demonstrating new technologies for
  - Autonomous rendezvous and docking with small spacecraft for telescope re-configuration
  - A low-cost active deformable mirror
- Operate as long as necessary to accomplish the objectives (90 days) post commissioning
- Accomplish the mission inexpensively for a 2015 launch
- Gather engineering data that enables the next system development

Mission Architecture



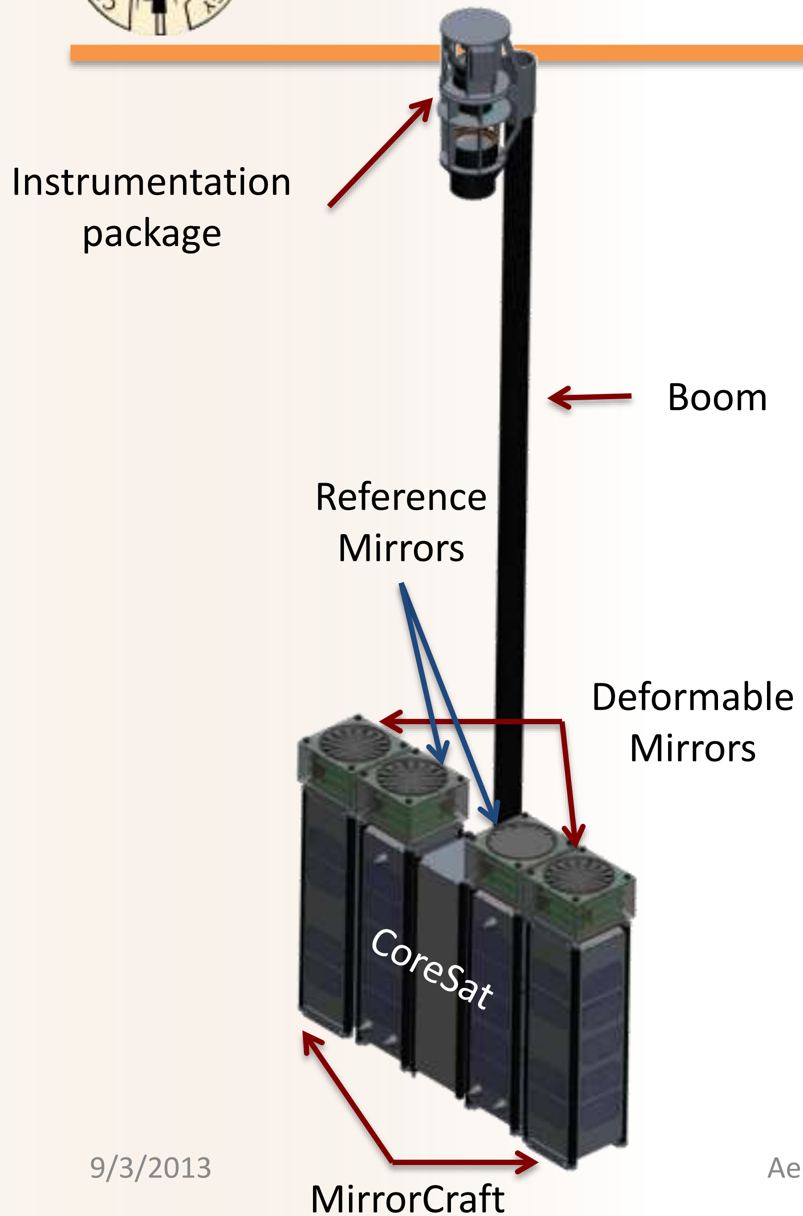
Primary spacecraft and payload ops will be run by Univ of Surrey

- Existing comm and ops infrastructure
- Includes spacecraft commanding and health monitoring
- Outreach

Remote payload monitoring will be done at Caltech

- Initial mirror calibration
- Mission planning (target selection)
- Engineering data analysis and reduction
- Outreach

Elements



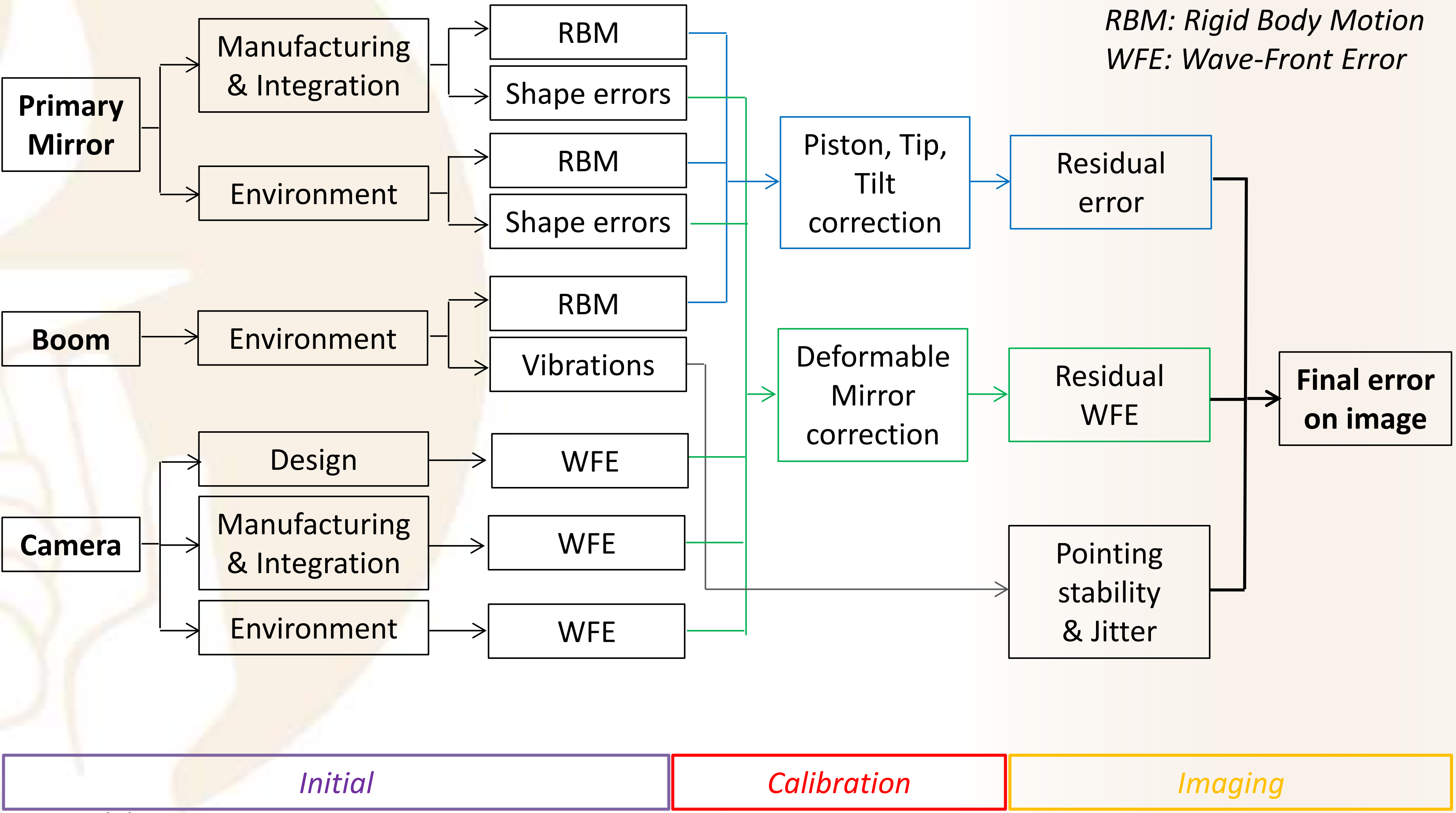
1. MirrorCraft (x2) – 3U cubesats with deformable mirrors on top with rendezvous and docking capability
2. CoreSat – main spacecraft with primary power, communications, primary ACS, docking capability

<u>Payload</u>

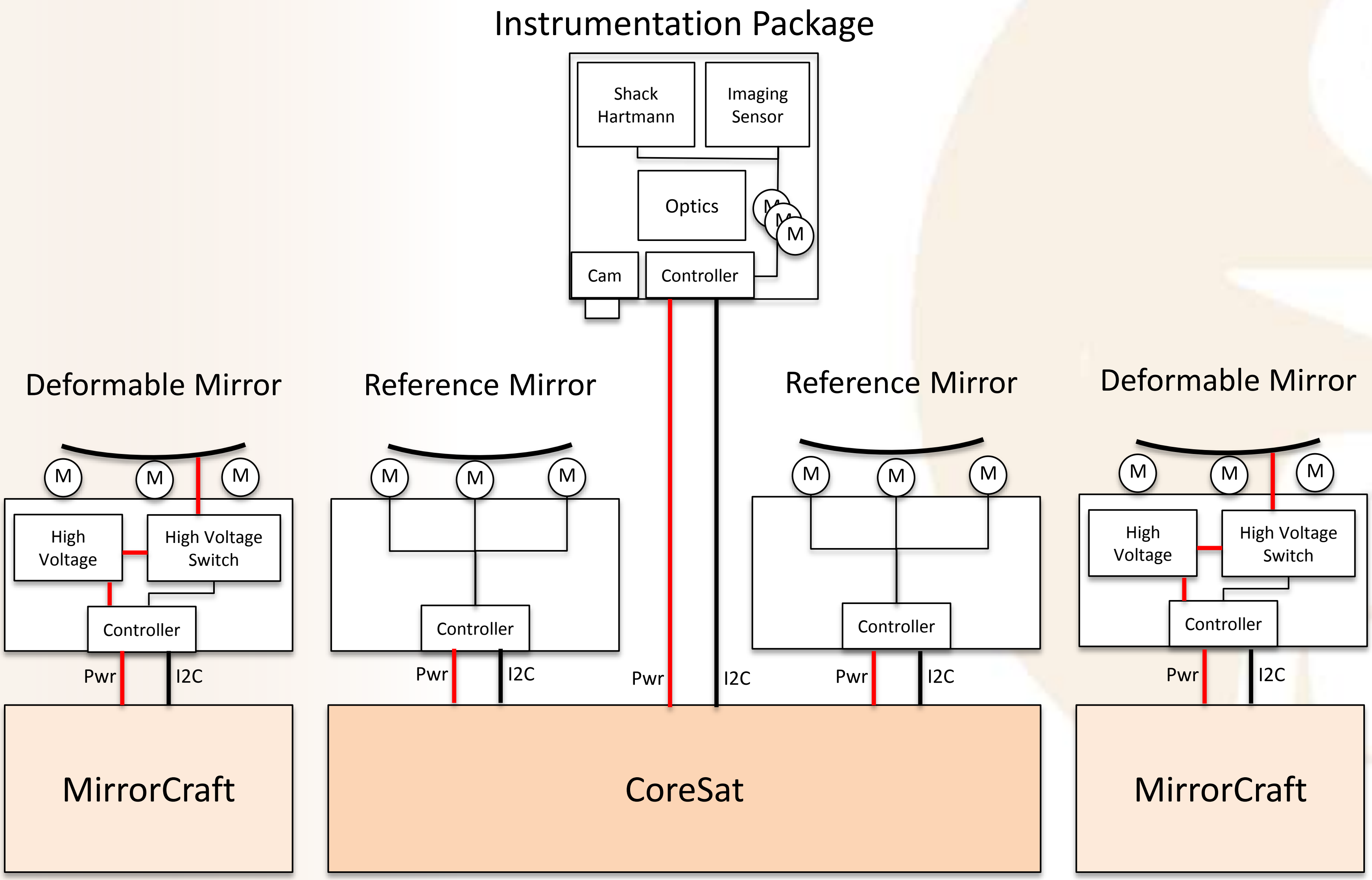
1. Mirror assemblies – 2 active deformable mirrors, 2 fixed glass reference mirrors with tip/tilt positioning
2. Instrumentation package – Telescope optics, detectors, wave front sensor, aperture mask
3. Boom – 1.2m deployable composite

Error Budget

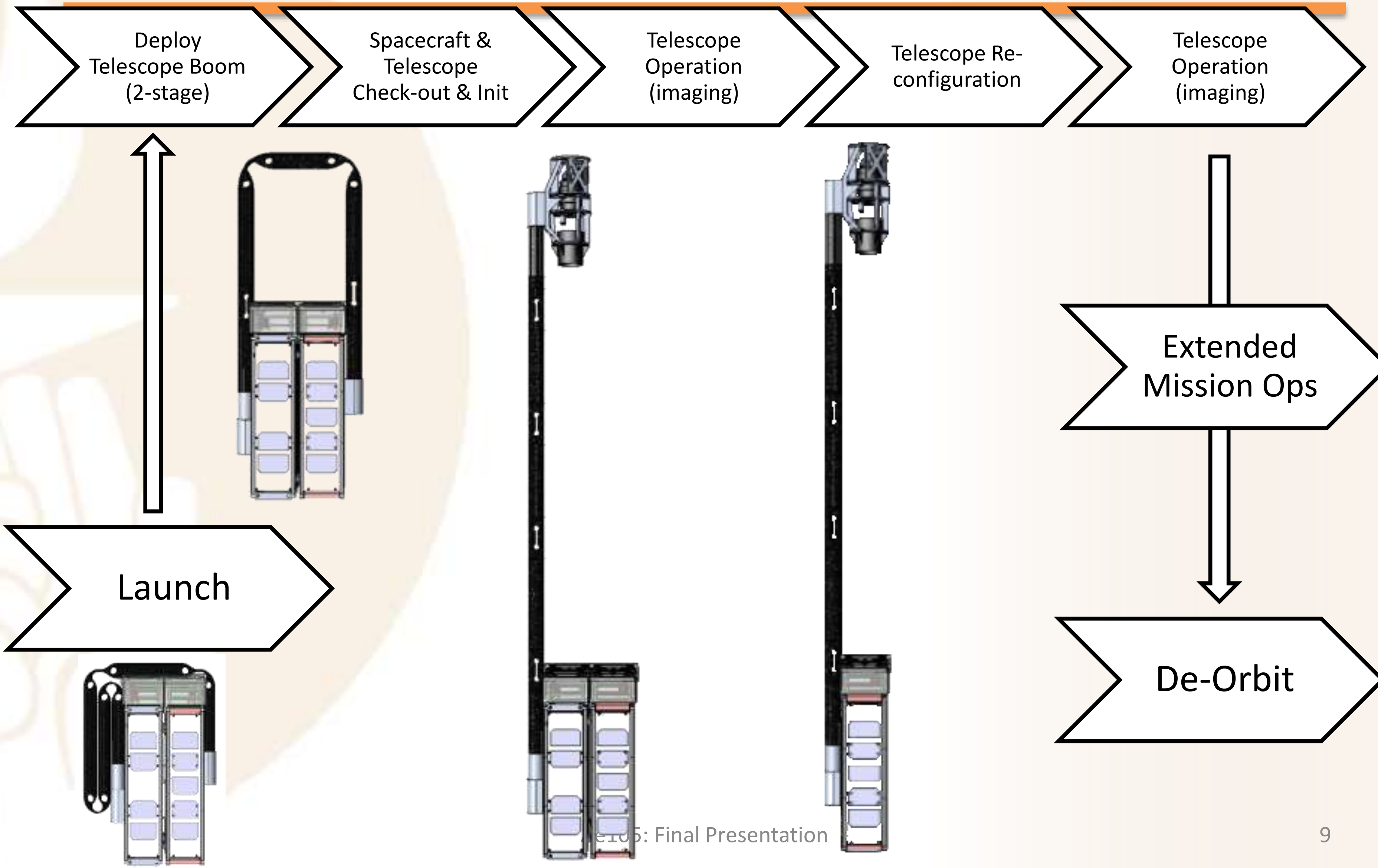
RBM: Rigid Body Motion
WFE: Wave-Front Error



Payload Block Diagram



Concept of Operations



Accomplishments in Past Year

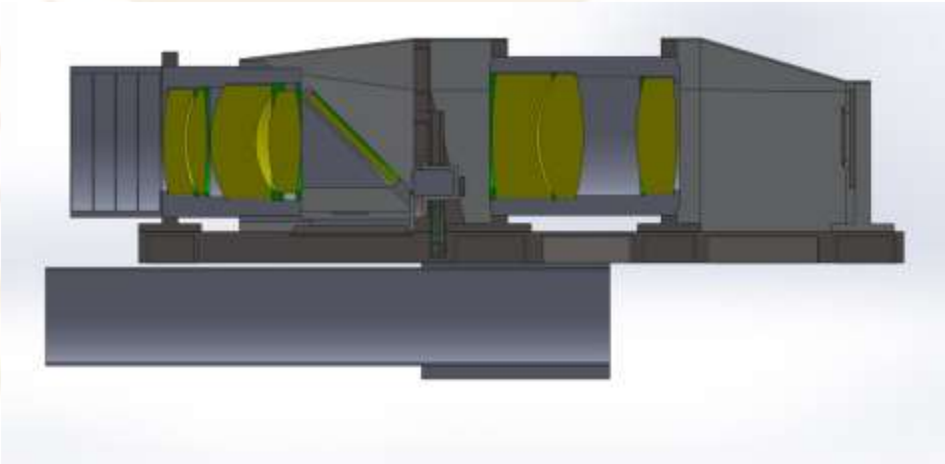
- **AE105 class performed**
  - Boom development and deployment testing
  - Disturbance analysis
  - Updated optical system design and stray light analysis and test
  - Thermal analysis
- Active mirror technology has been matured in the lab, initial testing looks great, additional testing is underway.
  - Prototype of mirror high voltage switching board has also been tested
- 2-D reconfiguration demonstrations have been performed in the lab using electromagnetic control
- Preliminary spacecraft, telescope and ops concept have been defined
  - Total mass of 40kg is well within secondary launch capability
- We have identified the key requirements and flowed them down to the spacecraft and telescope subsystems to understand the important performance requirements and design drivers
- STRaND-2 (spacecraft) to payload interfaces are simple, with a lot of heritage from STRaND-1 which has flown.

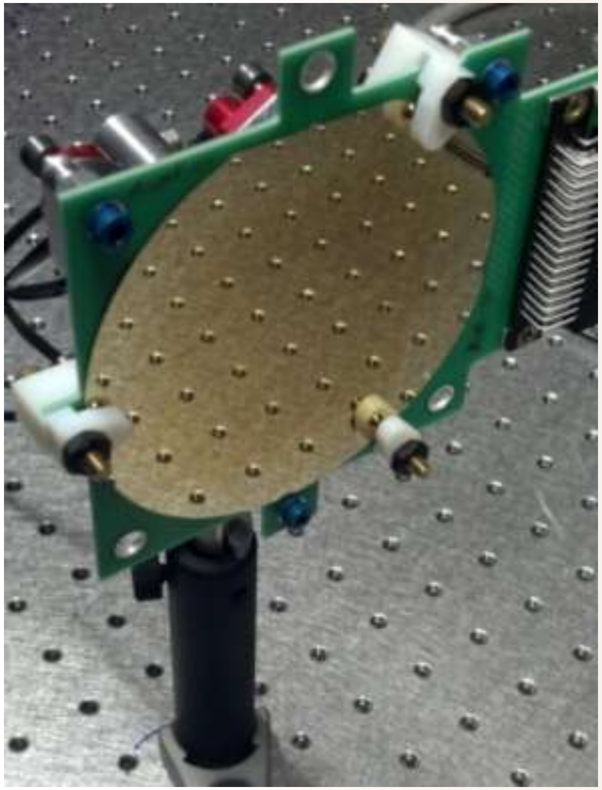
Ae105 Project Scope

John Steeves

AAReST Research Activities

- Develop enabling technologies for AAReST
  - Deformable mirror
  - Deployable boom
  - Camera/Sensors
- Integration with Surrey S/C





Goals of Ae105 Project

- Perform tasks which complement ongoing research activities

- Provide useful information towards the AAReST mission as a whole

- Gain experience working in a practical aerospace environment

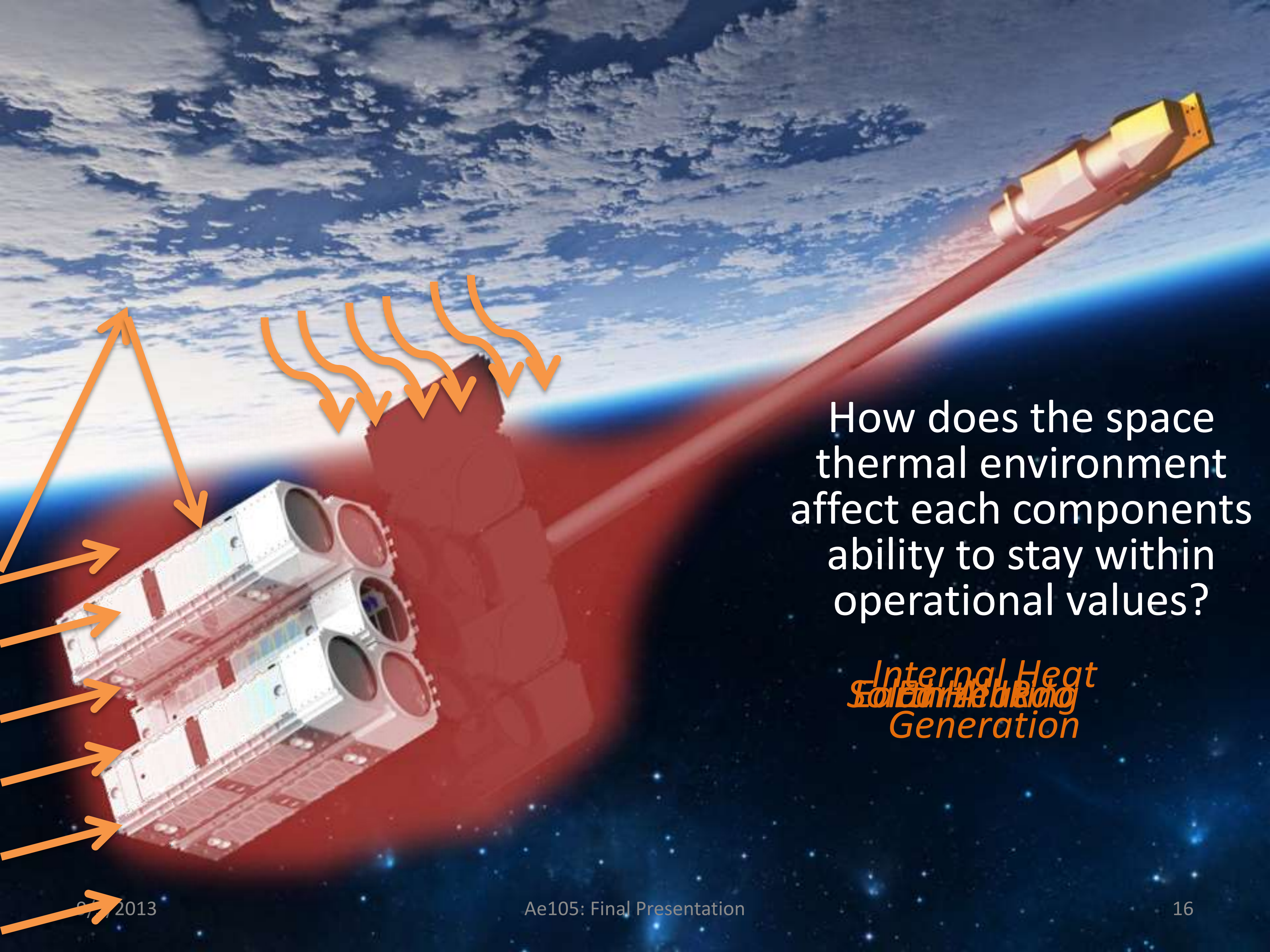
2012/2013 Project Tasks

- Thermal environment
- External/Internal disturbances
- Deployable boom characterization
- Deformable mirrors
- Camera design

Thermal Environment and Design

Heather Duckworth

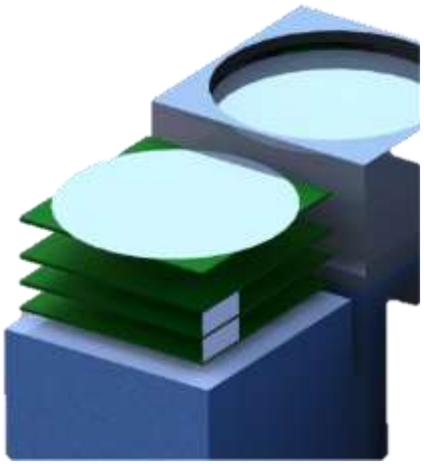
Mentor: Kristina Hogstrom

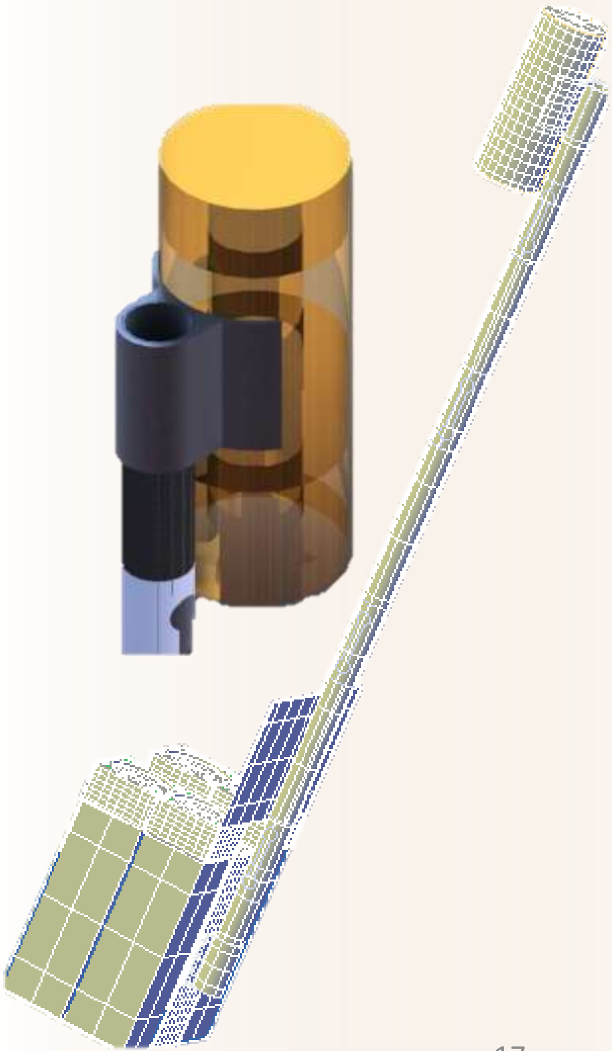


How does the space thermal environment affect each components ability to stay within operational values?

Outline

- Orbital mechanics
- Thermal check
- The model
- The results
- The conclusions

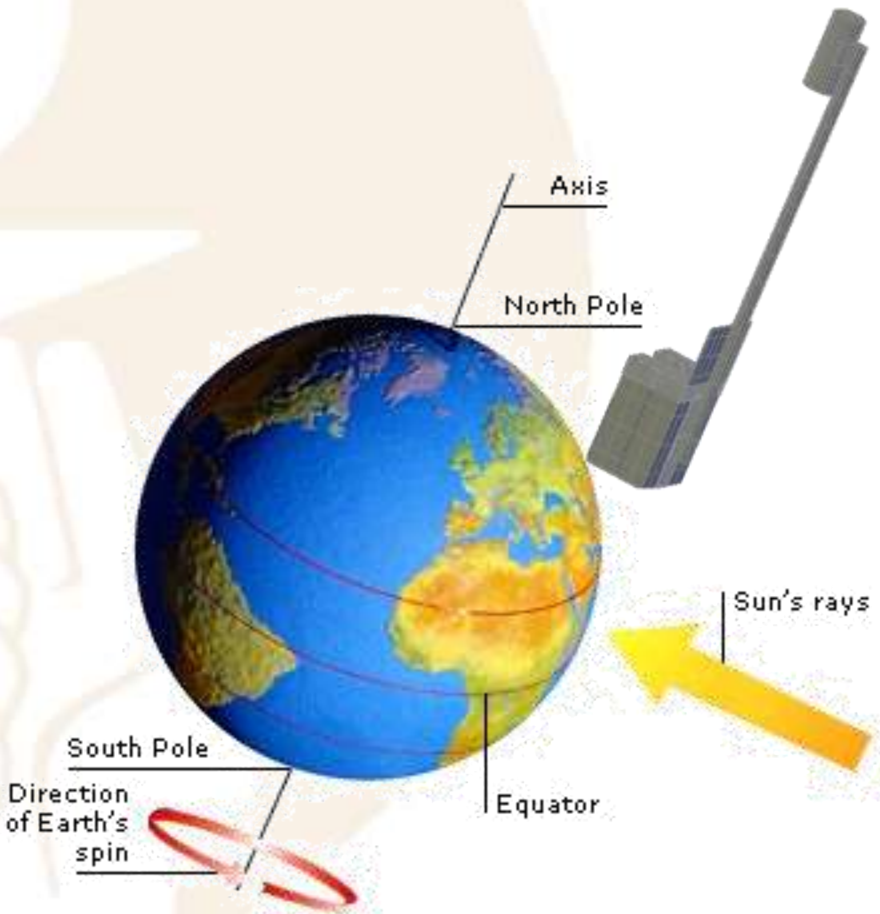




Orbital Mechanics

- Orbit #1 Constant Sun:
  - Sun-Synchronous
  - “Dawn/Dusk”
  - 650 km and 98° inclination
  - Angle with respect to the Sun remains constant
  - Orbital plane rotates ~1°/day
- Orbit #2 Varying Sun:
  - ISS Orbit
  - 400 km, 51.6° inclination
  - Angle larger, so more sun and shade variance

Star Pointing

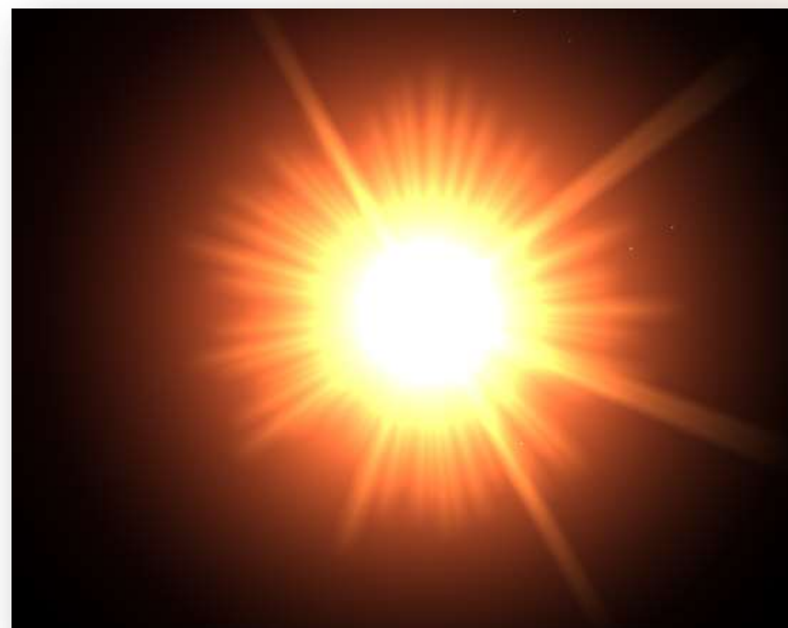


Need camera pointed at star due north:

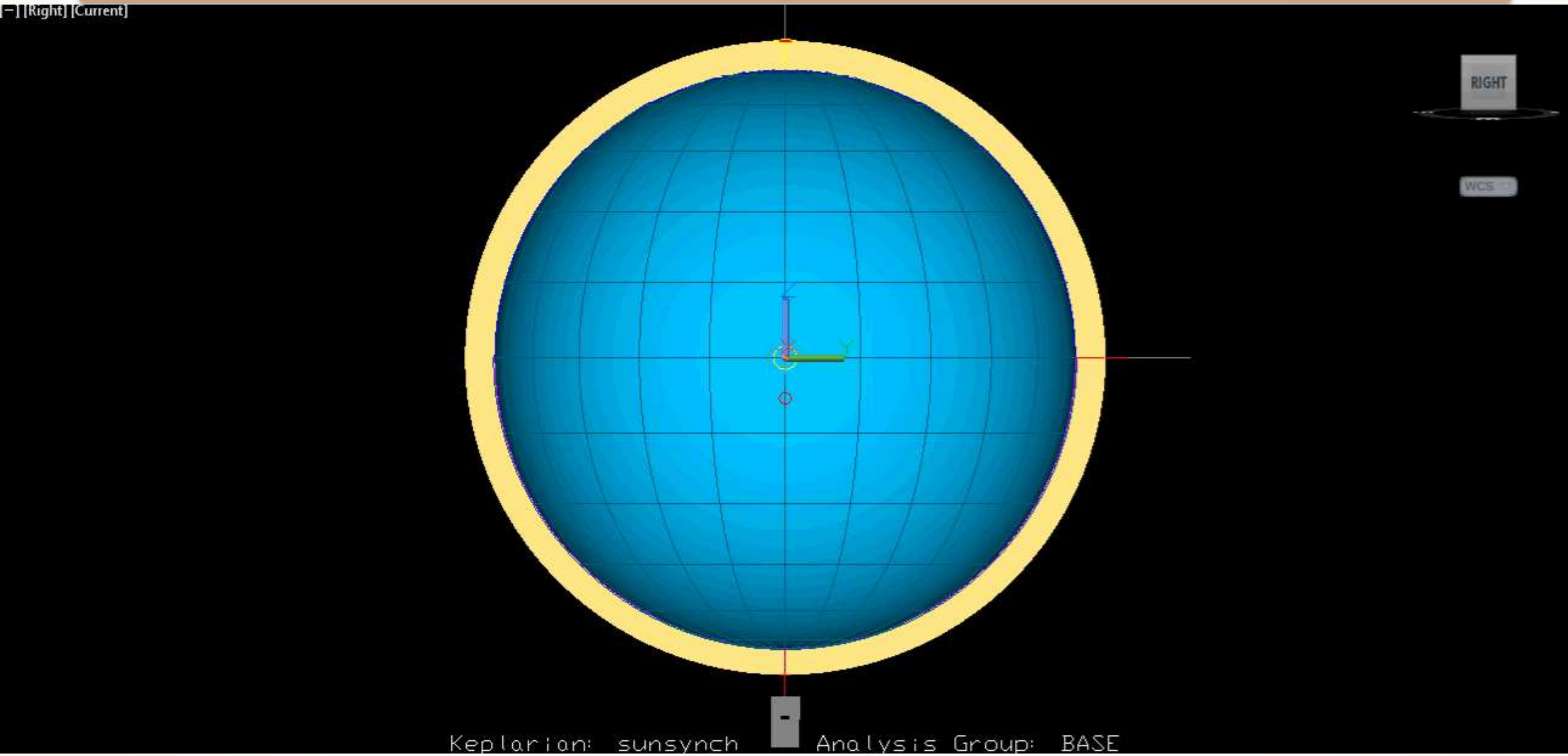
POLARIS

RA: 37.5°

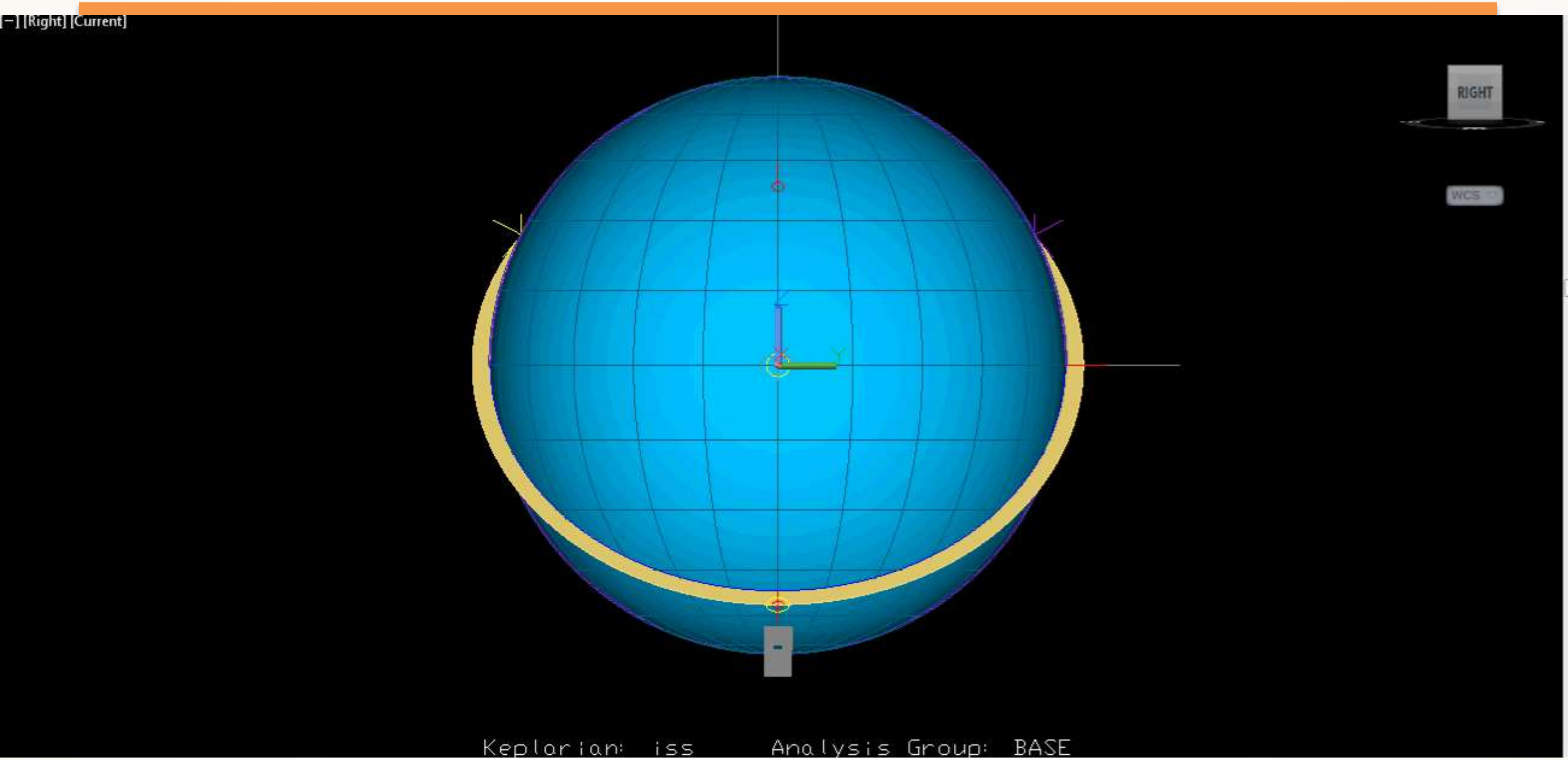
DEC: 90°



Sun Synchronous



ISS



Thermal Check

$$\underbrace{Q_S + Q_R + Q_I}_{\text{absorbed}} + \underbrace{Q_W}_{\text{internally generated}} = \underbrace{Q_E}_{\text{emitted}} + \underbrace{Q_C}_{\text{converted}}$$

$$T_{\max(S/C)} = \left[\frac{A_C G_S \alpha + A \alpha a G_S K_a F + A q_I \varepsilon F + Q_W}{A \sigma \varepsilon}\right]^{1/4}$$

$$T_{\min(S/C)} = \left[\frac{A q_I \varepsilon F + Q_W}{A \sigma \varepsilon}\right]^{1/4}$$

$Q_{\text{absorbed}(SA)} = Q_{S(SA)} + Q_{R(SA)} + Q_{I(SA)}$	$Q_{\text{emitted}(SA)} = \sigma \varepsilon_b A_b T_{eq(SA)}^4 + \sigma \varepsilon_t A_t T_{eq(SA)}^4$	$Q_{\text{powergenerated}(SA)} = G_S A_t \eta$
HEAT ABSORBED: ALBEDO, EARTH IR, SOLAR IR	*HEAT RADIATED TO SPACE*	*INTERNAL HEAT GENERATED*

COLD CASE T_{min}= 189K

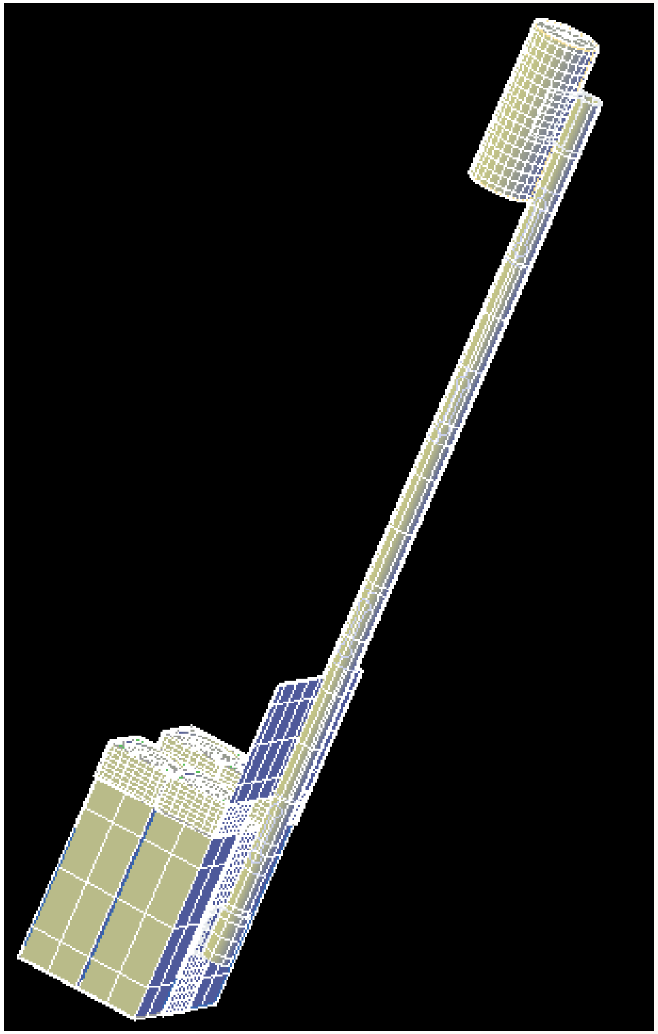
HOT CASE T_{max}= 405K

Compare with 2012

	Cold Case	Hot Case
All Off [0W]	190	315
Sensor On [1W]	220	330
Sensor On [1W] + Heaters [4W]	308	380

The Model

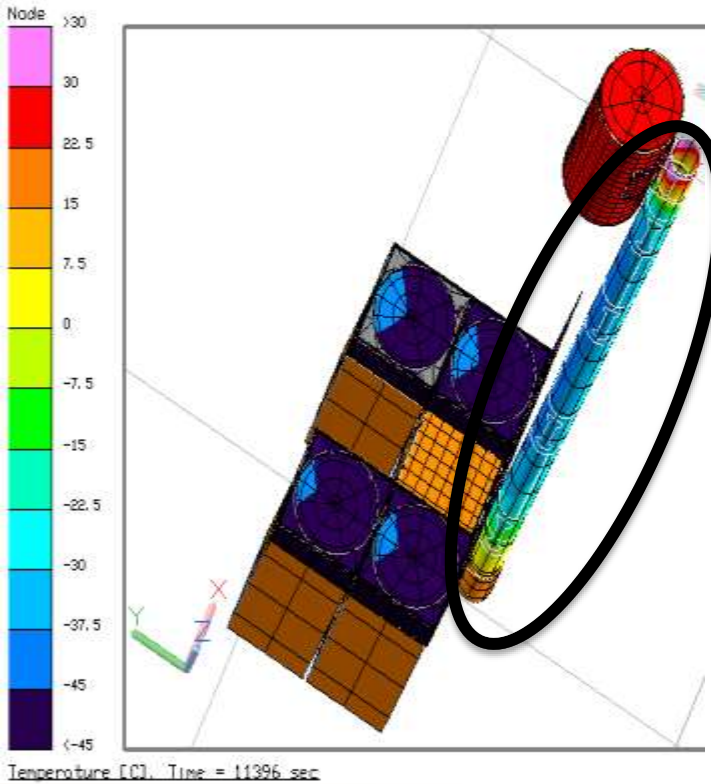
AAReST	External Surface	Material	Internal Heat Load	Heat Max and Min
Mirror Crafts (x2)	Solar Panels (sides), black paint (bottom)	Aluminum	6W/Craft	-
Core Craft	Solar Panels (sides), Black Paint (bottom)	Aluminum	18W	-
Mirror Boxes (x4)	Polished Aluminum	Aluminum	2W/Mirror	Range: dT<30K (+/- 15°C)
Mirrors	Aluminum Out, White Under Side	Glass/Pyrex	No Heat	Range: dT<30K (+/- 15°C)
Camera	MLI	Titanium (6AL-4V)	Hot: 300 & 600 mW Sensors Cold: 0 W	Range: -50 to 70 °C
Boom	Hot: Black Cold: White	Carbon Fiber (orthotropic)	No Heat	-



The Boom

Carbon Fiber
White Paint (α: 0.25) vs. Black Paint (α: 0.9)

Material	Conductivity (W/m/K)	Density (kg/m^3)	C_p (J/kg/K)
Carbon Fiber	35 (axial) & 10 (circumferential)	2,000	700



ORBIT	HOT: Black Paint (°C)	COLD: White Paint (°C)
Sun Sync (longitude)	Hottest: 35± 23 Coldest: 35± 25	Hottest: -10 ± 25 Coldest: -10 ± 30
ISS (longitude)	Hottest: 35± 23 Coldest: -45± 48	Hottest: -10± 23 Coldest: -40± 48
Sun Sync (circumferential)	Hottest: 60± 3 Coldest: 12± 3.5	Hottest: 15± 2 Coldest: -37± 2.5
ISS (circumferential)	Hottest: 55± 2 Coldest: -85± 2	Hottest: 10± 2 Coldest: -85± 2

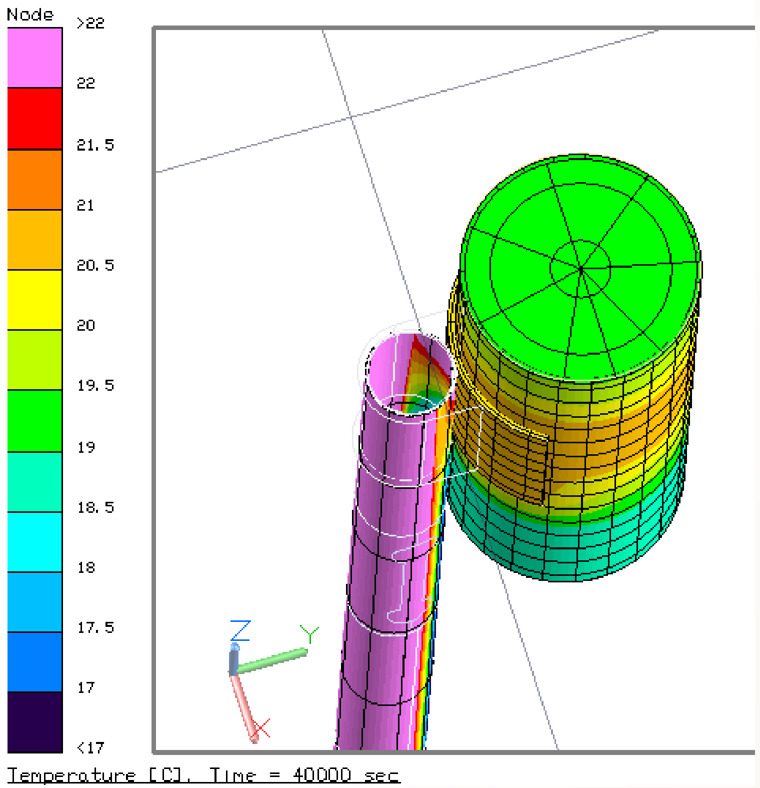
The Camera

MLI Exterior (ε = 0.02)

Operating Limits: -50 to 70° C

Material	Conductivity (W/m/K)	Density (kg/m³)	C_p (J/kg/K)
Titanium (6AL-4V)	6.7	4,430	563

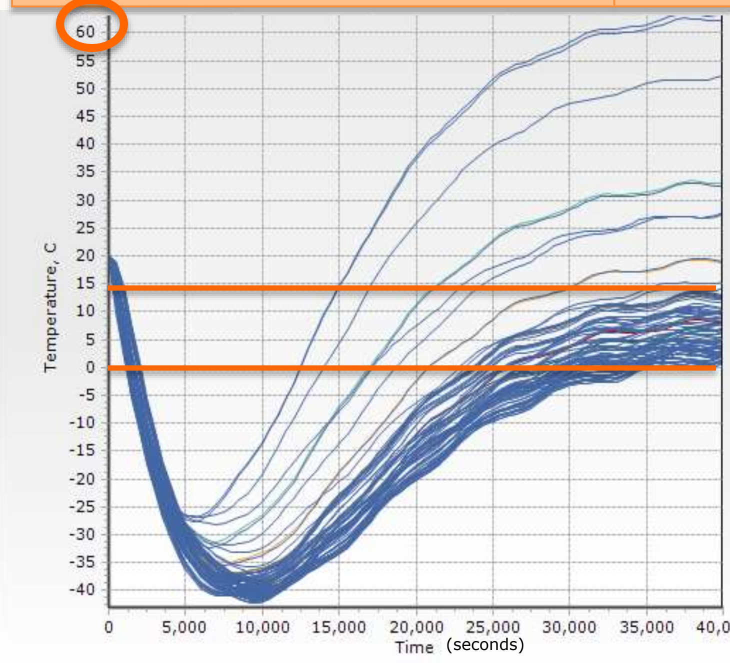
ORBIT	2 Sensors ONLY (HOT: always on, °C)	MLI ONLY (HOT: always on, °C)	MLI ONLY (COLD: always off, °C)
Sun Sync (longitude)	38	25 ± 1.5	19.8 ± 1.1
ISS (longitude)	25 ± 4 over orbit period	13.5 ± 4	8 ± 4
Sun Sync (circumferential)	38	26.5 ± 0.25	18.5 ± 0.1
ISS (circumferential)	25 ± 0.5 over orbit period	13.5 ± 2	8 ± 2



The Mirrors

Operating Limits: +/- 15°C (preferably 0 to 30°C)
Tested from -70°C to +110°C

Material	Conductivity (W/m/K)	Density (kg/m^3)	C_p (J/kg/K)
Mirrors: Pyrex	1.005	2230	750
Box: Aluminum	240	2770	873

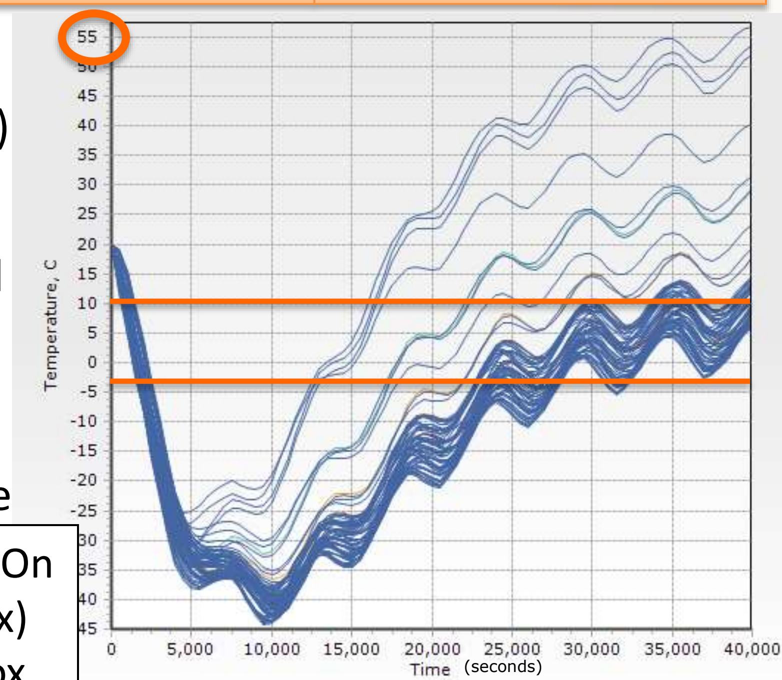


Sun Synchronous

White (α: 0.25) vs. Black Paint (α: 0.9)

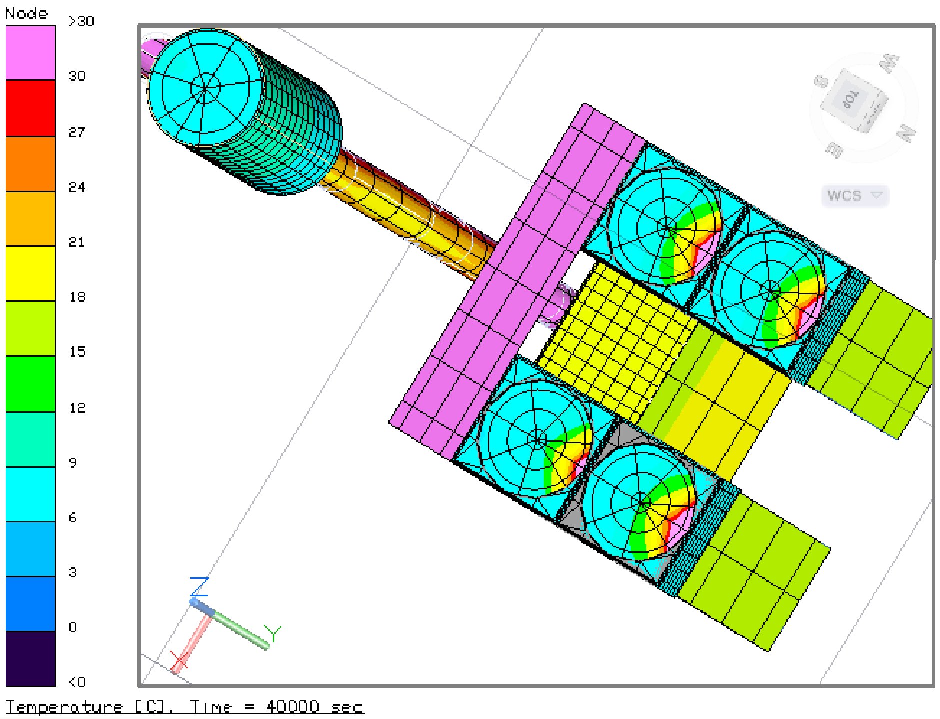
Best Case:
- Boxes Not Isolated
- Painted Box
- Sun Shield with Solar Panel Outside Black Chrome Inside

HOT CASE: E-Boards On
(4 W per Mirror Box)
White and Black Box



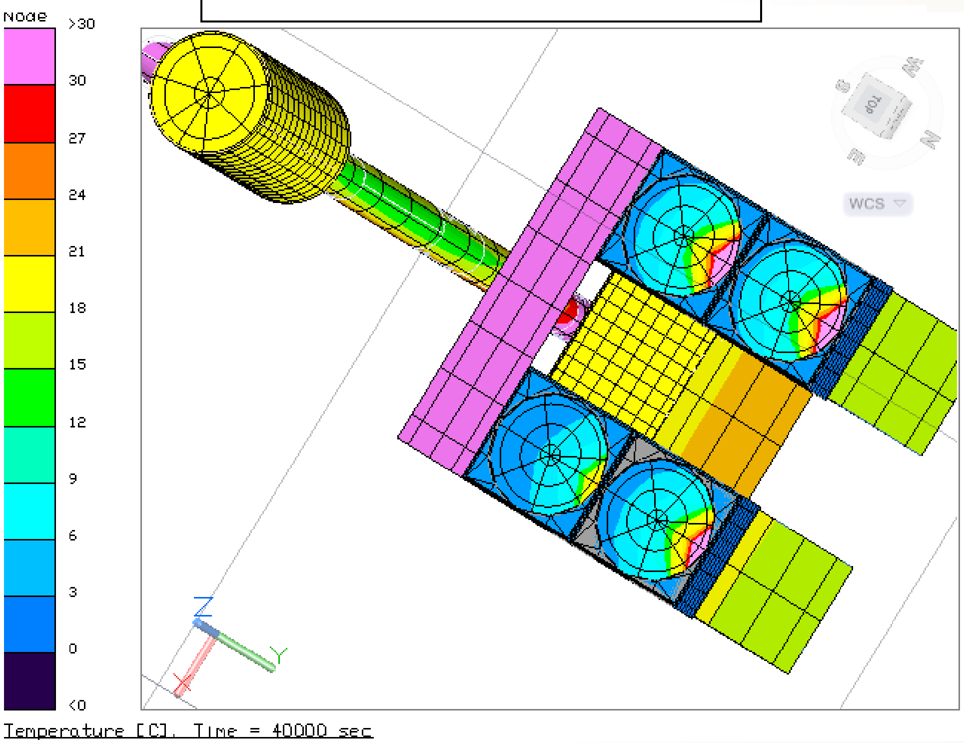
ISS

Best Case Mirrors



ISS: -5 to 15° C

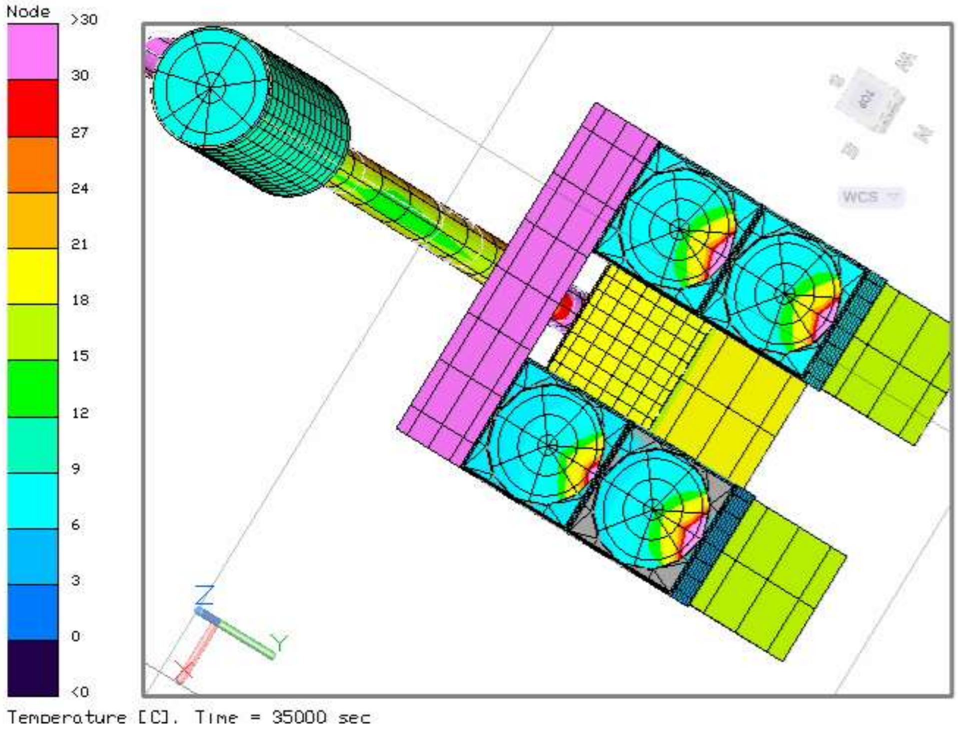
Best Case:
White Box Outside
Black Box Inside
Mirror Bottom White



Sun Synchronous: 0 to 15° C

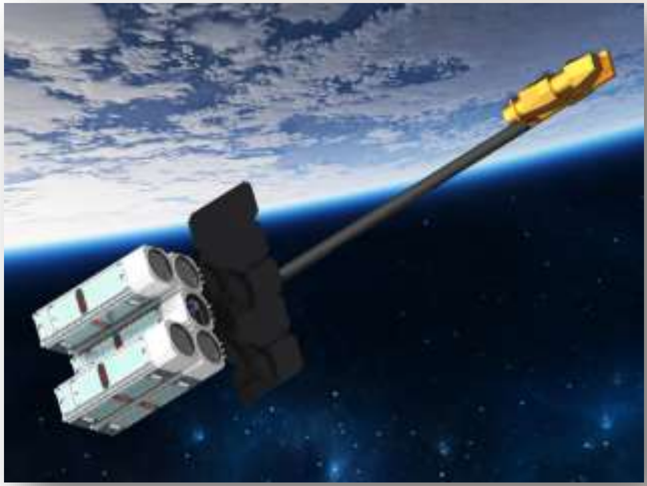
Recommended Heat Load:
4W per Mirror Box

Best Case Mirrors



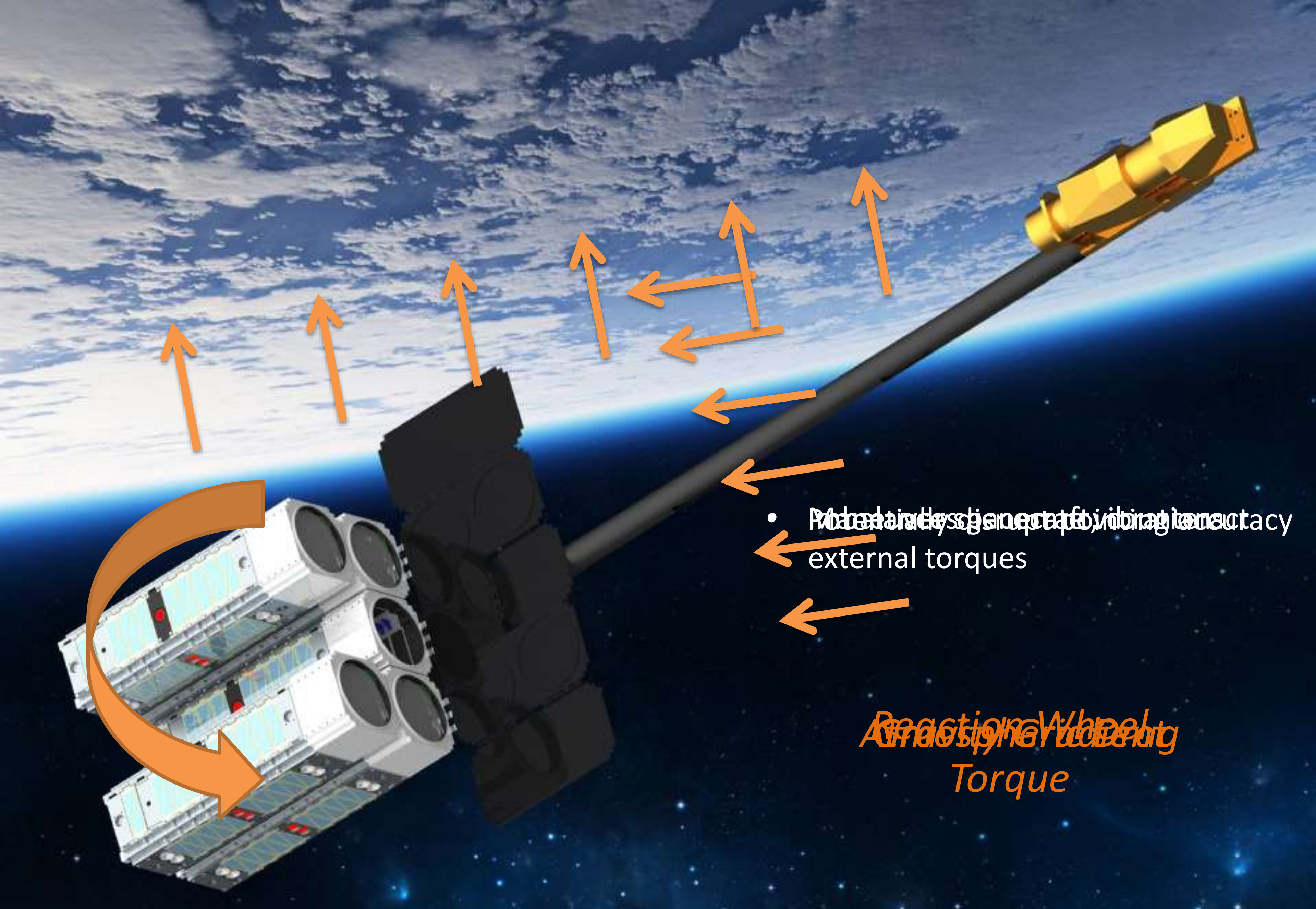
Conclusions

- Optimal orientation for Sun Sync and ISS orbit: Pointed at Polaris
- Boom variance higher at lower temps due to conductivity pts
  - White paint would be better, but creates light scatter
- Camera remains within operational values for sensors
- Recommended mirror design in order to remain 0 to 30°C:
  - 4W heat load/box
  - White paint exterior box
  - Black paint interior box
  - White paint bottom mirror

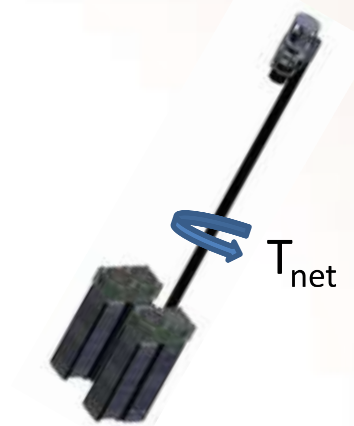


Disturbance Analysis

Kevin Rosenberg
Hunter Zhao
Mentor: Lee Wilson


external torques
Torque

1. Given a specific orbit/orientation



2. Calculate net torque from atmospheric drag & gravity gradient for entire orbit

Translate net torque into required wheel speeds for orbit, Ω(t)

$$F(t), M(t) = \sum_i C_i \Omega^2 \sin(2\pi h_i \Omega t)$$

3. Input wheel speeds to empirical model to calculate forces and moments, F(t) and M(t) respectively

4. Input dynamic loads F(t), M(t), calculate displacement of optical package

1. Given a specific orbit/orientation

2. Calculate net torque from atmospheric drag & gravity gradient for entire orbit

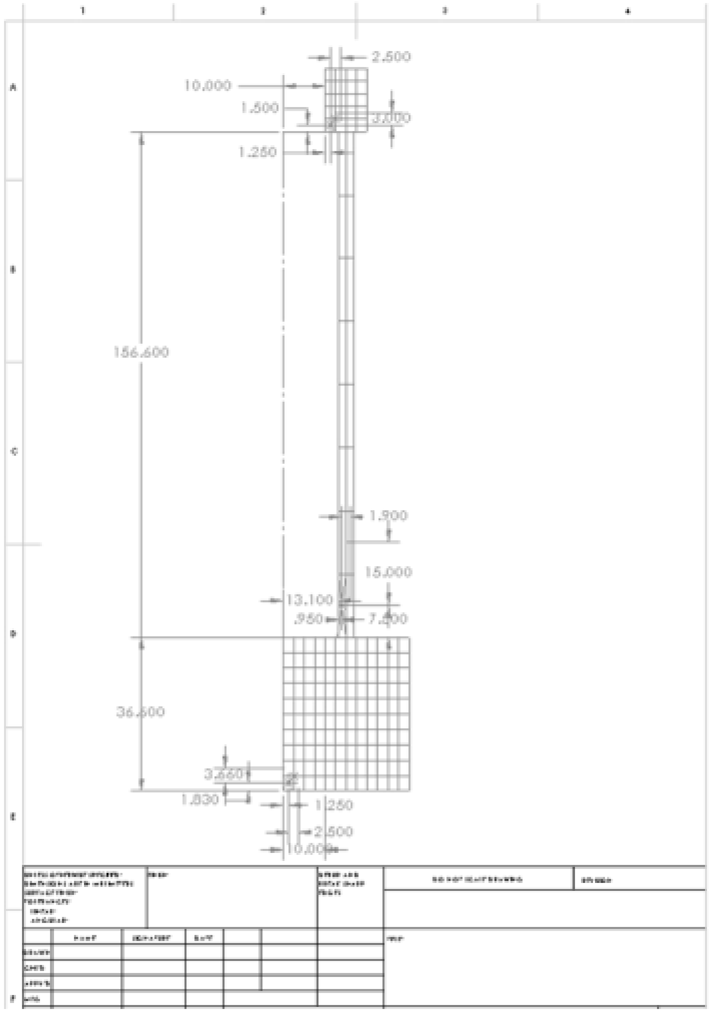
Translate net torque into required wheel speeds for orbit, Ω(t)

$$F(t), M(t) = \sum_i C_i \Omega^2 \sin(2\pi h_i \Omega t)$$

3. Input wheel speeds to empirical model to calculate forces and moments, F(t) and M(t) respectively

4. Input dynamic loads F(t), M(t), calculate displacement of optical package

Mesh Generation



DC Disturbances

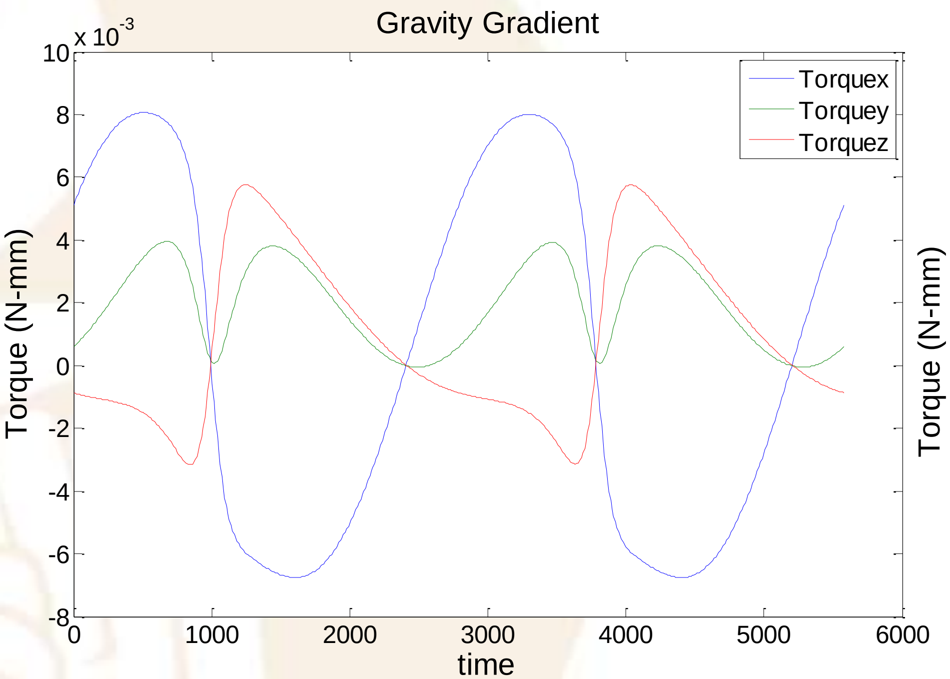
<u>Atmospheric drag</u>

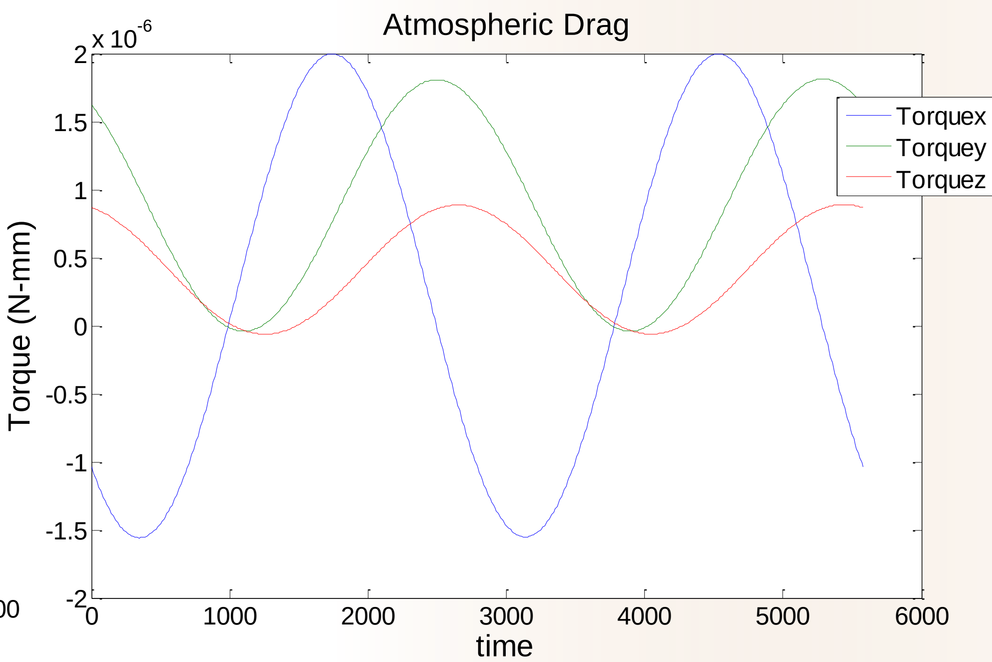
- Simplified drag model
  - Density function of altitude
  - $C_d = 1.17$ for flat square plate
  - Input: position, velocity, orientation (Earth frame)
  - Output: total force, total torque (spacecraft frame)

<u>Gravity gradient</u>

- Simplified mass distribution model
- $F_g = \frac{-GMm}{r^2}$

External Loading





- External disturbance torques are periodic
- Gravity gradient is dominant
- Do not need wheel speed adjustments throughout orbit

1. Given a specific orbit/orientation

2. Calculate net torque from atmospheric drag & gravity gradient for entire orbit

Translate net torque into required wheel speeds for orbit, Ω(t)

$$F(t), M(t) = \sum_i C_i \Omega^2 \sin(2\pi h_i \Omega t)$$

3. Input wheel speeds to empirical model to calculate forces and moments, F(t) and M(t) respectively

4. Input dynamic loads F(t), M(t), calculate displacement of optical package

Empirical Model

- Based on Masterson et. al (2001)
- Vibrations modeled as series of discrete harmonics

Force/Moment

Wheel speed

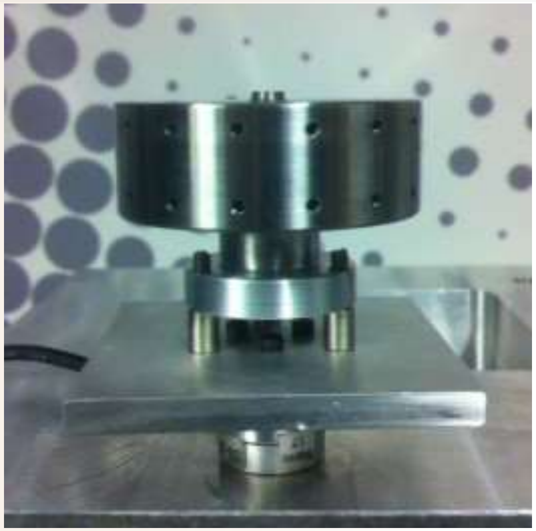
$$m(t) = \sum_i C_i \Omega^2 \sin(2\pi h_i \Omega)$$

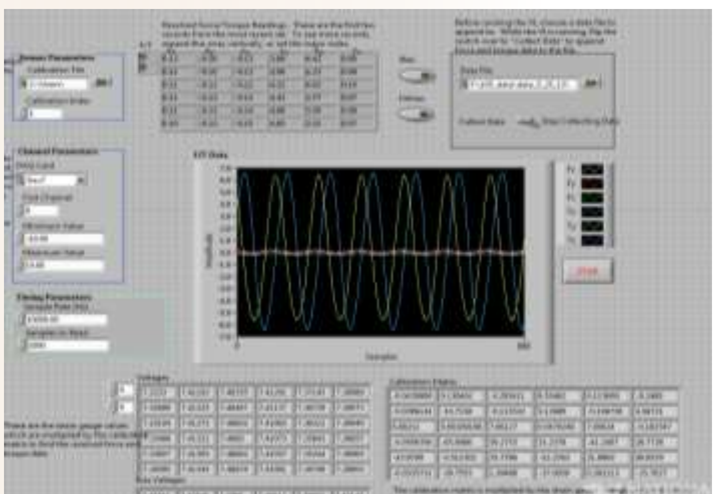
Amplitude Coefficients

Harmonic numbers

Obtained experimentally

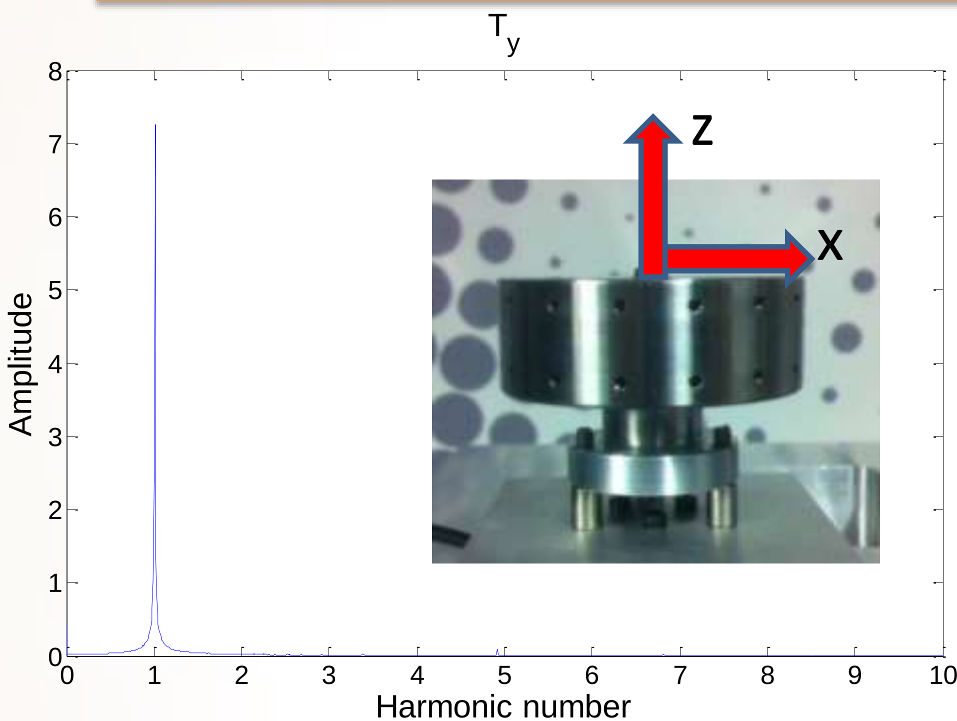
Experimental Setup

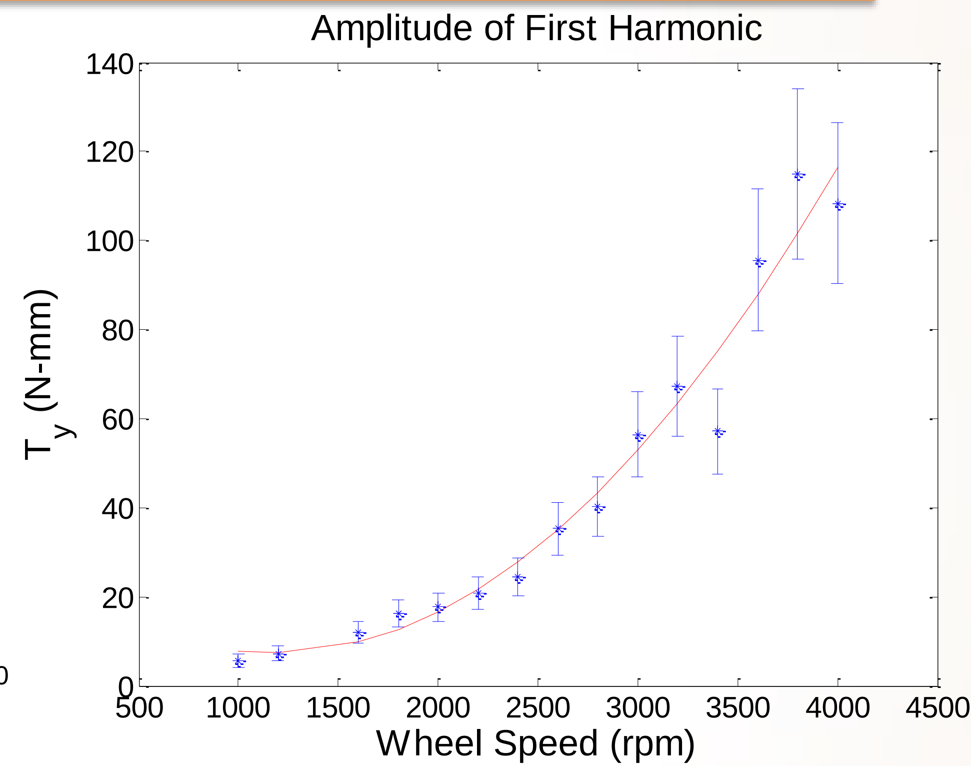




- 6-dof load cell
- Connected via interface plates
- Recorded 6-dof measurements for 15 wheel speeds ranging from 1000 rpm to 4000 rpm

Results





- T_x and T_y are dominant
- Error based on RSS uncertainty

1. Given a specific orbit/orientation

2. Calculate net torque from atmospheric drag & gravity gradient for entire orbit

Translate net torque into required wheel speeds for orbit, Ω(t)

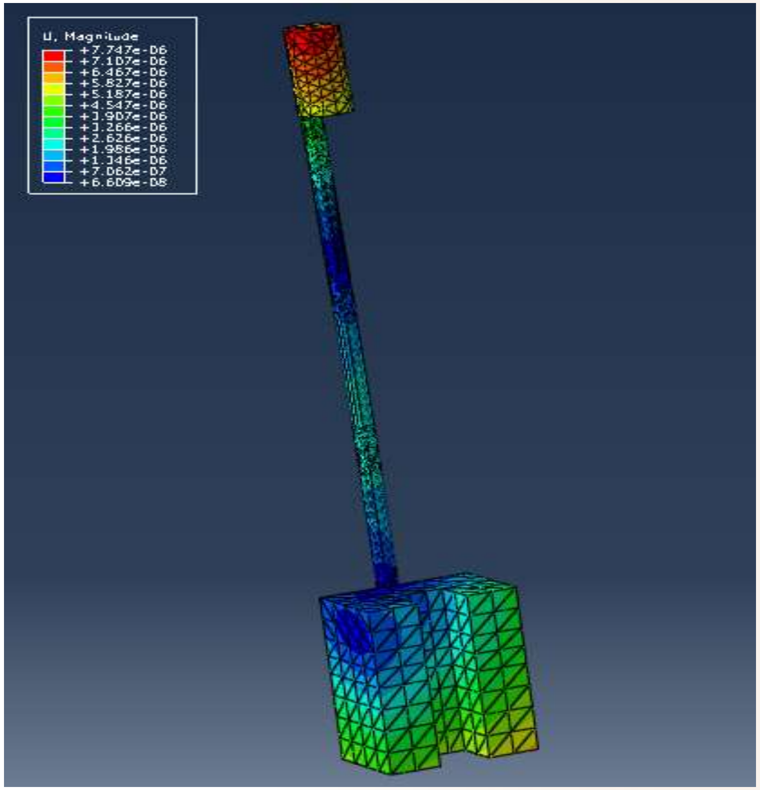
$$F(t), M(t) = \sum_i C_i \Omega^2 \sin(2\pi h_i \Omega t)$$

3. Input wheel speeds to empirical model to calculate forces and moments, F(t) and M(t) respectively

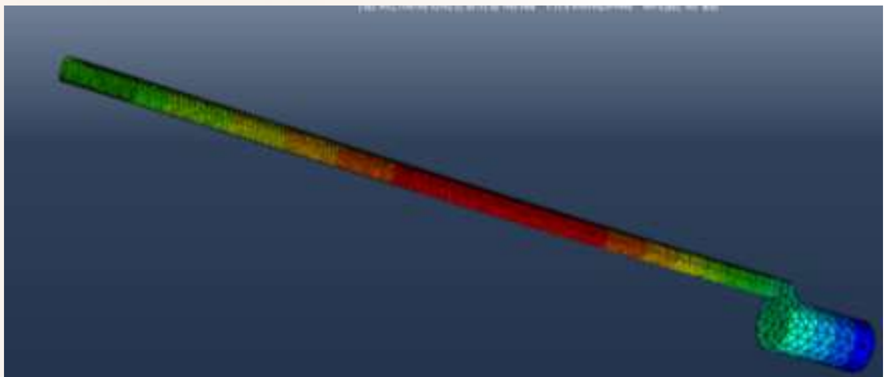
4. Input dynamic loads F(t), M(t), calculate displacement of optical package

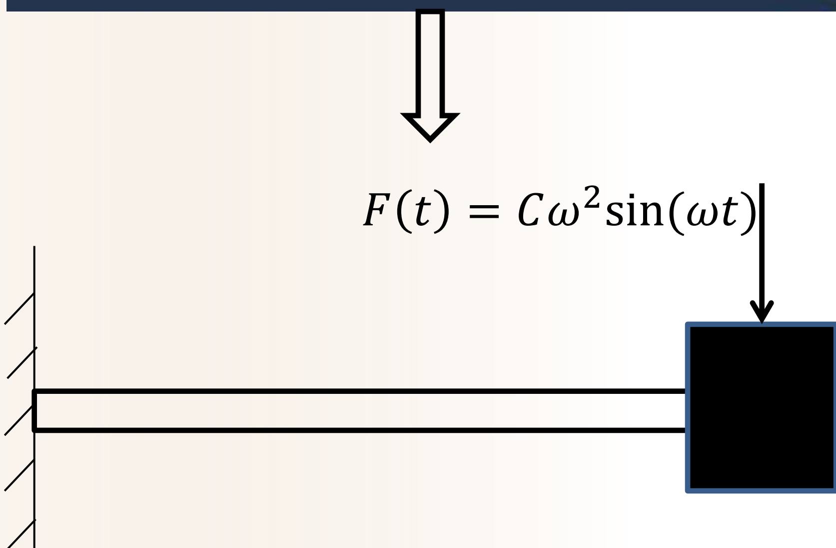
FEA of Disturbances

- Simplified 3D model of spacecraft
  - Abaqus
  - Camera, boom, base
- AC disturbance
- Simulated camera deflection



FEA Validation

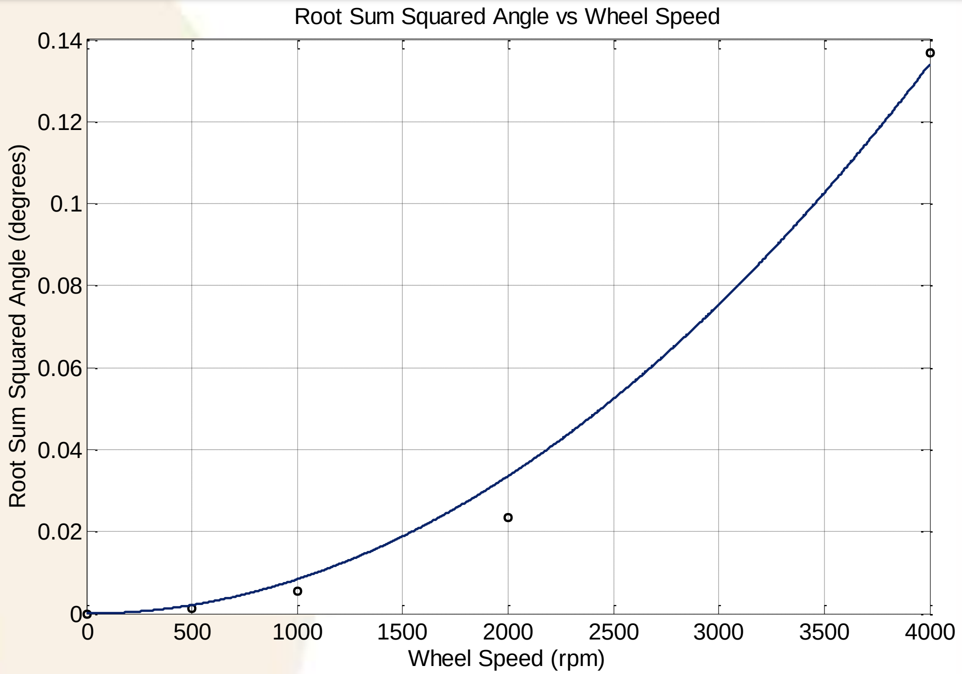




- Used simplified cantilever model to validate FEA simulations

- Results are consistent within an order of magnitude

FEA of Disturbances



$y = p_1 x^2 \Leftrightarrow$ force α Cw^2

$p_1 = 8.378 * 10^{-9}$

R-square = 0.9911

Upper bound on deflection angle: ~ 0.002 degrees

Wheel Speed (rpm)	**Root Sum Squared Deflection (mm)**			**RSS Deflection Angle (degrees)**
	x	y	z	
500	0.01889	0.01383	0.00849	0.0012
1000	0.09279	0.05887	0.03713	0.0054
2000	0.4307	0.1964	0.1185	0.0233
4000	2.5	1.2	0.7	0.1368

Recommendations

- Attempt to balance reaction wheel to obtain more realistic vibration data
- Place stringent upper bounds on wheel speed to maintain pointing accuracy requirements
- Investigate use of isolators to mitigate vibrations at higher frequencies

Future work

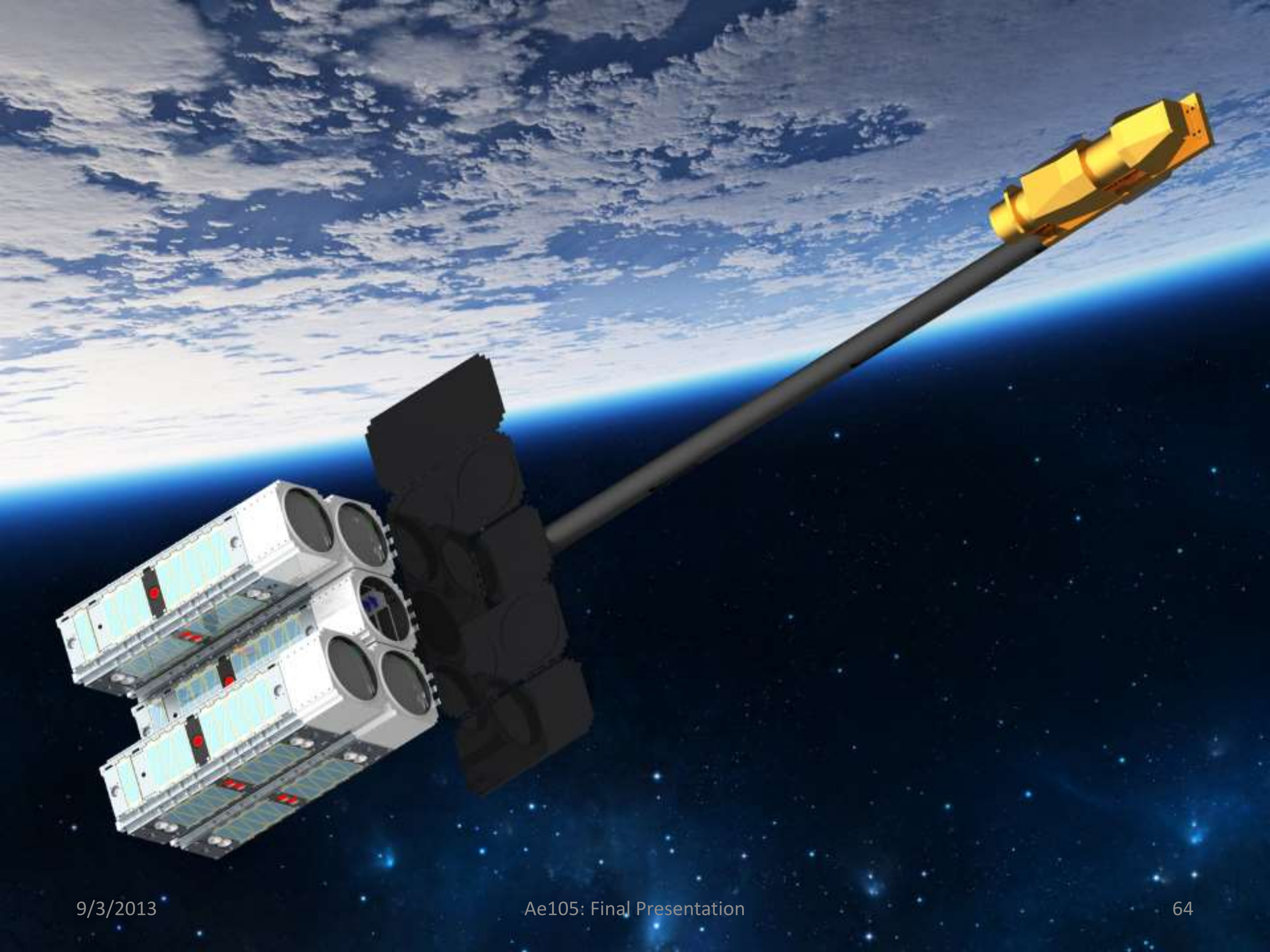
- Design control system for reaction wheel
- Consider magnetic effects
- Gyroscopic precession incurred during orientation adjustments

Deployable Boom

Carlos Laguna

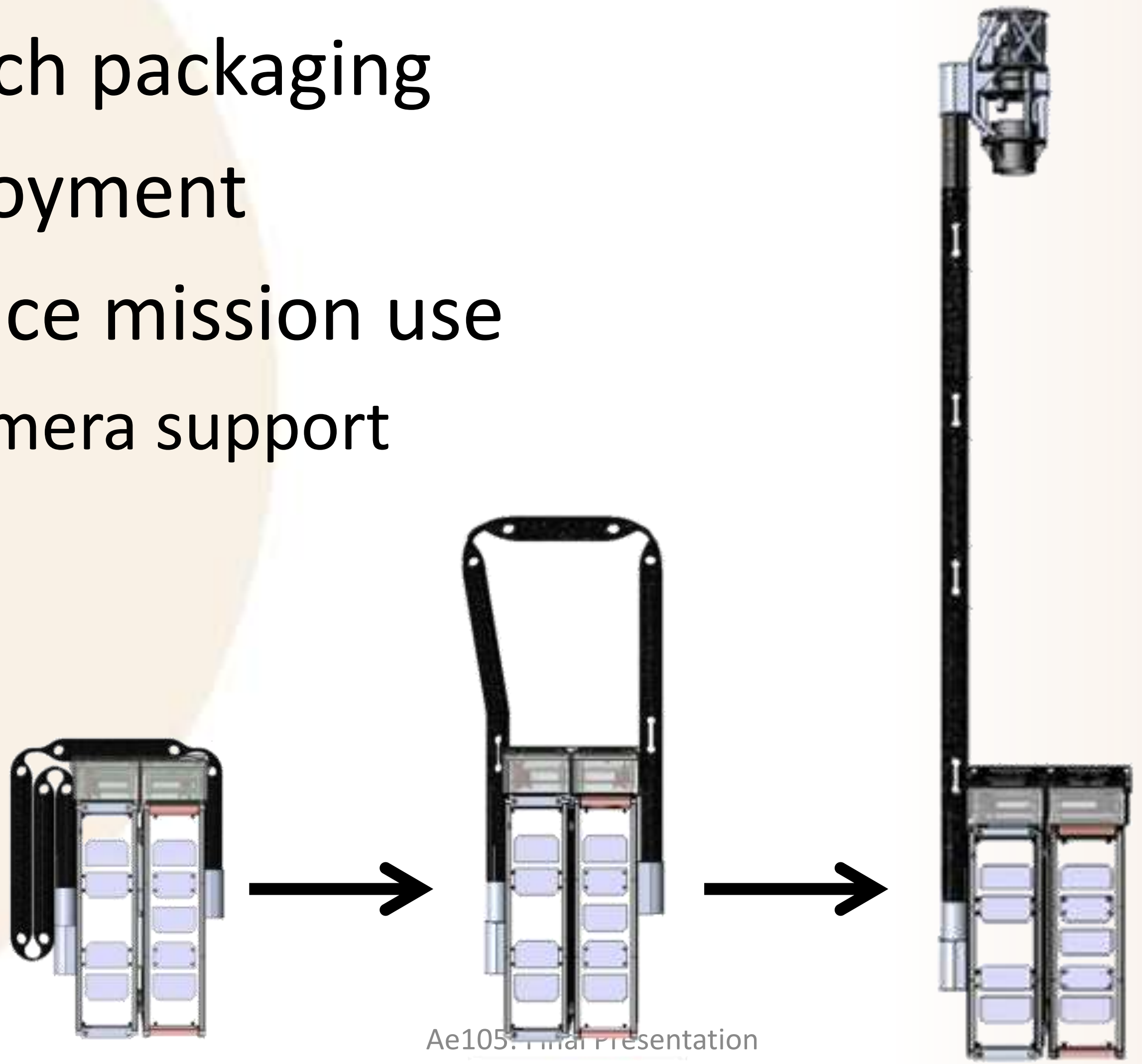
Timothy MacDonald

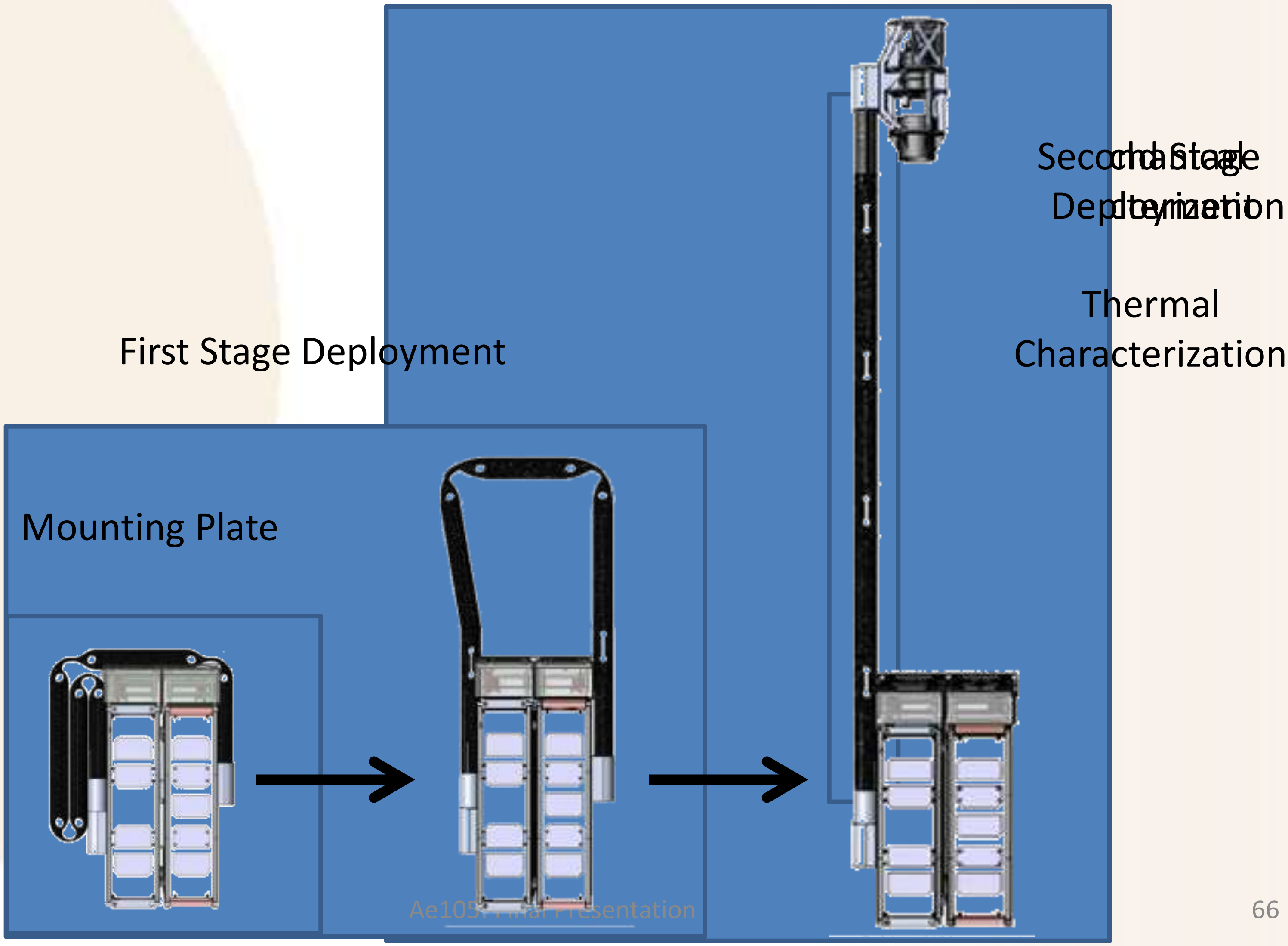
Mentor: John Steeves



Boom Requirements and Use

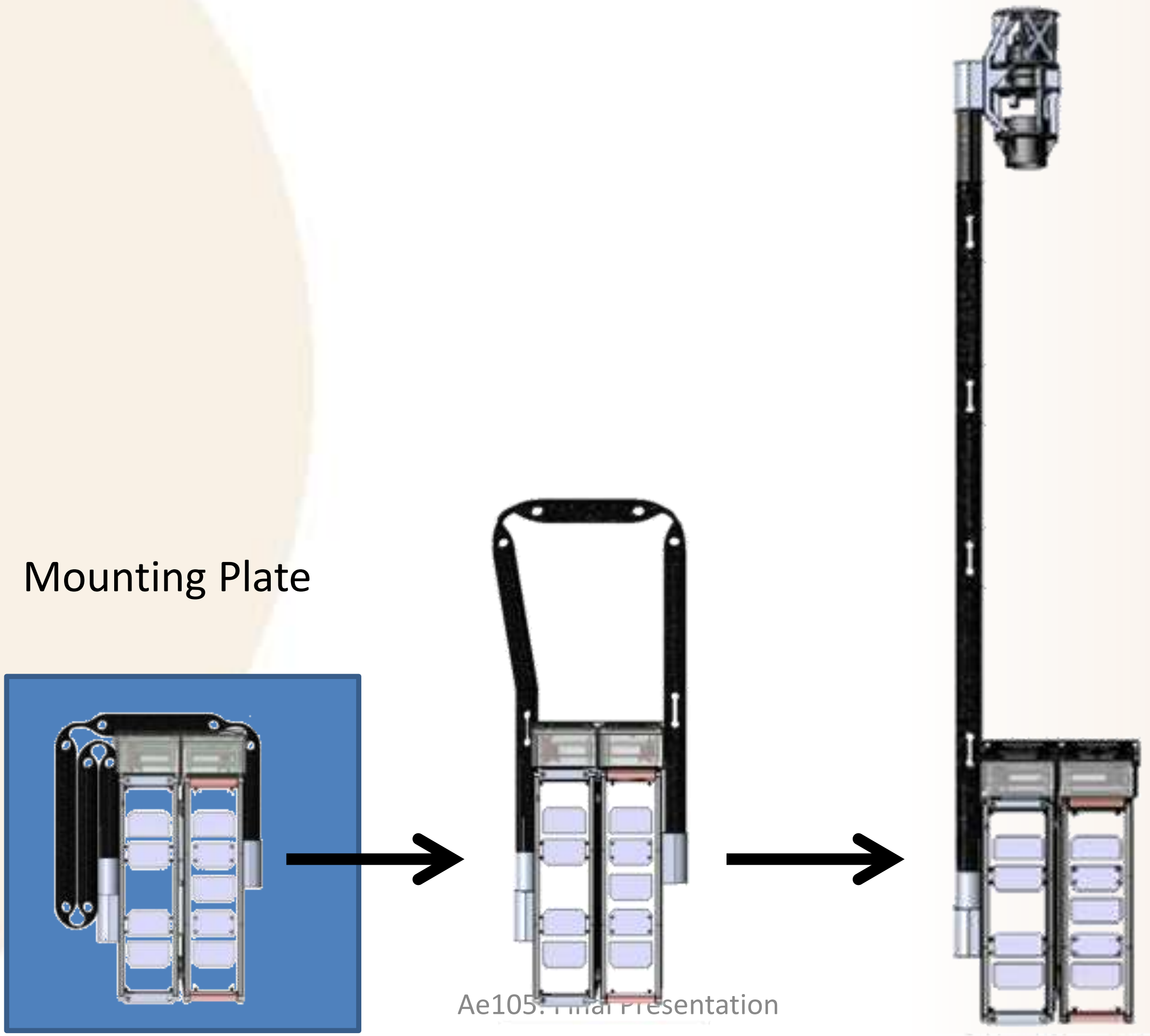
- Launch packaging
- Deployment
- Science mission use
  - Camera support



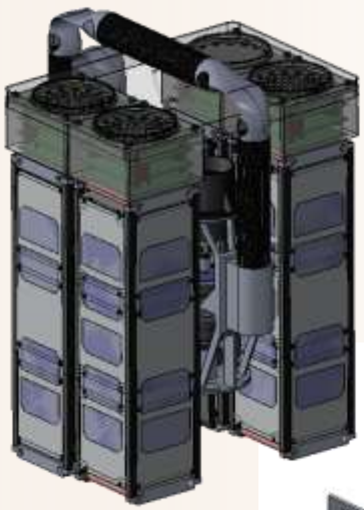


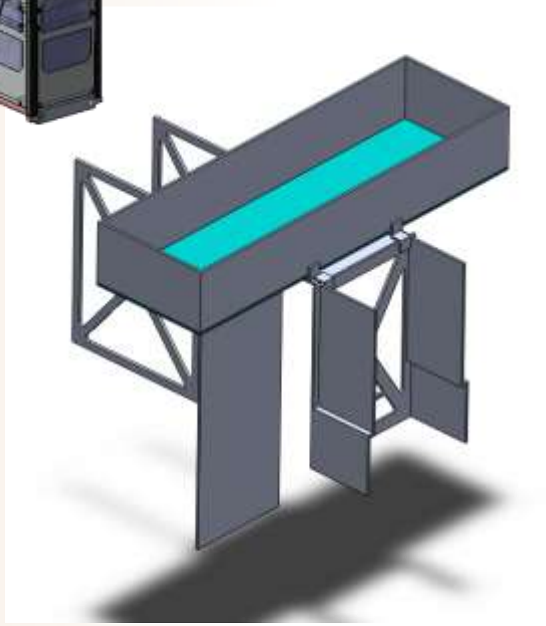
Second Stage Deployment
Thermal Characterization
First Stage Deployment
Mounting Plate

Mounting Plate



Mounting Plate



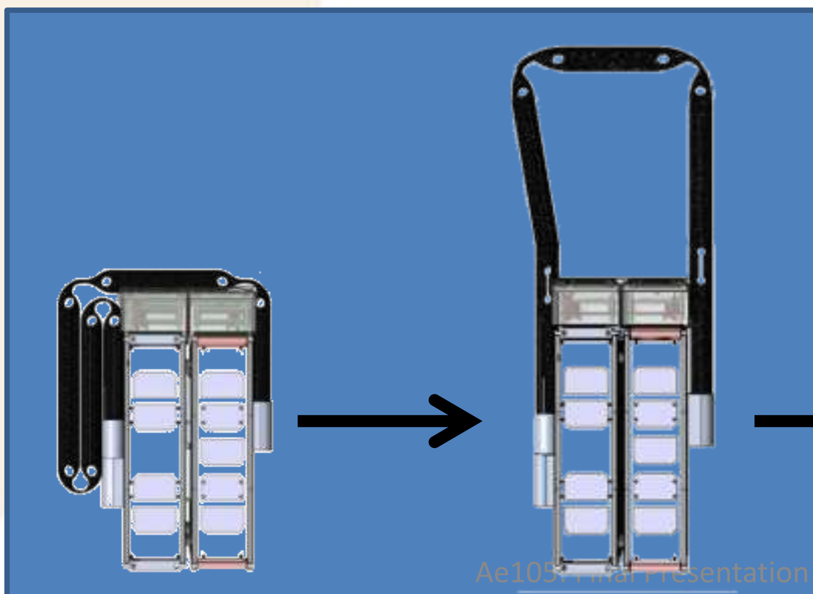


Carbon Fiber

Aluminum

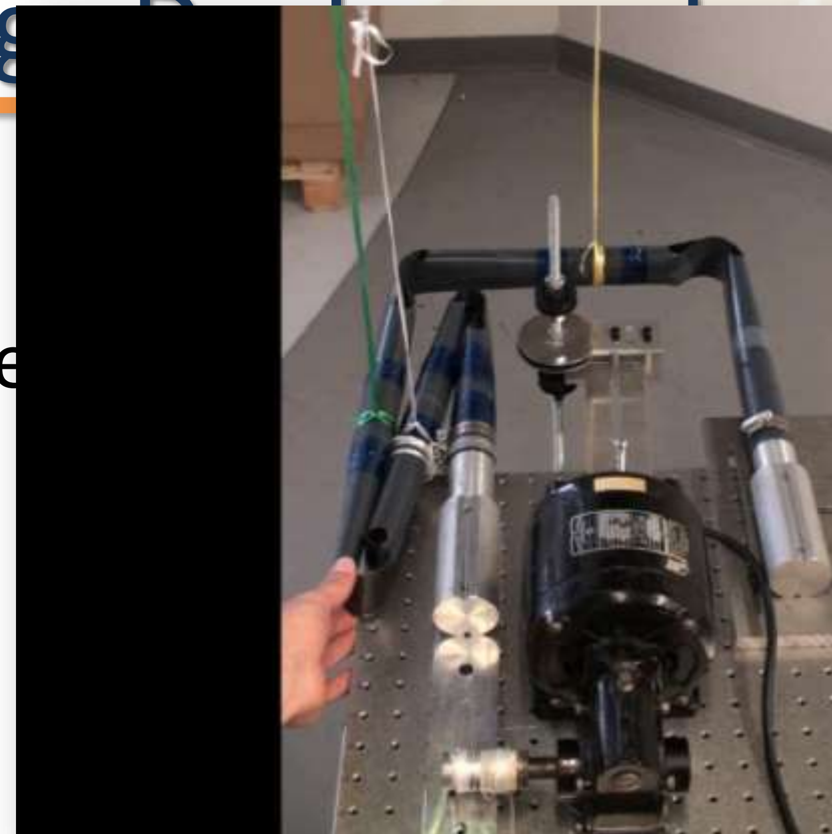
- Must be lightweight and stiff
- Low CTE material required for mirrors
- Kinematic mounting
- Easy integration with S/C

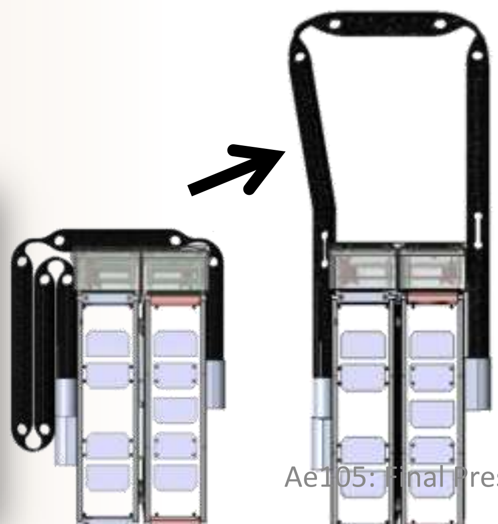
First Stage Deployment

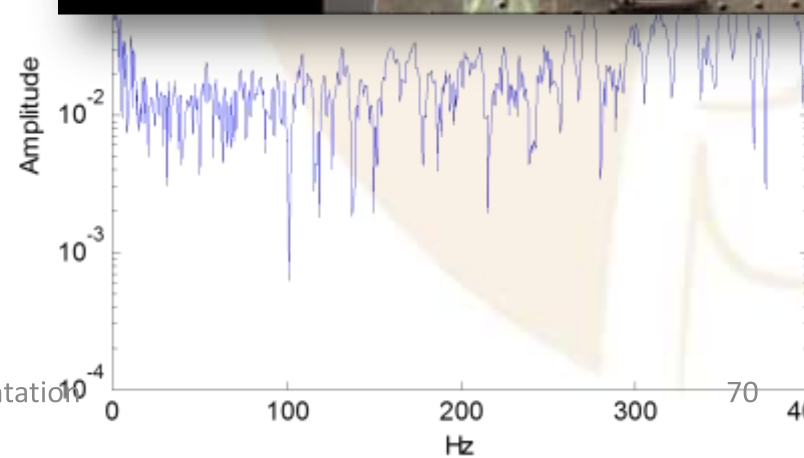


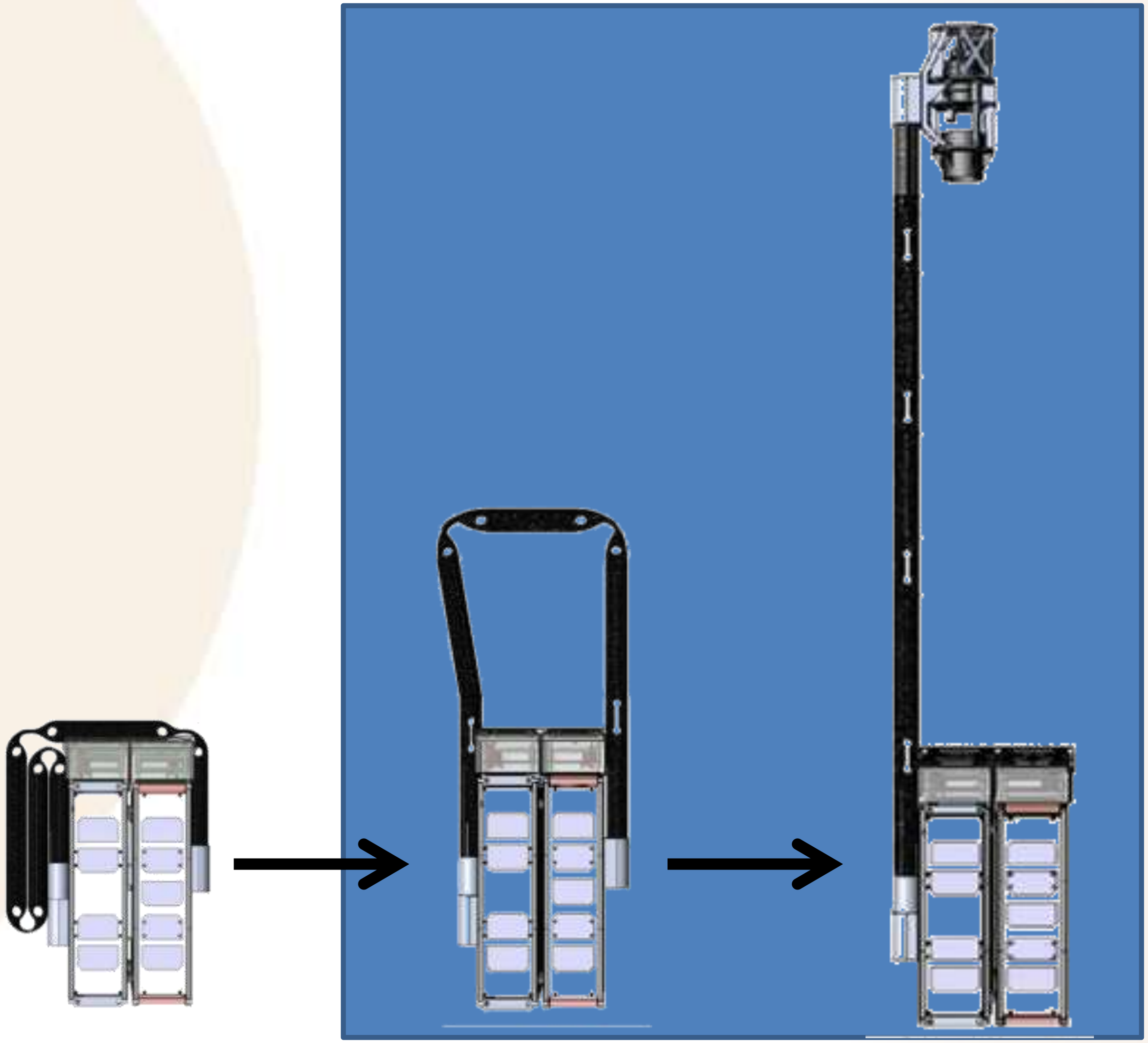
1st Stag

- Intermediate stage
- Kinetic properties measure
- Broadband frequency
- Max Torque 0.4 Nm



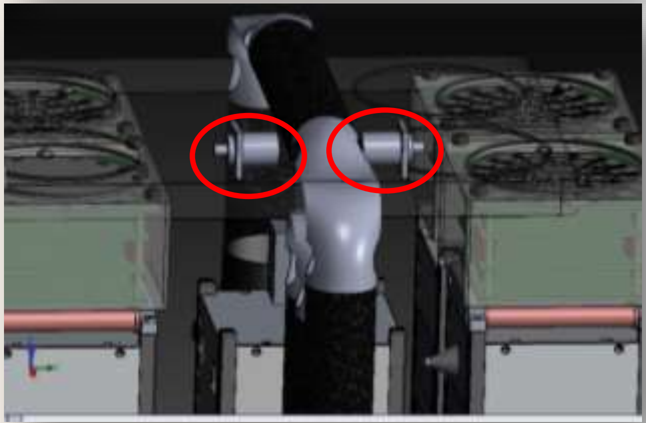




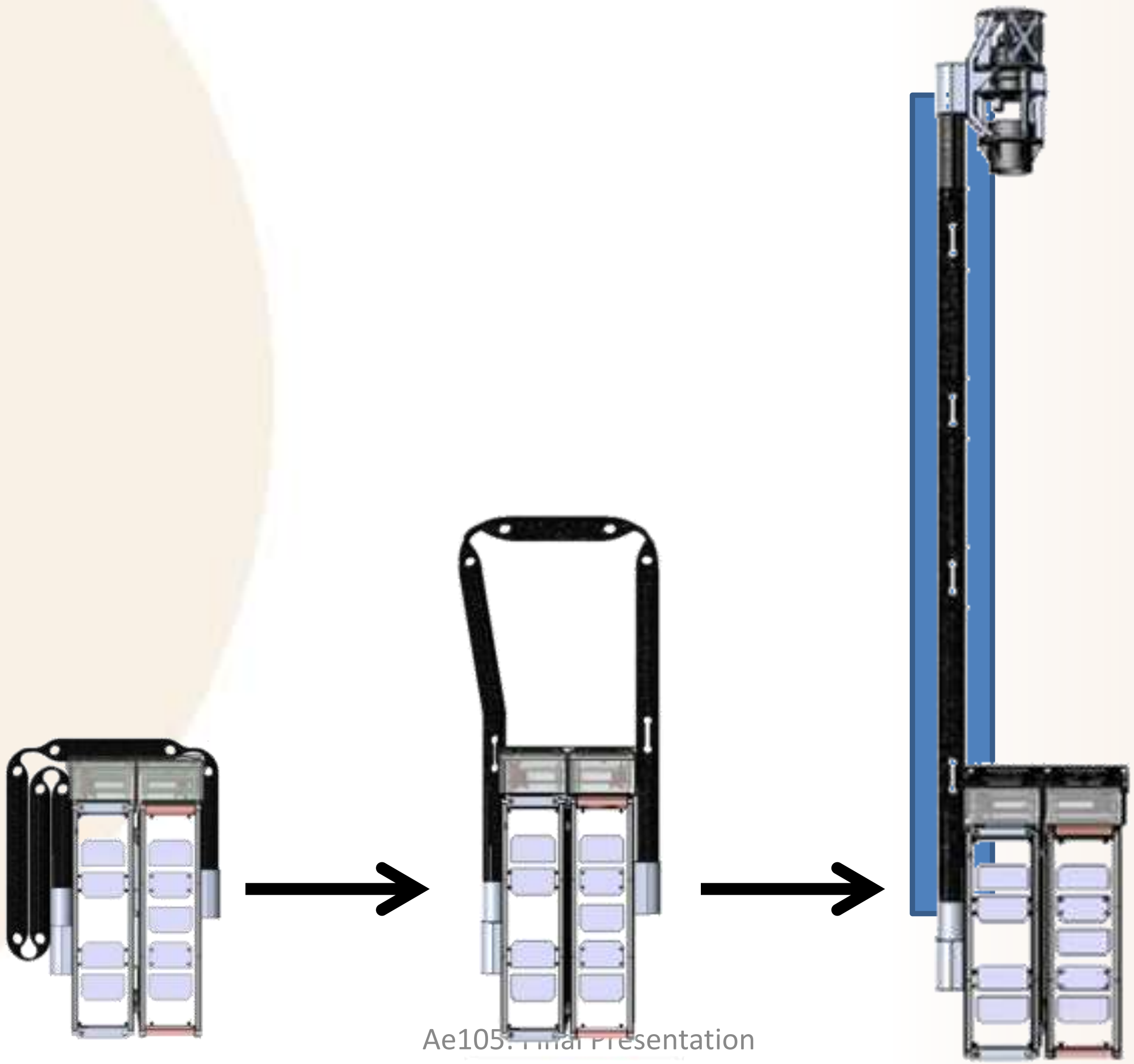


Second Stage Deployment

2nd Stage Deployment

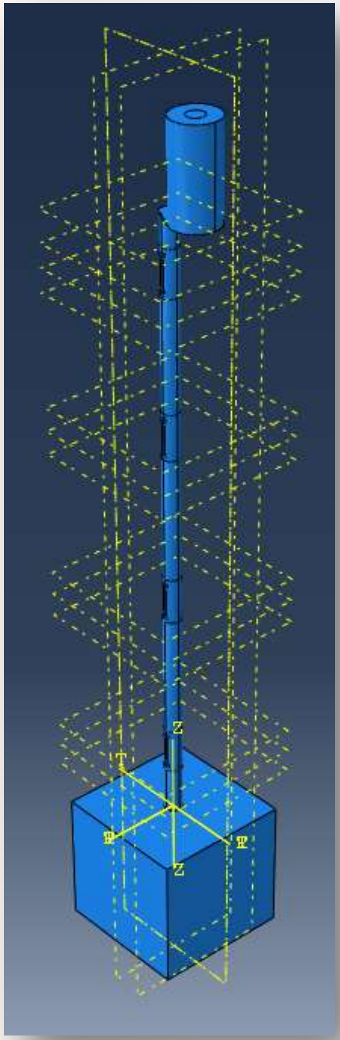


- Final stage
- Quasi-static deployment (cable guided)
- Tip mass (camera) can’t experience shock loading



Deployed Characteristics

Deployed Characteristics



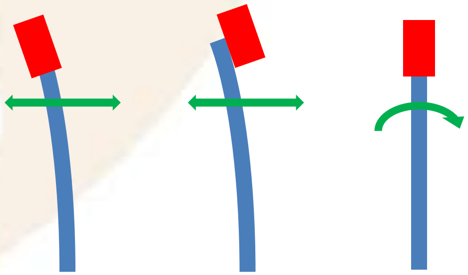
- Boom response to disturbances
- Mechanical properties
- Thermal properties
- Modeling and experiments

Mechanical Characterization

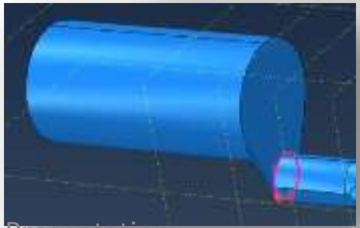
- Abaqus model
- Fixed and free S/C end
- Masses represent ends

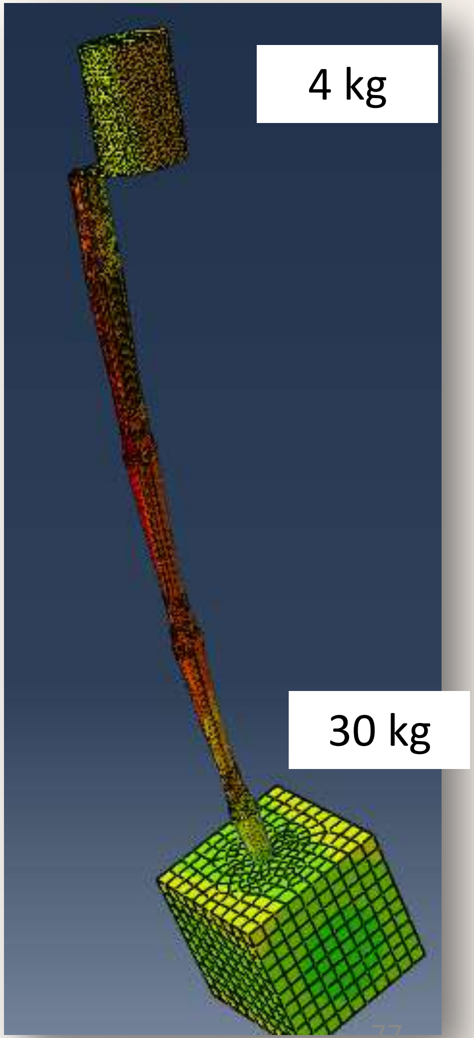
Type	Mode 1	Mode 2	Mode 3
Fixed 4kg	1.27	1.45	6.91
Free 4kg	4.94	6.20	7.24

Fixed Modes:



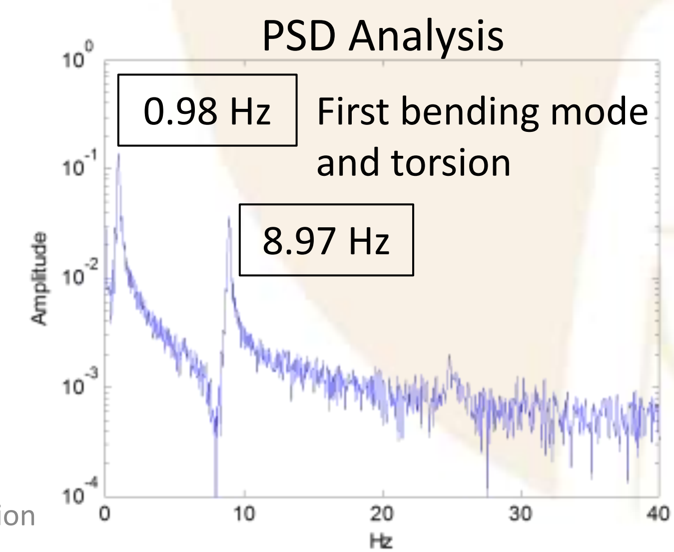
Bending 1 Bending 2 Torsion





Mechanical Characterization

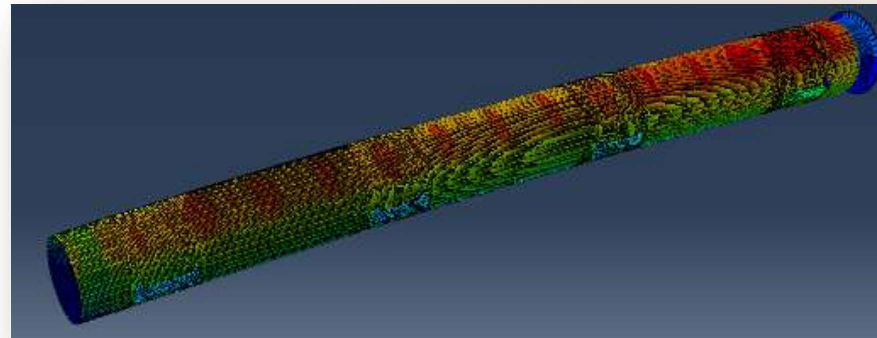
- Fixed end experiments
- Experimental frequency and damping
  - 4.6 kg mass

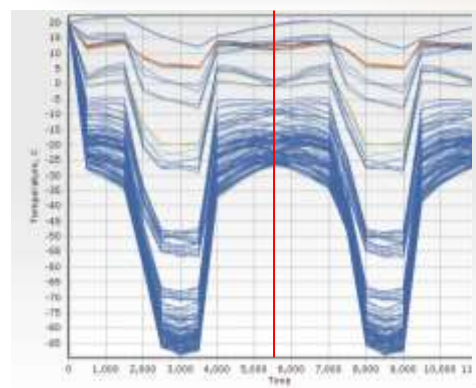


Thermal Characterization

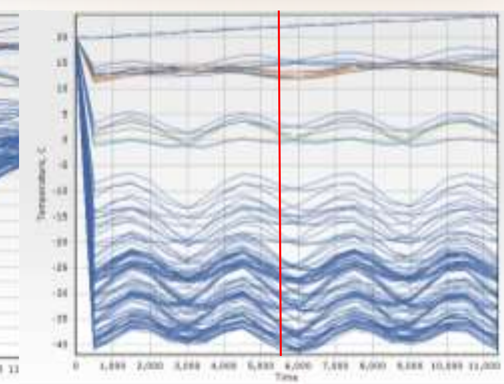
- Boom axial displacement and deflection cause out of focusing.
- CTE measured with DIC
- Temperature profiles provided by thermal environment analysis
- Two different booms: white or black paint
- Two orbits: ISS and Sun-synchronous

Temp Range: 297-332 K



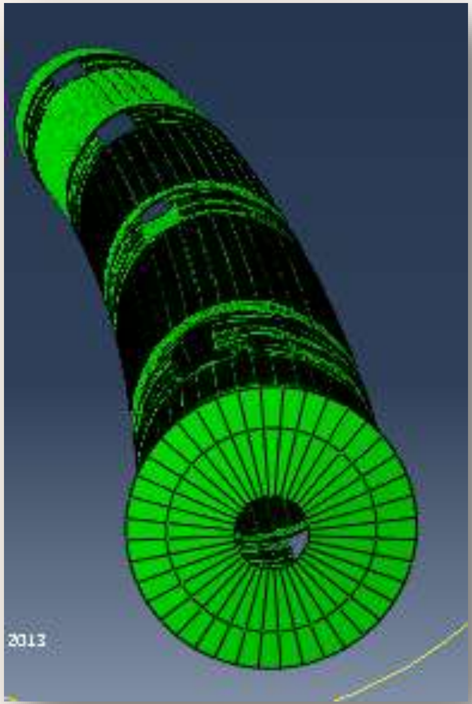


ISS



Sun-synchronous

Thermal Characterization



Deformed shape

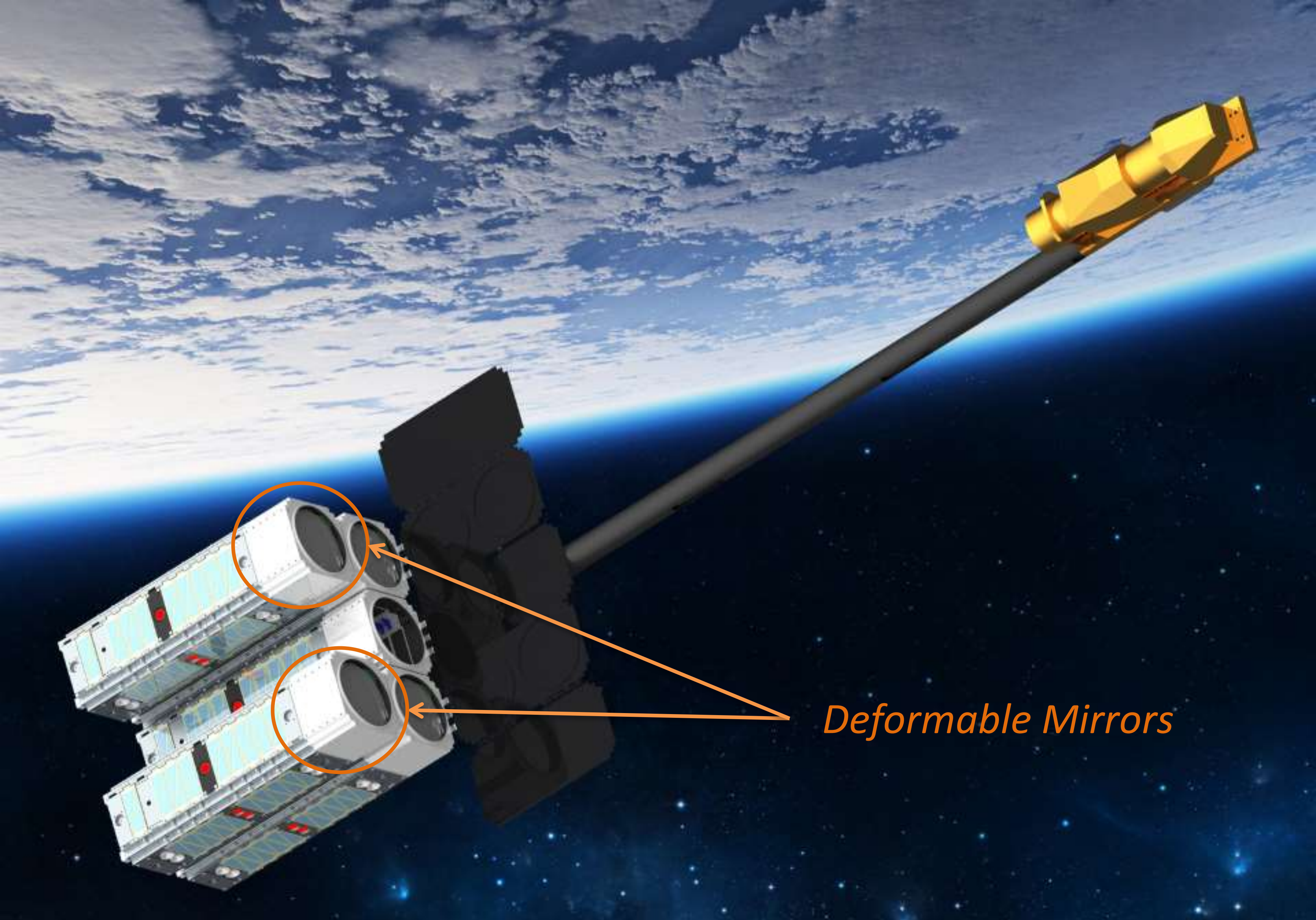
Boom coating	Orbit	Axial Displacement [um]	Bending [um]
Black paint	ISS	222	357
	Sun-Synchronous	216	431
White paint	ISS	177	165
	Sun-Synchronous	172	218

Overall Results

- Preliminary mounting plate design
- Characterized first stage deployment
  - Broadband reaction load
  - 0.4 Nm torque
- Characterized second stage deployment
  - Cable restraint system
- Deployed characteristics
  - Natural frequencies near 1 Hz
  - Damping properties determined
  - Deflection due to thermal environment
    - Max axial displacement
    - Max bending

Deformable Mirrors & Calibration

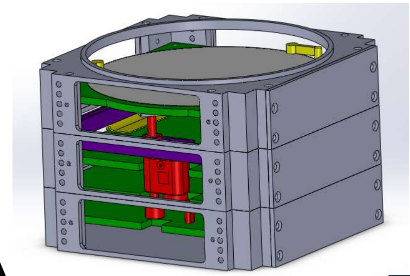
Mélanie Delapierre
Vicky Tian
Mentors: Keith Patterson, Marie Laslandes


Deformable Mirrors

Timeline

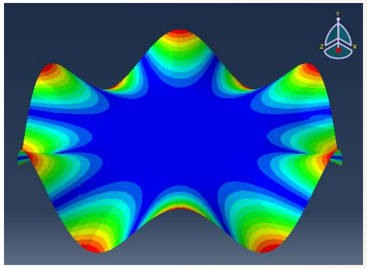
Flight Package

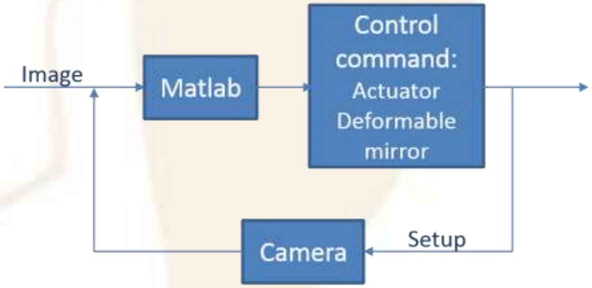
Preliminary design



Launch

Survivability analysis





Calibration

Mirror pointing and coarse focusing

Operation

Mirror environmental testing

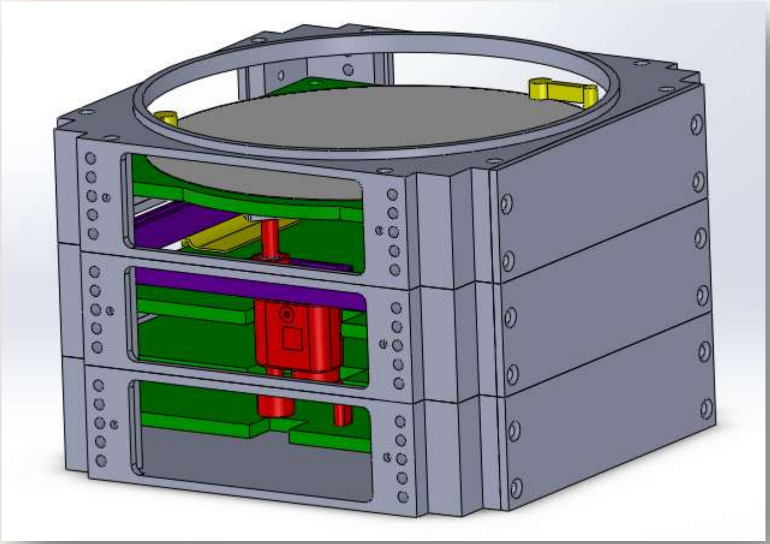
Timeline

Flight Package Design

Launch

Calibration

Operation

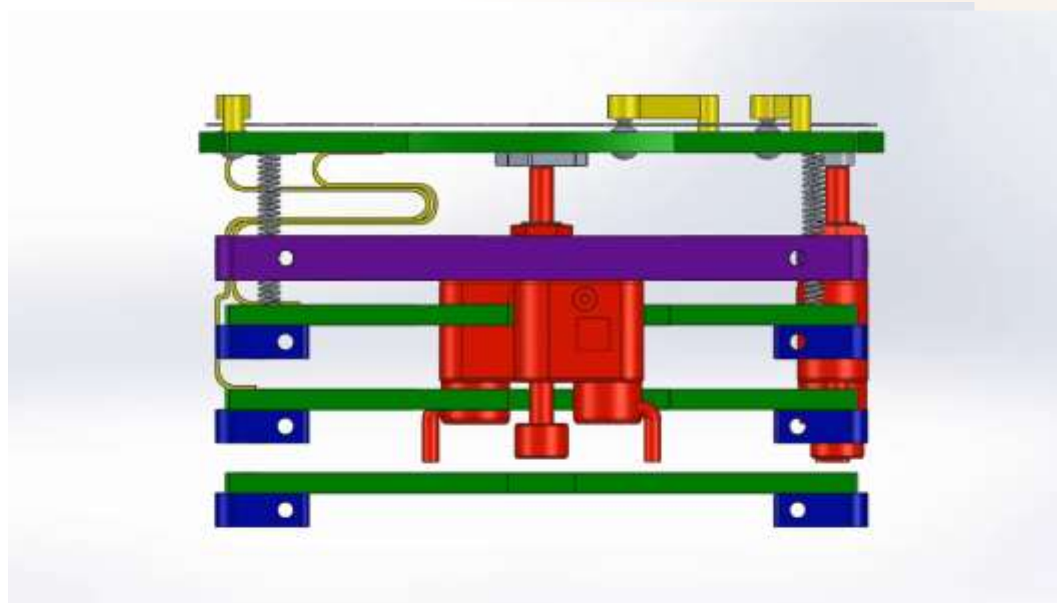


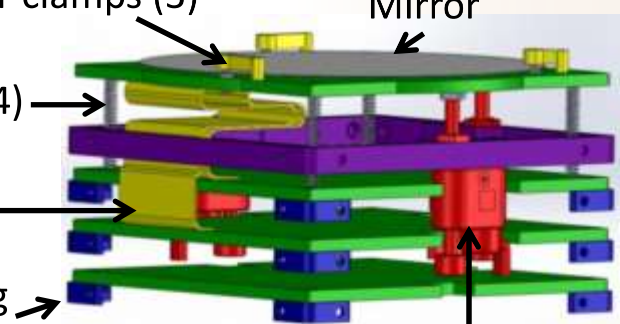
Mirror Flight Package Design

Approach:

Design package following Surrey's mirror craft design including:

- Deformable mirror & restraint system
- Boards: Mirror, Amplifier, & Multiplexers
- 3 axis gimbal w/ open loop picomotor actuators
- Flexible cables





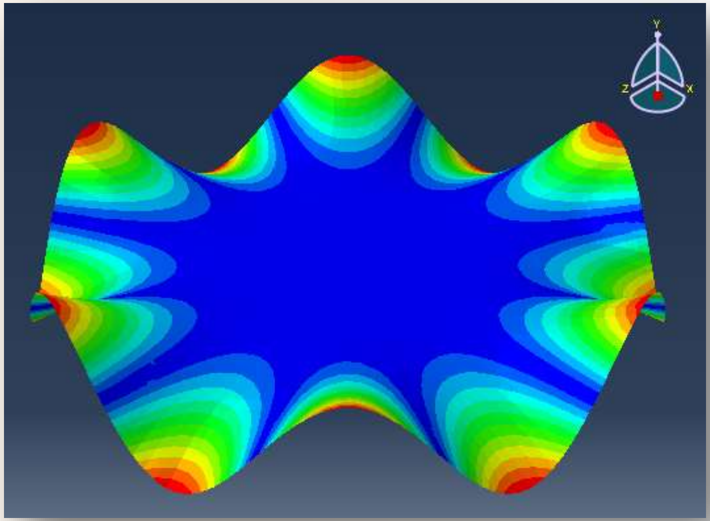
Timeline

Flight Package Design

Launch

Calibration

Operation

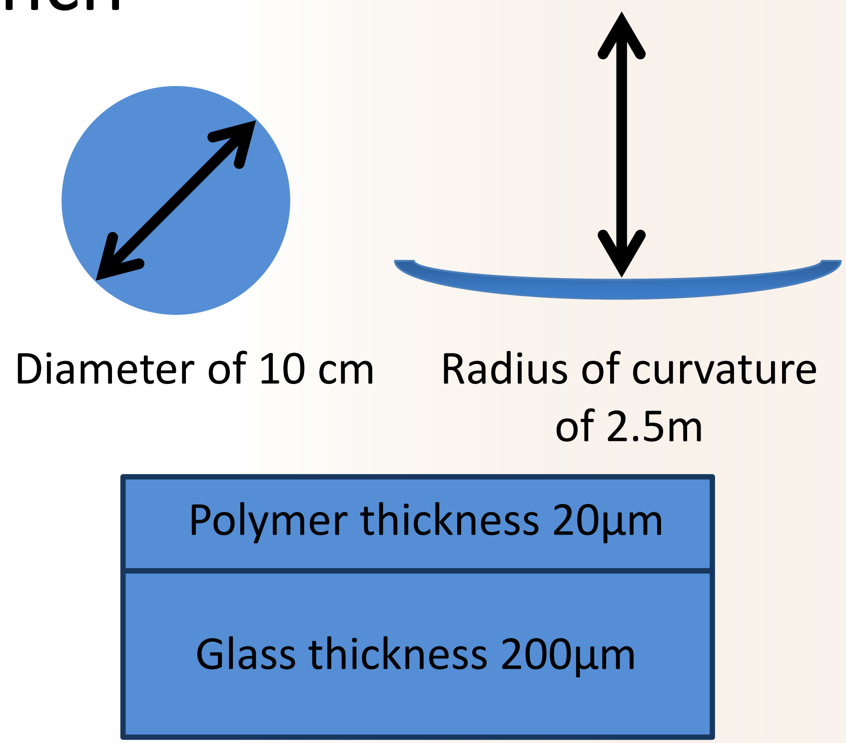


Launch Loads Analysis

Perform an FEA of the mirror to predict survivability through launch

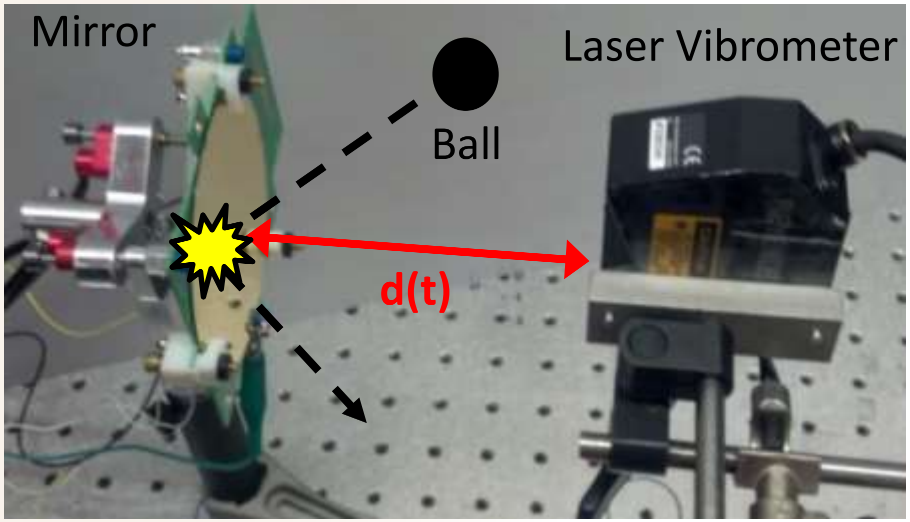
Approach:

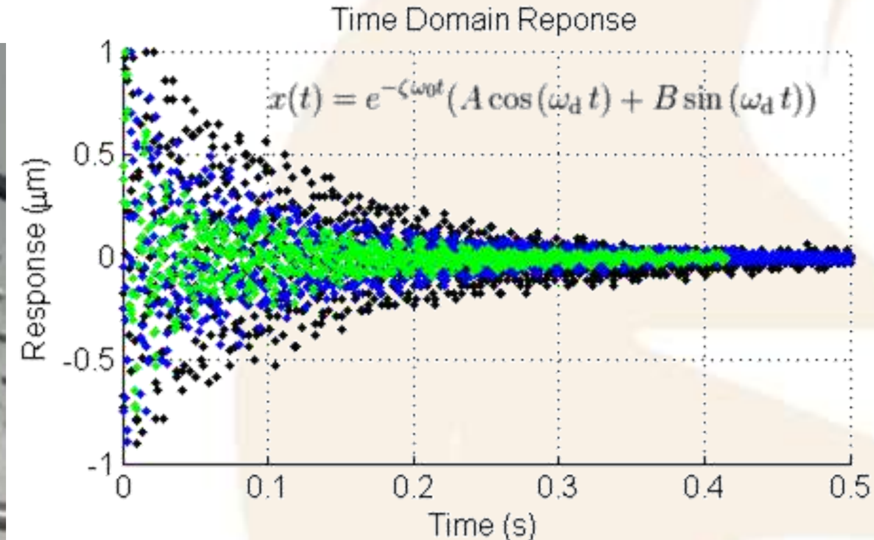
- Measure the damping
- Model the mirror in Abaqus
- Apply gravitational loads
- Apply acoustic loads
- RSS for failure prediction



Mirror Setup

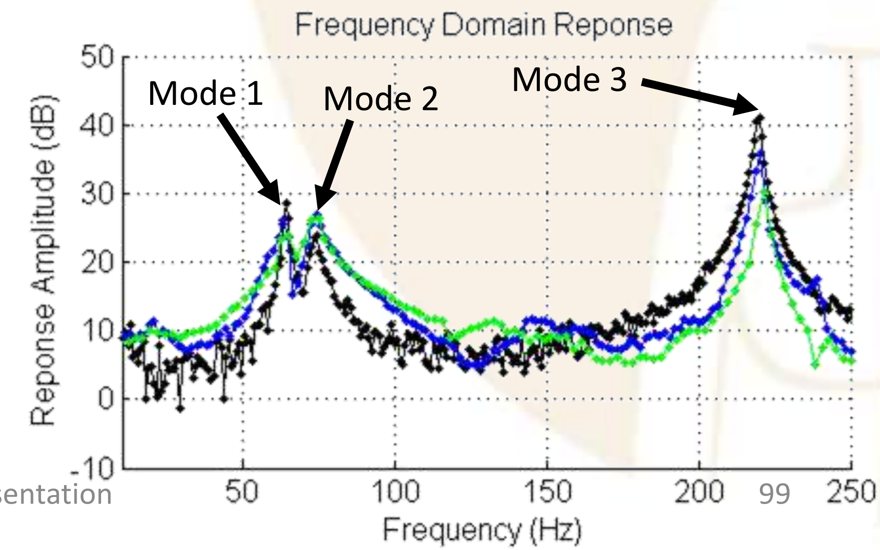
Vibrational Behavior





Substrate: Glass

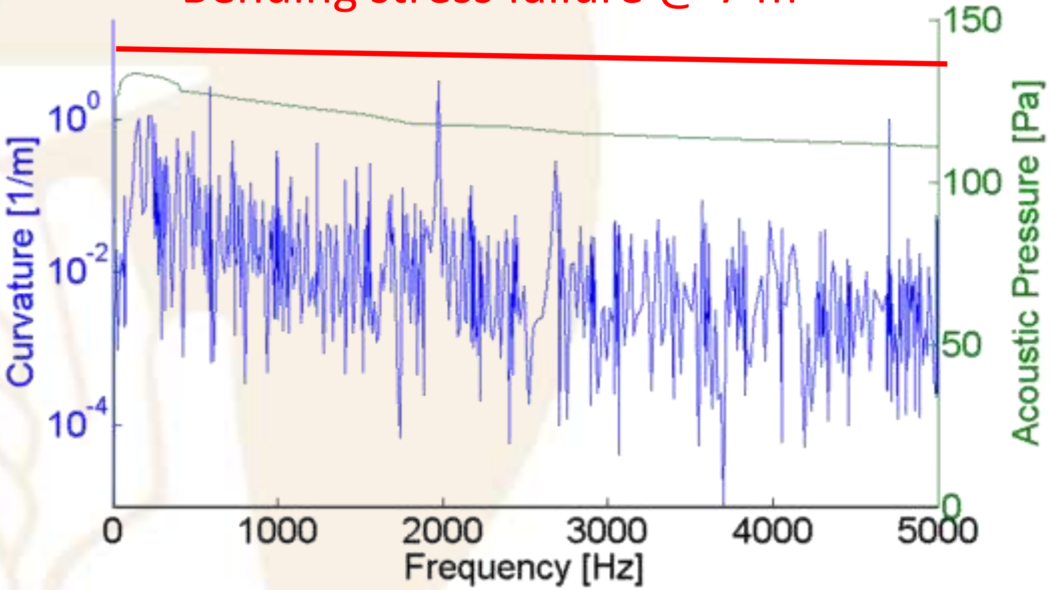
	(Experiment)	(FEM)
Damping Ratio, ζ	0.12	(0.12)
Mode 1	63 Hz	70 Hz
Mode 2	74 Hz	81 Hz
Mode 3	220 Hz	257 Hz

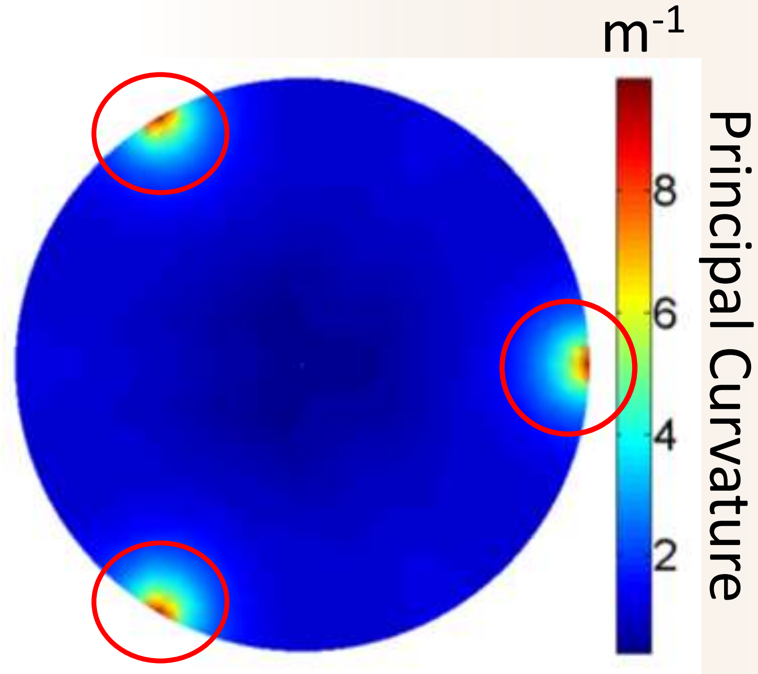


Launch Loads Analysis

- Delta IV-Heavy acoustic loads
- Clamping points are critical

Bending stress failure @ 7 m^{-1}





Frequency vs Curvature of mirror

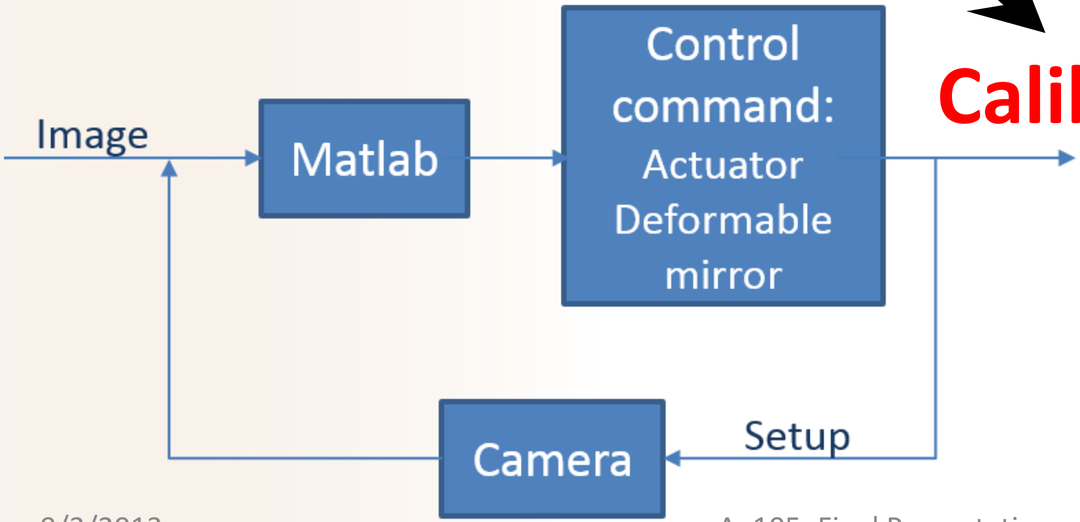
RSS of curvature over all freqs

Timeline

Flight Package Design

Launch

Calibration



Operation

Mirror Pointing and Focusing

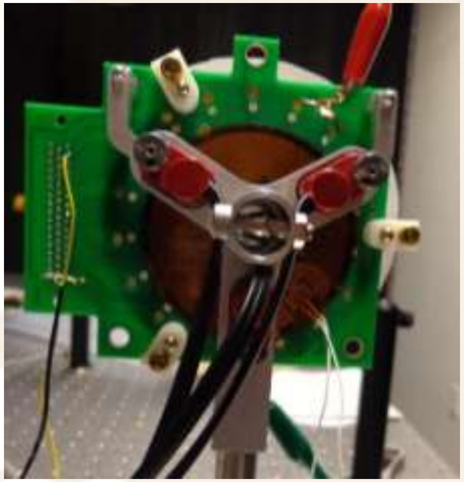


Fig 1: Actuators

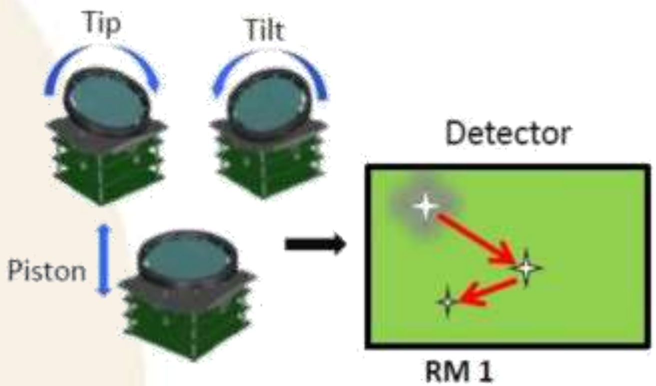


Fig 2: Degrees of freedom

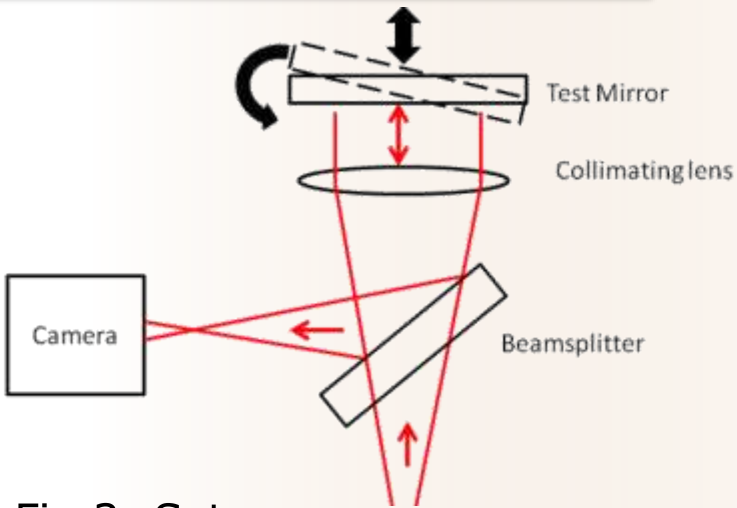


Fig 3: Setup

Approach:

Blind Search (Find spot) → **Pointing** (center image) → **Coarse Focusing** (spot radius) → **Wavefront control** (Shack Hartman sensor)

Process:

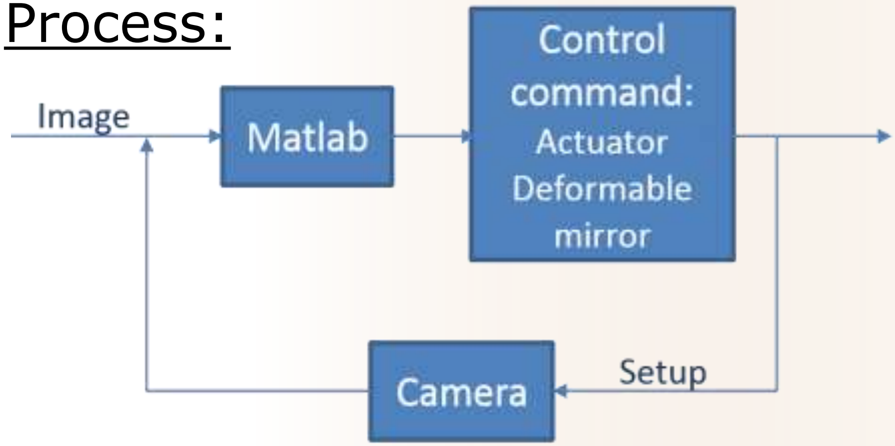
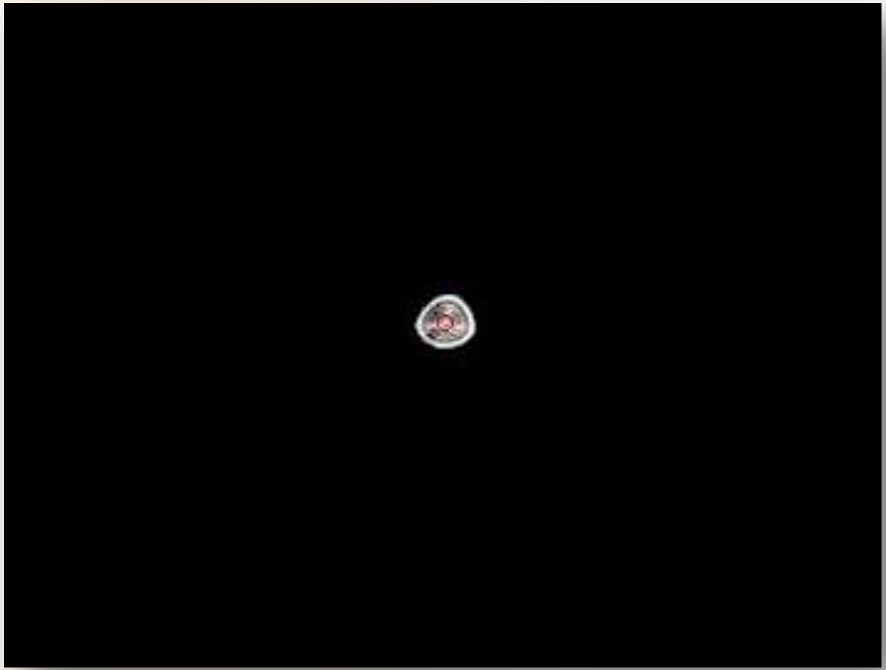


Image Processing

⇒ Automatically find position and estimate radius of the spot

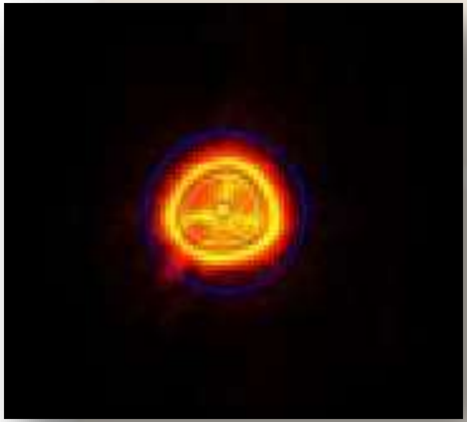
Position:

Barycenter of the intensity

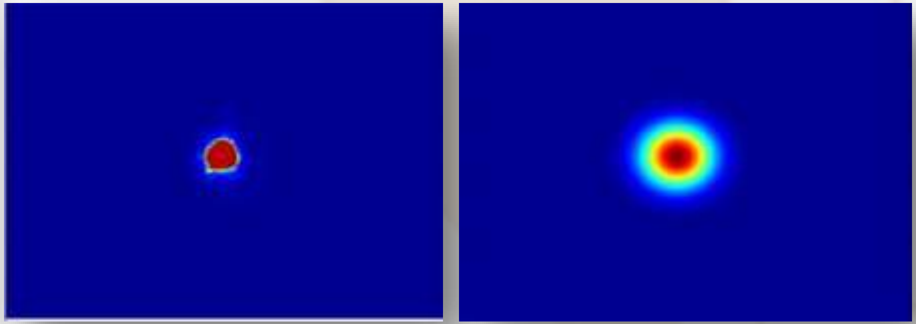


Radius: Two methods

1-Encircled Energy:



2-Gaussian fit*:



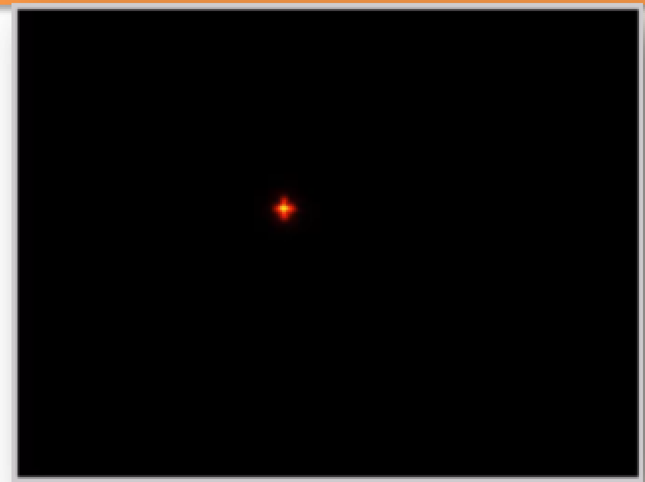
*From MatlabCentral

Blind Search

<u>Theory:</u>

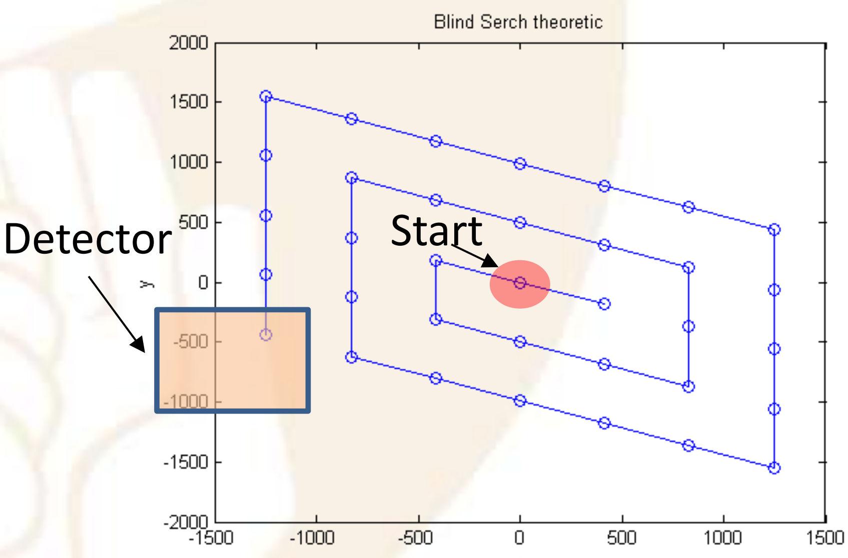
-Use an open loop

-Do a spiral path not to miss the camera

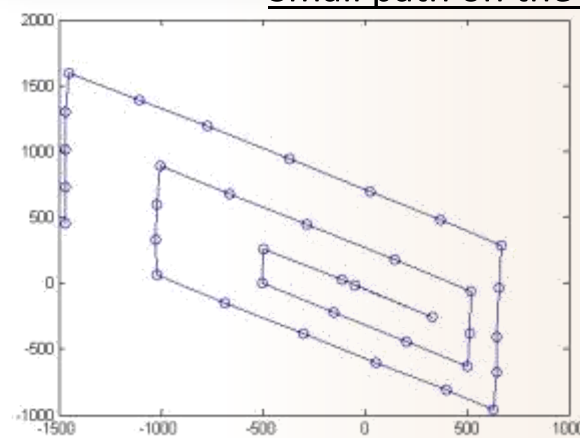


<u>Small path on the camera</u>

<u>Results:</u>



<u>Fig1: Theoretical path of the blind search</u>

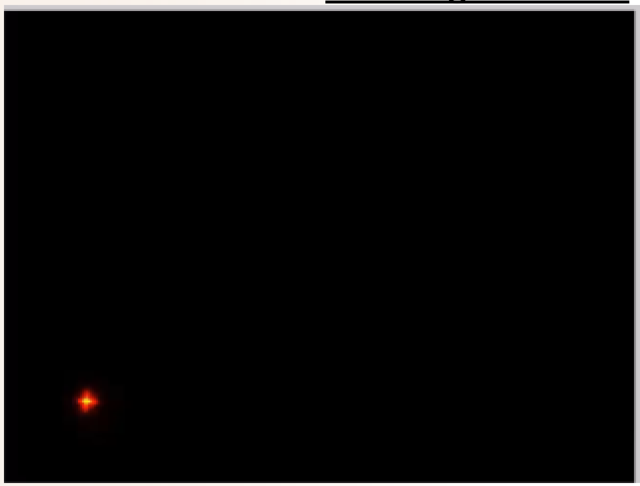


<u>Fig2: Actual path (error of the actuators)</u>

Pointing

Results:

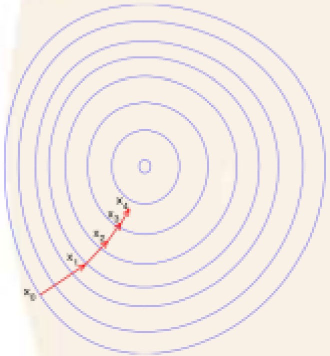
Pointing beta=0.2



Pointing beta=0.4

- **Gradient descent**

We assume that the image displacement is linear with the actuator position and we iterate.

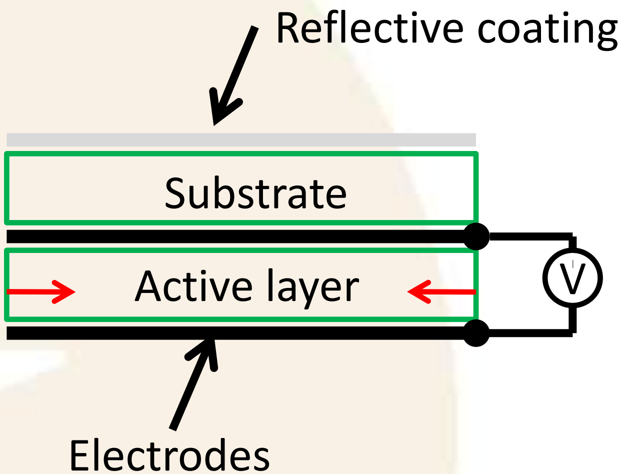


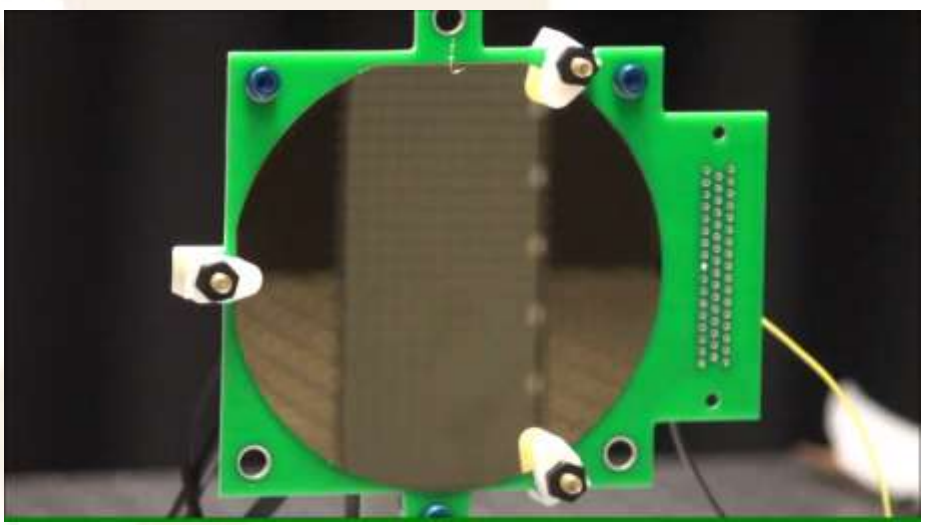
- 2 Inputs: t_B, t_C (we only need two actuators over three)
- Parameters: β step time (fix in our case)
- Unknowns X(t_B, t_C), Y(t_B, t_C)

$\Rightarrow$ Precision<50µm after 15 iterations

size of the camera : 3,6 mm *4,8 mm

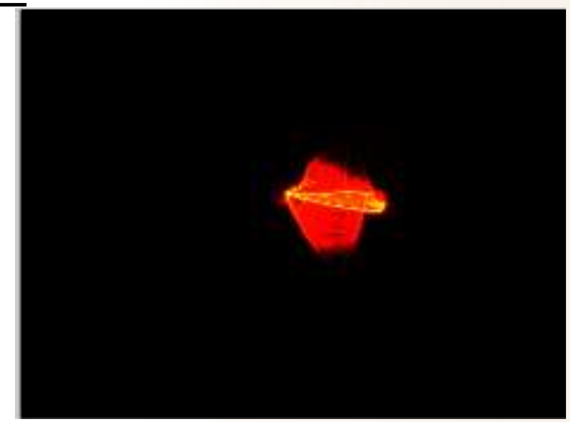
Coarse Focusing

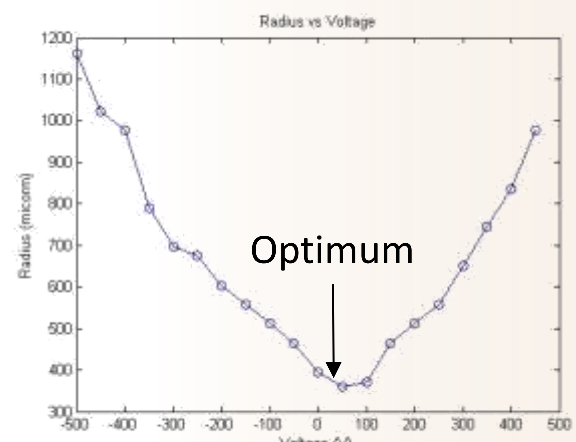




⇒ Scan through -500V to 500V and find the minimum spot size.

<u>Results:</u>





⇒ Precision < 410 um

Timeline

Flight Package Design

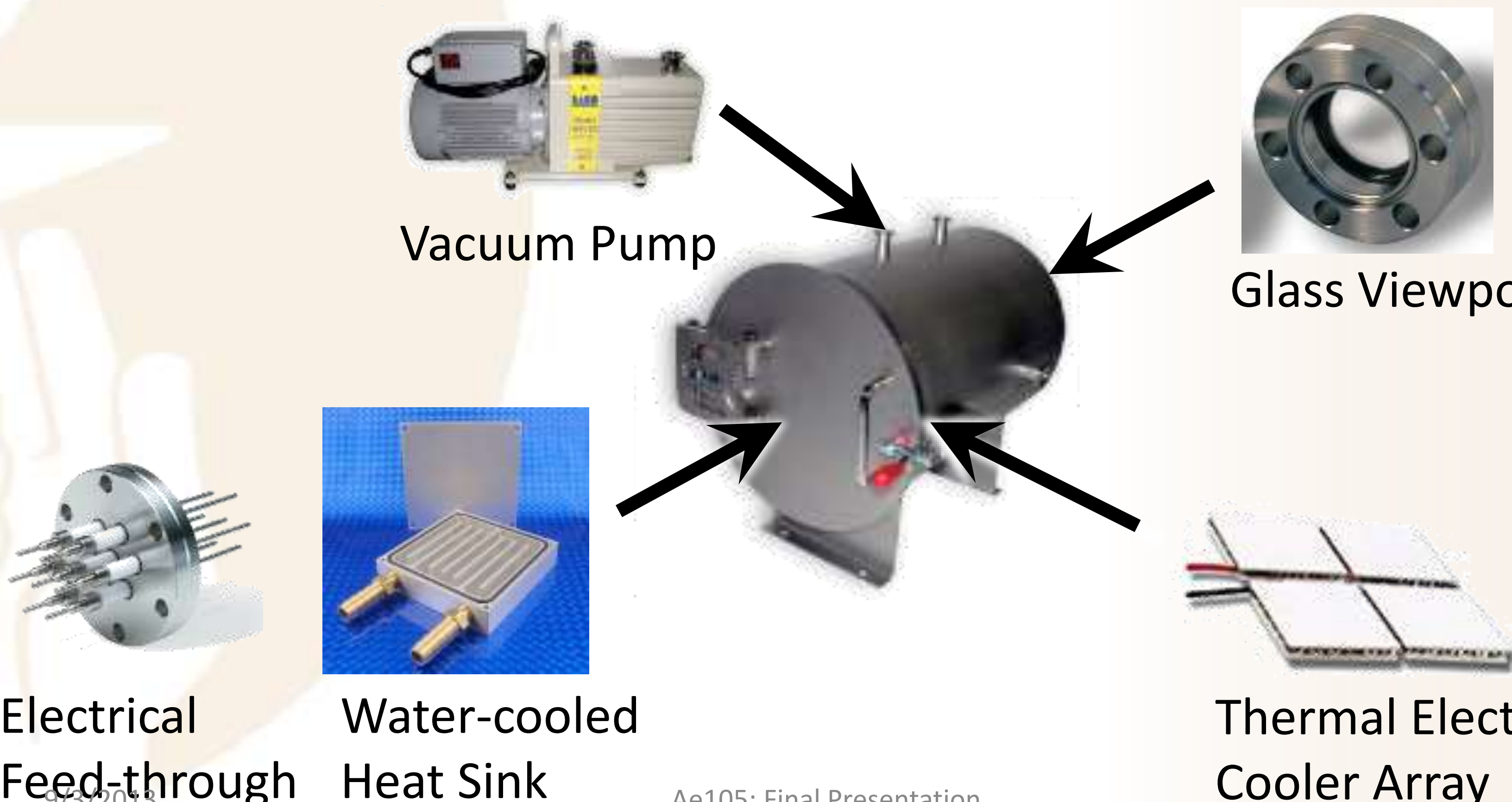
Launch

Calibration

Operation

Operation: Thermal Test Design

Design a vacuum test chamber that will simulate the space environment



Conclusion

Mirror Flight Package

- Preliminary package design complete
- Redesign mirror clamps to prevent cracking during launch
- Update design as needed

Finite Element Analysis of Mirror

- FEM of gravitational and acoustic pressure loads complete
- Experimental shock test to be performed
- Natural frequencies show possible resonance with reaction wheel

Conclusion

<u>Calibration</u>

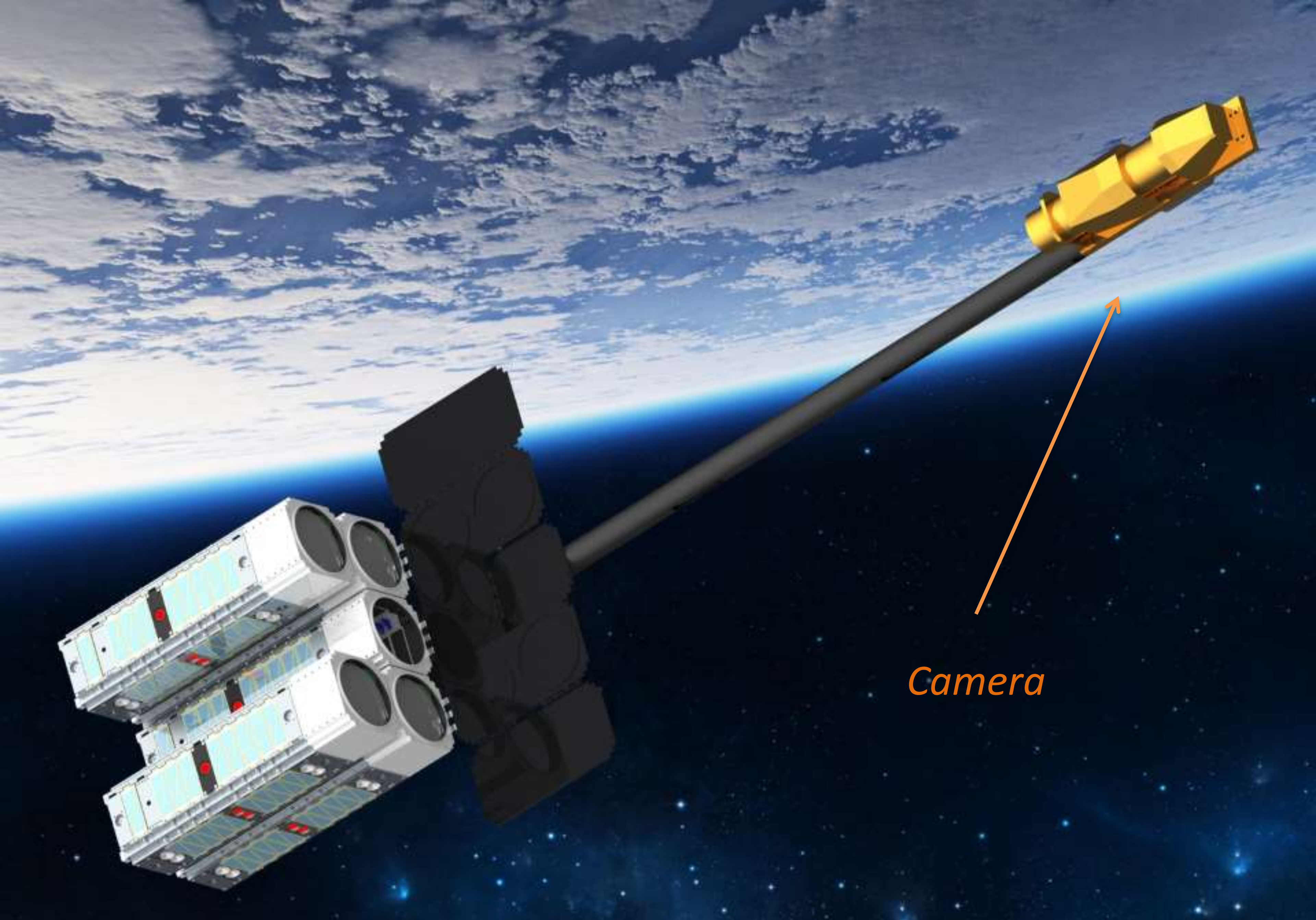
- Algorithms implemented
- Speed of the algorithm can be improved
- Actuator choice re-evaluation may be necessary
- Use several voltages to deform the mirror
- Modify algorithms for several mirrors

<u>Thermal Test Design</u>

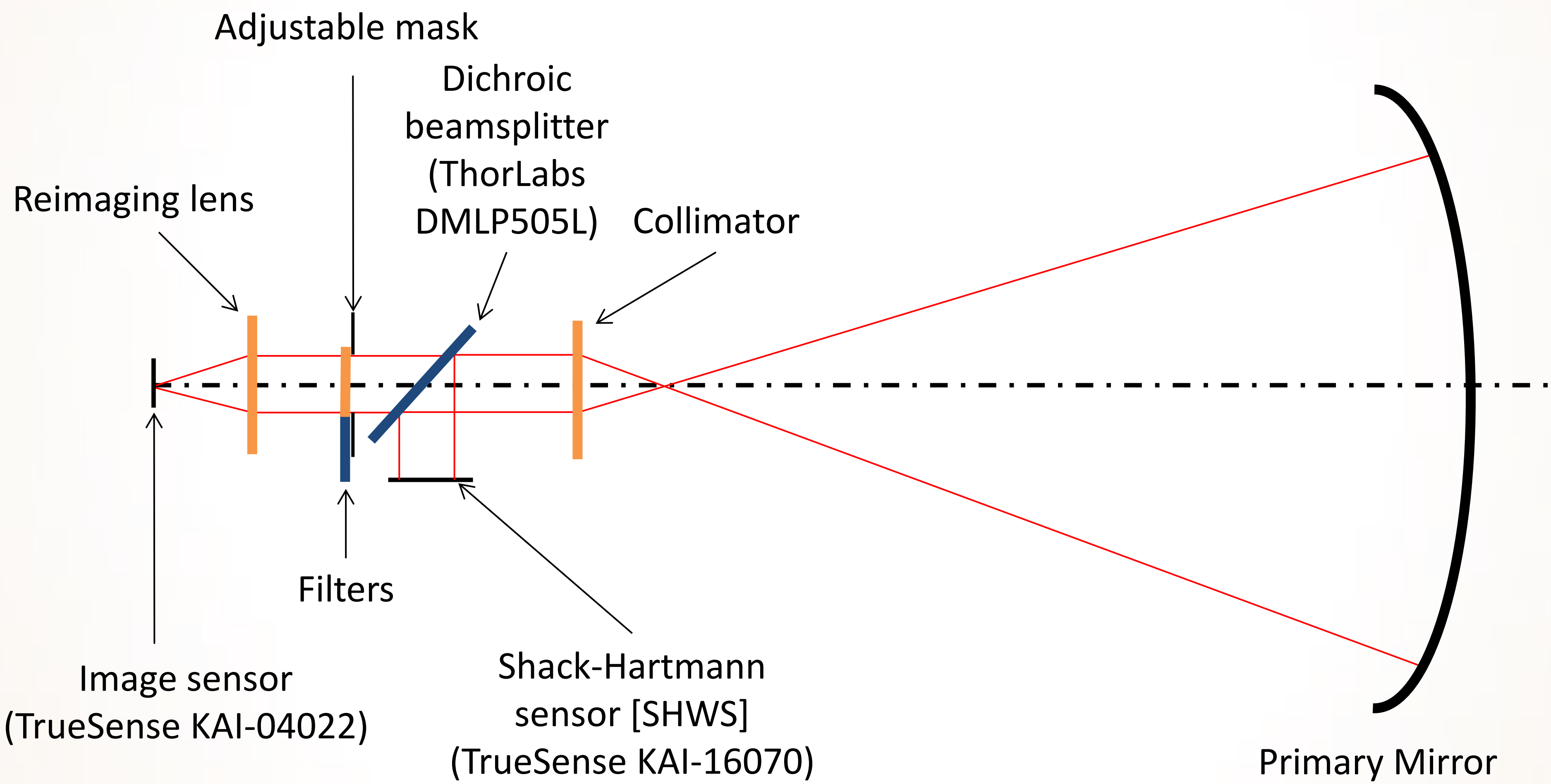
- Preliminary components identified
- Interfacing plates between mirror package and chamber to be designed
- Chamber to be built this summer

Optics

Altemurcan K. Kursunlu
Mary Nguyen
(Mentor: Manan Arya)


Camera

Overall Camera Setup



2013 Goal

Improve on last year's work, especially by addressing complexity.

- Lens Prescription
- Mechanical Design
- Data Analysis

Trade-Offs: A Second Look

1 deg FOV

f/2

Large Bandwidth

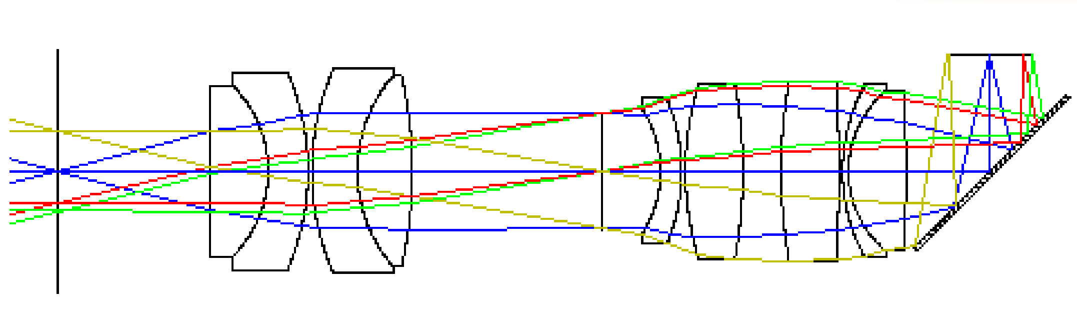
10 cm x 10 cm x 40 cm

Reasonable lenses

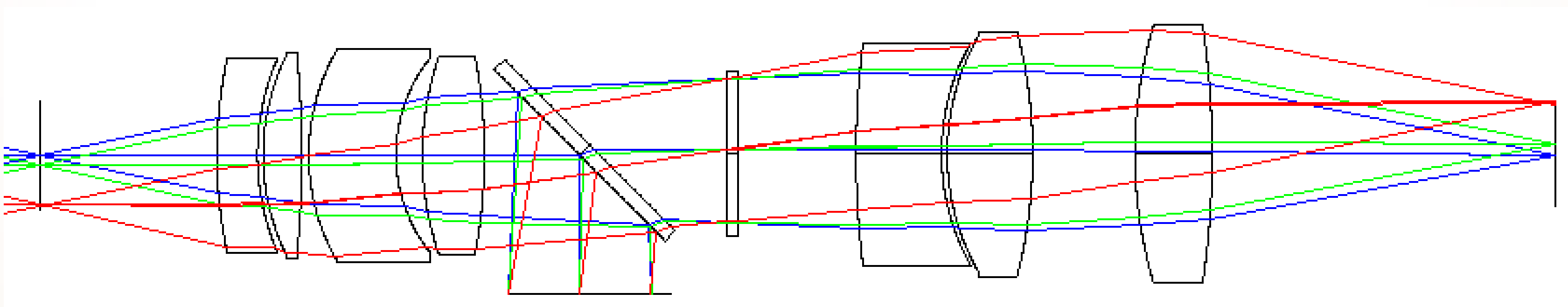
4.0 kg

Lens Prescription

2012



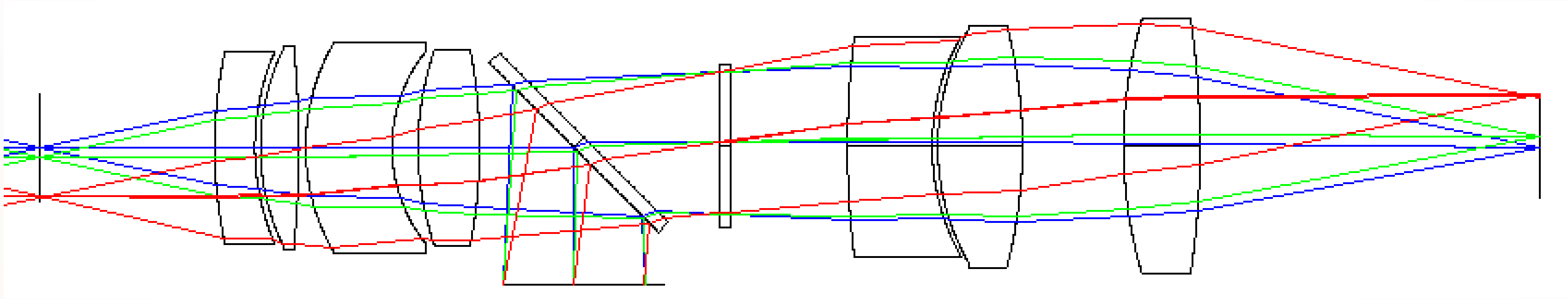
2013



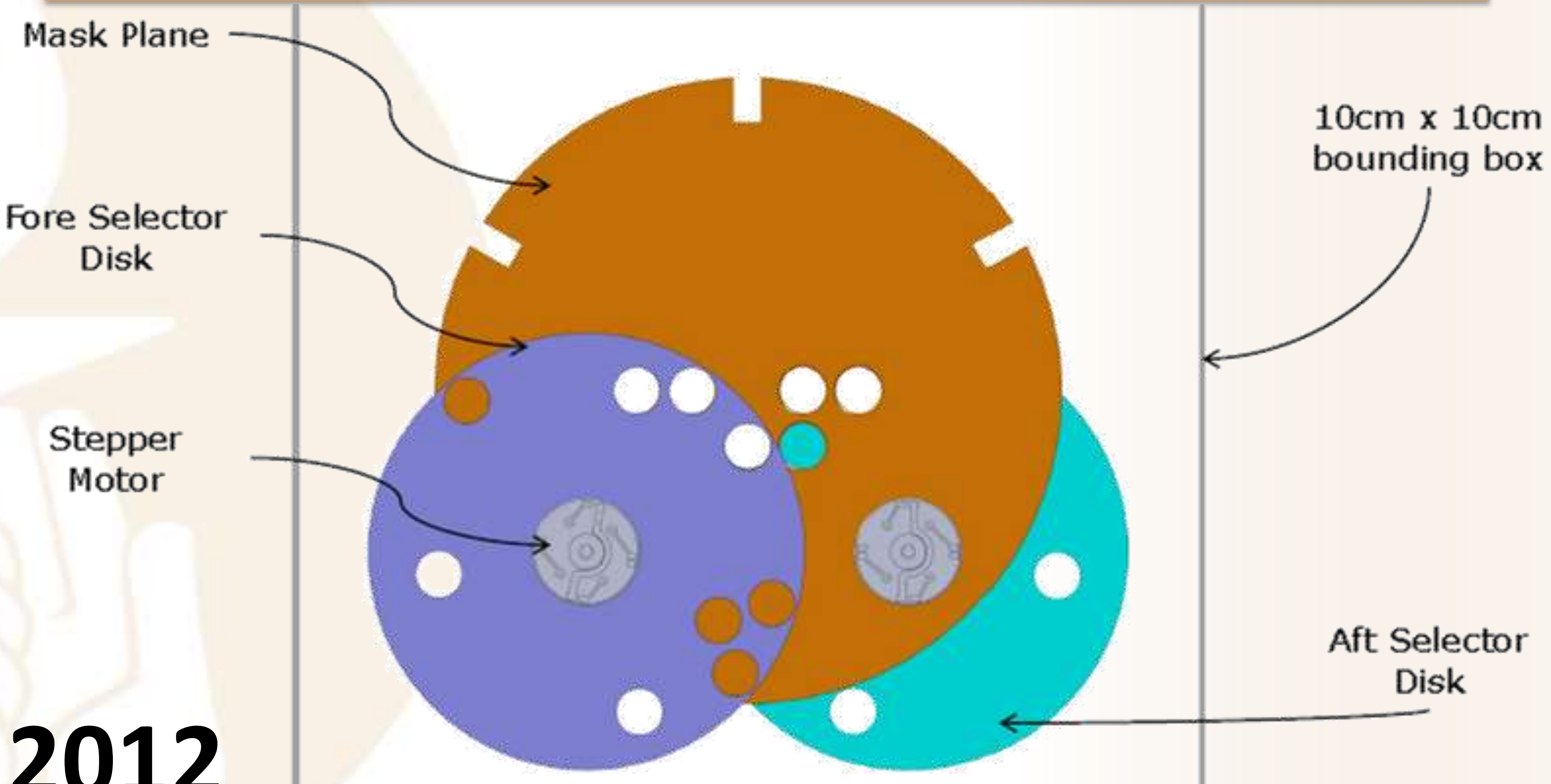
Lens Prescription

2013

Characteristic	2012	2013
Mass (Collim. + Reimag. lenses)	526.240 g	561.062 g
Total Length (from Prime Focus)	264.4 mm	318.8 mm
# Lenses + Filters	10	9
# Cemented Doublets	3	0
Min Abs. Curvature	26.984 mm	32.717 mm
Max. Cost Rel. to BK7	16.20	3.00
# Moving Parts	2	1



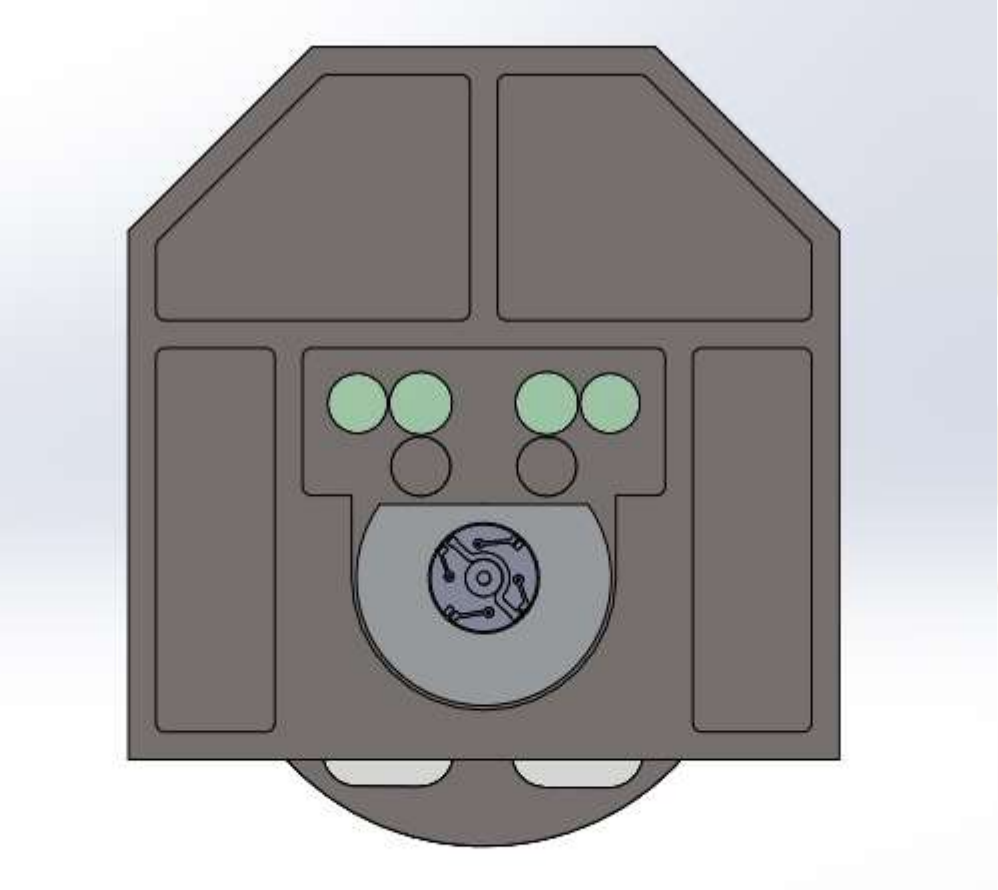
Mask Design- Last Year



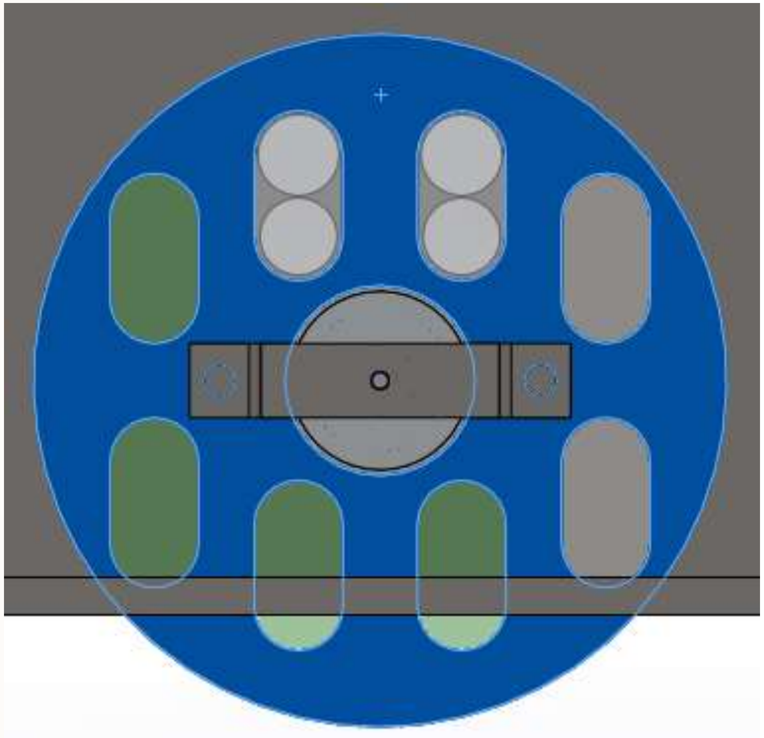
2012

Mask Design

- One fixed mask and a filter wheel
- Why do we need a fixed mask?
- Stepper Motor activated
- Four modes:
  - Two pupil modes
    - Wide/narrow
  - Two bandpass modes
    - Filter/glass
- Latching mechanism

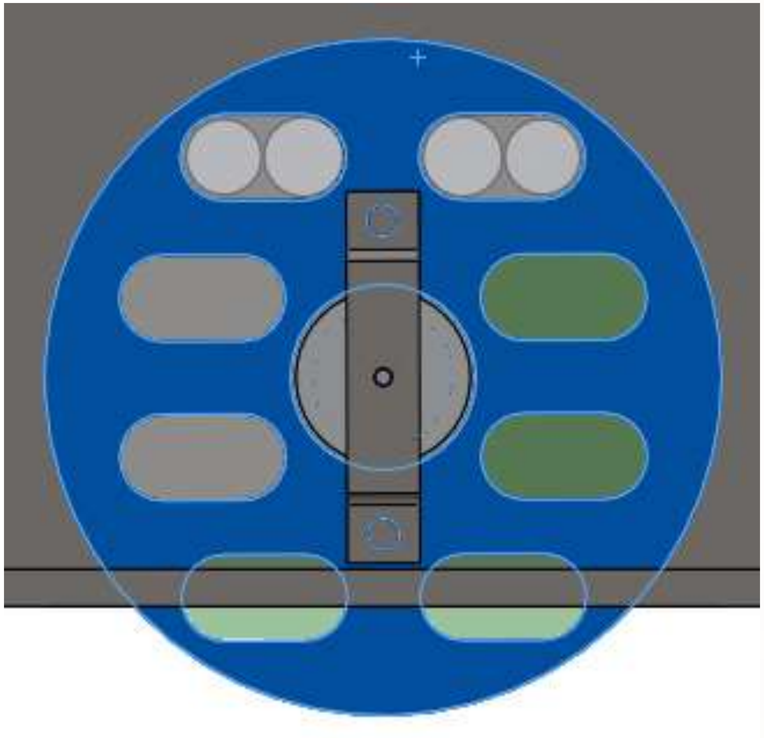


Mask Design



Narrow Pupil Configuration

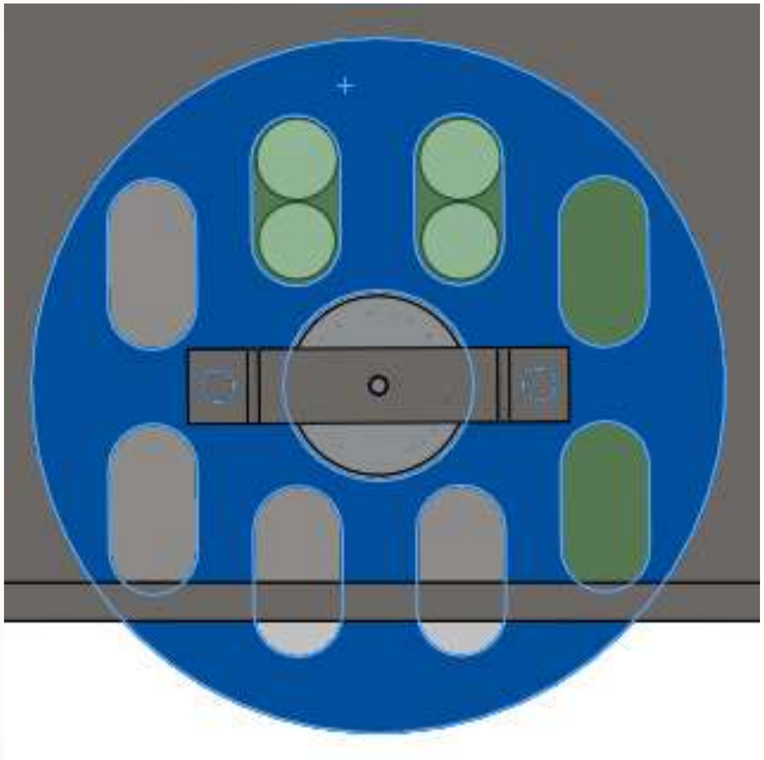
Pointing Bandpass



Wide Pupil Configuration

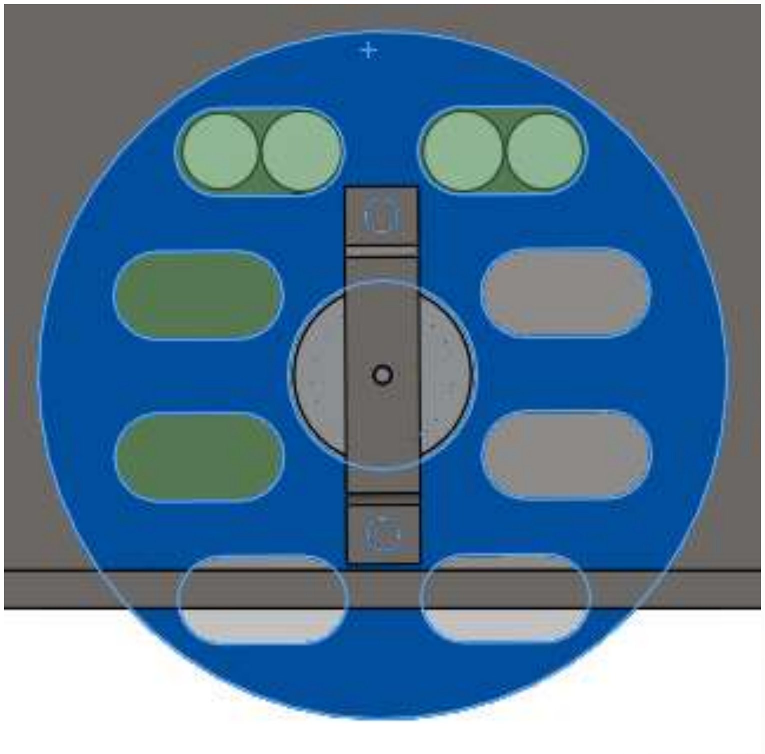
Pointing Bandpass

Mask Design



Narrow Pupil Configuration

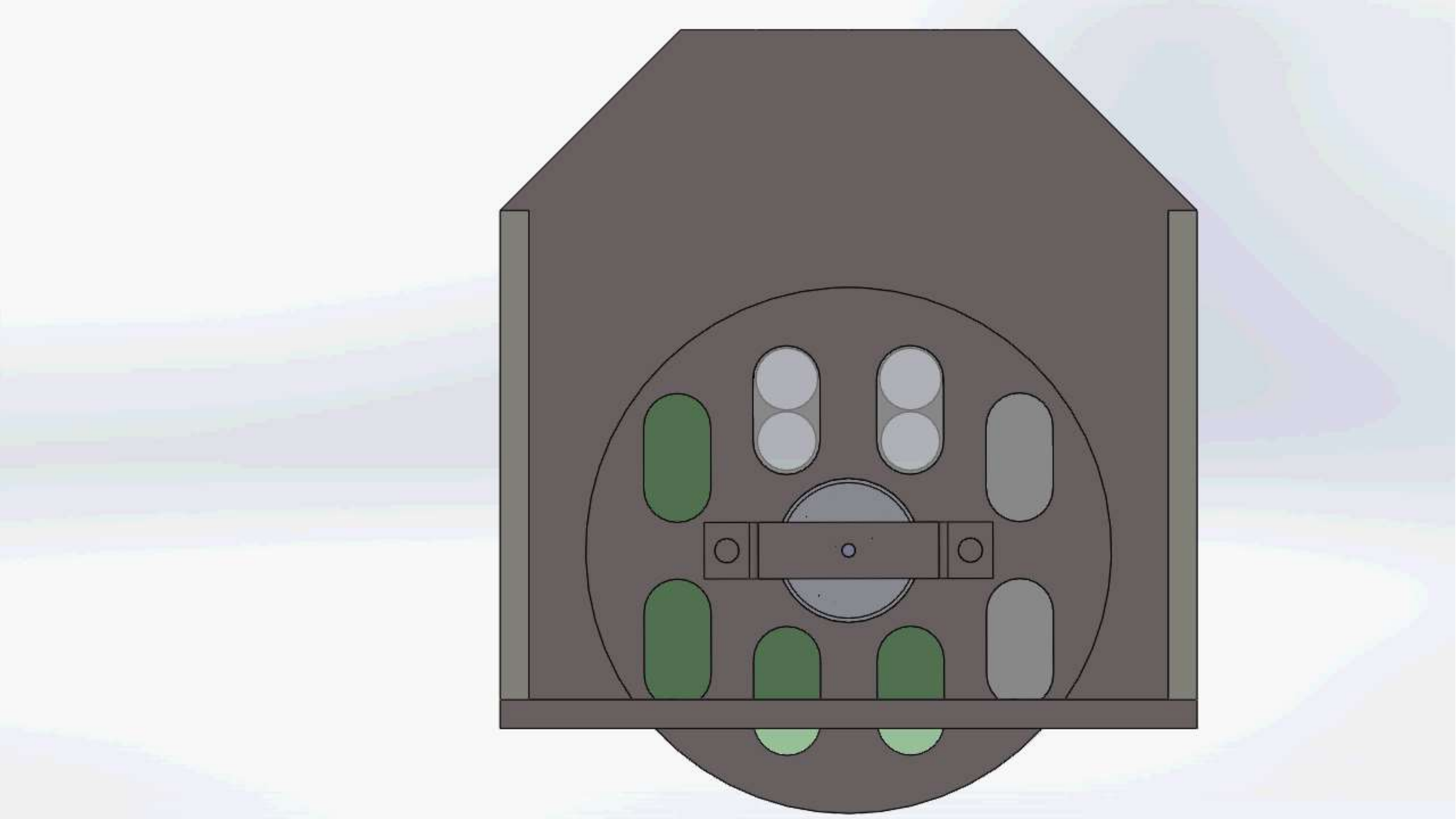
Imaging Bandpass



Wide Pupil Configuration

Imaging Bandpass

Mask Design



Mask Design- Last Year

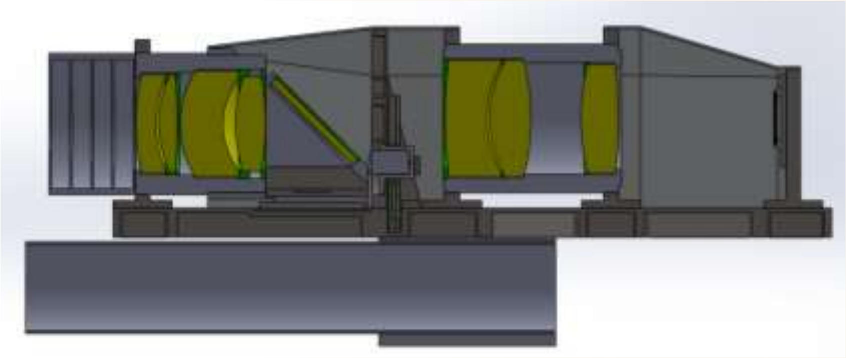
- Different objectives

Criterion	2012	2013
Number of modes	Individual hole pattern	Four modes
Number of stepper motor	2	1
Number of disks	3	2
Mass	106.5 g	141.2 g
Energy Consumption	1.2 W	0.6 W

- Less complicated design

Conclusions

- Constraints met:
  - Mass: 2.8 < 4.0 kg
  - Power: 3.4 < 4.0 W
  - Volume: 320mm x 80mm x 80 mm
- Imaging Performance:
  - 80% encircled energy: 8.589 um (Dif Limit: 5.58 um)
  - SHWS Wavefront Error: 2.7457 waves P2V / 0.6335 waves RMS
- **Cheaper, and simpler!**



Future Work

- Structural analysis to survive launch and deployment loads
- Thermal analysis
- Tolerancing
- More detailed mechanical design
- Electronics design
- Machine and test components

Concluding Remarks

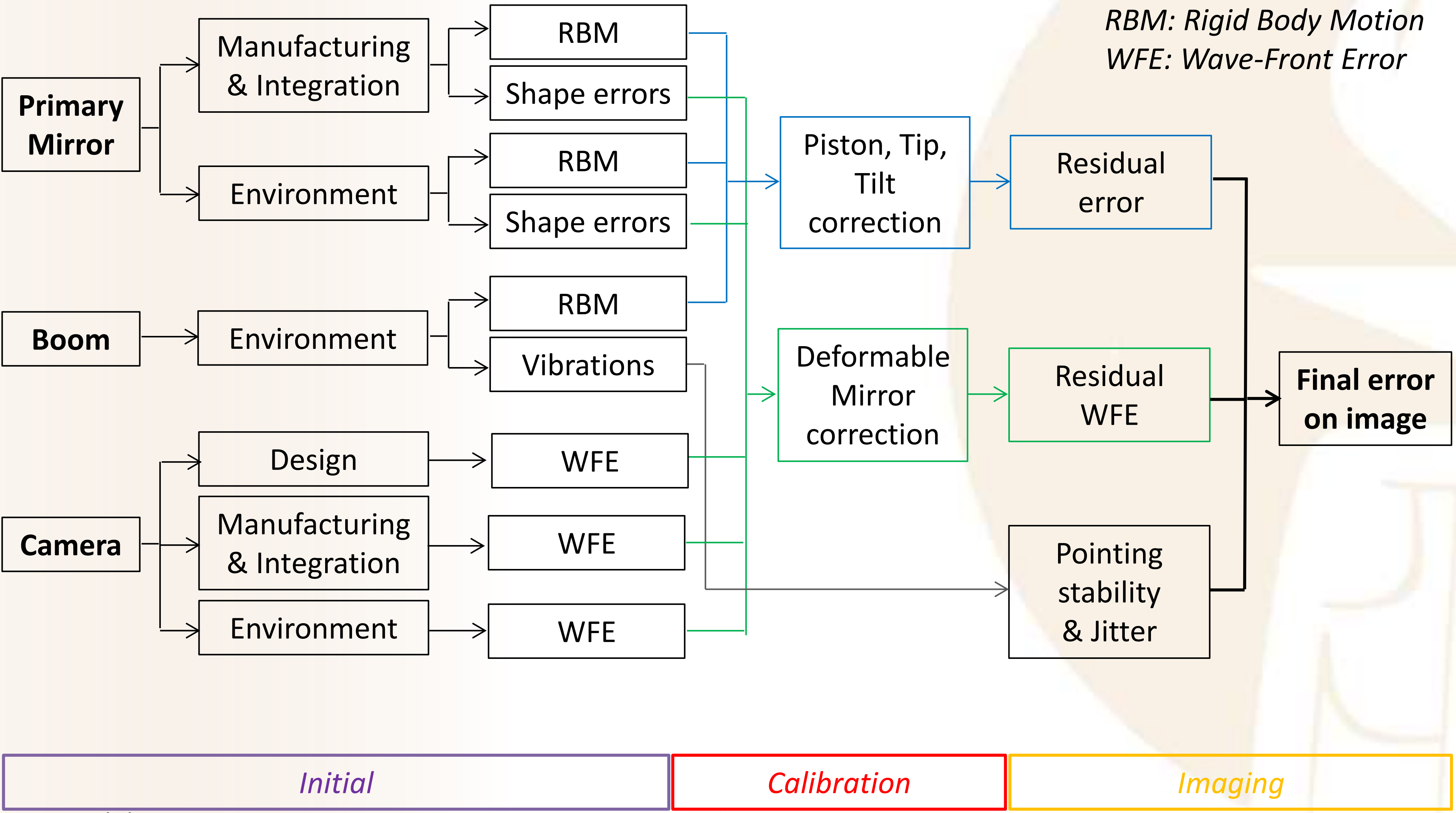
John Steeves

2012/2013 Project Tasks

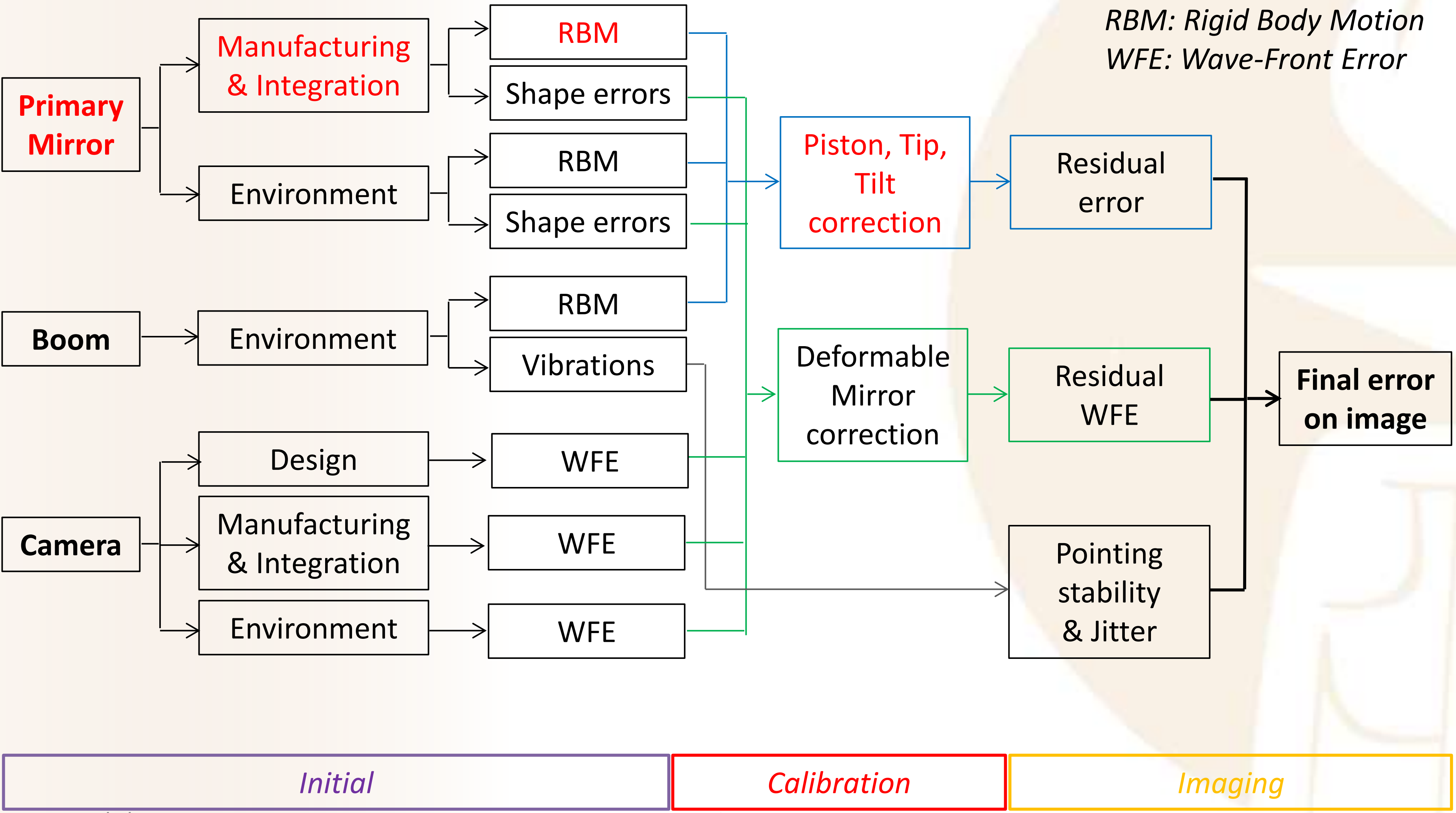
- Thermal environment
  - Thermal profiles obtained for a number of orbits/orientations
- External/Internal disturbances
  - Quantification of S/C response to disturbances (pointing stability)
- Deployable boom
  - Characterization of deployment process
  - Determination of deployed properties
- Deformable mirrors
  - Design of flight package
  - Coarse focusing algorithms
- Camera design
  - Optimized design of corrective lenses
  - Opto-mechanical design of masking mechanism

Error Budget

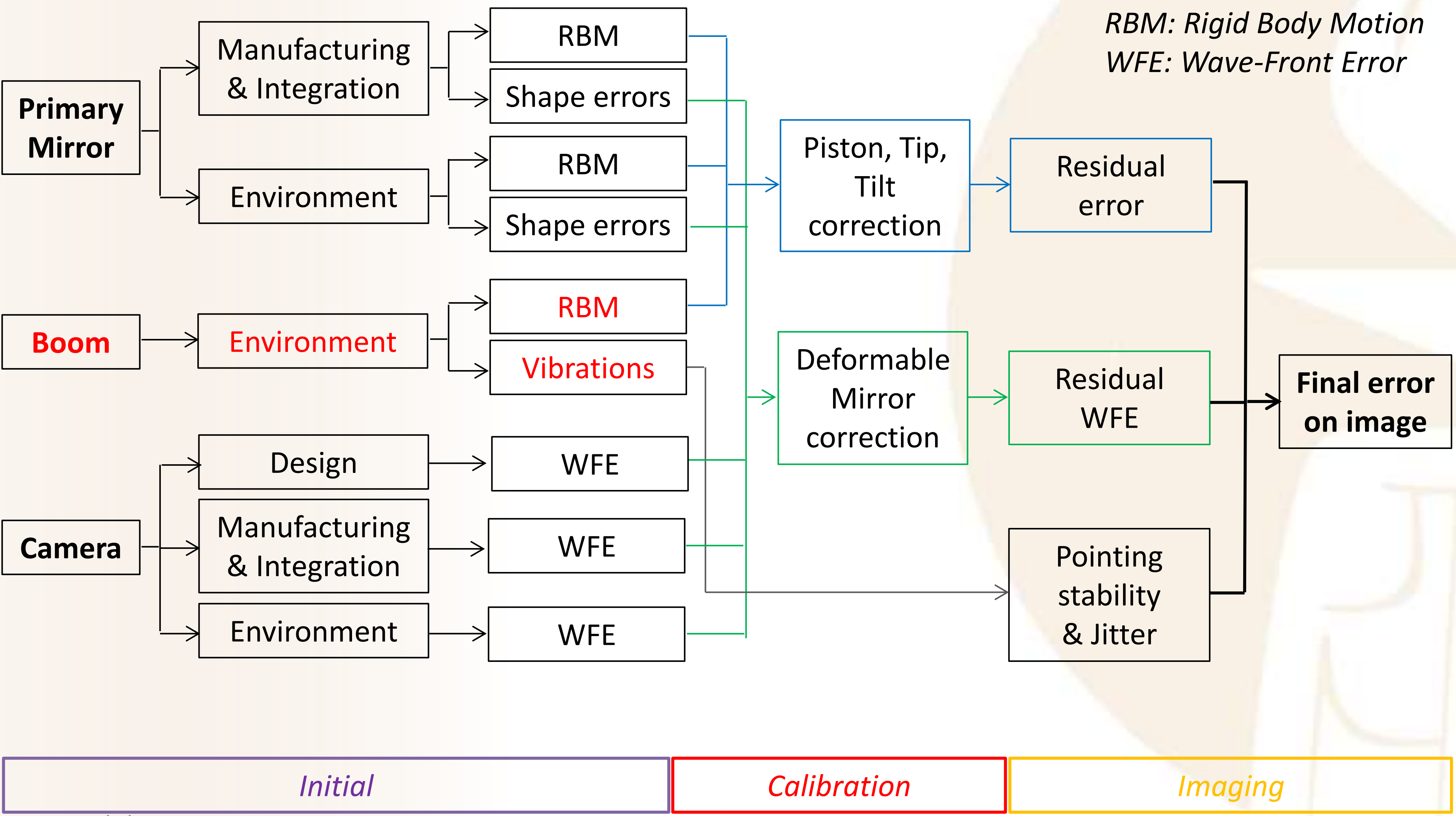
RBM: Rigid Body Motion
WFE: Wave-Front Error



Error Budget

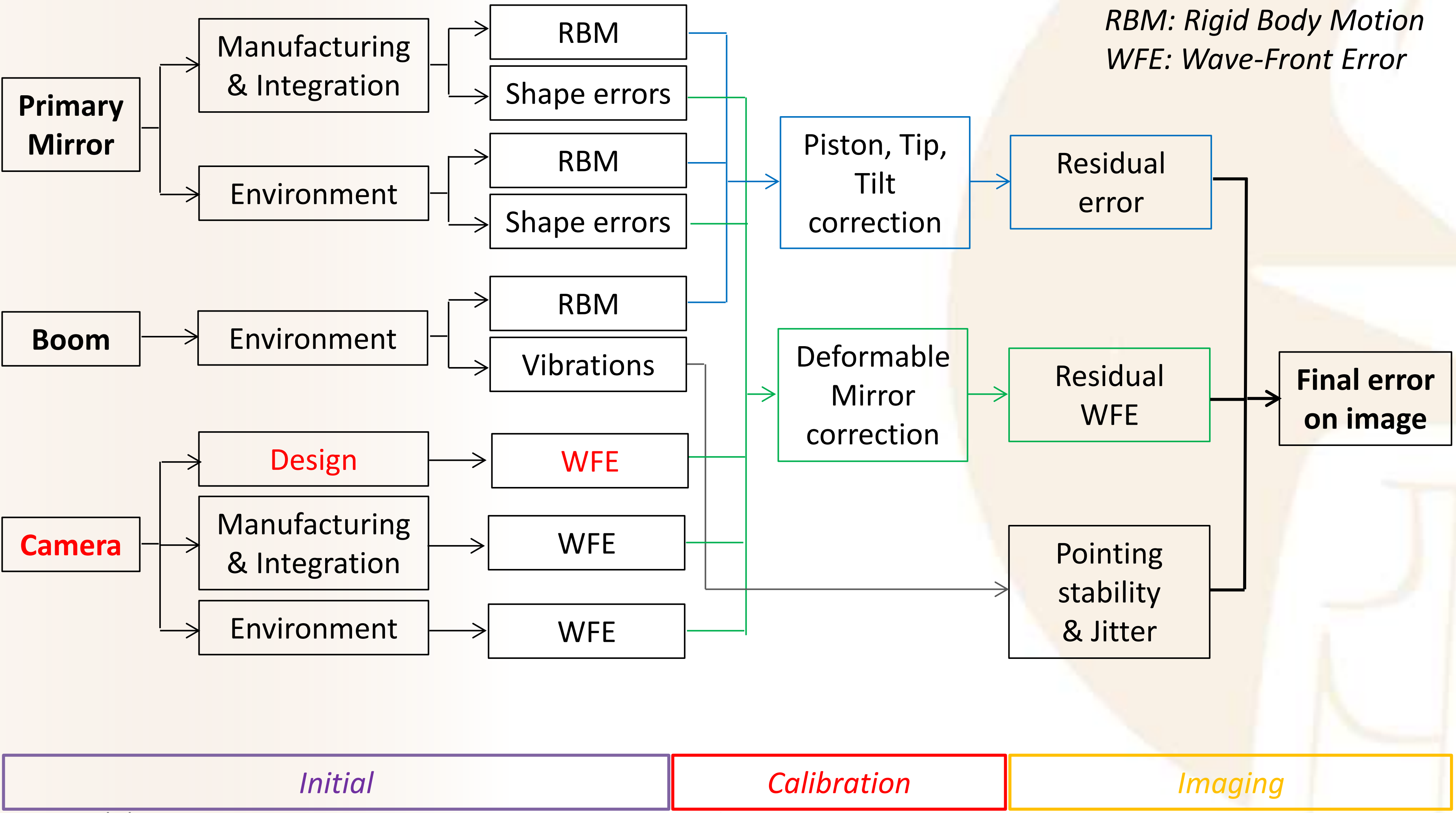


Error Budget



Error Budget

RBM: Rigid Body Motion
WFE: Wave-Front Error



Questions?