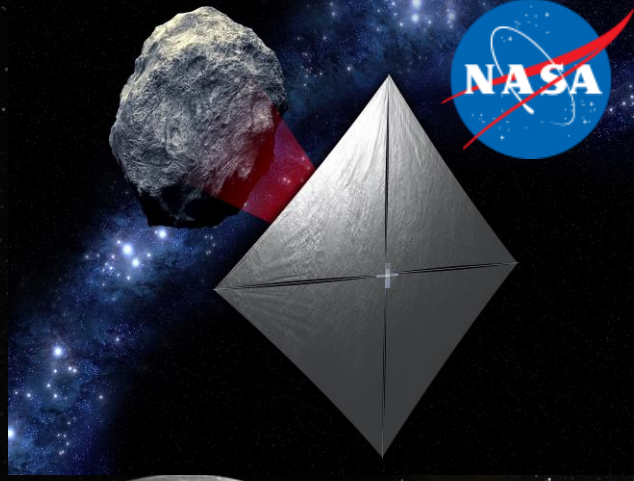
PROPULSION & ENERGY 2015

Solar Sail Propulsion for Interplanetary CubeSats



Les Johnson, Barbara Cohen, and
Leslie McNutt (NASA MSFC)
Julie Castillo-Rogez (NASA JPL)

Space Launch System (SLS) Secondary Payloads

- **HEOMD's Advanced Exploration Systems (AES) selected 3 cubesats for flight on SLS EM1**
- **Primary selection criteria:**
  - Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
  - Life cycle cost
  - Synergistic use of previously demonstrated technologies
  - Optimal use of available civil servant workforce

Payload *NASA Centers*	**Strategic Knowledge Gaps Addressed**	**Mission Concept**
BioSentinel ***ARC****/JSC* 	**Human health/performance in high-radiation space environments** • Fundamental effects on biological systems of ionizing radiation in space environments	Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth
Lunar Flashlight ***JPL****/MSFC* 	**Lunar resource potential** • Quantity and distribution of water and other volatiles in lunar cold traps	Locate ice deposits in the Moon's permanently shadowed craters
Near Earth Asteroid (NEA) Scout ***MSFC****/JPL* 	**Human NEA mission target identification** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Flyby/rendezvous and characterize one NEA that is candidate for a human mission

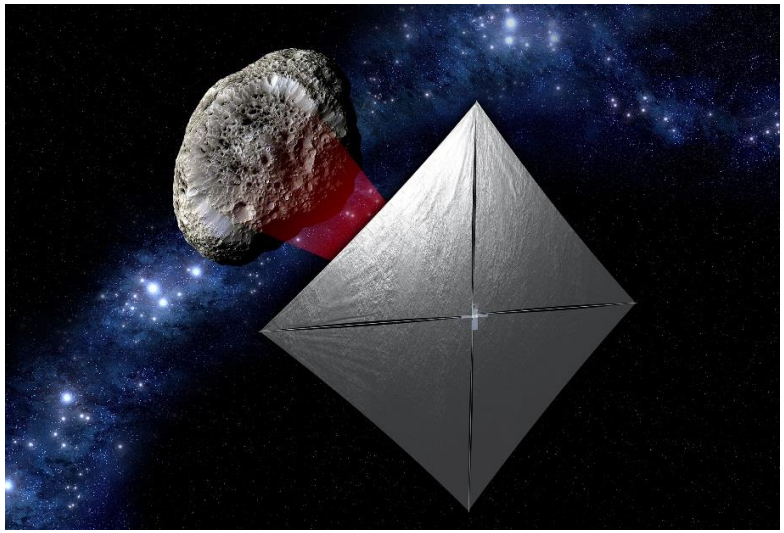
NEA Scout / Lunar Flashlight Roles and Responsibilities

- Near Earth Asteroid Scout
  - Project Manager: Leslie McNutt (MSFC)
  - Science PI: Julie Castillo-Rogez (JPL)
  - Solar Sail PI: Les Johnson (MSFC)
  - Spacecraft System: JPL
  - Solar Sail System: MSFC
- Lunar Flashlight
  - Project Manager: John Baker (JPL)
  - PI: Barbara Cohen (MSFC)
  - Spacecraft System: JPL
  - Solar Sail System: MSFC

Near Earth Asteroid Scout Overview

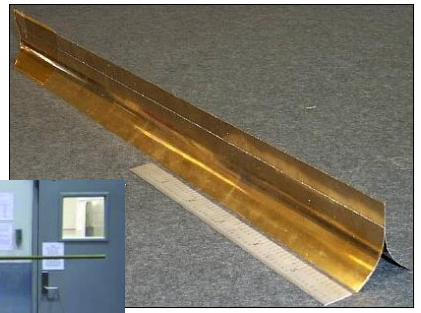
The Near Earth Asteroid Scout Will

- Image/characterize an asteroid
- Demonstrate a low cost asteroid reconnaissance capability



Key Spacecraft & Mission Parameters

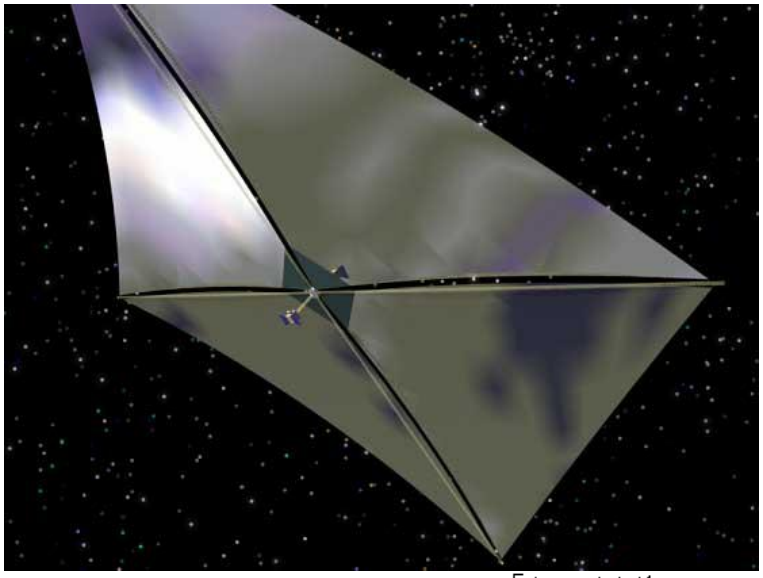
- 6U cubesat (20 cm X 10 cm X 30 cm)
- ~85 m^2 solar sail propulsion system
- Manifested for launch on the Space Launch System (EM-1/2018)
- Up to 2.5 year mission duration
- 1 AU (93,000,000 mile) maximum distance from Earth



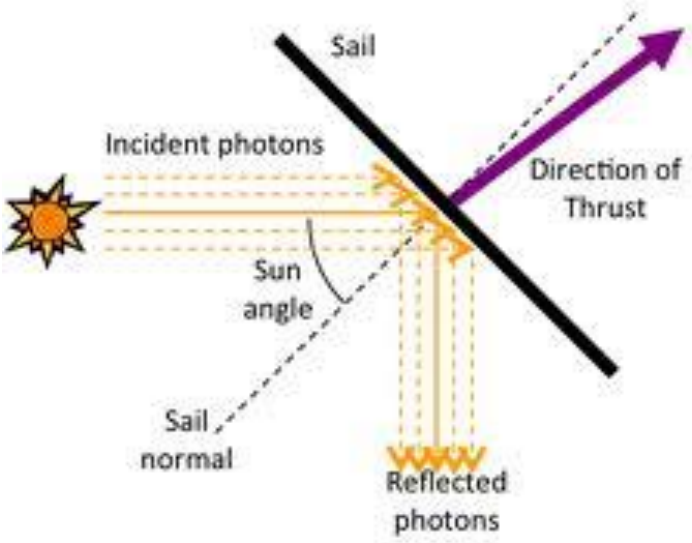
Solar Sail Propulsion System Characteristics

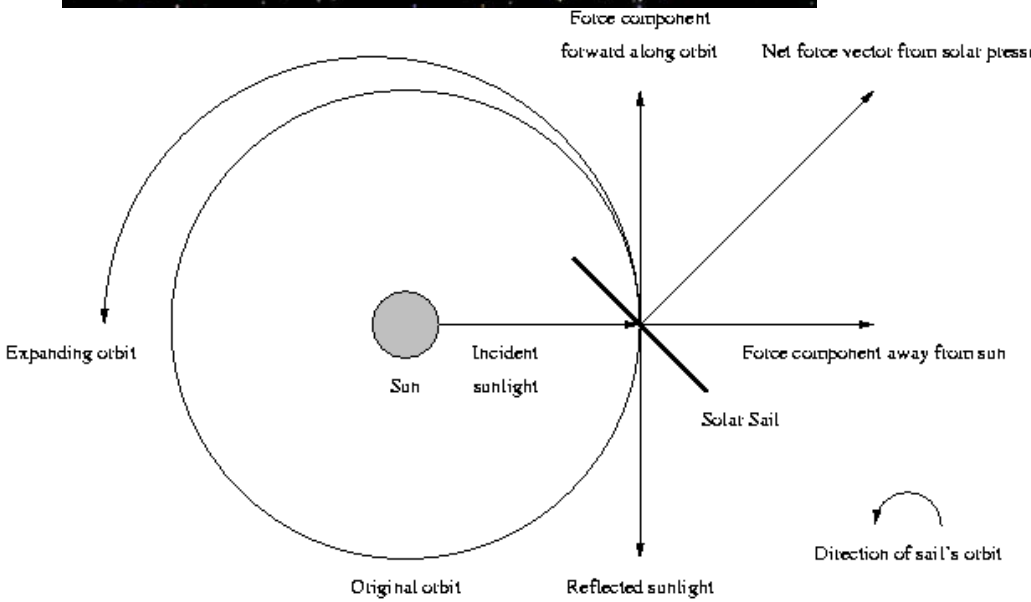
- ~ 7.3 m Trac booms
- 2.5μ aluminized CP-1 substrate
- > 90% reflectivity

How does a solar sail work?



Solar sails use photon “pressure” or force on thin, lightweight reflective sheet to produce thrust.

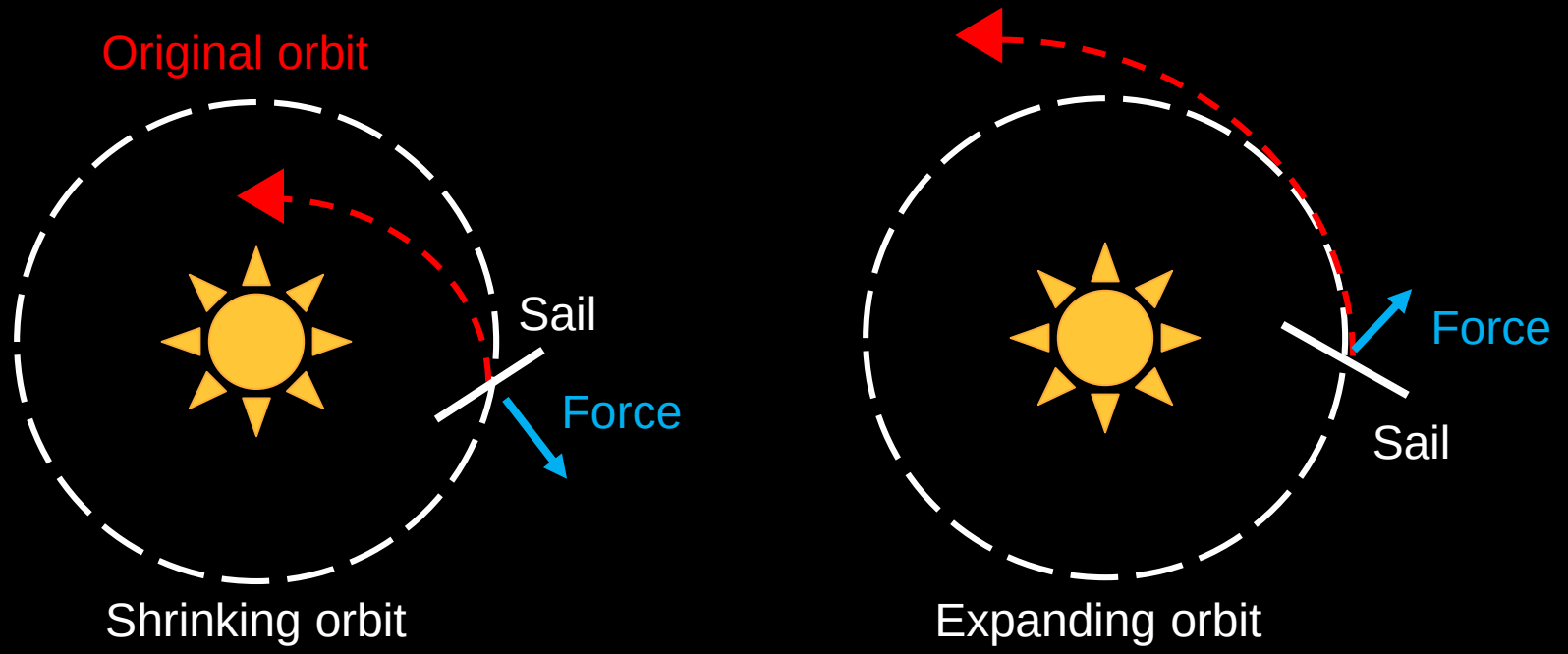




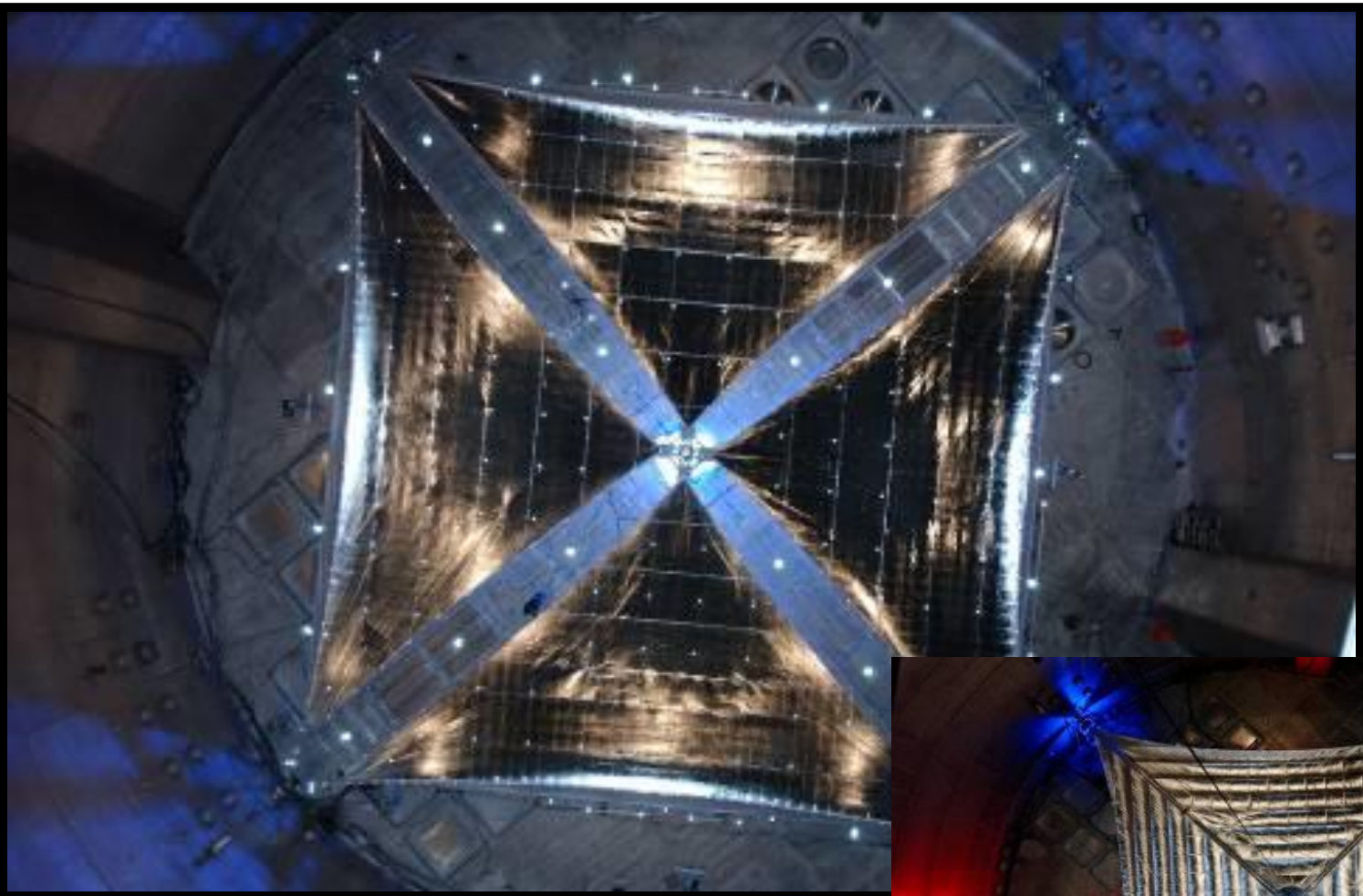
Solar Sail Trajectory Control

- Solar Radiation Pressure:

Inward and outward Spiral

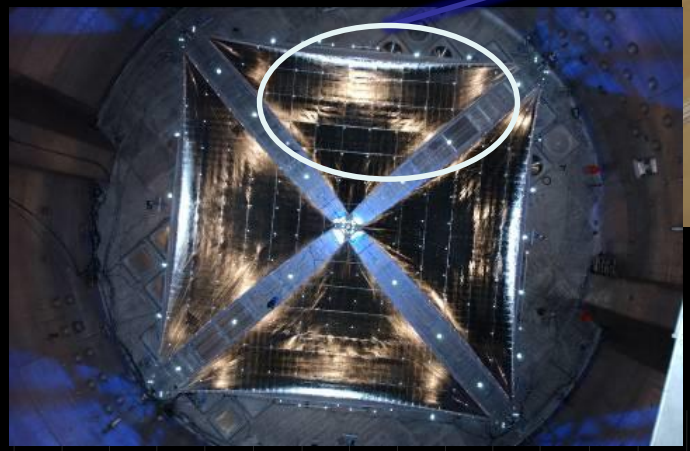


NASA Ground Tested Solar Sails

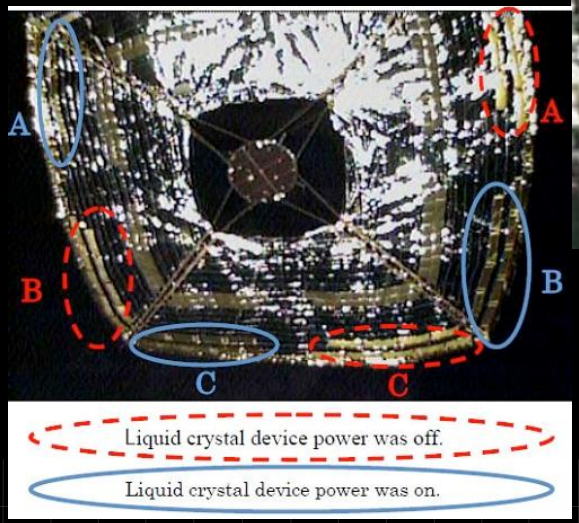


NanoSail-D Demonstration Solar Sail

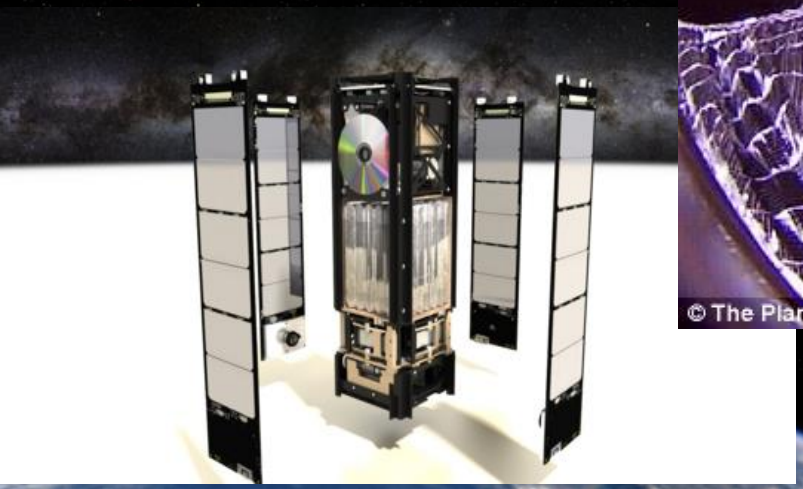
- 10 m^2 sail
- Made from tested ground demonstrator hardware

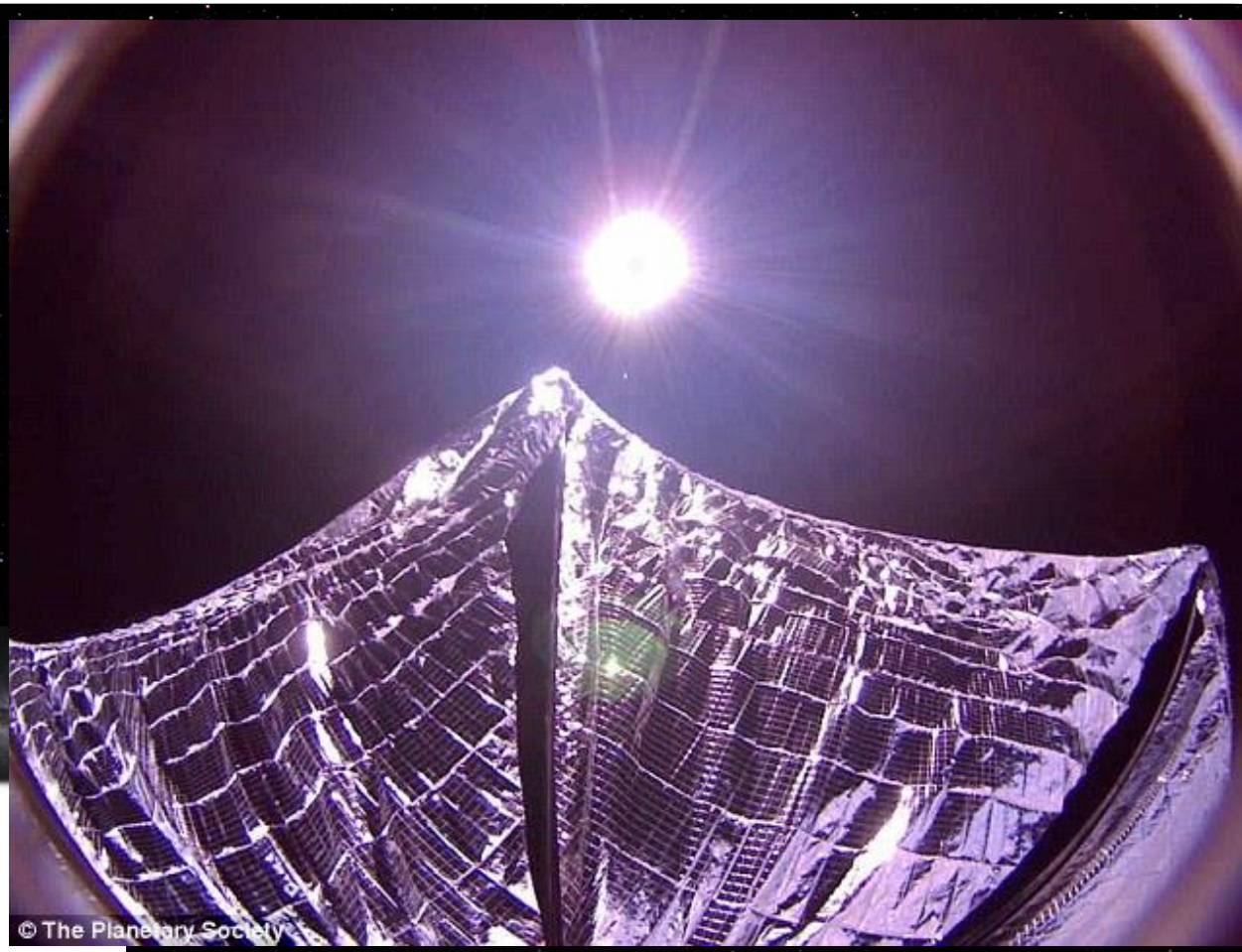


Interplanetary Kite-craft Accelerated by Radiation of the Sun (IKAROS)



LightSail

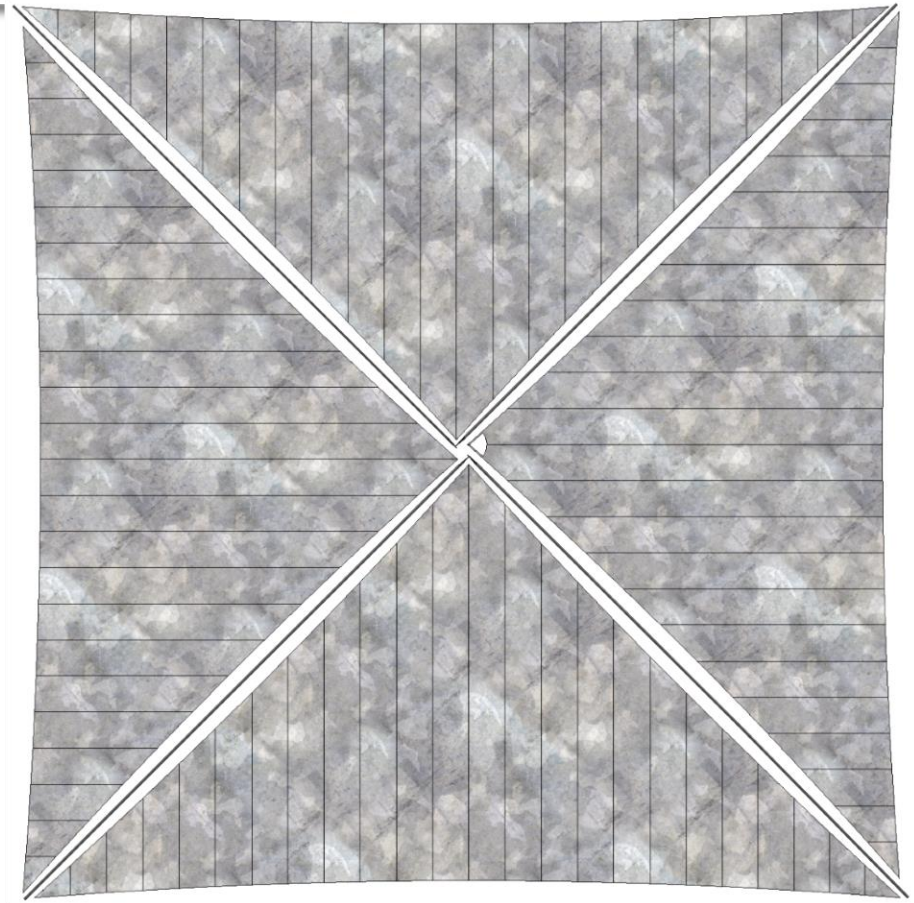




- Aluminized 4.5 micron Mylar film
- 32m^2

NEA Scout Approximate Scale

Deployed Solar Sail



School Bus

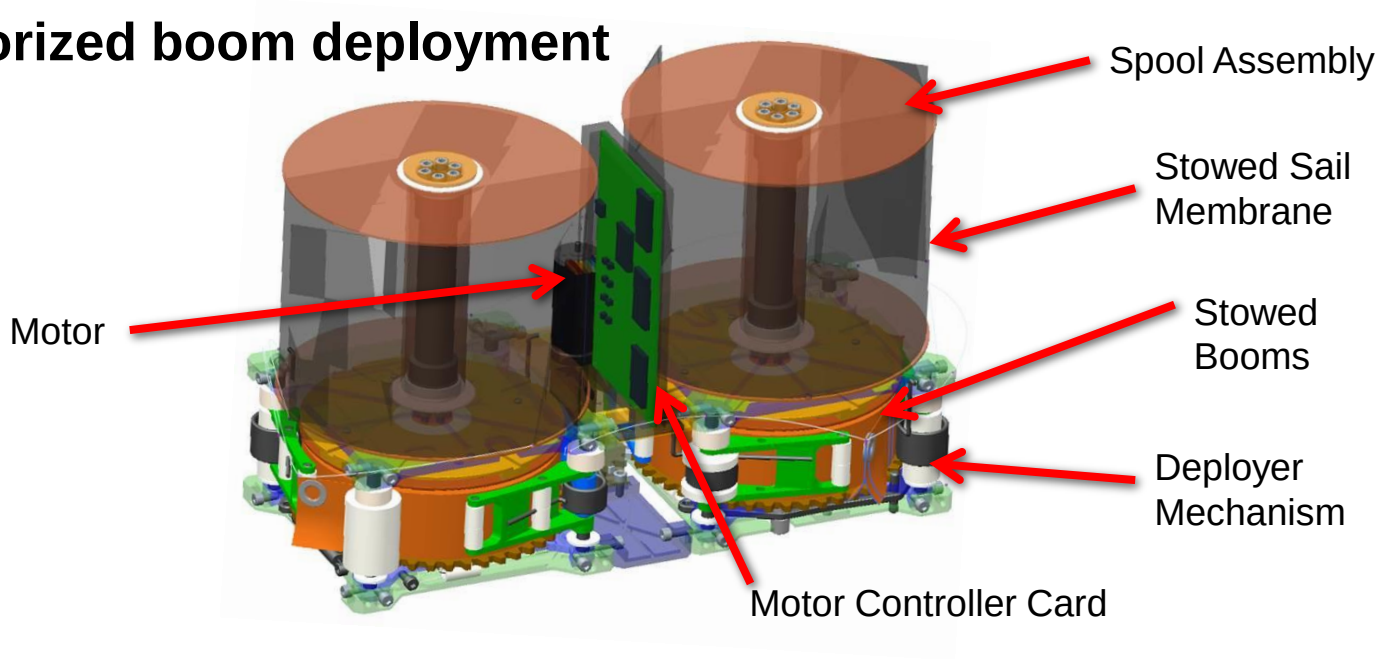
Human

6U Stowed Flight System

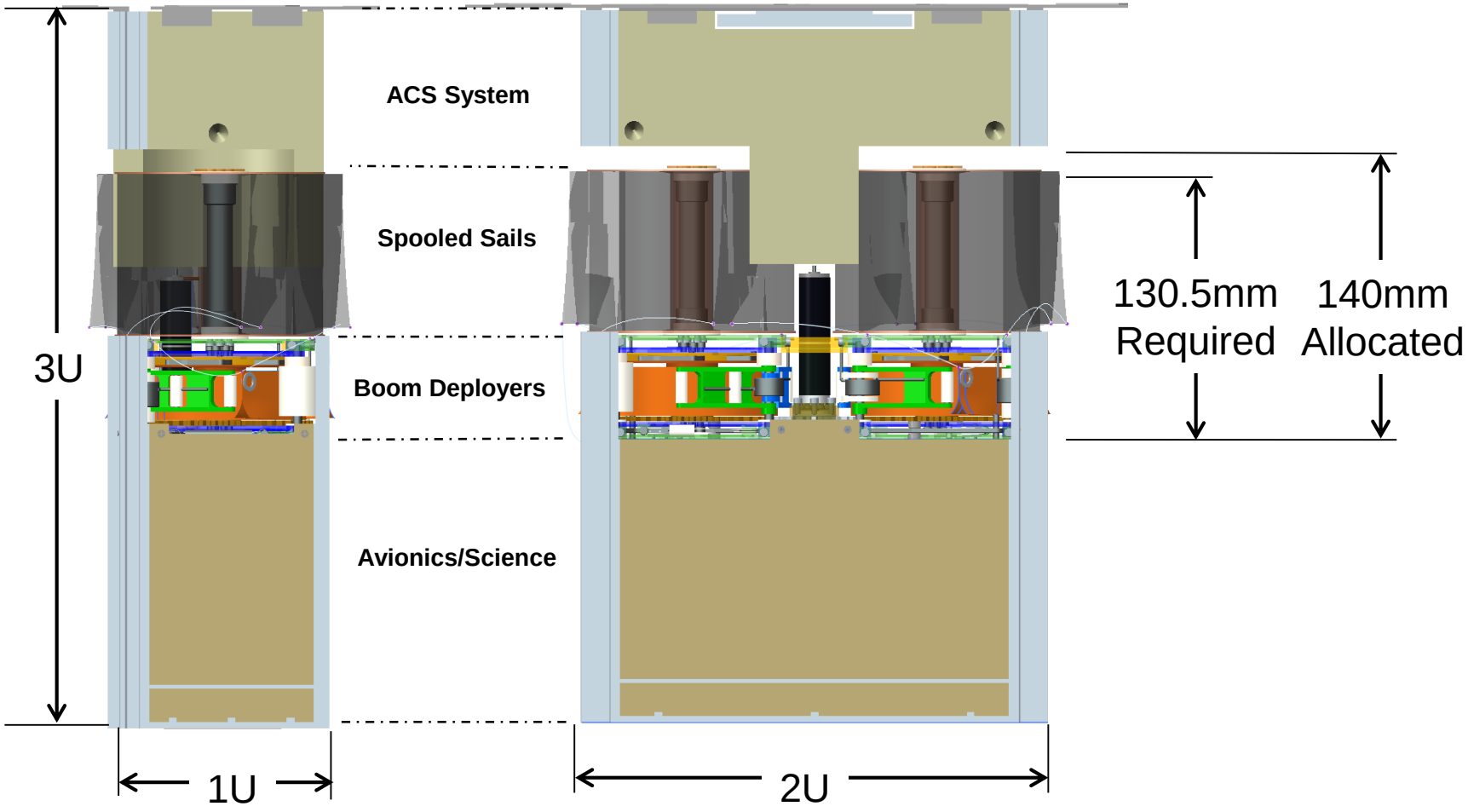
Folded, spooled and packaged in here

Solar Sail Mechanical Description

- 4 quadrant sail – redesign in progress to single piece sail
- 85 m^2 reflective area
- 2.5 micron CP1 substrate
- Z folded and spooled for storage
  - 2 separate spools with 2 sail quadrants folded onto each
- 4 7-meter stainless steel TRAC booms coiled on a mechanical deployer
  - 2 separate deployers and each deployer releases 2TRAC booms
  - Motorized boom deployment



Solar Sail Volume Envelope

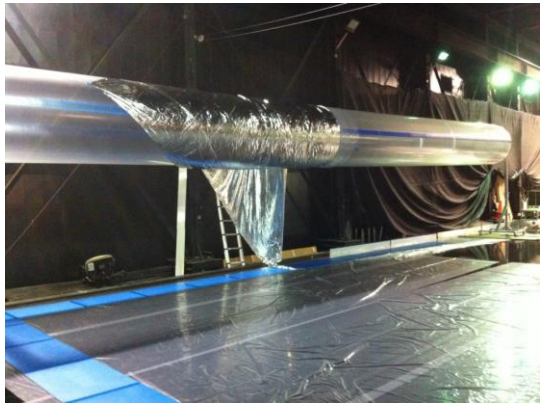


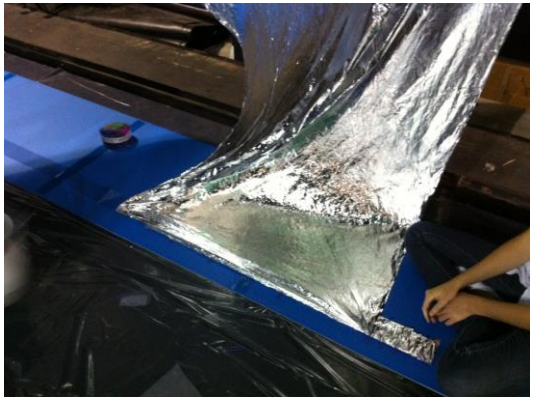
Sail Packing Efficiency

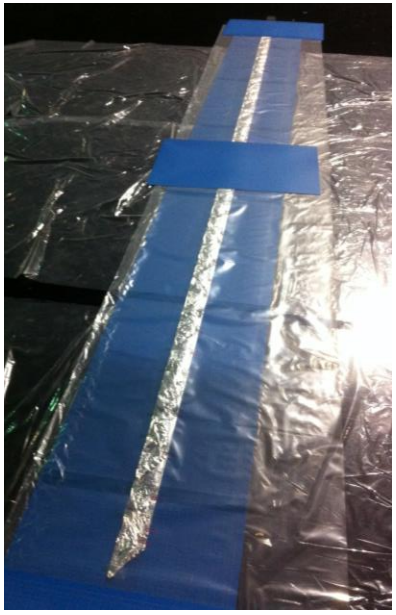
Calculated Value:

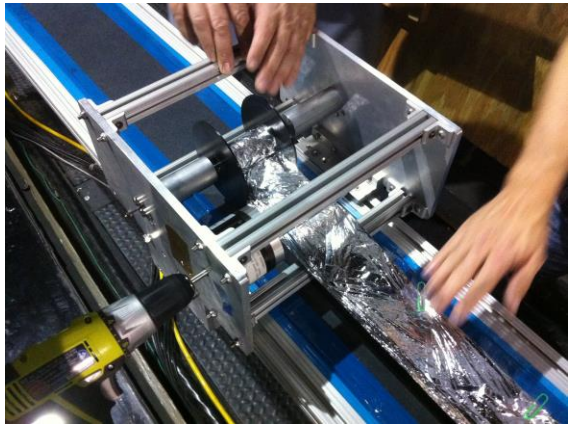
- Fabricated 2 flight size 10m sails from existing 20m CP1 sail.
- Z-folded and spooled 2 sail quadrants onto the hub.
- Calculated new packing efficiency to be **27.5 %**

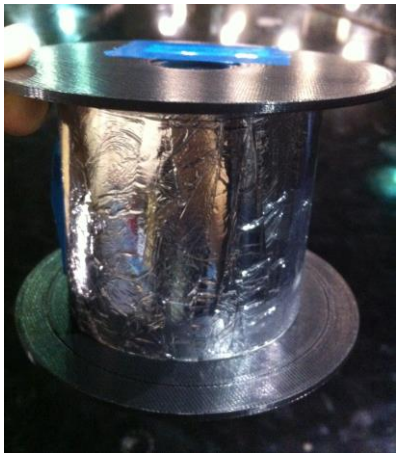
Higher percentage results in tighter packaging and thus more volume margin for design space.





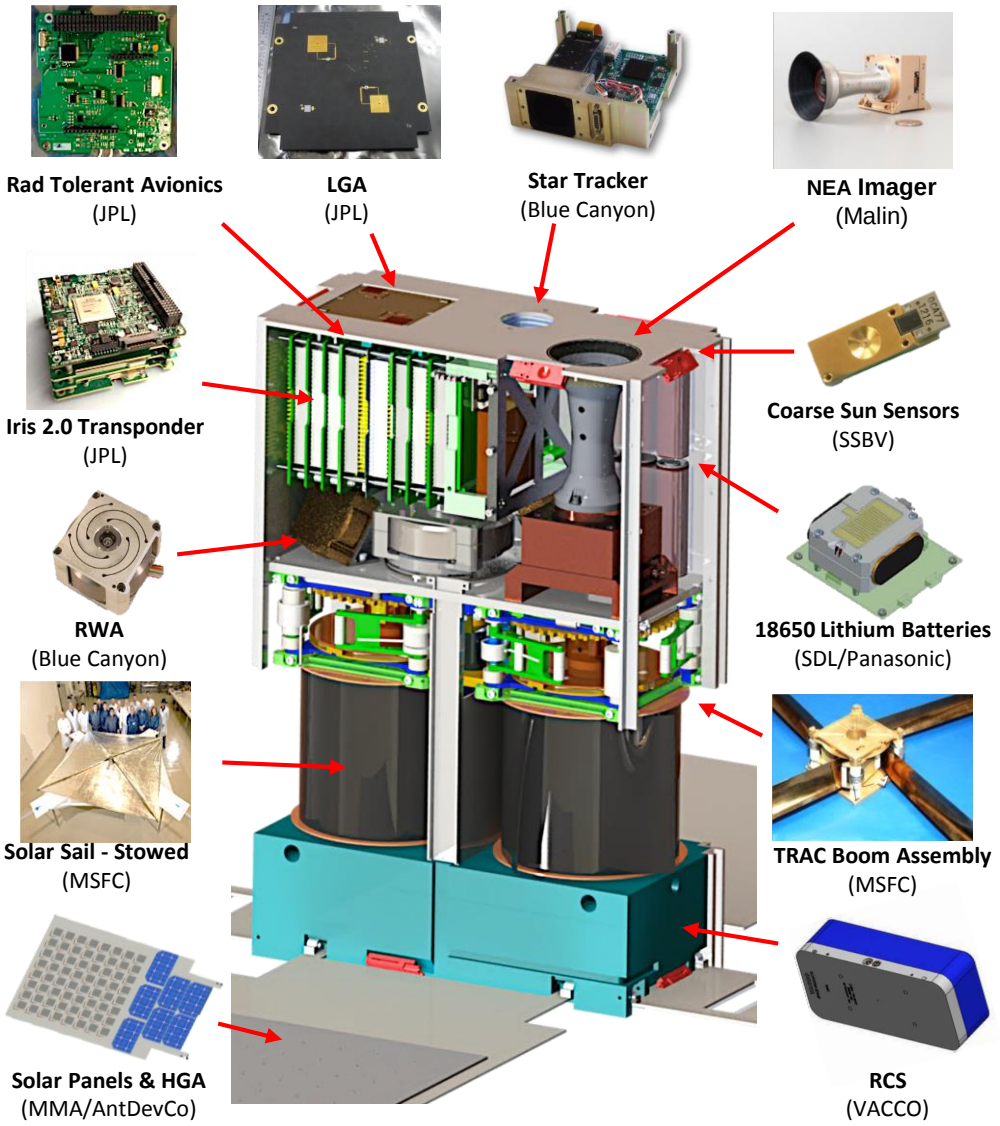






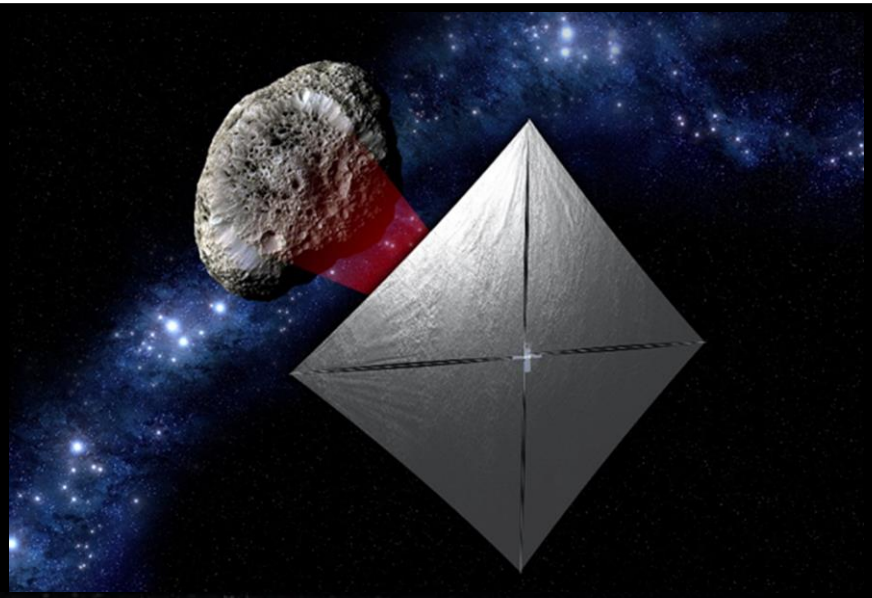
NEA Scout Flight System Overview

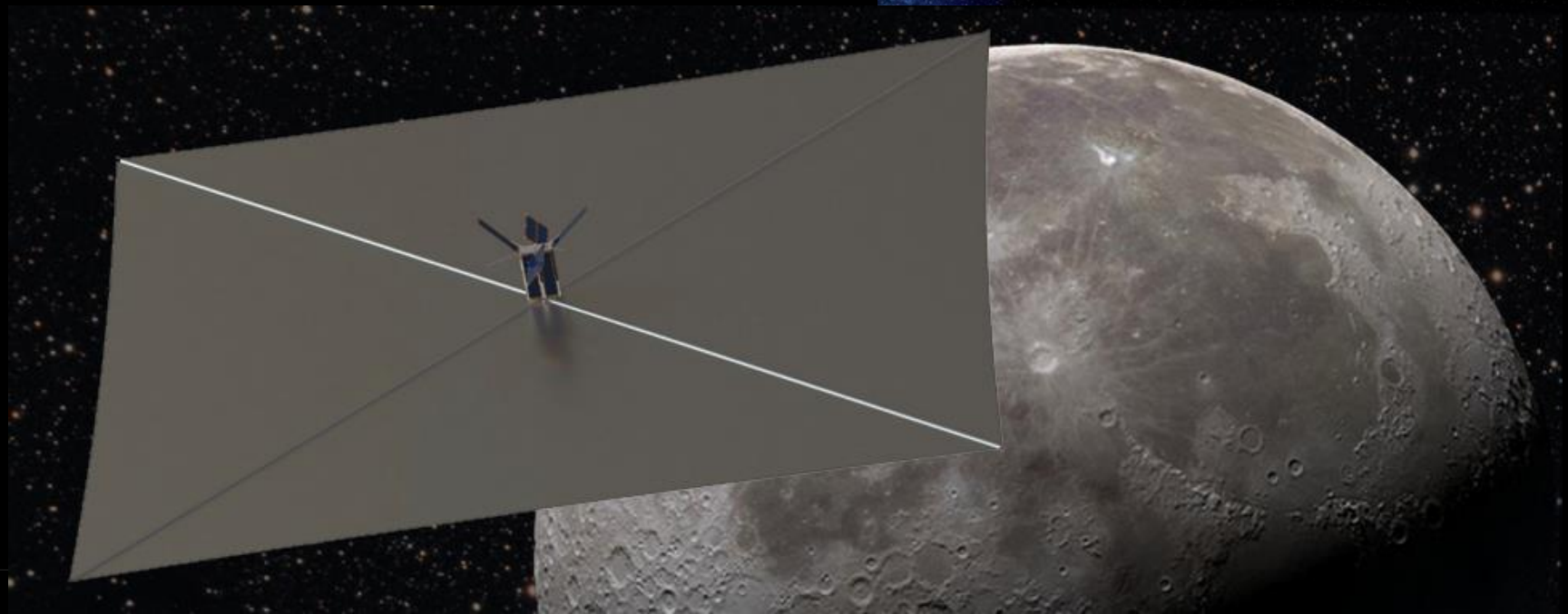
Mission Concept	• Characterize a Near Earth Asteroid with an optical instrument during a close, slow flyby
Payload	• Malin Space Science Systems ECAM-M50 imager w/NFOV optics • Static color filters (400-900 nm)
Mechanical & Structure	• "6U" CubeSat form factor (~10x20x30 cm) • <12 kg total launch mass • Modular flight system concept
Propulsion	• ~85 m^2 aluminized CP-1 solar sail (based on NanoSail-D2)
Avionics	• Radiation tolerant LEON3-FT architecture
Electrical Power System	• Simple deployable solar arrays with UTJ GaAs cells (~35 W at 1 AU solar distance) • 6.8 Ah Battery (3s2p 18650 Lithium Cells) • 10.5-12.3 V unregulated, 5 V/3.5 V regulated
Telecom	• JPL Iris 2.0 X-Band Transponder; 2 W RF SSPAs; supports doppler, ranging, and D-DOR • 2 pairs of INSPIRE-heritage LGAs (RX/TX) • 8x8 element microstrip array HGA (TX) • ~500 bps to 34m DSN at 0.8 AU
Attitude Control System	• 15 mNm-s (x3) & 100 mNm-s RWAs • Zero-momentum slow spin during cruise • VACCO R134a (refrigerant gas) RCS system • Nano StarTracker, Coarse Sun Sensors & MEMS IMU for attitude determination



NEA Scout and Lunar Flashlight

Both Use Solar Sail Propulsion and 6U CubeSats





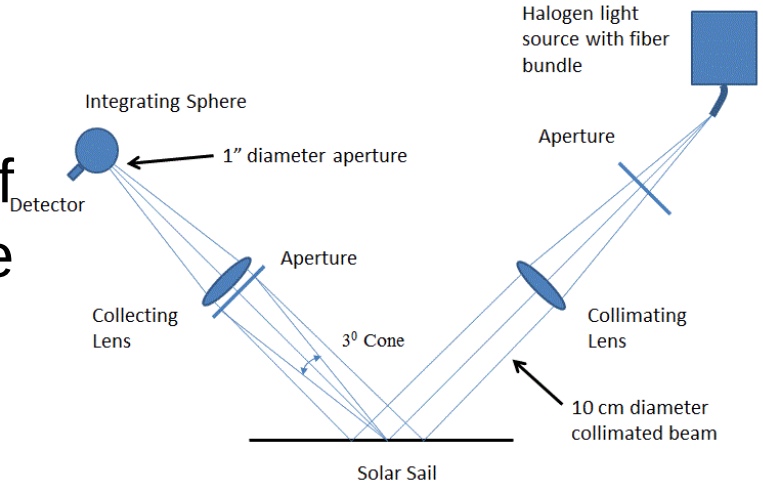
Lunar Flashlight Objective

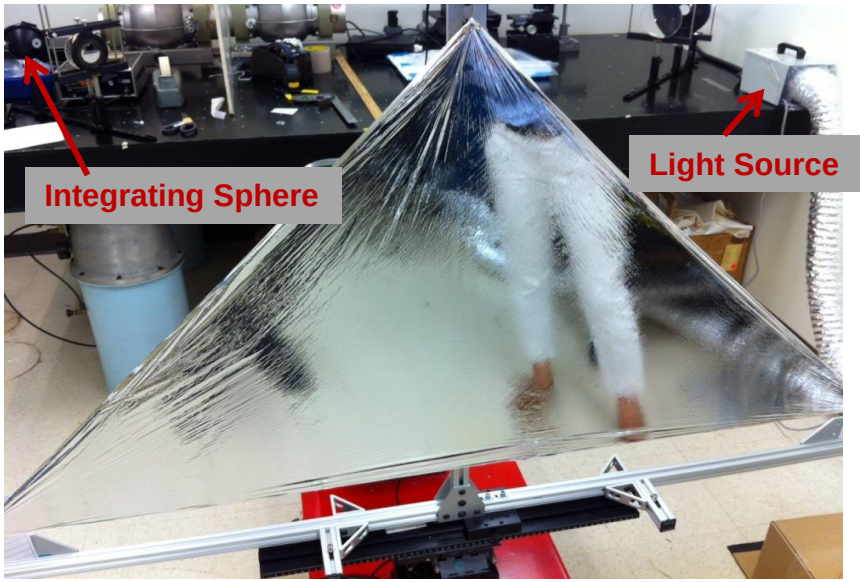
Sunlight is reflected off the sail down to the lunar surface. Light reflected off the lunar surface enters the spectrometer to distinguish water ices from regolith.

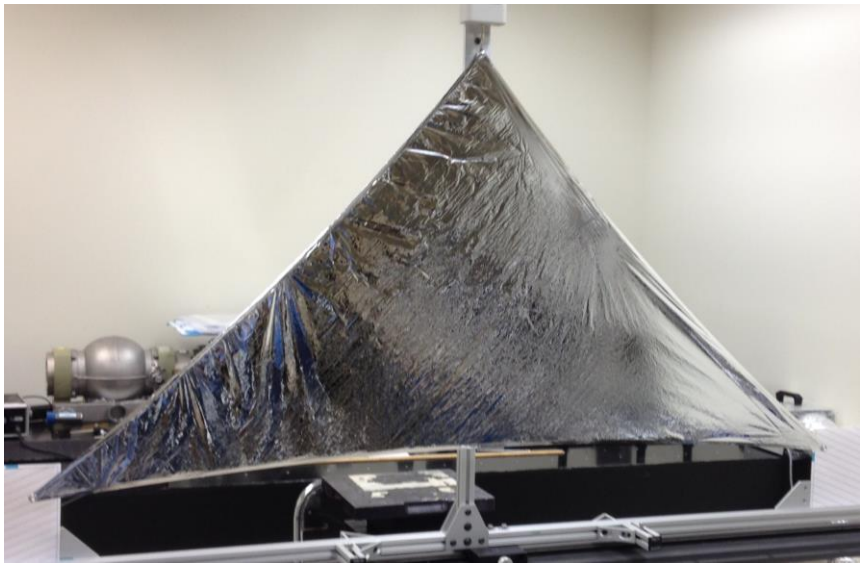
Surface Illumination Test

Lunar Flashlight Requires Surface Illumination:

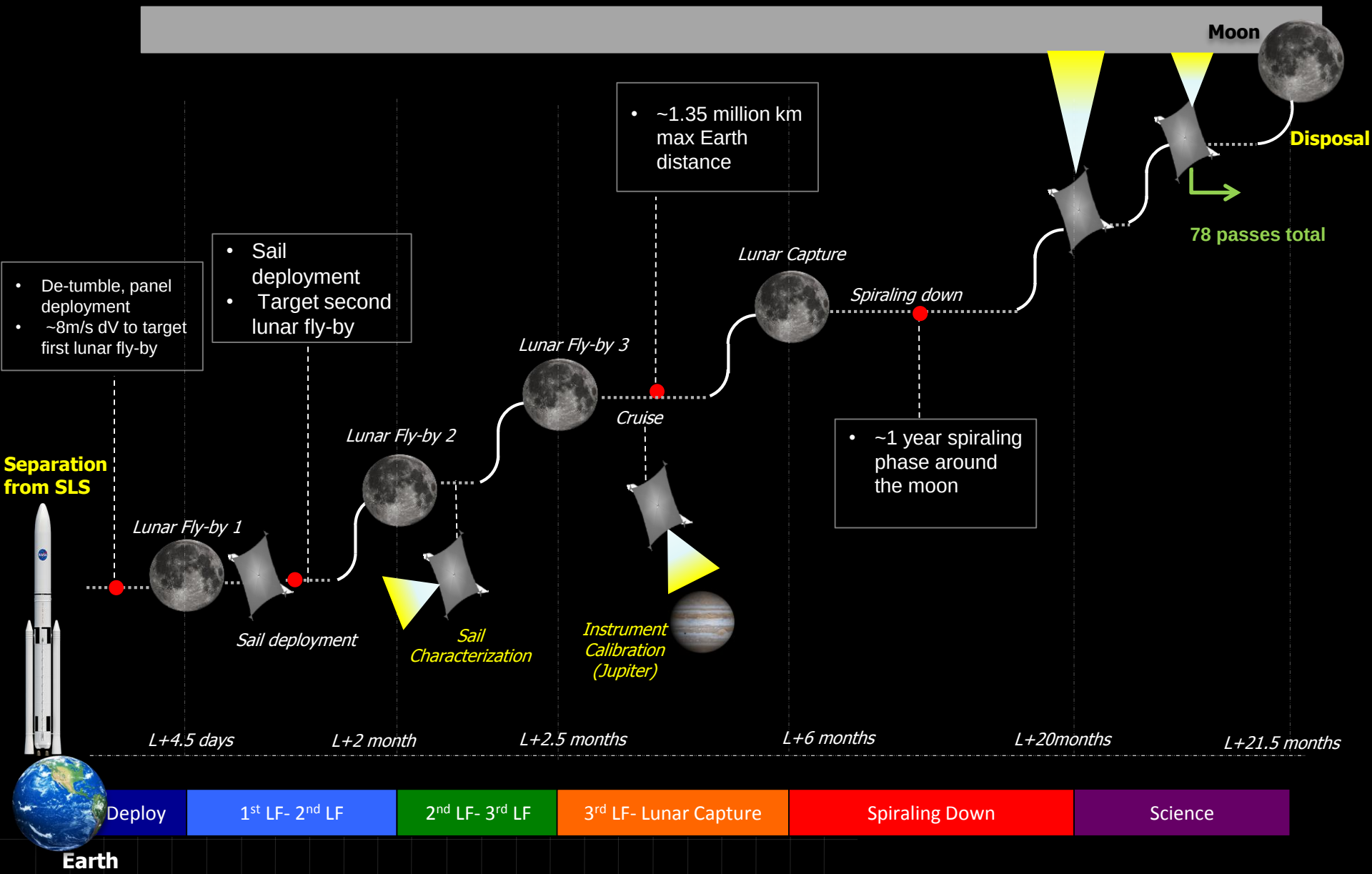
- Determine the capabilities of the solar sail in regard to the amount of light that the sail can reflect into the desired 3 degree cone onto a surface.







ConOps Overview (Lunar Flashlight)



Assembly, Integration, and Test (AI&T): Overview