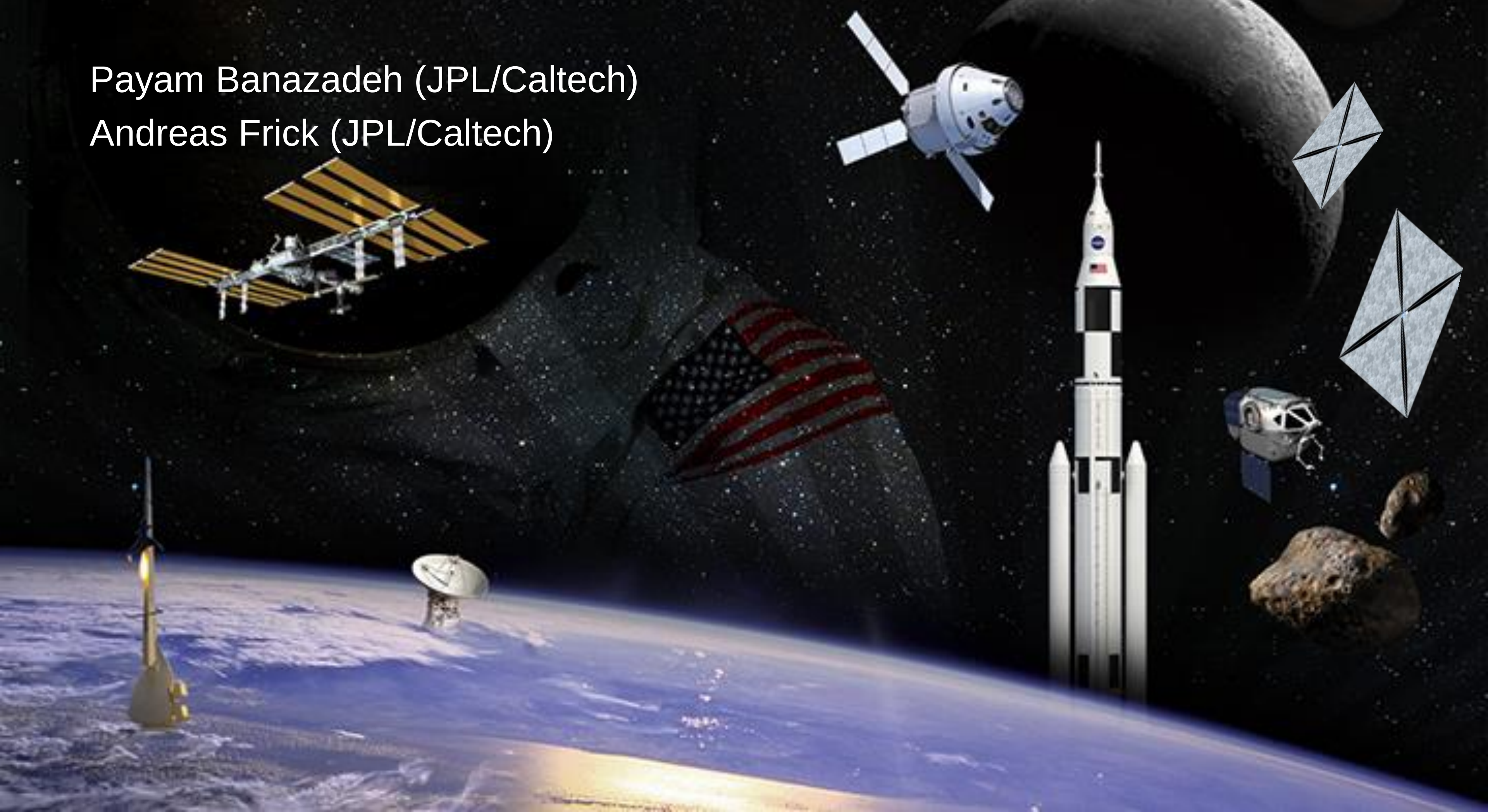
Lunar Flashlight & NEA Scout

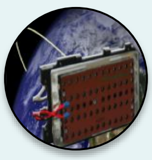
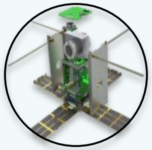
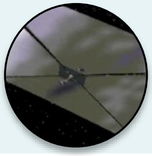
A NanoSat Architecture for Deep Space Exploration

Payam Banazadeh (JPL/Caltech)
Andreas Frick (JPL/Caltech)



EM-1 Secondary Payload Selection

- **19 NASA center-led concepts were evaluated and 3 were down-selected for further refinement by AES toward a Mission Concept Review (MCR) planned for August 2014**
- **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/MHS* 	**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* 	**NEA Characterization** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Slow flyby/rendezvous and characterize one NEA in a way that is relevant to human exploration

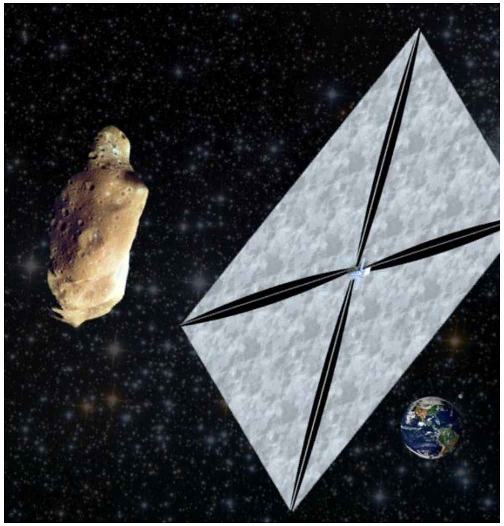
EM-1: Near Earth Asteroid (NEA) Scout concept

WHY NEA Scout?

- Characterize a NEA with an imager to address key Strategic Knowledge Gaps (SKGs)
- Demonstrates low cost reconnaissance capability for HEOMD (6U CubeSat)

LEVERAGES:

- Solar sail development expertise (NanoSail-D, Sunjammer, LightSail-1)
- CubeSat developments and standards (INSPIRE, University & Industry experience)
- Synergies with Lunar Flashlight are in review (Cubesat bus, solar sail, communication system, integration & test, operations)



MEASUREMENTS: *NEA volume, spectral type, spin mode and orbital properties, address key physical and regolith mechanical SKG*

- ≥80% surface coverage imaging at ≤50 cm/px
- Spectral range: 400-900 nm (incl. 4 color channels)
- ≥30% surface coverage imaging at ≤10 cm/px

Key Technical Constraints:

- 6U Cubesat and ~80 m^2 sail to leverage commonalities with Lunar Flashlight, expected deployer compatibility and optimize cost
- Target must be within ~0.5 AU distance from Earth due to telecom limitations
- Slow flyby with target-relative navigation on close approach

EM-1: Lunar Flashlight concept

WHY Lunar Flashlight?

- Recent robotic mission data (Diviner, Mini RF, LCROSS) strongly suggest the presence of ice deposits in permanently shadowed craters
- Look for ice deposits and identify favorable locations for in-situ extraction and utilization
- SKG Understand the quantity and distribution of water and other volatiles in lunar cold traps

LEVERAGES:

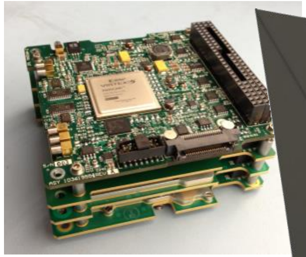
- Solar sail development expertise (NanoSail-D, Sunjammer, LightSail-1)
- CubeSat developments and standards (INSPIRE, Morehead State University & Industry experience)
- Synergies with NEA Scout (CubeSat bus, solar sail, communication system, instrument, integration & test, operations, are in review)

MEASUREMENTS: *Lunar ices (water, methane, ammonia, and carbon dioxide) trapped in permanently shadowed cold craters*

- high-resolution spectra in the 3-μm region during nighttime at all latitudes could help solve problem of thermal contamination of existing near-IR (M^3, etc.) spectra

Key Technical Constraints:

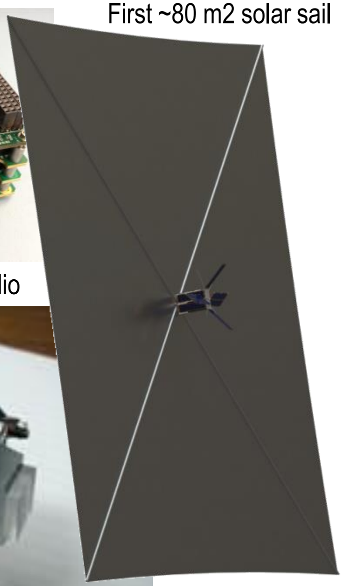
- 6U Cubesat and ~60-90 m^2 sail to leverage commonalities with NEA Scout, 30W, expected deployer compatibility and optimize cost



JPL X-Band IRIS Radio

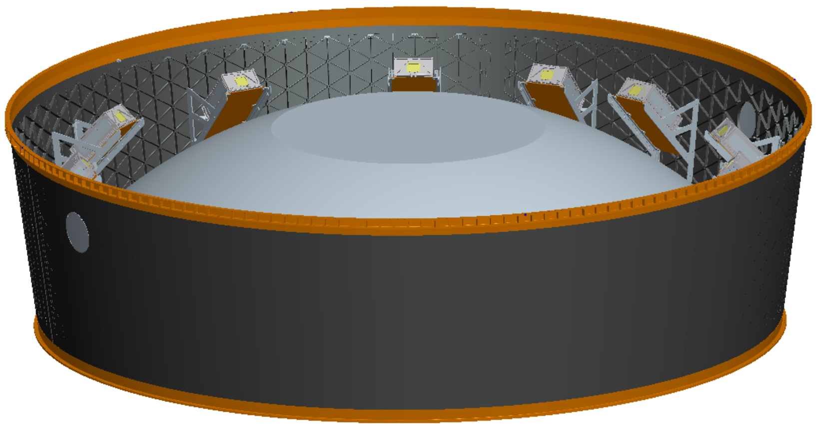
MSSS MARDI Camera

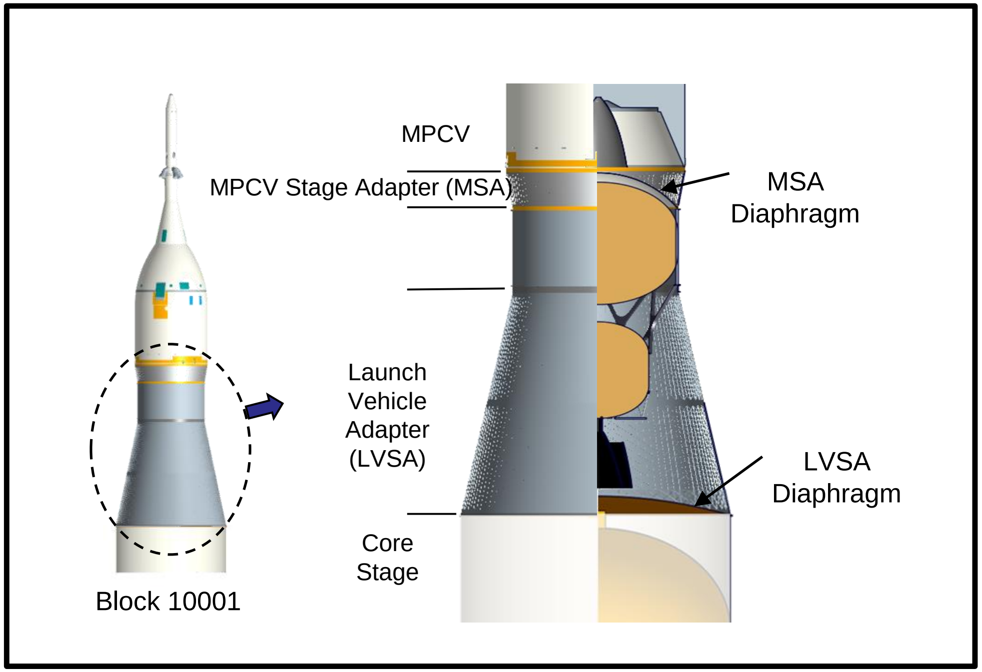
First ~80 m2 solar sail



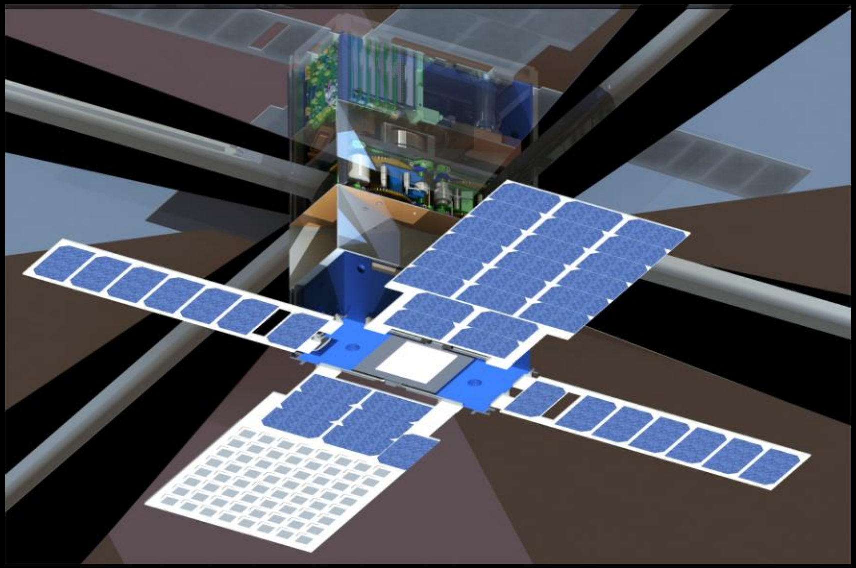
SLS Integration

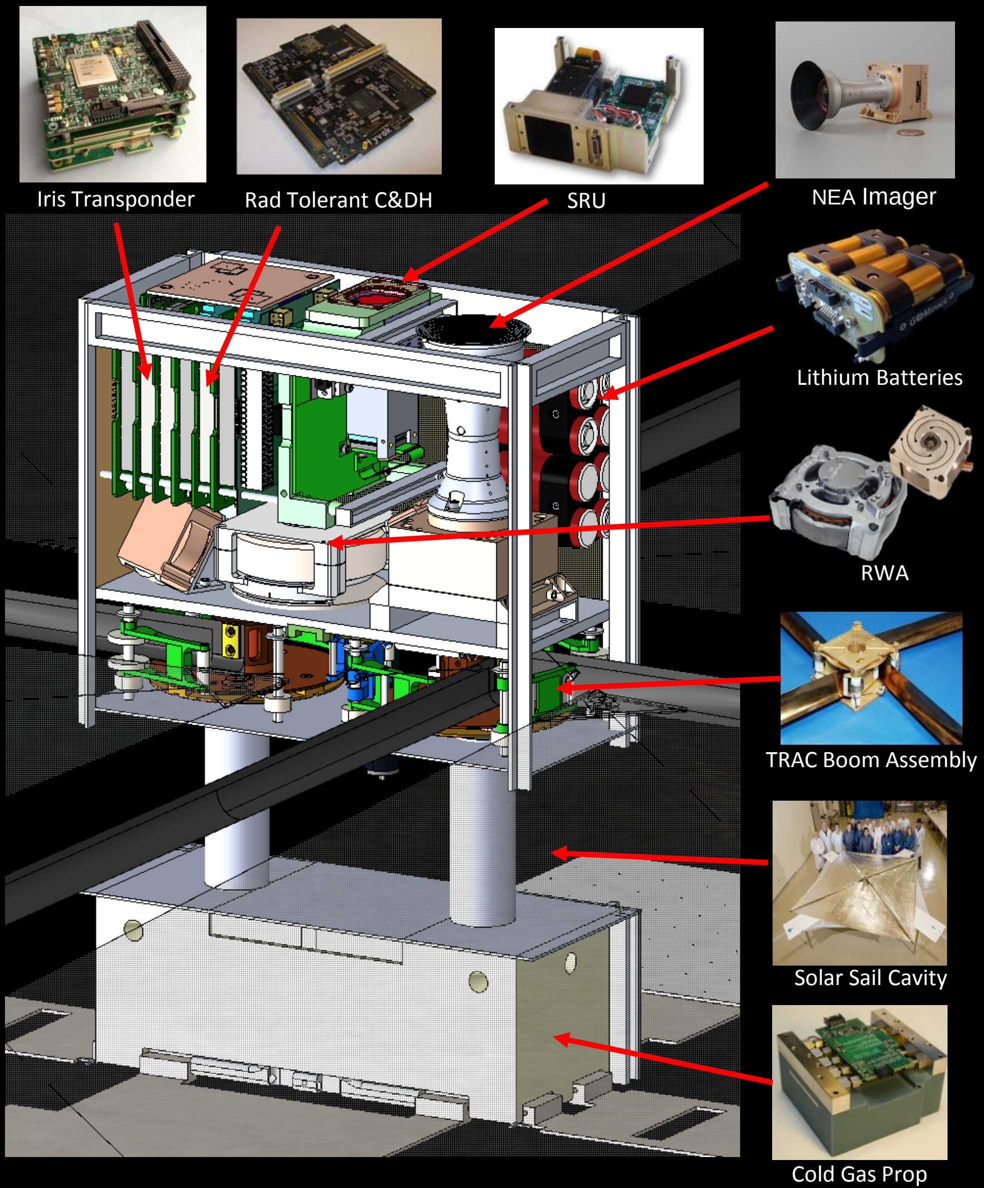
- Notional Launch on SLS EM-1 (Dec. 2017)
- Secondary payloads will be integrated on the MPCV stage adapter (MSA) on the SLS upper stage.
- Secondary payloads will be deployed on a trans-lunar trajectory after the upper stage disposal maneuver.





NEA Scout Flight System Overview





Bus: JPL Deep Space NanoSat Bus (based on INSPIRE)

Propulsion: MSFC ~80 m^2 Solar Sail (based on NanoSail-D)

Payload: COTS NEA Imager, e.g. MSSS ECAM M-50

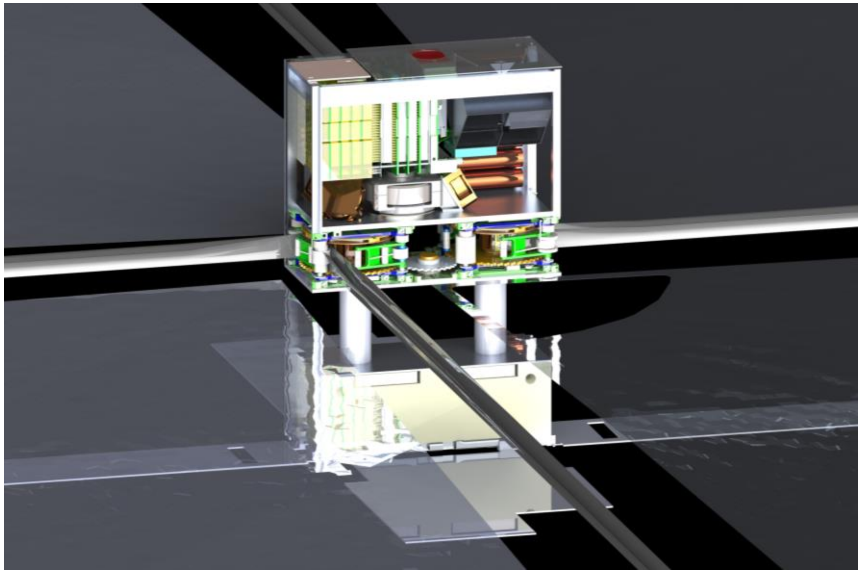
Command & Data Sys.: Radiation tolerant LEON3 architecture

Attitude Control: 3-Axis Control (Zero-momentum spin cruise)

Electrical Power: ~35W (@1 AU) with gimbaled solar panels

Telecom: JPL Iris, Inspire LGA (2 Pair) + Microstrip Array HGA (>1 kbps @ 0.25 AU to 34m DSN)

LF Flight System Overview



Mission: Locating ice deposits in the Moon's permanently shadowed craters

Approach: "6U" Solar-Sail Propelled CubeSat (<12 kg)

Launch Opportunity: SLS EM-1 (Dec 2017 notional launch)

Bus: JPL Deep Space NanoSat Bus (leveraging INSPIRE)

Propulsion: MSFC ~80 m^2 Solar Sail (based on NanoSail-D)

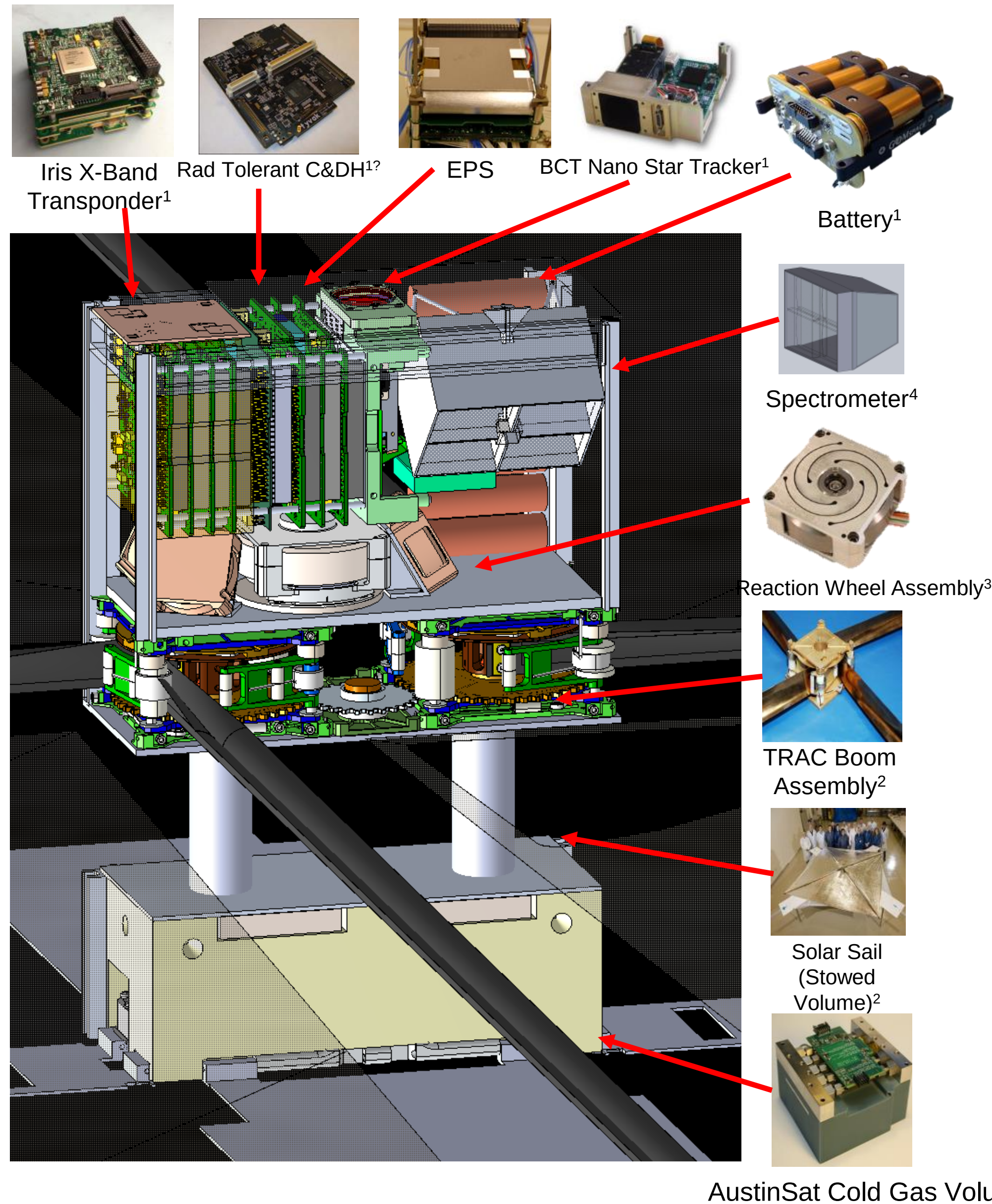
Payload: COTS 4-band spectrometer

C&DH: Rad Tolerant LEON-3 architecture, JPL Protos FSW

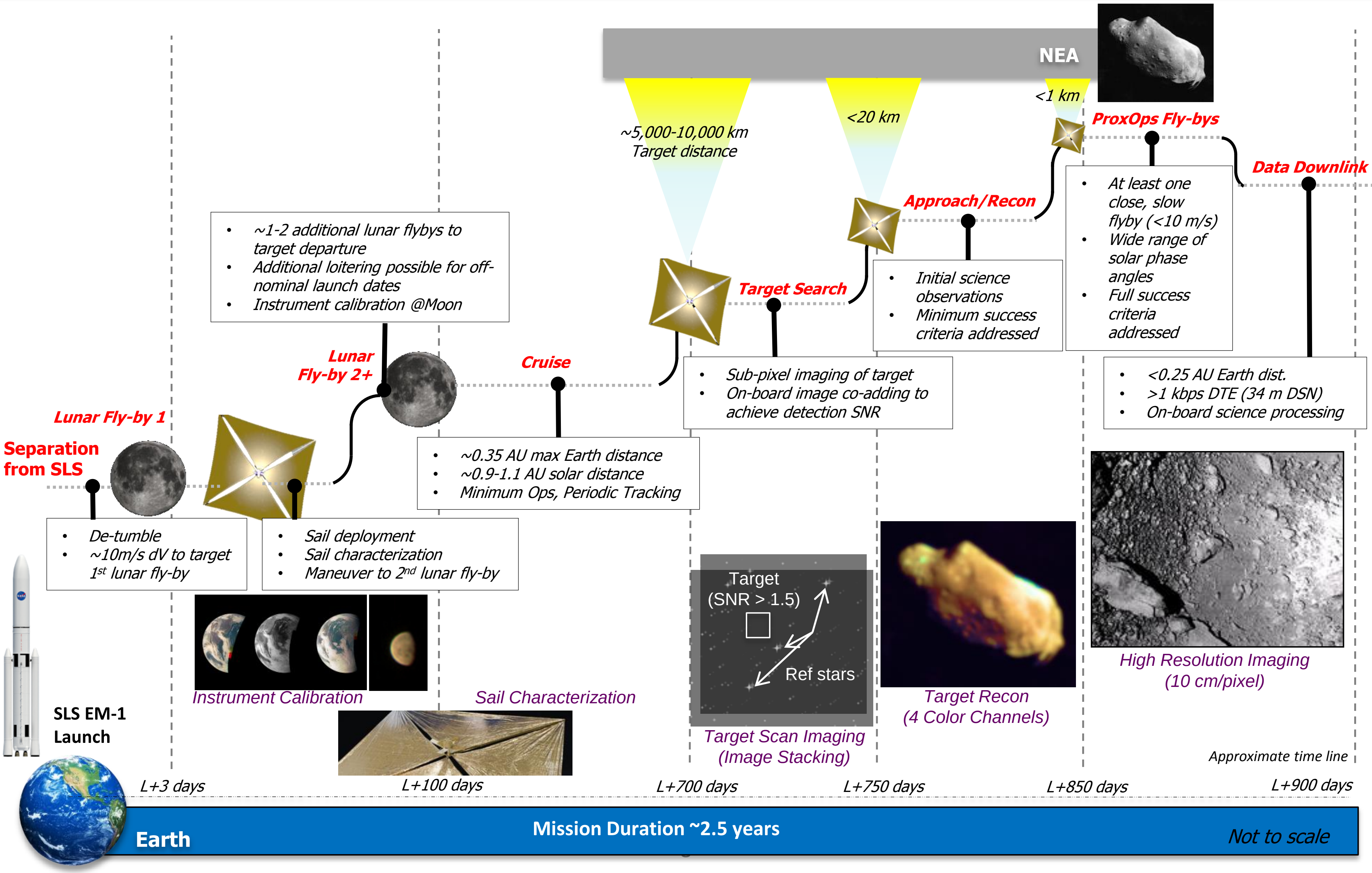
ADCS: COTS Cold Gas, RWA, SRU, IMU, CSS

Power: ~30W with gimbaled solar panels

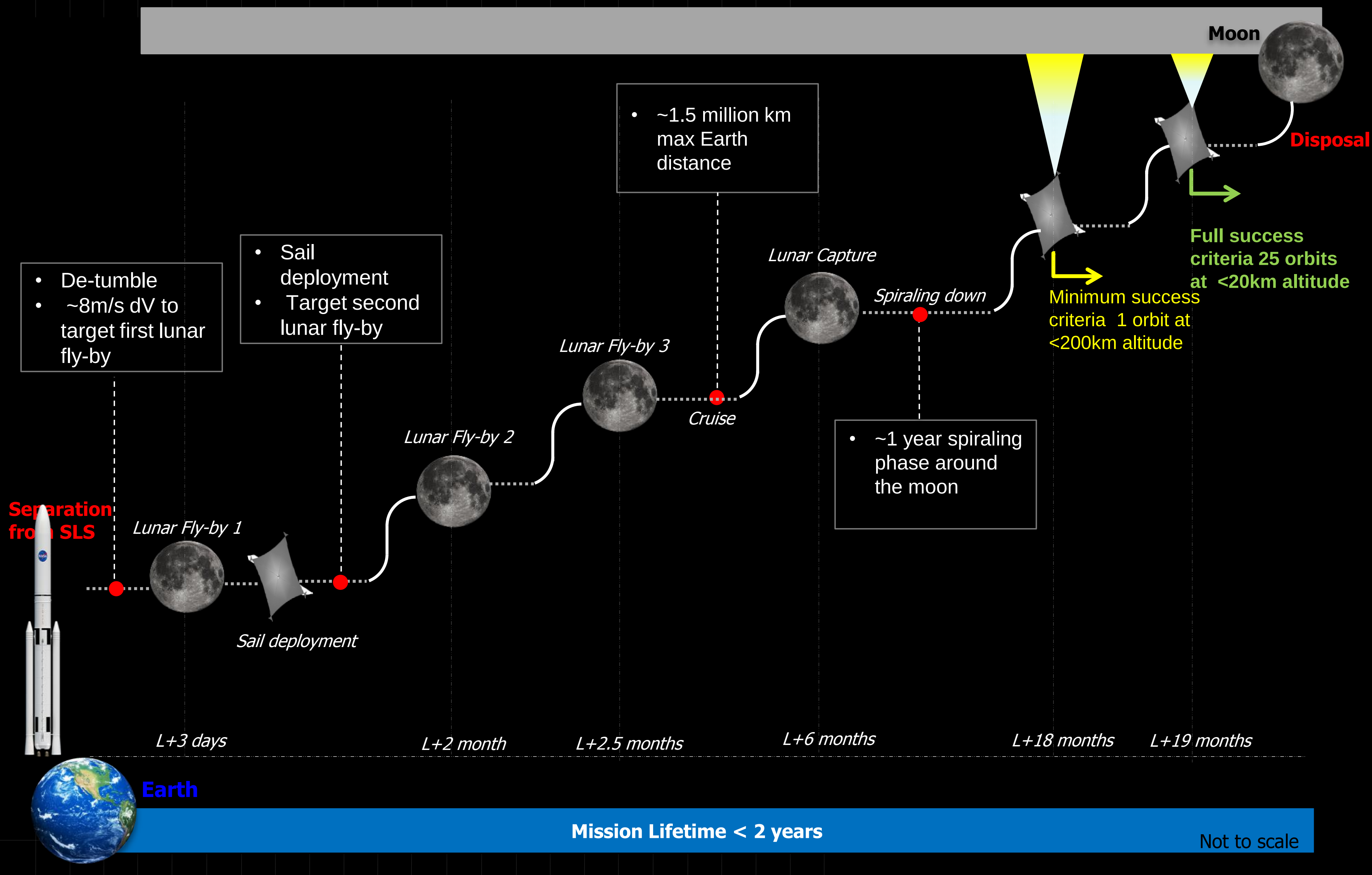
Telecom: JPL Iris X-Band Transponder + Patch Antenna (~1 kbps nominal @ Lunar Distance with Morehead State)

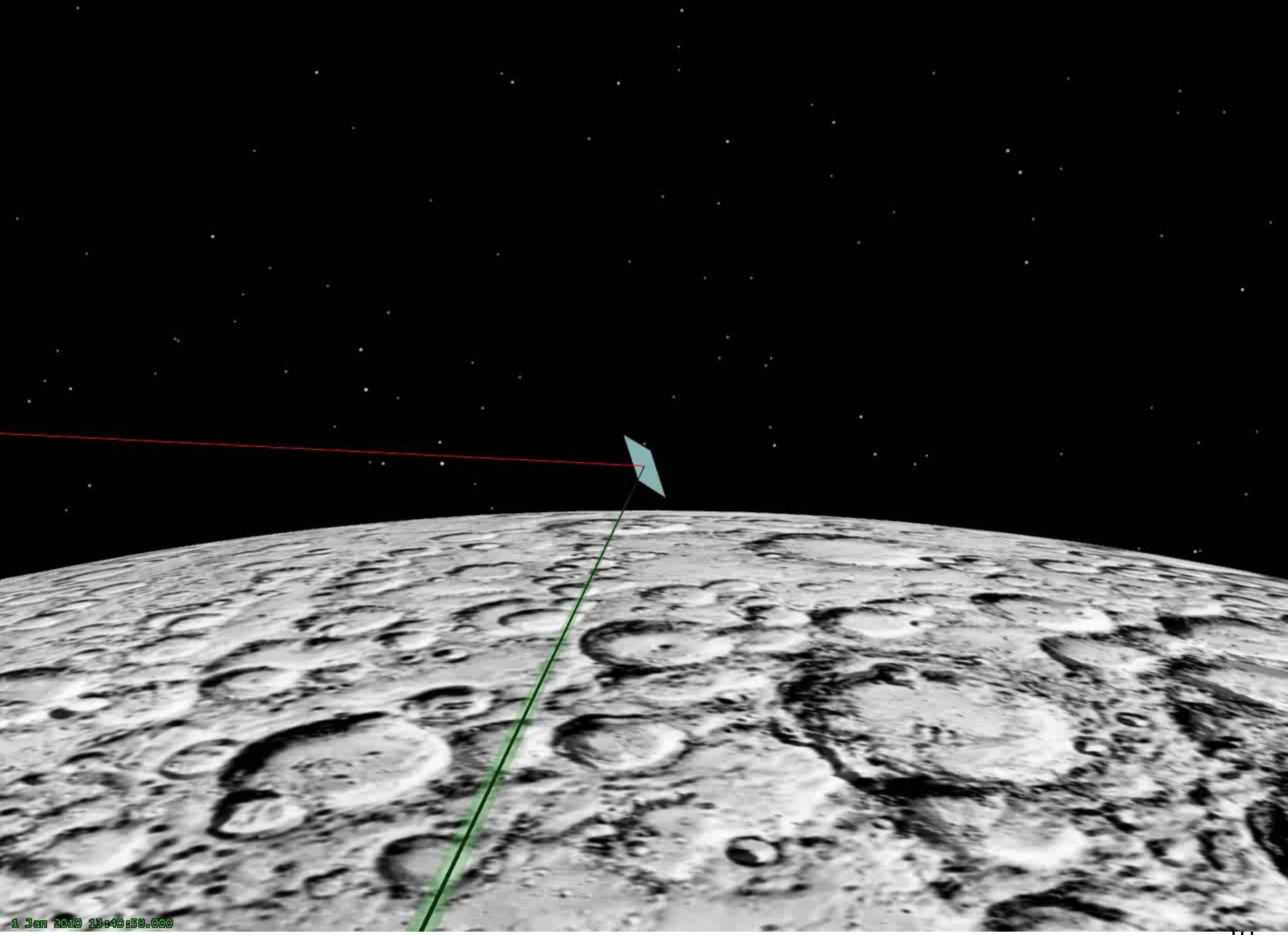


NEA Scout ConOps Summary



Lunar FlashLight ConOps



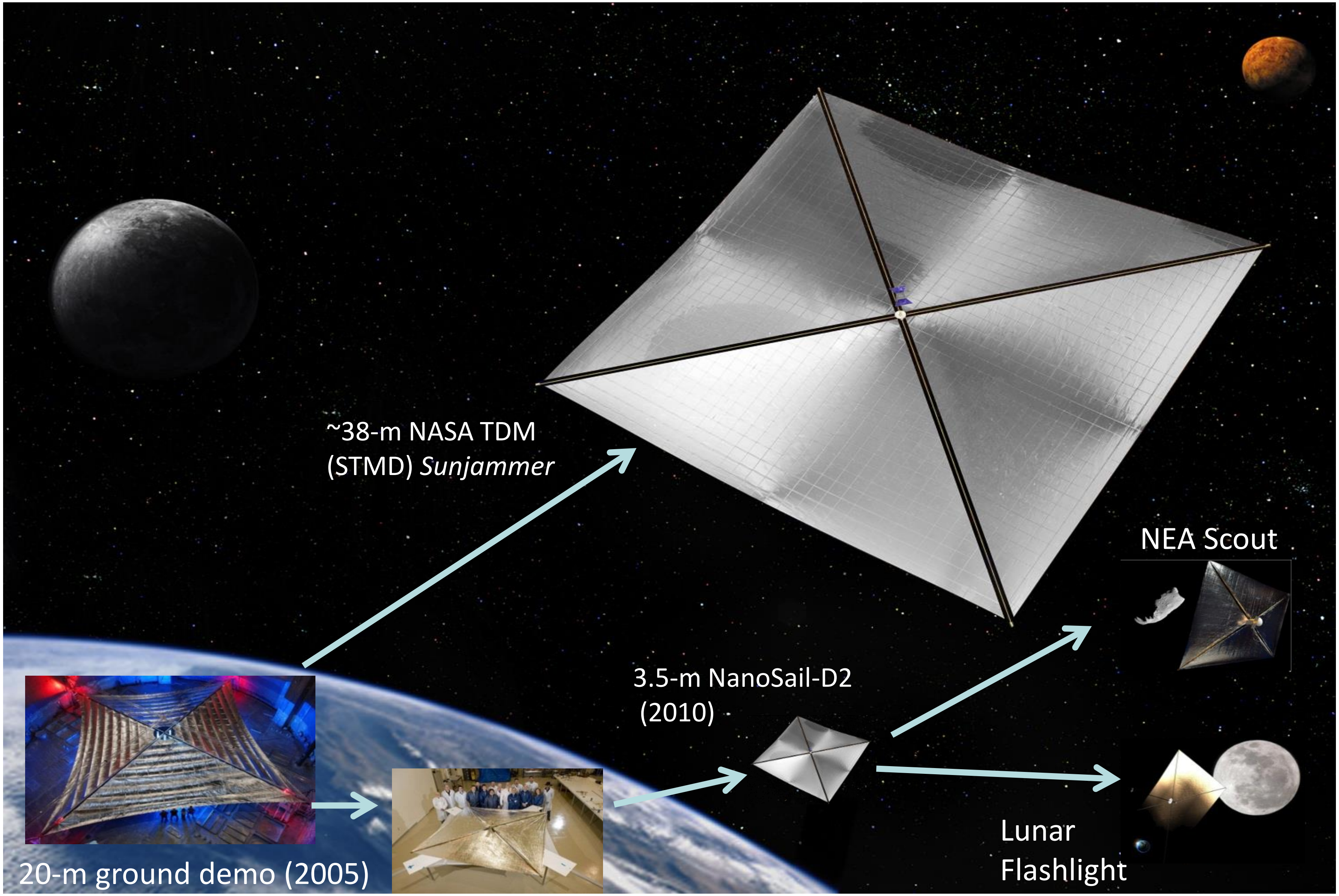

1 Jan 2010 13:40:58.000

NEA Scout Accessible Targets

- **Several potential NEA Targets exist between 2017 and 2021**
  - Times and rendezvous distances are approximate pending solar sail design, launch conditions (time and trajectory), and trajectory optimization
  - Mission duration can be a challenge, especially given limitations of hosted payloads (no choice of launch date and initial trajectory)
  - Assumes deployment on trans-lunar trajectory with small cold gas maneuver (~10 m/s) to target lunar flyby, 12 kg spacecraft mass, and 80-90 m^2 solar sail
  - High OCC targets may require complementary observations by ground-based or orbiting assets to further constrain target location prior to rendezvous

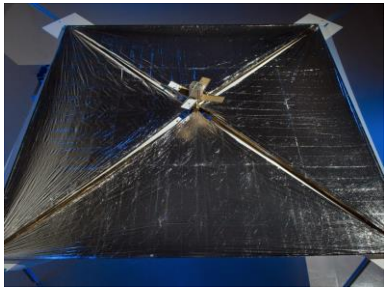
Name	Minimum Time of Flight (2017-2021)	Time of Flight for Notional Launch (Dec. 2017)	Rendezvous Distance from Earth	Abs. Mag	30% albedo Dia. (m)	5% albedo Dia. (m)	Orbit Condition Code	Observation Opportunity before launch?
1991 VG	<1.5 years	~1.5 years	~0.5 AU	28.5	5	12	2	YES (optical)
2001 GP2	<2 years	~2.5 years	0.2-0.05 AU	26.9	10	25	6	After 2019?
2007 UN12	<1.5 years	>3 years	0.25-0.1 AU	28.7	4	11	4	No
2008 EA9	<1.5 years	~3 years	0.25-0.1 AU	27.7	7	17	5	No
2012 UV136	~2.5 years	~3 years	0.5-0.01 AU	25.5	19	47	1	YES (optical/radar)

Solar Sail Development History



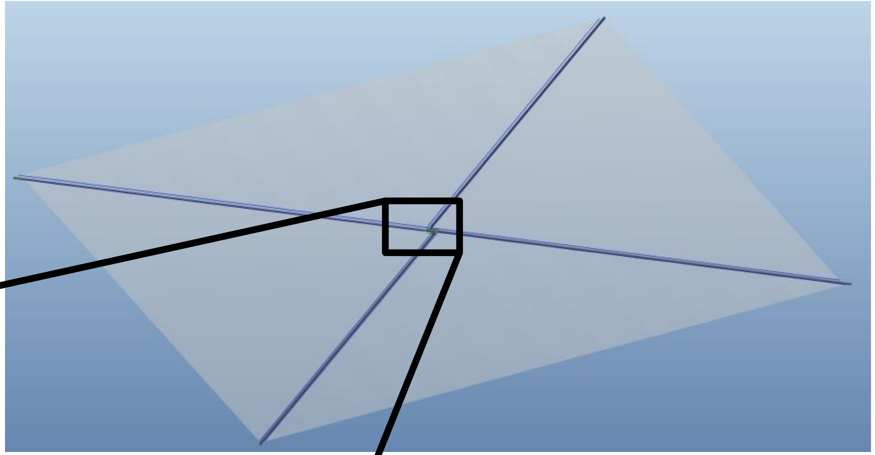
Solar Sail Design

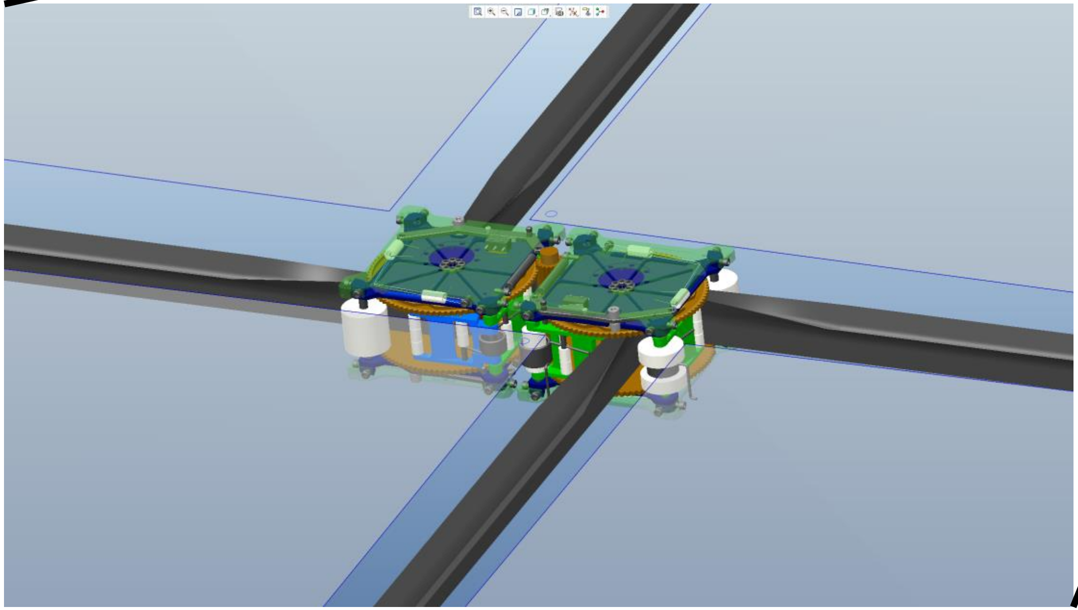
Sail Design by MSFC

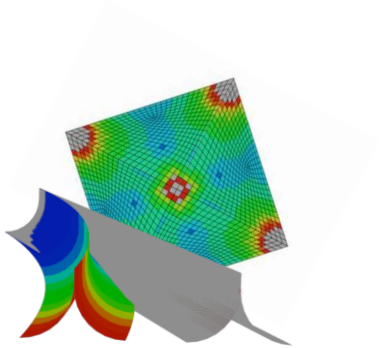


NanoSail-D2 (flown in 2010)

TRAC Boom Deployer

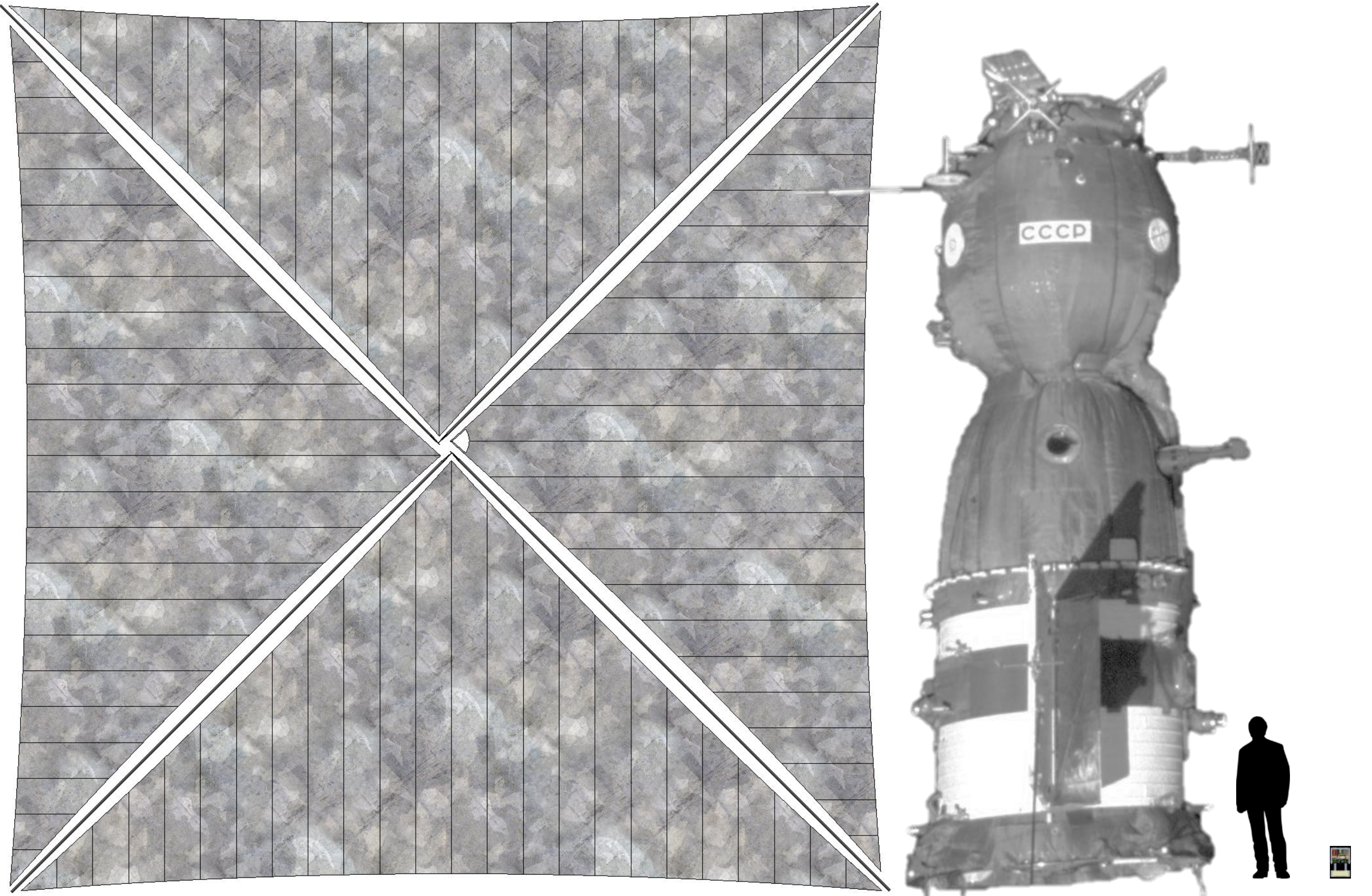






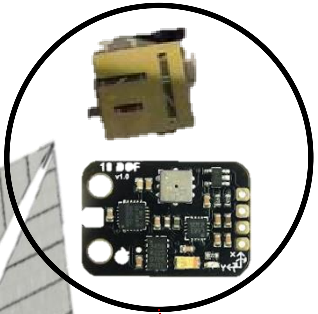
Structural Analysis by LaRC

Size comparison

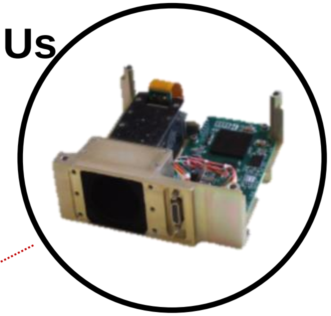


ACS Architecture

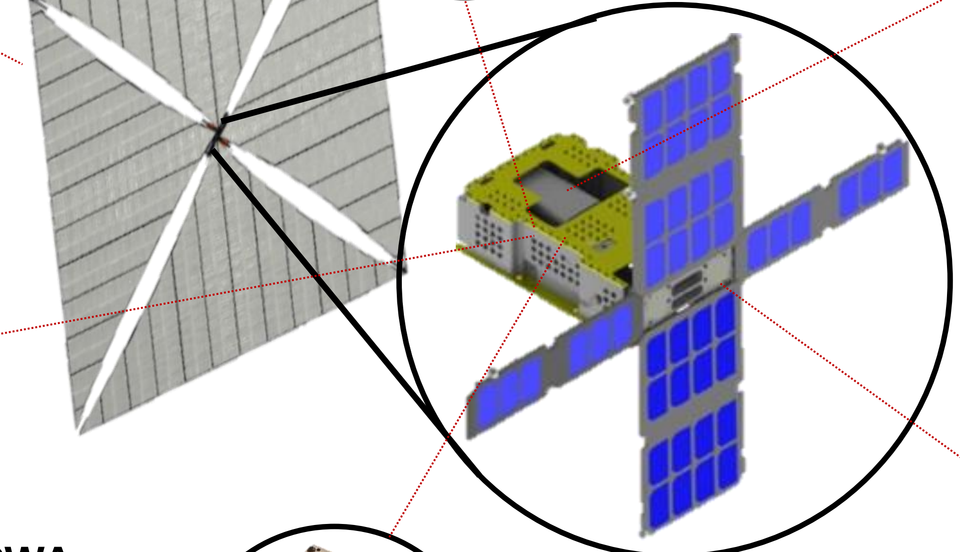
Spinning Sail
- Induce a slow, 1 rev/hour spin about the norm of the sail
- Averages momentum accumulation over mission



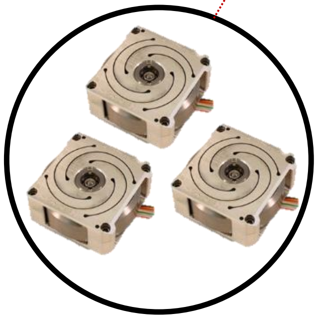
Sun Sensors/IMUs
- Detumbling
- Safe mode
- Rapid slews



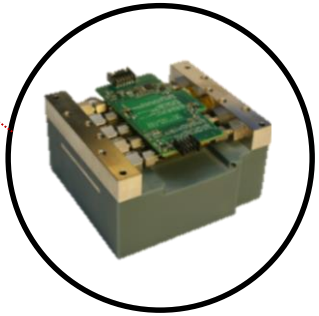
Star Tracker
- ~0.01 deg accuracy
- Fine pointing in interplanetary space



Zero-Momentum RWA
- One >= 100 mNms wheel
- Controls spin of the sail
- Maintain a zero-momentum system



Steering RWA
- Three 15 mNms wheels
- Attitude control for science, telecom, and nav. pointing



Cold Gas System
- Isp>= 60s
- ~ 1 kg of fuel
- Momentum mgmt
- Initial delta-V burn

Impact and Future Outlook

- **Contribution to the CubeSat Community**
  - Long-lived CubeSat bus for deep space missions (C&DH, EPS, ADCS, Deep Space Transponder)
  - Further characterization of deep space environment effects on CubeSats (building on INSPIRE)
  - First science-grade observations of solar system objects
  - Mature CubeSat Solar Sail propulsion

- **Future Potential of Small Missions for Big Science**
  - Secondary spacecraft hosted on interplanetary missions
  - Both NEA Scout and Lunar Flashlight could be repeated to characterize additional NEAs or increase coverage of lunar ices (possibly with different, complementary payloads)
  - Other solar sail applications (e.g. Space Weather Monitoring constellation at Lagrange Points)