# Solar Torque Management for the Near Earth Asteroid (NEA) Scout CubeSat Using Center of Mass Position Control

## AIAA SciTech 2018


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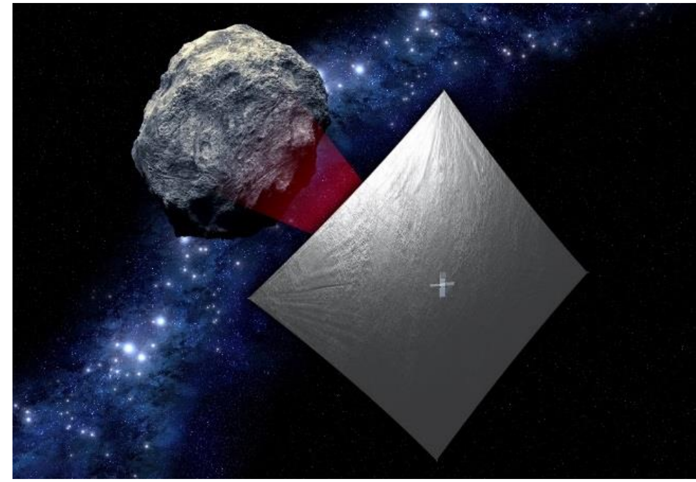
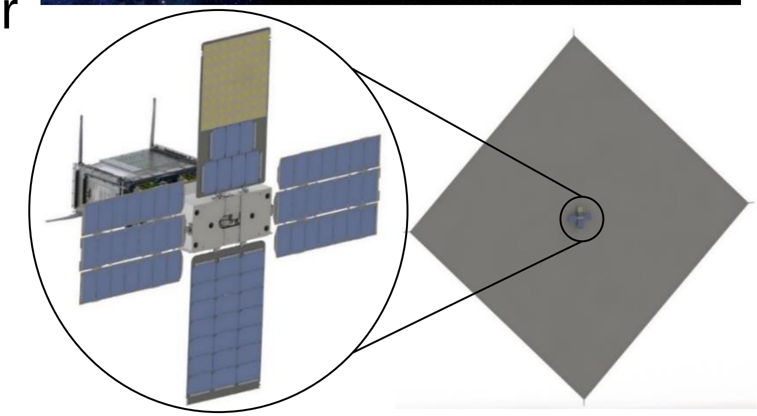
# Agenda

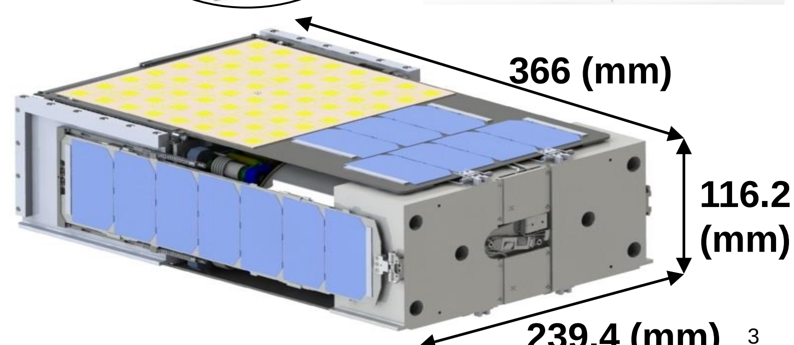
- Brief Mission Overview
- Spacecraft Subsystems and Sensors
- Active Mass Translator (AMT) Control Law
- Simulation Results
- Conclusions

# Mission Overview

- Launch on NASA's Space Launch System (2019)
- Image a NEA during a slow flyby
- Demonstrate low-cost solar sail propulsion, using an 86 $m^2$ sail deployed from a 6U spacecraft
- Rendezvous with the 1991VG asteroid after a 2.5 year mission duration

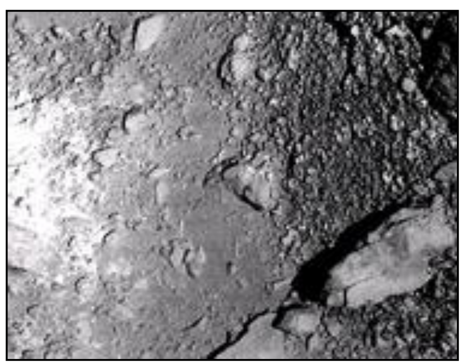






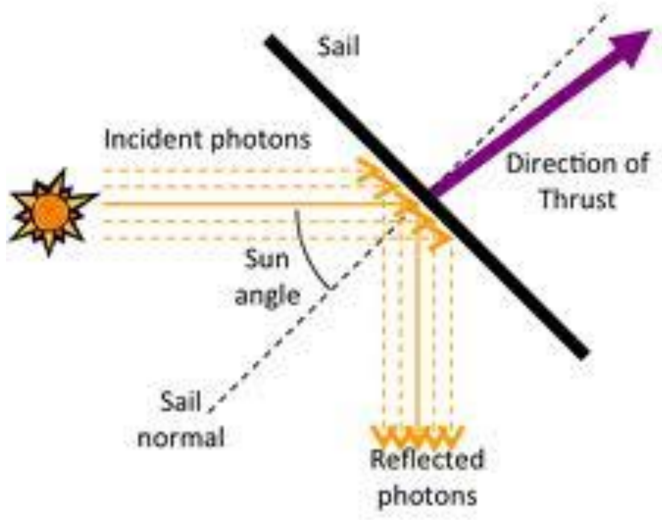


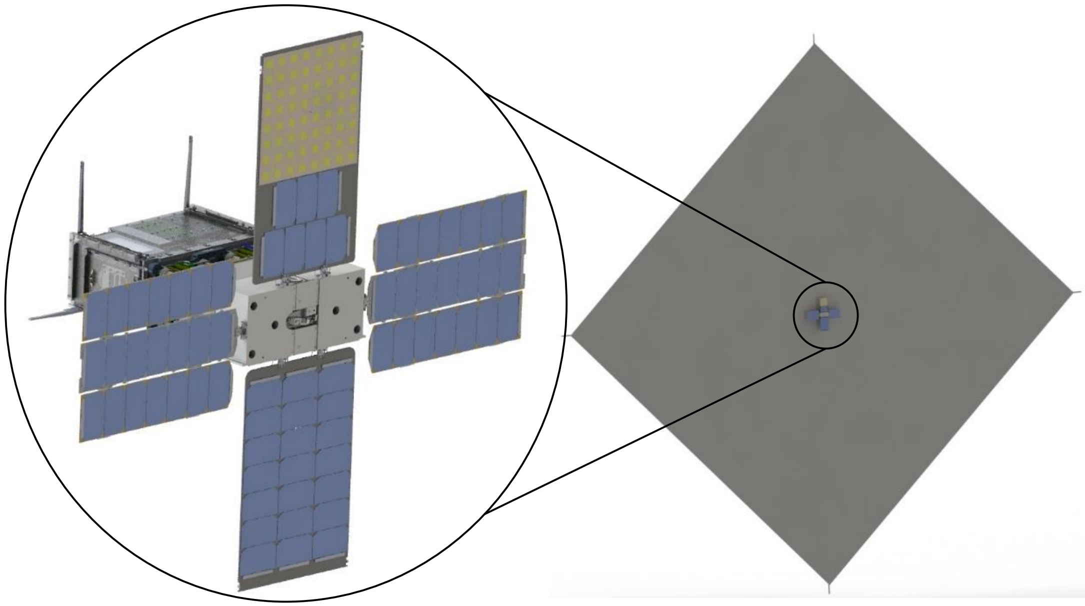
**Reconnaissance with medium field imaging**

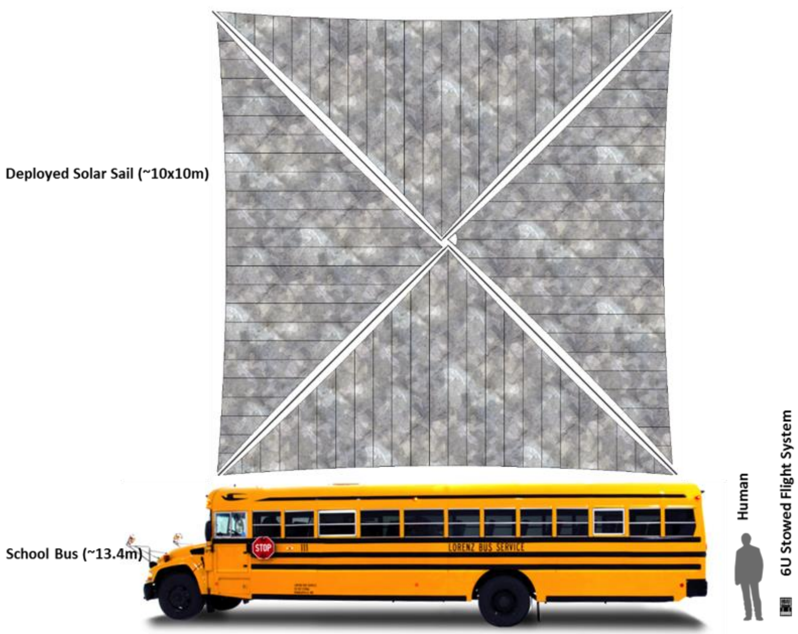


**Close Proximity Imaging**

# Solar Sail Propulsion

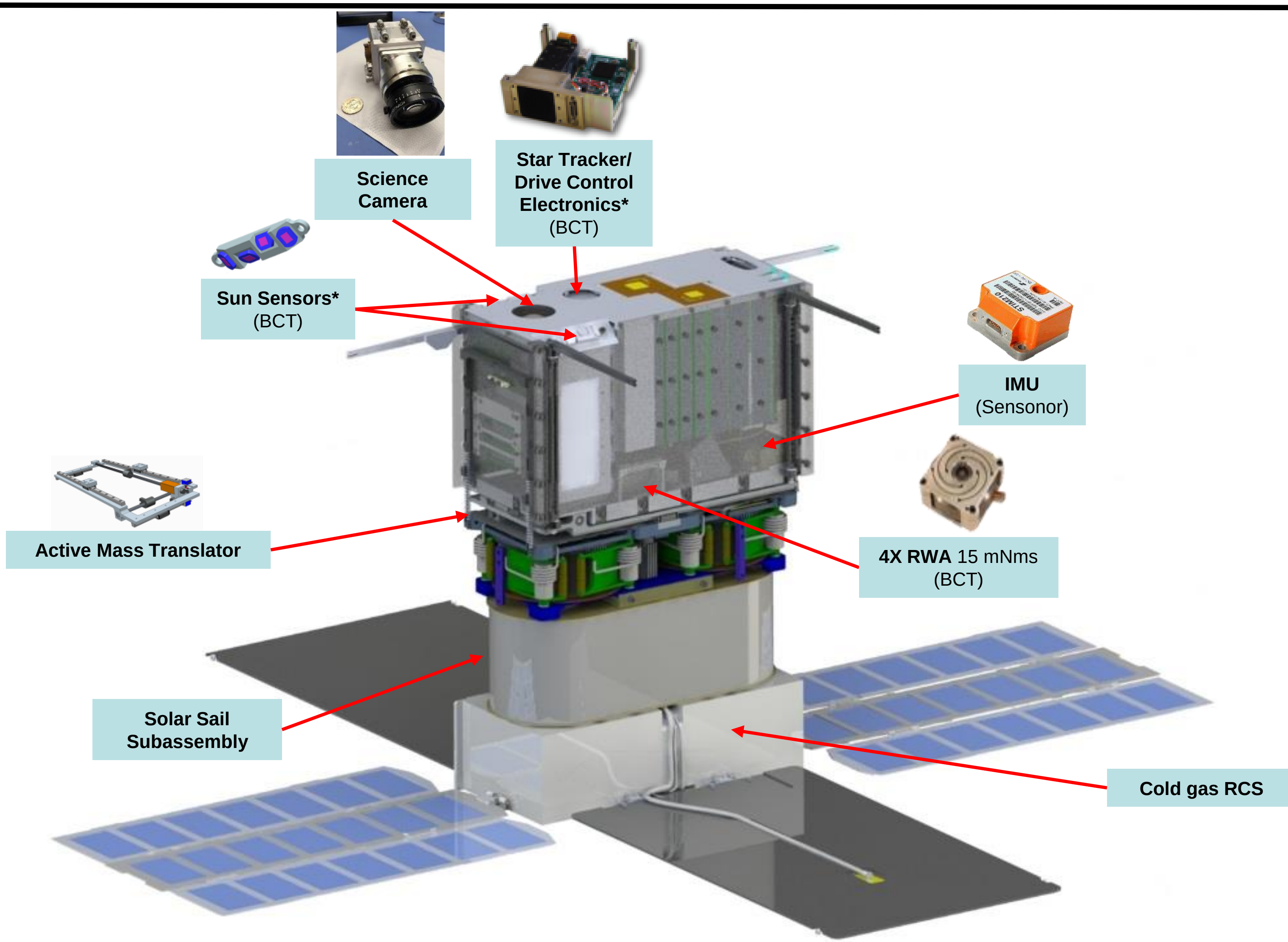


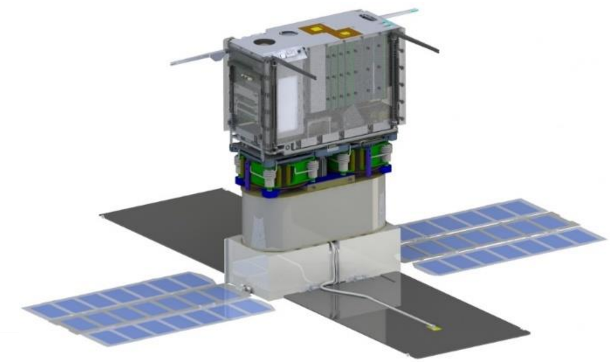



- Light reflects off of the Solar Sail, providing a small but continuous amount of thrust
- ‘Fuel’ never runs out

# NEAS Control System Overview

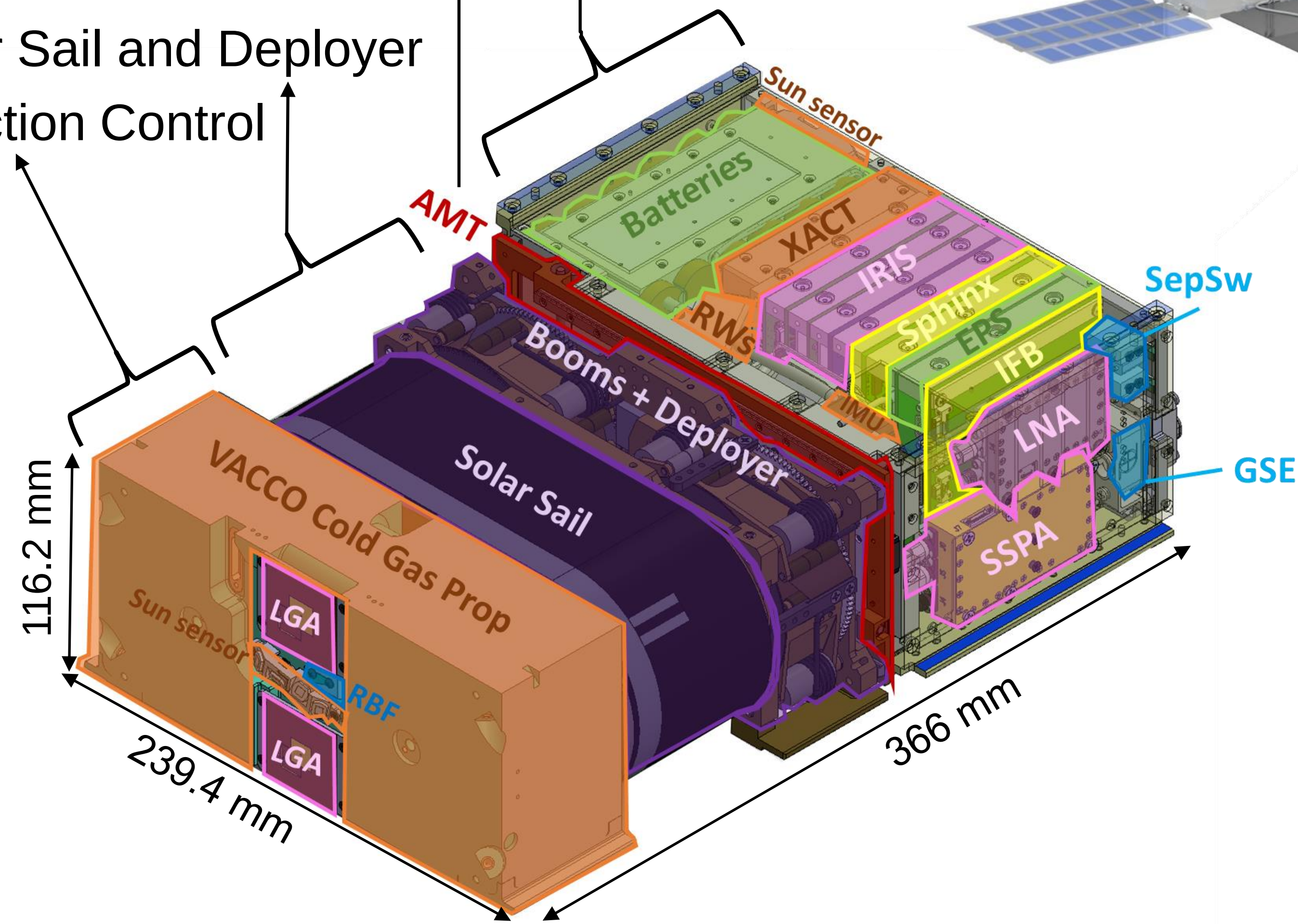


# NEA Scout's Mechanical Configuration



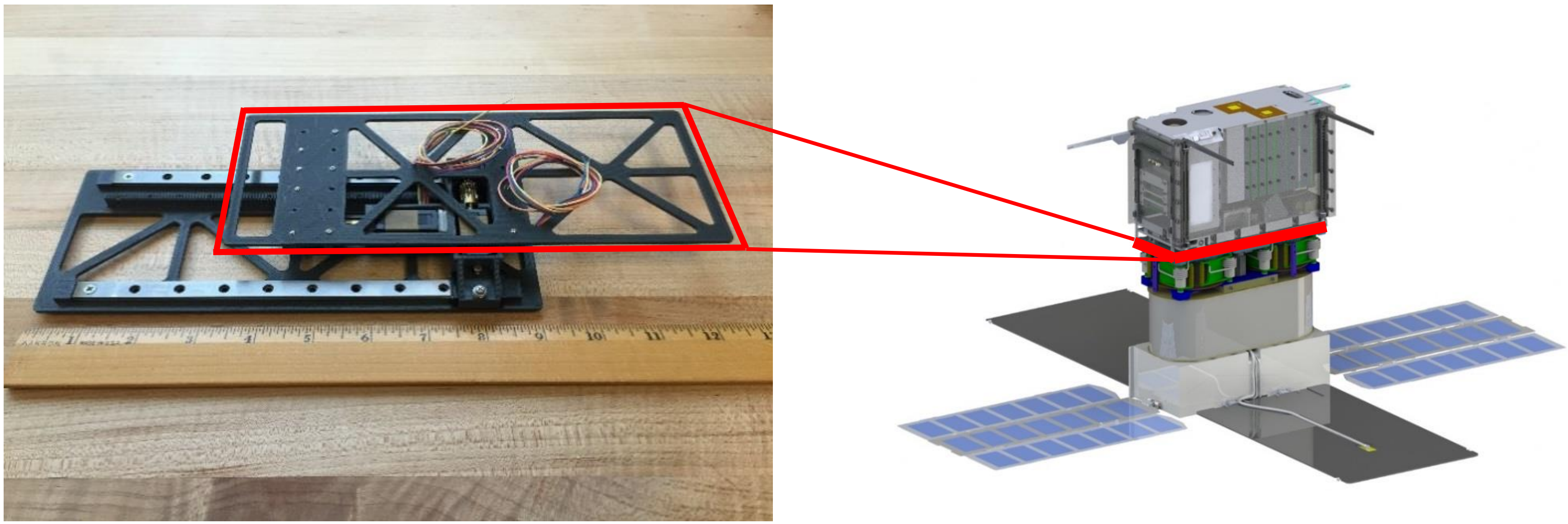
**NEA Scout is split into three major parts:**

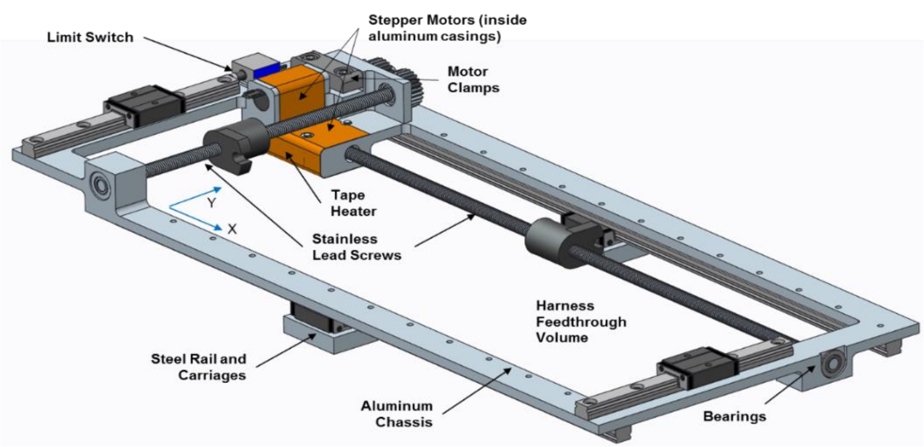
1. Avionics
2. **Active Mass Translator**
3. Solar Sail and Deployer
4. Reaction Control



# NEA Scout's Active Mass Translator (AMT)

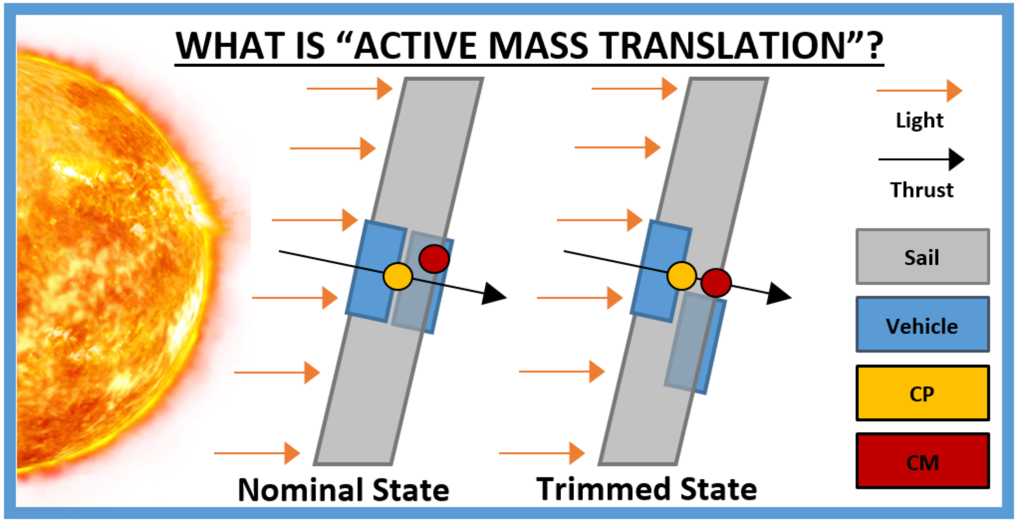
## The AMT allows NEA Scout's two *halves* to move relative to each other

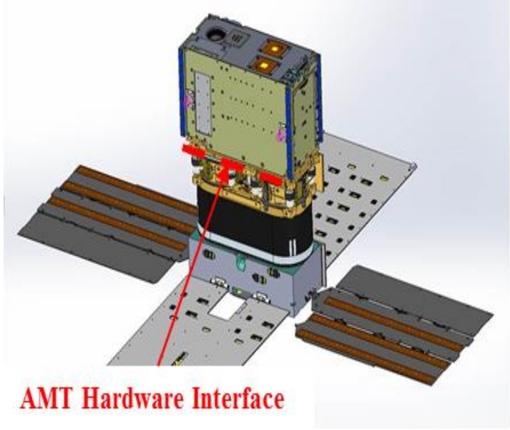


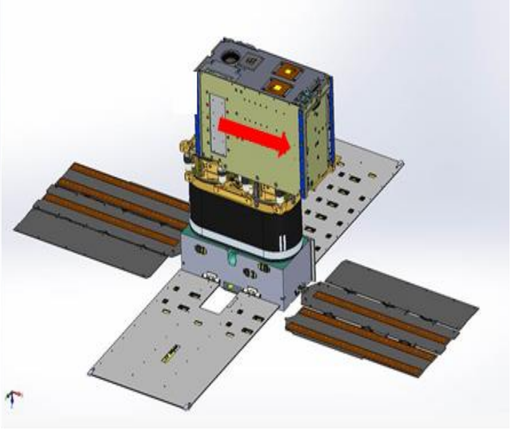


# NEA Scout's Unique Active Mass Translator (AMT)

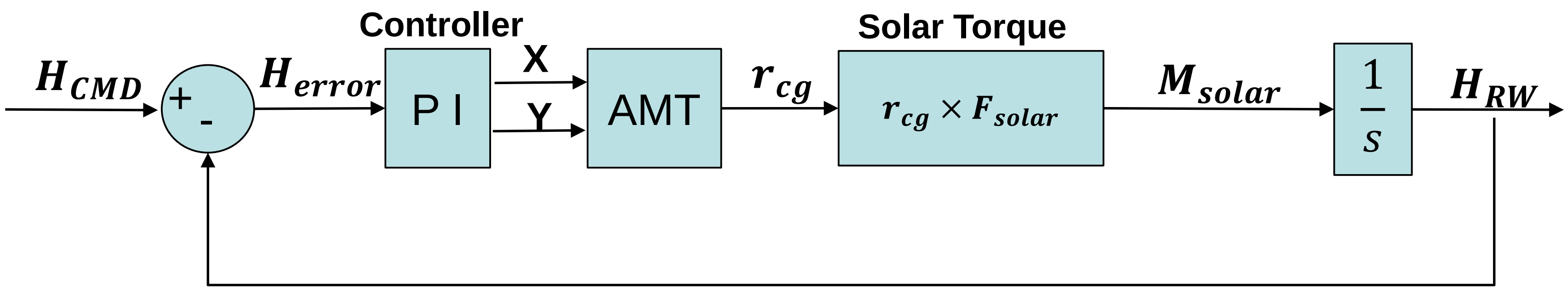
The AMT shifts the Center of Mass (CM) relative to the solar sail's Center of Pressure (CP) to trim the solar torque



**A closed-loop proportional and integral controller is used on the the spacecraft momentum error**




$$H_{CMD} = -[I_{sc}]\omega_{cmd}$$

$$H_{RW} = \int M_{solar}\, dt$$

$\mathbf{H}_{\mathbf{CMD}}$: Commanded Momentum Vector

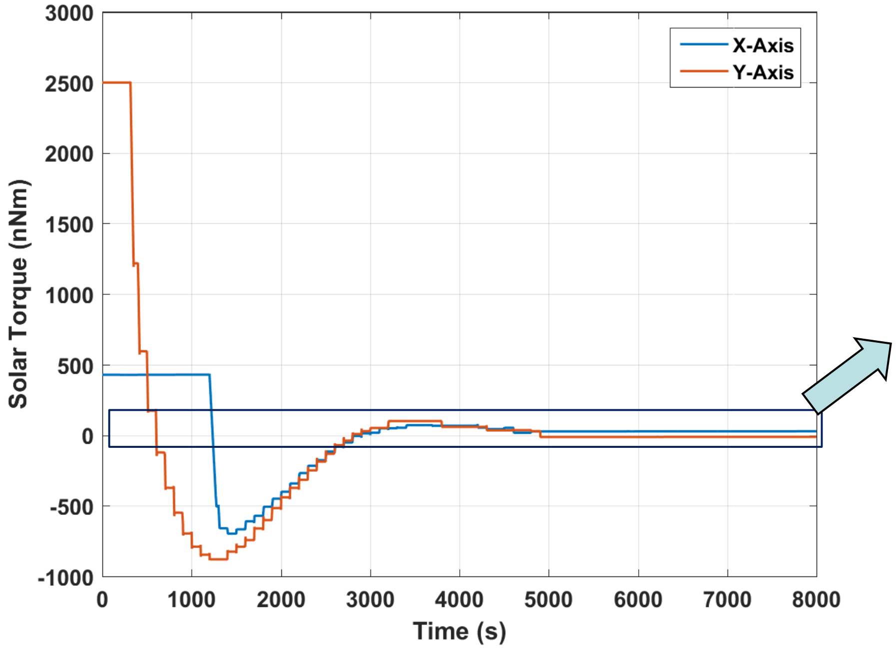
$\boldsymbol{\omega}_{cmd}$: Spacecraft commanded body rate vector

$[I_{sc}]$: Spacecraft Moment of Inertia (MOI) matrix

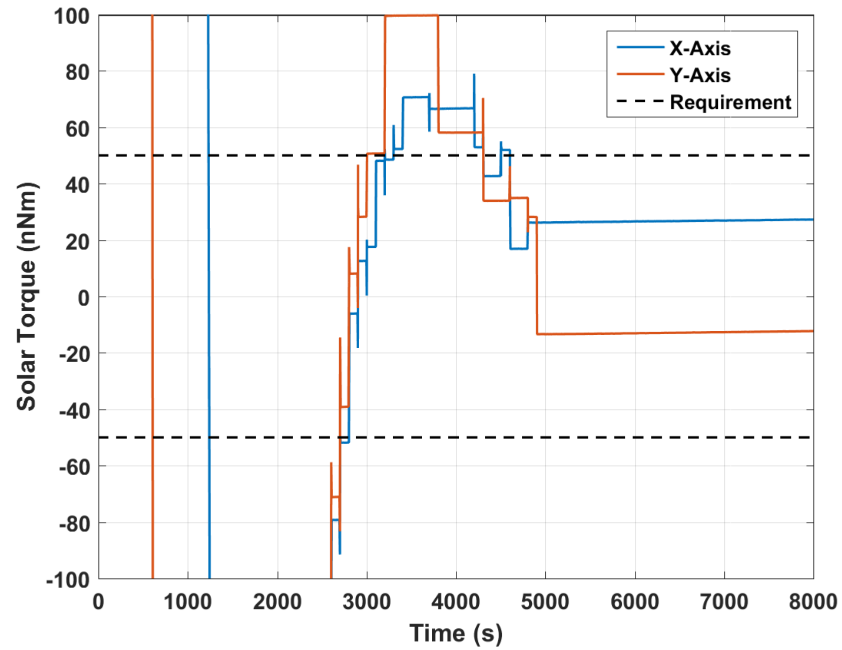
$\mathbf{H}_{RW}$: Reaction Wheel Momentum Vector

# Attitude Hold – 45 deg. Sun Incidence Angle

Solar Torque



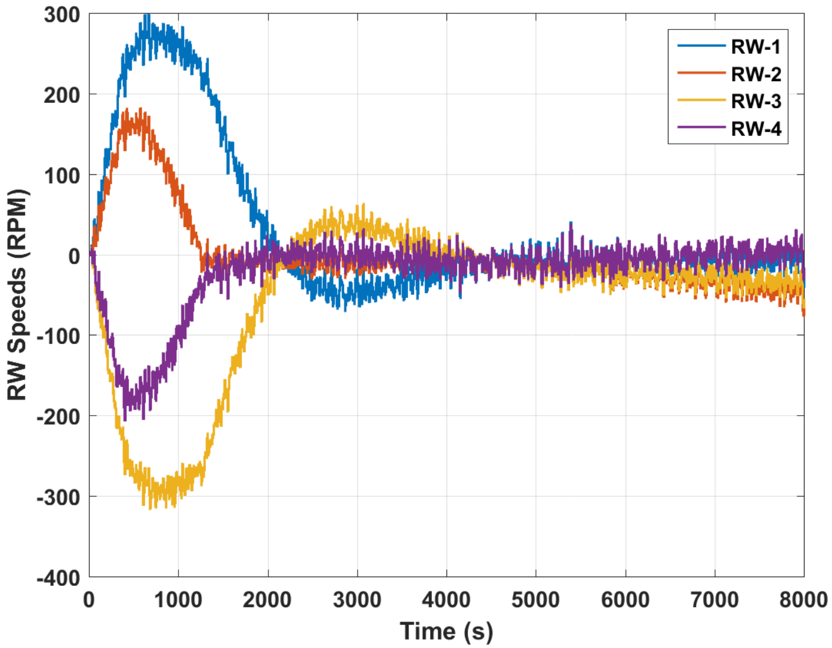

Zoom-In



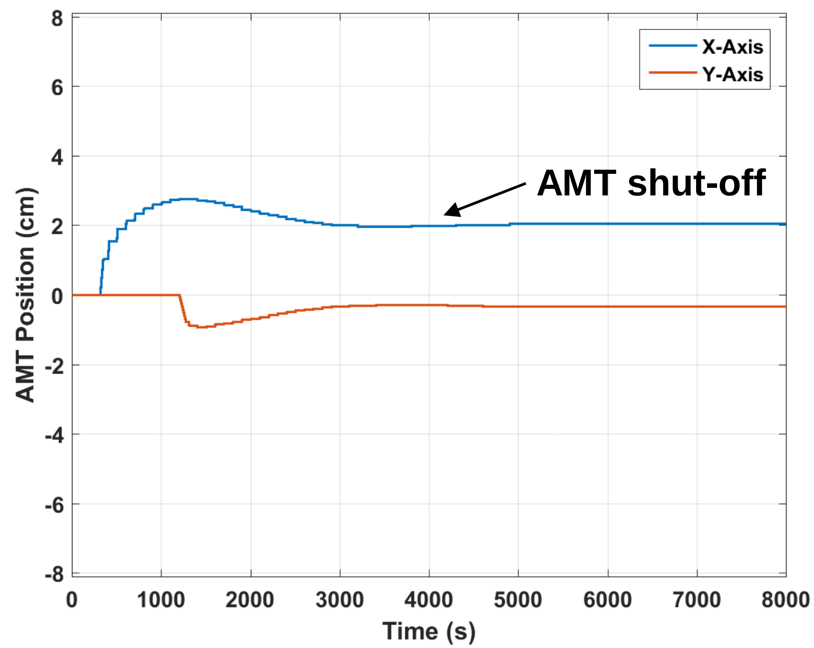

- Solar torque at a simulated 45 degree Sun Incidence Angle (SIA)
- AMT controller brings the solar toque down within the 50 (nano-Newton meters) requirement

# Attitude Hold – 45 deg. Sun Incidence Angle (SIA)

## Reaction Wheels

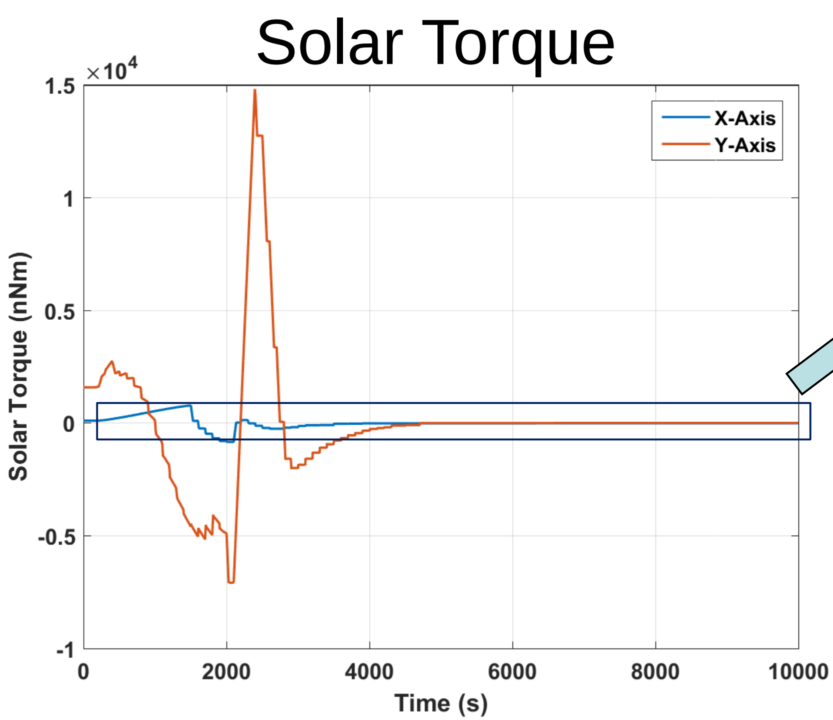


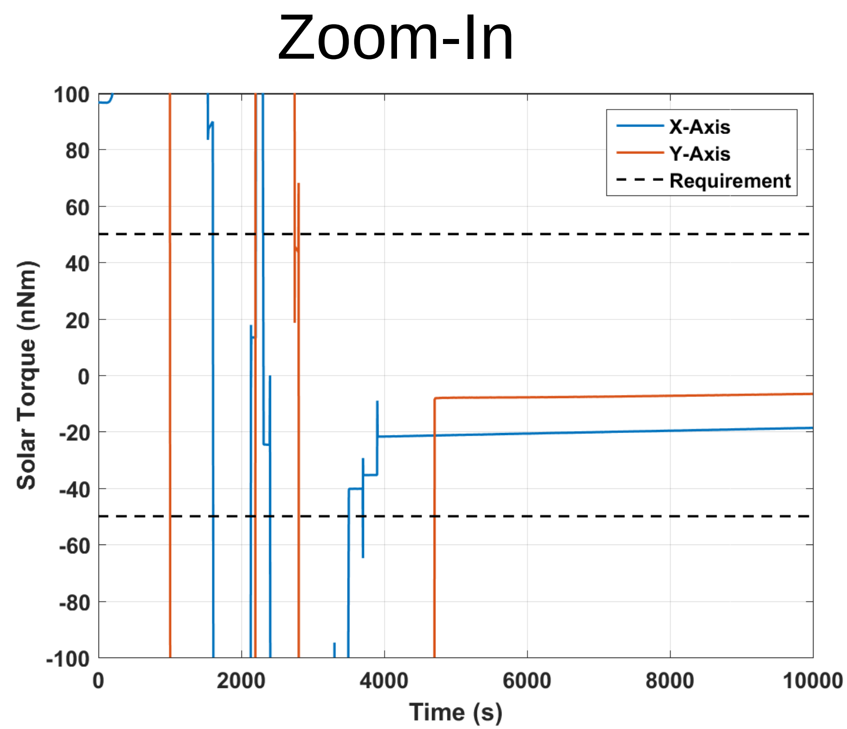

## AMT: X-Y Position




- **Reaction wheel momentum (RPMs) is controlled by the AMT**
- **Once the solar torque and the reaction wheel momentum are below the desired thresholds, AMT controller is shut-off at ~5000 seconds**

# Slew: 0 to 70 deg. Sun Incidence Angle

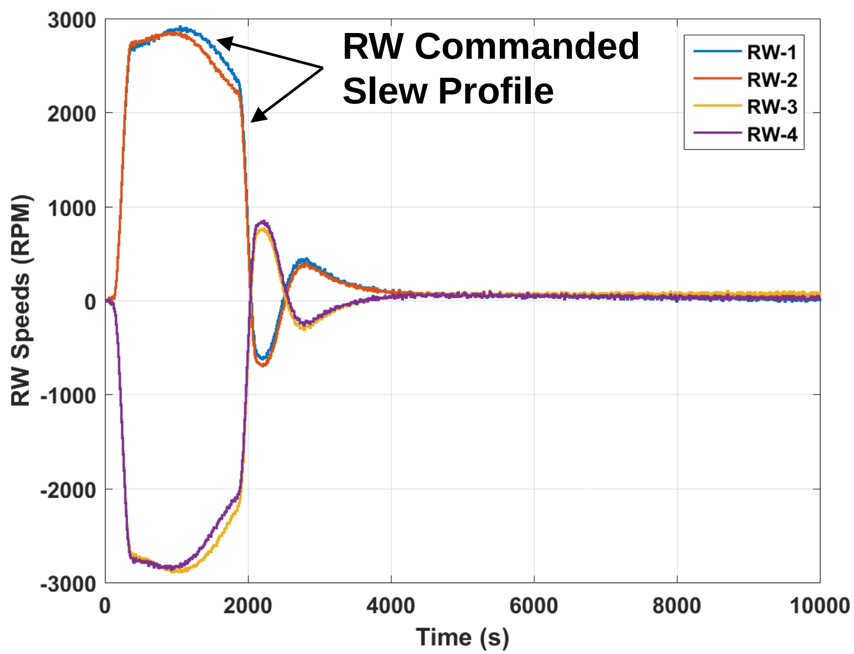


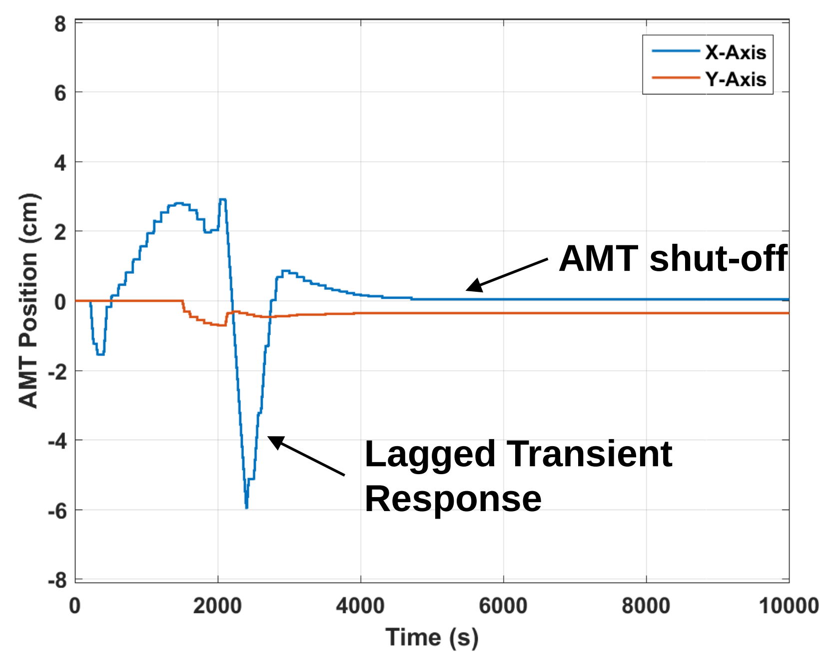

- **Solar torque during a simulated 0 to 70 degree (SIA) slew**
- **AMT controller brings the solar toque down within the 50 (nano-Newton meters) requirement**

# Slew: 0 to 70 deg. Sun Incidence Angle

## Reaction Wheels



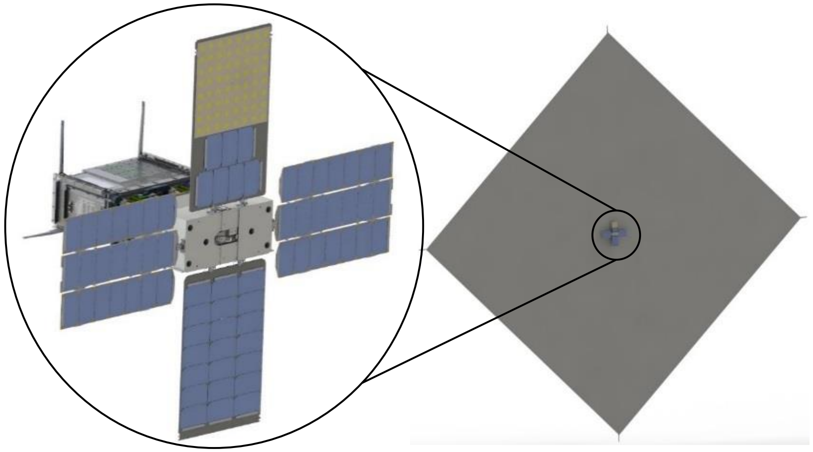

## AMT: X-Y Position

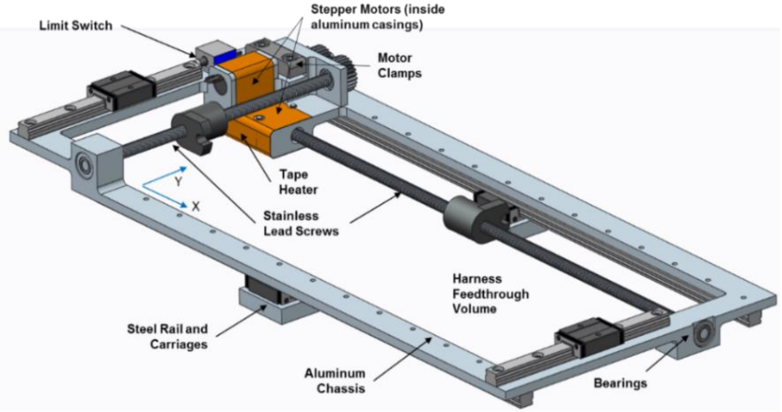



- **AMT control responds only to commanded momentum error**
- **Once the solar torque and the reaction wheel momentum are below the desired thresholds, AMT controller is shut-off at ~5000 seconds**

# Conclusions

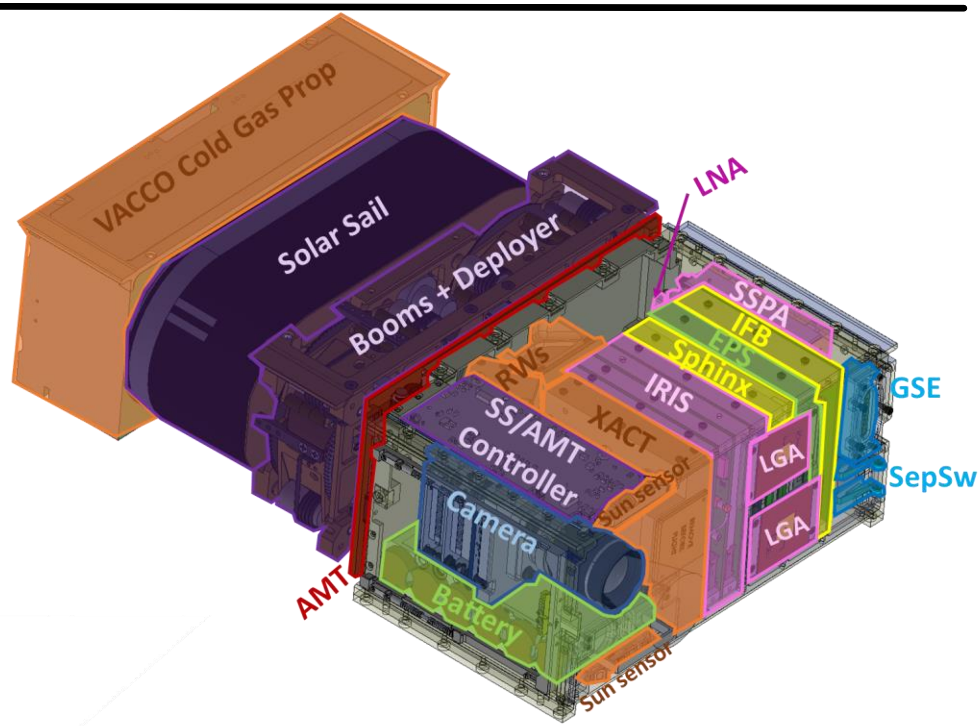
- NEA Scout uses Active Mass Translator to control the large pitch/yaw solar torques caused by the solar sail
- AMT control is autonomous for all phases of the mission, essential for deep-space missions with limited ground contact
- AMT compact design allows solar torque control (pitch/yaw) without propellant, decreasing mass and volume requirements, and improving solar sail acceleration performance
- Improved solar sail performance is key to reach more targets within the radiation lifetime of the avionics

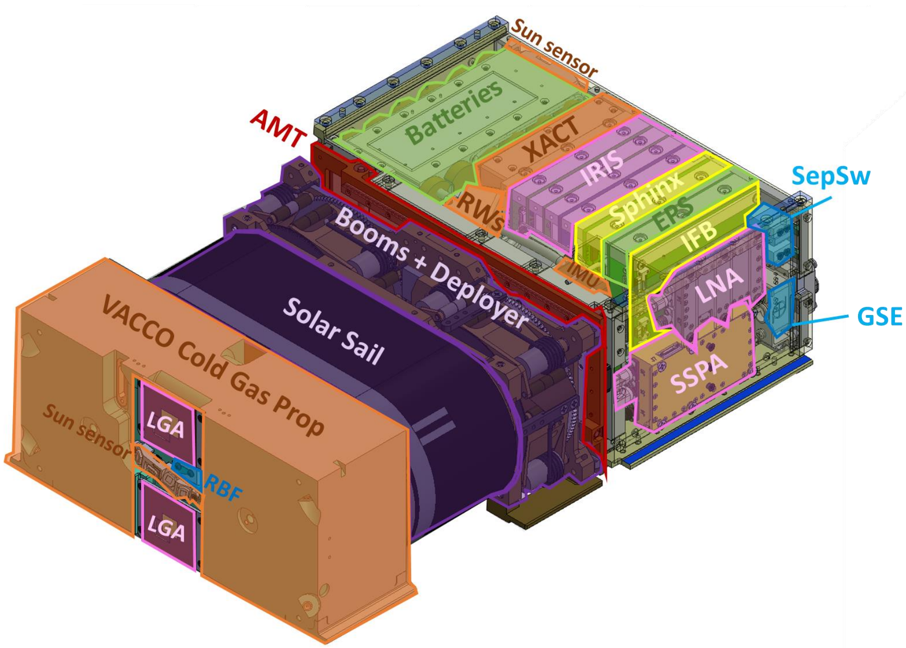




# BACKUP

# NEA Scout Mechanical Layout (alt. view)



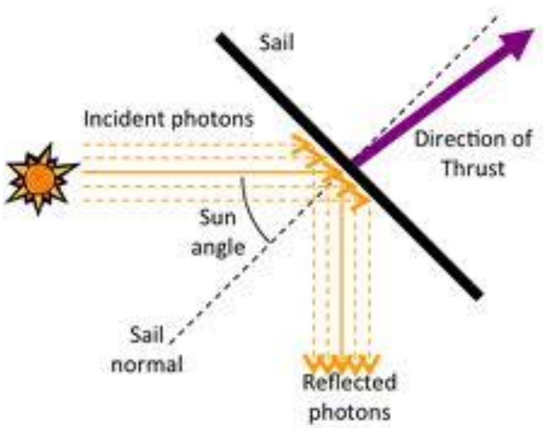



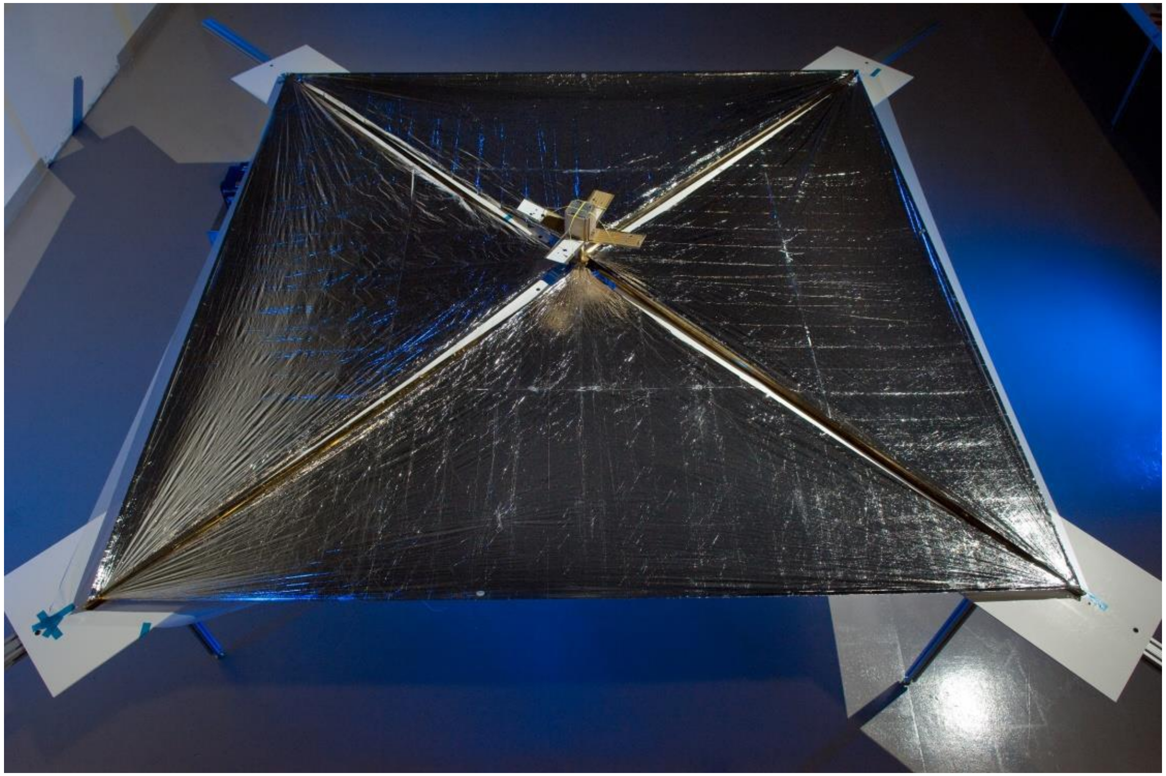
# NEA Scout Solar Sail Technology

Light reflects off of the Solar Sail

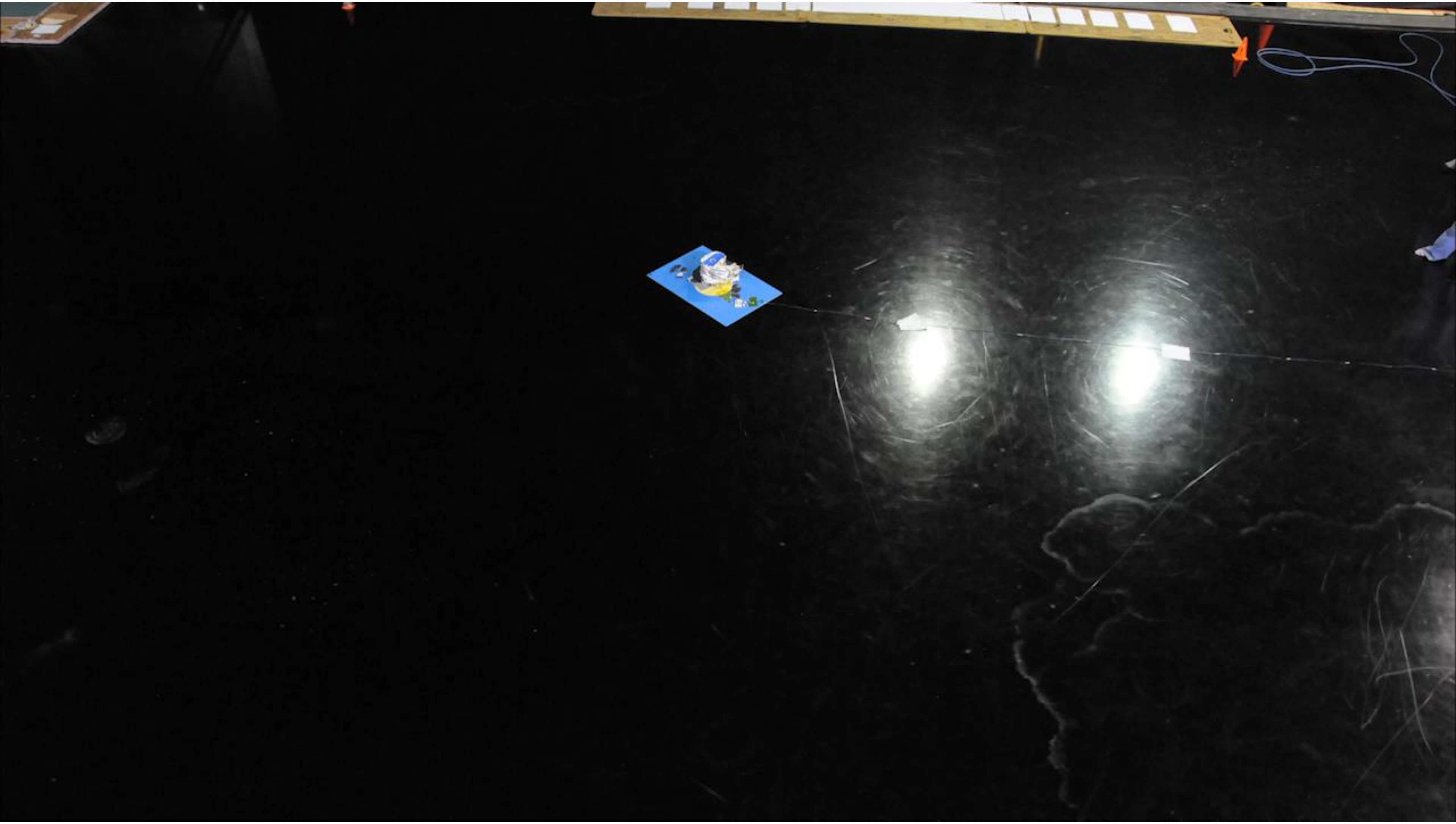
Provides a small but steady amount of thrust

'Fuel' never runs out!



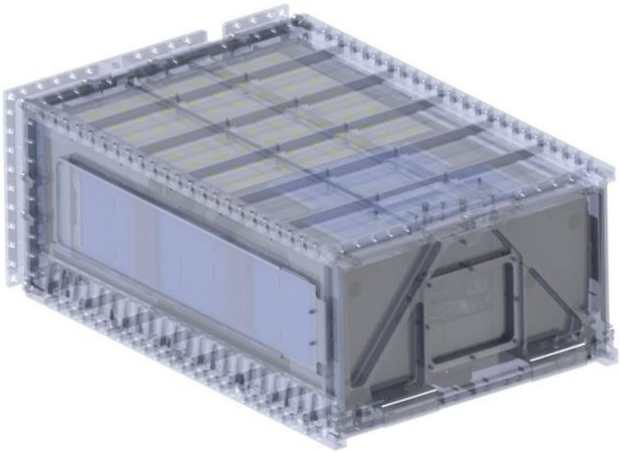



# 1st Full Scale Solar Sail Ground Deployment

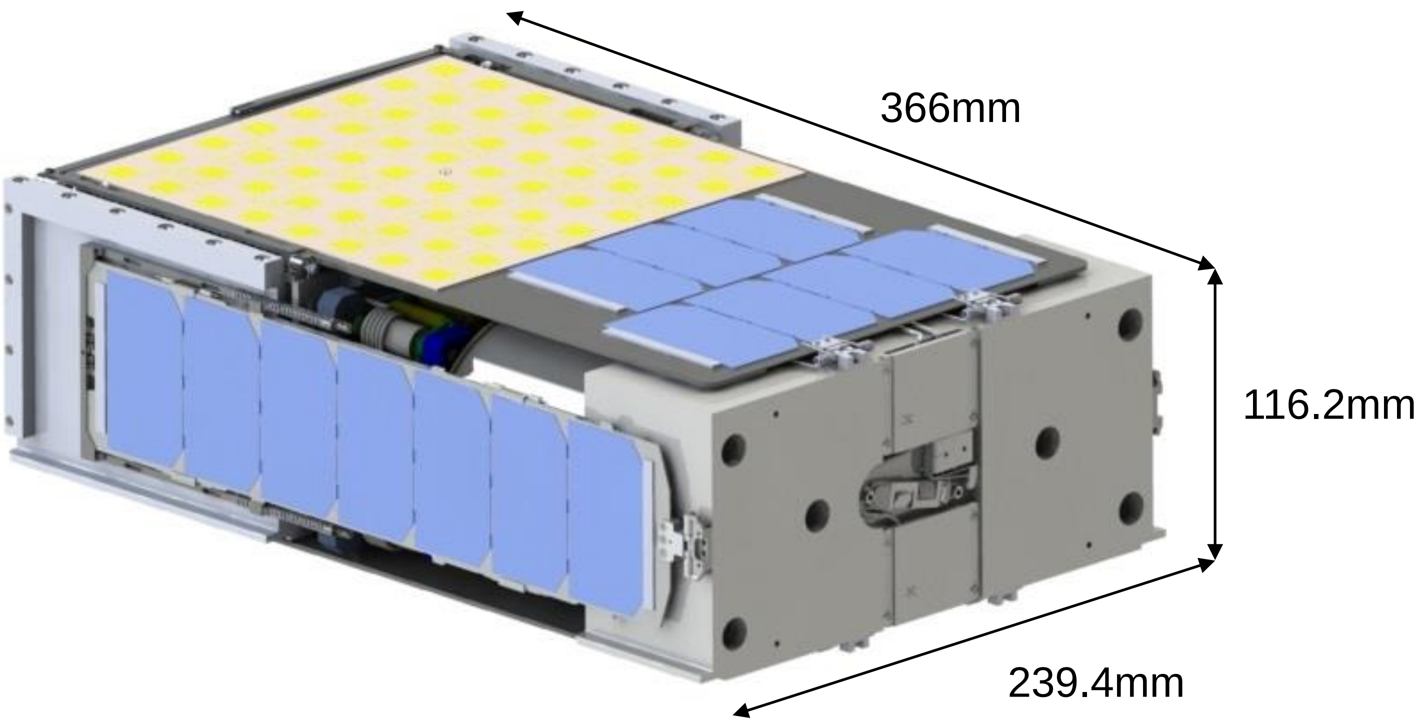


# Simulated NEA Scout Mission CONOPS

# Flight System Configuration – Stowed

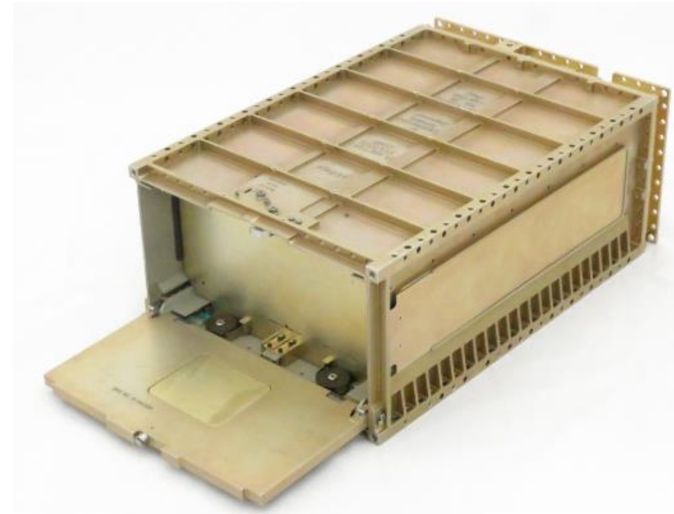


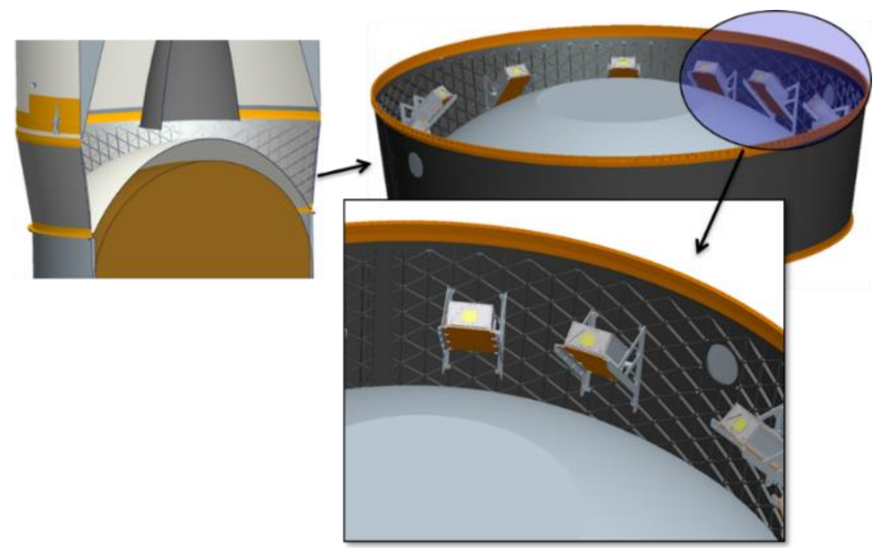
NEAS Inside PSC
6U Dispenser



# SLS Interface

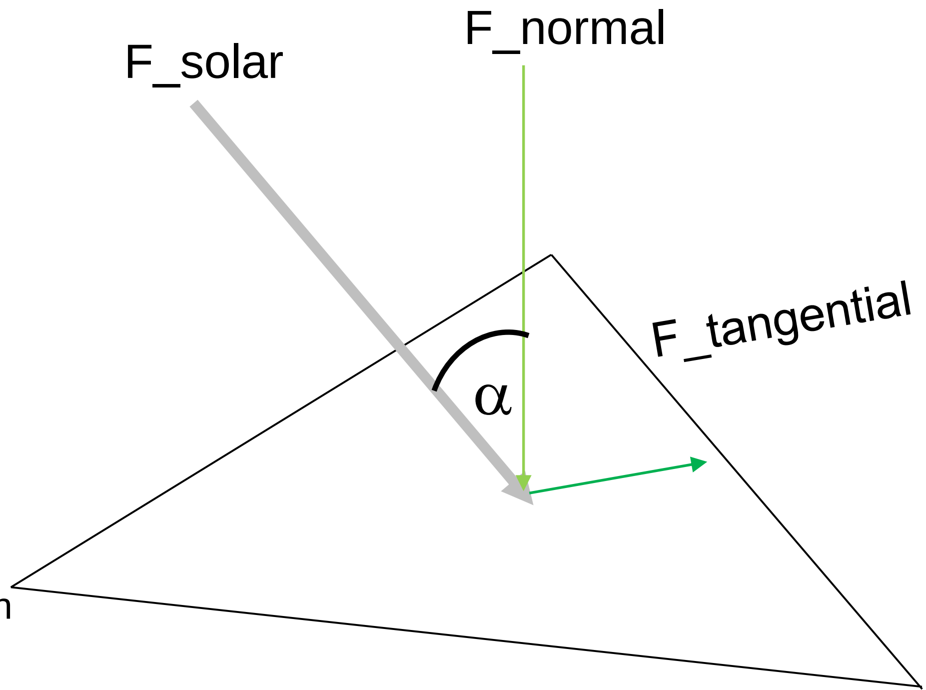
- Manifested on SLS EM-1; mounted in MSA and housed within Planetary Systems Corp. Cannisterized Satellite Dispenser (CSD)
- Project interfaces with Secondary Payload Office (SLS) and Launch Services Program (Dispenser)
- Handover to GSDO installed in dispenser and powered-off
- After Orion separation, ICPS performs disposal maneuver
- Post-disposal, secondary payload sequencer activated
- Each payload dispensed at designated times via signal from sequencer
- Separation switches on payload activated upon deployment, powering on spacecraft





# Thrust Model: Underlying Physics

- **Flat Plate optical model published in Wright and cited by McInnes**
- **Shows tangential and normal components**
- **Tangential component important to torque**




P = solar pressure

A = area

$\tilde{r}$ = total reflectivity

s = fraction of reflection that is specular

$\alpha$ = sun incidence angle

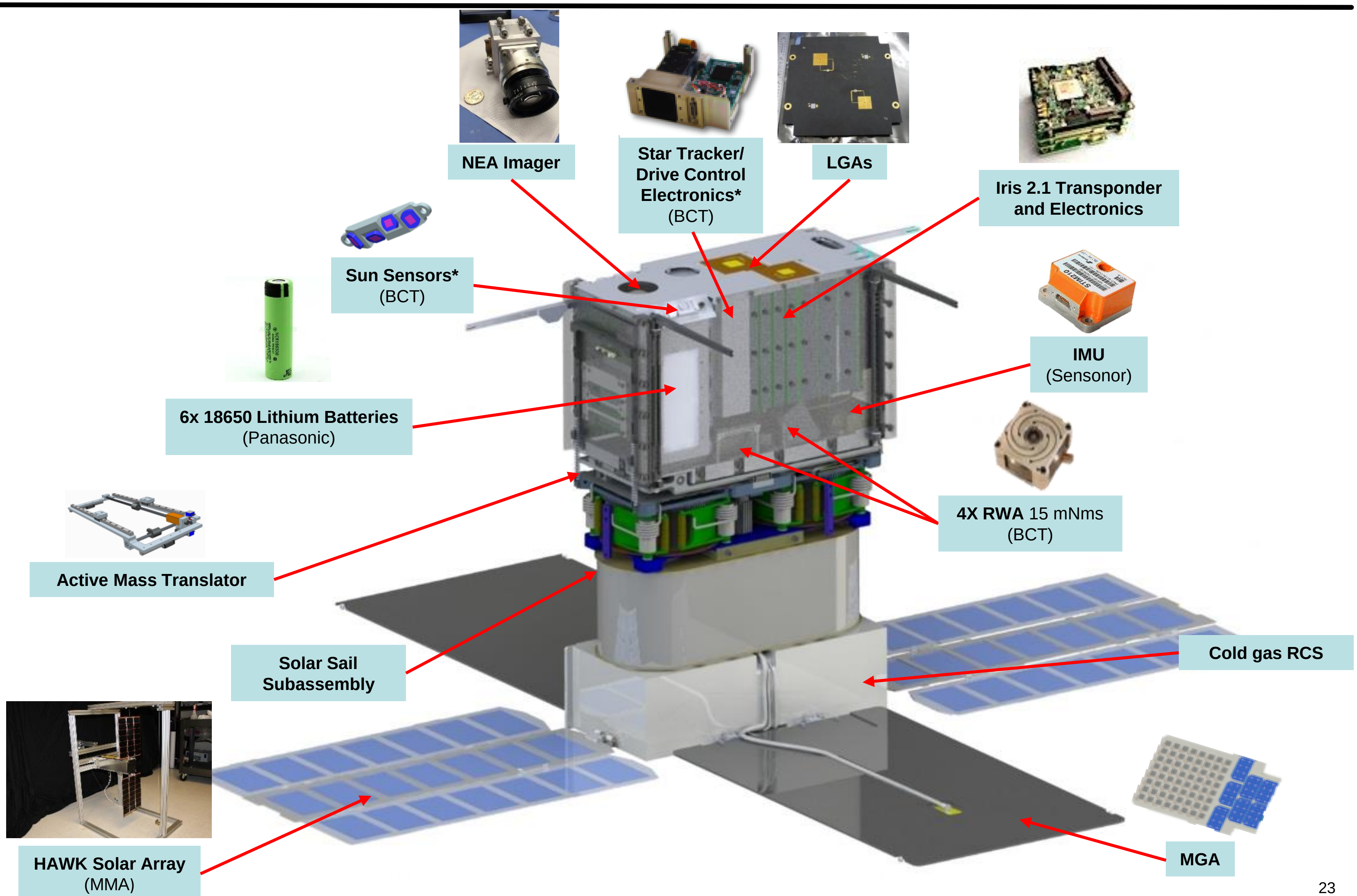
Bf, Bb = front and back side non-Lambertian coefficients

ef, eb = front and back side emissivities

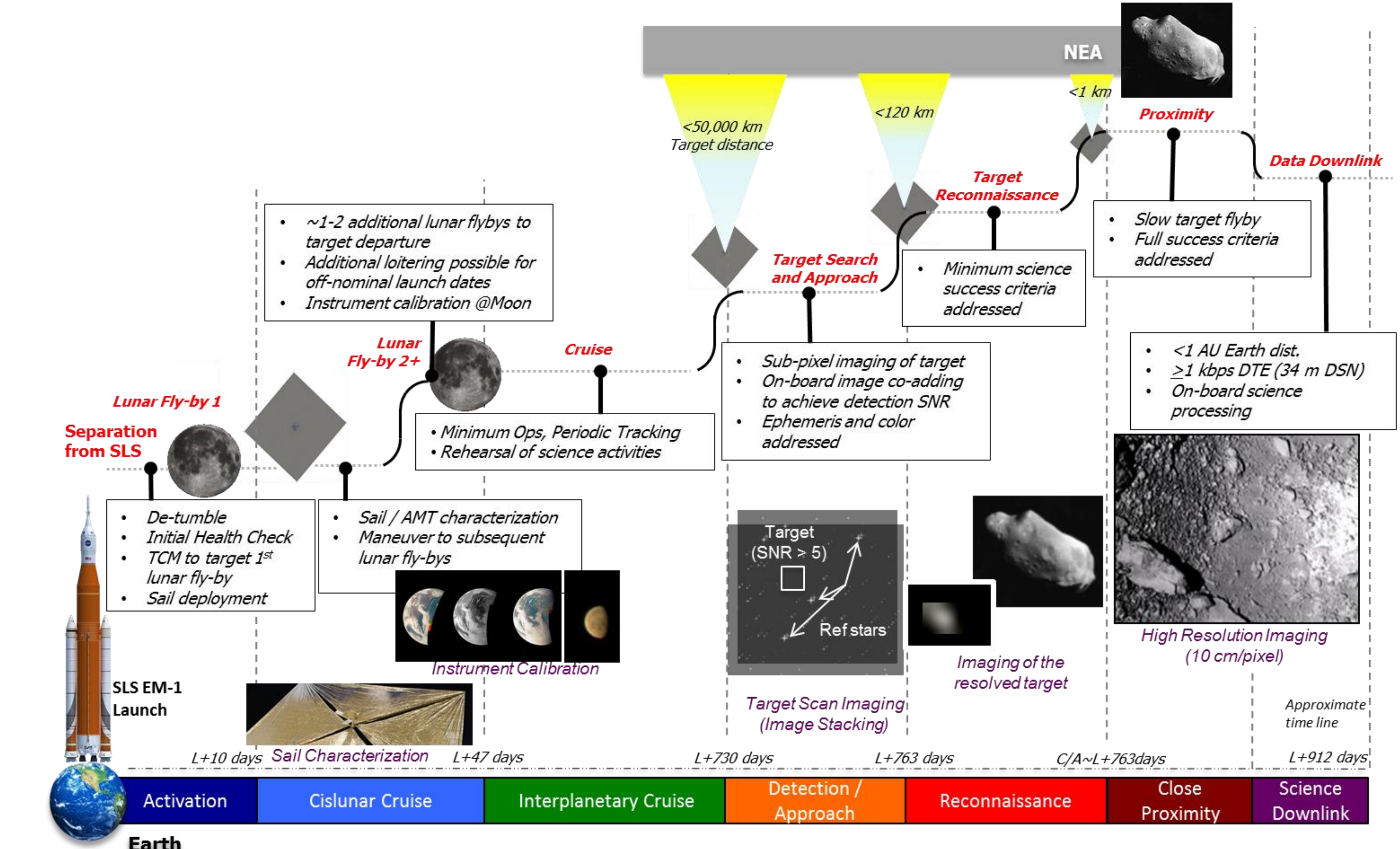
$$f_n = PA\left\{(1+\tilde{r}s)\cos^2\alpha + B_f(1-s)\tilde{r}\cos\alpha + (1-\tilde{r})\frac{\varepsilon_f B_f - \varepsilon_b B_b}{\varepsilon_f + \varepsilon_b}\cos\alpha\right\}$$

$$f_t = PA(1-\tilde{r}s)\cos\alpha\sin\alpha\, t$$

# Flight System Overview

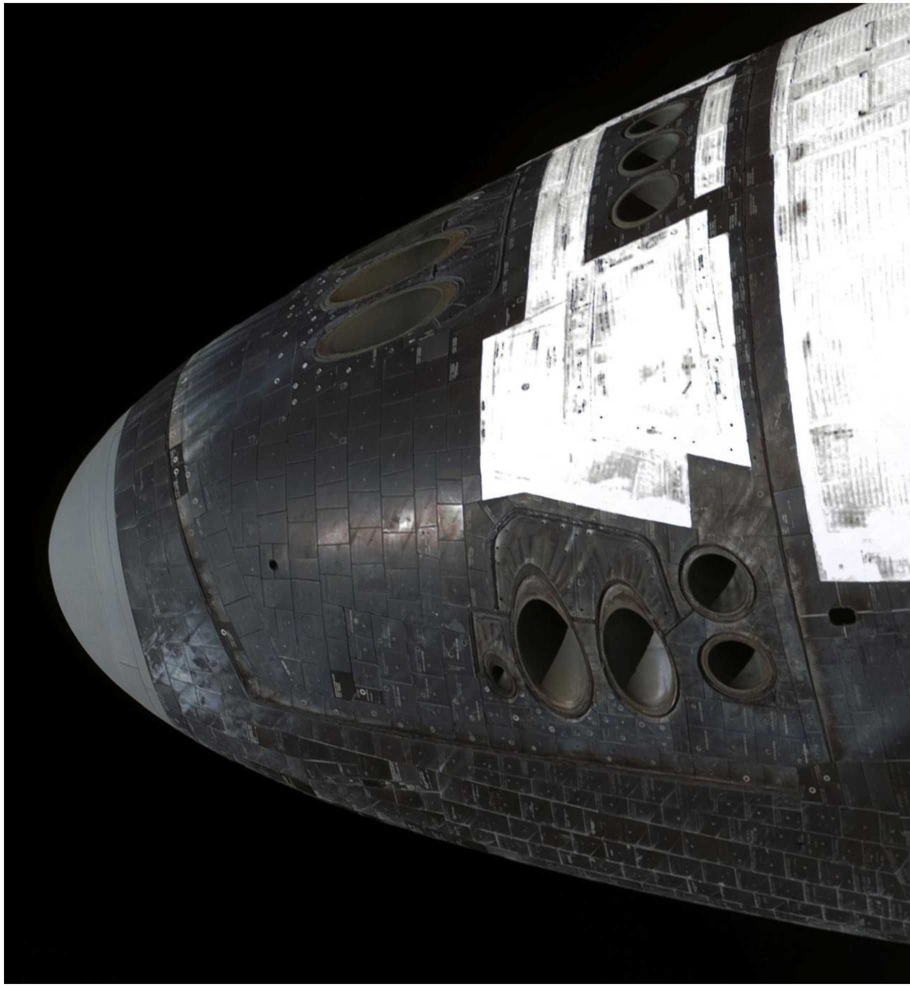


# Mission ConOps




*time not to scale

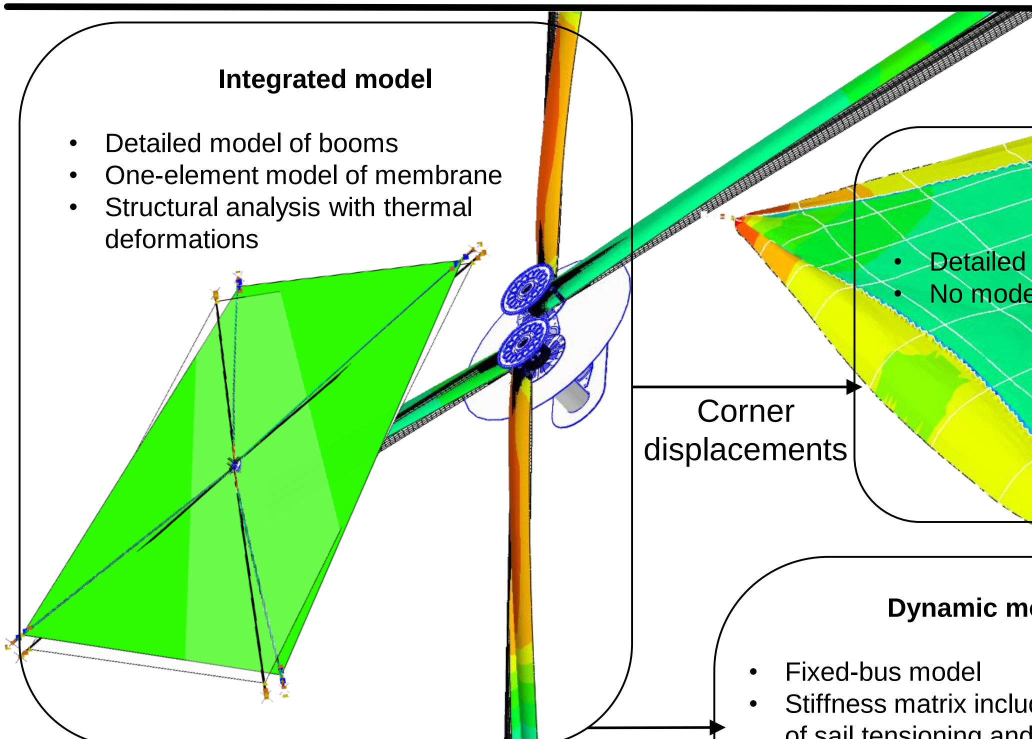
# Other Reaction-Jet Control System (RCS)



# Solar Sail Thrust Model and Analysis Flowchart

**Integrated model**

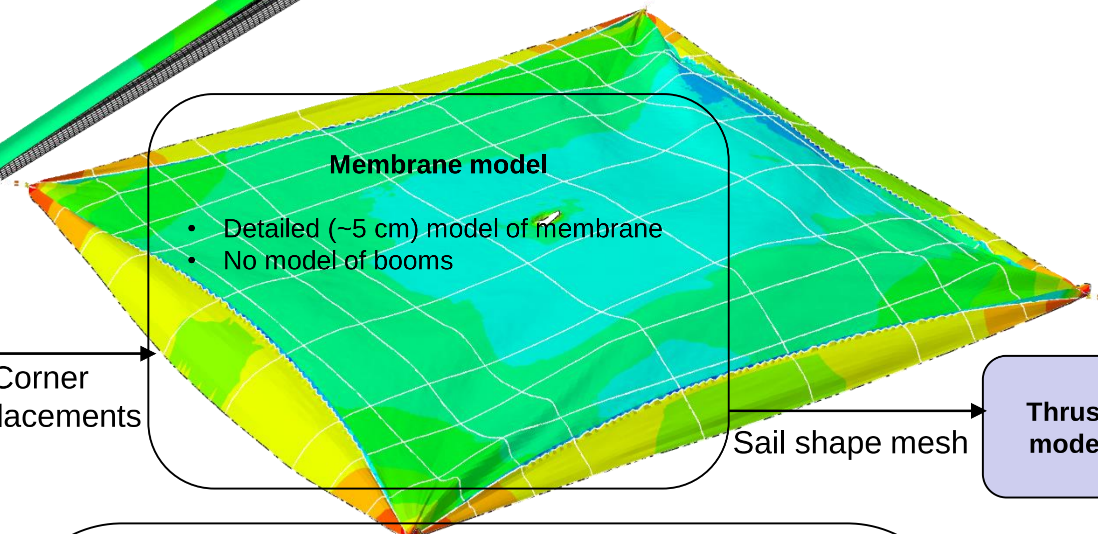
- Detailed model of booms
- One-element model of membrane
- Structural analysis with thermal deformations



Corner displacements

**Membrane model**

- Detailed (~5 cm) model of membrane
- No model of booms



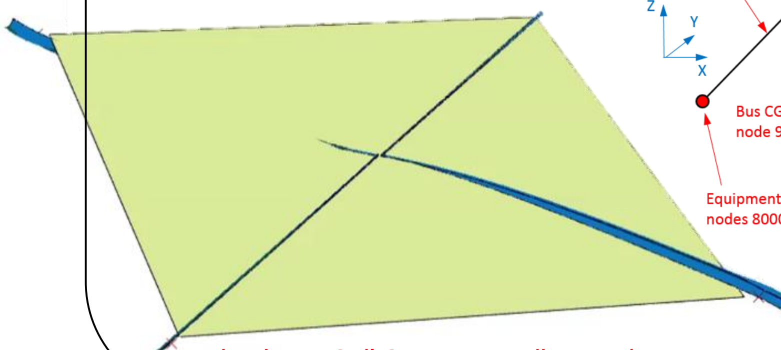
Sail shape mesh

**Thrust model**

Shape solution

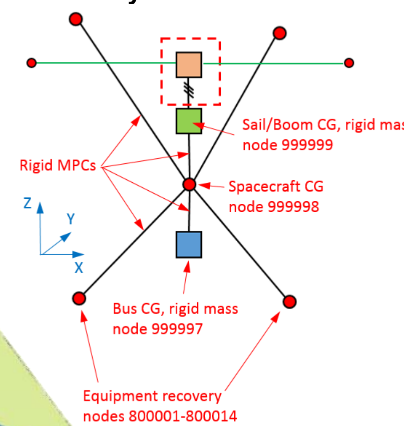
**Dynamic model**

- Fixed-bus model
- Stiffness matrix includes the effects of sail tensioning and thermal loading
- Reduced dynamic model is integrated with the spacecraft bus for attitude control studies



Fixed-Bus Sail System Bending Mode

**Reduced/simplified dynamic model**




**Attitude control model**

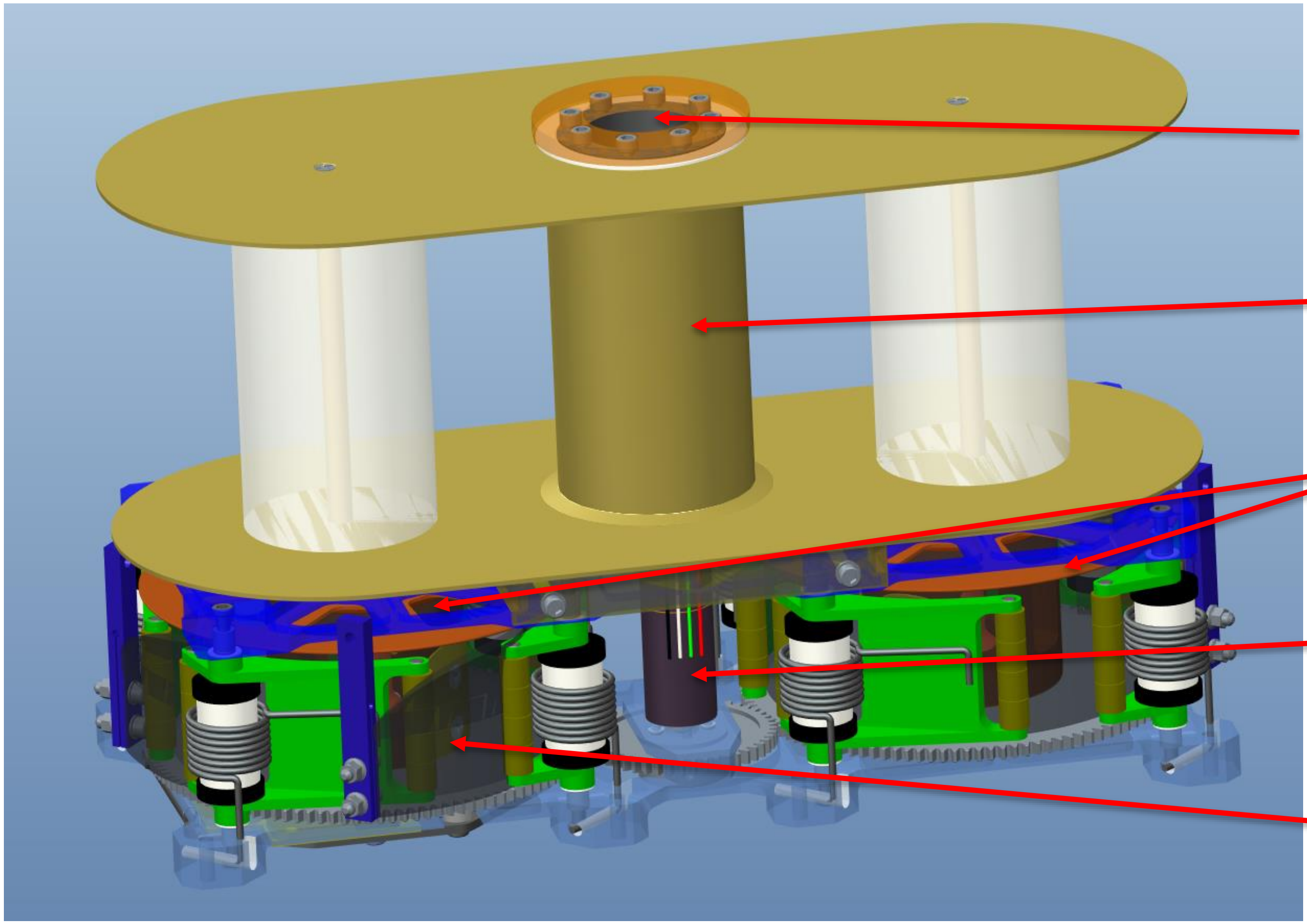
**Thermal model**

- Radiative and conductive heat transfer

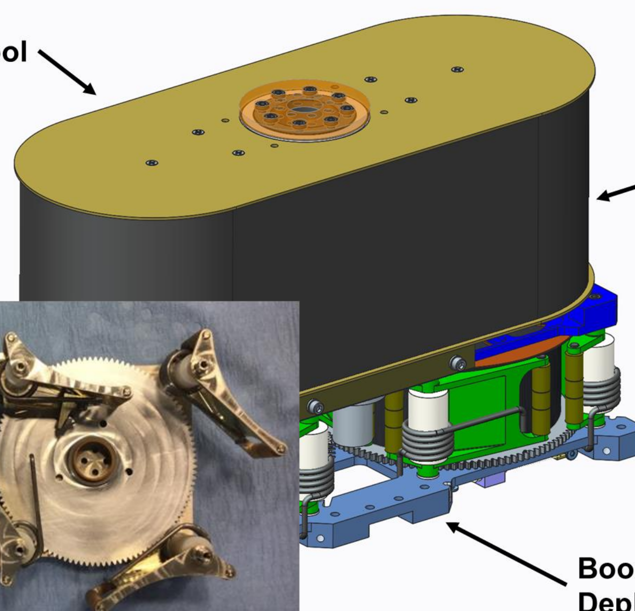
# Summary & Project Status

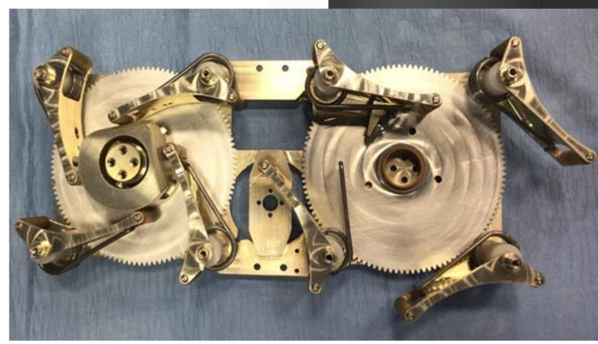
- **Summary**
  - Numerous challenges exist in implementing a Solar Sail mission, particularly within a CubeSat form factor
  - Extensive design, analysis, and testing has been performed to-date to address these challenges
  - Difficulty in validating analytical models and performing ground (1G) demonstrations given gossamer nature of Solar Sails
  - NEA Scout flight on SLS EM-1 flight opportunity (2018) will provide a giant leap forward in clarifying our understanding of Solar Sail modeling and performance
- **Project Status**
  - On track for August Design Review with significant flight procurements to follow
  - Flight System integration starts June 2017
  - Manifested on SLS EM-1 for 2018 deep space flight opportunity
  - NEA flyby anticipated in 2021

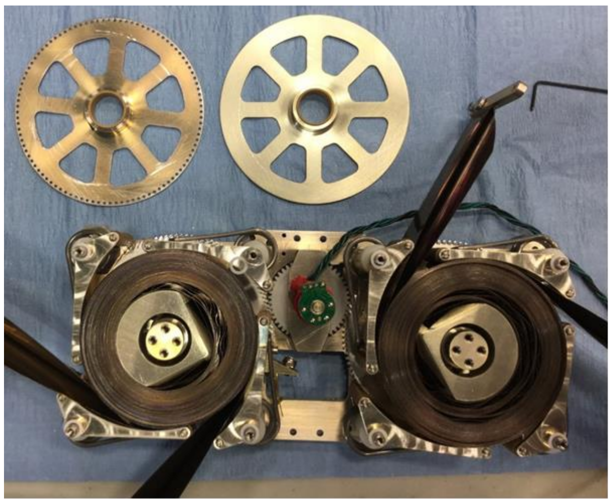
# Solar Sail Subsystem Overview

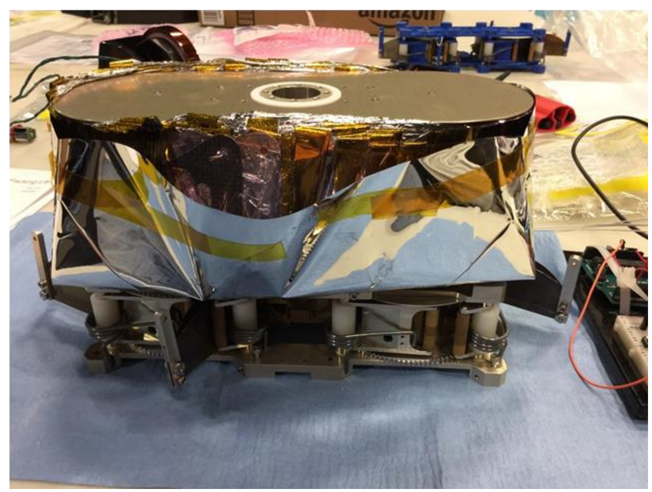


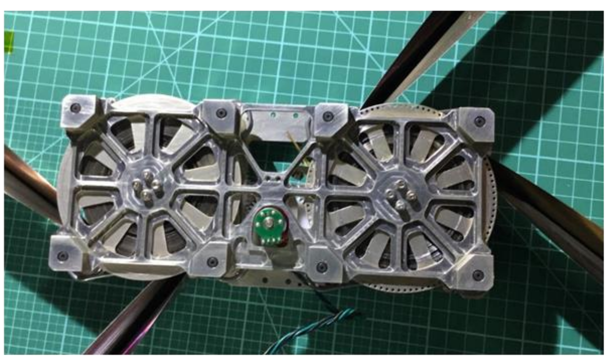
# Solar Sail Subsystem Overview



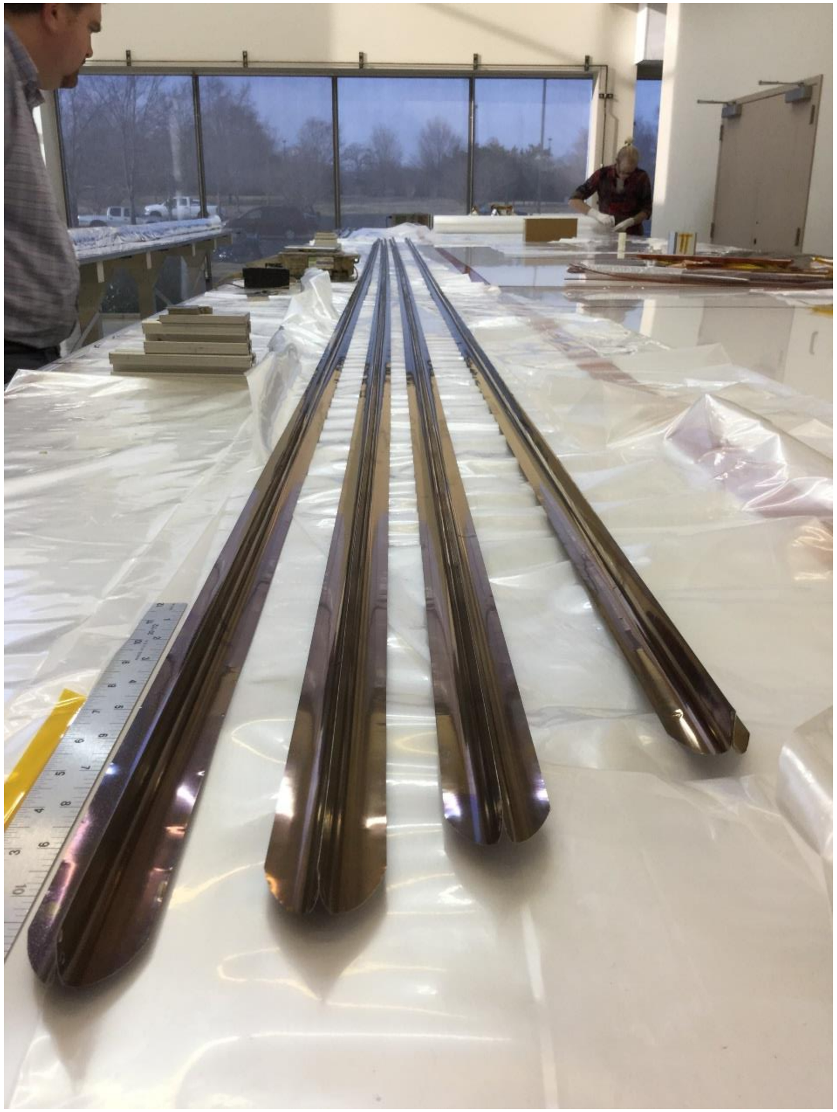







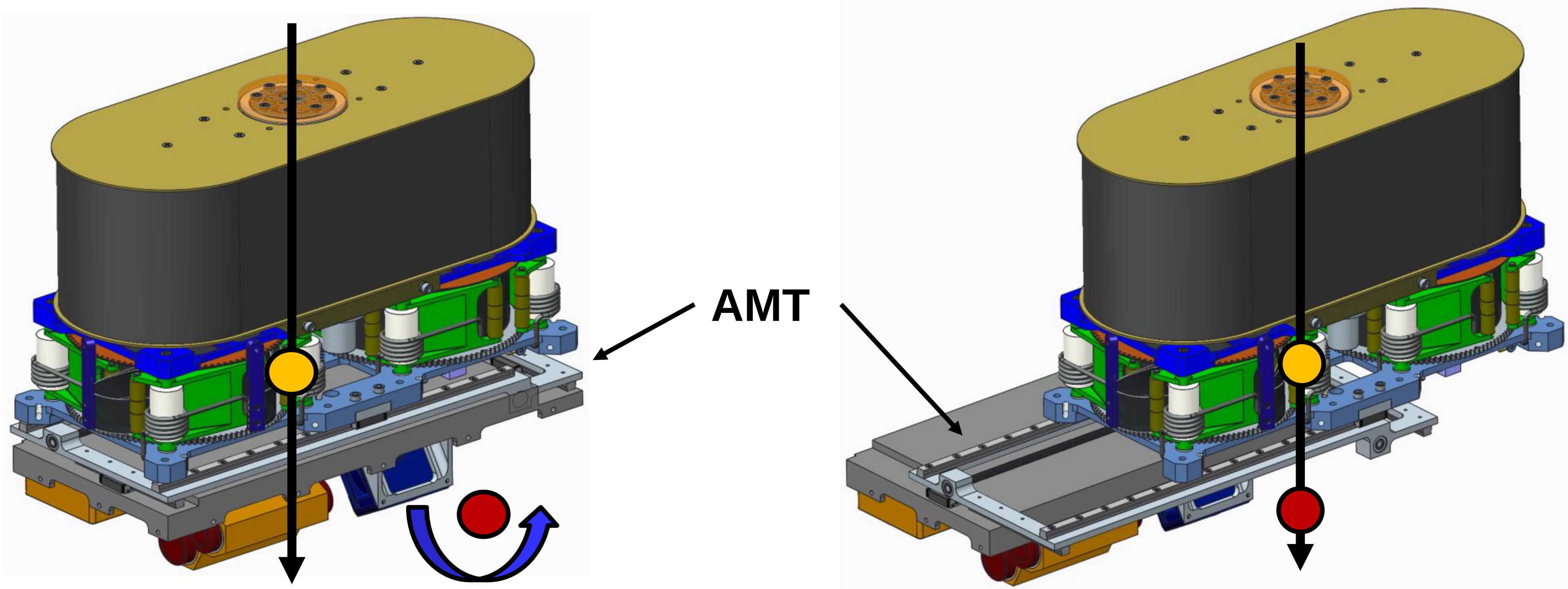


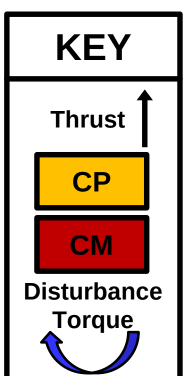
# Solar Sail Booms (@NeXolve)

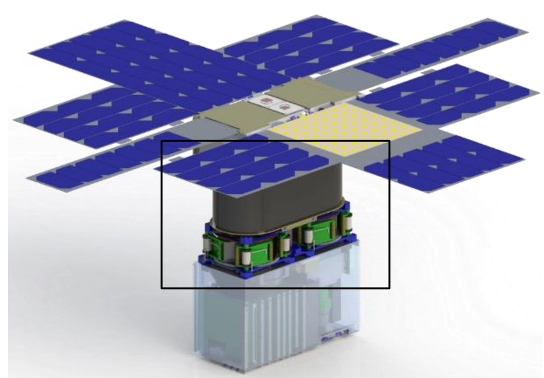


# Disturbance Torques: Active Mass Translator (AMT)

**Nominal State** | **Trimmed State**

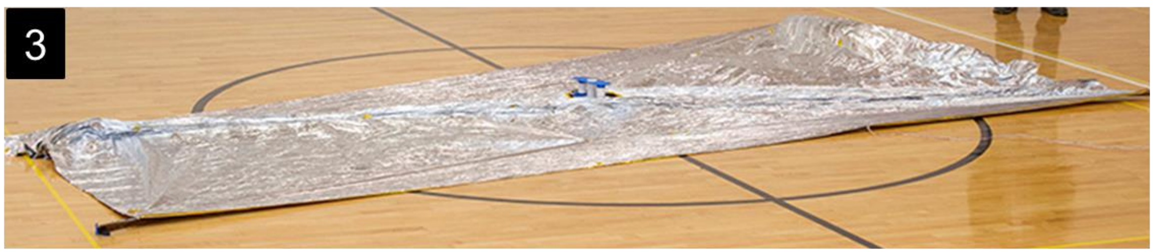


# Transient Solar Sail Deployment – Shape Phases








Single sail membrane drives initial ‘bow tie’ effect: Booms are do not maintain 90deg relative orientation (less predictable induced disturbance force) and direct sunlight on booms drive significant thermal deflections

# NEA Scout Science