Lessons for Interstellar Travel from the Guidance and Control Design of the Near Earth Asteroid Scout Solar Sail Mission

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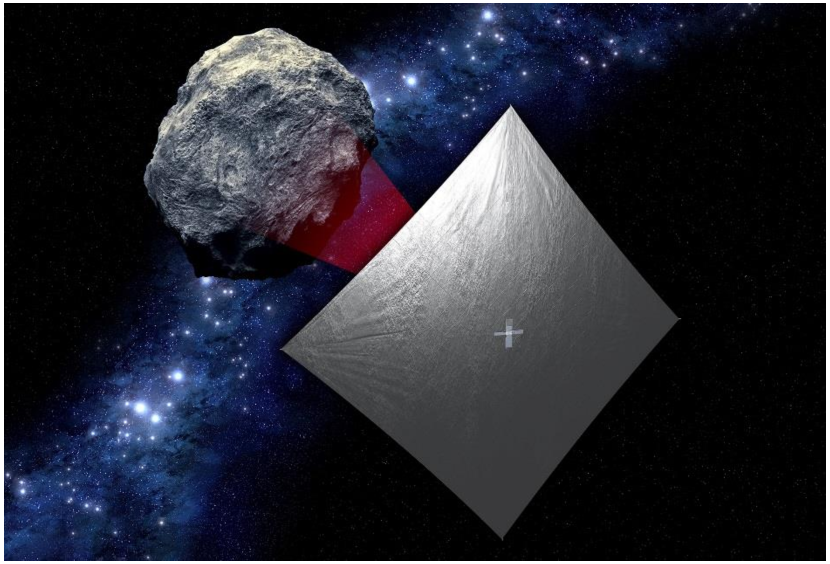
Outline

- Introduction
- Scientific objectives
- Navigation and Guidance
- Force and Torque Modeling
- Attitude Dynamics and Control
- Conclusions
- Next Steps

Introduction – NEA Scout

The Near Earth Asteroid Scout Will

- Image/characterize a NEA during a slow flyby
- Demonstrate a low cost asteroid reconnaissance capability

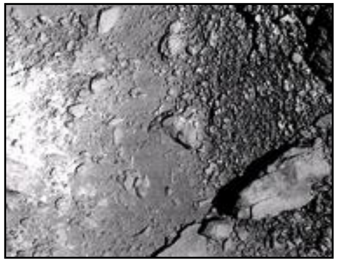


Key Spacecraft & Mission Parameters

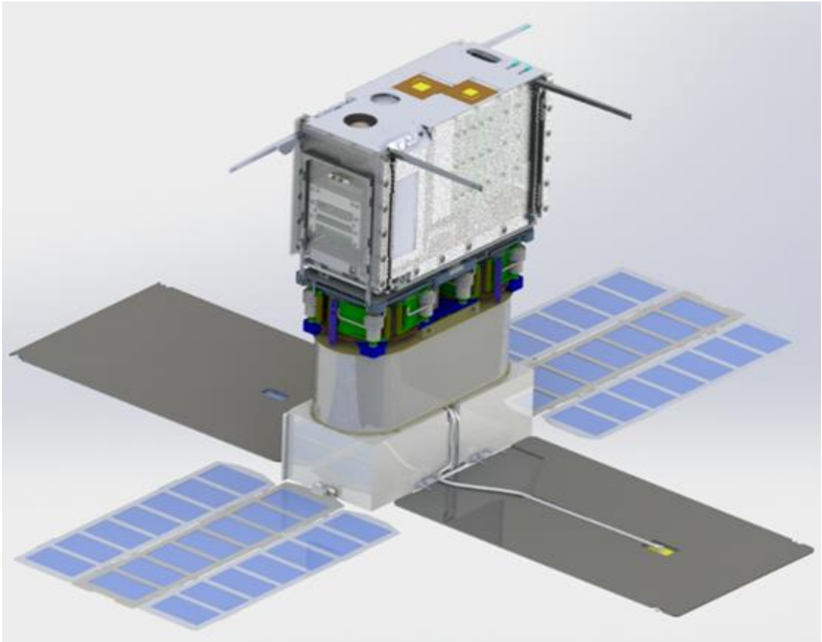
- 6U cubesat (20 cm X 10 cm X 30 cm)
- ~86 m^2 solar sail propulsion system
- Manifested for launch on the Space Launch System (EM-1 in 2019)
- Up to 2.5 year mission duration
- < 1 AU maximum distance from Earth

Leverages: Combined experiences of MSFC (PM, SE, Solar Sail, AMT, G&C, and Mission Operations) and JPL (Flight System Bus, Instrument, Science) with support from GSFC, JSC, and LaRC

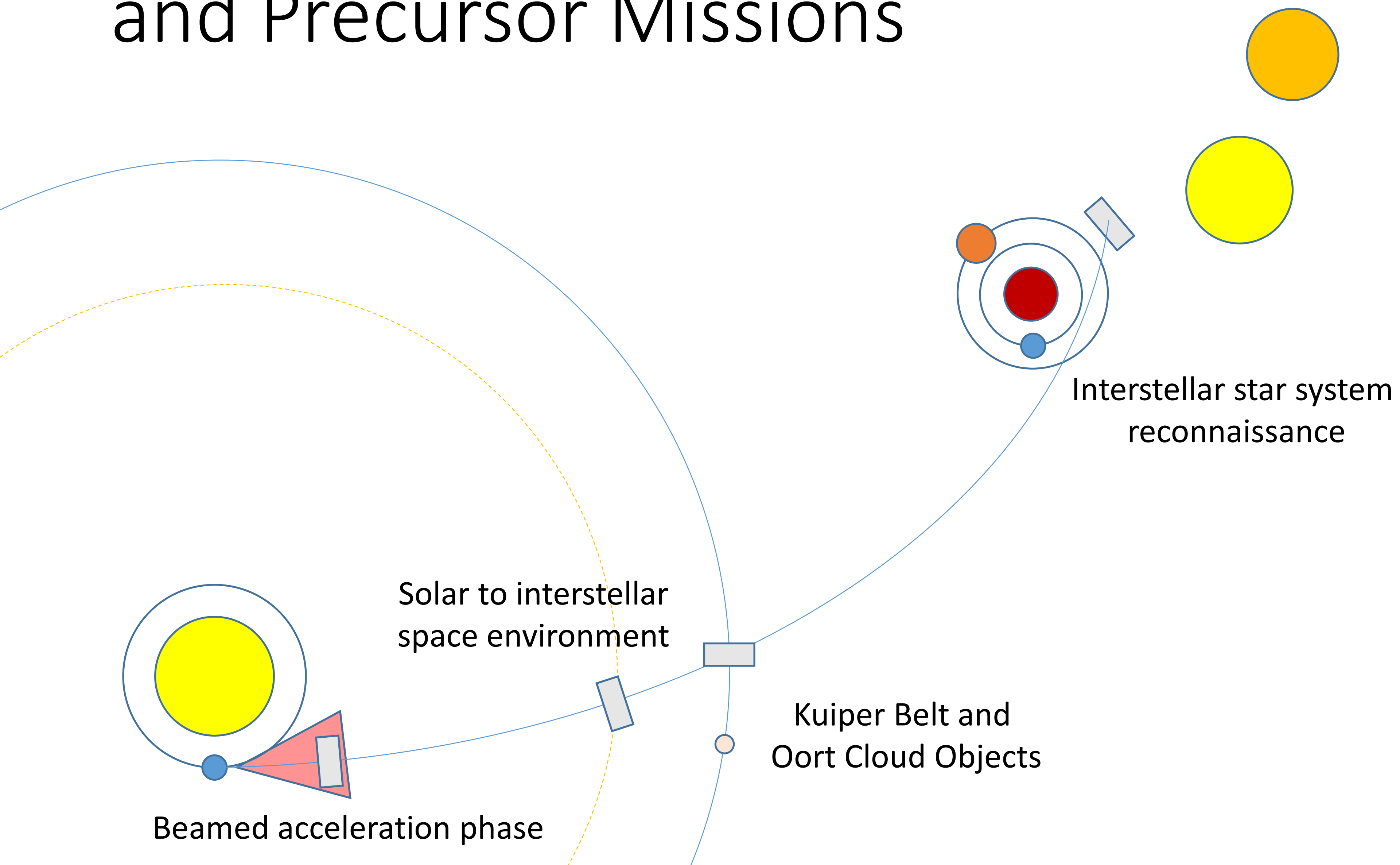
Target Reconnaissance with medium field imaging
Shape, spin, and local environment



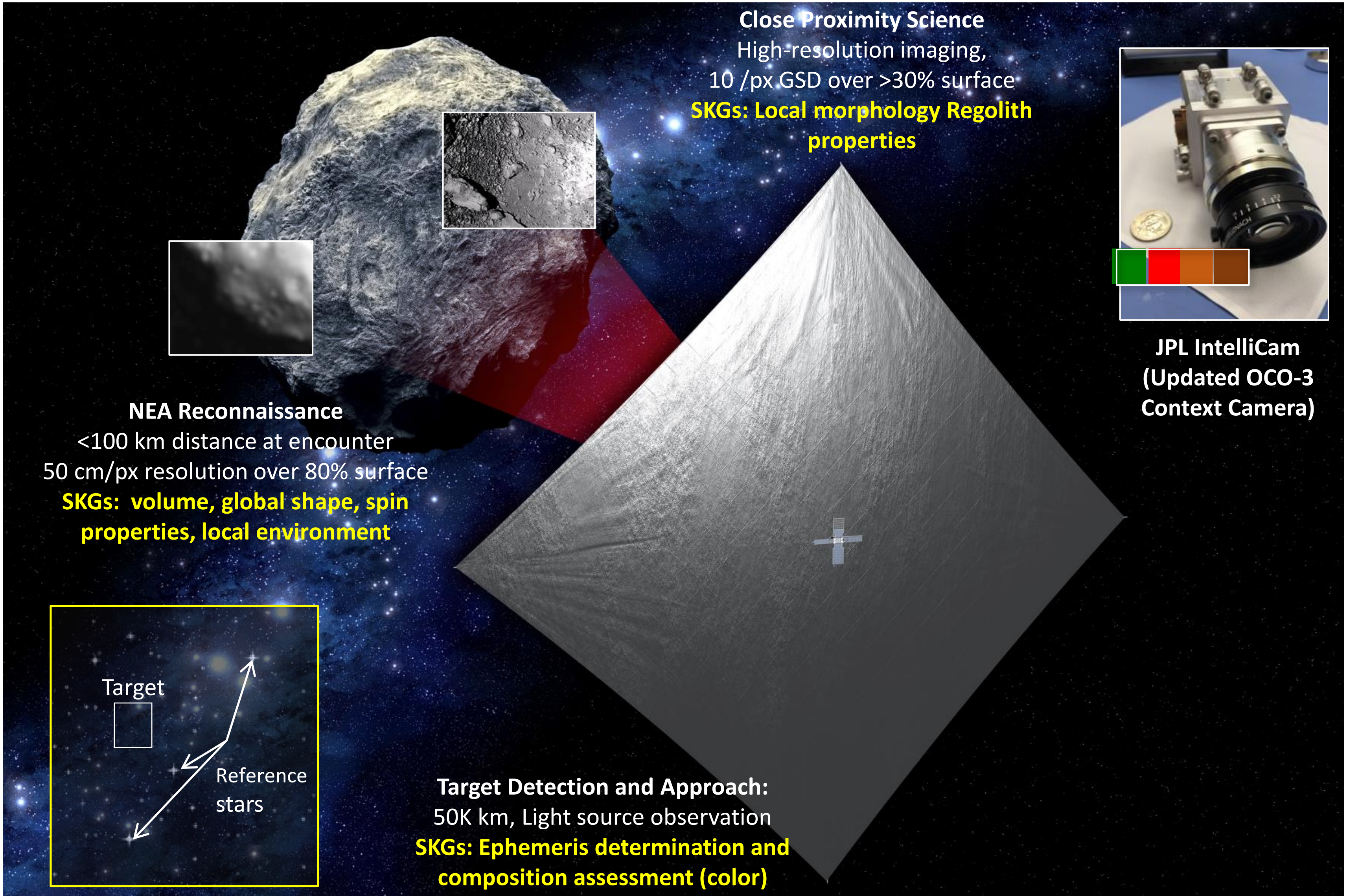
Close Proximity Imaging
Local scale morphology, terrain properties, landing site survey



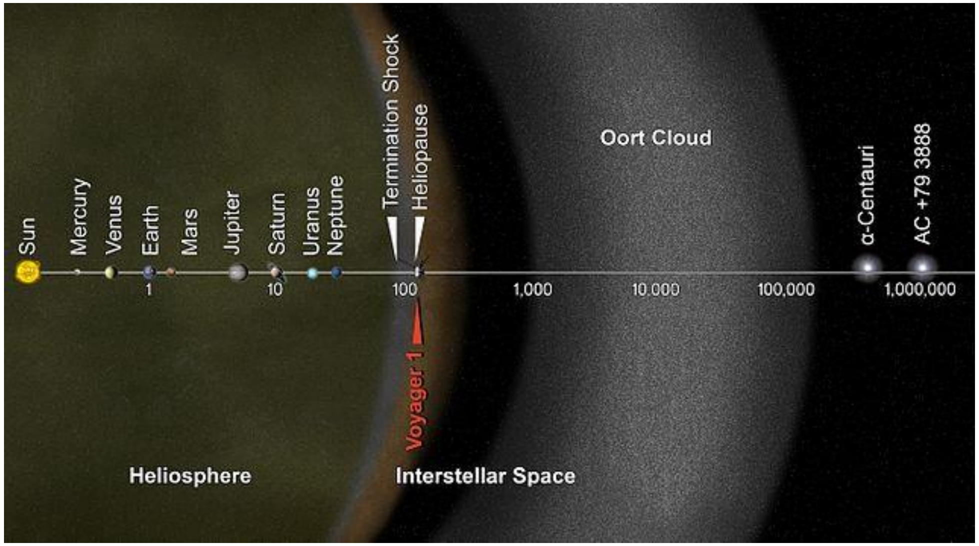
Introduction – First interstellar and Precursor Missions



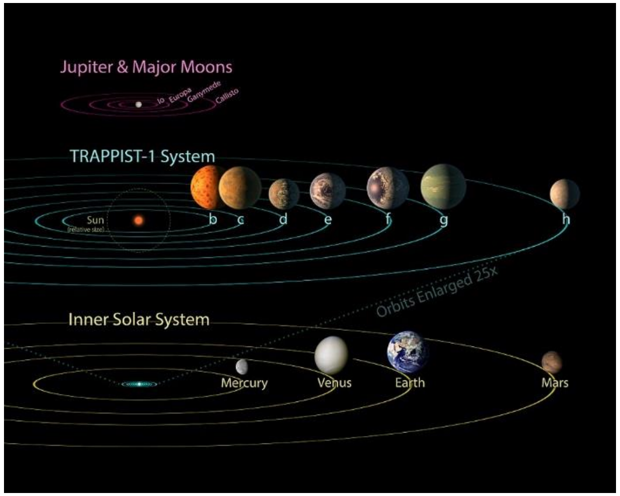
Scientific Objectives - NEA Scout

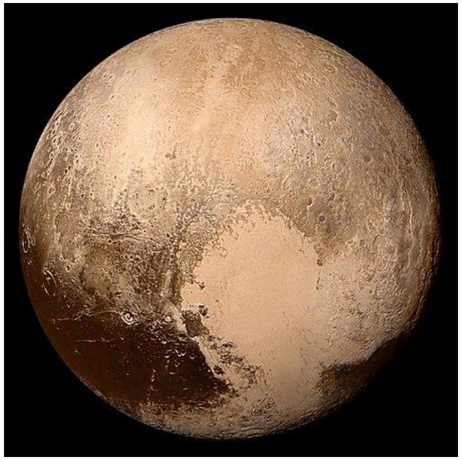


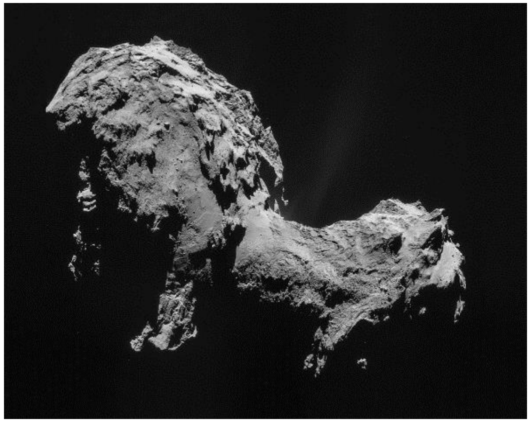
Scientific Objectives – Interstellar and Precursor



- Precursor
  - Space environment transition from the sun to interstellar space
  - Kuiper Belt and Oort Cloud objects
- Interstellar
  - Characterize stars & planets for follow-on missions

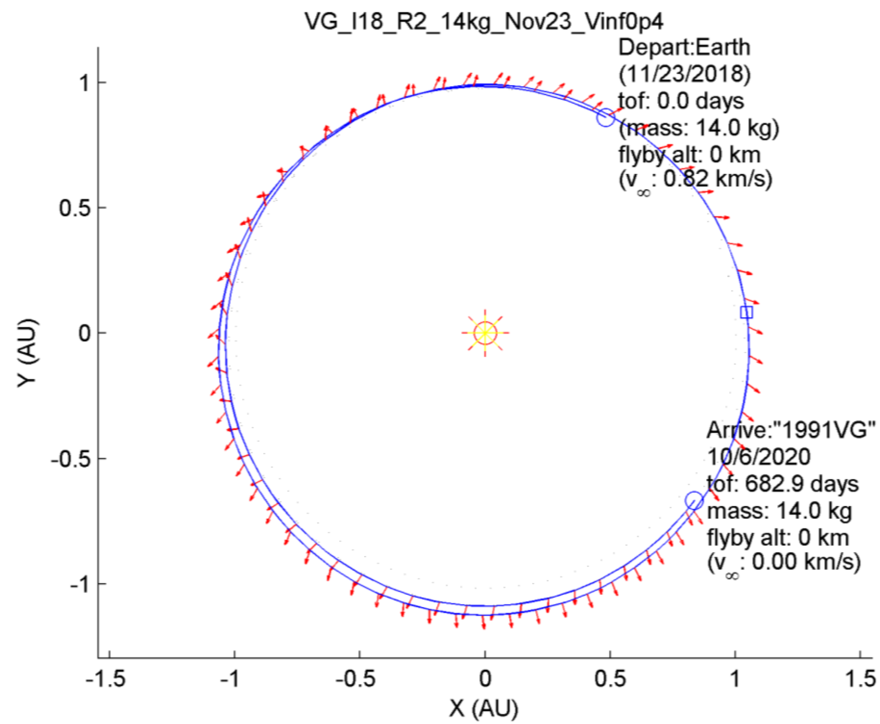






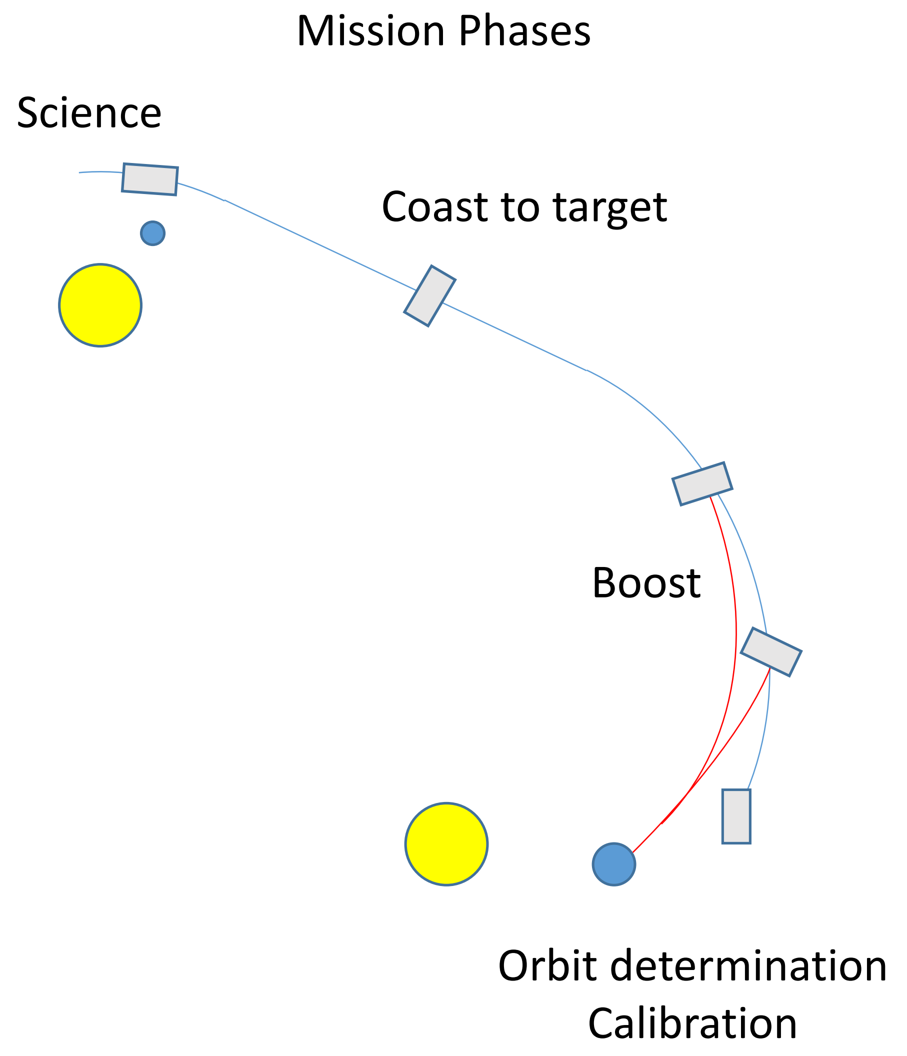
Navigation and Guidance – NEA Scout

- Periodic radio ranging for orbit determination
- Periodically update sail steering to correct trajectory
- Optical navigation on asteroid approach to correct flyby
- Correct trajectory throughout mission



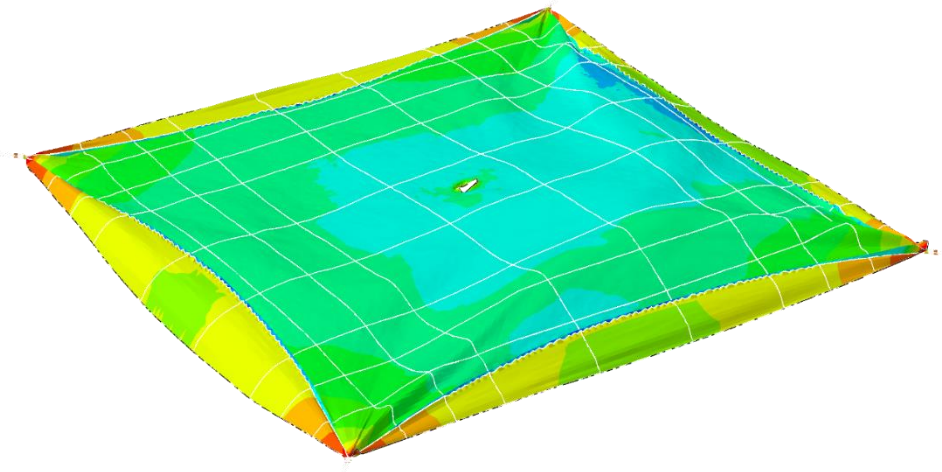
Navigation and Guidance – Interstellar and Precursor

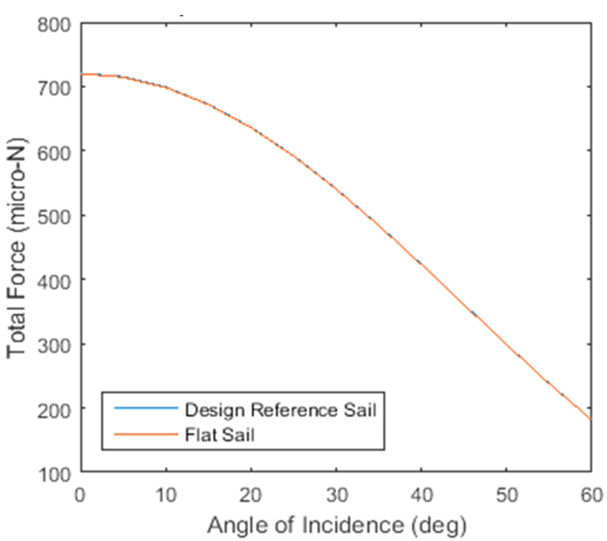
- Orbit determination of spacecraft and sail & beam calibration before boost phase
- Steer beam from moving platform to illuminate sail at predicted position
- Repeat if more than one boost maneuver used
- Spacecraft coasts to target
- Requires
  - Distance and speed sufficient for science
  - Knowledge of target sufficient for pointing
- Precursor
  - Shorter distance
  - Better knowledge of target orbits
  - Space environment missions don't need to target celestial bodies

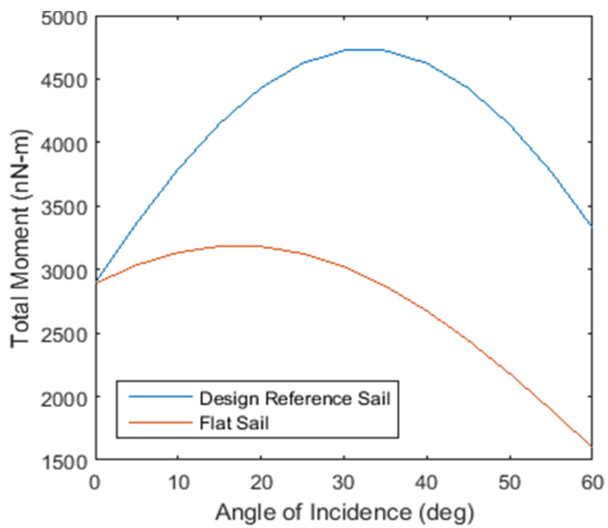


Force and Torque Modeling – NEA Scout

- Finite element model of sail shape
- Optical testing of sail film
- Combined shape & optics tensor force & torque model

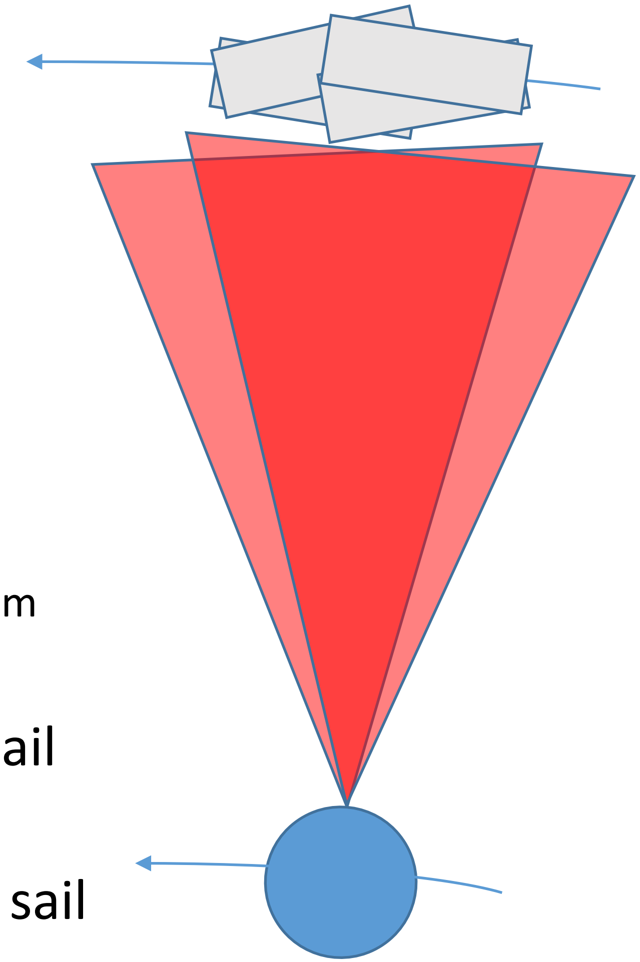






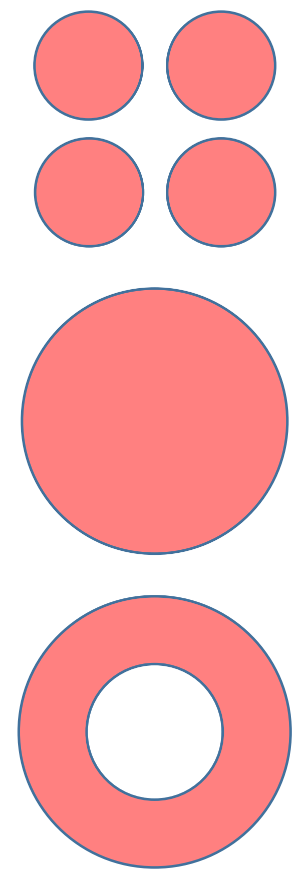
Force and Torque Modeling – Beamed Propulsion Sail

- Force & torque on sail as function of
  - Beam
    - Power & distribution
    - Distance to sail
  - Sail
    - Shape
    - Optical properties
    - Attitude relative to beam
    - Position in beam
- Uncertainties of beam & sail parameters
- Orbital motion of beam & sail

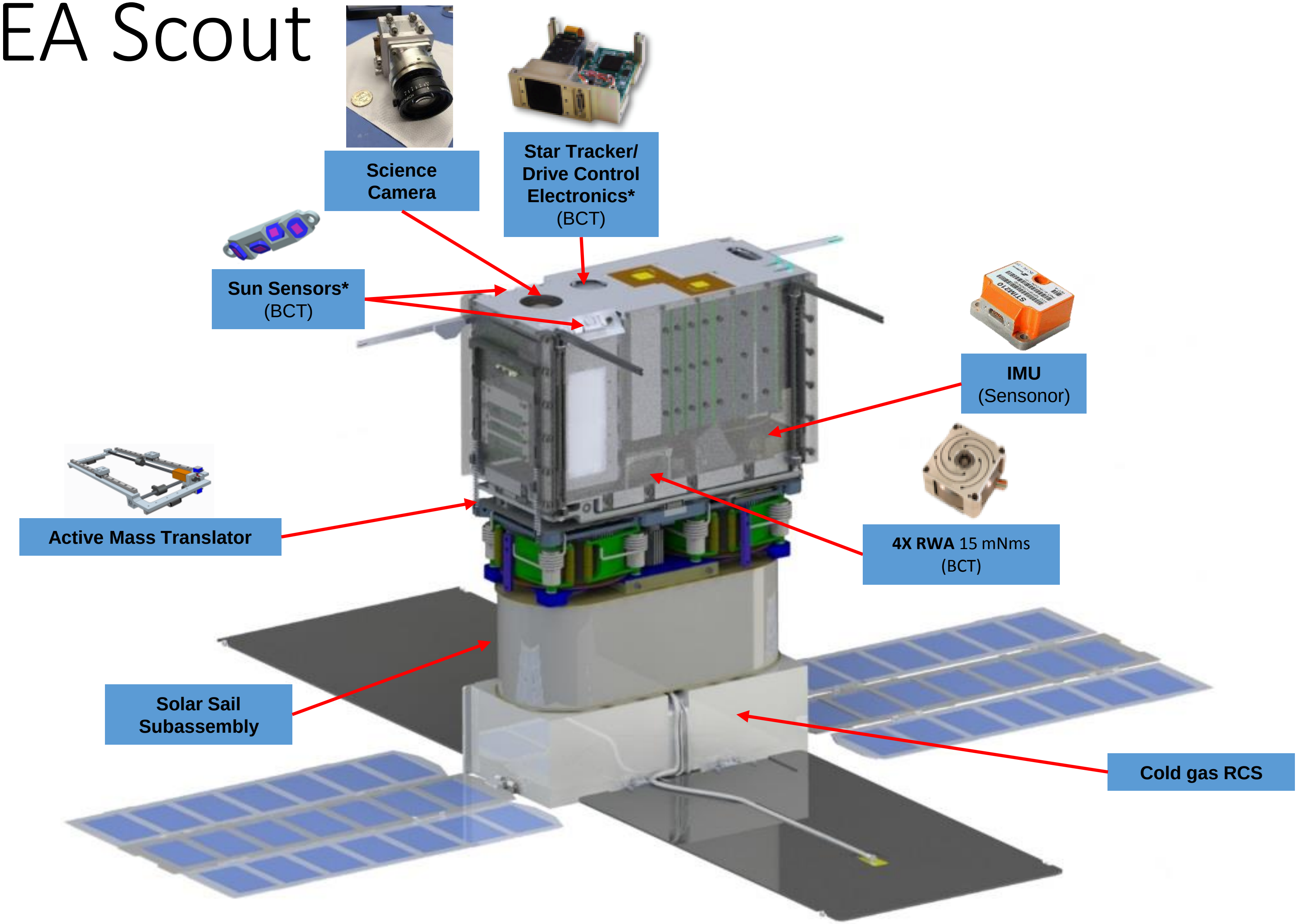


Moving beam targeting moving sail

Beam Patterns

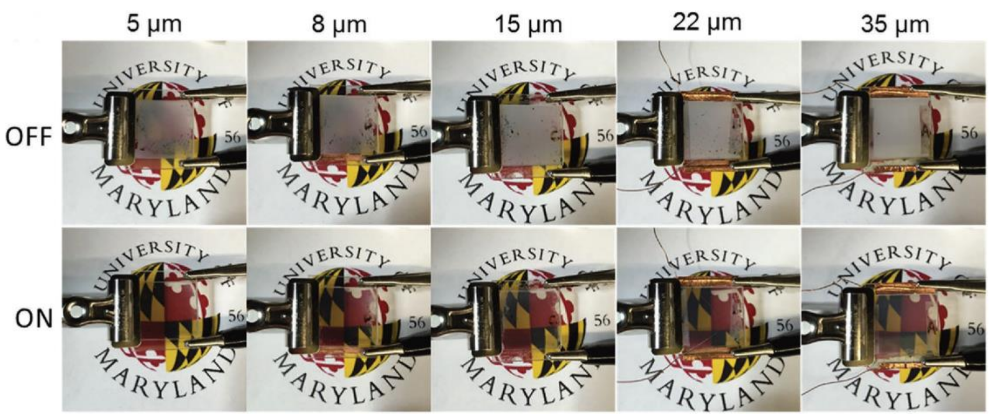


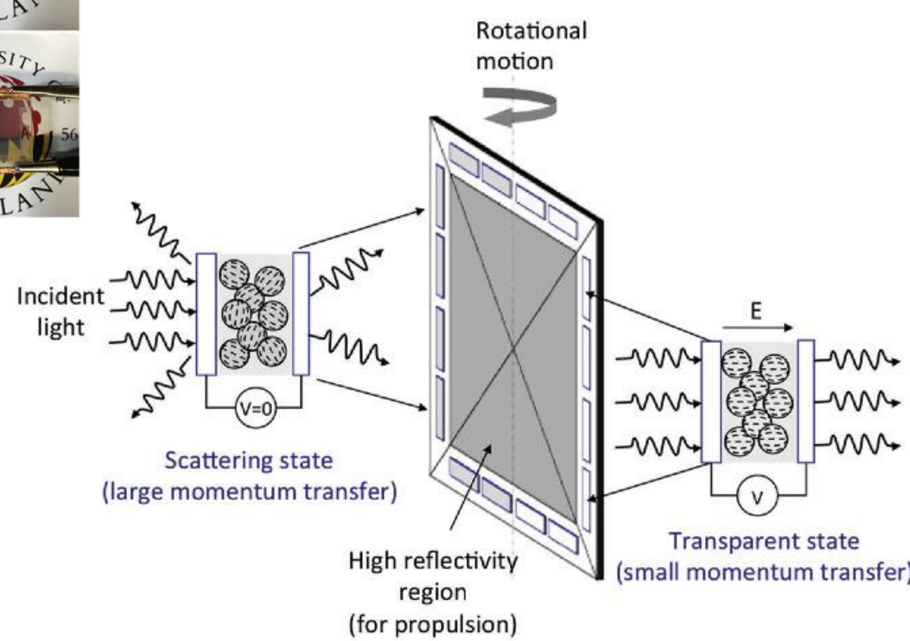
Attitude Dynamics and Control – NEA Scout



Reflective Control Devices

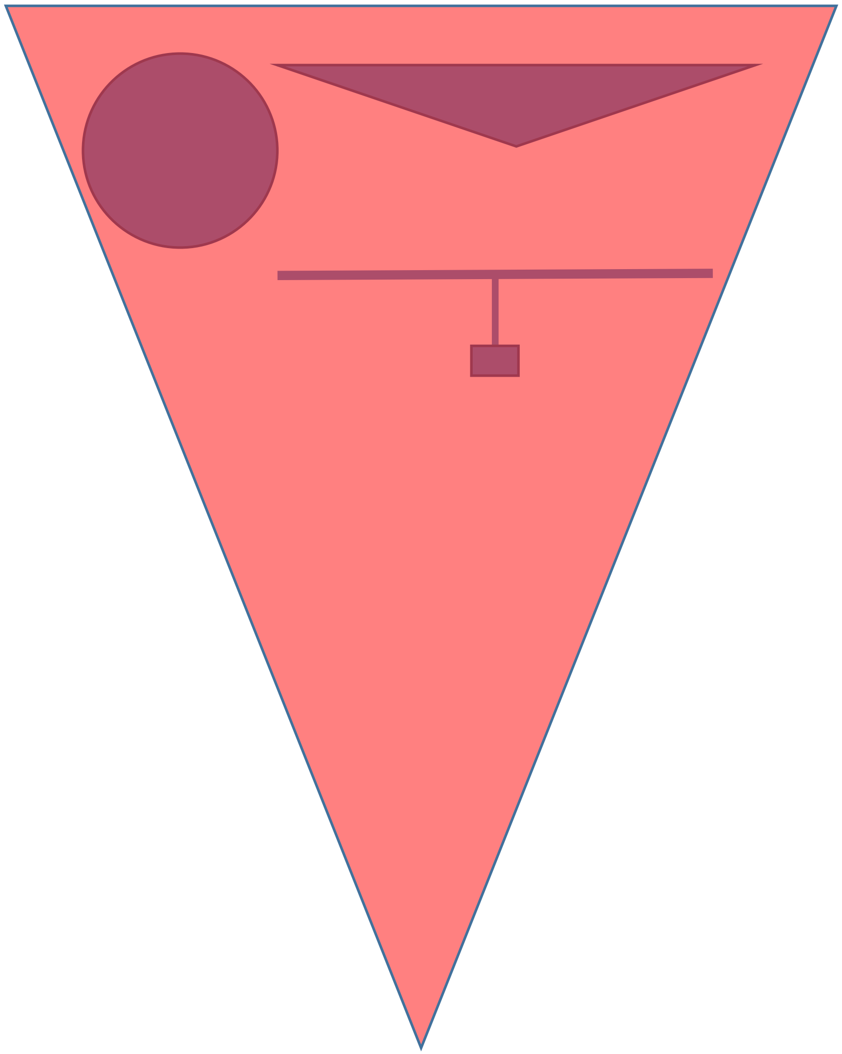
- Electronically change from diffuse reflection to transparency
- Solar torque without moving parts by changing which side is on
- Flight tested in IKAROS solar sail
- University of Maryland developing prototypes for NASA MSFC for use on future solar sails





Attitude Dynamics and Control – Beamed Propulsion Sail

- Passive stability on beam
  - Position & attitude return to beam-center and beam-pointing
- Active control
  - Attitude sensing
    - Star tracker, rate gyro, light sensors
  - Attitude control
    - Reflectivity control
    - Shape control (vanes)
    - CM control (AMT)



Conclusions

- NEA Scout mission design
  - Complete mission design linking science objectives at target to trajectory and attitude dynamics & control accuracy and uncertainties
  - Regular opportunities throughout mission to correct trajectory and retarget destination
- Beamed propulsion requires similar analysis
  - Trajectory requirements much more stringent
  - Few opportunities to correct trajectory
  - Critical to understand & reduce uncertainties
  - Consider active control
  - Calibrate beam & sail after launch & deployment
  - Consider breaking up boost phase to correct errors
- Solar physics missions to flight test technology
  - Relaxed trajectory requirements

Next Steps

- Simulate
  - Sail in orbit accelerated by a beam to a target destination
  - Test sail shapes & optical models
  - Spacecraft design & mass properties
  - Passive vs. active stability
  - Monte-Carlo dispersions of system uncertainties
- Uncertainty requirements
  - Characterize how accurate beam, sail, orbit determination, attitude & position dispersions must be to meet science objectives
- Set technology goals
  - State-of-the-art capabilities that don’t meet requirements

Backup

Abstract

NASA is developing the Near Earth Asteroid (NEA) Scout mission that will use a solar sail to travel to an asteroid where it will perform a slow flyby to acquire science imagery. A guidance and control system was developed to meet the science and trajectory requirements. The NEA Scout design process can be applied to an interstellar or precursor mission that uses a beam propelled sail. The scientific objectives are met by accurately targeting the destination trajectory position and velocity. The destination is targeted by understanding the force on the sail from the beam (or sunlight in the case of NEA Scout) over the duration of the thrust maneuver. The propulsive maneuver is maintained by accurate understanding of the torque on the sail, which is a function of sail shape, optical properties, and mass properties, all of which apply to NEA Scout and beam propelled sails. NEA Scout uses active control of the sail attitude while trimming the solar torque, which could be used on a beamed propulsion sail if necessary. The biggest difference is that NEA Scout can correct for uncertainties in sail thrust modeling, spacecraft orbit, and target orbit throughout the flight to the target, while beamed propulsion needs accurate operation for the short duration of the beamed propulsion maneuver, making accurate understanding of the sail thrust and orbits much more critical.