Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

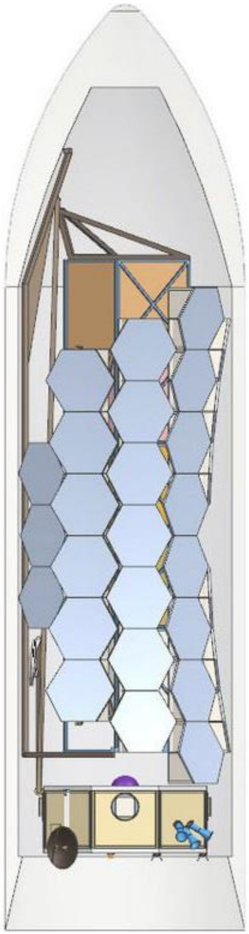
Mission Overview

Maria Sakovsky

Building Large Space Telescopes

- Mirror dia. of current and planned space telescopes limited by constraints of a single launch
  - Hubble (1990): Ø 2.4 m
  - JWST (2018): Ø 6.5 m
  - HDST (2030+): Ø 11.7 m
- New paradigms needed for Ø 30 m+ segmented primary:
  - Autonomous assembly in orbit
  - Active ultralight mirror segments
- Active mirrors relax tolerances for assembly and manufacturing, correct thermal distortions
- Modular, robust, low-cost architecture

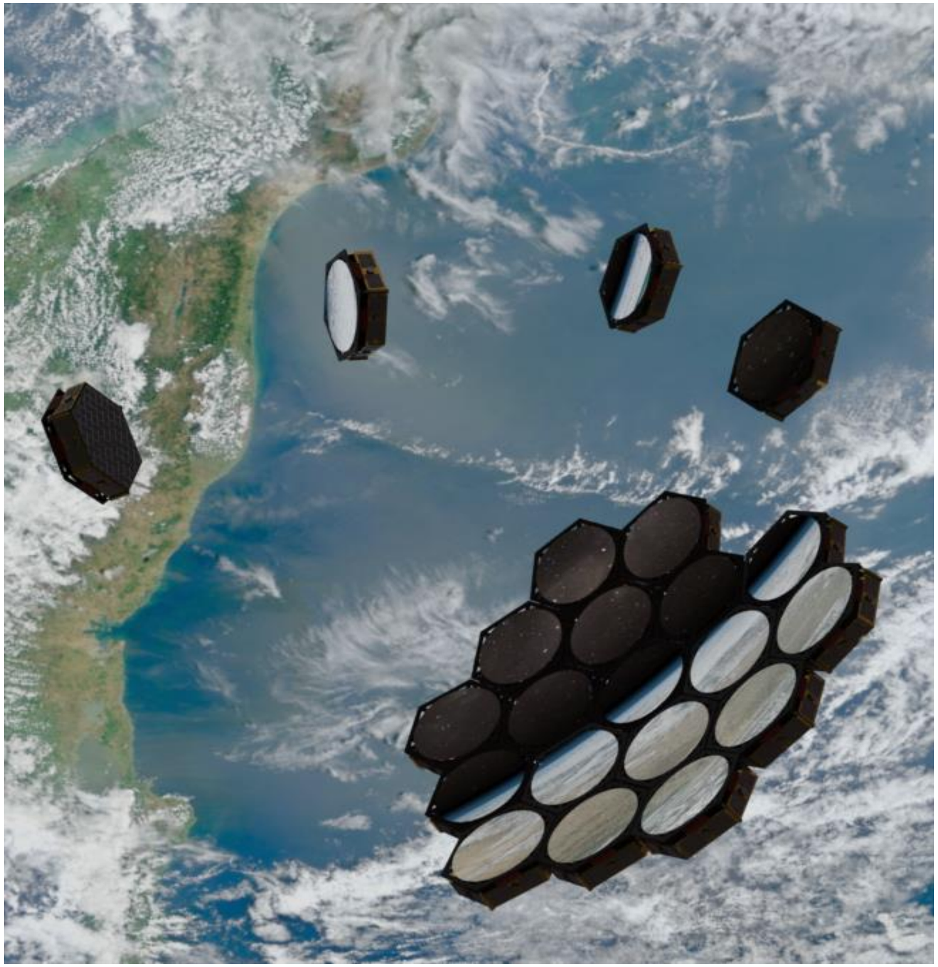
JWST



HDST

Building Large Space Telescopes

- Mirror dia. of current and planned space telescopes limited by constraints of a single launch
  - Hubble (1990): Ø 2.4 m
  - JWST (2018): Ø 6.5 m
  - HDST (2030+): Ø 11.7 m
- New paradigms needed for Ø 30 m+ segmented primary:
  - Autonomous assembly in orbit
  - Active ultralight mirror segments
- Active mirrors relax tolerances for assembly and manufacturing, correct thermal distortions
- Modular, robust, low-cost architecture



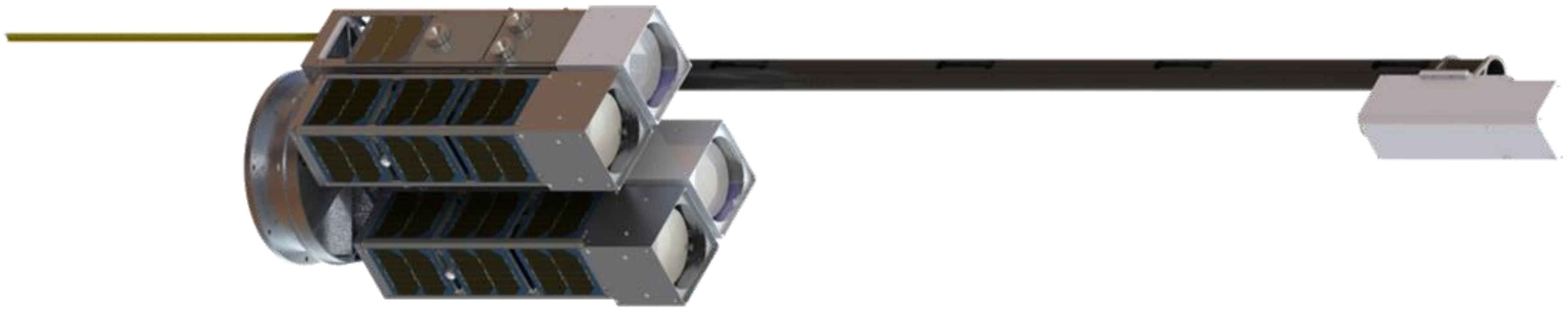
Caltech

AAReST Objectives

- Demonstrate key technologies:
  - Autonomous assembly and reconfiguration of modular spacecraft carrying mirror segments
  - Active, lightweight deformable mirrors operating as segments in a primary
- Operate for as long as necessary to accomplish the objectives (~90 days)
- Gather engineering data to enable development of the next system

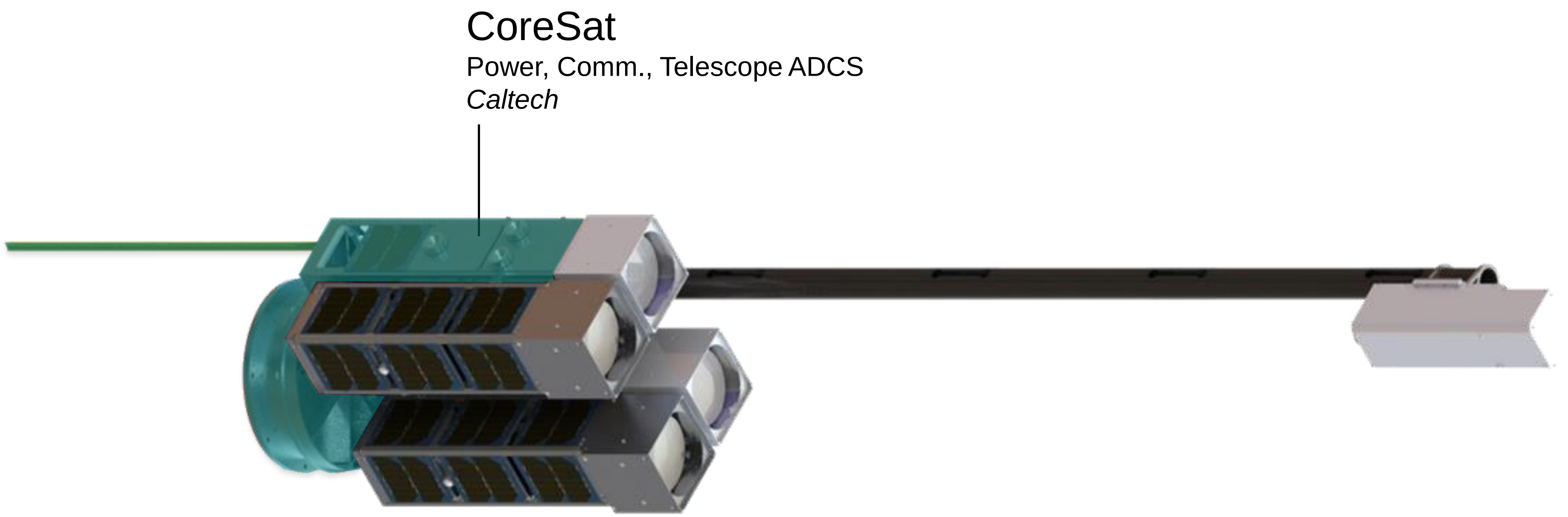
Caltech

AAReST Spacecraft



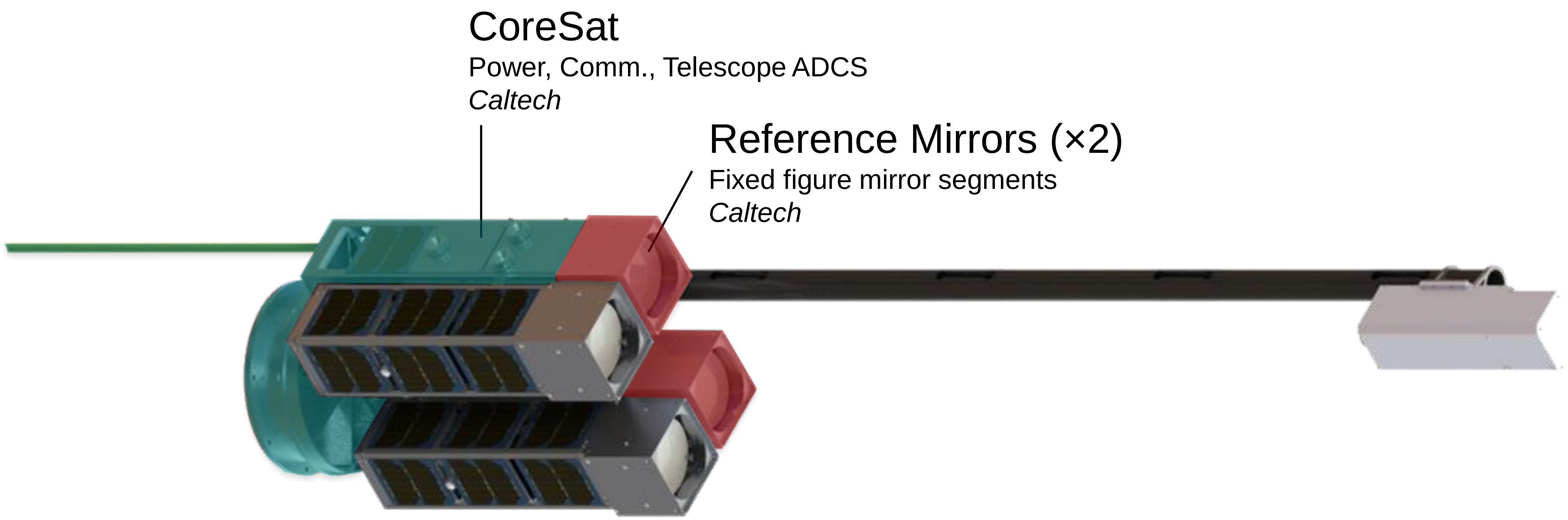
Caltech

AAReST Spacecraft

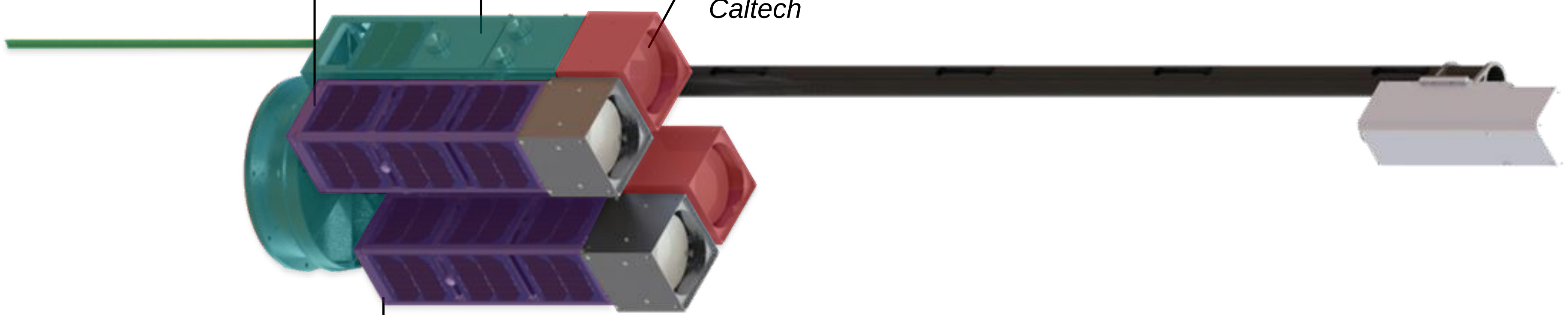


Caltech

AAReST Spacecraft



AAReST Spacecraft



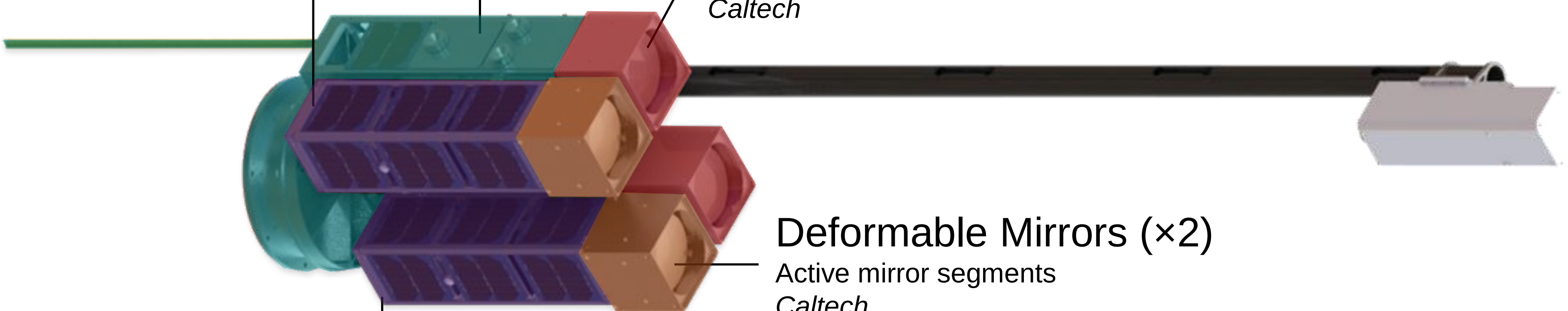
Caltech

AAReST Spacecraft

MirrorSat (×1)
Reconfigurable free-flyers
U. of Surrey

CoreSat
Power, Comm., Telescope ADCS
Caltech

Reference Mirrors (×2)
Fixed figure mirror segments
Caltech

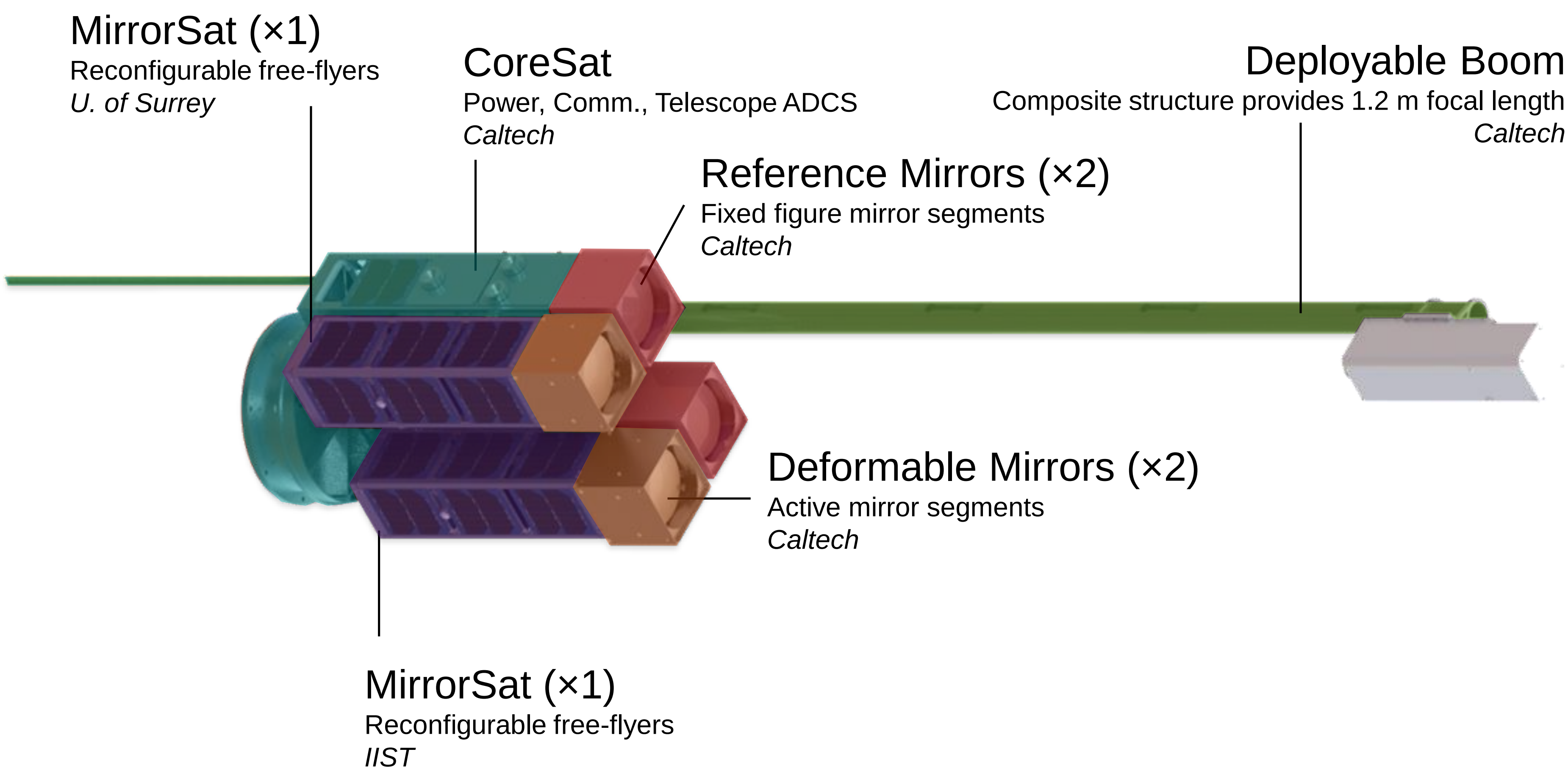


Deformable Mirrors (×2)
Active mirror segments
Caltech

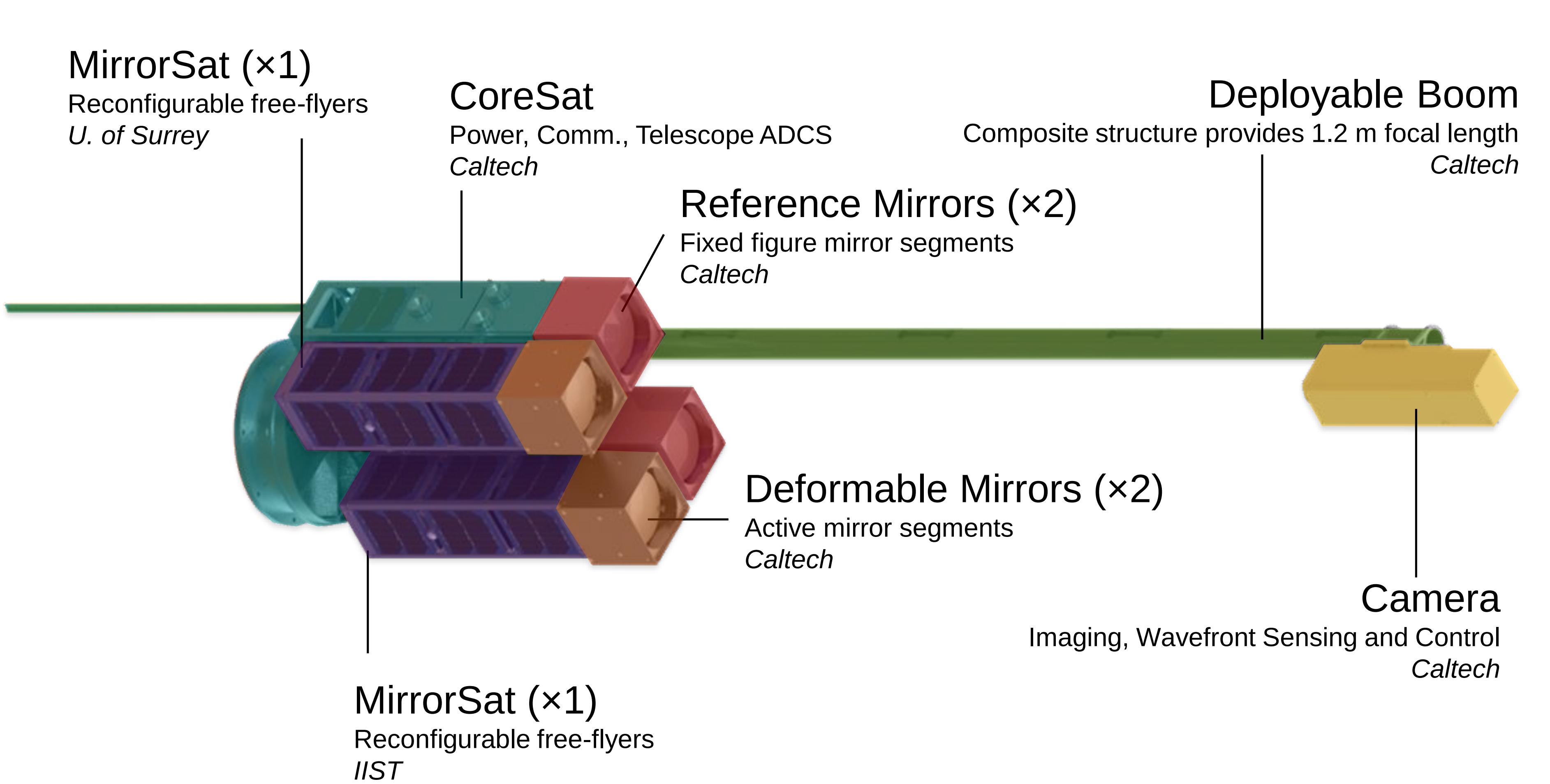
MirrorSat (×1)
Reconfigurable free-flyers
IIST

Caltech

AAReST Spacecraft



AAReST Spacecraft



Caltech

Mission Requirements

- Minimum mission
  1. Produce one focused image from a deformable mirror
     - 80% encircled energy radius from point source < 25 μm
  2. Perform at least one in-flight autonomous spacecraft reconfiguration maneuver to demonstrate space assembly capability
- Extended mission
  1. Produce one focused image from a deformable mirror after reconfiguration
  2. Coalign images to improve SNR and demonstrate precursor to co-phasing
  3. Produce at least two images of other sources (e.g. Earth and Moon) for outreach purposes

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

Launch in a compact, stowed volume

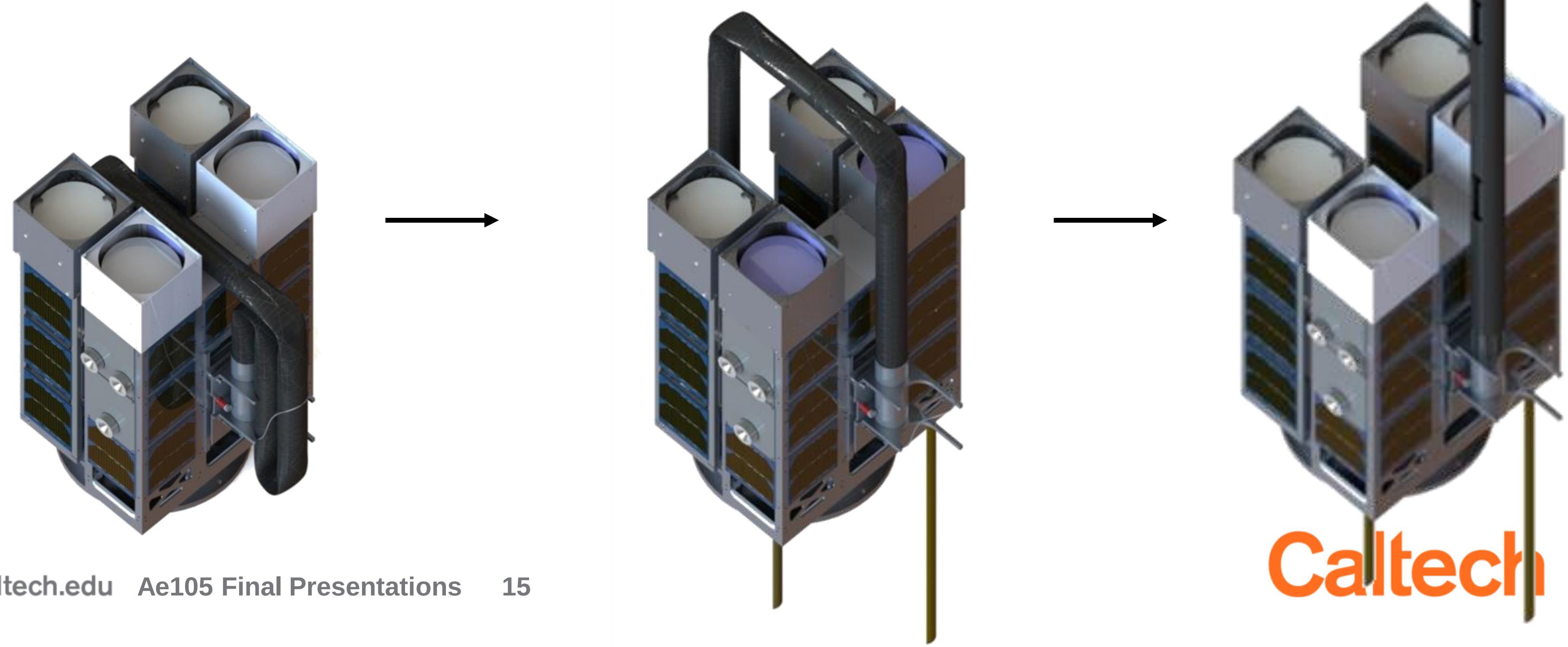
- 46 cm × 34 cm × 30 cm

Caltech

Concept of Operations

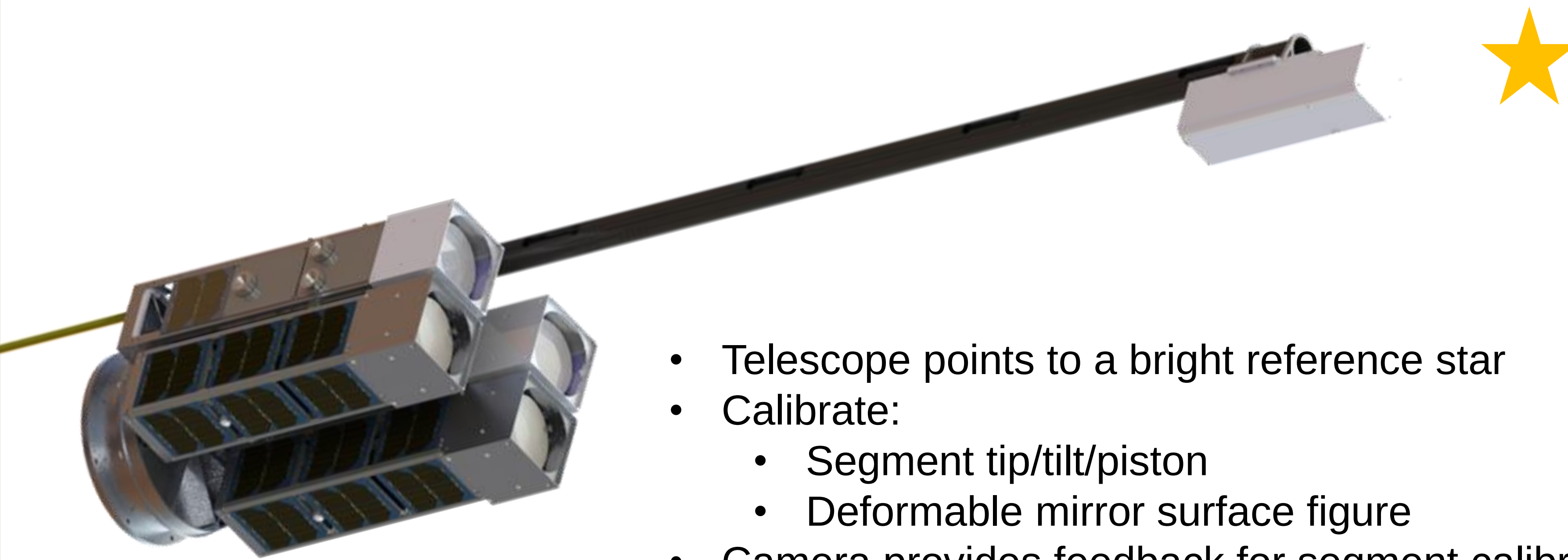
1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6 Extende Missio

- Satellite health check, detumble, antenna deployment
- Deploy boom in two stages
- Uncage deformable mirrors



Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission



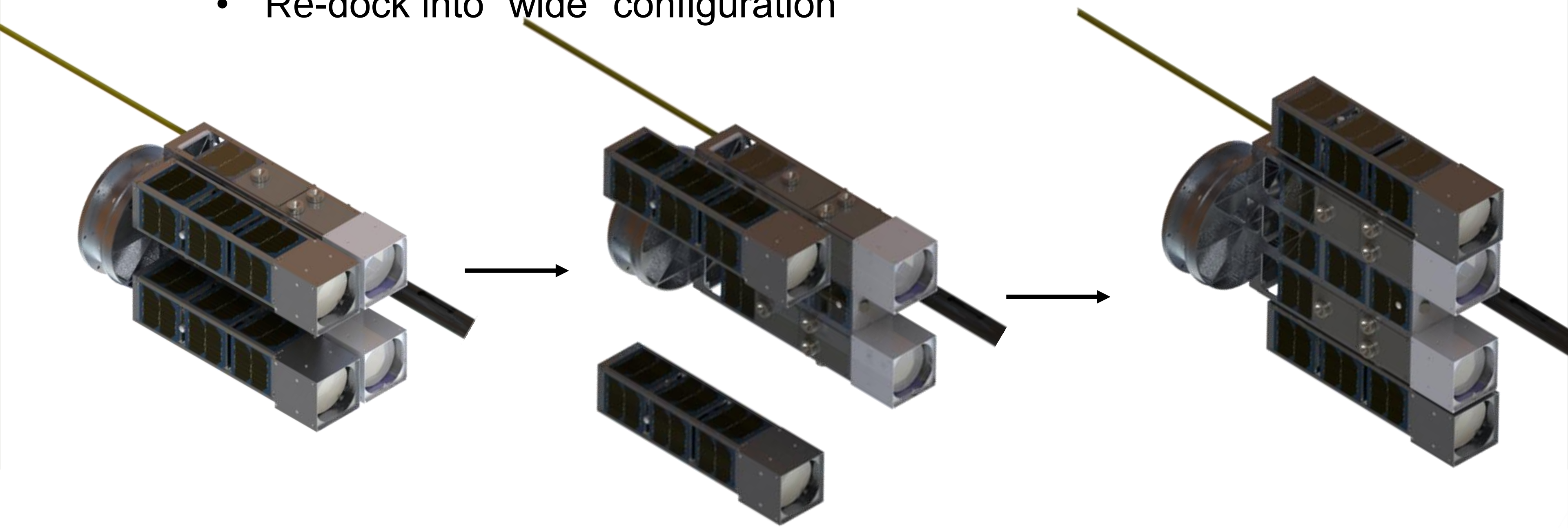
- Telescope points to a bright reference star
- Calibrate:
  - Segment tip/tilt/piston
  - Deformable mirror surface figure
- Camera provides feedback for segment calibration

Caltech

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

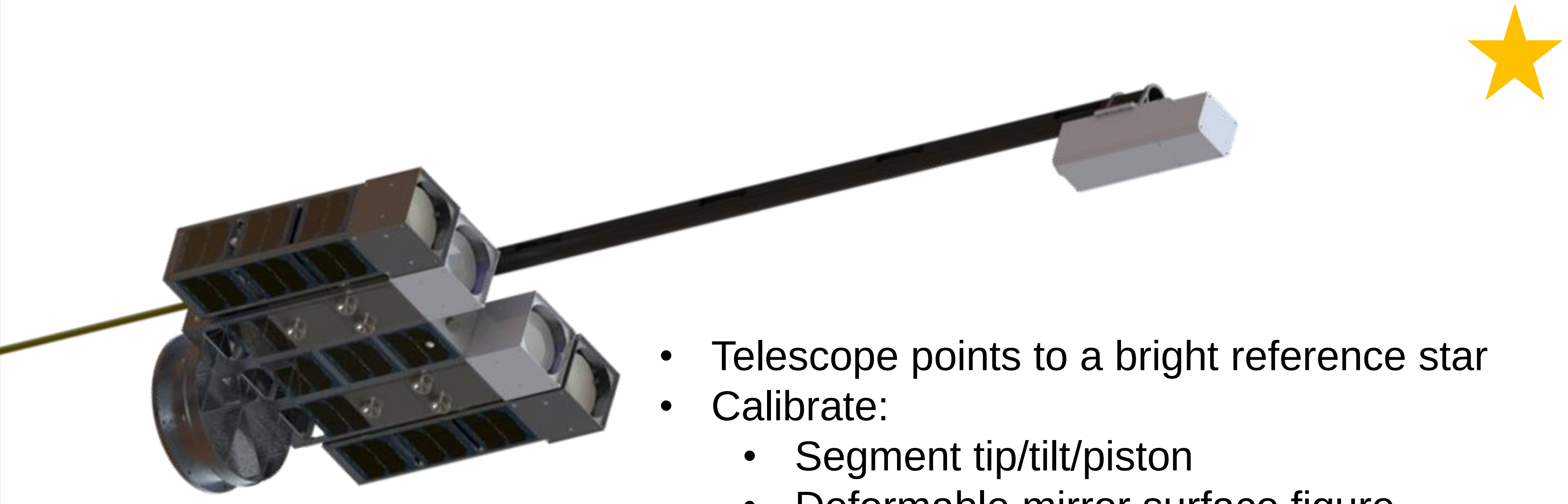
- MirrorSats release from CoreSat using electromagnets
- Fly out ~30 – 50 cm
- Re-dock into “wide” configuration



Caltech

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission



- Telescope points to a bright reference star
- Calibrate:
  - Segment tip/tilt/piston
  - Deformable mirror surface figure
- Camera provides feedback for segment calibration

Caltech

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

- Co-align star images from different segments to improve SNR
  - Pre-cursor to co-phasing
- Produce images of extended sources (e.g. Moon, Earth) for outreach

AAReST History

2008 November: Large Space Apertures KISS workshop

2010 June: Ae105

- Initial mission design; mission requirement definition

2012 September: Mission Concept Review

2013 September: Preliminary Design Review

2014 September: Detailed Design Review

2015 September: Complete Design Review

2016 June: Ae105

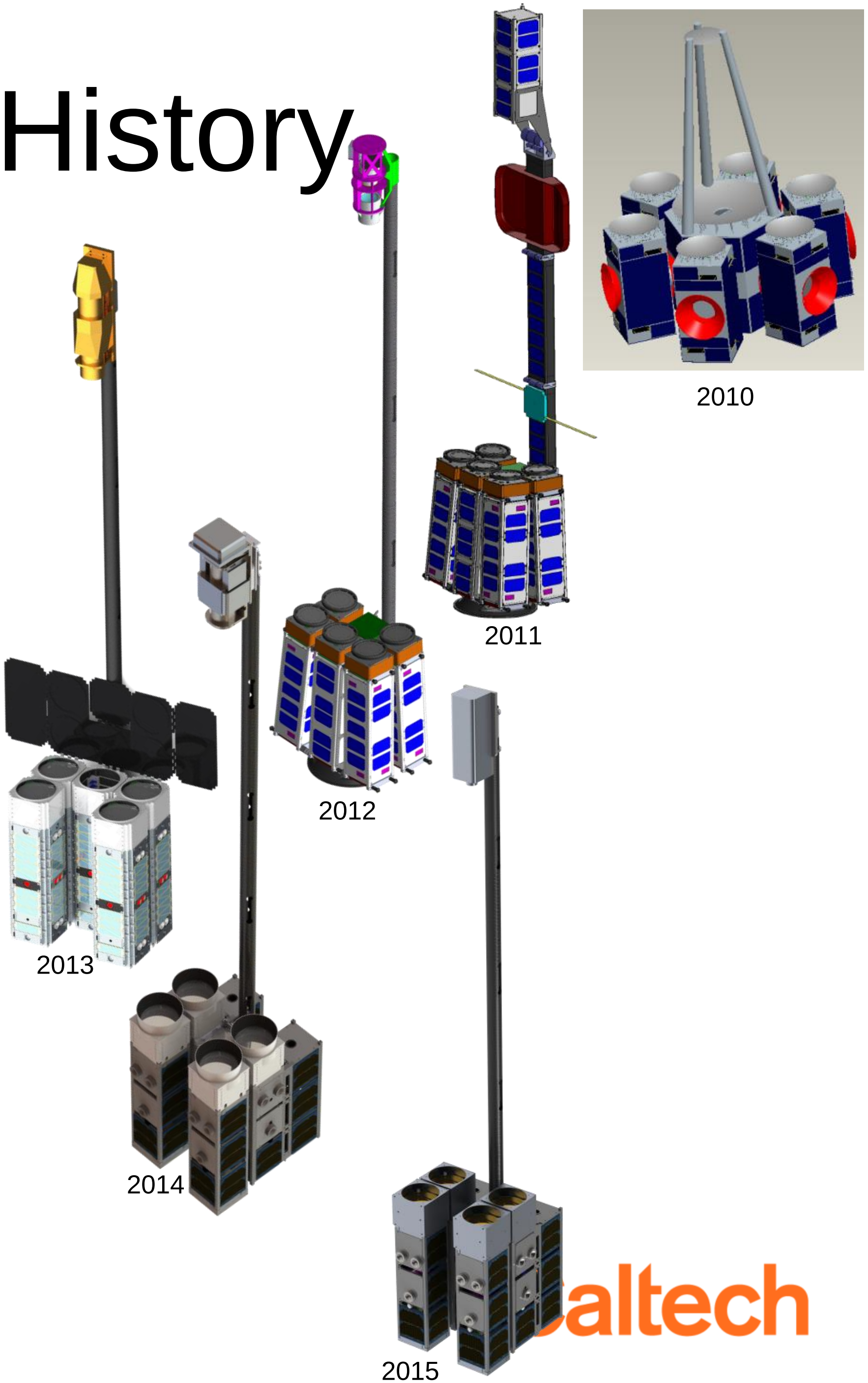
- Environmental testing of telescope systems
- Electronics and software design

2017 January: Telescope Complete Design Review

2017 June: Ae105

- Preliminary design of CoreSat
- Hardware selection, spacecraft modelling & analysis

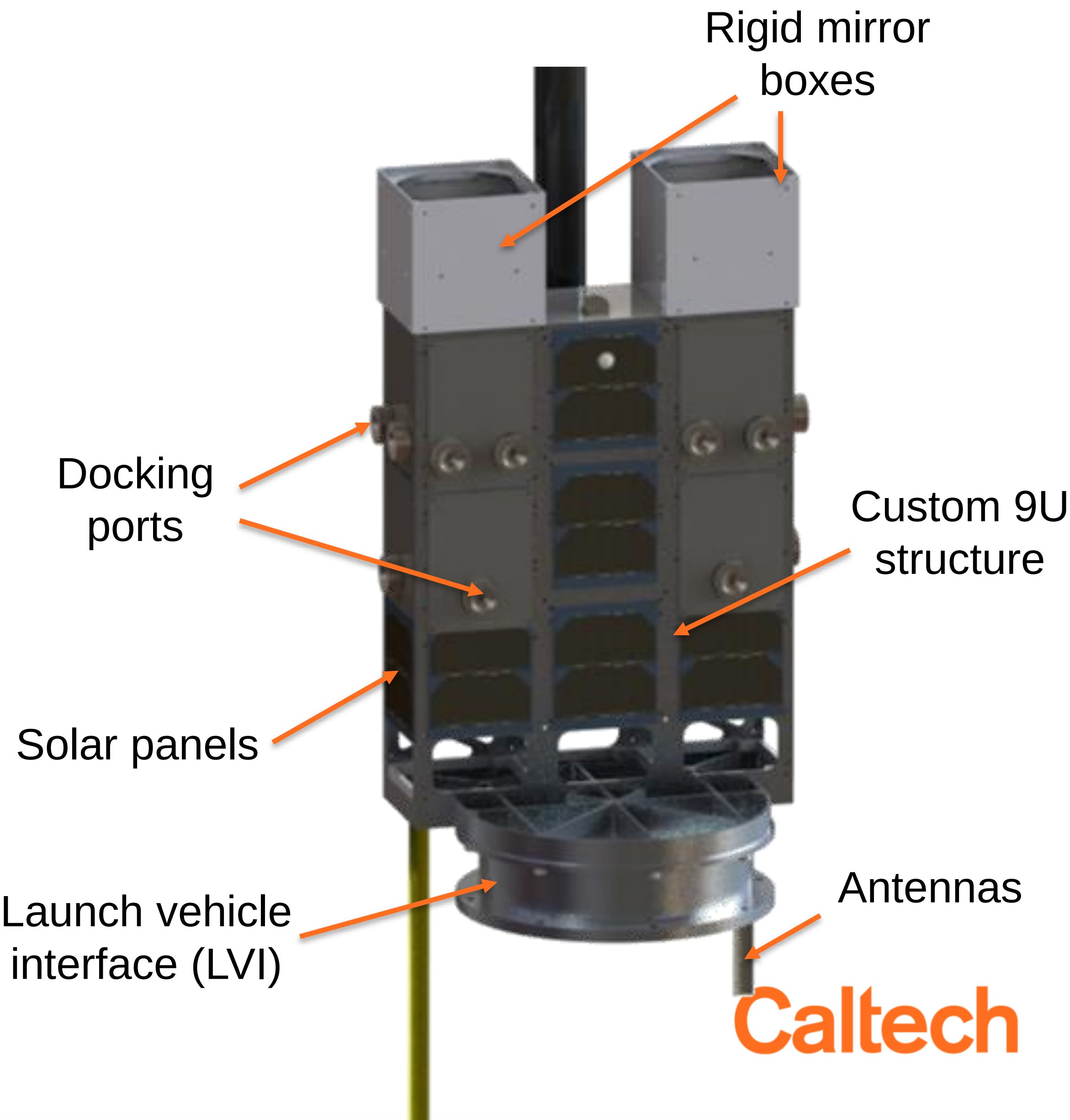
2017 September: Complete Design Review of three satellites



CoreSat Overview

Ae105 Projects:

- Systems Engineering
- Power
- Avionics & Comms
- ADCS
- Structures



Acknowledgement

The AAReST project is supported by:

- The Keck Institute for Space Studies
- Division of Engineering and Applied Science
- Provost’s Innovation in Education Fund

Caltech

Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

Caltech

Systems Engineering Team

Team:
Adrian Costantino
Kate Davies
Mohit Malik
Talia Minear
Bryan Sinkovec

Mentor: Fabien Royer

Systems Engineering Team Goals

- Orbit determination modeling
  - Lifetime estimate
  - Communications analysis
  - Power collection validation
- Docking maneuver
  - Kinematic analysis and orbital visualization
- Calibration targets and science targets
- CoreSat requirements, mass budget

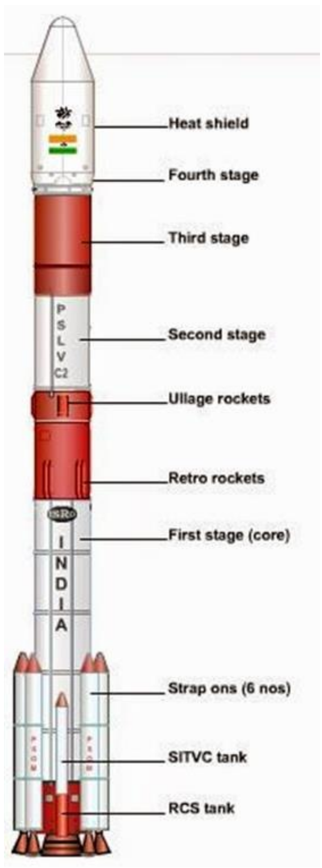
Orbit Determination Modeling

- Polar Satellite Launch Vehicle (PSLV)
  - Noon / midnight Sun-synchronous polar orbit
  - Inclination ~ 98°
  - Altitude 500 - 800 km

- Analysis tool: AGI STK

https://www.agi.com/downloads/media-center/logos/AGILogo2.jpg

PSLV



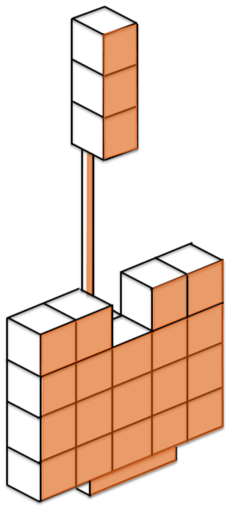
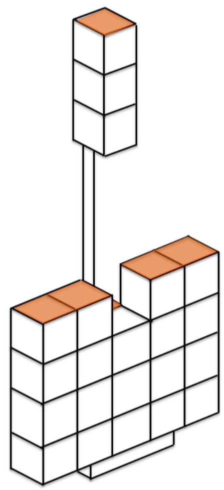
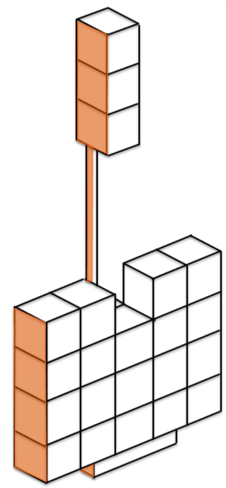
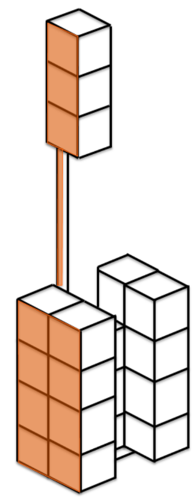
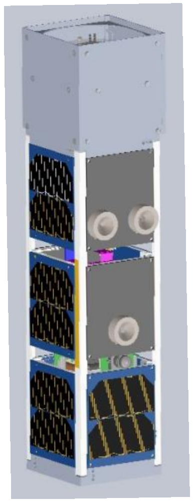
Credit: Indian Space Research Organisation (ISRO)

Lifetime Estimate

- 25-year maximum lifetime mandate

Assumptions:

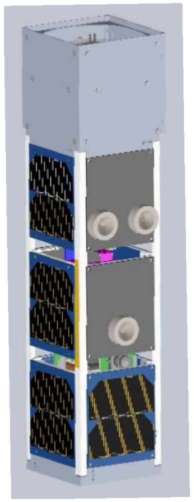
- Mass: 32 kg
- Drag areas based on current structure

Motion					Tumble
Configuration					
500-km Altitude	6.8 yrs	20.0 yrs	19.0 yrs	11.3 yrs	13.4 yrs
600-km Altitude	21.7 yrs	>100 yrs	>100 yrs	>100 yrs	>100 yrs

Lifetime Estimate

- 25-year maximum lifetime mandate

Assumptions:
- Mass: 32 kg
- Drag areas based on current structure

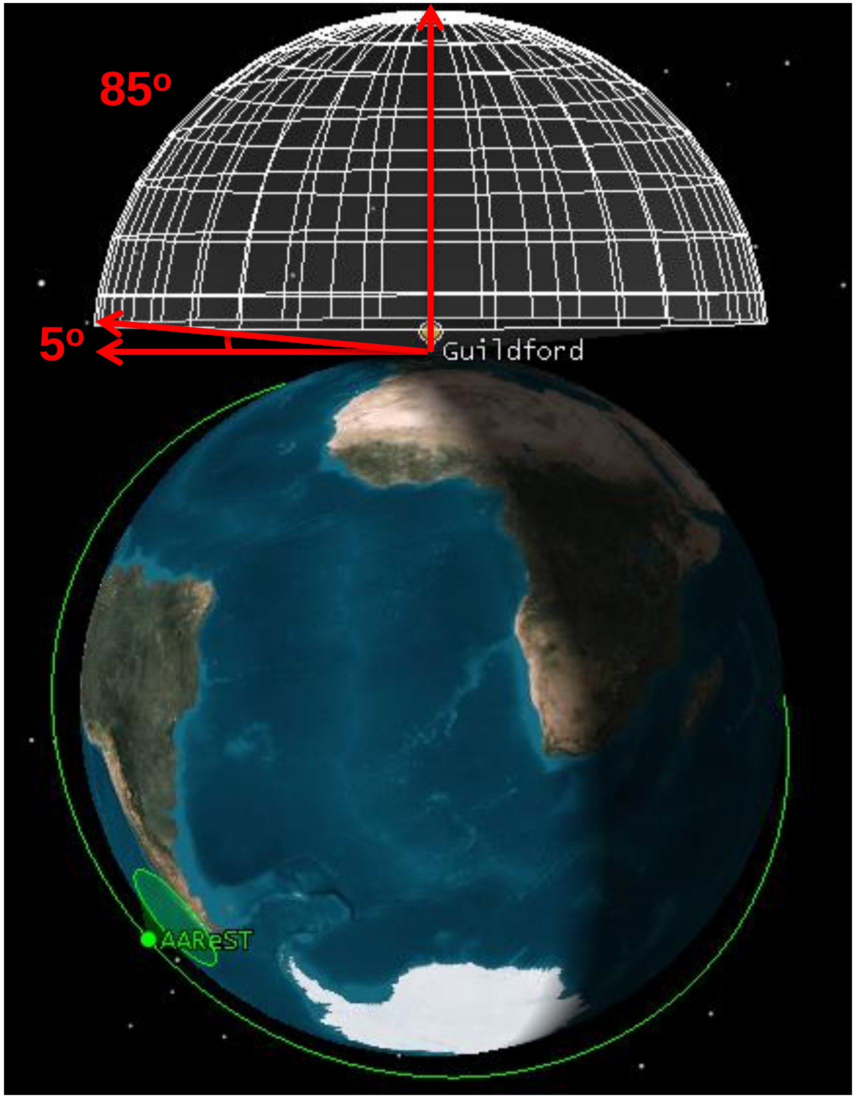
Motion					Tumble
Configurati					
500-km Altitude					13.4 yrs
600-km Altitude	21.7 yrs	>100 yrs	>100 yrs	>100 yrs	>100 yrs

Takeaways

- Reduced design space to 500-600-km altitude
- Potential mitigation techniques for higher orbits:
  - Add thruster(s) to aid de-orbiting
  - Add deployable solar panels to increase drag area

Caltech

Communications Access Range



- One ground station
  - Guildford, U.K. (University of Surrey)
  - 170º total field of view
- Assumption: AAReST can control attitude to point at ground station at all times when within field of view

Caltech

Access Time in 6-Month Time Interval

- Communications Team initially estimated **3 passes / day** with **8 minutes** of visibility / orbit ~ access of **24 min / day**

500-km Altitude	
Average Passes / Day	5.1
Maximum Duration (min)	9.3
Minimum Duration (min)	0.2
Average Duration (min)	7.3
Passes Over 8 min / Day	2.7
Access Time (min / day)	36.8

600-km Altitude	
Average Passes / Day	5.5
Maximum Duration (min)	10.5
Minimum Duration (min)	0.6
Average Duration (min)	8.3
Passes over 8 min / Day	3.6
Access Time (min / day)	45.5

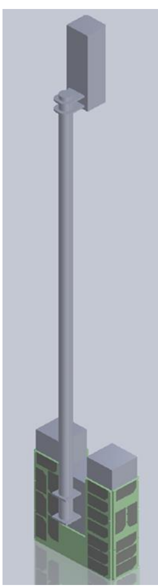
- Worst-case scenario (500-km altitude) is sufficient
- First iteration of link budgets generated based on assumptions and design choices made by Communications Team

On-orbit Power Collection

- Import CoreSat model into STK
- Estimate power collection

CAD

- Model simplification



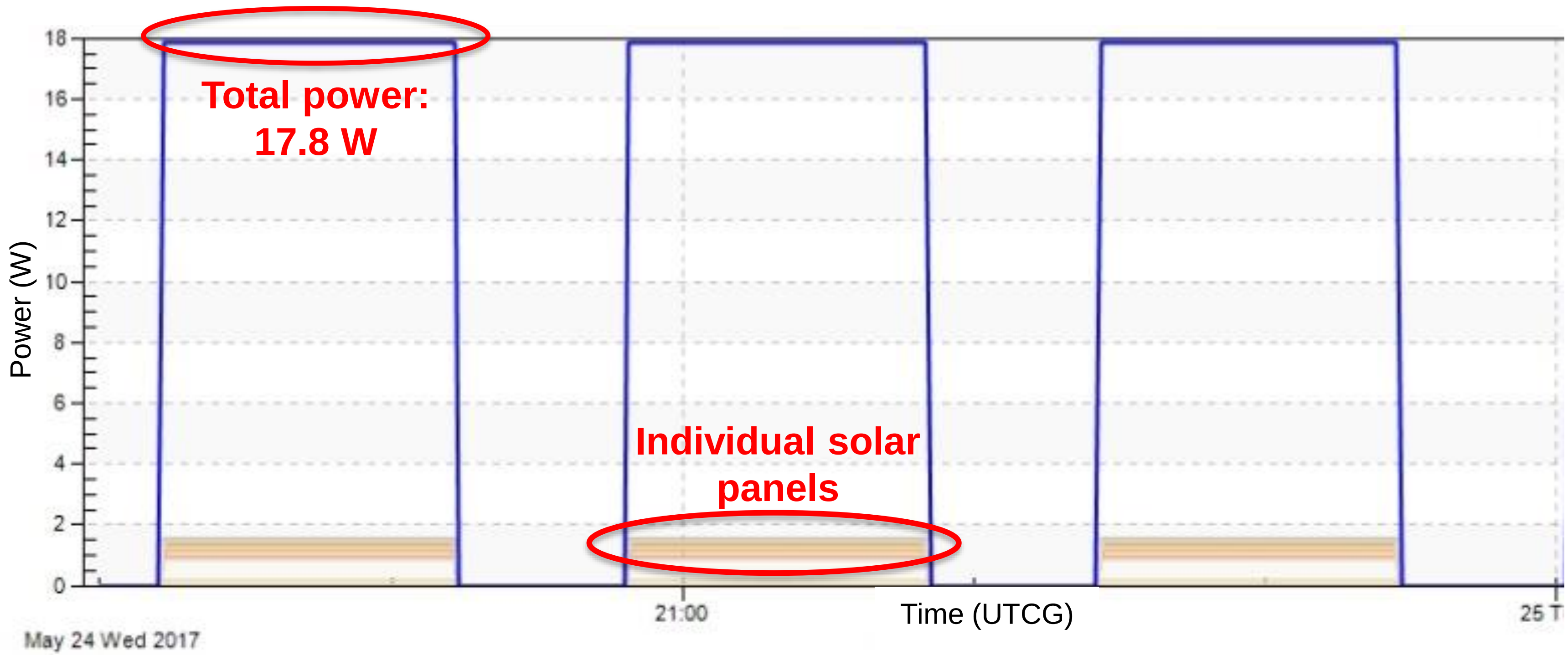
Blender

- Apply 3D modeling to define solar pan


```xml
<?xml version = "1.0" standalone = "yes"?>
<ancillary_model_data version = "1.0">
    <articulations>
        <articulation name = "Generisat" type = "transform">
            <stage init = "1" max = "1" min = "0" name = "Size" type = "uniformScale" />
            <stage init = "0" max = "360" min = "-360" name = "Roll" type = "xRotate" />
            <stage init = "0" max = "360" min = "-360" name = "Pitch" type = "yRotate" />
            <stage init = "0" max = "360" min = "-360" name = "Yaw" type = "zRotate" />
            <stage init = "0" max = "1000" min = "-1000" name = "MoveX" type = "xTranslate" />
            <stage init = "0" max = "1000" min = "-1000" name = "MoveY" type = "yTranslate" />
            <stage init = "0" max = "1000" min = "-1000" name = "MoveZ" type = "zTranslate" />
            <assigned_nodes>
                Generisat-Bus-Cm
            </assigned_nodes>
        </articulation>
    </articulations>
    <pointing_data>
        <pointing node = "Generisat-Panels-Cm" vector = "0 0 1" />
    </pointing_data>
    <solar_panel_groups>
        <solar_panel_group efficiency = "28" name = "SolarPanel">
            <assigned_nodes>
                SolarCells
            </assigned_nodes>
        </solar_panel_group>
    </solar_panel_groups>
        <sensor_origins>
                Camera_AttachPoint
        </sensor_origins>
</ancillary_model_data>
```


Caltech

On-orbit Power Collection



Parameters:

- Altitude: 600 km
- Noon / midnight SSPO
- Attitude: Sun pointing (-X)
- Solar panel efficiency: 0.30

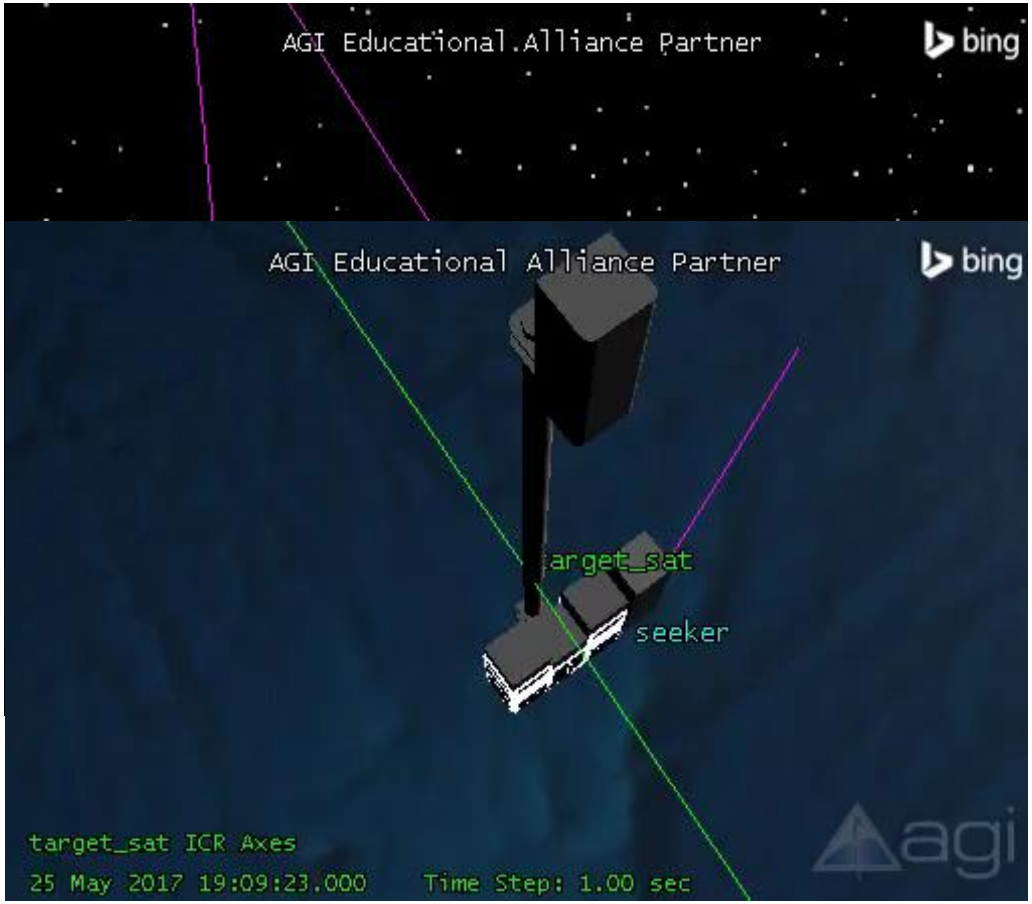
Refinement:

- Chose optimal charging attitude, so need to extend to other mission phases

Caltech

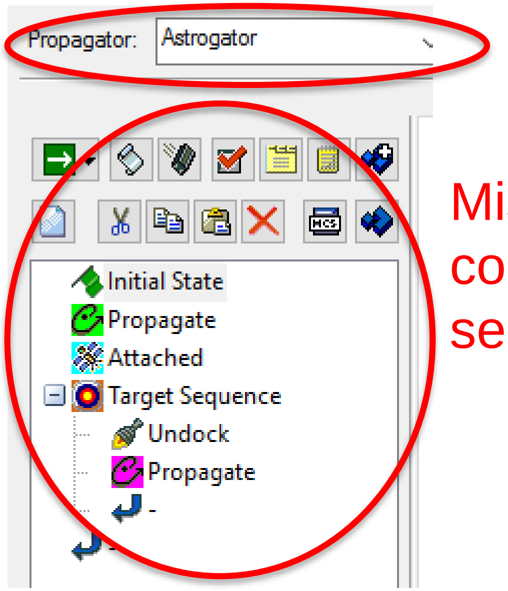
On-Orbit Visualization

- Power collection



- Docking maneuver

- Goals
  - Implication on power consumption during rendezvous
  - Validation of kinematics analysis



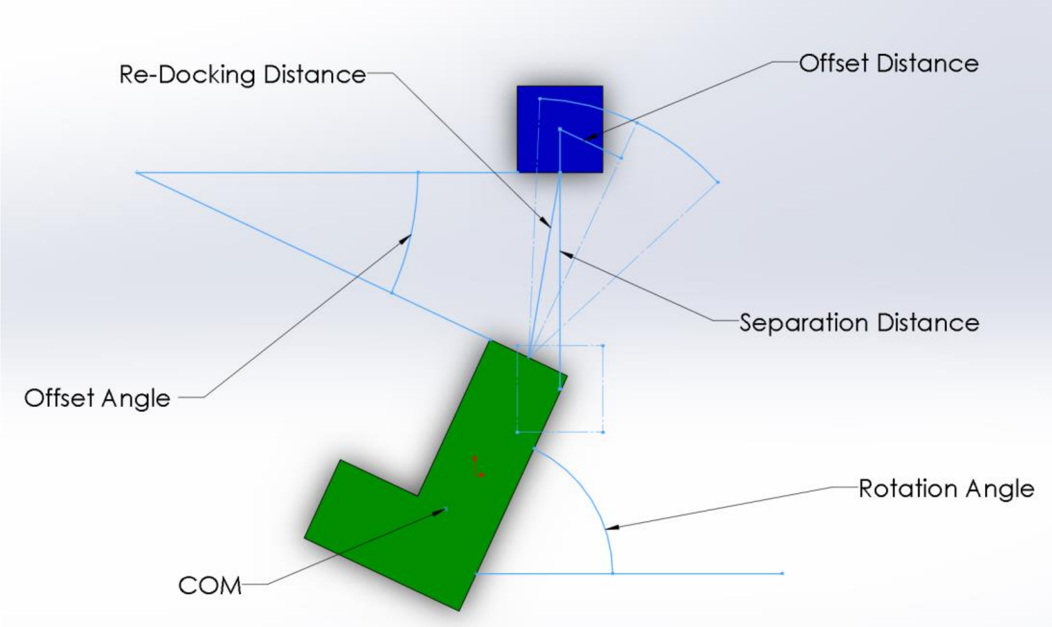
Mission control sequence

Caltech

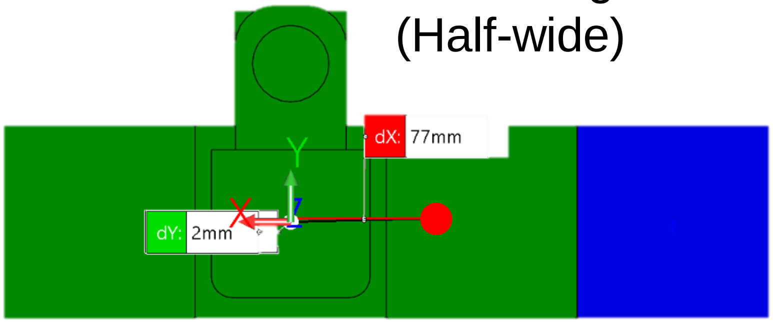
Docking Maneuver Analysis

Goals:

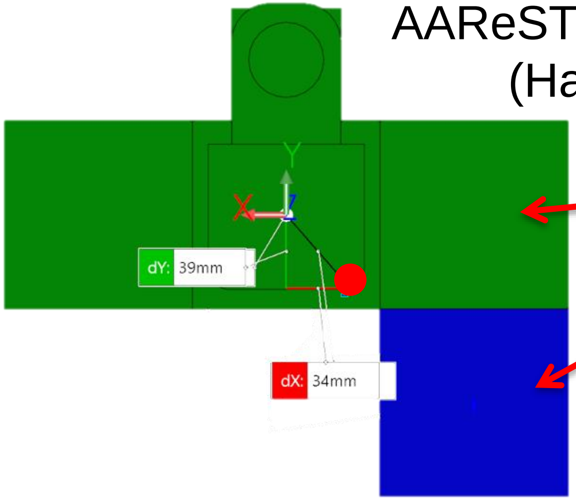
- Minimize torque on satellite
- Maximize probability of successful docking procedure
- Inputs: Rotation angle and separation distance
- Accomplished by minimizing re-docking distance, offset angle, and separation distance between MirrorSat and CoreSat



AAReST I configuration (Half-wide)



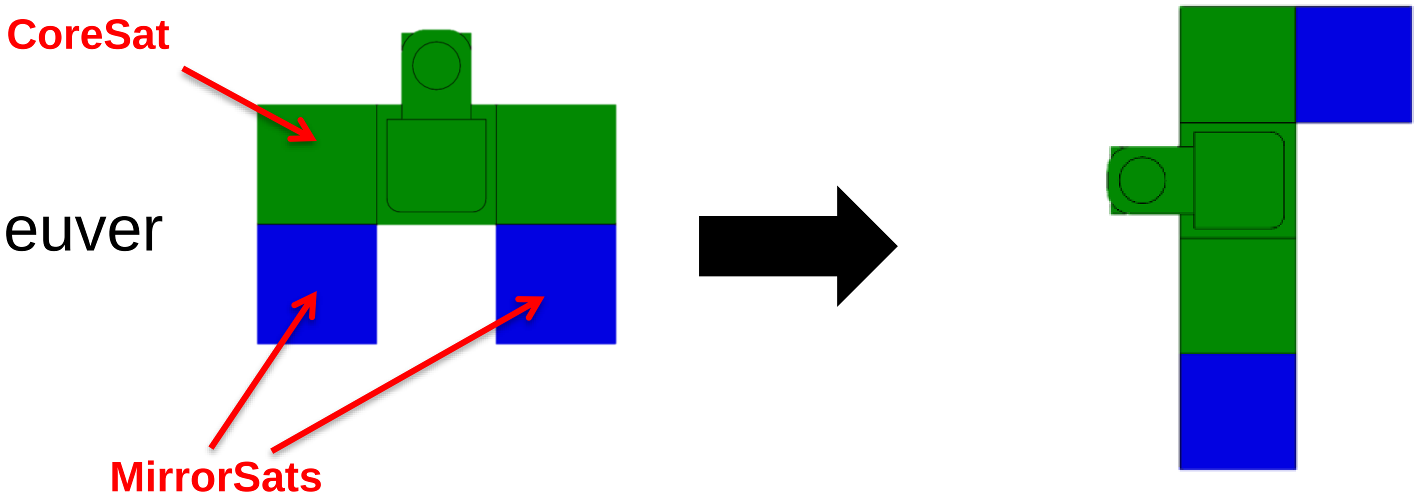
AAReST L configuration (Half-narrow)



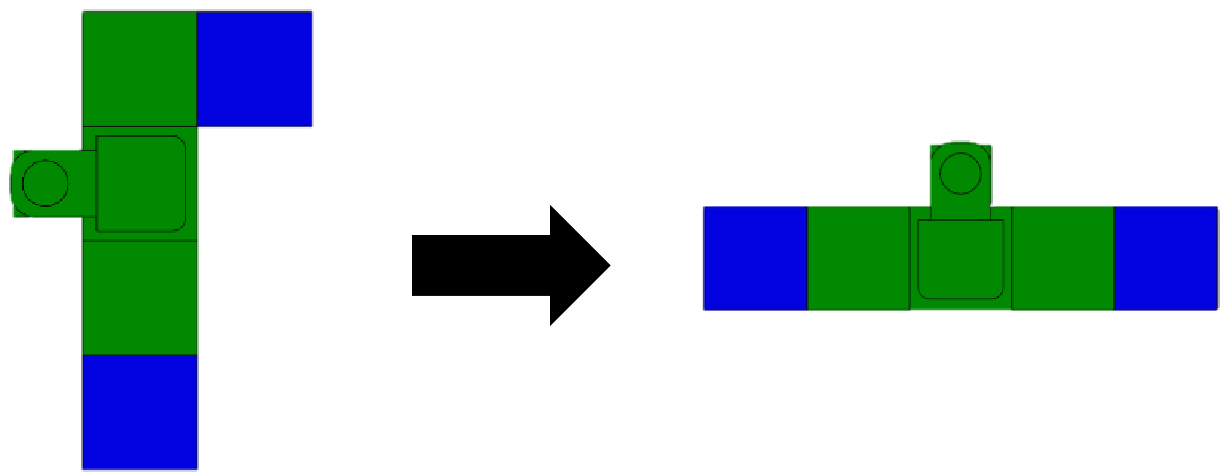
Caltech

Docking Maneuver Visualization

First maneuver

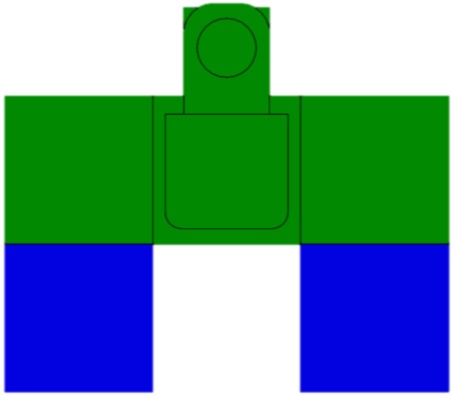


Second maneuver



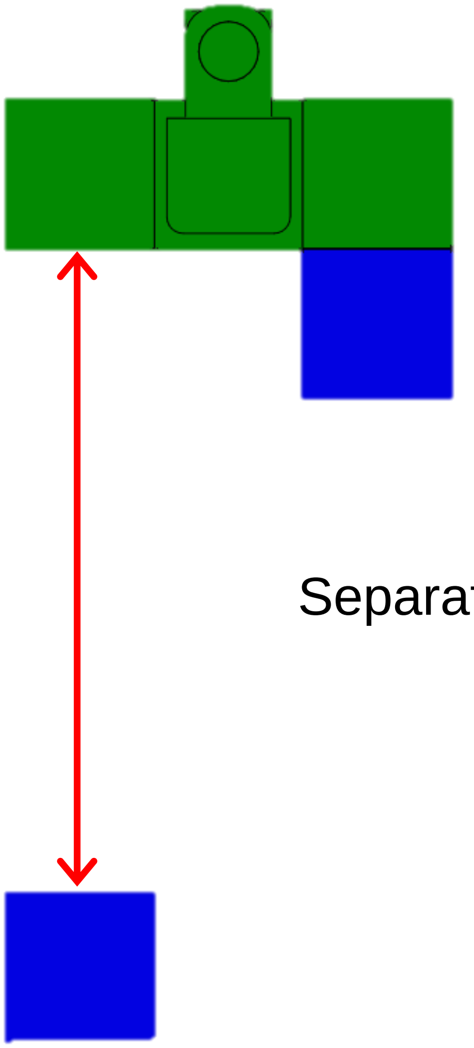
Caltech

Starts in Full-Narrow Configuration

1. 

First MirrorSat Separation

2.

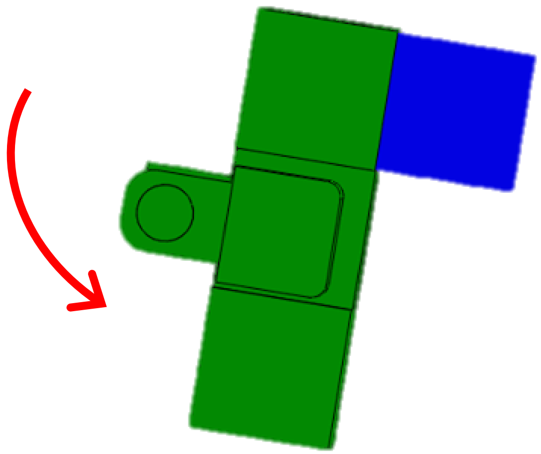


Separation distance = 332 mm

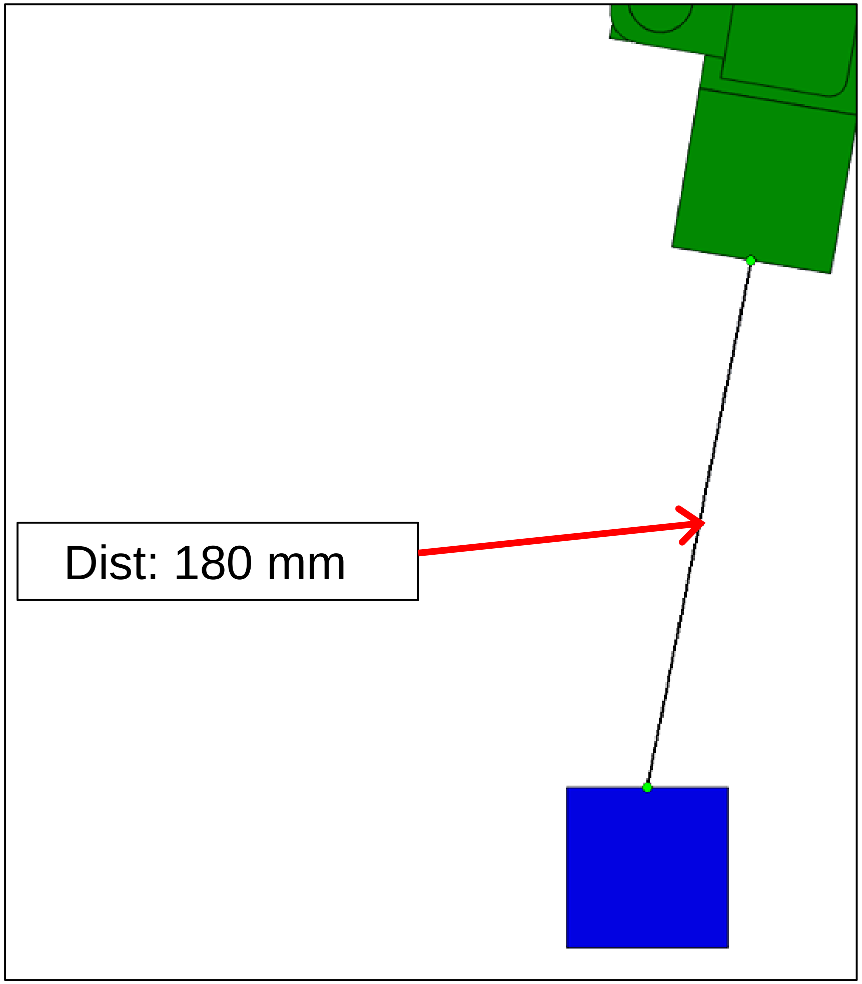
Caltech

First Rotation

3.

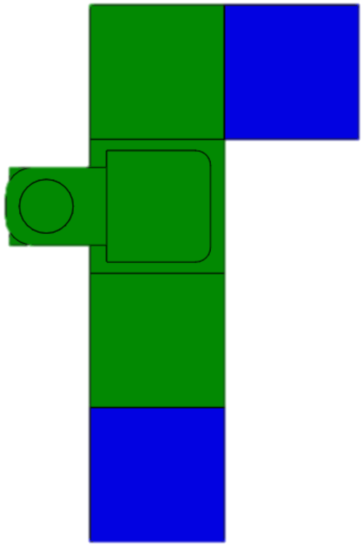


Angle of first rotation = 76.5º
Total time for first rotation = 55.3 s



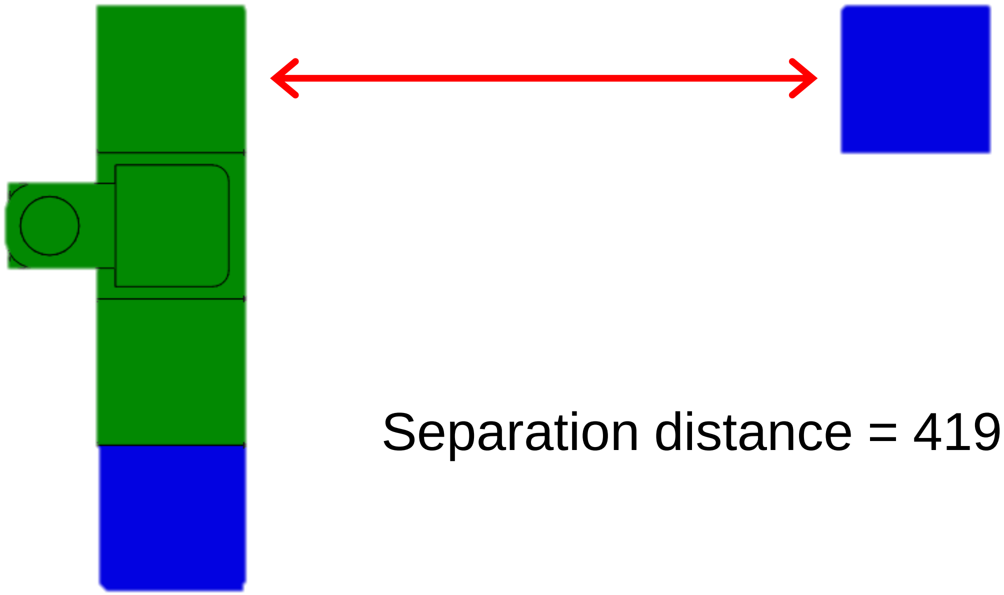
First MirrorSat Re-docks

4.



Second MirrorSat Separation

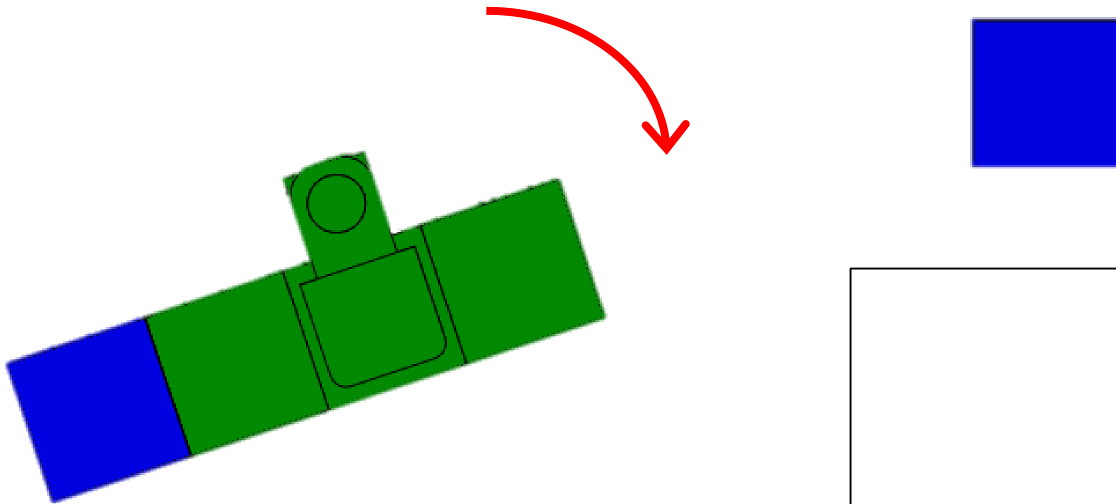
5.

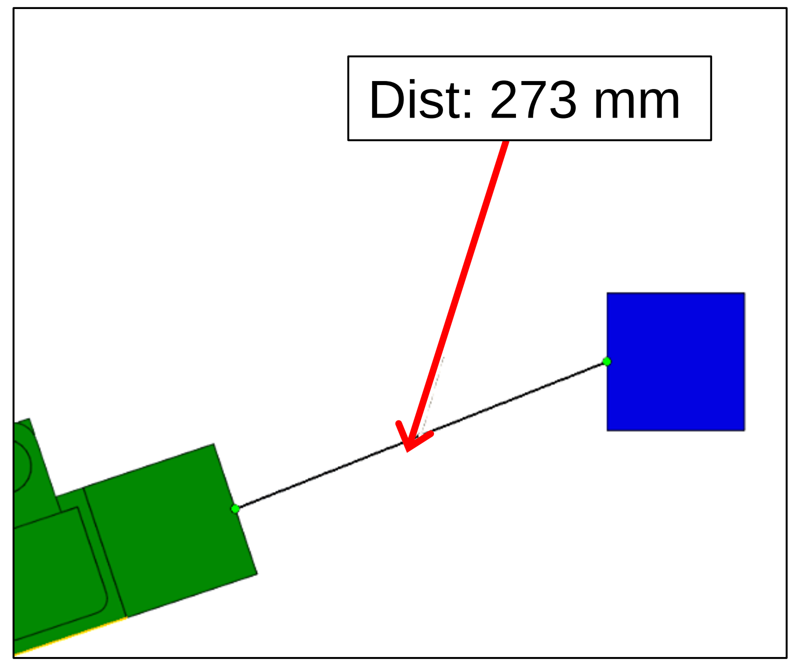


Separation distance = 419 mm

Second Rotation

6.

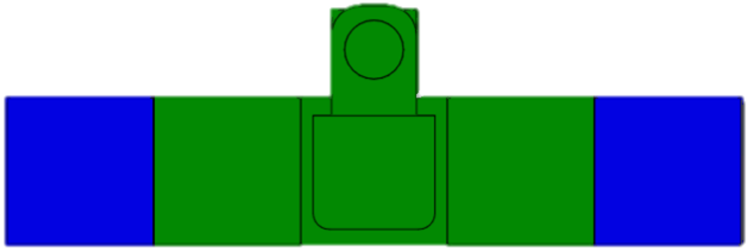




Angle of second rotation = 71.0º
Total time for second rotation = 54.3 s

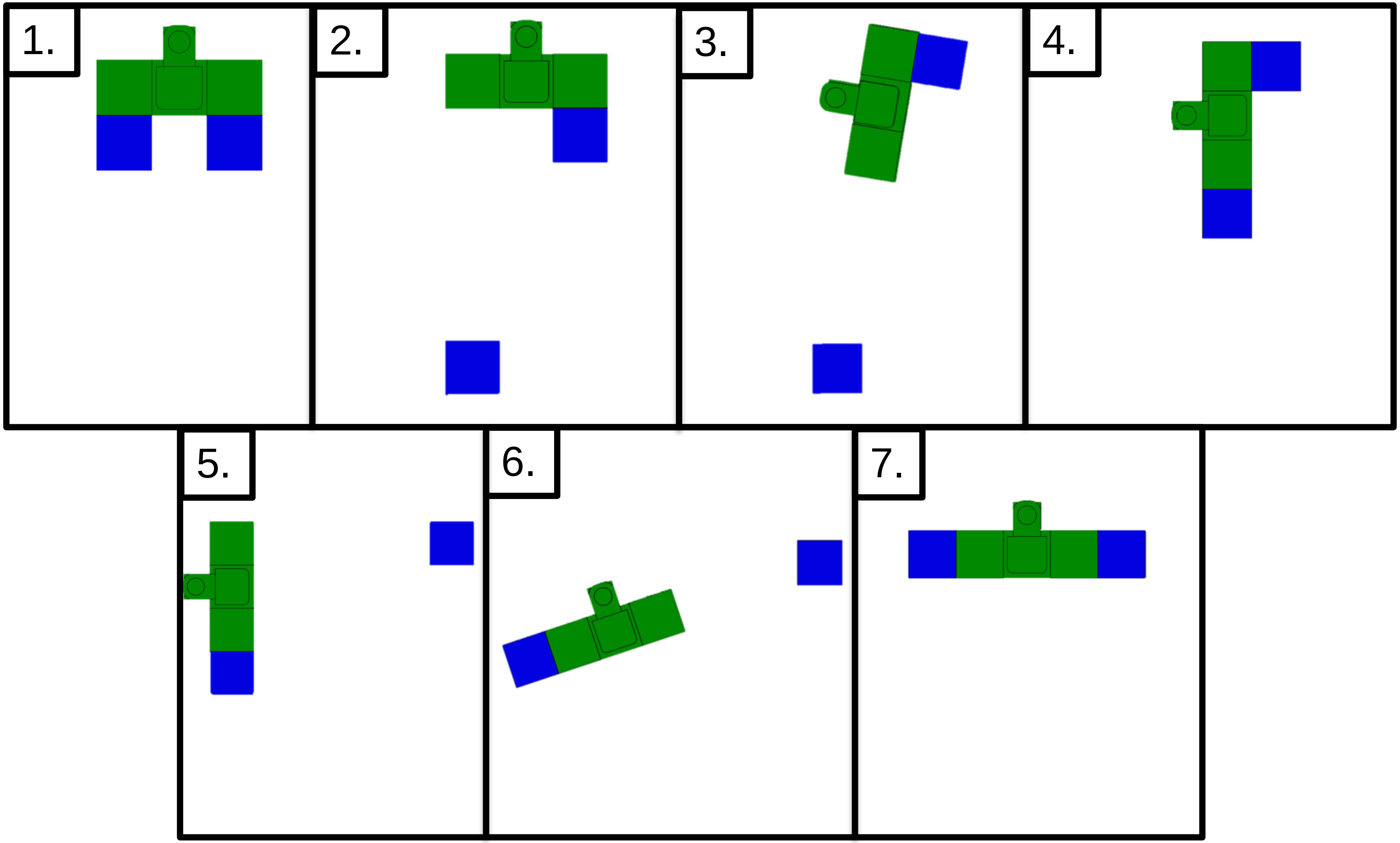
Ends in Full-Wide Configuration

7.



Caltech

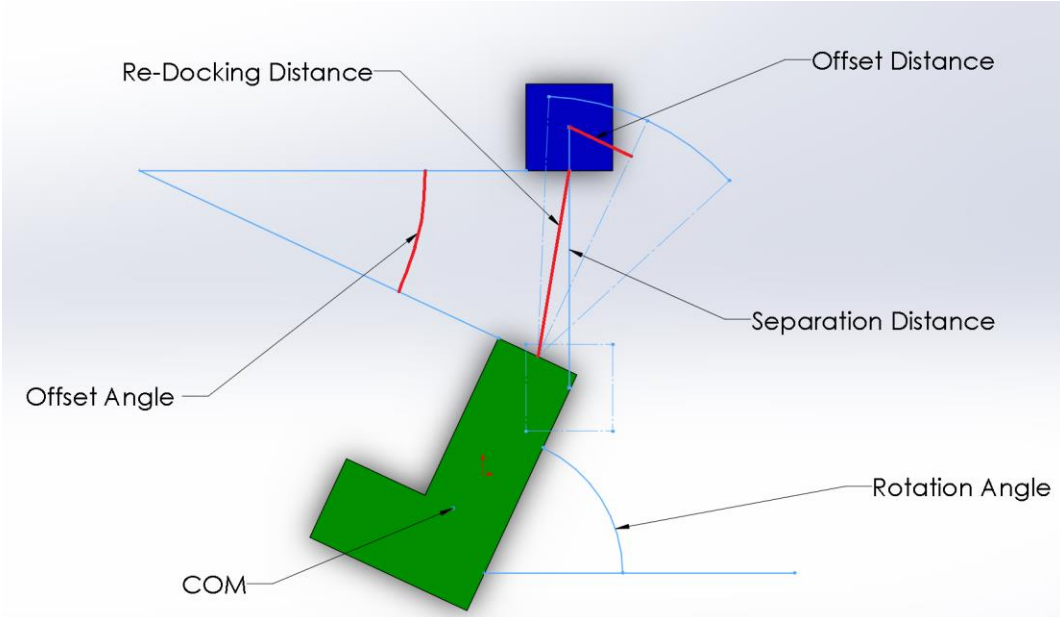
Docking Maneuver Summary



Caltech

Docking Numerical Optimization

- Score = C1*(offset distance) + C2*(misalignment angle) + C3*(re-docking distance)
- C1, C2 qualitatively assigned based on input from discussion with ADCS
- C1 > C2 >> C3
- C1:C2 sensitivity is low
- C3 was iterated upon so local minimum fell within the constrained region
- For this analysis: C1 = 3, C2 = 1, C3 = 0.035



Caltech

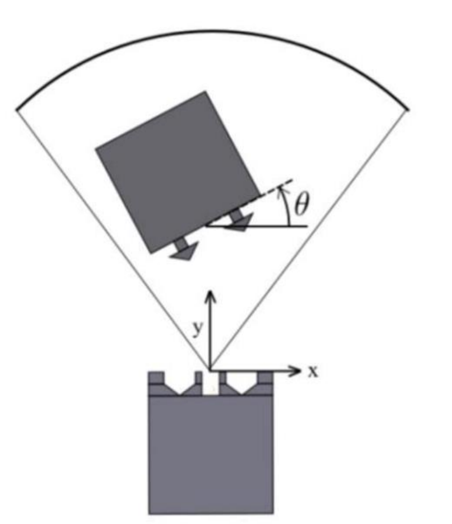
Docking Constraints

Acceptable offset tolerances:

5 cm = ±10º pitch / roll / yaw

15 cm = ±20º pitch / roll / yaw

30 cm = ±30º pitch / roll / yaw

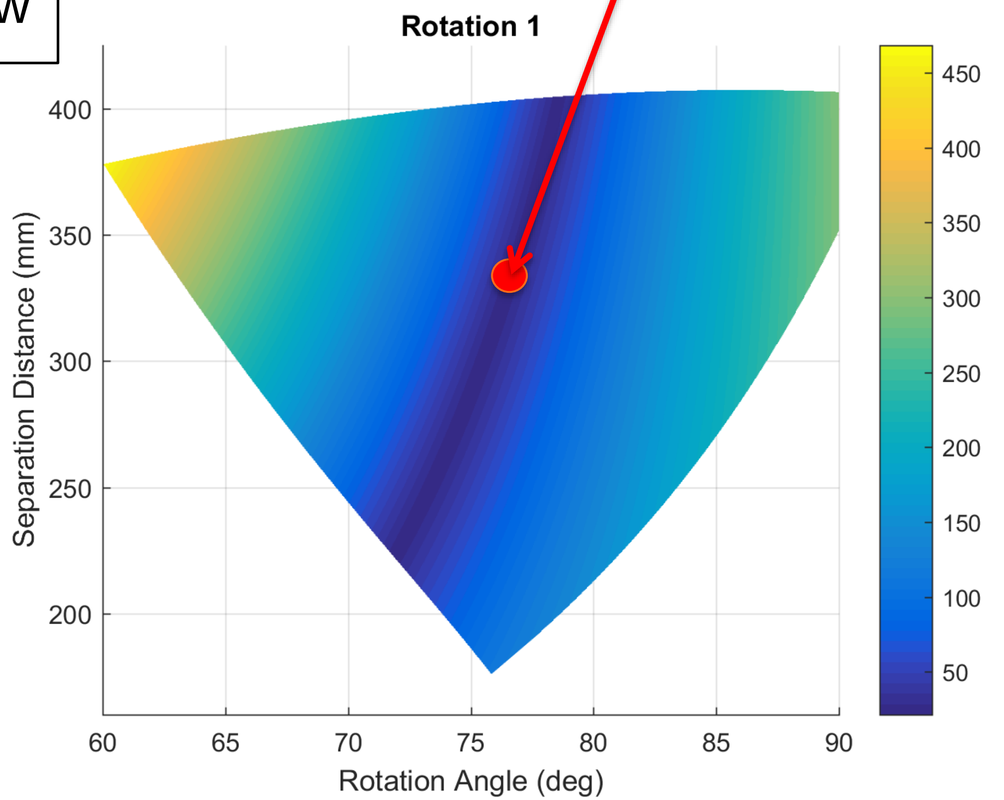


Acceptable capture area:

45º circular sector

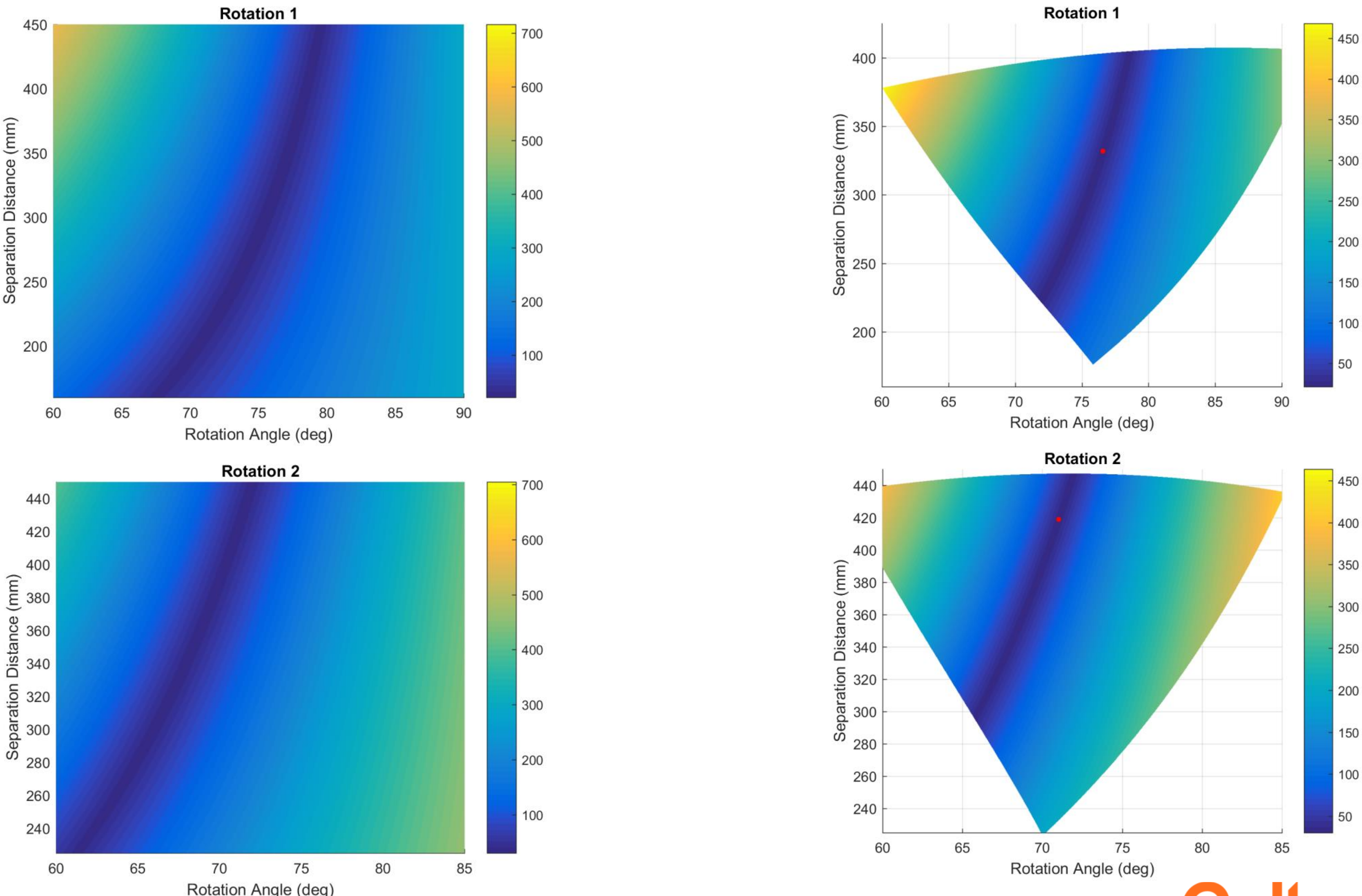
R = 300 mm

Dark blue area: Near optimal combination of rotation angle and separation distance
Red dot: optimal solution



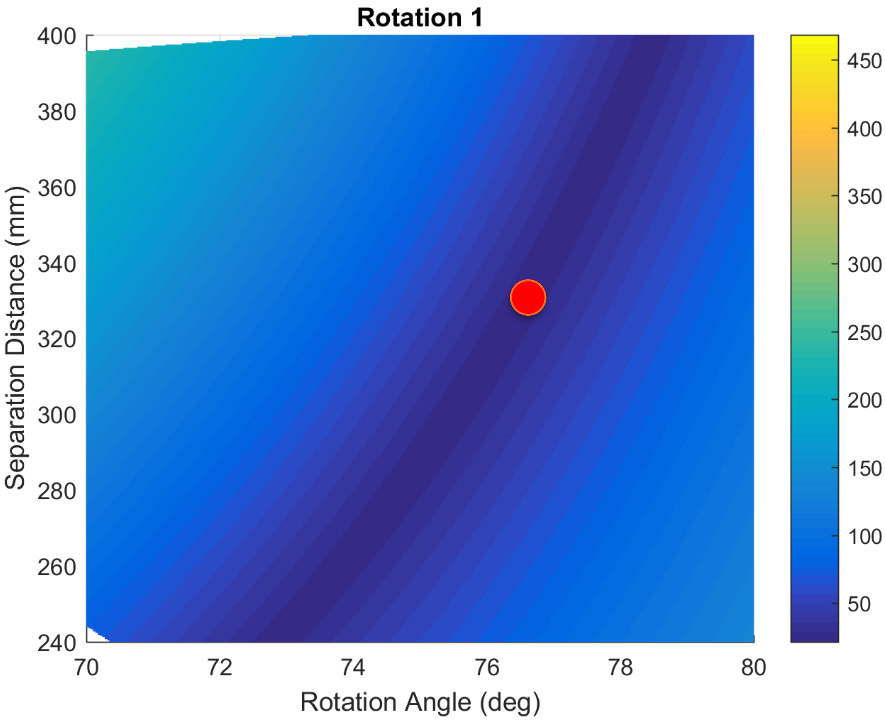
Caltech

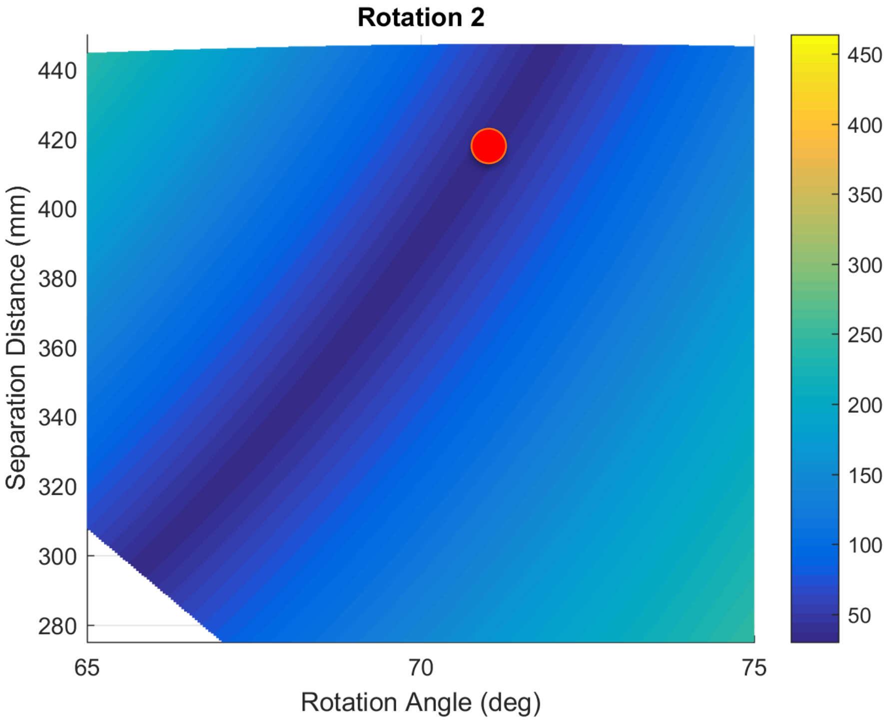
Docking Constraints Visualized



Caltech

Docking Maneuver Plots





Red dot: optimal separation distance and rotation angle

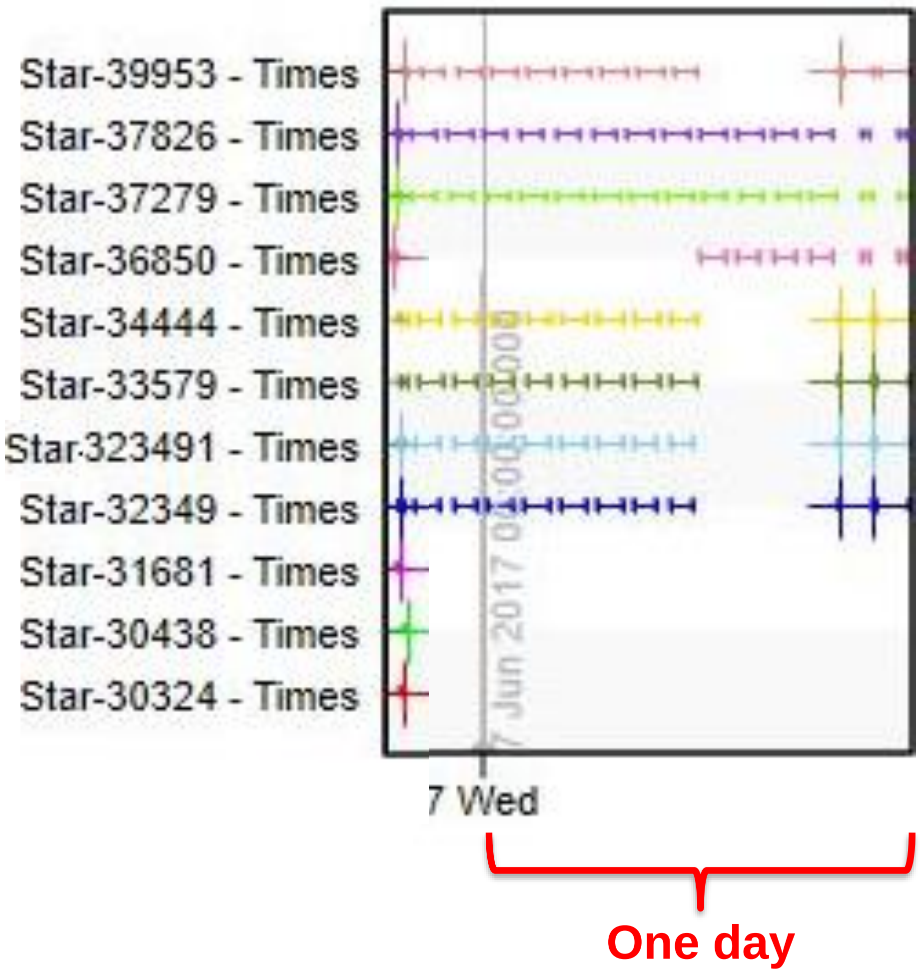
Caltech

Optical Calibration Targets

- Repeated calibration of deformable mirrors needed throughout mission
- Maneuver as little as possible to point at calibration stars
- Limited range of star magnitude (-2 to 2) due to science camera sensitivity
  - 49 candidate stars (e.g. Sirius: -1.46)
- Use STK to determine visible stars

Caltech

Example Analysis for One Day



- Many candidate stars available, must determine when to point at them
- May be limited to eclipse phases

Caltech

CoreSat Requirements Eye Chart

Avio Systems s ecoms

AAReST must have a COTS transmitter/receiver operating at UHF/VHF

Pointing accuracy: error < 0.1° 3σ all axes

Vertical clearance of Launch Vehicle Interface, with respect to the MirrorSats, must be 5 cm

The batteries must be able to power the satellite during tumbling phases

Telescope must point away from the sun, at a minimum of 20° angular separation of the sun

Mass Budget

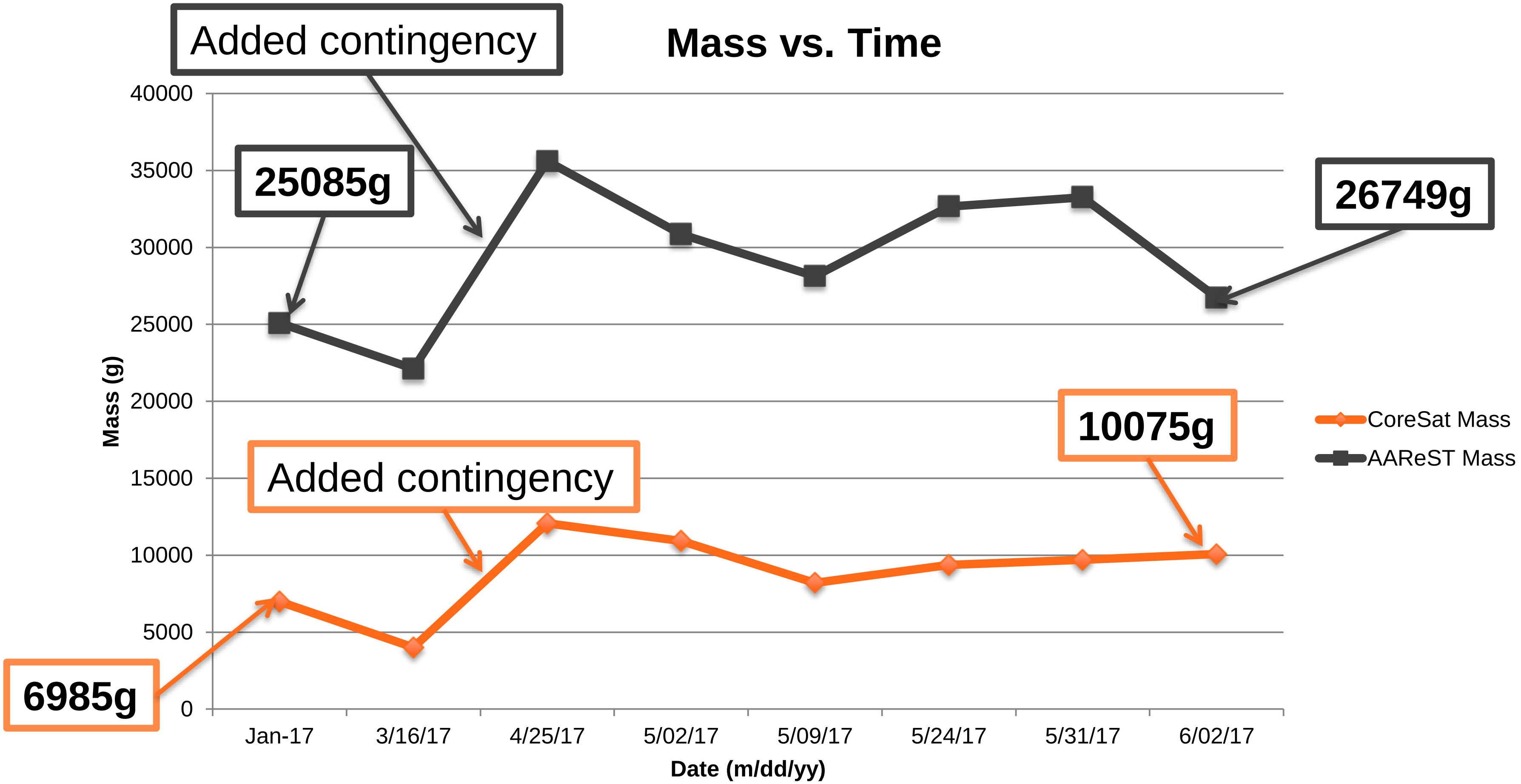
Contingency Scale:

- 0 = verified
- 10 = COTS
- 15 = COTS + fabrication
- 20 = Fabrication only
- 30 = Very rough estimate

Team	Component	Max Mass (g)	Contingency (%)	Max Mass + contingency (g)	Change since 5.31.2017 (g)
ADCS	Docking Units	1700	20	2040	0
ADCS	ADCS Stack + Reaction wheels	1106	10	1216.6	0
ADCS	Star Camera	166	20	199.2	0
ADCS	Payload Interface Board	200	20	200	0
Avionics/Comms	Transceiver	78	10	85.8	0
Avionics/Comms	Antenna	100	20	100	0
Power	Solar Panels	520	30	676	0
Power	EPS + Batteries	675	10	742.5	0
Power	Mounting board	270	20	324	0
Structural	Chassis	1350	20	1620	**60**
Structural	Surface Structural Panels	140	10	154	0
Structural	Launch Interface	600	10	660	0
Structural	Launch Interface mount	860	15	989	**40.25**
Structural	HDRM - 2 for antennas, 2 for MirrorSats, 1 for Camera	400	10	440	**88**
Structural/ Power	Circuit Boards (c.8)	560	30	728	**182**
Core Sat Total		**8725**		**10075g**	**370.25**
	Wiring	**436.25**	30	[illegible]	**19.825**
From January 2017	MirrorSat (incl. propulsion)	8000	15	9200	**-6900**
	Camera	3206.7	0	3206.7	0
	Rigid Mirror Box	1900	0	1900	0
	Deformable Mirror Box	1200	0	1200	0
	Boom + Camera Interface + CoreSat Interface	600	0	600	0
Total System Mass		**24067.95**		**26749g**	**6509.925**

Caltech

Mass Properties



Caltech

Systems Team Summary

- Lifetime framework established
- Communications access determined
- Validation of power collection framework set up
- Optimal docking maneuver parametric framework developed
- Calibration star access modeled
- CoreSat requirements document draft completed
- Mass budget template generated

Future Work

- Adapt lifetime estimate for future structural modifications
- Continue developing link budget
- Extend power analysis to complete mission scenario
- Extend docking to include disturbances and complete STK modeling
- Select calibration and science targets
- Continue tracking mass budget

Questions?

AGI Educational Alliance Partner
Earth Inertial Axes
16 Mar 2017 19:00:00.000
Time Step: 30.00 sec
agi

Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

Caltech

AAReST CoreSat Power System

Team:
Chris Bradley

Charlie Dorn

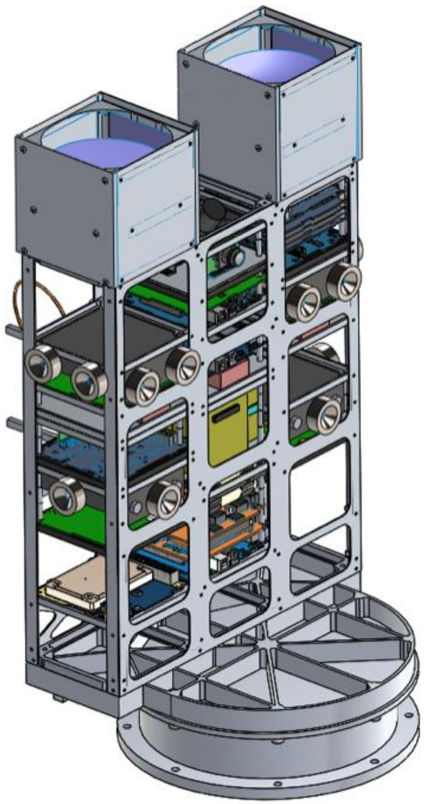
Juliane Preimesberger

Mentor: Ashish Goel

Power Team Goals

- Analyze power consumption and generation

- Design power system solution
  - Commercial EPS, battery, and solar cell selection
  - Solar panel fabrication
  - Wiring and solar cell arrangement
  - Develop testing procedures



Caltech

High Level Requirements

- Power each subsystem, including MirrorSats, for all operating modes
- Meet average and peak voltage and current requirements for each subsystem
- Allocate enough energy storage for detumble and eclipse

Caltech

Power Budget

	Operating mode	Burn wire	Detumble	Actuator release	Nominal	Ground comm	Science	Docking	Mirrorsat Charging	Battery heating
	Configuration	Narrow	Narrow	Narrow	Both	Both	Both	Both	Both	Both
Power	Battery heater									6
	EPS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ADCS	CubeComputer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	CubeSense	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	CubeControl	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	CubeWheel - Large	1.5	6.6	1.5	1.5	1.5	1.5	3.2	1.5	2.5
	Star Camera						0.9	0.9		
Avionics	UHF/VHF Transceiver					5.4				
	Payload Interface Computer						3			
Docking	WiFi						1	1		
	Electromagnets							13		
	LEDs							1		
Payload	Rigid Mirror Payload						7			
	MirrorSat Charging								10	
	Camera						5			
Others	Boom Deployment	4								
	Actuators			25						
	Misc (health monitoring sensors)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Total Power (W)	9.73	11.04	30.94	5.94	11.34	22.81	23.51	15.94	12.94
	Total Power with 30% Margin (W)	**12.65**	**14.35**	**40.22**	**7.72**	**14.74**	**29.65**	**30.56**	**20.72**	**16.82**
	3.3 V bus peak current (A)	1.74	3.35	1.80	1.80	3.44	2.06	2.58	1.80	3.92
	5 V bus peak current (A)	0	0	0	0	0	3.2	3	2	0
	16 V bus peak current (A)	0.25	0	1.56	0	0	0	0	0	0
	Max Mode Duration	<2 min	<2 orbits	30 sec	free	<8 min	<10 min	2 min	free	5 min

Good estimate
Subject to change

EPS Selection

- Considered several CoTS options
- Three finalists
- Deciding factors
  - Power limit
  - Number of input channels
  - Compatibility with other systems

Gomspace NanoPower P60

	# Input Channels	Max Current In (A)	Max Voltage In (V)	# Output Channels	Max Current Out (A)	Max Voltage Out (V)	Power (W)	Comms	Cost
~~Astro Dev~~	~~4~~	~~2~~	~~9 - 22~~	~~9~~	~~2~~	~~3.3,5~~	~~16~~	~~I2C~~	~~-~~
NanoPower P60	6	2	32	9	2	3.3,5,8,12,18	64	CAN/I2C	$19,000
~~NanoPower P31u~~	~~3~~	~~2~~	~~16~~	~~6~~	~~2.5~~	~~3.3,5~~	~~30~~	~~I2C~~	~~$5,250~~

https://gomspace.com/Shop/subsystems/power-supplies/nanopower-p60.aspx

Solar Cell Selection

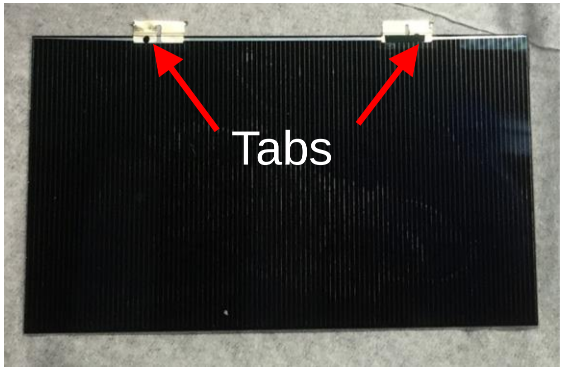
- Commercial panels versus cells
  - $24,000 versus $6,000 (for 20 cells)
- CIC: coverglass-interconnected-cell
- Three finalists for commercial CICs:

	Efficiency	**Surface area (cm^2)**	**Price per cell**	**Lead time (weeks)**
Spectrolab XTJ	30.7%	27.2	$285-310	10-12
Spectrolab UTJ	28.3%	26.6	$300	5-6
Azurspace 3G30A	29.3%	30.2	$302	8-12

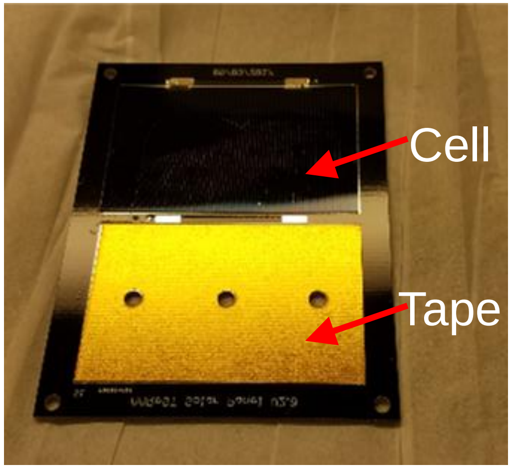
Example Panel Fabrication

- Modified CU Boulder procedure
- Finalized procedure steps:
  - Cut tabs
  - Laser cut double-sided Kapton tape
  - Vacuum bagging
  - Solder and add conductive epoxy

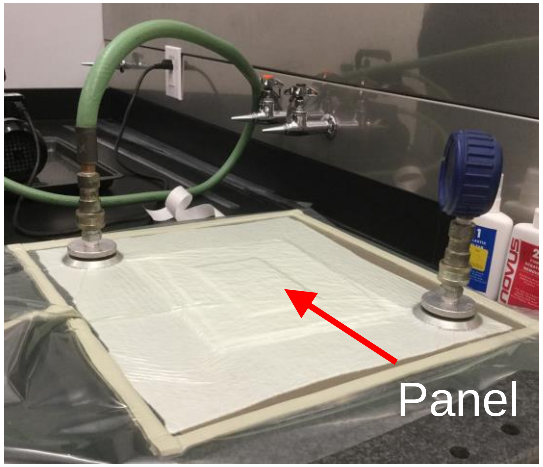
Cut tabs



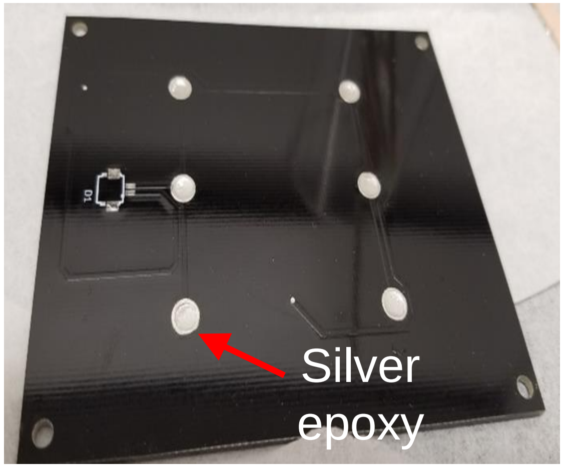
Align tape



Vacuum bagging



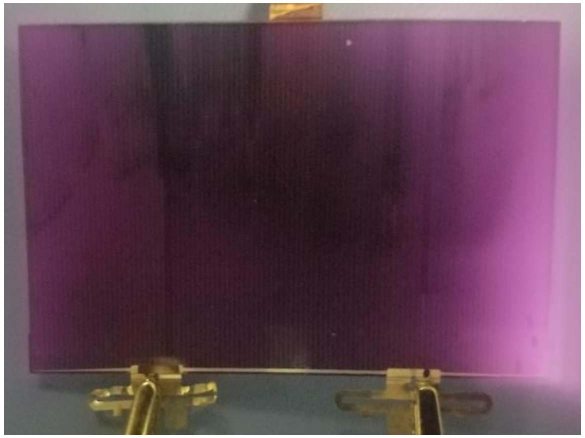
Add epoxy



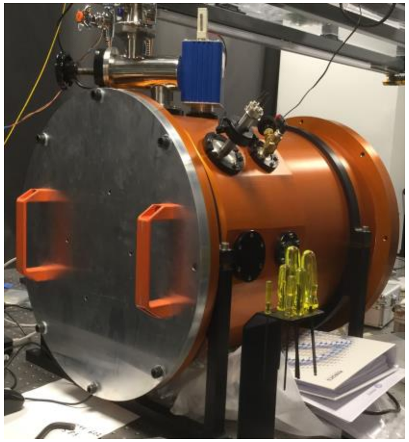
Example Panel Testing

- Fabricated and tested three functioning panels

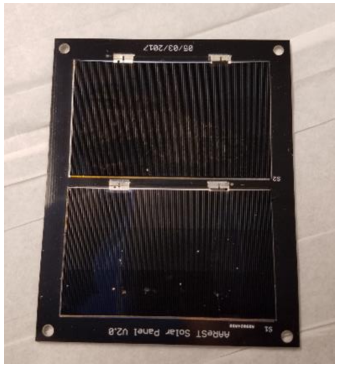
Electroluminescence



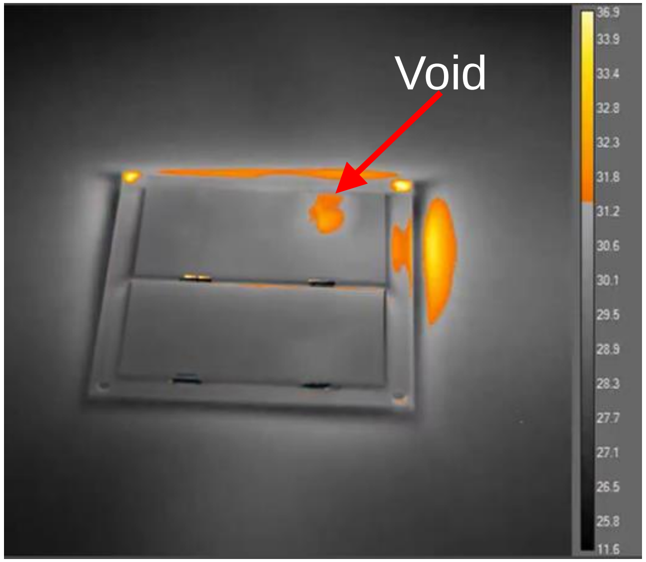
Vacuum



Example panel



IR imaging

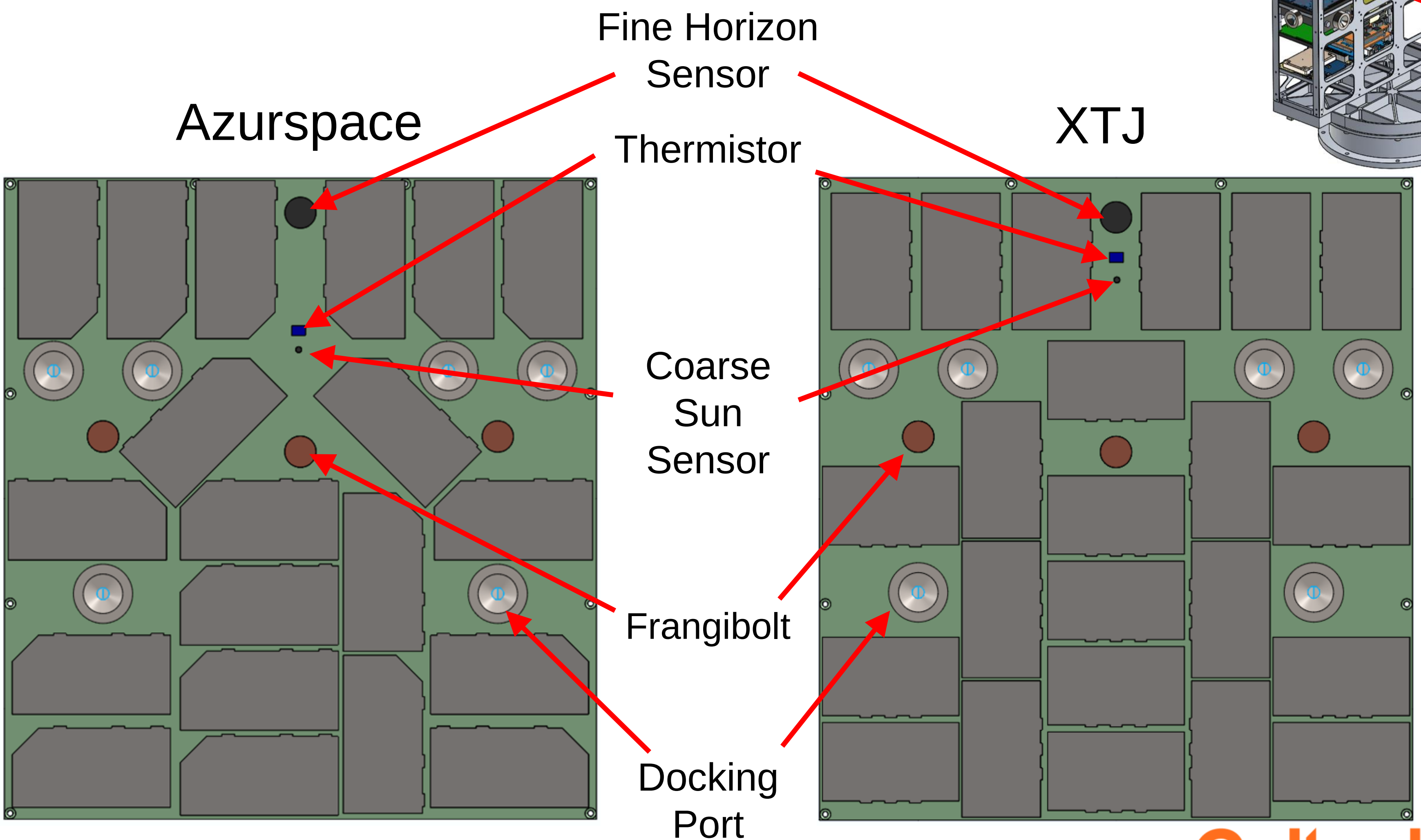


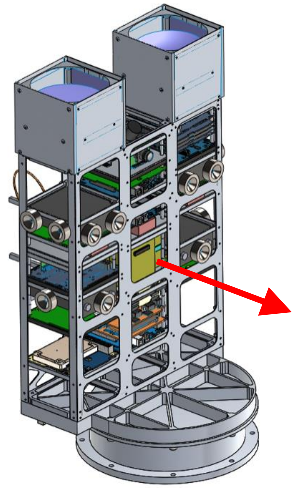
Illumination

	Before fabrication	**After fabrication**
Cell A	6.7 mA, 0.51 V	9.7 mA, 0.63 V
Cell B	5.3 mA, 0.79 V	10.6 mA, 0.78 V
Solar panel	-	11.37 mA, 1.46 V

Caltech

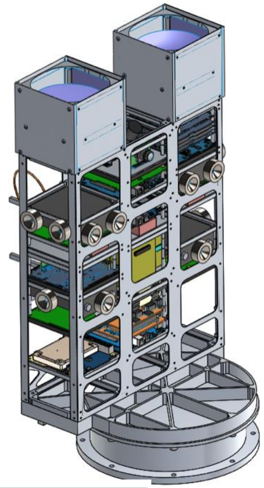
Solar Cells +X Face

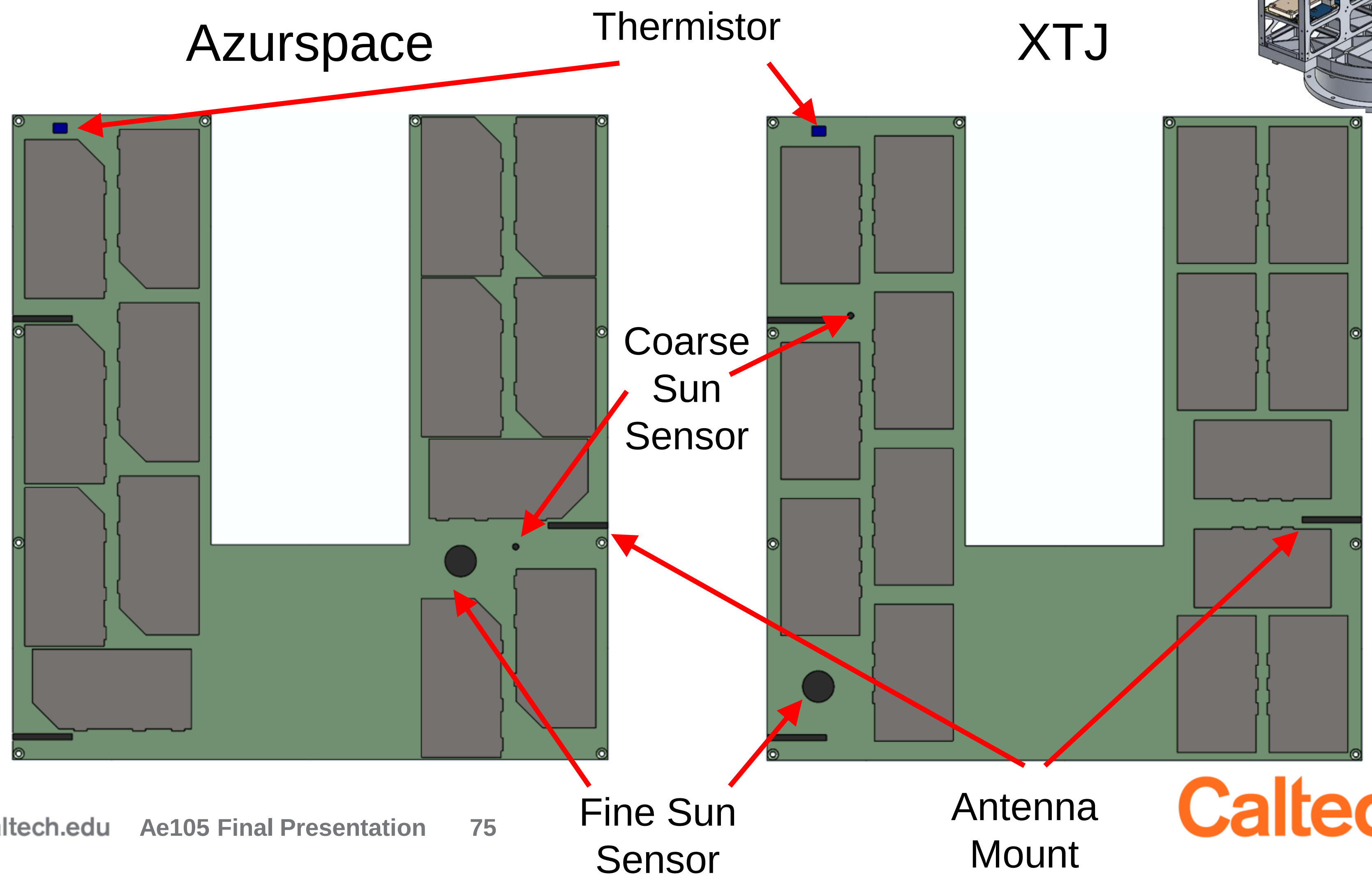




Caltech

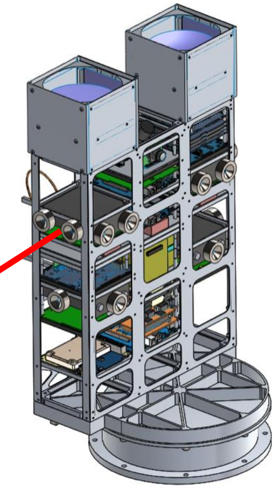
Solar Cells -X Face

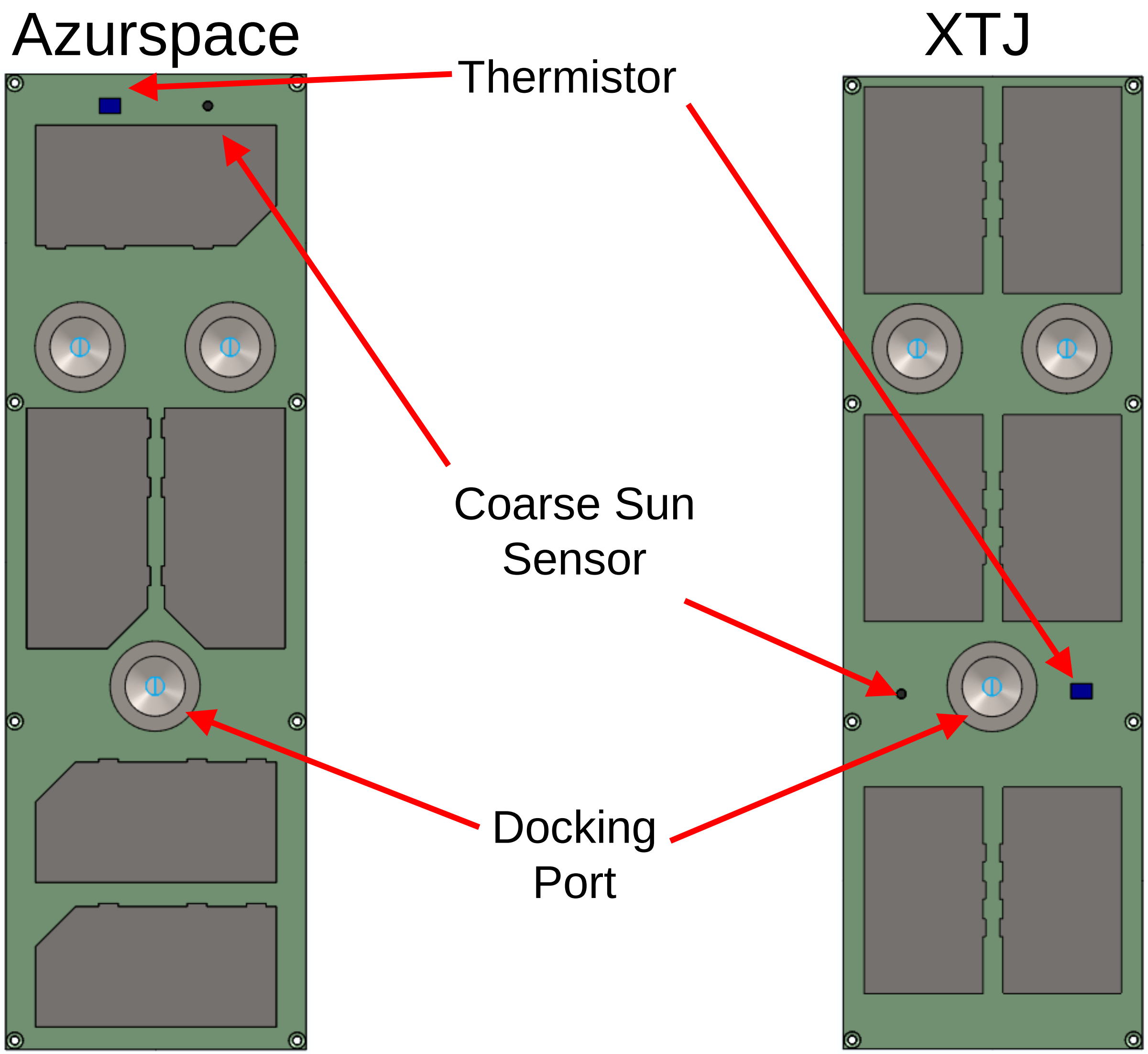




Caltech

Solar Cells +/-Y Face





Caltech

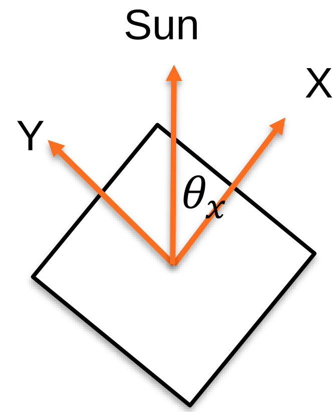
Configuration Analysis

- Azurspace and XTJ are final candidates
- UTJ cells hold no advantages

	-X	+X	-Y	+Y	Total	Power per Cell (W)
Azurspace	18	24	7	7	56	1.21
XTJ	19	27	8	8	62	1.14
~~**UTJ**~~	~~19~~	~~27~~	~~8~~	~~8~~	~~62~~	~~0.95~~

Caltech

Power Generation



- XTJ cells are best option

	Spectrolab XTJ Cells		Azurspace 3G30A Cells	
Orientation	CoreSat (W)	Total (W)	CoreSat (W)	Total (W)
Narrow optimal (θ_x=35°)	18.3	22.6	18.1	22.0
Wide optimal (θ_x=0°)	24.6	35.6	23.2	34.8
Detumble	7.9	12.3	7.6	12.3

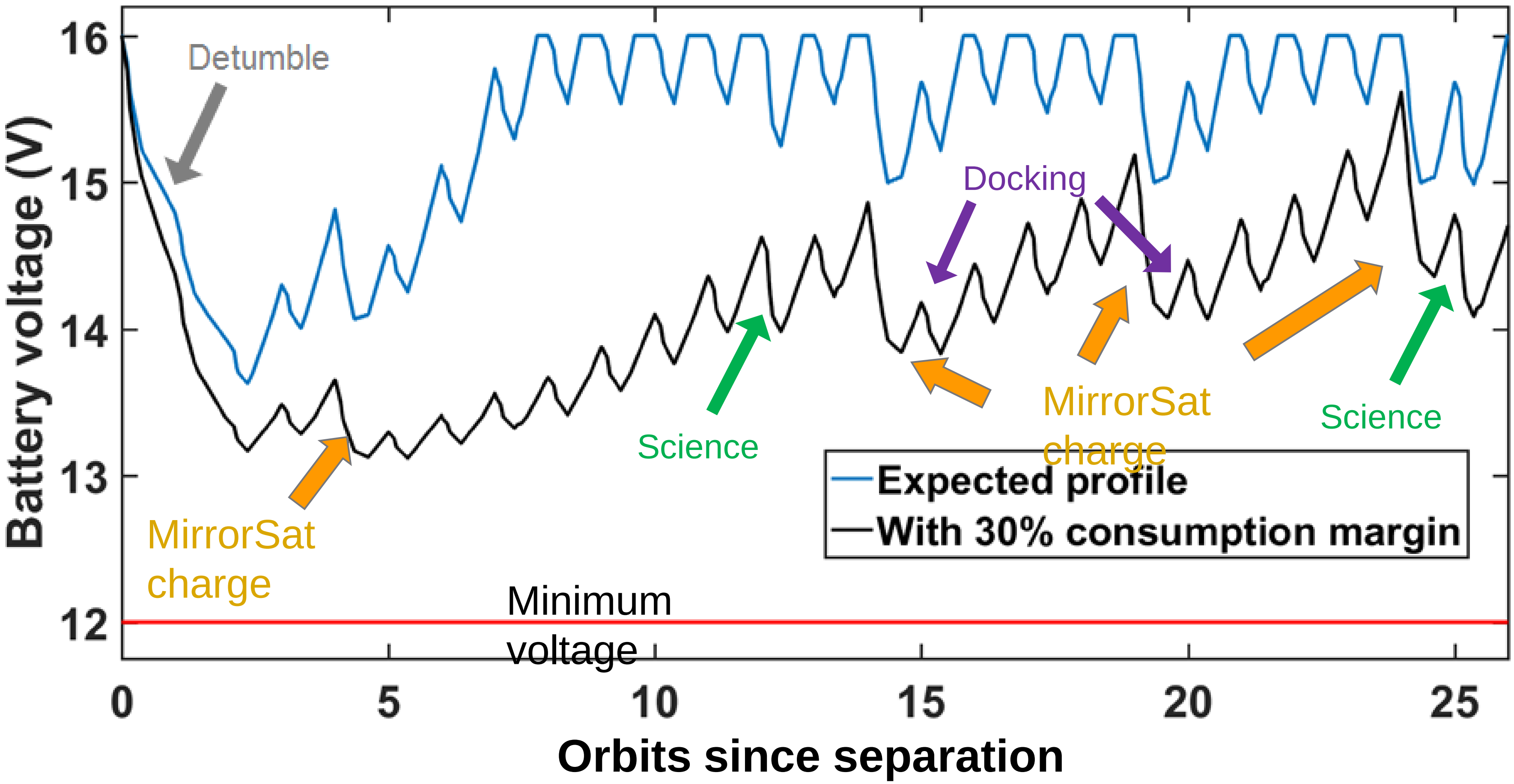
Battery Pack Selection

- GomSpace NanoPower BPX
  - 77 Whr
  - 500 g
  - $8,250
  - Integrated heater
  - 8 week lead time

https://gomspace.com/Shop/subsystems/batteries/nanopower-bpx.aspx

Caltech

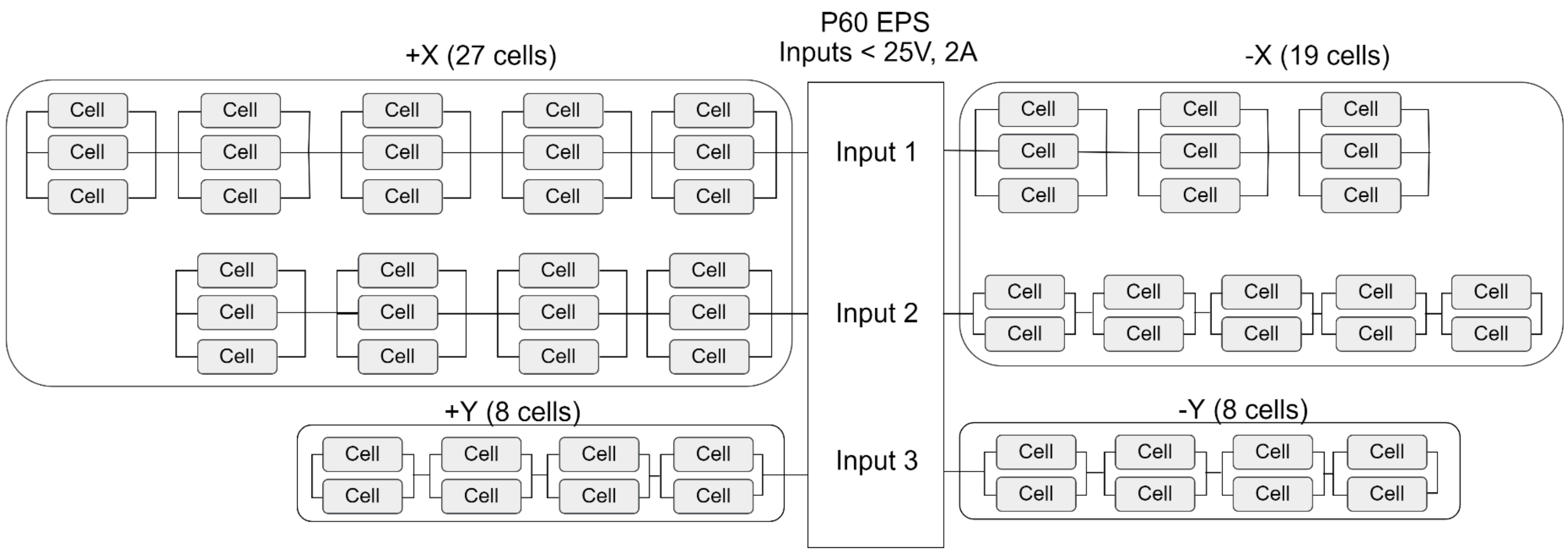
Representative Battery Voltage Profile



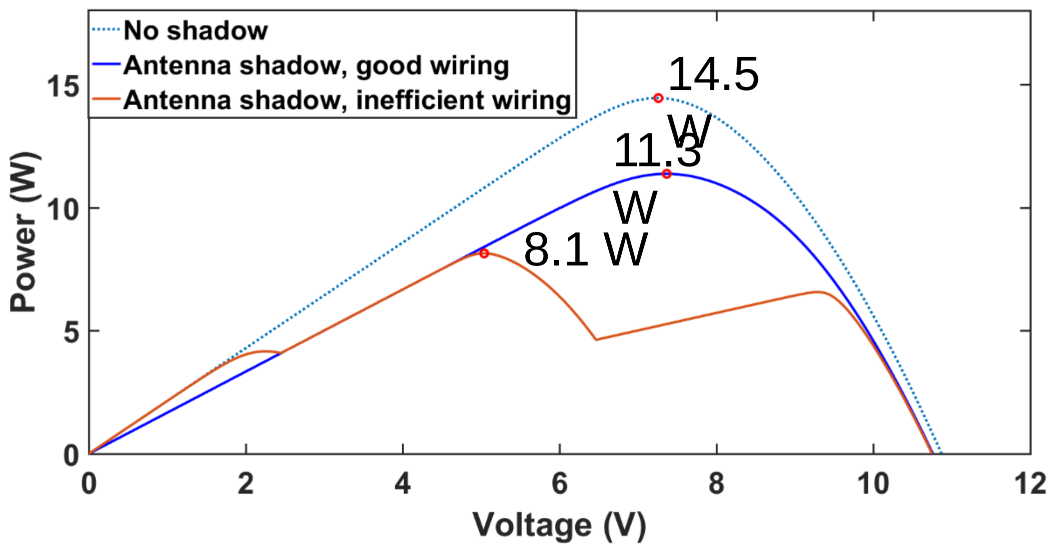
- GomSpace BPX battery (77 Whr) provides sufficient storage
- Noon-midnight sun synchronous orbit, 600 km
- Detumble is largest strain on battery (needs further analysis)

Caltech

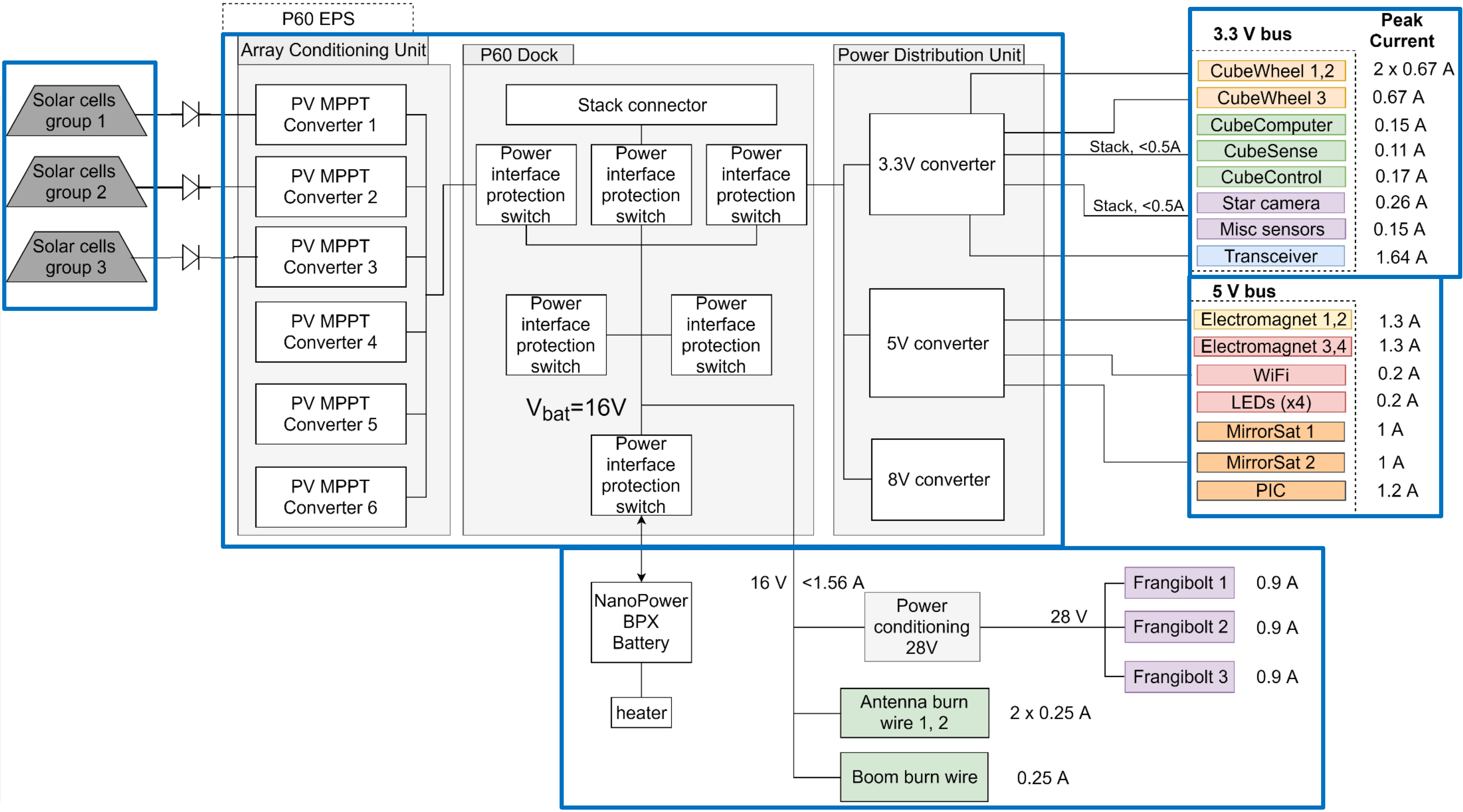
Solar Cell Wiring and Shadowing



- Inefficient wiring of shadowed cells leads to large power losses
- Shadowing due to folded antennas, boom
- Folded antenna shading analysis



P60 EPS System Diagram



- EPS output current requirements can be met for the P60

Summary

- Analyzed power generation and consumption
- Selected components: P60 EPS, BPX battery, XTJ solar cells
- Developed fabrication procedure
- Designed optimal solar cell layout
- Created EPS wiring diagram

Future Work

- Order power system components
- Finalize solar cell mounting configuration
- Fabricate flight solar panels
- Finalize system wiring scheme
- Test components and systems

Questions?

Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

Avionics and Telecoms Team

Nishant Desai

Jorge Llop

Antonio Pedivellano

Eduardo Plascencia

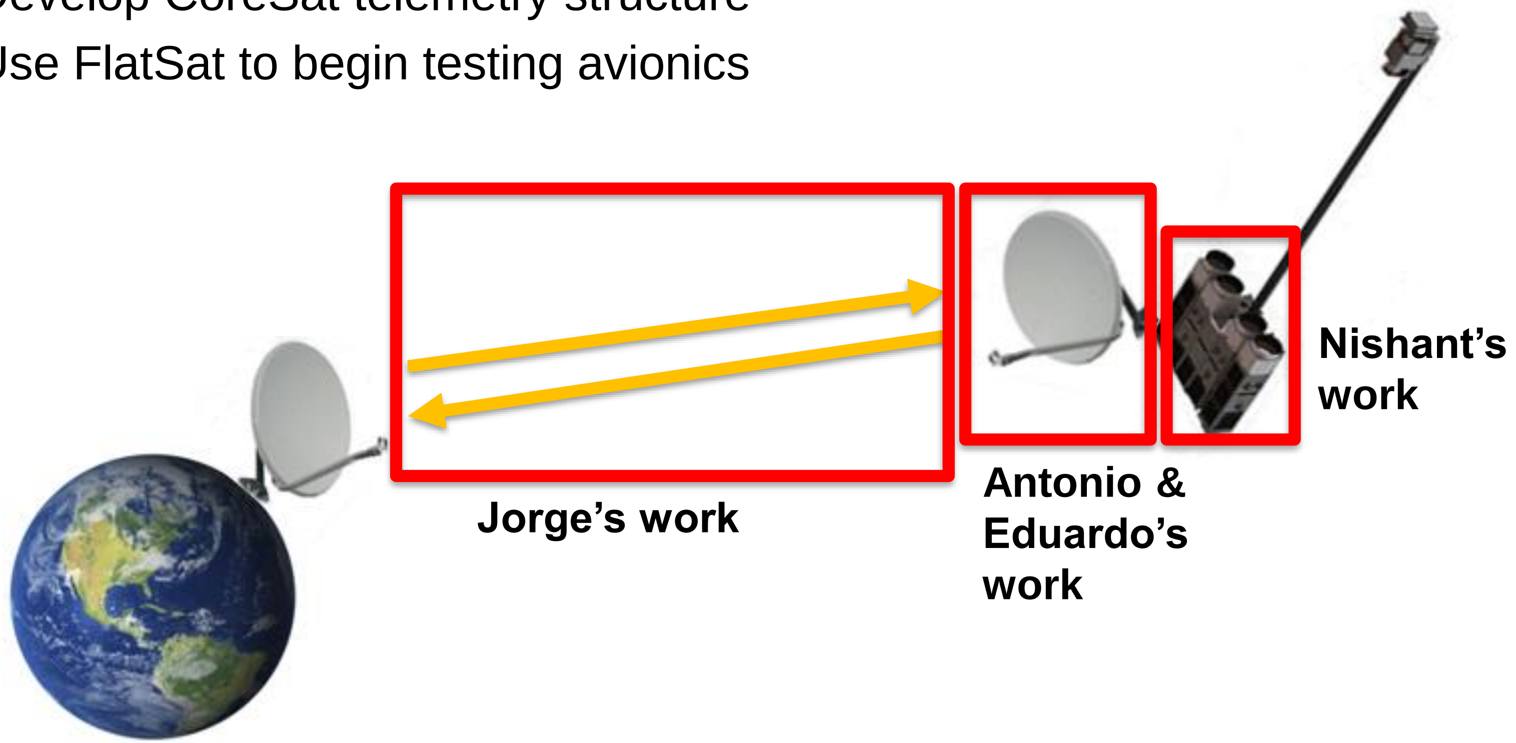
Mentors

Thibaud Talon

Maria Sakovsky

Team Goals

- Design, build, and test communications system capable of establishing data transmission between AAReST and ground station
  - Uplink
  - Downlink
- Develop CoreSat telemetry structure
- Use FlatSat to begin testing avionics



Caltech

Driving Requirements
Avionics

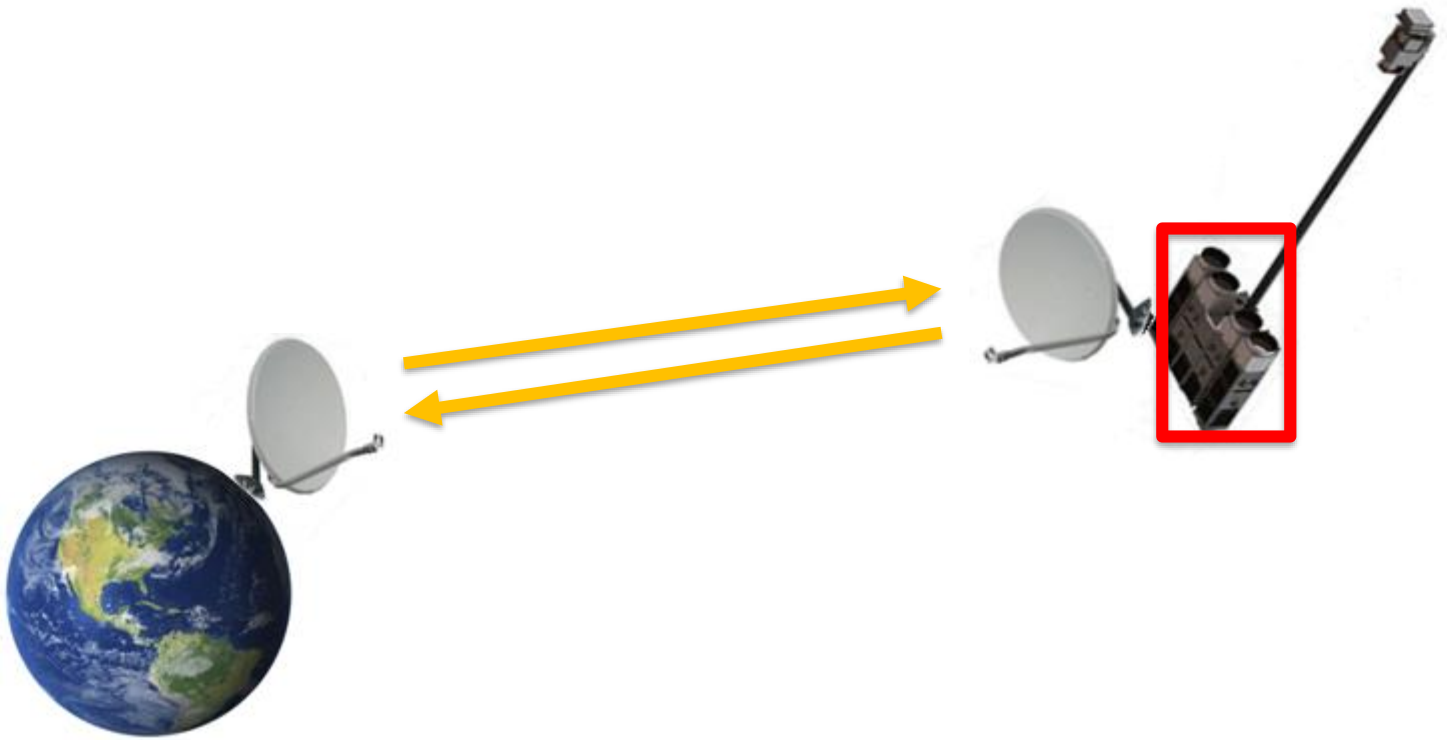
- Need protocols to ensure telemetry, data, and commands are transmitted and received in a reliable, error-free way
- Must use real-time and interrupt-driven software within satellite
- Implement specified On-Board Computer (OBC) interfaces:
  - I^2C
  - UART
- Monitor safety variables of satellite and engage safe mode if needed

Caltech

Driving Requirements
Communications

- Satellite needs to communicate with the ground station using amateur band radio (VHF uplink / UHF downlink)
- Power consumption must stay within the capabilities of the power system
- Antennas must be folded during launch and deployed once in orbit
- Must find an optimal position for the antenna in order to reduce losses due to pointing and EM interference with the CoreSat

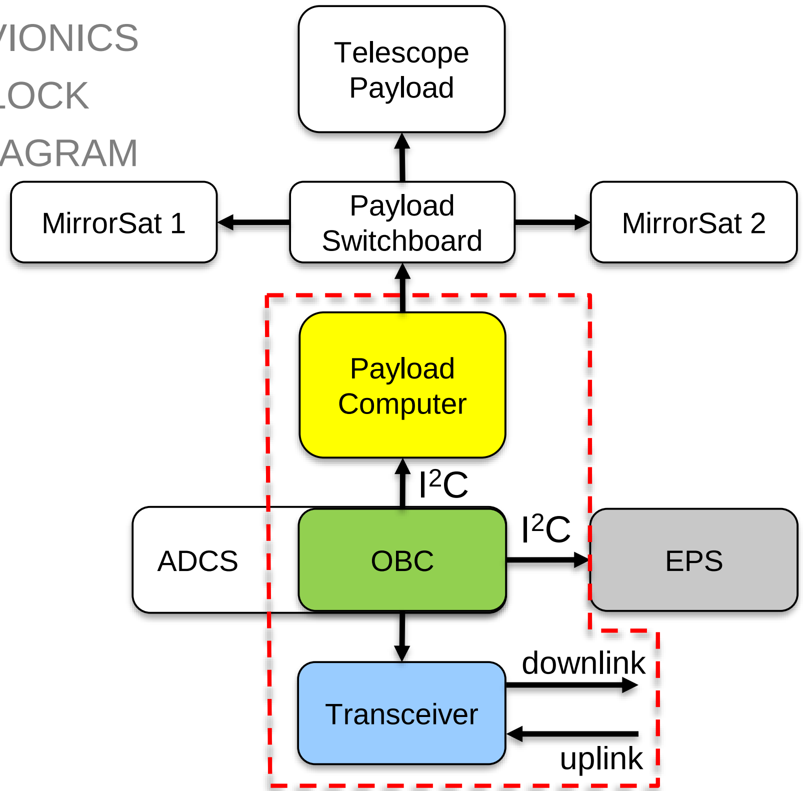
FlatSat



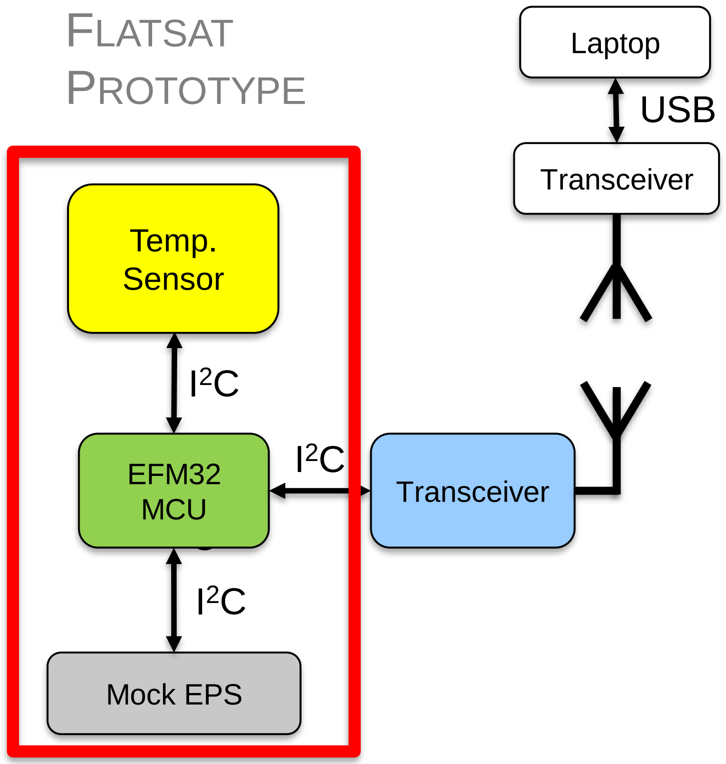
FlatSat Introduction

- FlatSat setup mimics spacecraft electronics for testing

AVIONICS BLOCK DIAGRAM



FLATSAT PROTOTYPE

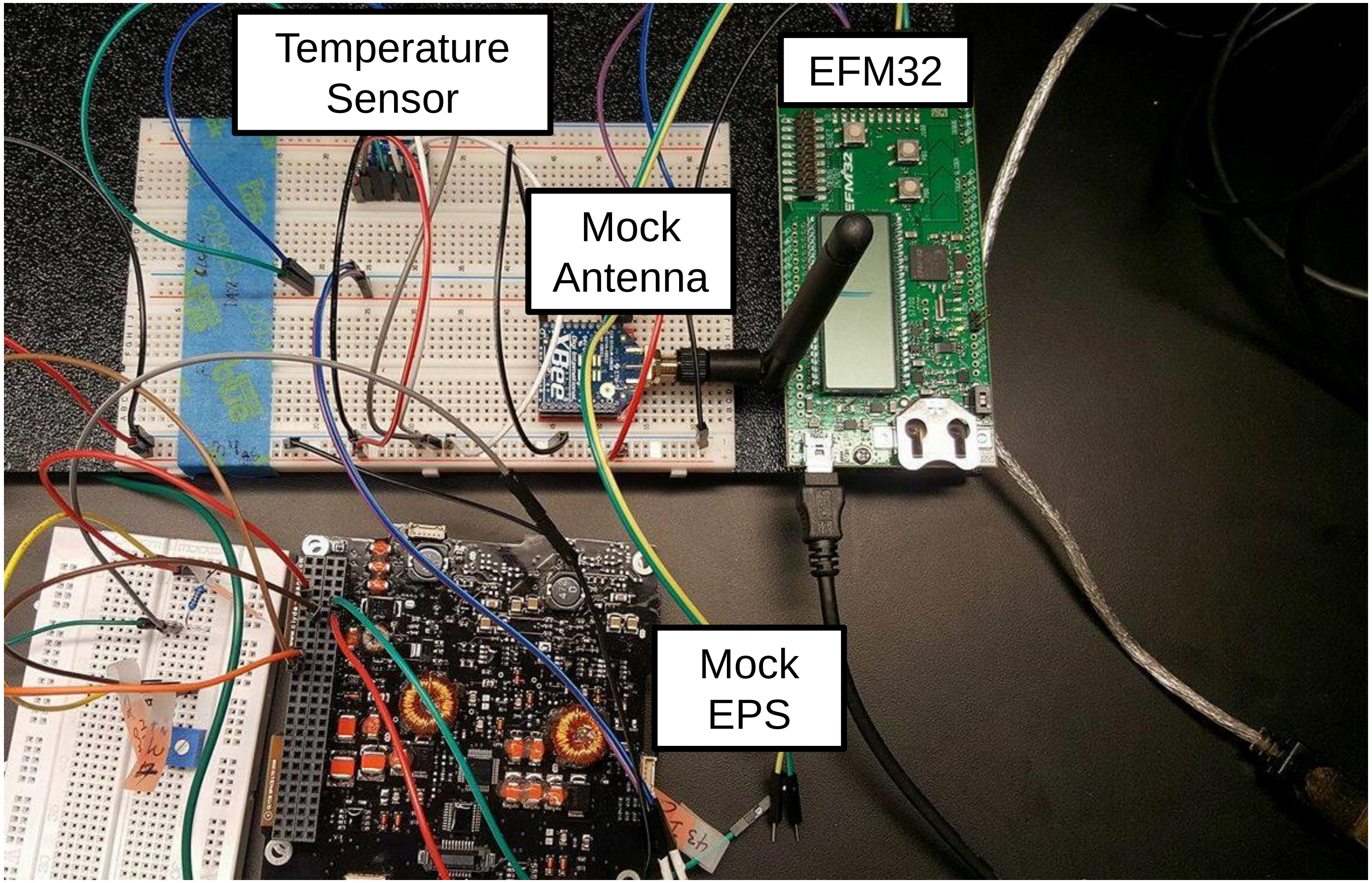


Caltech

FlatSat Introduction

- FlatSat setup mimics spacecraft electronics for testing

FLATSAT IN LAB

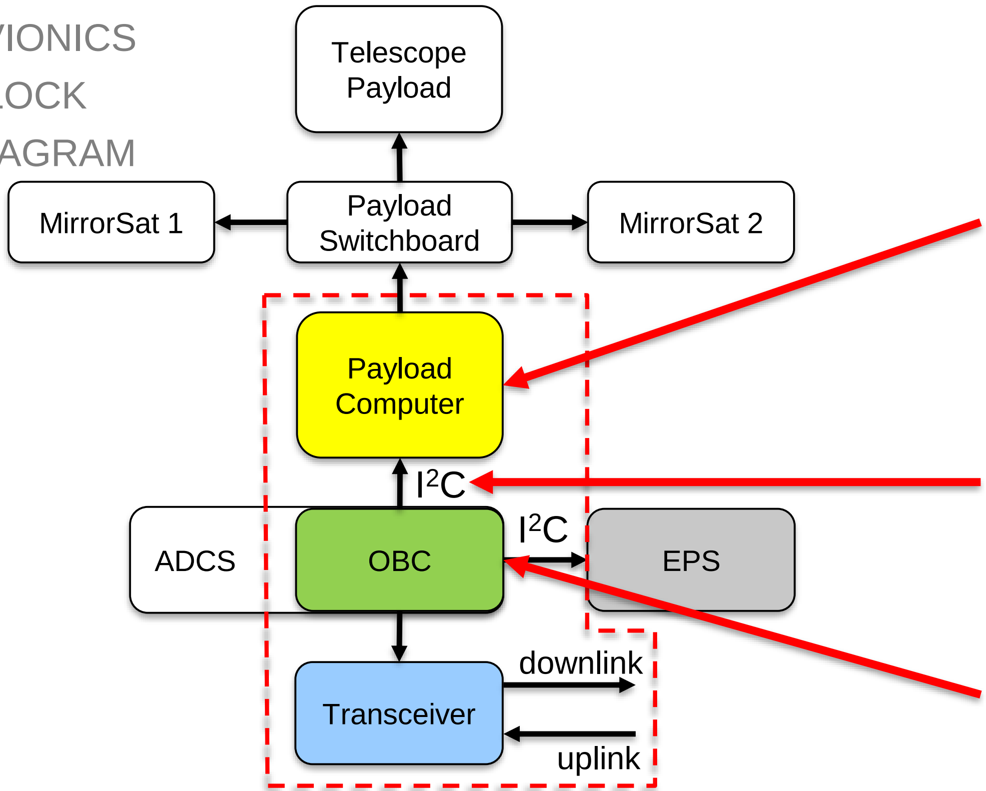


Caltech

OBC Software Architecture

- Software design follows hardware

AVIONICS BLOCK DIAGRAM



Each subsystem gets its own "task": a program on the OBC to talk to it

Subsystem tasks call lower-level tasks like "send/receive over I²C"

Higher-level tasks read information

- All tasks are controlled in real-time: RTOS

Example of a Successful Temperature Read

Temperature task told to check temperature every (e.g.) 1 second

Temperature task tells I^2C task to send message to sensor and read data

I^2C task sends message, reads data, gives data to temperature task

Test: Retrieves room temperature 23.8° C

Test: With finger on sensor, increases to 27.5° C

Caltech

Challenges and Results

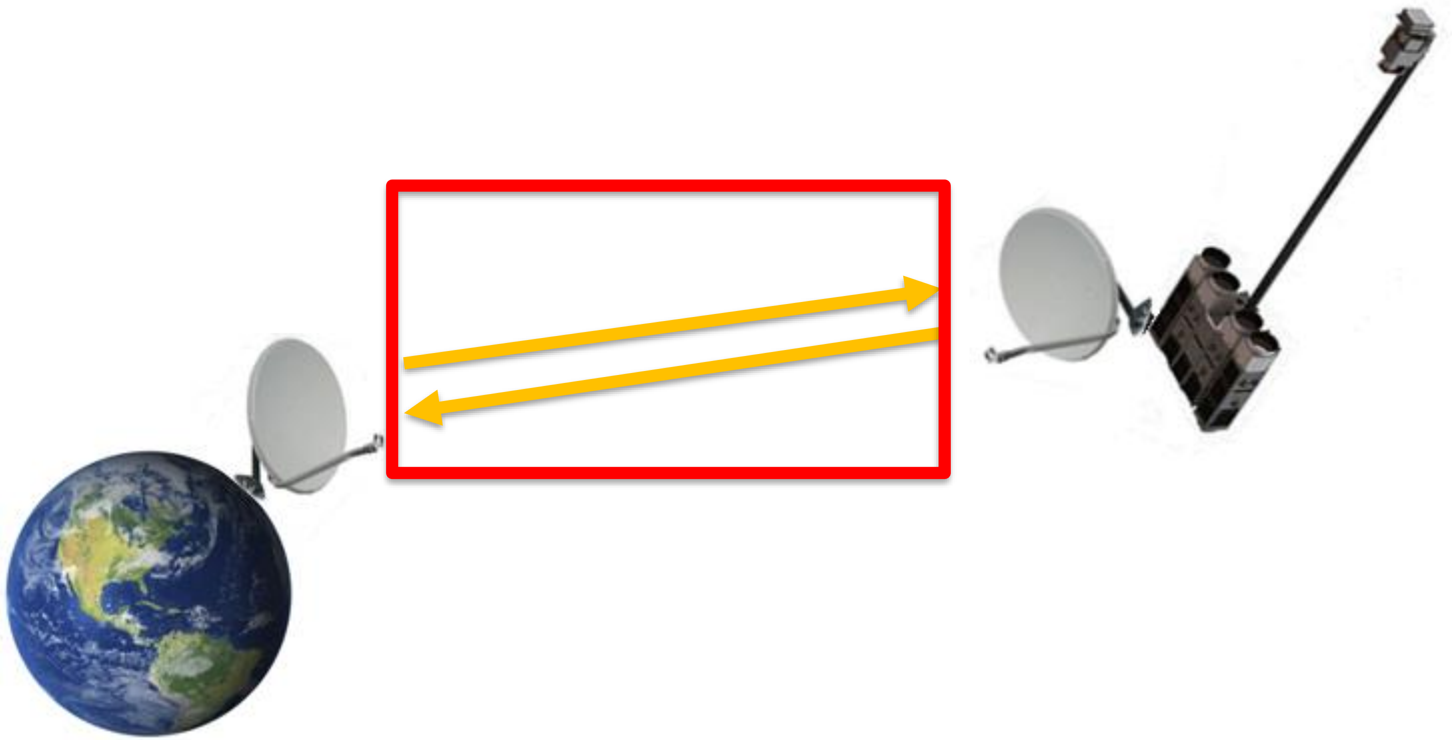
Challenges:

- Compatibility: getting I^2C functions to work with RTOS
- Timing between RTOS and EFM32
- Memory allocation of RTOS

Results:

- Wrote example software to retrieve temperature over I^2C
  - Can be replicated to any I^2C-interfacing component
- Tested software and demonstrated that it works

Telemetry/Telecommand and File Transfer



Caltech

Saratoga File Transfer Protocol

File Transfer Protocol:

- Saratoga protocol is the best fit for the mission: fast, scalable, simple, and robust
- Saratoga protocol has heritage from Surrey missions

Telemetry/Telecommand Protocols

Telemetry protocols:

- HDLC protocol
  - After looking at options like AX.25 and HDLC, we selected HDLC
  - Robust and compact
- Data Scrambler:
  - G3RUH modem design to encode data packet
  - Heritage from Surrey missions

Data packet design:

2 Bytes	5 Bytes	3 Bytes		1 Byte	1 Byte	Variable Length	1 Byte
Decoder Flag	**Callsign (AAReST)**	**Length of Message**	**Number of Increments**	**Group ID**	**Message ID**	**Payload Channels**	**Decoder Flag**

Example:

ADCS Telemetry, spacecraft velocity (v_x, v_y, v_z).

C010	**27FB281A20**	**000e**	**52**	**4D**	**07**	**0x3e9ff4a3**	**0x4090874a**	**0x4090f47a**	**C0**

- 000e: Length of message in Bytes
- 52: Number of increments in sequence
- 4D: Group ID: ADCS
- 07: Message ID: Read ADCS state
- 0x4090874a: V_x, V_y, V_z

Caltech

Telemetry: End-to-End Test

UART

OBC / EFM32

PC/MATLAB code:

- MATLAB code receives Telemetry/Data packet
- This code parses the packet and decodes the Telemetry information

On Board Computer (EFM32):

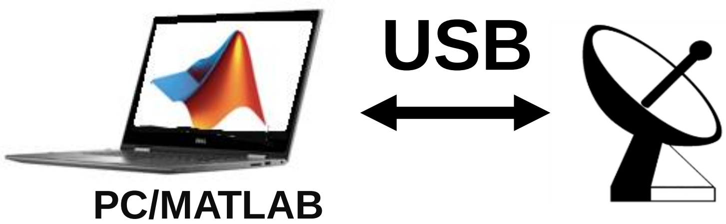
- Telemetry/Data packet builder program is integrated in the OBC
- The OBC (EFM32) sends the Telemetry/Data packet to the antenna

USB

PC/MATLAB

Caltech

Telecommand:
End-to-End Test

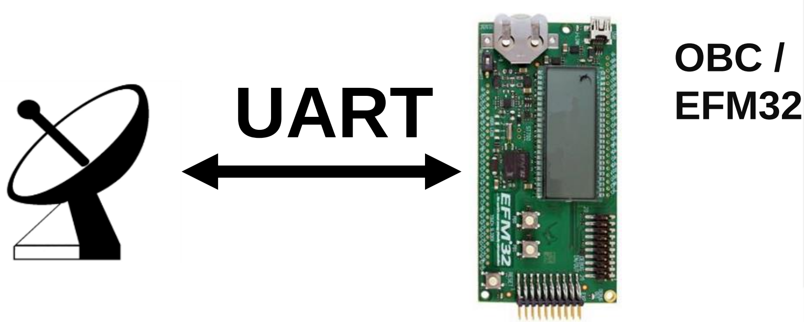


On board computer (EFM32):

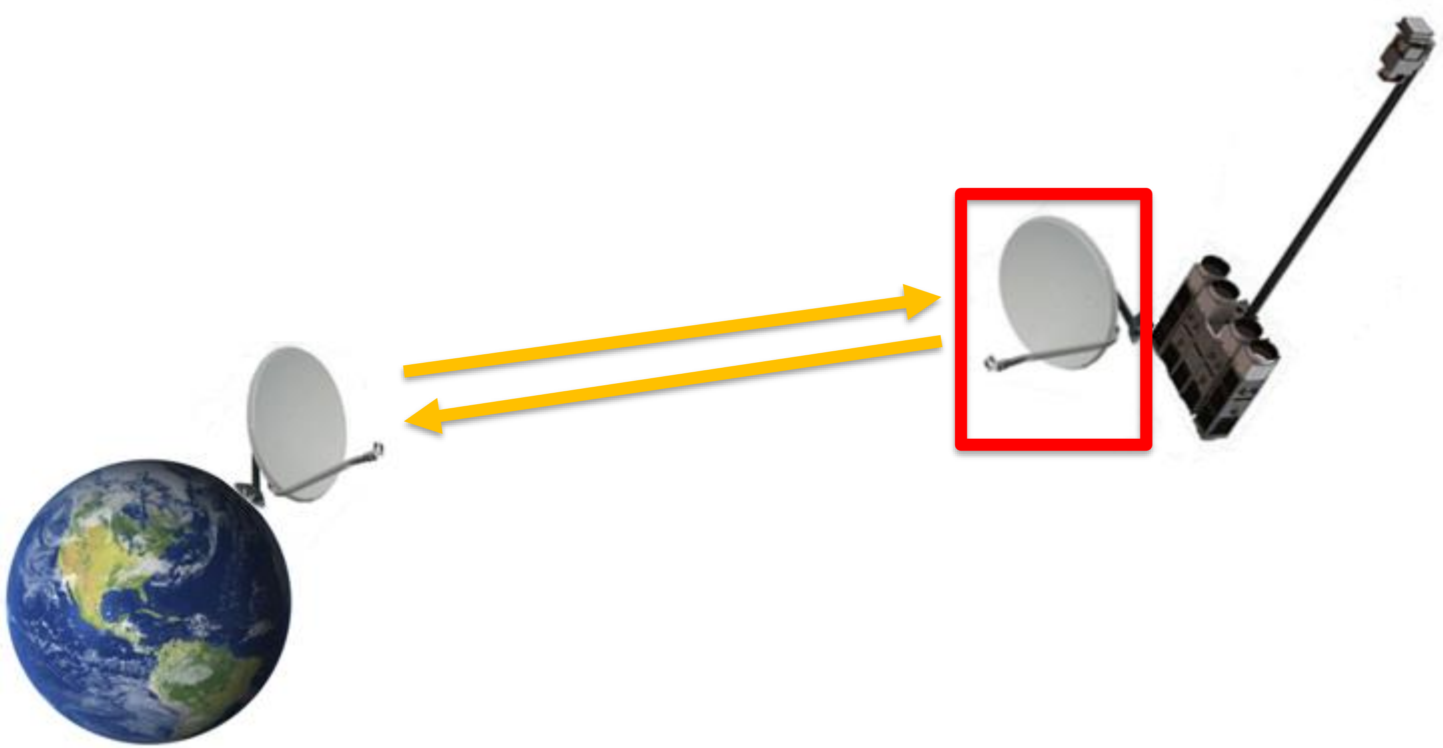
- The Telecommands are received and parsed

PC/MATLAB code:

- MATLAB code builds Telecommand packet using the protocol formatting
- A MATLAB code places the packet on the machine port



Communications

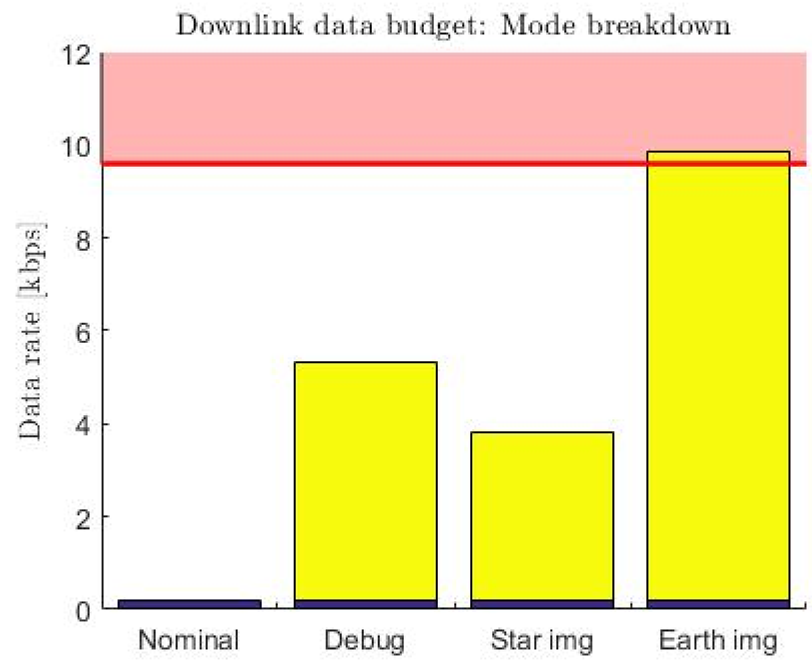


Caltech

Downlink Data Budget

Assumptions

- Downlink at **450 MHz**
- Maximum data rate: **9.6 kbps**
- Average daily communication time: **36.8 min**



Mode	Description
Nominal	Critical state variables
Debug	Log history from subsystem
Star imaging	Windowed images from SD* + SHWS**
Earth/Moon imaging	Full resolution images from SD* + SHWS**

* Science Detector
** Shack Hartmann Wavefront Sensor

Conclusions

- Data exceeding the threshold can still be sent in multiple days
- UHF will be considered for frequency allocation filing

Caltech

Transceiver Selection Criteria

- Transmit at UHF (400-450 MHz) and receive at VHF (100-150 MHz)
- Conforms to CubeSat size format
- Data protocol (HDLC) and bus interface (not I^2C) requirements

Transceiver Selection Results

- Surveyed suppliers on Cubesat.org and AstroDev contact – 7 options considered
- Selected AstroDev Helium transceiver

Product	Transmit Frequency Range (MHz)	Receive Frequency Range (MHz)	Max Downlink Bit Rate (kbps)	Bus Interface	Data Protocol	Flight Heritage
AstroDev Helium Radio	400-450	120-150	38.4	UART	HDLC	Y
~~**SatCOM UHF Digital Radio**~~	~~433-440~~	~~433-440~~	~~>9.6~~	~~UART, CAN~~	~~Modified AX.25~~	~~N~~
~~**ISIS UHF Down/VHF Up Transceiver**~~	~~420-450~~	~~140-150~~	~~>9.6~~	~~I^2C~~	~~AX.25, HDLC~~	~~Y~~

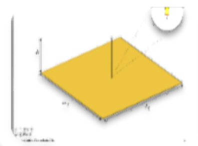
Caltech

Antenna Tradeoff

Design considerations

- Large beamwidth
- Minimize losses
- Space-saving
- Light-weight
- Deployable

Monopole offers a low-cost, light-weight, space-saving and high-gain solution

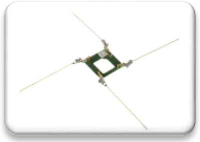


Monopole

- **Pros**: good gain, cheap, easy to manufacture
- **Cons**: Linear polarization, ground plane required

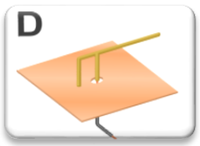
Dipole

- **Pros**: good gain, no ground plane
- **Cons**: very long



Crossed monopoles

- **Pros**: cross polarization
- **Cons**: space limitations

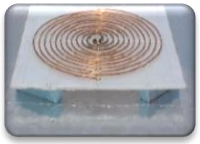


Inverted F monopole

- **Pros**: compact, easily tunable
- **Cons**: Less efficient than monopole, difficult to deploy

Helical antenna

- **Pros**: circular polarization
- **Cons**: Quite massive, difficult to manufacture



Spiral antenna

- **Pros**: Circular polarization
- **Cons**: Large, difficult to manufacture

Antenna Positioning

Bottom plate seems the best location for the antennas

Pros

- Available space
- Far enough from the MirrorSats' magnets

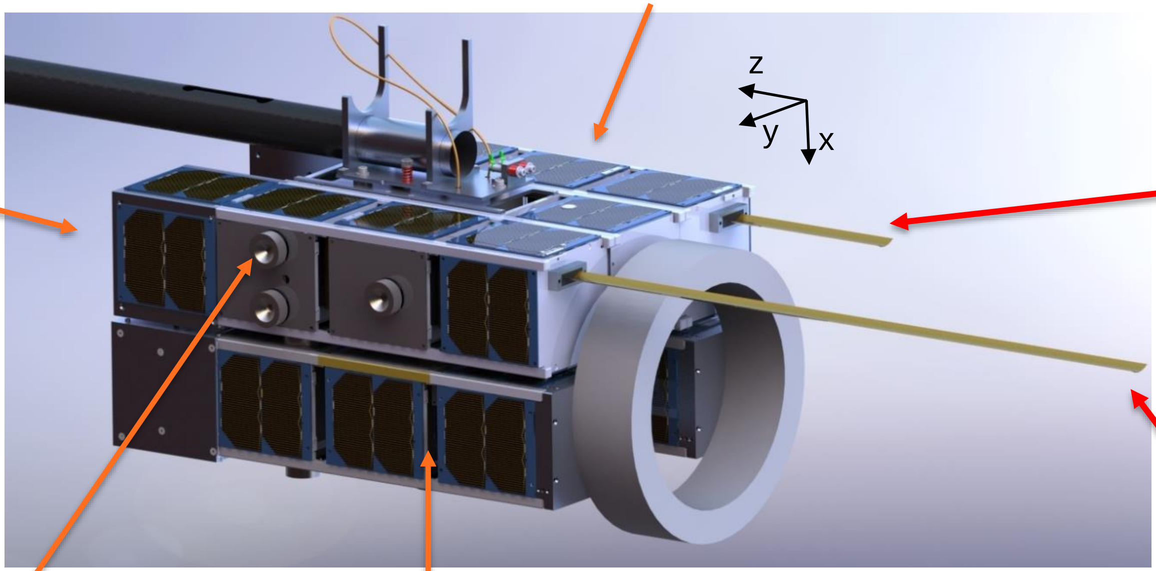
Cons:

- Close to the LVI ring
- EM analyses required to understand its effect on the radiation pattern

Solar panels on –X face

Mirrors on +Z face

170 mm UHF antenna @ 450 MHz



530 mm VHF antenna @ 150 MHz

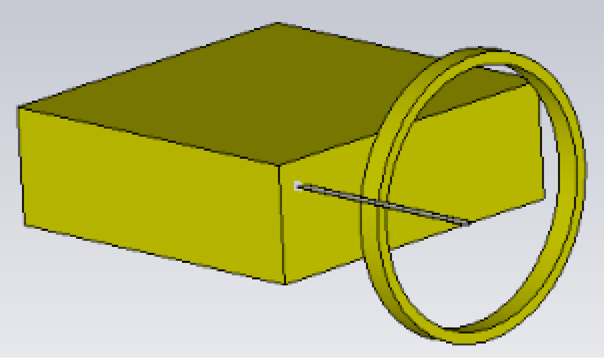
Magnets on ± Y faces

Folded boom on +X face

Caltech

Antenna Simulations

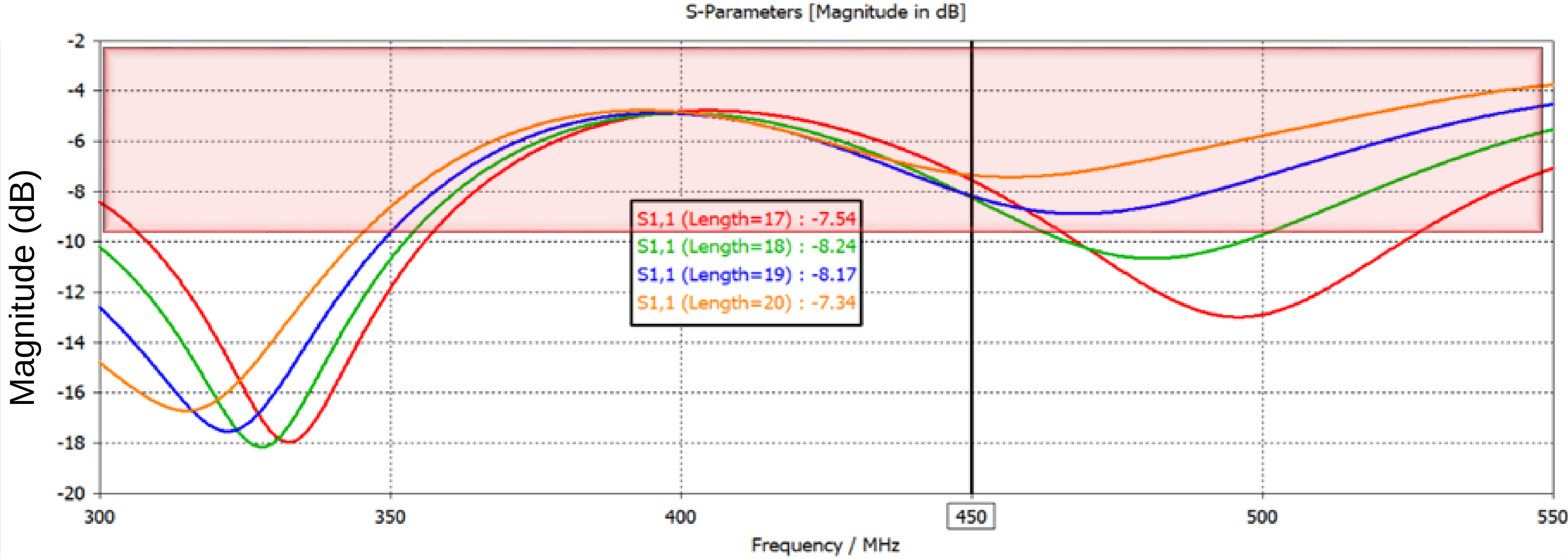
- Ran EM simulations to determine antenna properties
  - Used CST Studio Suite
- Two properties measured
  - S-Parameter $S_{1,1}$, how well antenna accepts electrical power
  - Antenna radiation patterns
- Assume operating frequencies of 150 MHz for VHF and 450 MHz for UHF



CoreSat & UHF Antenna Model with LVI Ring

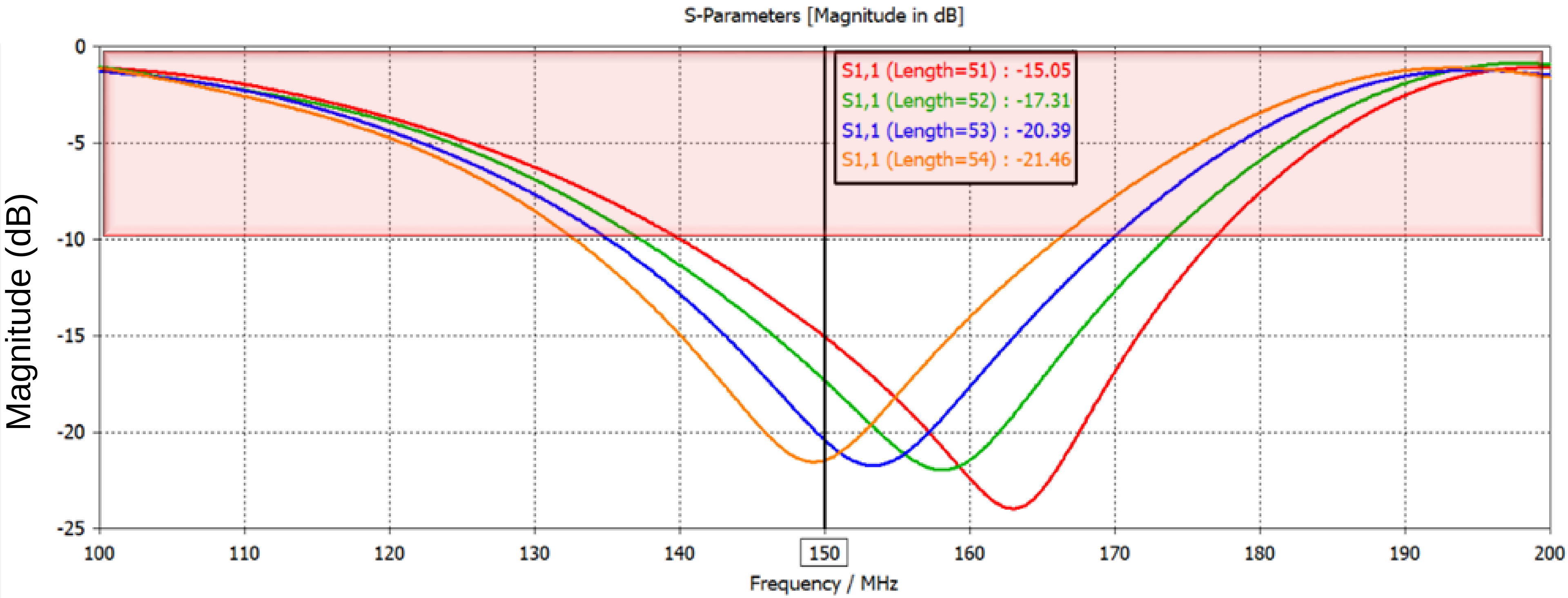
Caltech

Antenna EM Simulations
S-Parameter, UHF



- Requirement to operate with S-Parameter < -10 dB not satisfied here for any antenna length at the operating frequency, 450 MHz.
  - Options include angling antenna, placing it on –X face

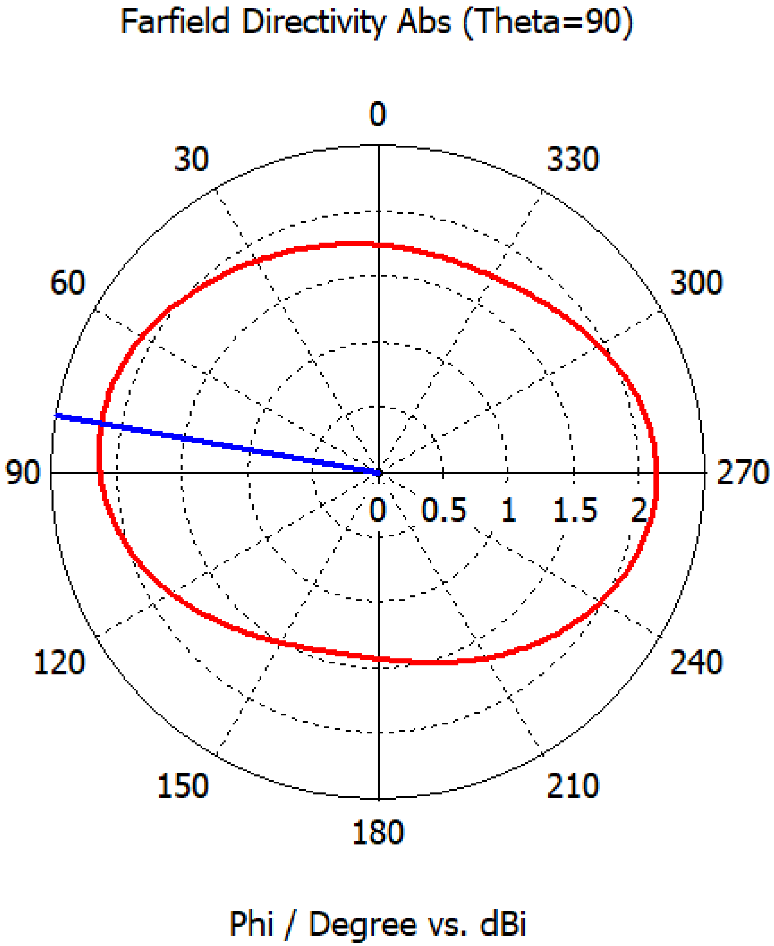
Antenna EM Simulations
S-Parameter, VHF

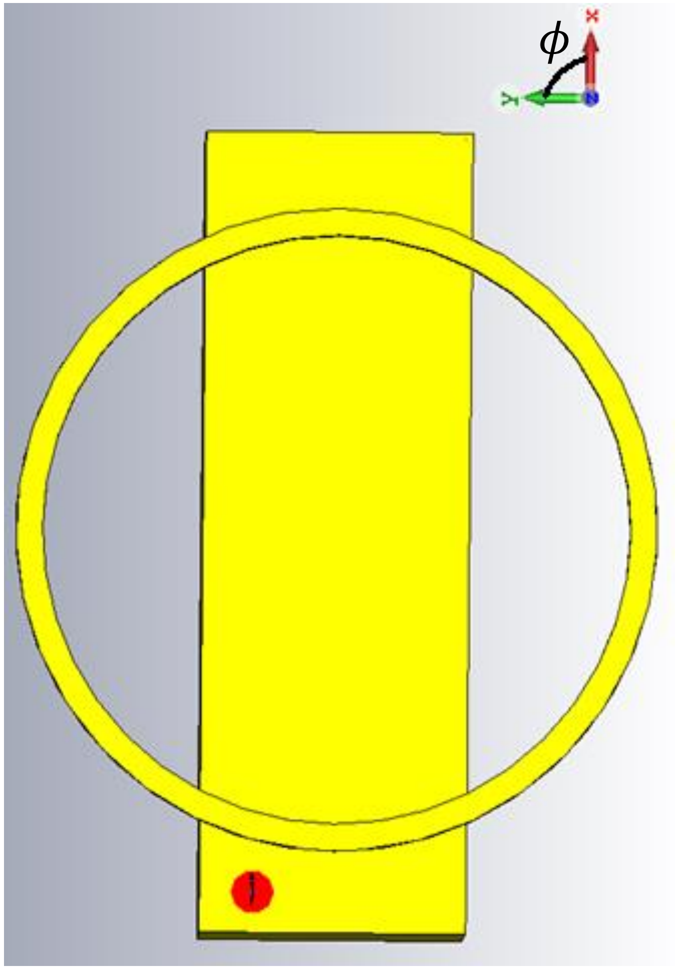


- Requirement to operate with S-Parameter < -10 dB satisfied for desired operating frequency for antenna lengths between 50-55 cm

Caltech

Antenna EM Simulations
Pointing Accuracy, VHF, Theta Plane



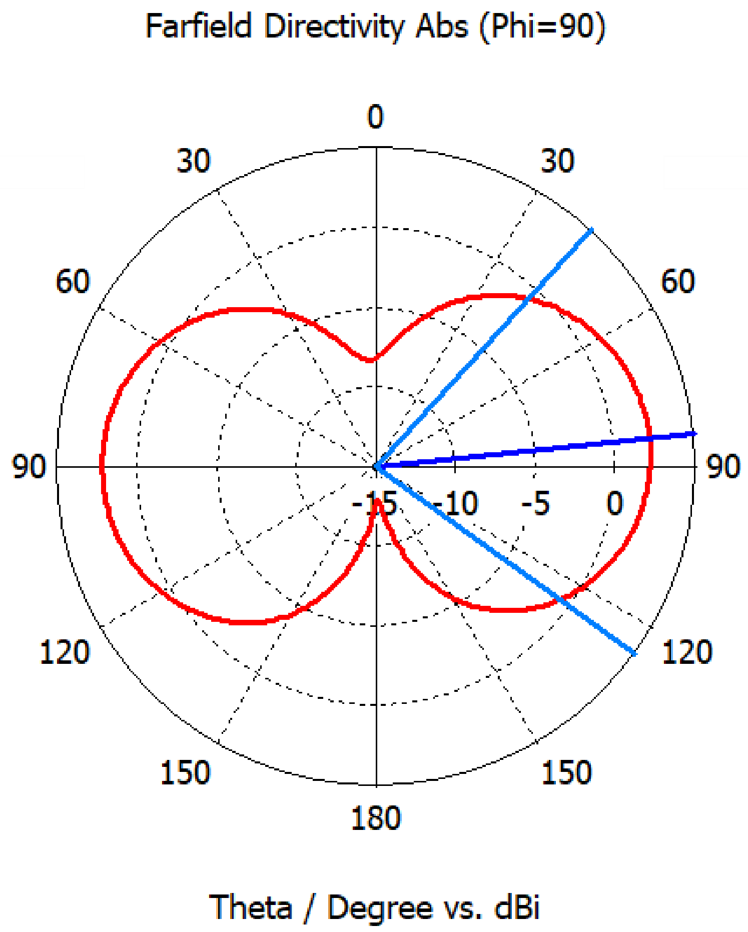


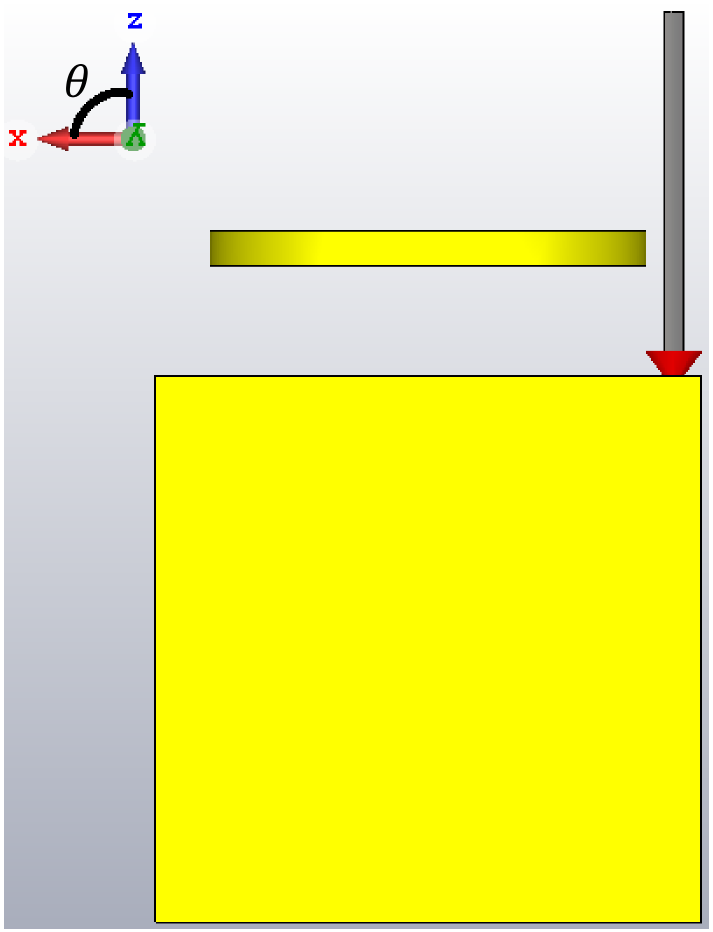
- Completely isotropic radiation pattern in plane, good gain
  - Max gain 2.15 dBi

Caltech

Antenna EM Simulations

Pointing Accuracy, VHF, Phi Plane





- Symmetric radiation pattern, smaller, dual beamwidths
  - 3 dB beamwidth of 83.9° (symmetric), max gain 2.18 dBi

Antenna EM Simulations

Conclusions

VHF: 150 MHz

- Antenna satisfies S-Parameter requirement for lengths between 50-55 cm
- Antenna has large beamwidth, performance close to isotropic

UHF: 450 MHz

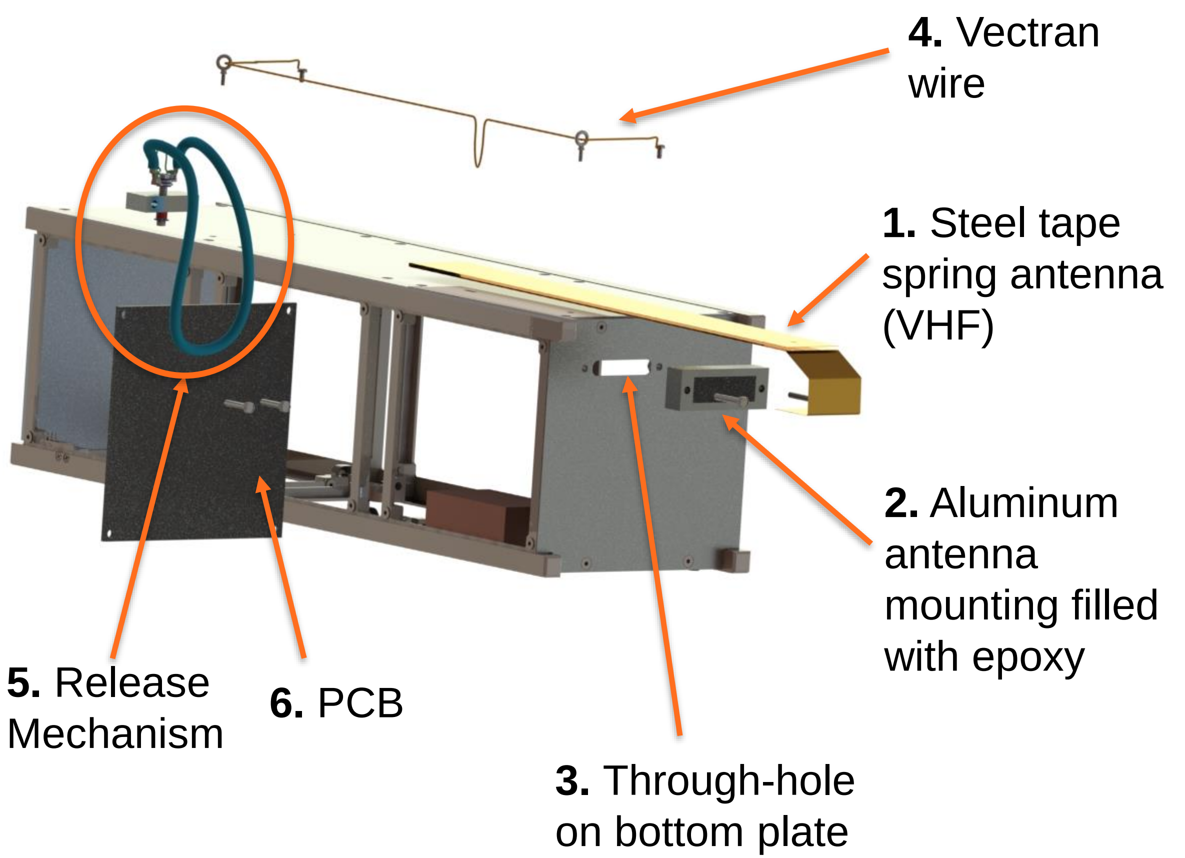
- Best operating lengths between 17-20 cm, but does not satisfy S-Parameter requirement
- Some pointing required to send/receive data
- Low resolution modeling due to limitations of software license; lab EM testing necessary to validate results

Caltech

Structural Design

Requirements

1. Antenna must be stiff and electrically conductive
2. Antenna must be insulated from ground plane and not flattened
3. Antenna must be connected to coaxial cable from transceiver
4. Hold antenna in folded configuration
5. Cut Vectran wire to deploy
6. Optimize space on external surface



Caltech

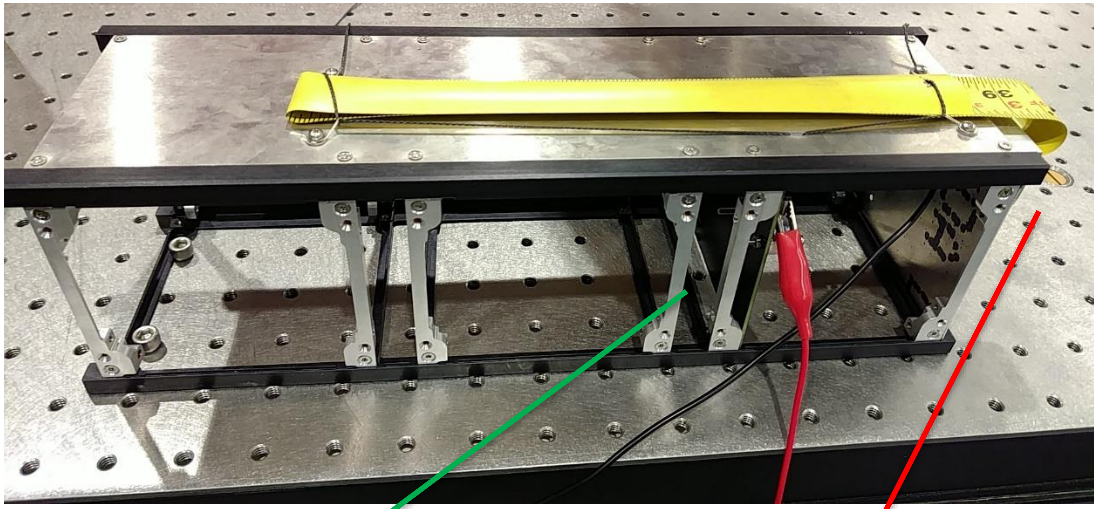
Deployment Tests

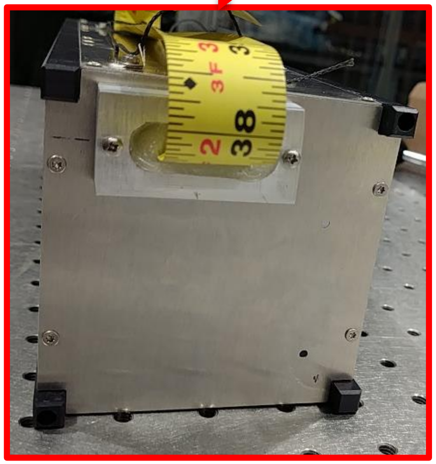
Test Goals

- Deploy against gravity
- Survive vibrations
- Test reliability of the separation device

Status

- Deployment tests in progress
- Vibration tests to be started





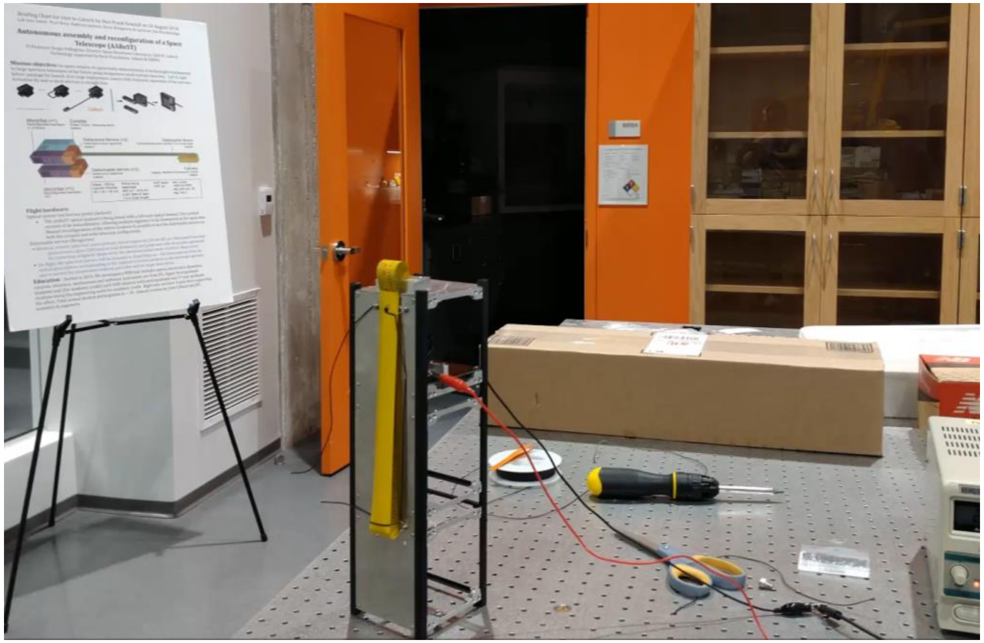
Caltech

Deployment Test

Test Parameters

- 2 A
- 1.2 V
- Deployment time ~22 s

Direction	Number of tests
Horizontal	1
Vertical	2



- Antenna successfully deployed
- Test results used to improve second iteration
- Tests in other directions to be performed soon

Caltech

Future Work

Avionics:

- Add UART low-level task to RTOS
  - Get Telemetry & Telecommands running in real-time
- Fully integrate EPS on I^2C bus
- End-to-end test: sensor read to telemetry receive

Communications:

- Design electrical connection between antenna and transceiver
- Run vibration tests in folded configuration
- Test antenna EM performance to solve $S_{1,1}$ issues

Caltech

Conclusions

Avionics:

- Using FlatSat, wrote example software to retrieve temperature over I^2C with real-time control
  - Demonstrated that the program works
- Protocols defined for Telemetry, Telecommand, and file transfer
  - Data packet design completed
- Demonstrated downlink communications in the lab. Uplink telecommand communications requires debugging
- Beacon list needs to be completed

Communications:

- Downlink data budget completed
  - More details about debug mode may be required
  - Uplink data budget to be done
- Chosen COTS transceiver
- Completed preliminary EM analyses
- Completed second iteration of structural design for UHF/VHF antennas
- Deployment procedure designed and tested

Thank you!

Questions?

Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

Attitude Determination and Control System (ADCS)

Team:
Carmen Amo Alonso
Patrick Hsu
Michael Marshall
Victor Venturi

Mentor: Daniel Pastor

Caltech

Term Goals

- Requirements development
- Hardware selection (reaction wheels, sensors, etc.)
- Magnetic disturbance modeling (during docking and science operations)
- Simulator development
  - Orbital and attitude dynamics, disturbance torque models
  - Controller and estimator
- Detumble analysis
- Hardware test plan

Legend:
Complete
In Progress
Future Work

Caltech

ADCS Driving Requirements

Detumble:

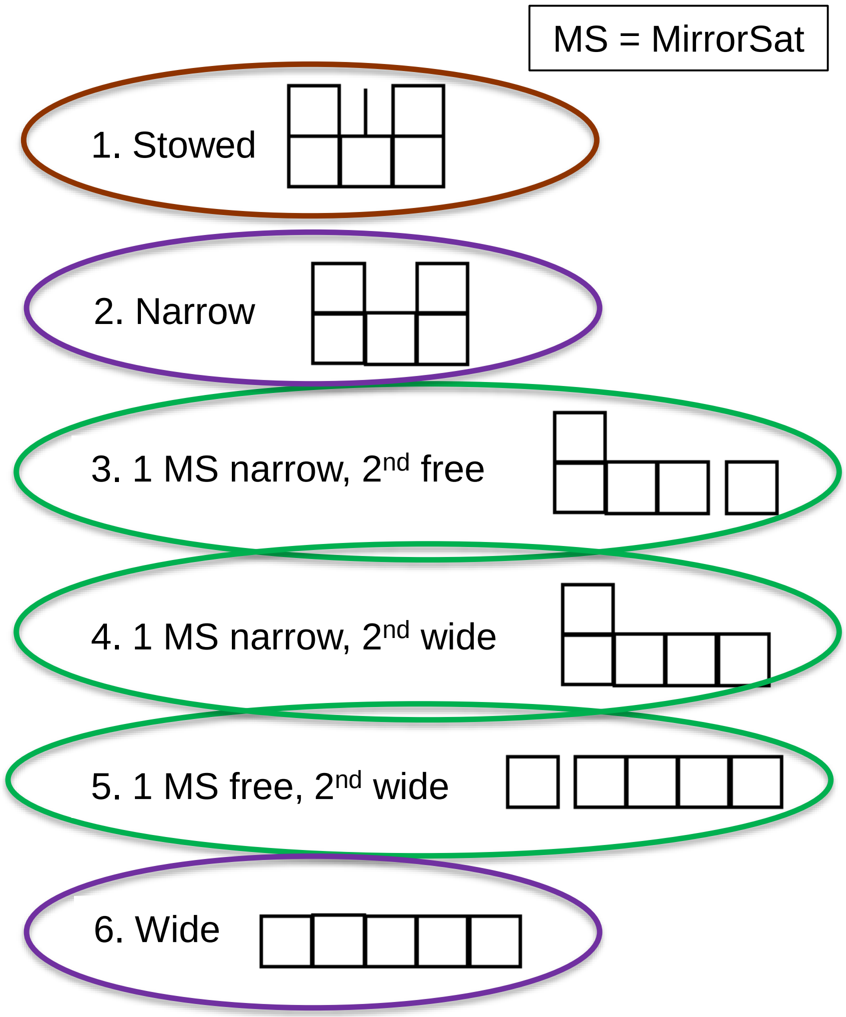
- Reduce body angular rate $< 0.3°/s$

Science:

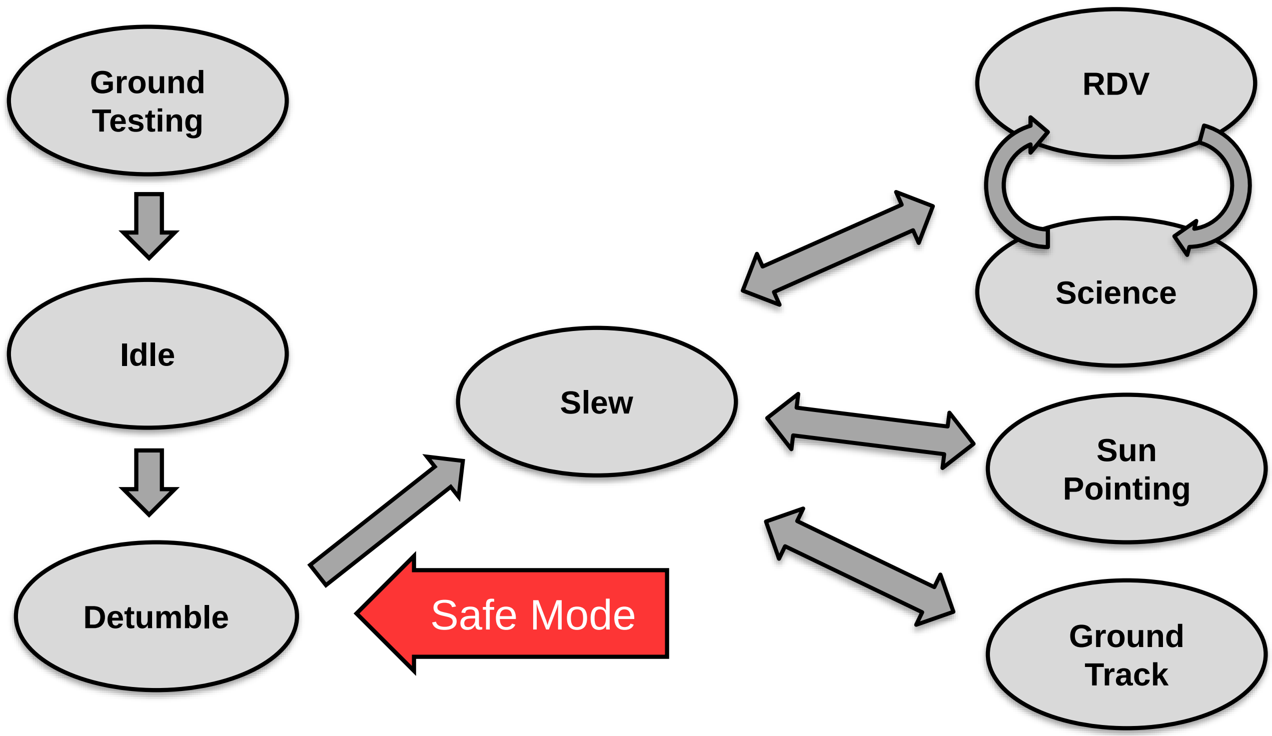
- Pointing accuracy – error $< 0.1°$ 3σ per axis
- Attitude stability – jitter $< 0.02°/s$ 3σ for 600s during science operations

Rendezvous and Docking (RDV):

- Rotate 90° in 60s about boom axis



Operational Modes



- Detumble is Safe Mode

Caltech

ADCS Generated Requirements

Operational Mode	Additional Requirements	Relevant Team(s)
Testing	• Achieve expected torque values and directions (ground console control)	• ADCS – Double check hardware functionality
Detumble	• Body angular rate < 0.3°/s • Complete this within 4 orbits	• ADCS – Reduce angular rate to be manageable by reaction wheels
Slew	• Bring satellite within 1° of desired pointing attitude	• Telecomm – Reorient for antenna • Power – Reorient for charging • ADCS – Reorient for star pointing
Ground Track	• Track ground station to TBD degrees	• Telecomm – Point antenna to ground station
Rendezvous and Docking (RDV)	• N/A	• N/A
Sun Pointing	• Maintain ± 10° of optimal charging angle	• Power – Allow for most efficient charging
Science	• N/A	• N/A

Caltech

Hardware Selection Criteria

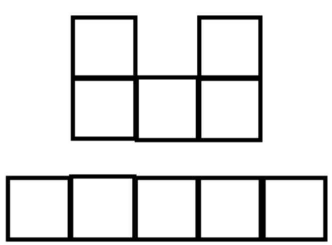
- Meets ADCS requirements (e.g. accuracy during science operations)
- Want integrated solution that includes all sensors and actuators (e.g. reaction wheels, star tracker, computer, etc.)
- Reaction wheels:
  - Need to consider different operational modes and spacecraft configurations
  - Capable of rejecting worst-case disturbance torques and executing required slew maneuver during RDV

Caltech

Reaction Wheel Sizing

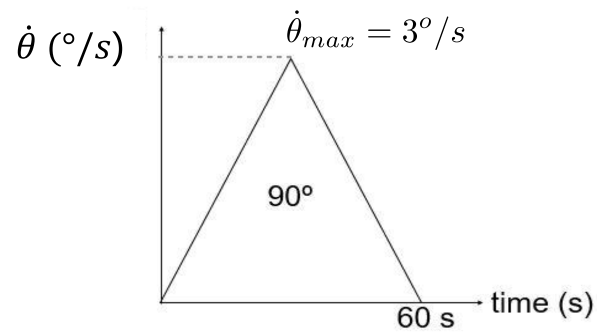
Science:

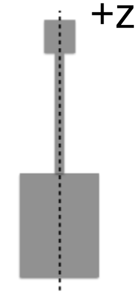
- Requirements –
  - Accuracy - 0.1° pointing accuracy
  - Drift - 0.02°/s for 600s
- Disturbance Torques –
  - Gravity gradient: ~ 10 μN-m
  - Magnetic: ~ 1 μN-m
  - Drag: ~ 1 μN-m
- Configurations –



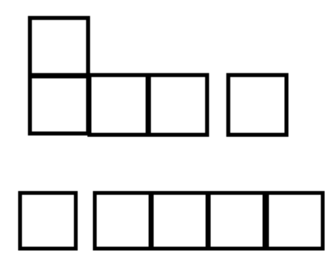
RDV:

- Requirements –
  - Rotate 90° in 60s
- Slew Maneuver –





- Configurations –



Caltech

Hardware Options

CubeSpace 3-Axis ADCS	Blue Canyon XACT-50 ADCS	Maryland Aerospace ADCS
Size: < 0.7 U Pointing accuracy: < 0.1º RMS all axes	Size: 0.75 U Pointing accuracy: 0.003° (x2) & 0.007°	Size: 0.52 U Pointing accuracy: 0.1° all axes
Flight heritage in progress	Extensive flight heritage	Some flight heritage
$52,000	$145,000	~ $?

- Maryland Aerospace – eliminated due to insufficient angular momentum storage to meet requirements
- Blue Canyon – eliminated due to excessive cost
- CubeSpace – least expensive option that meets requirements

Caltech

ADCS Simulator - Overview

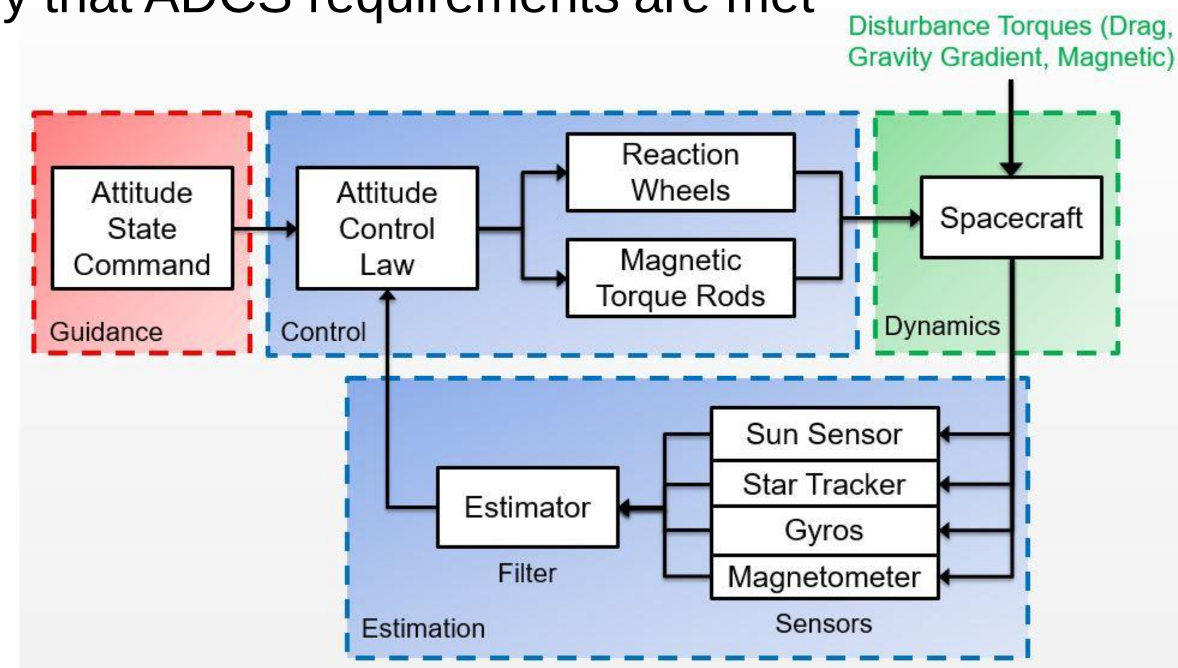
Goal:

- Model the complete ADCS (in Simulink)
- Execute "day in the life" simulations

Importance:

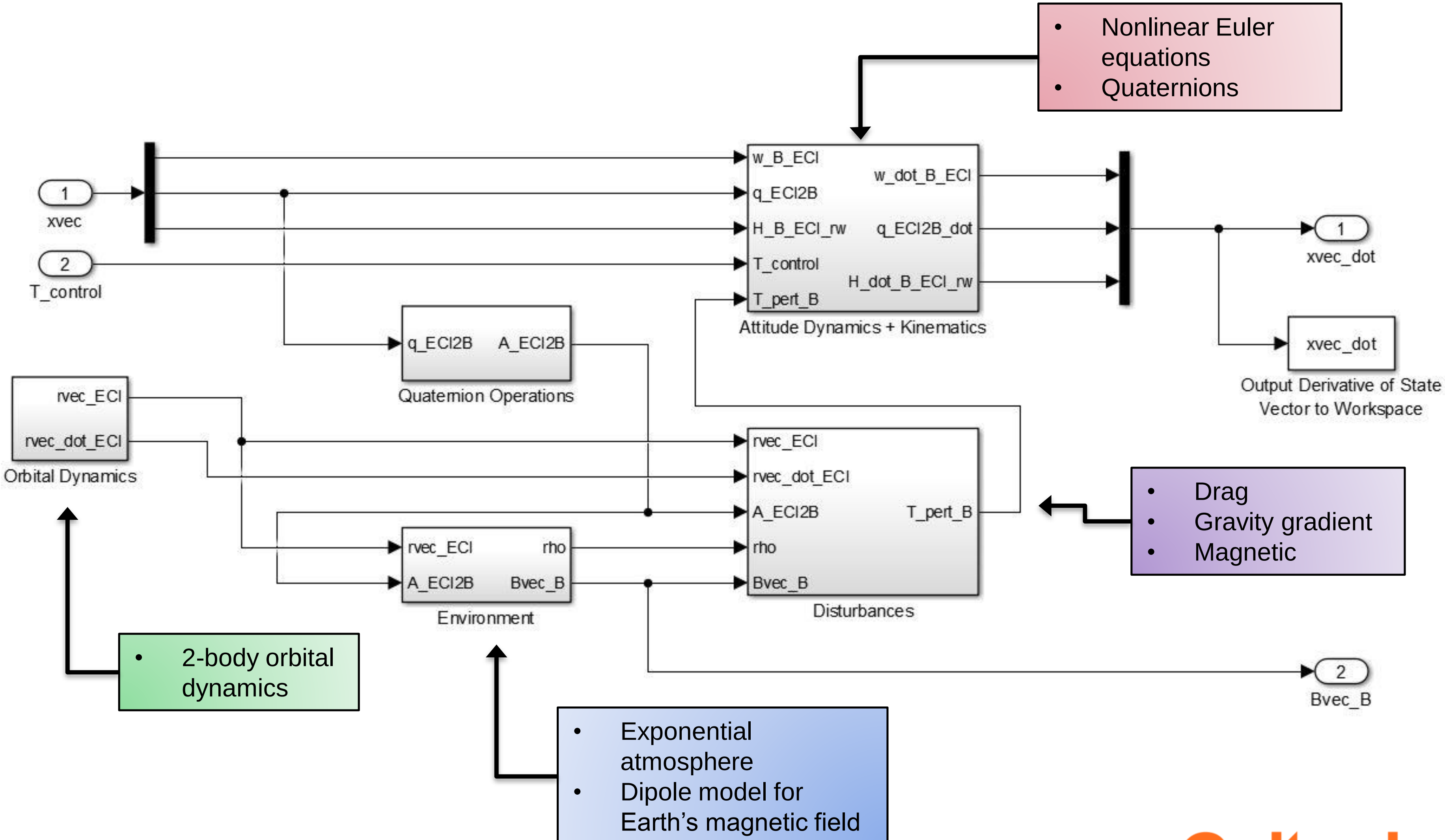
- Simulator used to verify that ADCS requirements are met

Legend:
Complete
In Progress
Future Work



Caltech

ADCS Simulator Models



Caltech

Disturbance Analysis

Goal: Verify that CubeSpace reaction wheels do not saturate in one orbit**

Assumptions:

- Inertially pointing (fixed attitude)
- Truth dynamics
- CBE worst-case inertia matrix for stability and pointing
- Magnetic torque rods at max
- Solar radiation pressure (SRP) is negligible

** For an inertially pointed spacecraft, disturbance torques are periodic with each orbit (to first order)

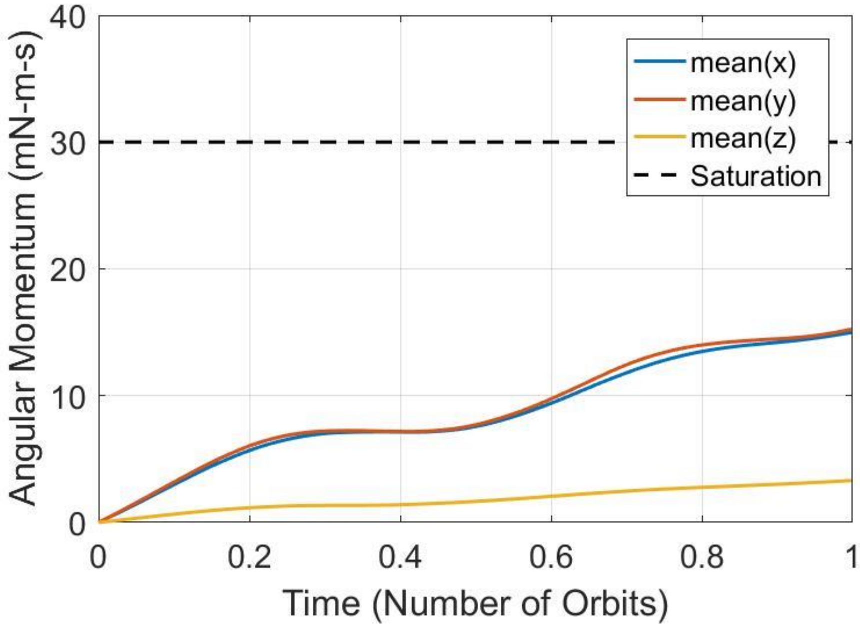
Disturbance Analysis (cont.)

Analysis:

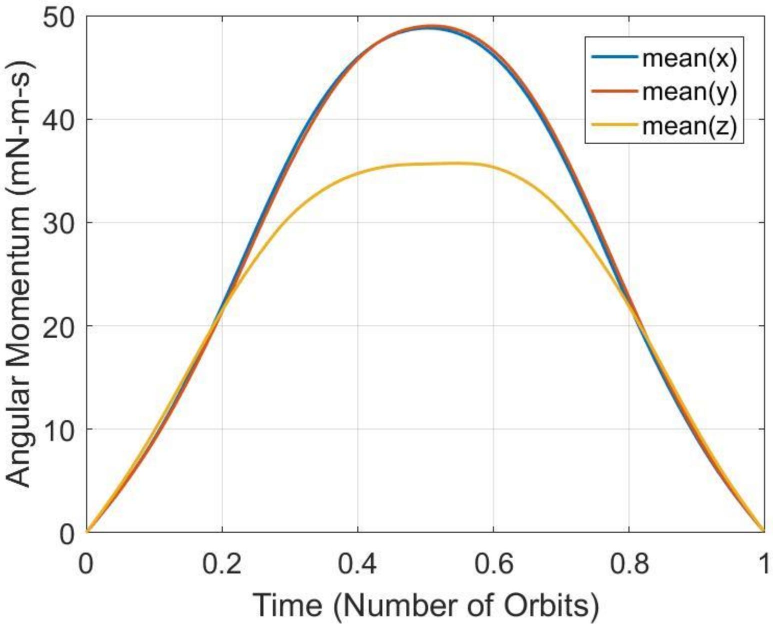
- Monte Carlo simulation with 1,000 runs in five nominal circular sun-synchronous orbits with altitudes between 500km and 600km
- Random variables - spacecraft attitude, magnetic moment
- Models cumulative angular momentum buildup in reaction wheels required to maintain fixed attitude

Caltech

Angular Momentum Buildup



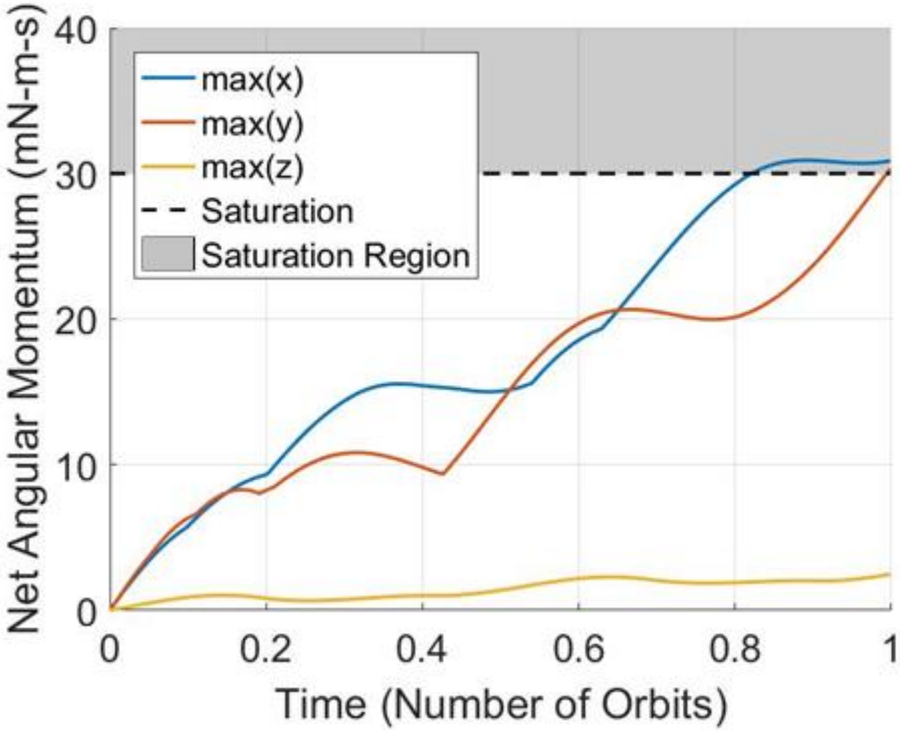
Nominal Angular Momentum Buildup from Disturbance Torques



Nominal Angular Momentum Removed by Magnetic Torque Rods

- Nominally, no net angular momentum buildup on spacecraft if reaction wheels continuously desaturated with torque rods

Angular Momentum Buildup



Worst-Case Net Angular Momentum

- At least 1 reaction wheel saturates in **0.7%** of simulations due to orientations that maximize gravity gradient torques

Detumbling Analysis

Importance:

- Satellite spinning after ejection from launch vehicle
  - Need to inertially point spacecraft to use telescope

Goal:

- Obtain an order of magnitude estimate for detumbling time

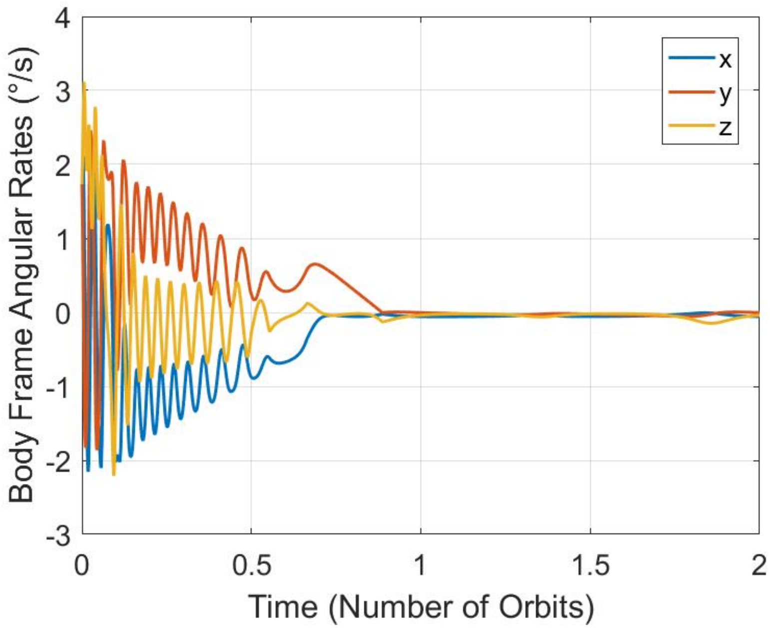
Assumptions:

- With ~3 °/s initial tumbling rate, reaction wheels saturate after removing ~1/2 of the spacecraft's angular momentum
  - Cannot use reaction wheels alone to detumble
- Detumbled when angular velocity < 0.3°/s (star tracker)
- Only gravity gradient and magnetic torques modeled
- Truth dynamics

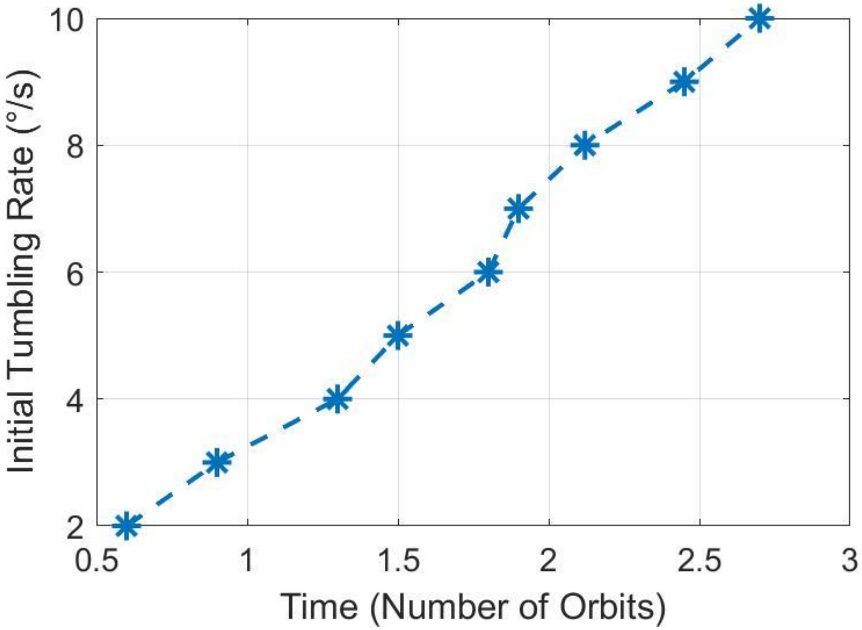
Caltech

Detumbling Analysis

- Magnetic torque rods with b-dot controller



Representative Detumbling Angular Velocity Time History



Initial Tumbling Rate vs. Time to Detumble

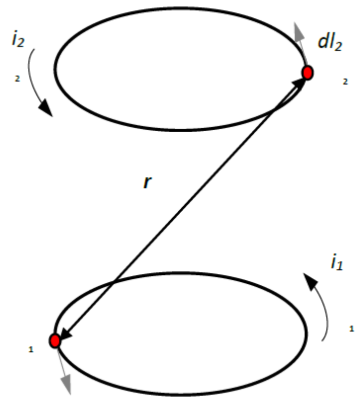
- Detumble time increases approximately linearly with initial tumbling rate
- 3°/s initial tumbling rate detumbles in ~1 orbit
- No power concerns with initial tumbling rates up to 10°/s

Magnet Disturbance Analysis

- Goal: Develop refined magnetic force model to more accurately estimate the magnetic forces during rendezvous and docking (RDV)

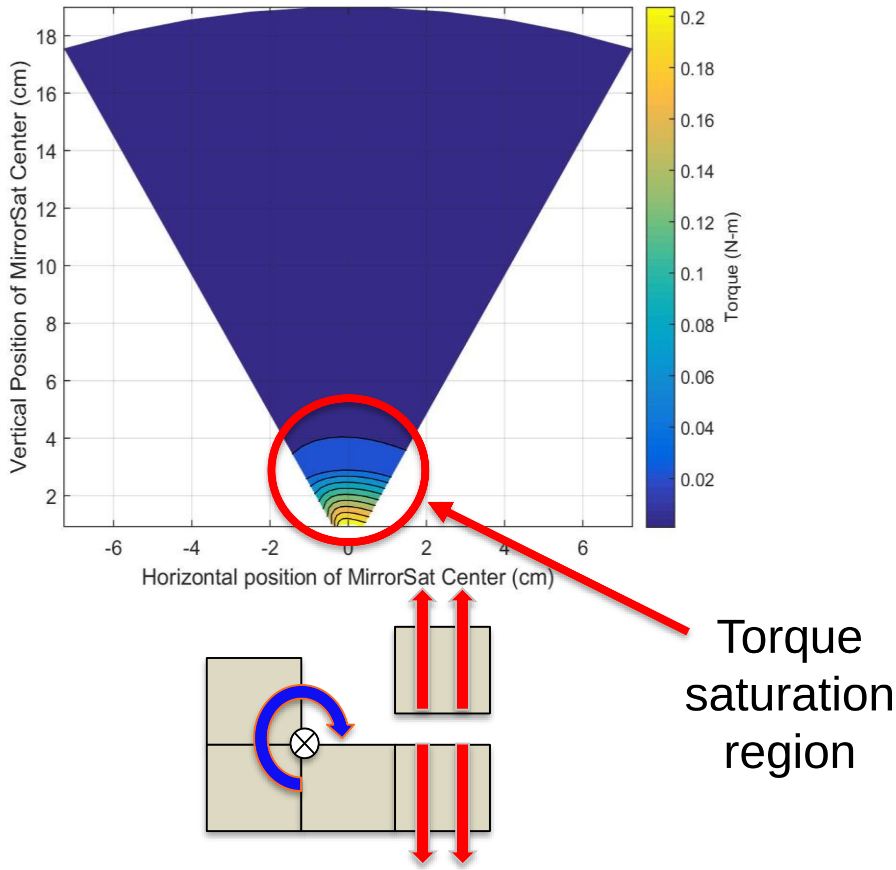
- Developed discretized coil model with the Biot-Savart Law

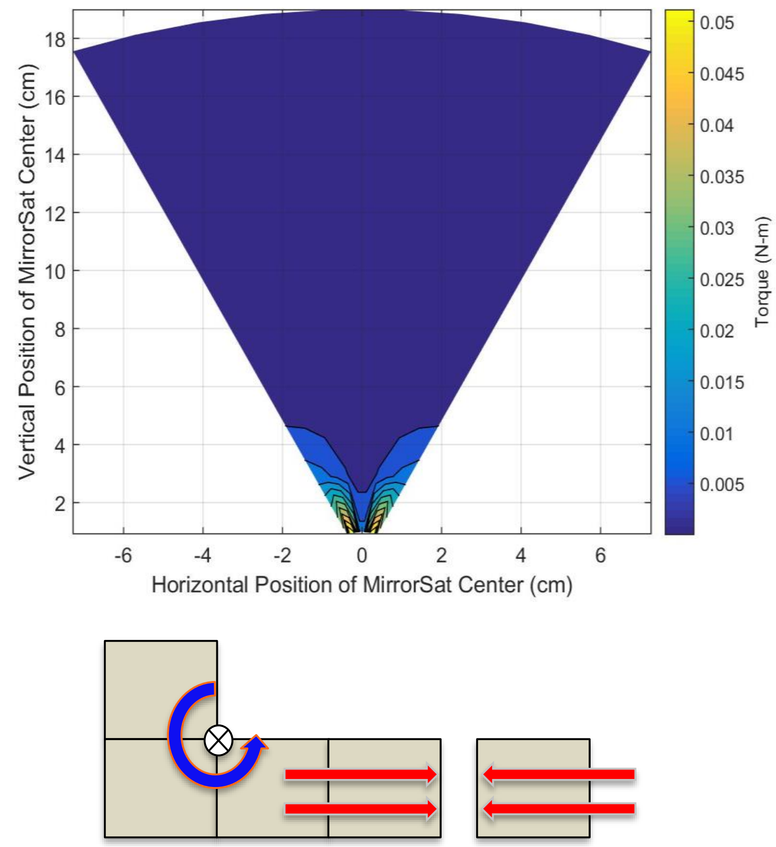
$$F_{12} = \frac{\mu N_1 i_1 N_2 i_2}{4\pi} \oint \left(\oint \frac{dl_1 \times \hat{r}}{\|r\|^2} \right) \times dl_2$$



Isotorque Lines

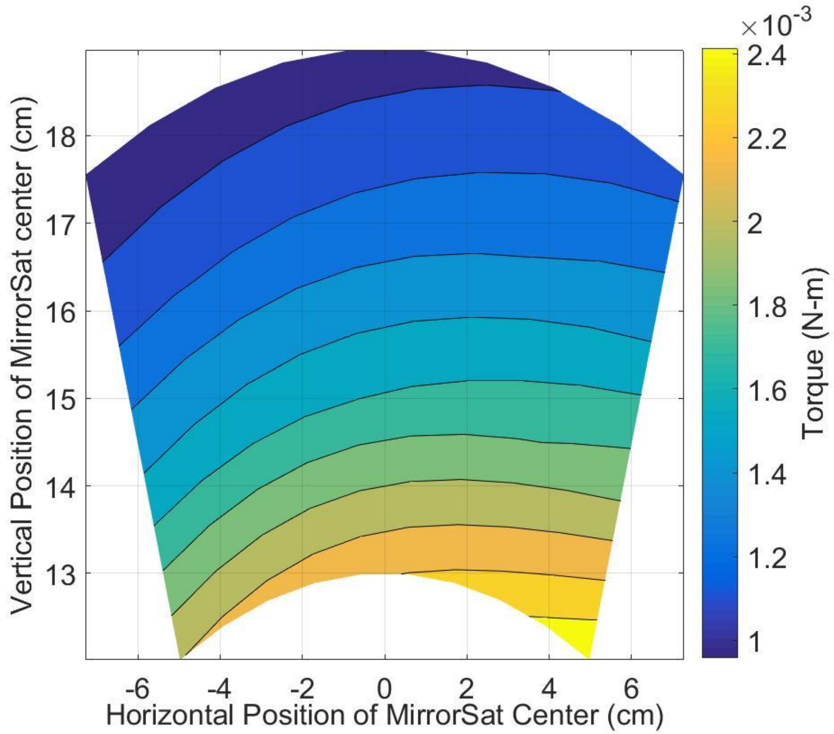
- Worst-case (most conservative) scenario: electromagnets at full power during entire RDV maneuver

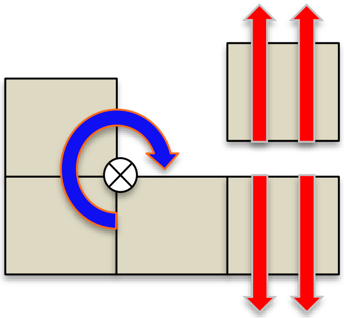




Unsaturated Region

- Zoom of isotorque lines past “torque saturation region” (~11 cm)

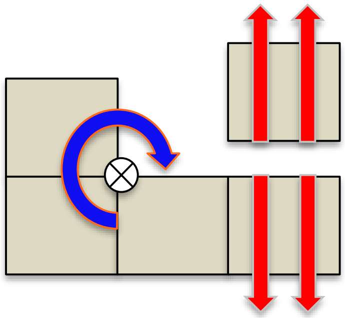




Caltech

Undocking Analysis

- Issue:
  - Worst-case scenario: high magnetic torques from MirrorSat electromagnets can exceed maximum torque from reaction wheels
  - CoreSat may rotate

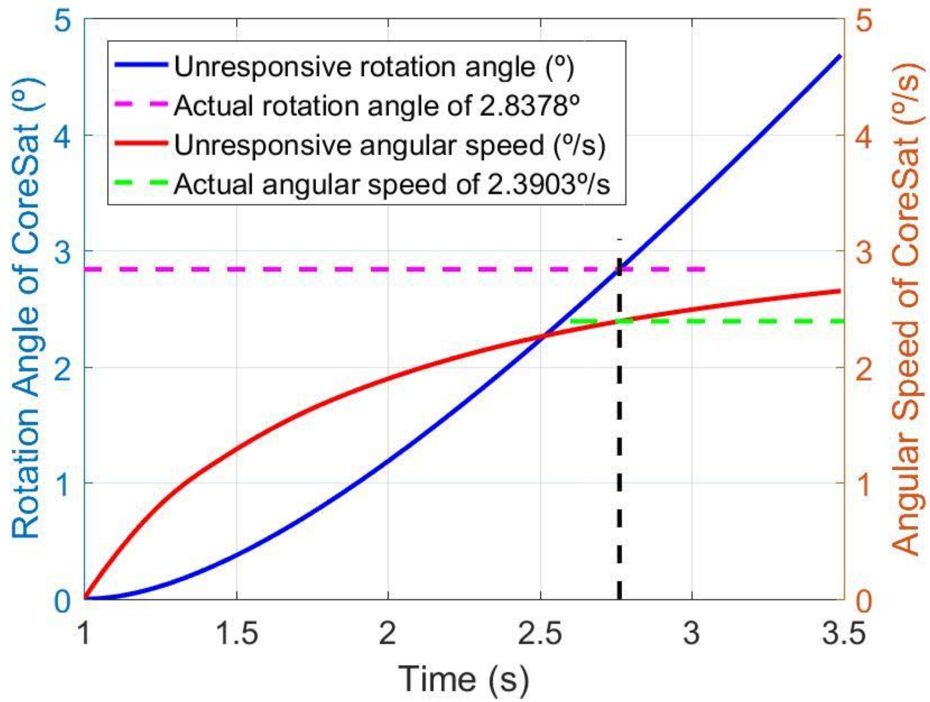


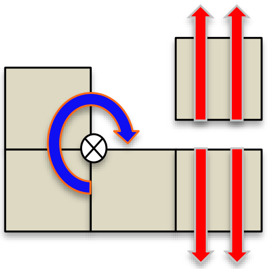
- Completed in-depth analysis
  - Computed rotation angle of CoreSat

Caltech

Worst-Case Rotation Angle

- Worst-case scenario: electromagnets fully powered during entire undocking maneuver
  - Very conservative assumption
  - Needs refinement
- MirrorSat leaves torque saturation region in $\boldsymbol{\Delta t \approx 2.7s}$
- Rotation angle: $\boldsymbol{\theta \approx 2.8}°$
- Angular velocity: $\boldsymbol{\dot{\theta} \approx 2.4°/s}$





Caltech

ADCS Summary

- Generated ADCS requirements
- Selected hardware
- Developed ADCS simulator
- Completed disturbance and detumbling analyses
- Created high-fidelity magnetic model and analyzed forces and torques during RDV

Future Work

- Add controller and estimator to simulator
- Conduct detailed ADCS analysis with complete simulator → requirements verification and validation (V&V)
- Develop hardware test plans
- ADCS integration, assembly, and testing (IA&T)

Thank you!

Questions?

Outline

2:00 pm: Introduction & Welcome

2:15 pm: Systems Engineering

2:45 pm: Power

3:15 pm: Avionics & Comms

3:45 pm: ADCS

4:15 pm: Structures

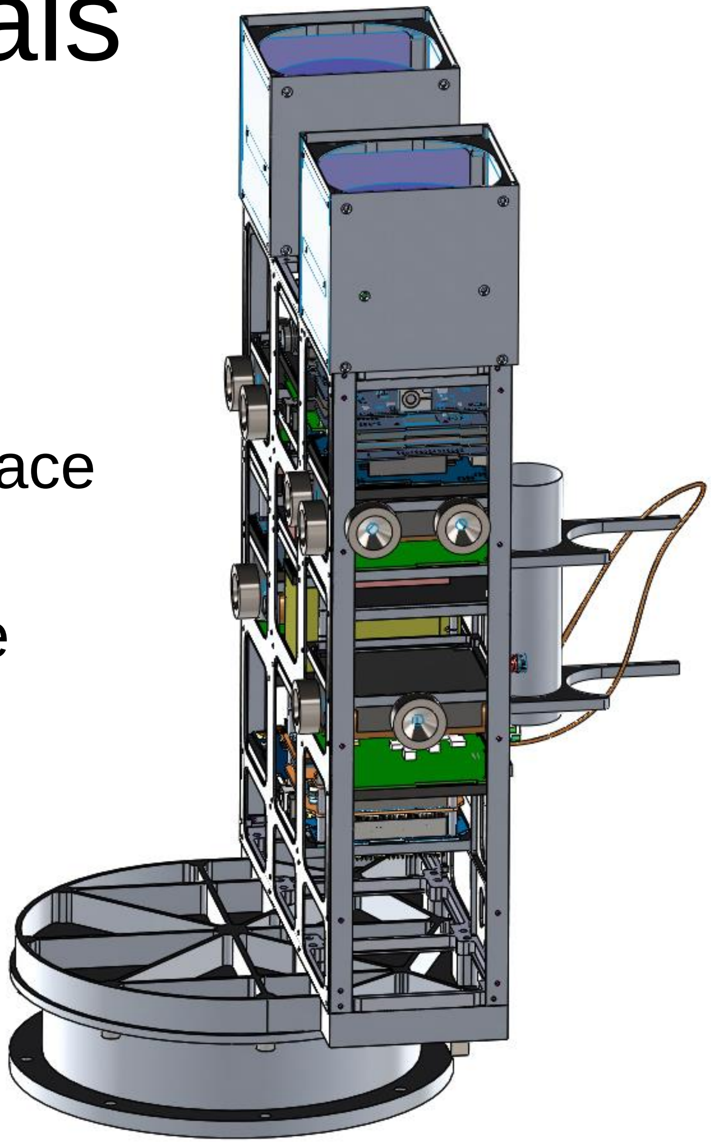
Structures Team

Students:
Cole Allen
Ludovic Gil
Stefan Lohaus
Mayra Melendez

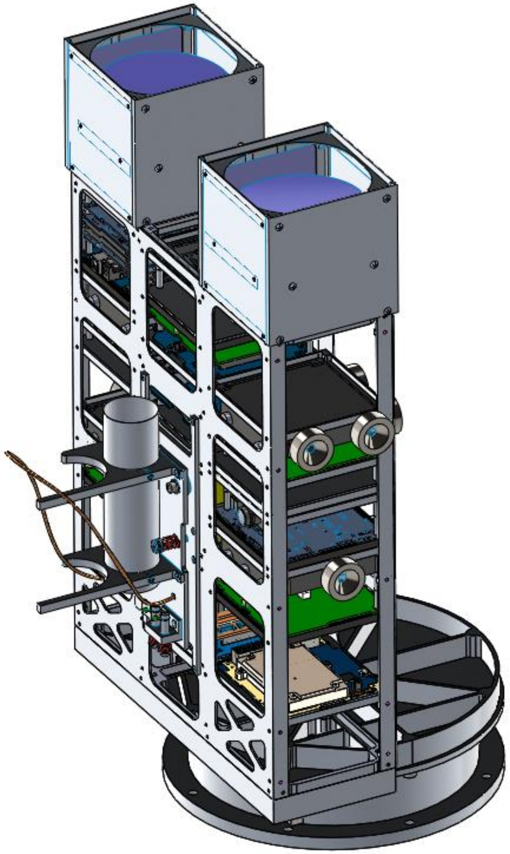
Mentor:
Christophe Leclerc

Team Goals

1. Design the CoreSat structure
2. Design the Launch Vehicle Interface (LVI) plate
3. Select a Hold Down and Release Mechanism (HDRM)



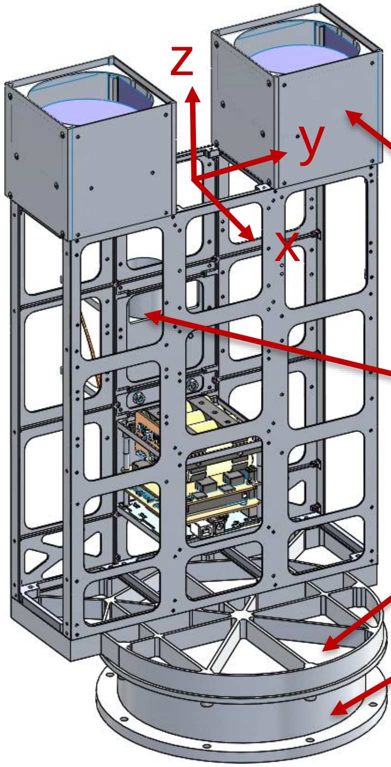
Main Structural Requirements



- Withstand launch environment, with critical acceleration of 25 g
- Provide accurate positioning of optical systems:
  - Mirror boxes
  - Boom support
  - Docking ports
- Provide mechanical support for all subsystems
- Use CubeSat standards for subsystem components (96 mm x 96 mm PCBs)
- Provide vertical clearance of 50 mm for MirrorSat docking maneuvers

Caltech

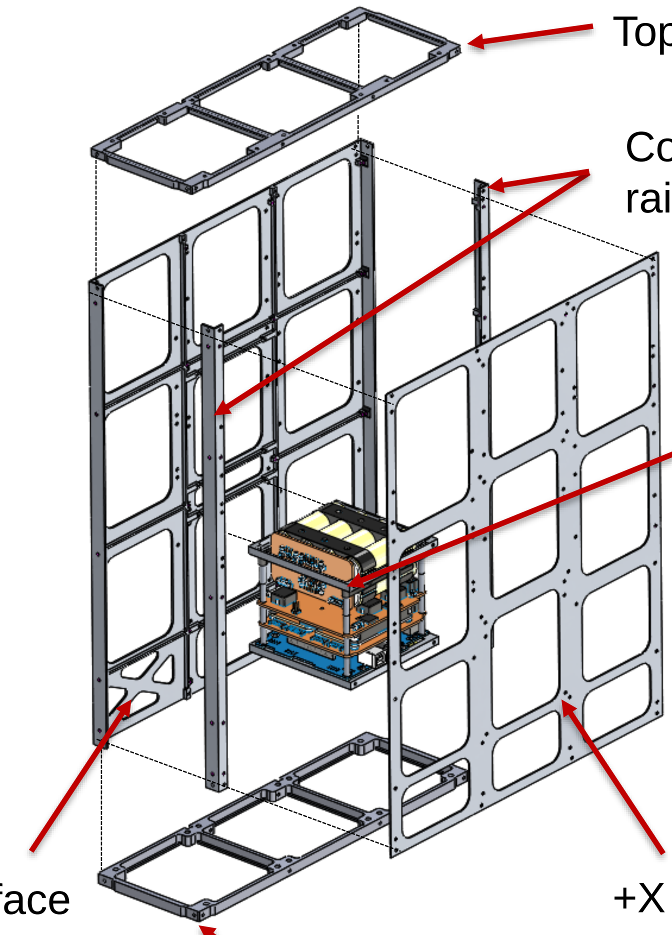
CoreSat Structural Design



Design Guidelines

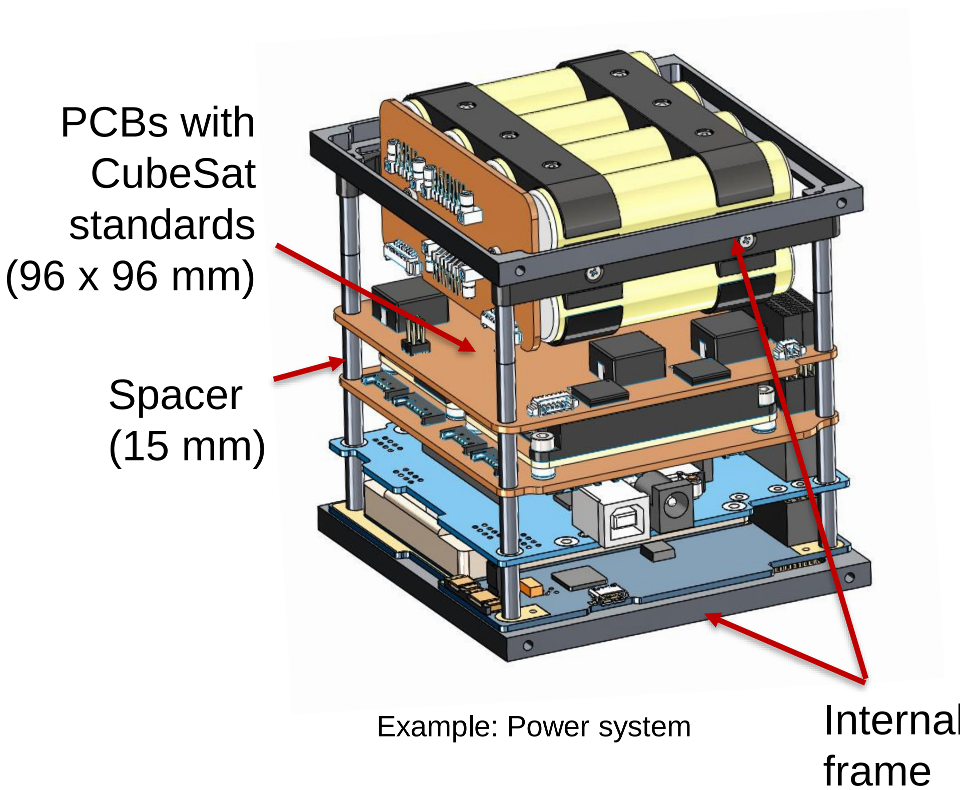
- Flexibility for components positioning
- Optical calibration independent of internal assembly
- Flexible clearance at the bottom

Frame Breakdown:



Caltech

Internal Module Assembly



Example: Power system

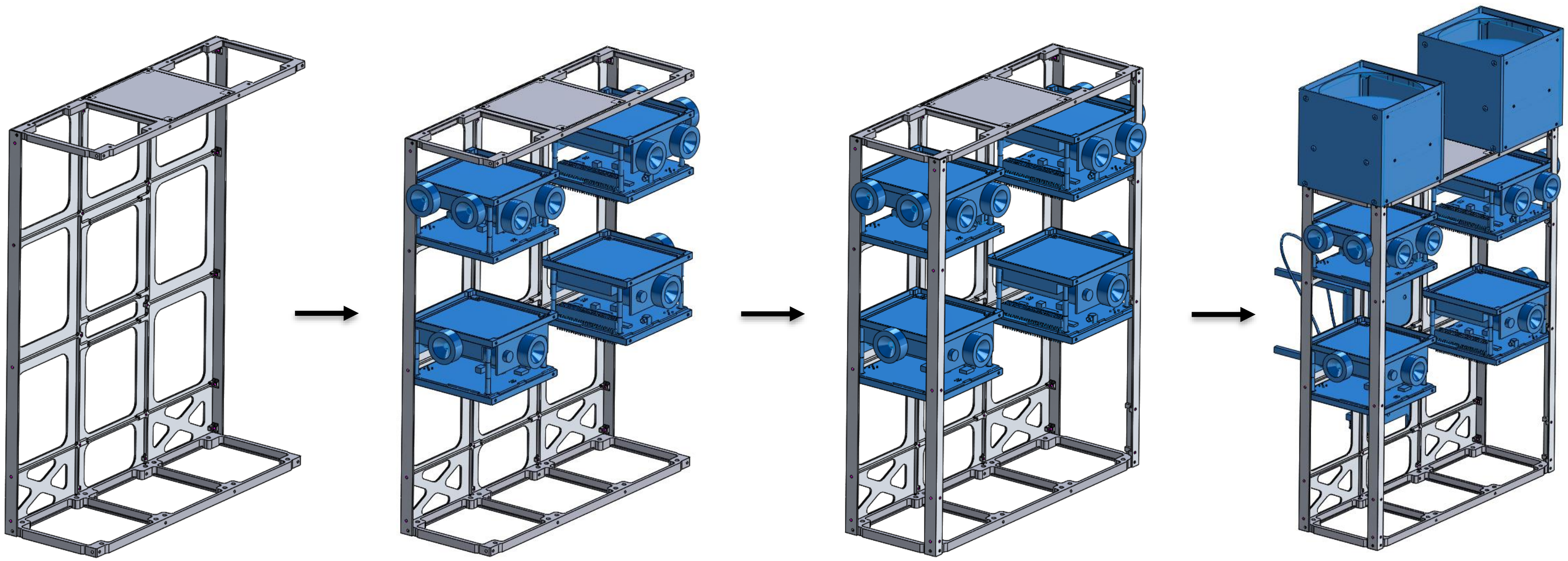
- Mount internal components in CubeSat standard PCBs
- Group internal components in modules
- Modules are mounted between +X and –X faces contributing to the stiffness and stability of the CoreSat

Modular design allows for modules to be assembled, tested, and replaced individually

CAD source: Gomspace

Caltech

Optical System Assembly



(1)
- -X face
- Top and bottom frames

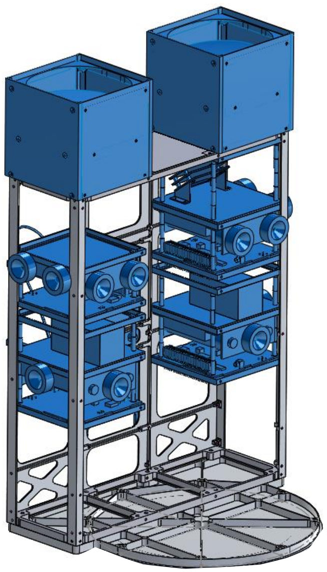
(2)
- Add docking ports

(3)
- Add corner rails

(4)
- Add remaining optical system
- Optical system can be aligned independently of other subsystems

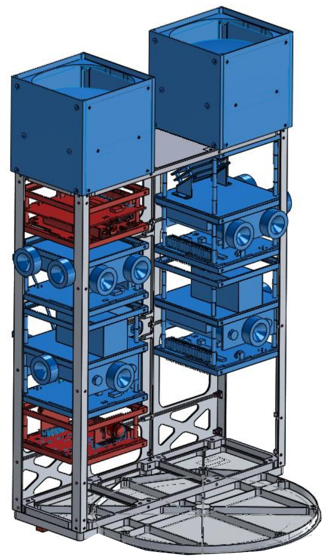
Structure
Optical system

Complete Assembly



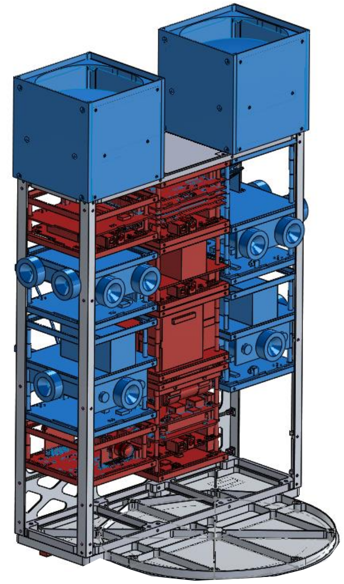
(5)

- Add LVI plate



(6)

- Add side components

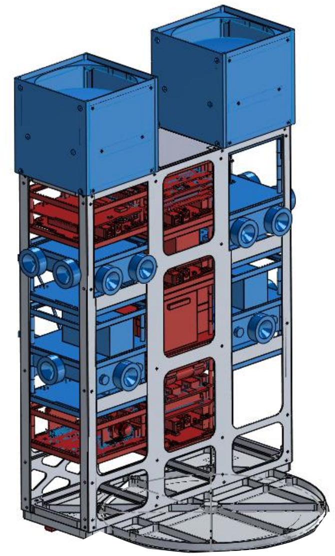


(7)

- Add central components

(8)

- Add solar panels



(9)

- Close +X face (with solar panels)

Structure
Optical system
Other components

Modular design allows for flexibility in assembly

Caltech

Latest Assembly

Caltech

Structural Analysis

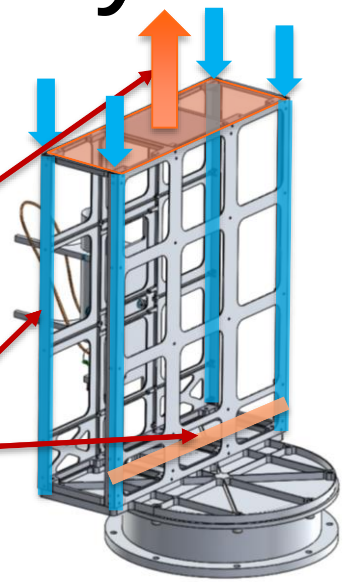
- Simple beam theory analysis
- Inputs to analysis:
  - 25 g peak acceleration
  - Aluminum 7075
  - Total mass 35 kg
- Results for critical modes:

Maximum axial stretching:
Safety factor of yield stress = 8

Maximum compressive loading:
Safety factor of buckling load = 15

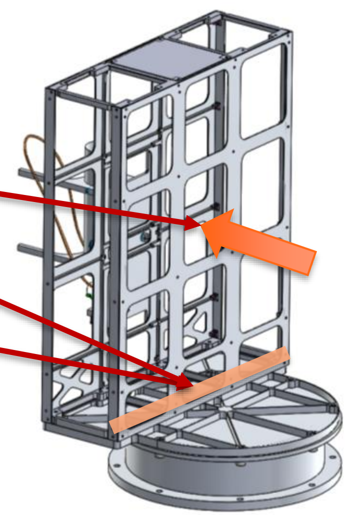
Maximum bending loading:
Safety factor of yield stress = 3

Maximum shear stress in screws:
Safety factor of critical stress = 4

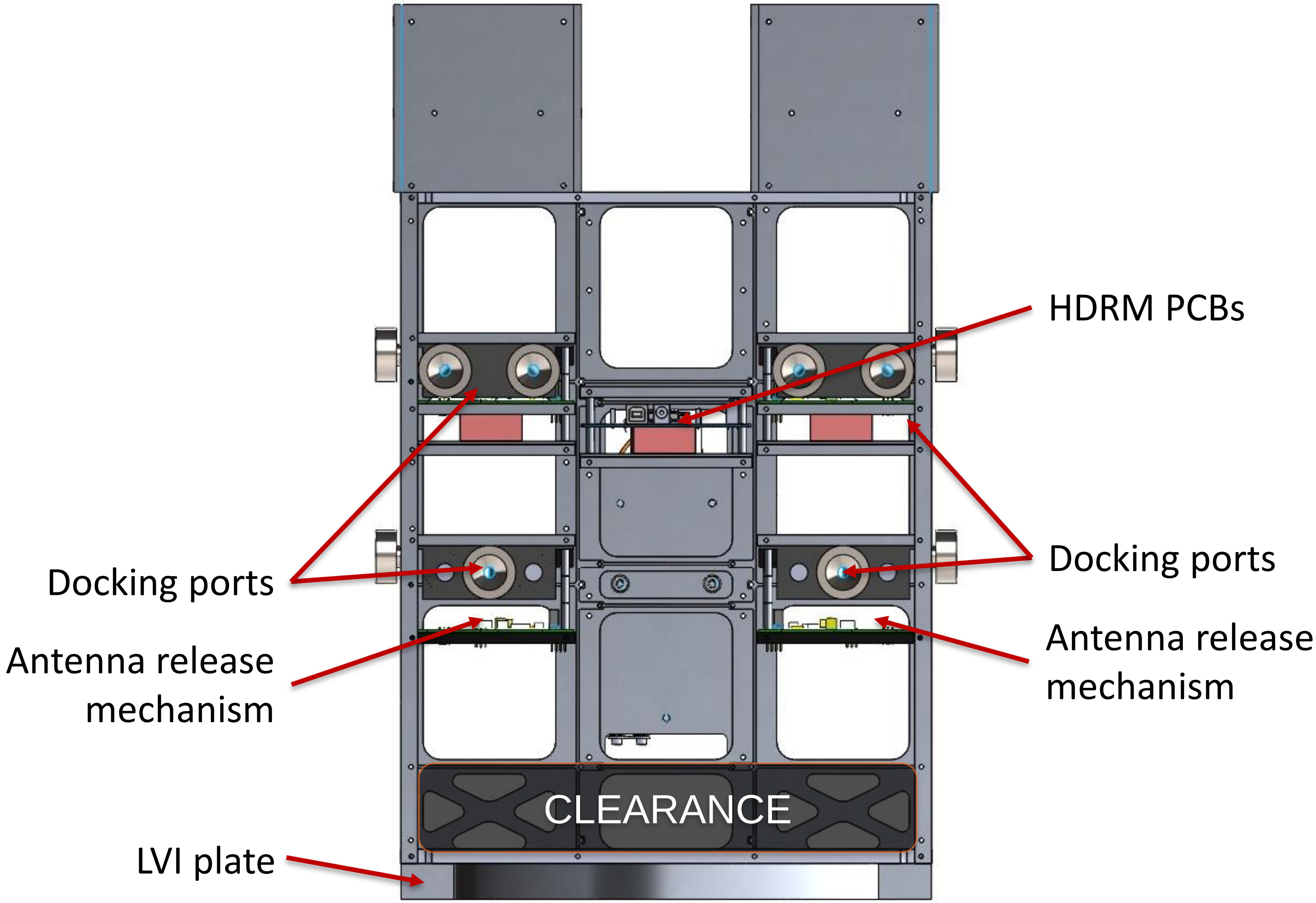


Frame: 1350 g
LVI plate: 1070 g
LVI ring: 600 g

Critical stretching zones
Loading path in compression

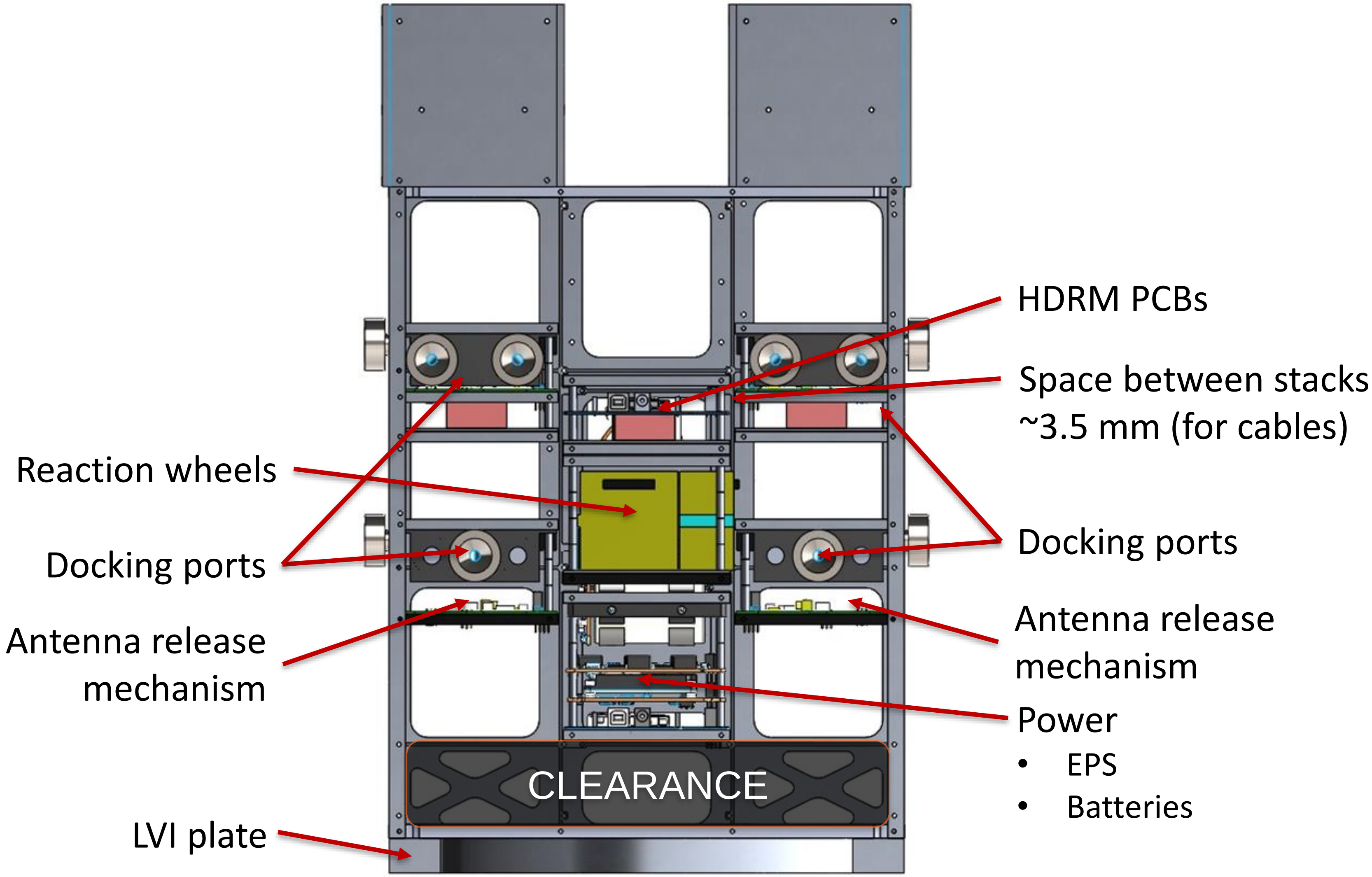


Positioning Of Components



Motherboards CAD samples: www.cubesatkit.com

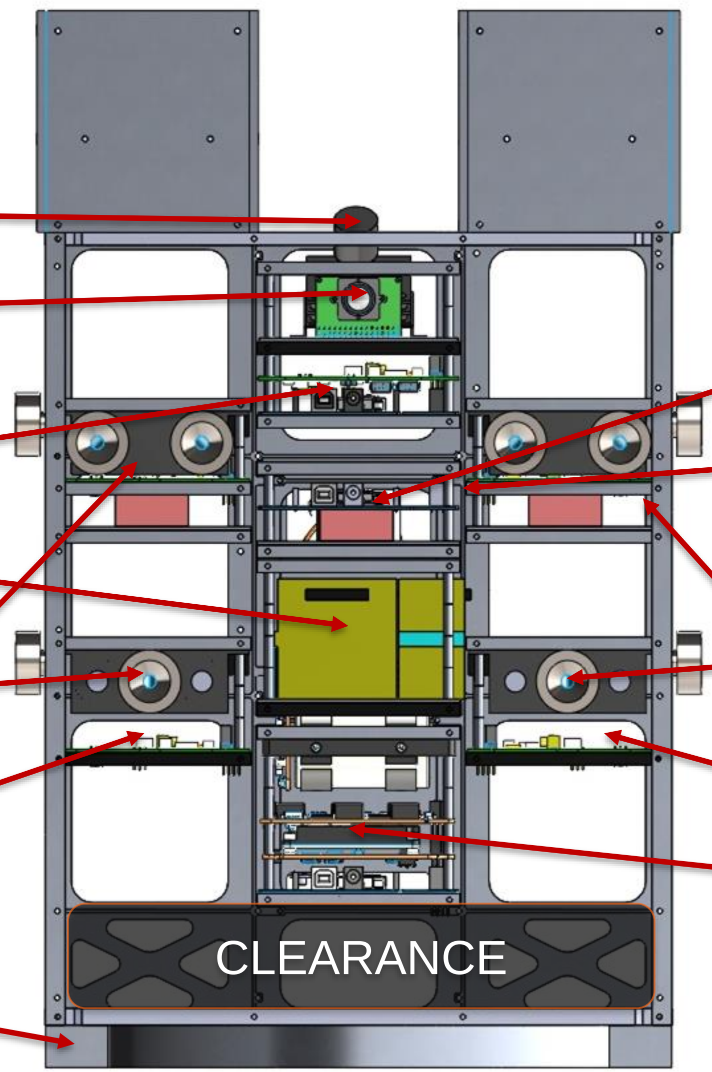
Positioning Of Components



Caltech

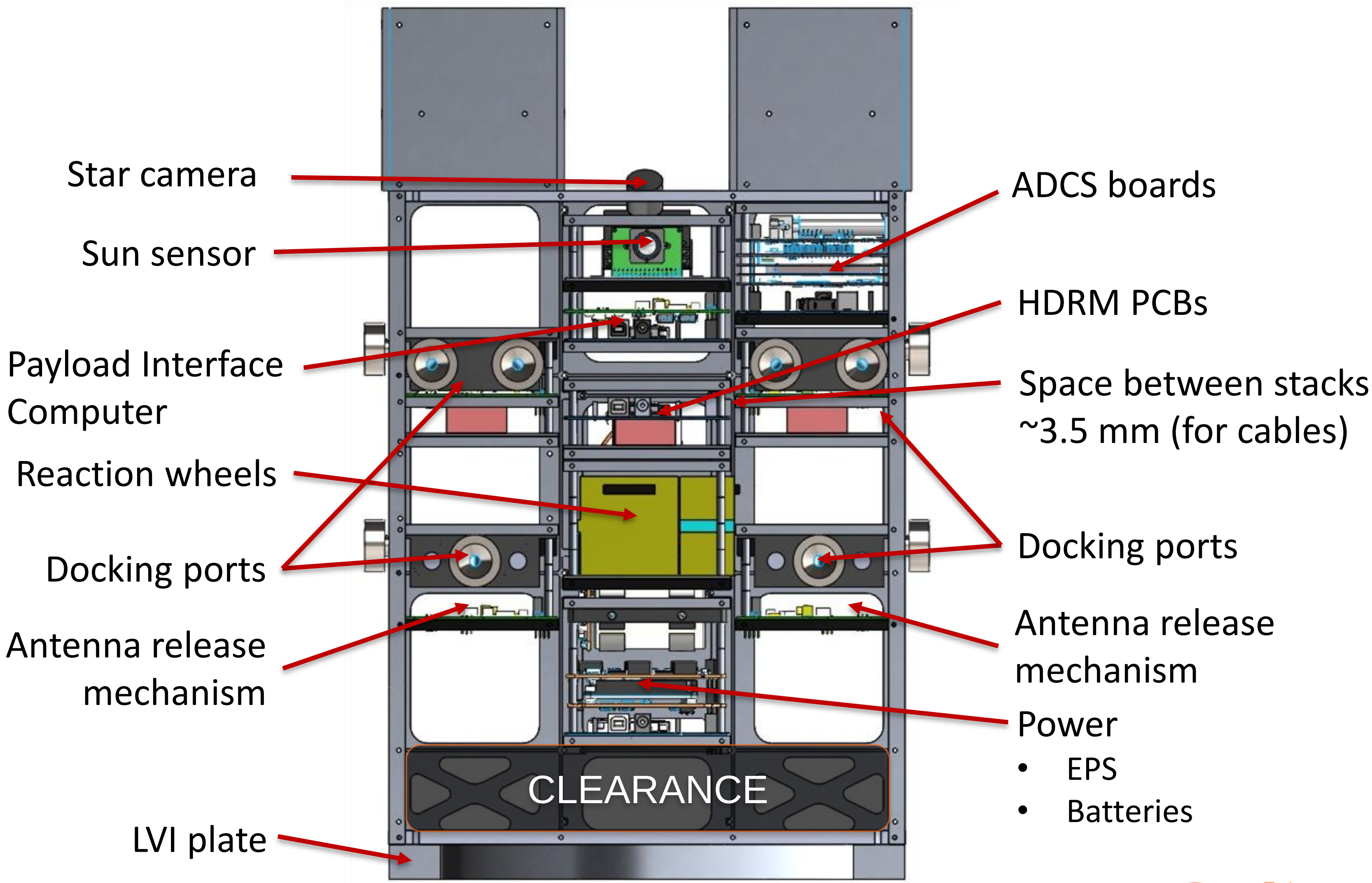
Motherboards CAD samples: www.cubesatkit.com

Positioning Of Components



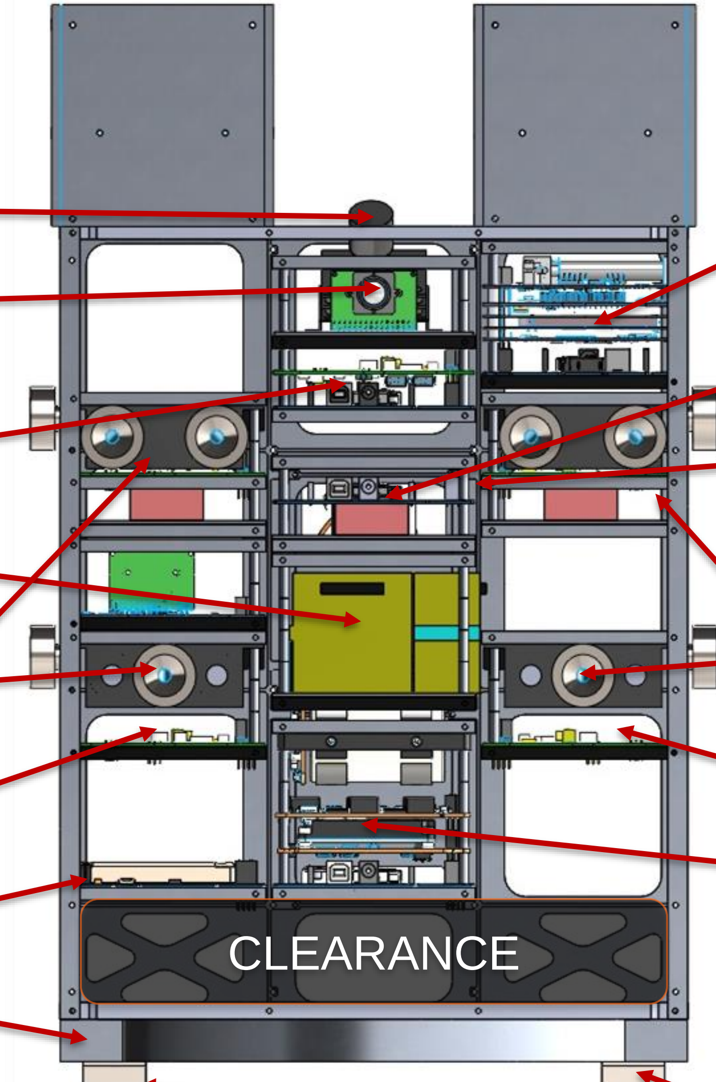
Motherboards CAD samples: www.cubesatkit.com

Positioning Of Components



Motherboards CAD samples: www.cubesatkit.com

Positioning Of Components



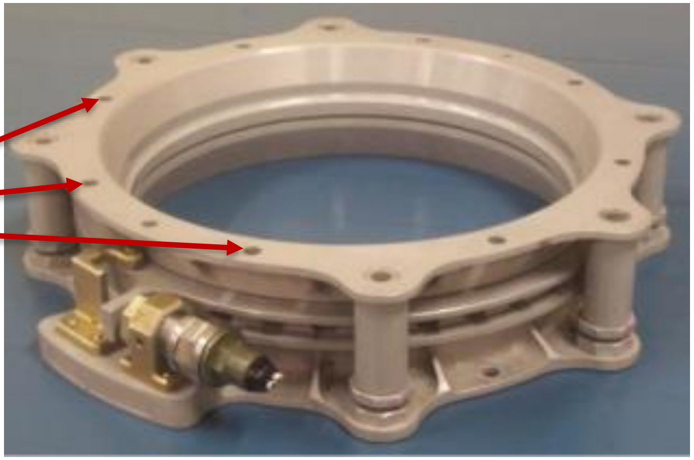
Motherboards CAD samples: www.cubesatkit.com

LVI Ring

- Indian Space Research Organisation (ISRO) IBL230 separation device used in PSLV
  - CoreSat must attach to this ring
- Dimensions and properties
  - 8 M6x1 mounting holes, clearance on ring
  - Pitch Circle Diameter (PCD) of 230 mm
  - 0.6 kg retained on satellite after separation

230 mm PCD

8 equally spaced mounting holes



Part of ring that remains **on launch vehicle** after separation

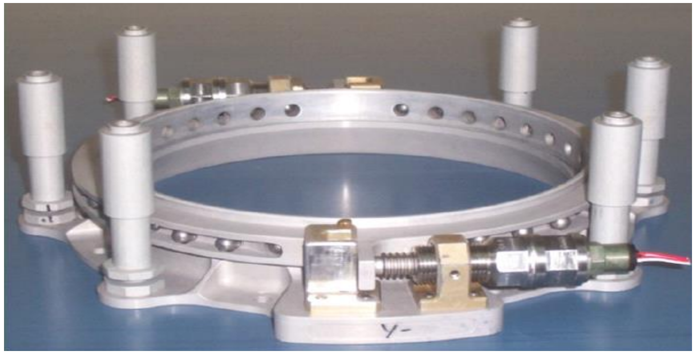
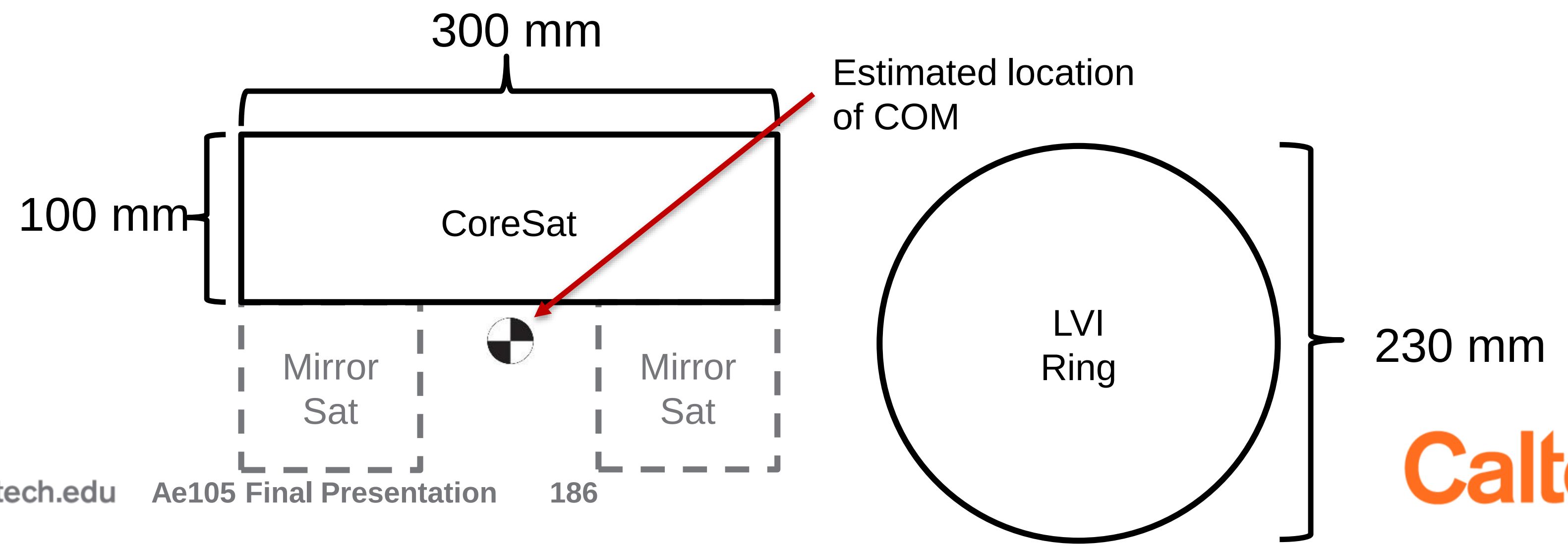


Image Source: IBL230 datasheet

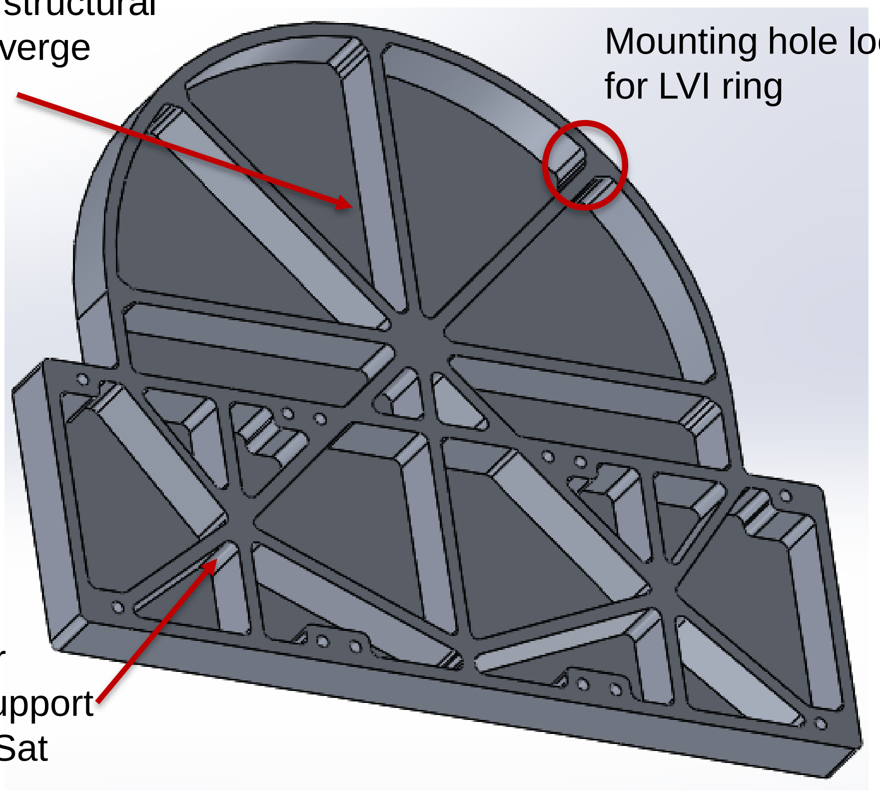
LVI Plate Requirements and Considerations

- Must withstand peak accelerations of 25 g during launch without failure (yield)
- Must place center of mass (COM) of AAReST in its stowed configuration over center of LVI ring
- Should utilize all 8 mounting holes on LVI ring
- Should distribute launch loads evenly
  - Concentration of loads in one location could result in failure

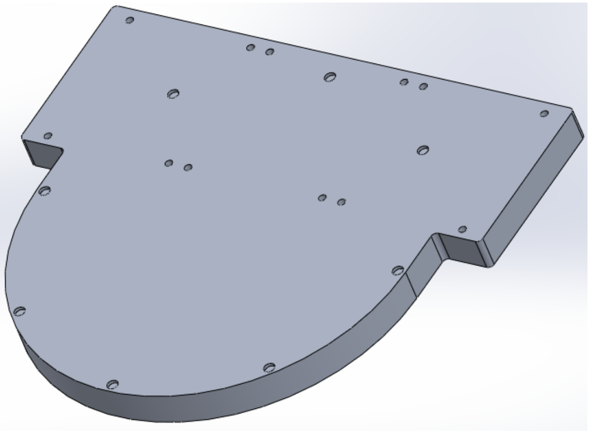


LVI Plate

- Mass: 1.07 kg
- Webbing thickness: 5 mm
- Webbing height: 20 mm

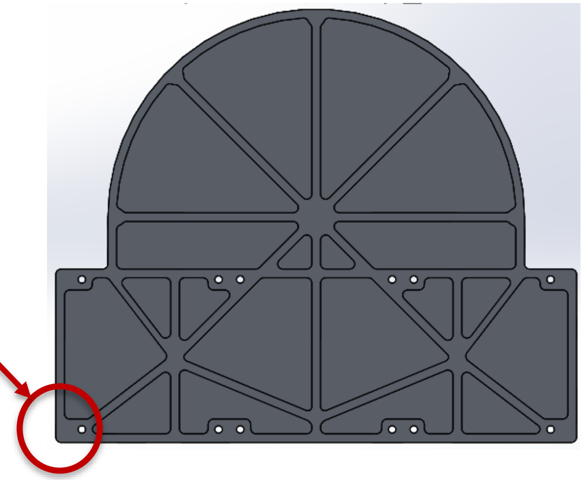


This face connects to bottom of CoreSat

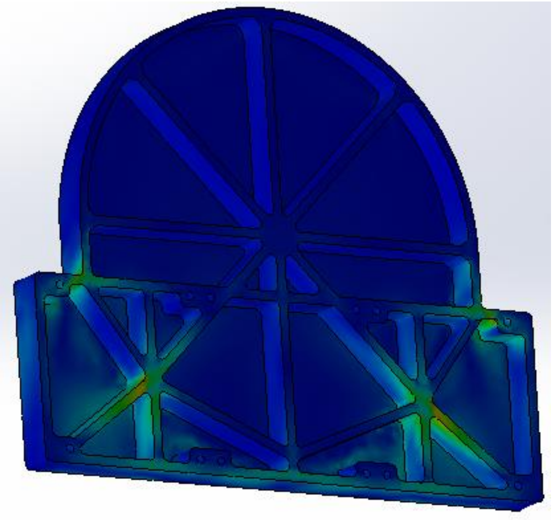


This face connects to top of LVI ring

LVI Plate Structural Analysis



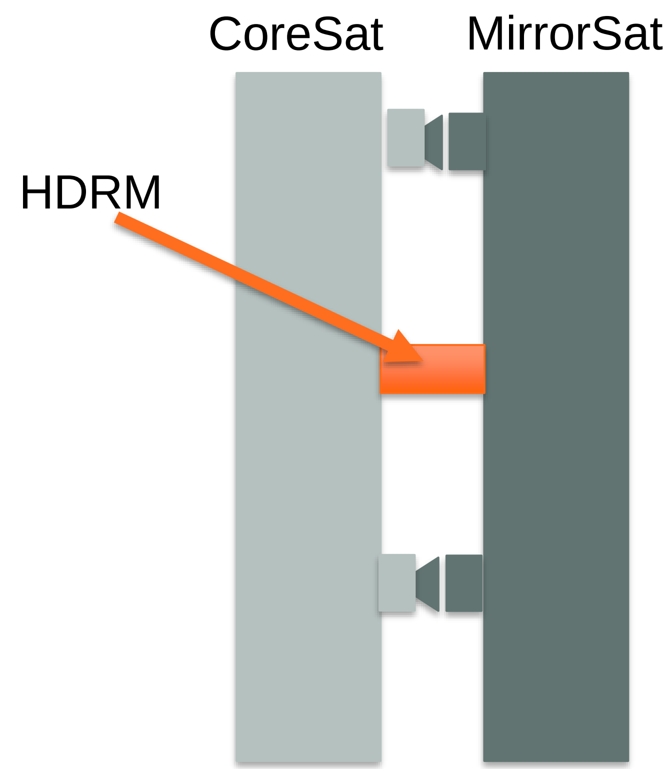
- Treat webs as beams, analyze effect of downward force on corners
  - 35 kg, 25 g, yield strength = 503 MPa, shortest beam length = 39 mm
  - Each corner has 3 beams supporting it
  - Critical moment: 168 Nm
    Max moment experienced: 112 Nm
- SolidWorks FEA
  - Fixed boundary condition at 8 mounting holes for LVI ring
  - 35 kg, 25 g acting at COM of CoreSat
    - Straight down onto rectangular portion of plate
    - At angles
  - Max stress experienced: 108 MPa

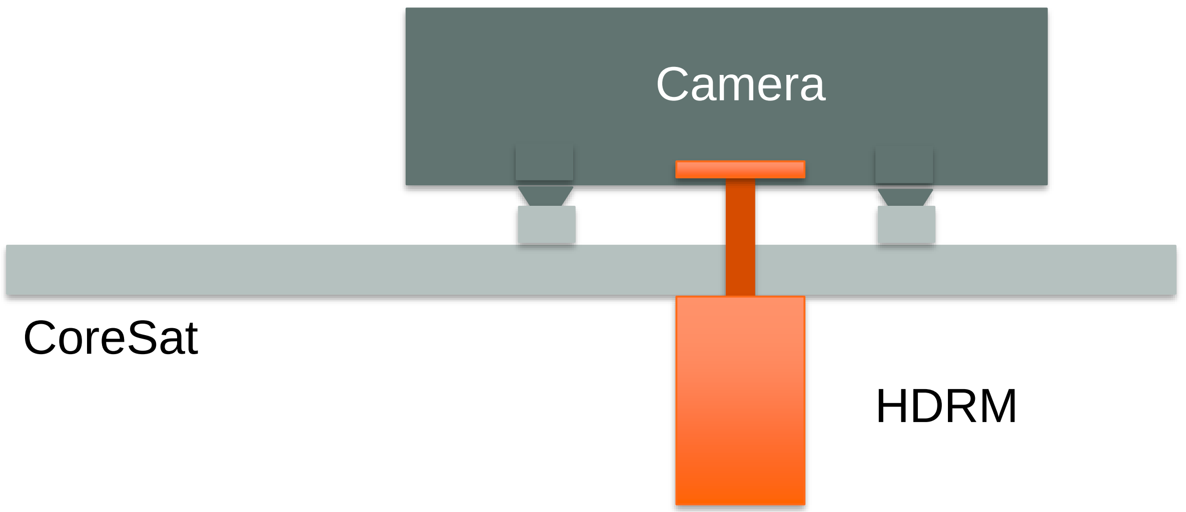


Caltech

HDRMs

- Hold Down and Release Mechanisms (HDRMs) required to hold down the MirrorSats and camera through launch
- Mount HDRM with limited internal and external accessibility





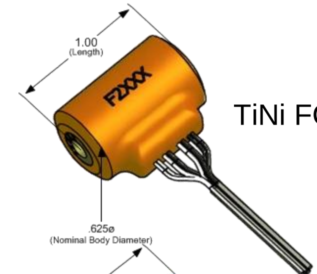
Caltech

HDRM Selection Criteria

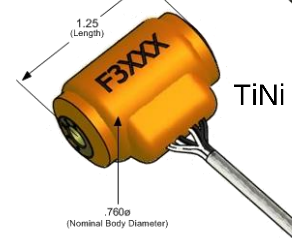
HDRM Requirements:
- Critical dimension: 2 cm (for MirrorSat)
- Critical load: MirrorSats 1.47 kN, Camera 0.98 kN

Power Guidelines:
- Max activation current: 2.0 A
- Max activation power: 25 W

Name	Type	Mass	Critical dim	Load support	Safety factor	Activation current	Activation power
TiNi FC2	Frangibolt	20 g	N/A	2.22 kN	1.51	0.90 A	25.2 W
TiNi FC3	Frangibolt	32 g	N/A	6.23 kN	4.23	1.75 A	49.0 W
SP-5025 HOP Actuator	Paraffin Pin-Puller	80 g	2.54 cm	1.16 kN	0.789	0.54 A	15.0 W
NEA Model 9100	Bolt Release	70 g	N/A	8.00 kN	5.44	4.0 A	32.0 W



TiNi FC2



TiNi FC3

SP-5025 HOP Actuator

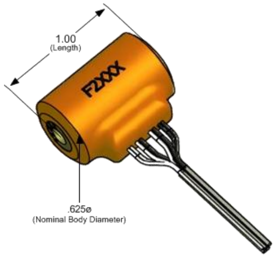
- Requirements met (green)
- Need deeper analysis (yellow)
- Requirements not met (orange)

NEA Model 9100

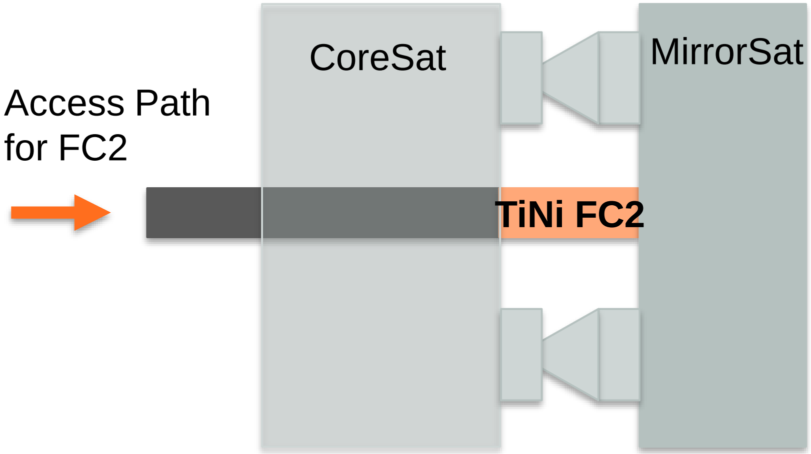
Image sources: www.tiniaerospace.com; www.neaelectronics.com; www.sncorp.com

Recommended HDRMs

The TiNi FC2

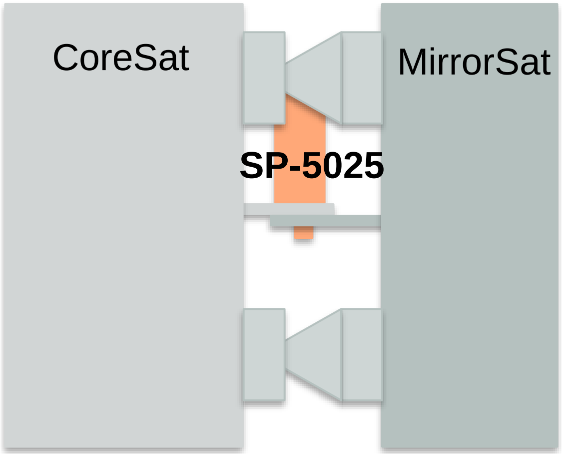


- Max load: 2.22 kN
- Safety factor: 1.51
- Advantage: light weight
- Disadvantage: needs access to the CoreSat interior after assembly



SP-5025 HOP Actuator

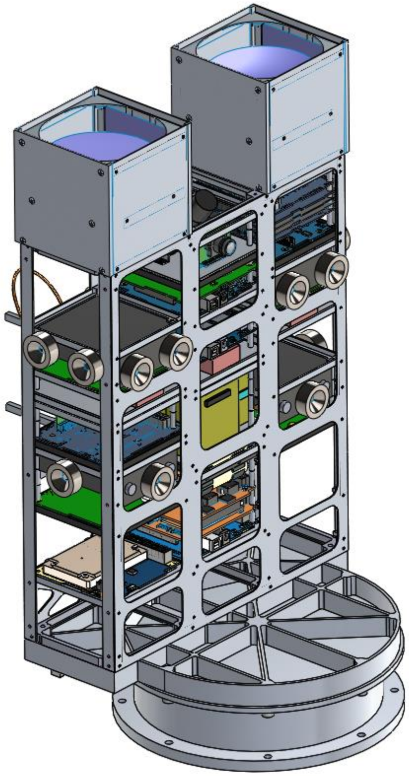
- Max load: 1.16 kN
- Safety factor: 1.58 (using two in parallel)
- Advantage: ease of final assembly
- Disadvantage: high volume, mass, and complexity



Caltech

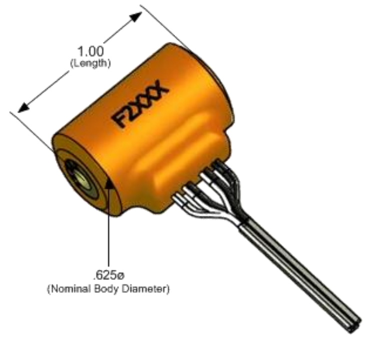
Summary

1. **Design the CoreSat structure**
   – Functional and flexible frame design
   – Assembly and optical alignment are independent
   – Withstands launch loads
   – Assembly proposal



2. **Design the Launch Vehicle Interface (LVI) plate**
   – LVI plate design
   – First structural analyses

3. **Select a Hold Down and Release Mechanism (HDRM)**
   – Trade-off analysis
   – Integration proposal



Caltech

Future Work

- Finalize design depending on final choice of components
- Design fixation for selected HDRM
- Build, assemble, and test a prototype
- Improve structural analyses for the LVI plate and the frame

Caltech

Questions

Caltech