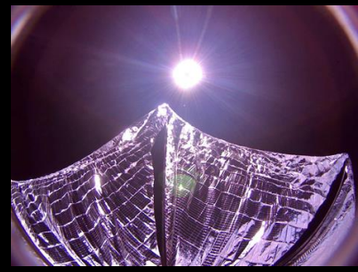
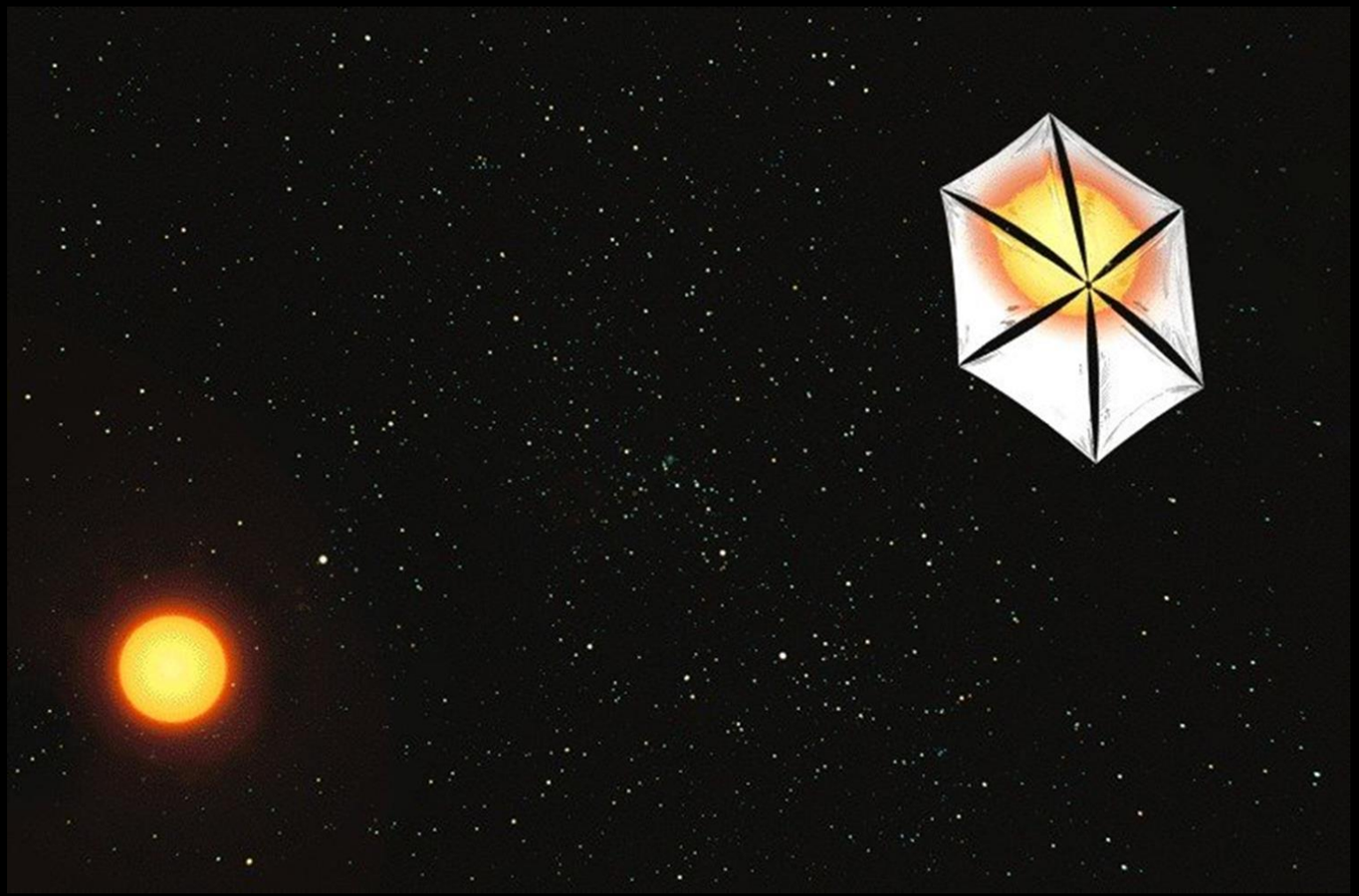
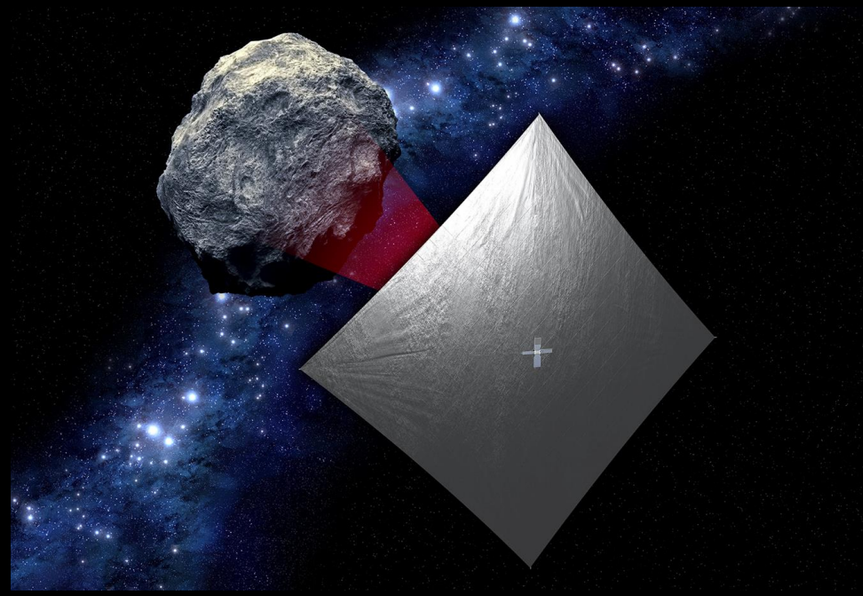
Solar Sail Propulsion Status







Les Johnson

NASA George C. Marshall Space Flight Center

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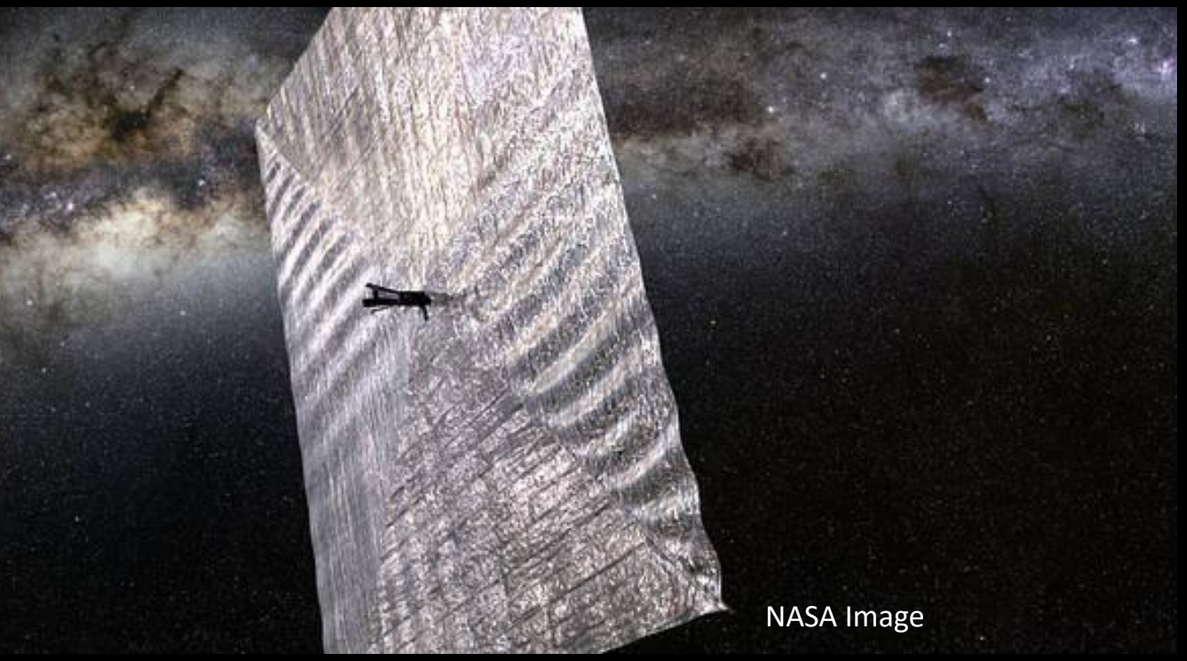
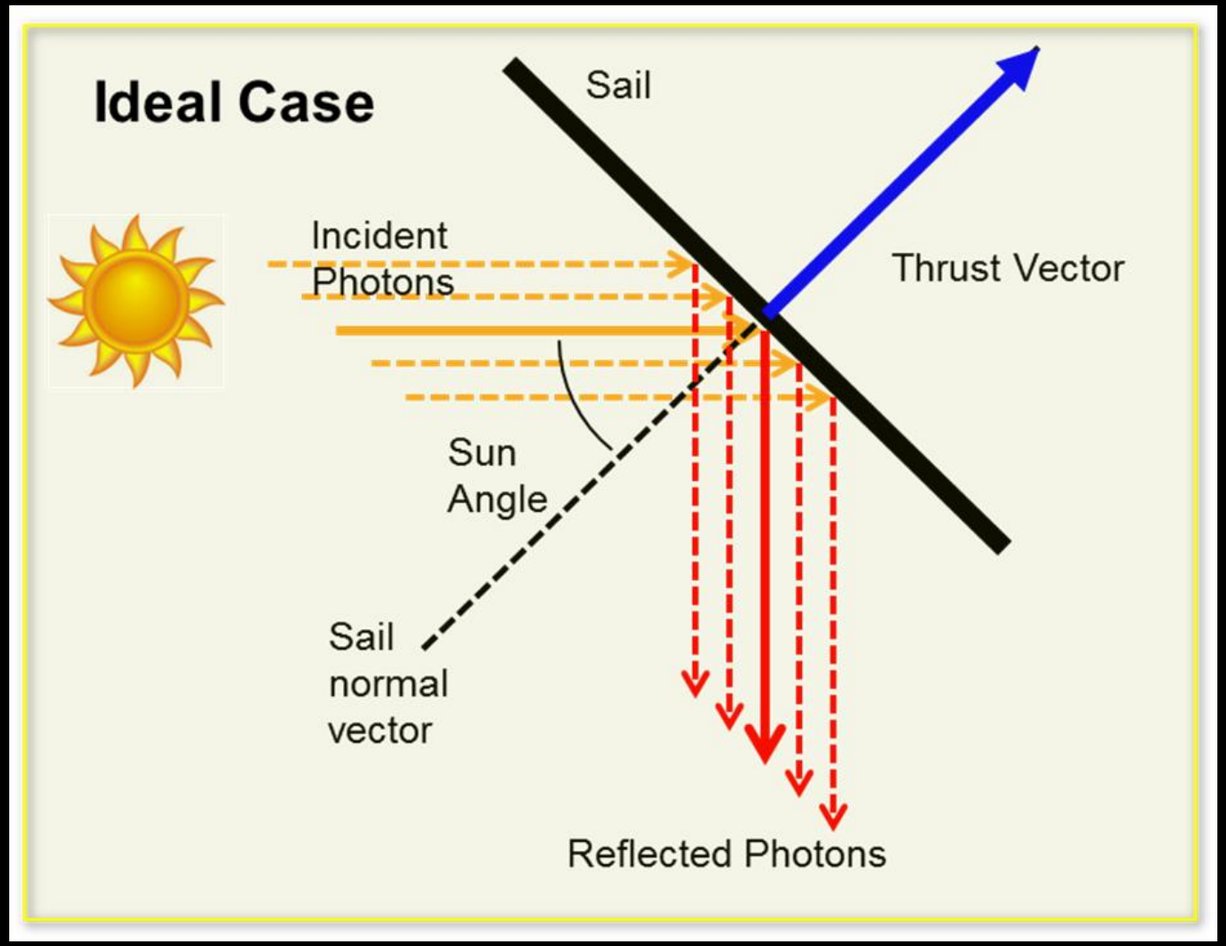
Solar Sails Derive Propulsion By Reflecting Photons

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

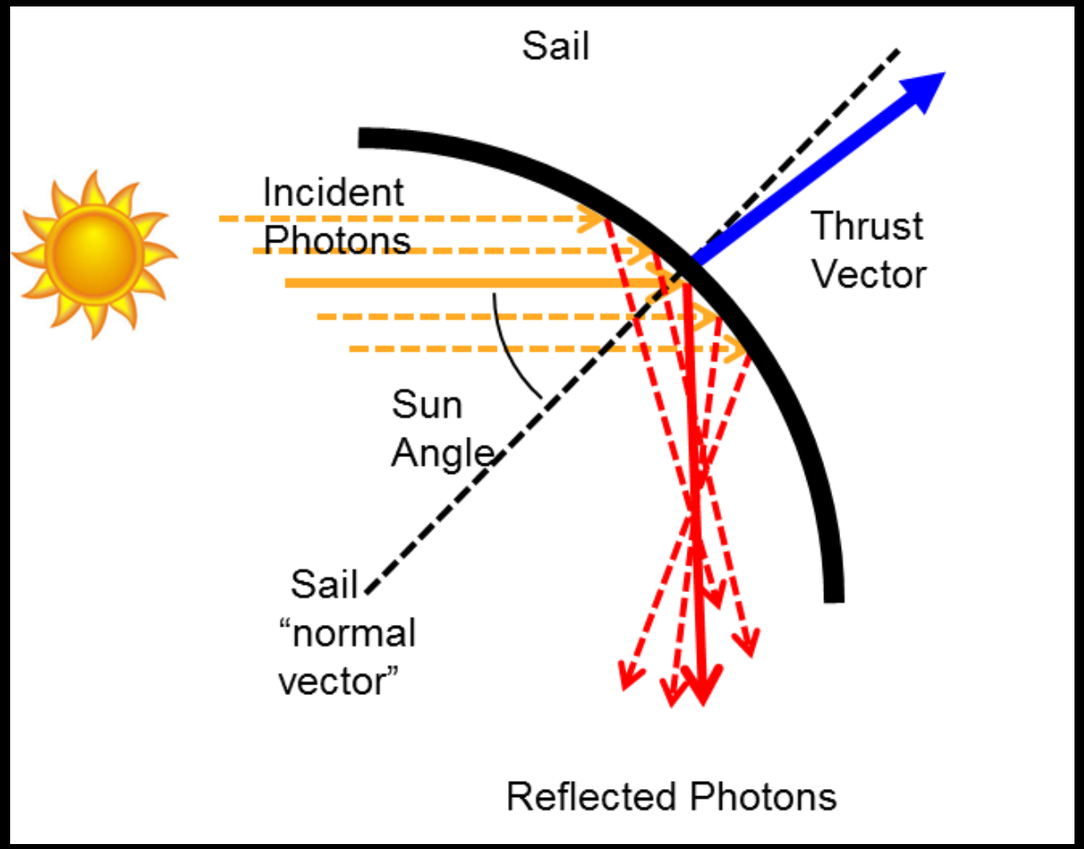


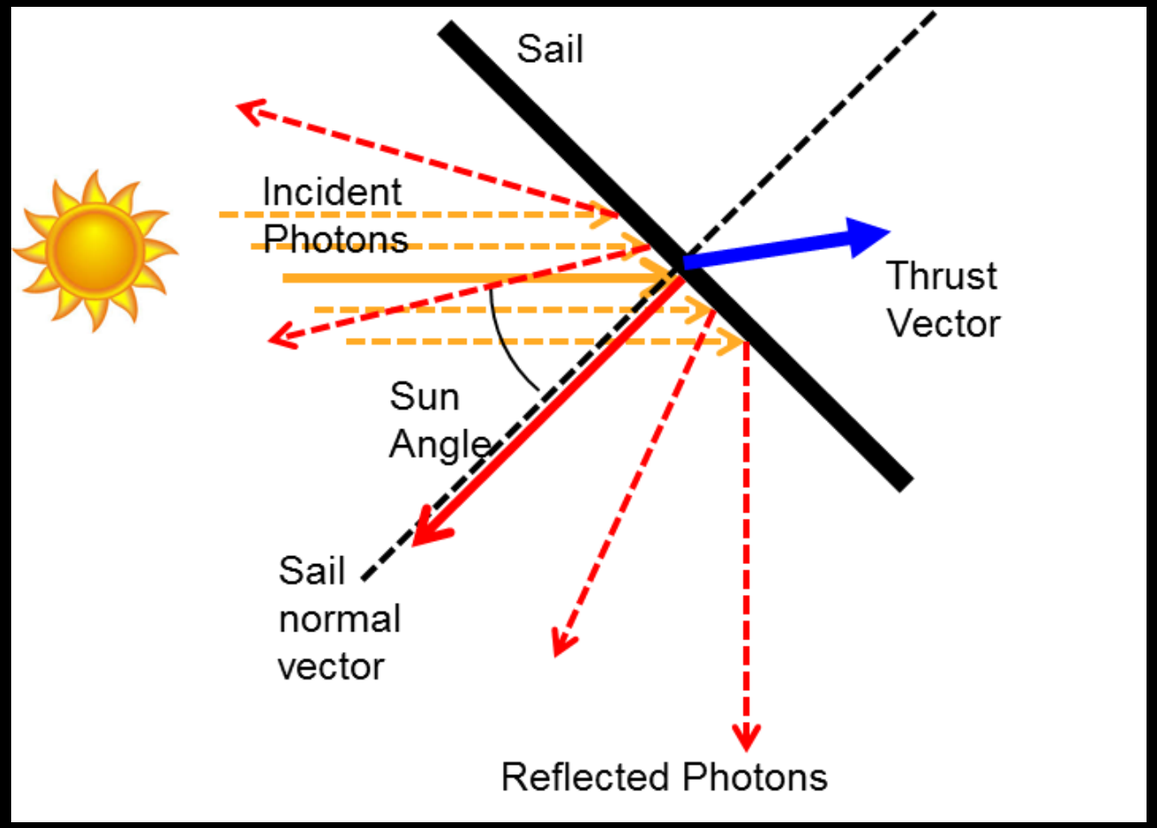
NASA Image



Real Solar Sails Are Not “Ideal”

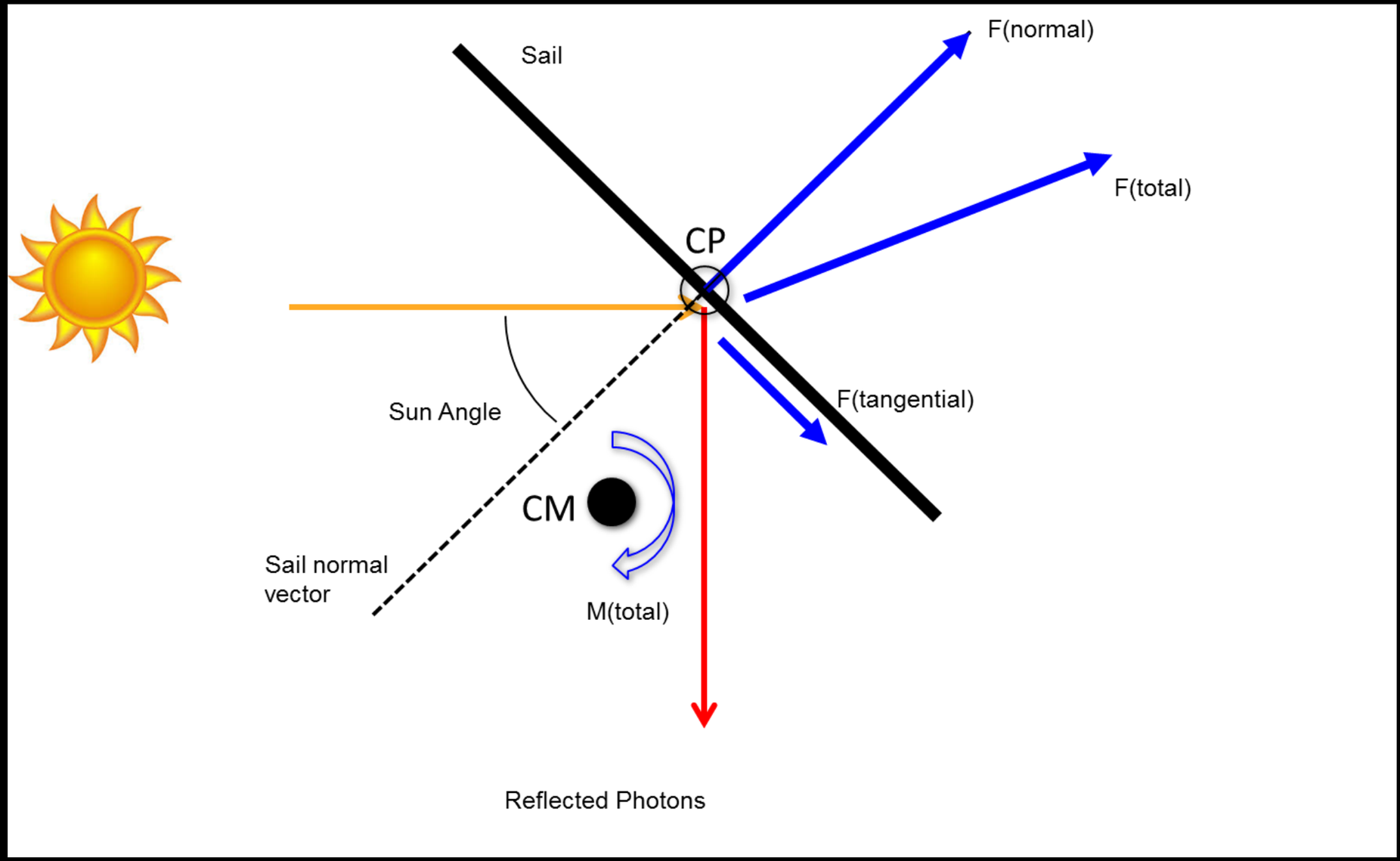
Billowed Quadrant



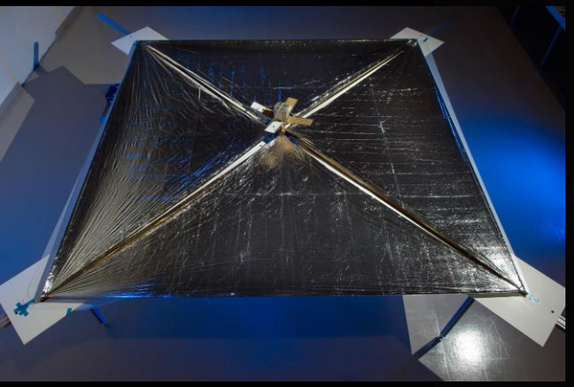


Diffuse Reflection

Thrust Vector Components



Solar Sail Missions Flown (as of May 2018)



NanoSail-D (2010)
NASA

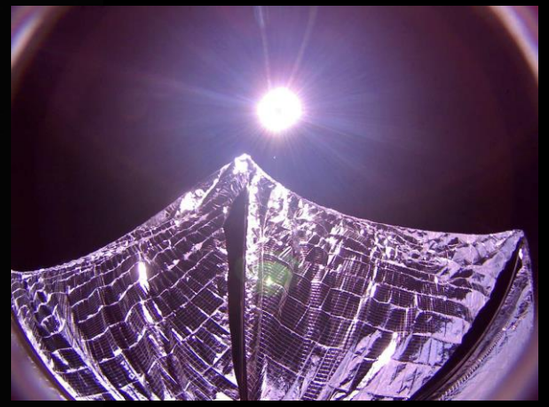
Earth Orbit
Deployment Only

3U CubeSat
10 m^2

IKAROS (2010)
JAXA

Interplanetary
Full Flight

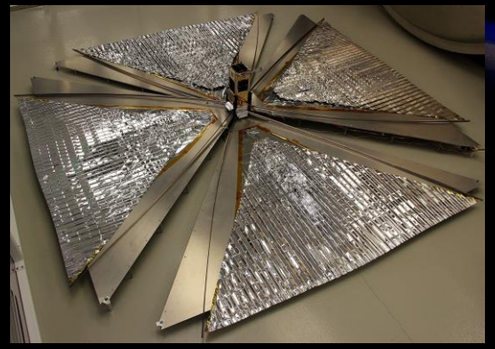
315 kg Smallsat
196 m^2



LightSail-1 (2015)
The Planetary Society

Earth Orbit
Deployment Only

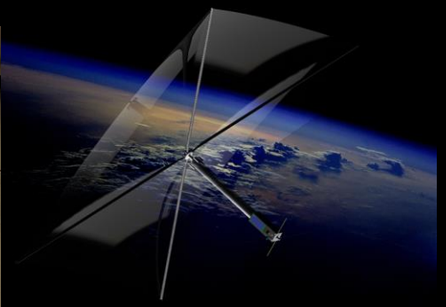
3U CubeSat
32 m^2



CanX-7 (2016)
Canada

Earth Orbit
Deployment Only

3U CubeSat
<10 m^2

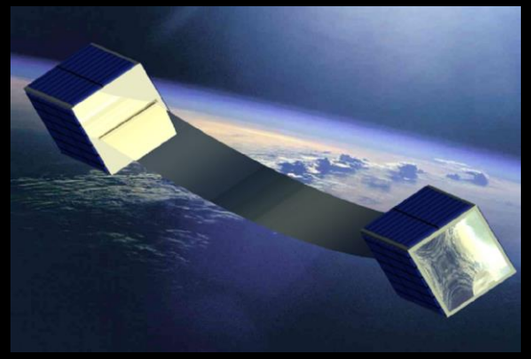


InflateSail (2017)
EU/Univ. of Surrey

Earth Orbit
Deployment Only

3U CubeSat
10 m^2

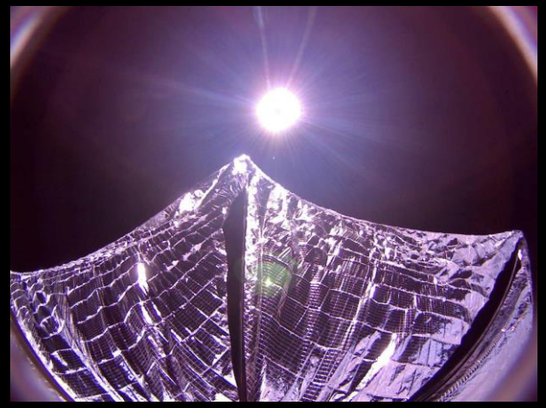
Current and Planned Solar Sail Missions



CU Aerospace (2018)
Univ. Illinois / NASA

Earth Orbit
Full Flight
In Orbit; Not yet deployed

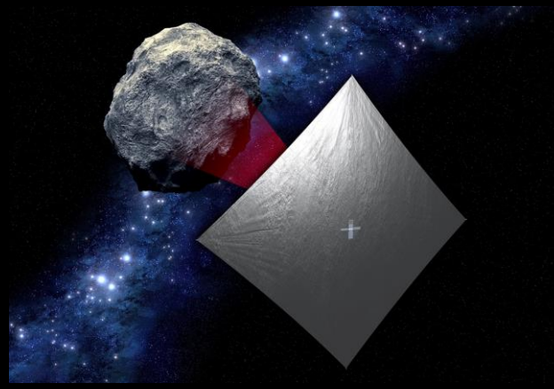
3U CubeSat
20 m^2



LightSail-2 (2019)
The Planetary Society

Earth Orbit
Full Flight
In Orbit; Successful

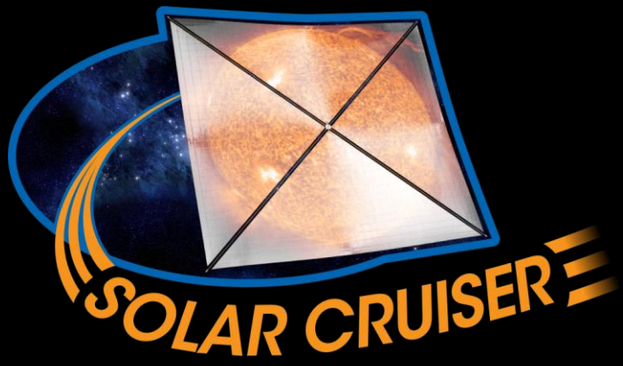
3U CubeSat
32 m^2



Near Earth Asteroid Scout (2020) NASA

Interplanetary
Full Flight

6U CubeSat
86 m^2



Solar Cruiser (2024)
NASA

L-1
Full Flight

90 Kg Spacecraft
1666 m^2

NASA's Near Earth Asteroid Scout

The Near Earth Asteroid Scout Will:

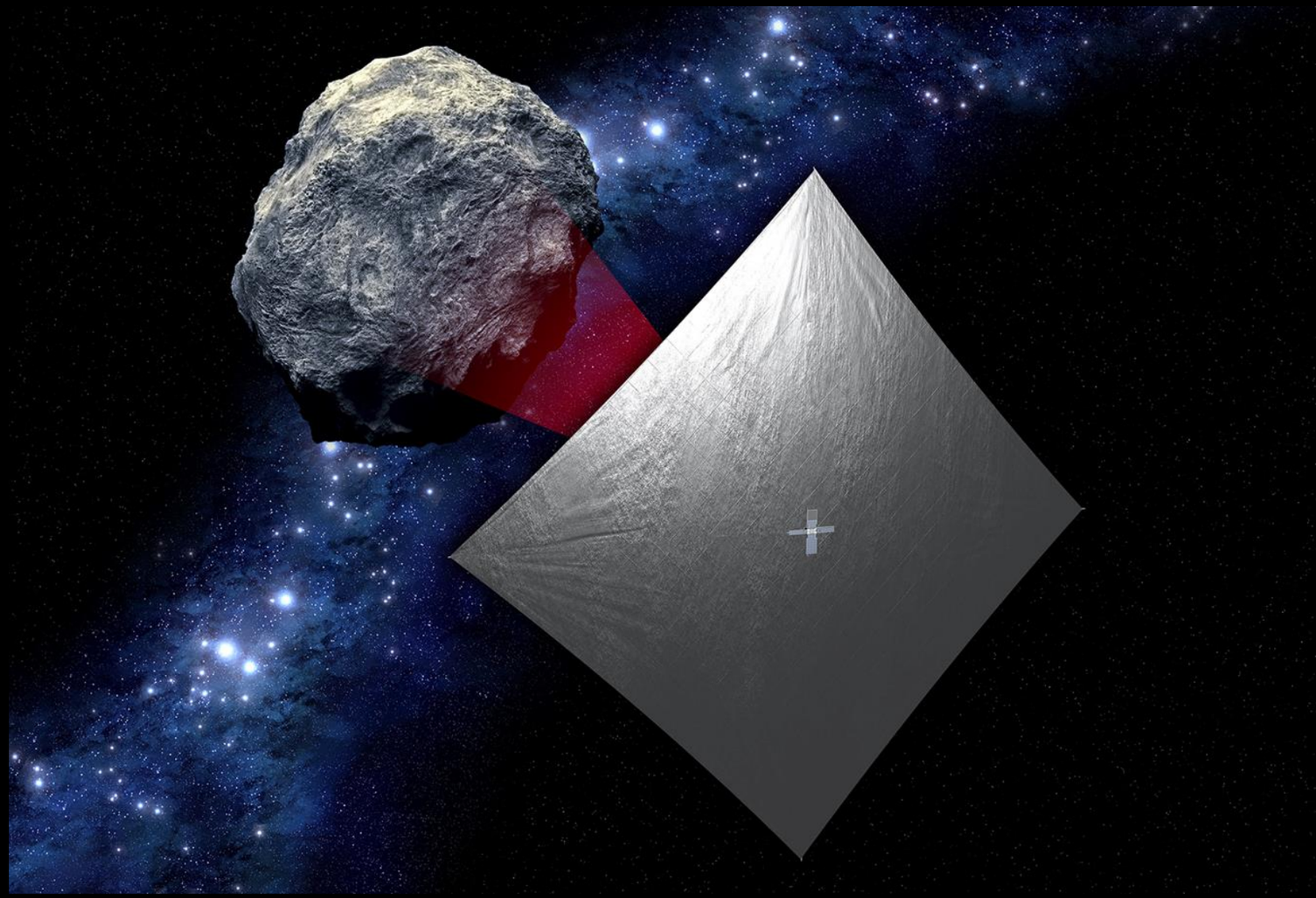
- Image/characterize a NEA during a slow flyby
- Demonstrate a low cost asteroid reconnaissance capability

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-1/2019)
- Up to 2.5 year mission duration
- 1 AU maximum distance from Earth

Solar Sail Propulsion System Characteristics

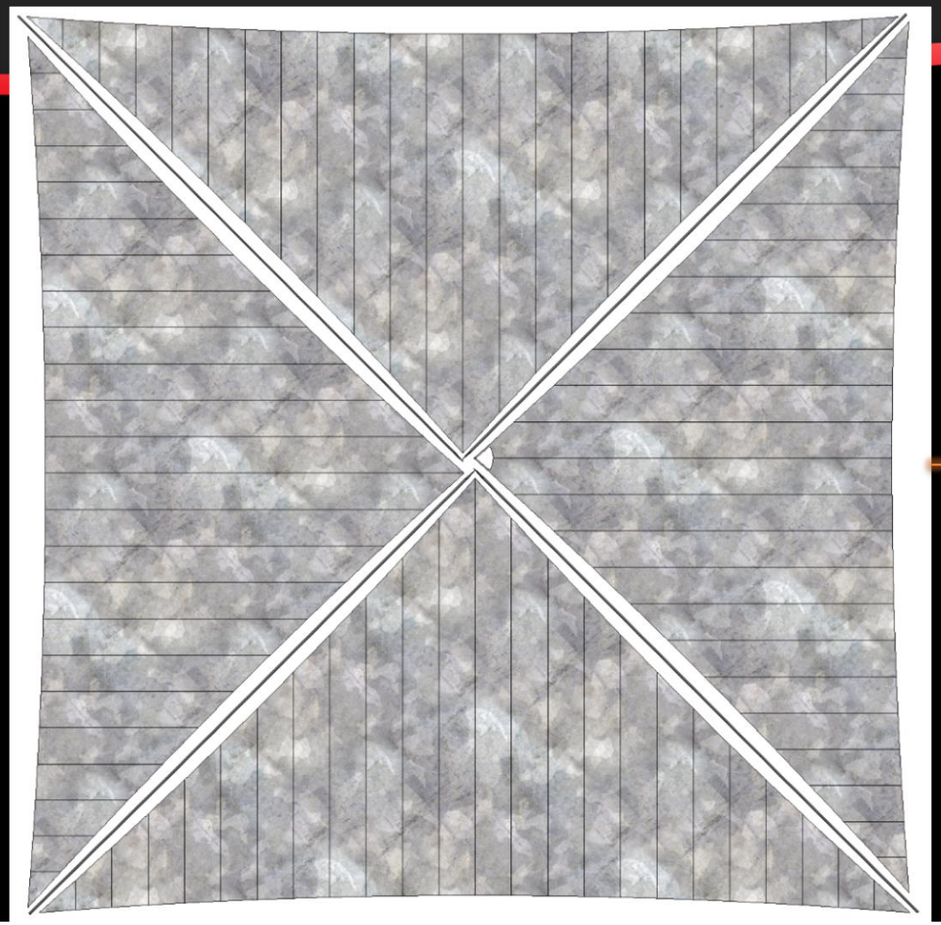
- ~ 7.3 m Trac booms
- 2.5μ aluminized CP-1 substrate
- > 90% reflectivity



NASA Image

NEA Scout Approximate Scale

Deployed Solar Sail



School Bus

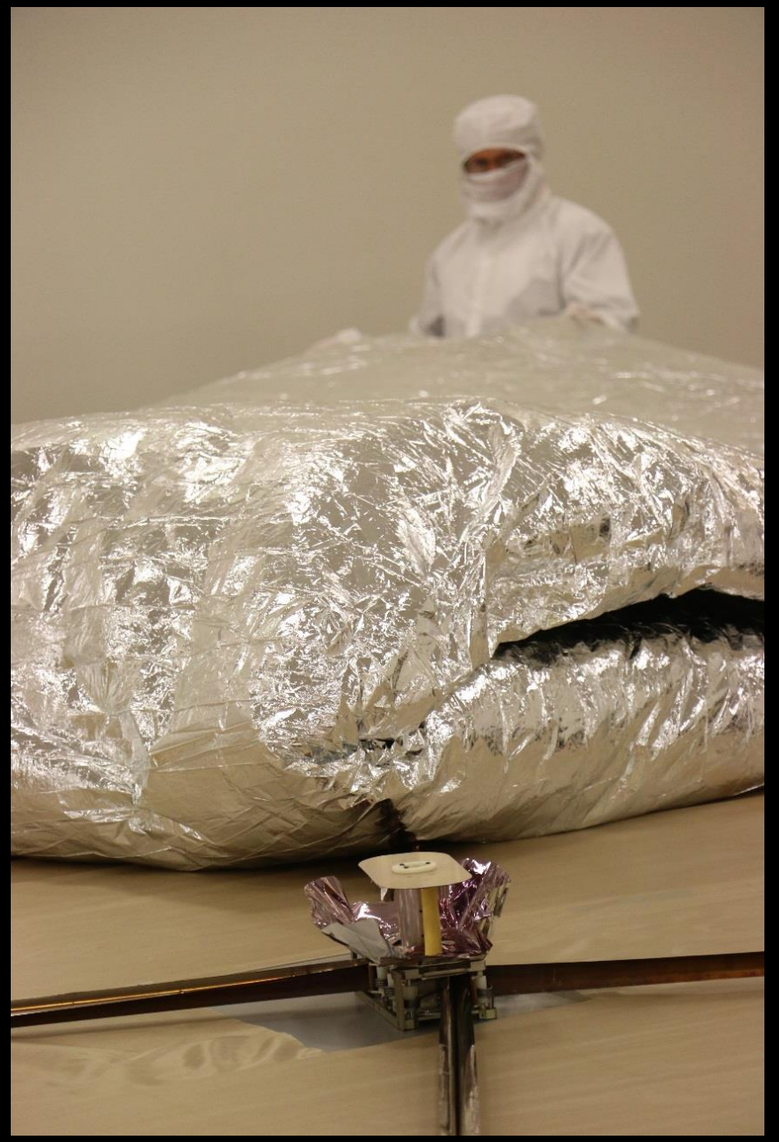
6U Stowed Flight System

Folded, spooled and packaged in here

NASA's Near Earth Asteroid Scout Full Scale Successful Deployment

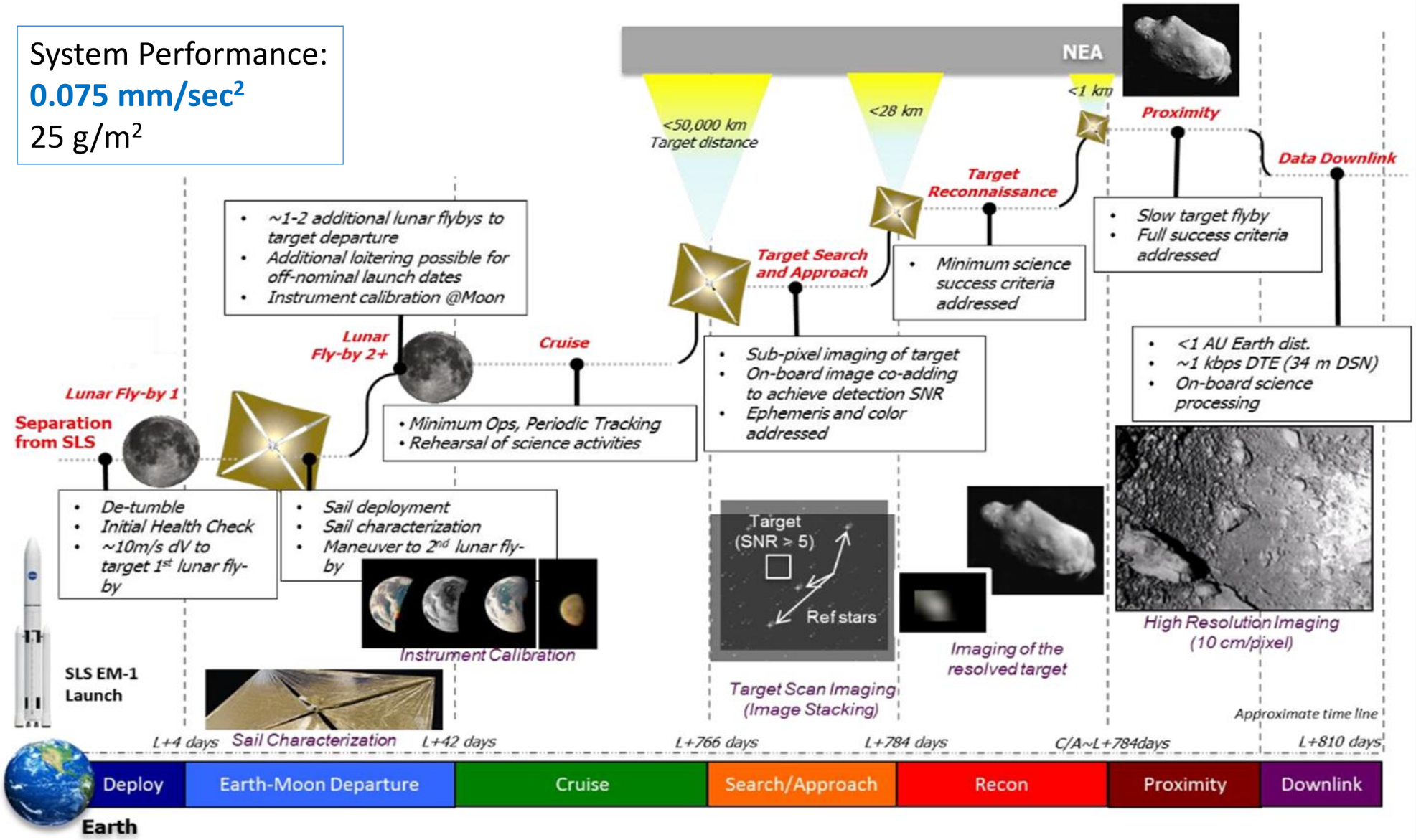
NASA Image

NASA's Near Earth Asteroid Scout Hardware



NEA Scout – Mission Overview

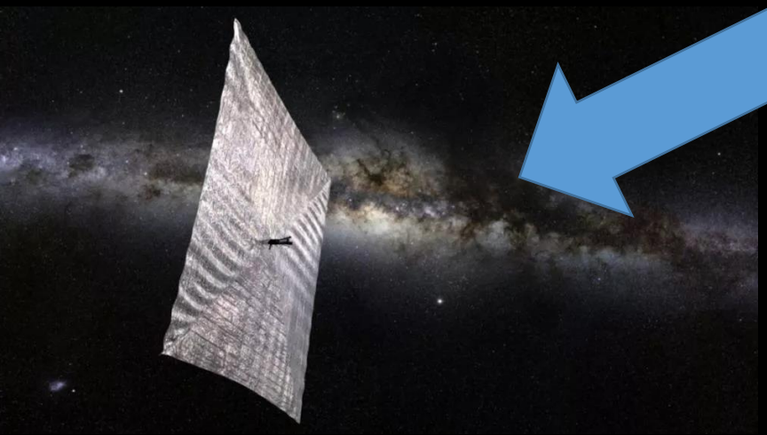
System Performance:
0.075 mm/sec²
25 g/m²



Solar Cruiser Selected for Phase A Concept Study

THIRD STAND ALONE MISSIONS OF OPPORTUNITY NOTICE (SALMON-3)
NNH17ZDA004O-HPTDMO
PROGRAM ELEMENT APPENDIX (PEA) L
2018 HELIOPHYSICS TECHNOLOGY DEMONSTRATION MISSION OF OPPORTUNITY

NOTICE: Amended August 28, 2018. This amendment makes the following changes to this PEA: in Section 9 it is noted that the dates for Notification Proposal, Final PEA Full Proposal Due (NSPIRES), and Final PEA Full Proposal Due (CD ROMs) have been changed. New text is in bold and deleted text is struck through.



- SMD release of the SALMON-3 AO
  - Release of Final SALMON-3 PEA: August 6, 2018
  - **Selections Made: August, 2019**
- Mission of Opportunity Parameters
  - Principal Investigator (PI) managed mission cost cap for all mission phases is $65M
  - 2 Tech Demos selected for a 9 month, $400K (FY19) Phase A concept study (streamlined Class D)
  - 1 or 2 Tech Demos will be selected to continue to Phase B and subsequent mission phases
- The AO solicited Small Complete Mission (SCM) proposals for space flight demonstrations of innovative medium TRL enabling technologies to address Heliophysics Scientific Objectives and Goals in a 15 year timeframe
- Proposal merit determined by magnitude of potentially enabling impacts on future Heliophysics science return in operational missions

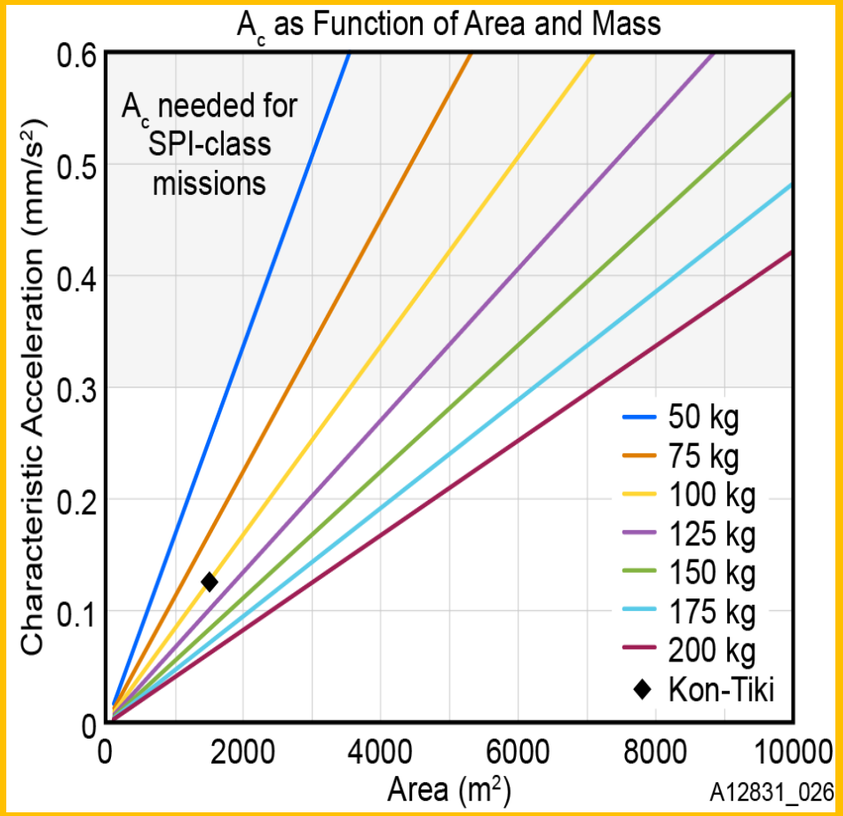
Solar Cruiser

Planned Technology Demonstrations

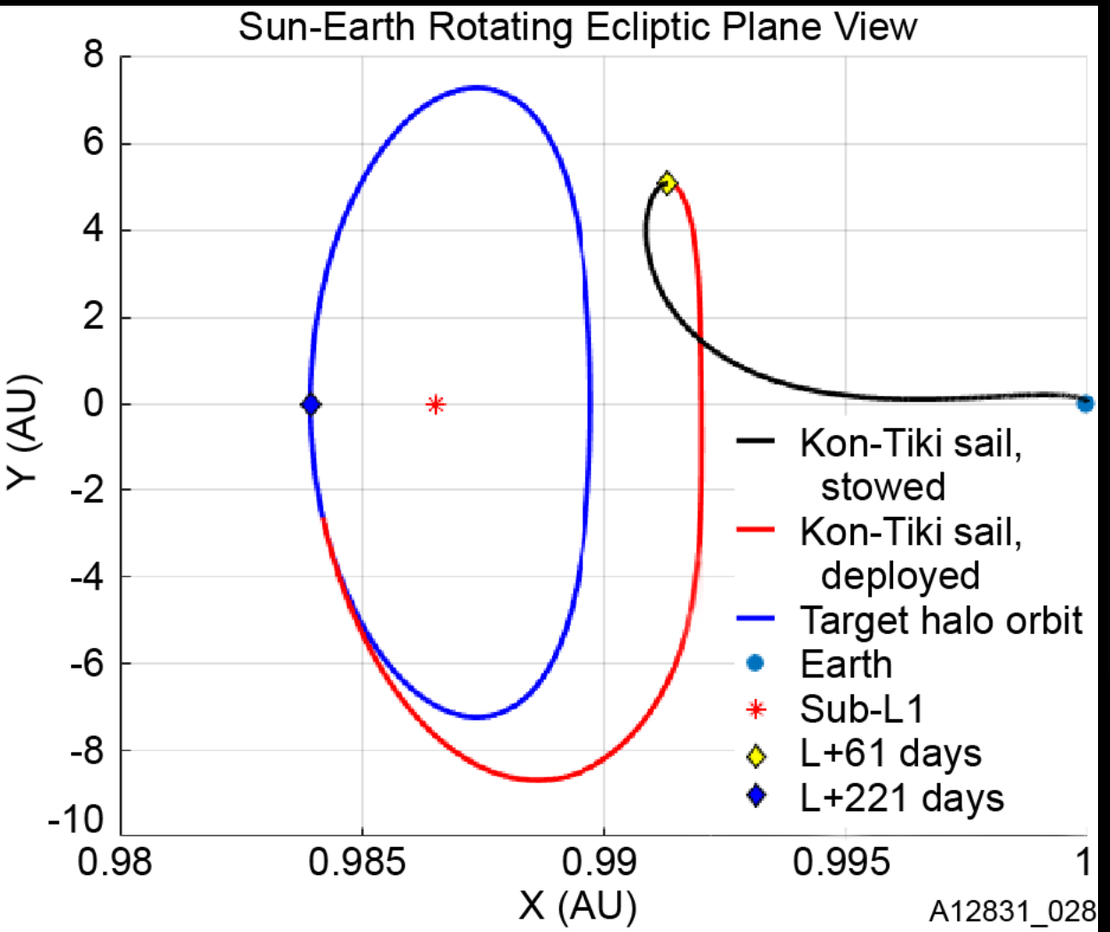
- Solar sail technologies are enabling for Solar Polar Imager (SPI)-class missions (Driving Mission; Decadal Survey emphasis-based selection)
- Miniaturized Imaging technology enabling revolutionary coronal science
- Solar sailcraft platform/imaging instrument compatibility

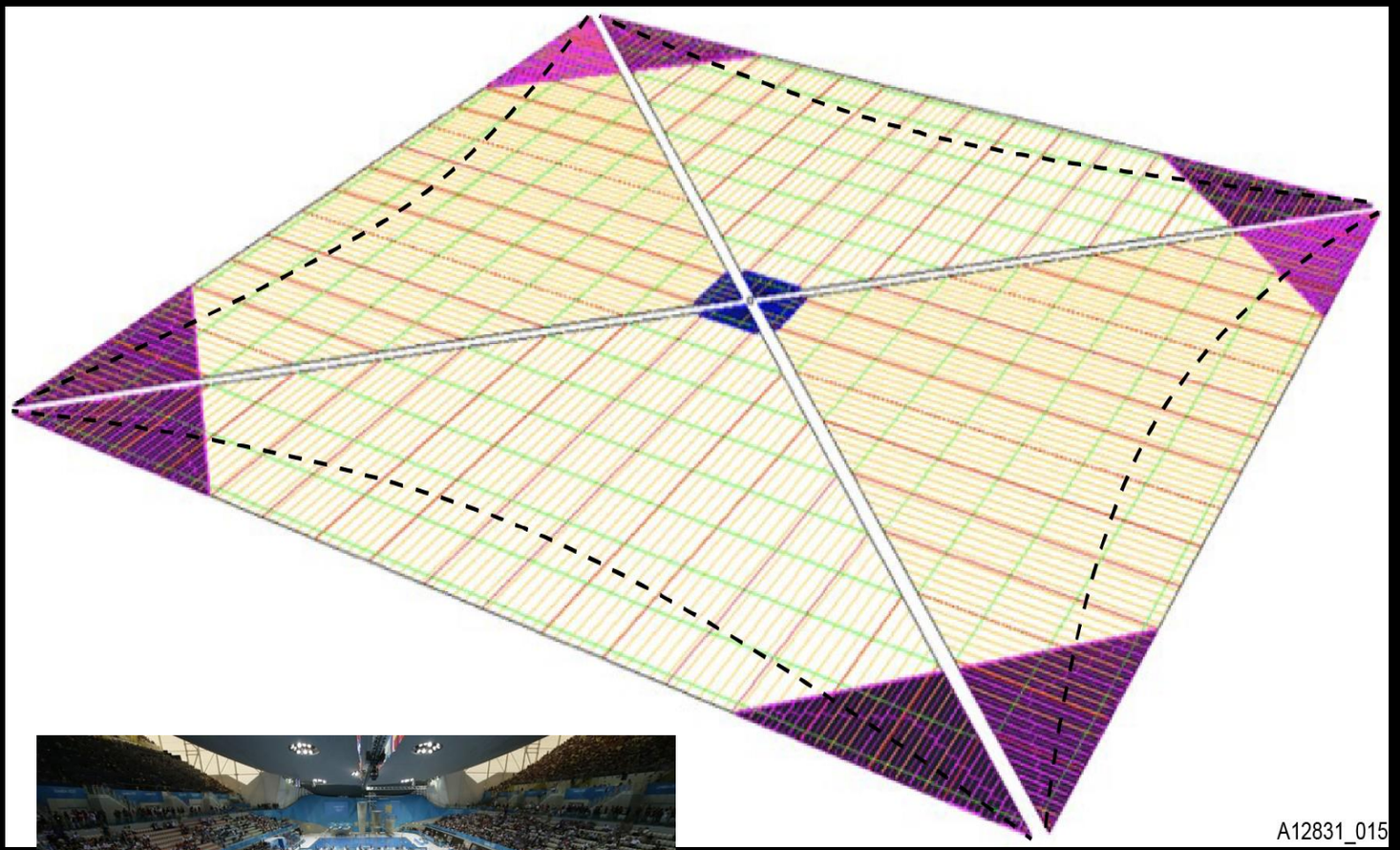
The Kon-Tiki sail:

- 1666 m^2; 3-axis stabilized, boom deployment, 2.5 micron film
- Characteristic Acceleration of 0.17 mm/sec2, 50% of and fully scalable to the required 0.3 mm/sec2 for SPI
- Incorporates embedded Reflectivity Control, LISA photovoltaic, TRAC Boom,™ and fabric technologies
- Directly enables, without scaling, new Heliophysics missions including sub-L1 solar storm warning, intermediate-class solar observation missions.
- A step toward the sail needed for Interstellar Probe



Solar Cruiser Sail and Preliminary Trajectory





Larger than an Olympic Swimming pool: 1666 m²

Interstellar Probe Using a Solar Sail

- 15 AU/year exit velocity
- 1 gm/m2 area1 density (sail material plus support structure)
- Radius of ~200 m
- Total Spacecraft Mass = ~246 kg.
- Sail unfurled at 0.25 AU
- Jettisoned at ~5 AU
- Total AV achieved is ~70 km/s.

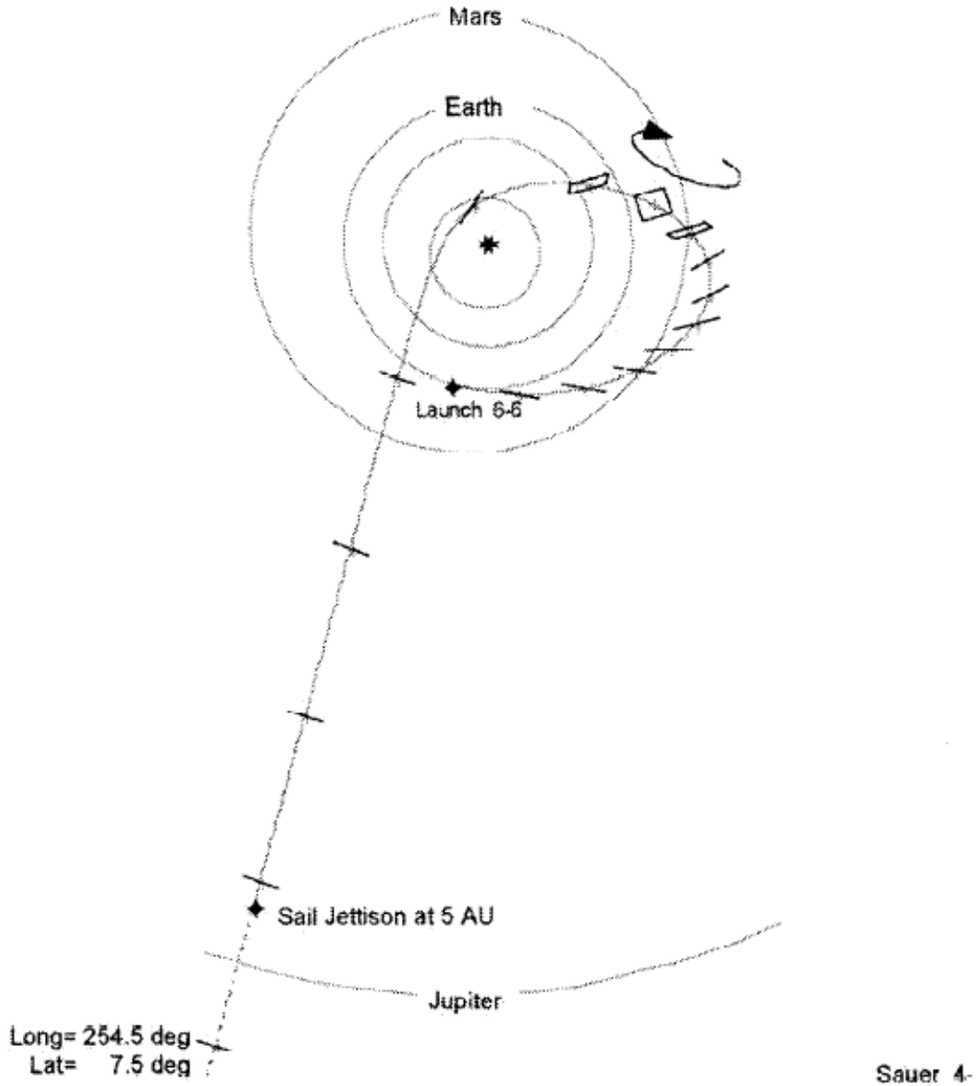


FIGURE 2. Interstellar Probe trajectory using a solar sail to reach a final velocity of 15 AU/year. The trajectory is towards the nose of the heliosphere, the shortest route to the interstellar medium. The orientation of the sail to achieve the proper thrust vector is also shown. The sail is jettisoned at 5 AU when further acceleration is negligible to avoid possible interference with some of the instruments.

Liewer, P. C., et al. "NASA's interstellar probe mission." AIP Conference Proceedings. Vol. 504. No. 1. AIP, 2000.

Solar Sail Characteristic Accelerations For Various Mission Classes

Table 5
Characteristics of solar sailing advanced mission concepts.

	Solar polar mission [79]	Solar storm monitor [96]	Interstellar probe [99]
Minimum Sun distance (AU)	0.48	0.969	0.25
Sailcraft mass (kg)	532	148	246
Sail area (m^2)	23,409	11,946	125,663
Sail loading (g/m^2)	8.4	5.7	1.0
Characteristic acceleration (mm/s^2)	0.4	0.7	3.7
Sailcraft areal density (g/m^2)	22.7	13.3	2.5
Lightness number	6.7E−02	1.0E−01	6.1E−01

NEA Scout = ~0.07 mm/s^2
Solar Cruiser = 0.17 mm/s^2

Interstellar Probe Goal = 2.0 - 3.7 mm/s^2

Conclusions

- Solar Sail propulsion has been demonstrated and is maturing
- The pace is much slower than originally envisioned
- NEA Scout and Solar Cruiser will significantly advance the state of the art, but are not sufficient for an Interstellar Probe Mission
  - Spacecraft and science instrument masses have declined, decreasing the performance increase required from solar sails
  - Solar sail size, mass, and performance must increase by several factors, perhaps an order of magnitude