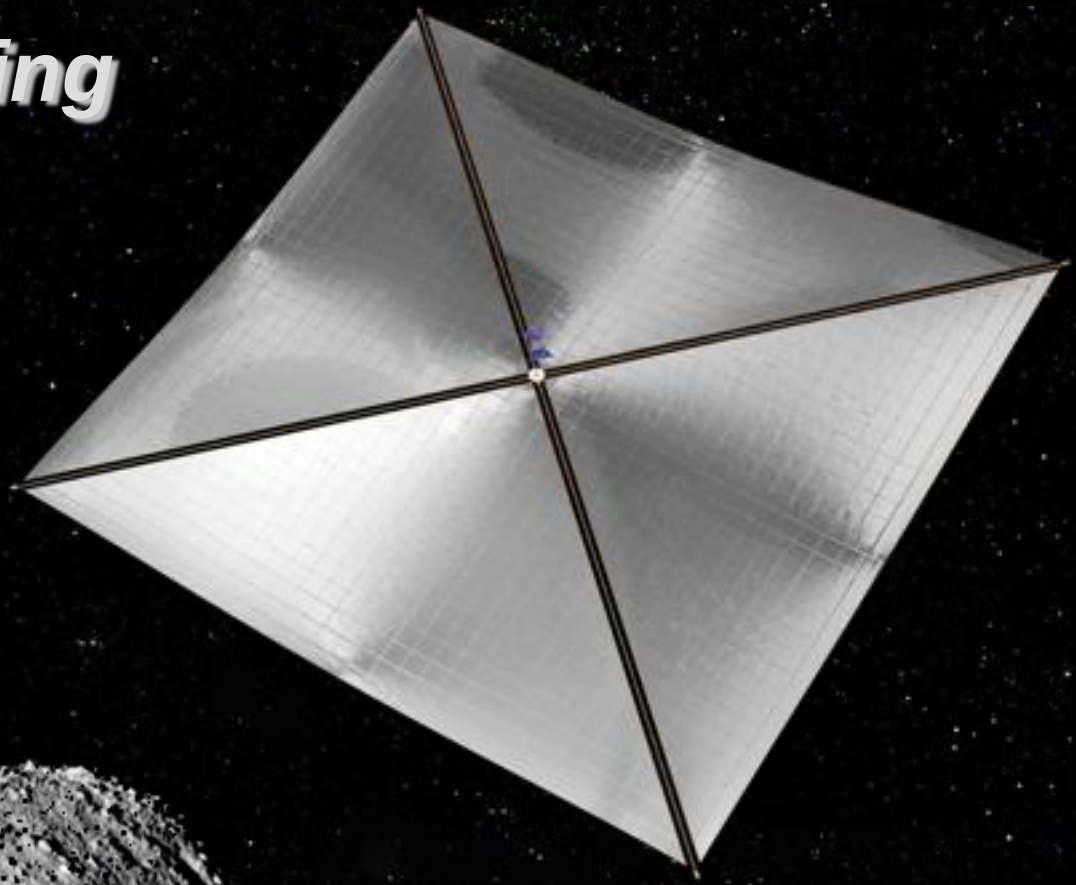
Multiple NEO Rendezvous Using Solar Sails



Les Johnson
MSFC Advanced Concepts Office

Overall Mission Concept

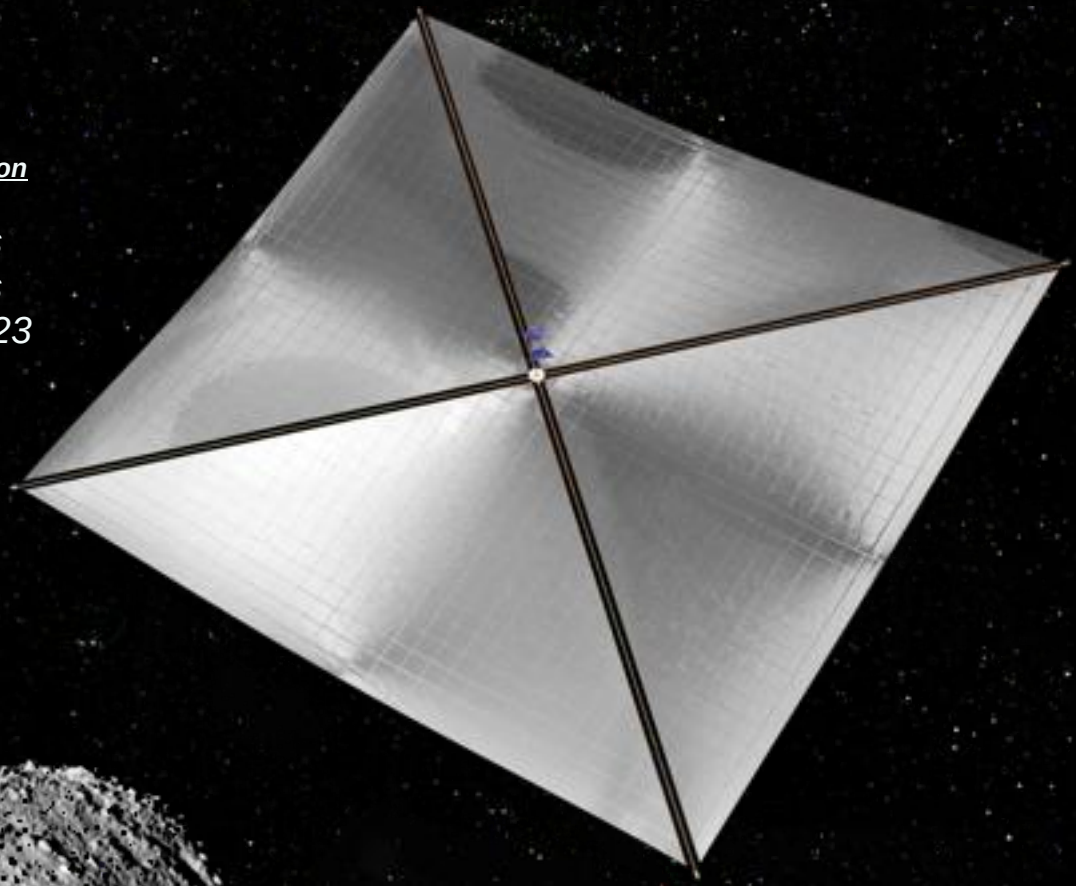
- **Assess the feasibility of using solar sail propulsion to enable a robotic precursor that would survey multiple Near Earth Objects (NEOs) for potential future human visits**
- **Ground Rules**
  - The solar sail should be the only technical risk
    - Baseline the sail technology demonstrated to TRL 5/6 by the NASA In-Space Propulsion Technology Project and selected for flight by NASA OCT as a Technology Demonstration Mission
    - Use State-Of-the-Art (SOA) instruments
    - Use only flight-proven spacecraft systems and hardware
  - Single spacecraft will rendezvous with and image 3 NEOs within 6 years of launch

Solar Sail Asteroid Rendezvous Mission:

Departure: *Aug 2017*

Candidate asteroids visited:

NEO	***Date***	***Observation Period***
1999 A010	*Mar 2019*	*35 days*
Apophis	*Dec 2021*	*30 days*
2001 QJ142		*July 2023 30 days*

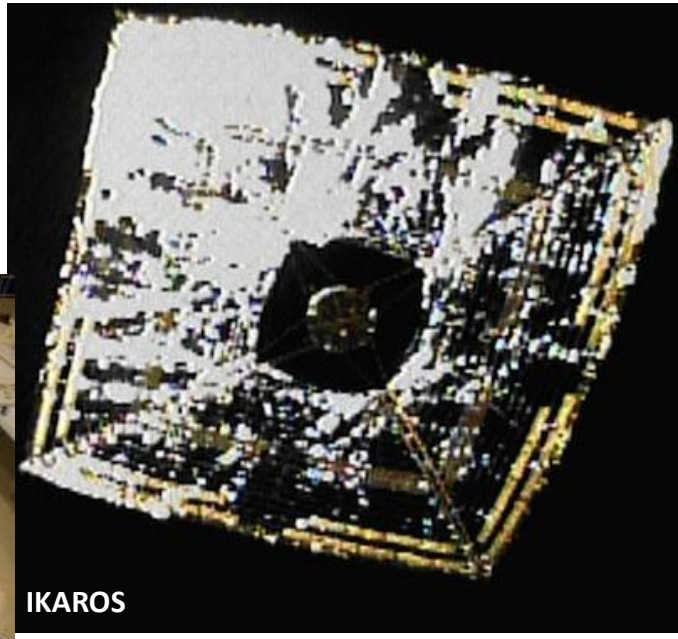


Spacecraft mass at destination:
228.4 kg

Cost:
$175M, plus launch vehicle and ops

Launch: Athena II

Solar Sail Propulsion Technology Status



- Two 20-m system ground demonstrations (ATK and L'Garde) designed, fabricated, and tested under thermal vacuum and flight-like conditions - 2005
- IKAROS (JAXA) successfully flying in deep space – 2010
- NanoSail-D flew in orbit (NASA MSFC) - 2010
- L'Garde funded by NASA OCT to demonstrate deep space solar sail propulsion (*Sunjammer*) as a Technology Demonstration Mission in ~2014

L'Garde 20-m System Ground Demonstrator (SGD)

Sail Membrane

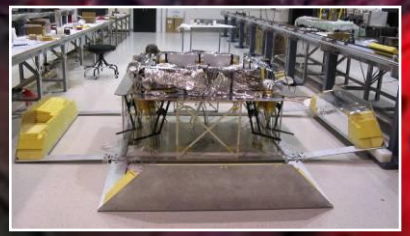
Inflatable Beams

Tip Vane

Tip Mandrel

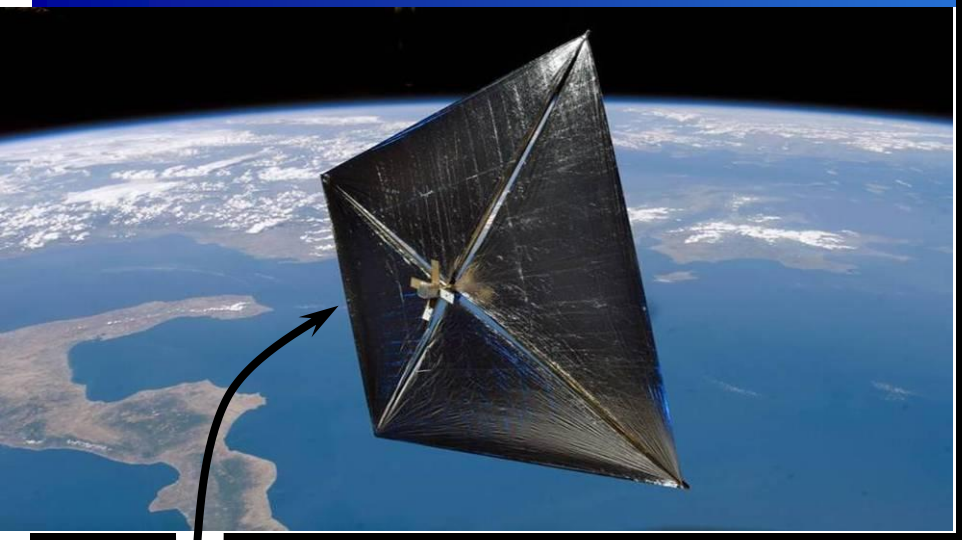
Vane Mechanism

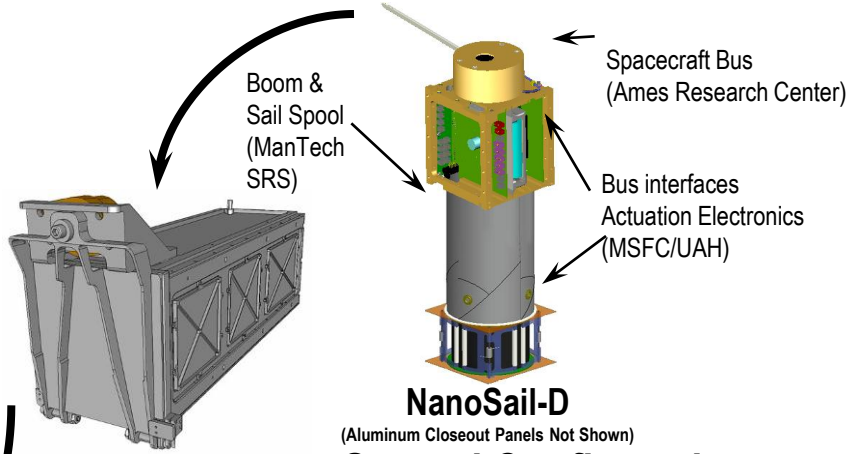
20-M SGD



Stowed Configuration

NanoSail-D Mission Configuration

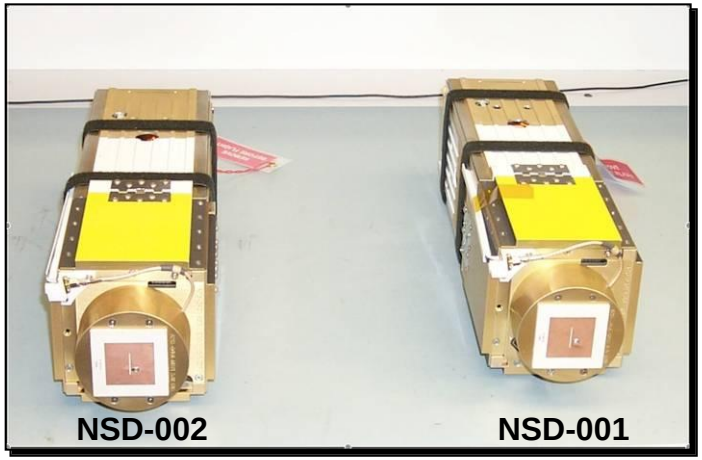




PPOD Deployer
(Cal-Poly)

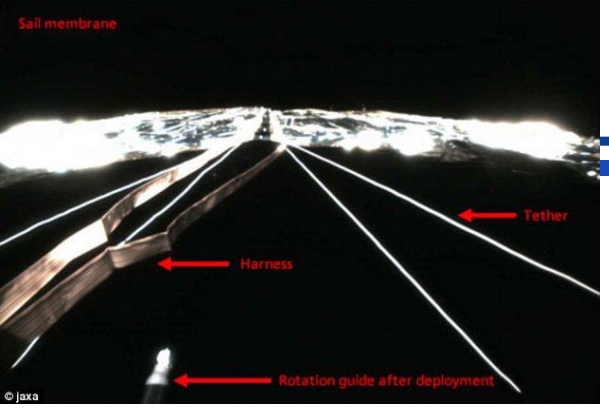
NanoSail-D
(Aluminum Closeout Panels Not Shown)
Stowed Configuration

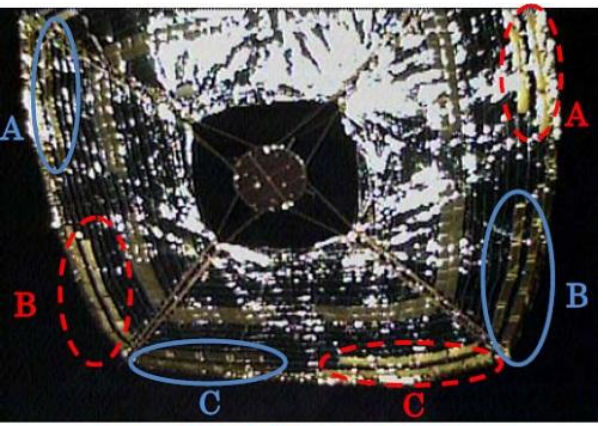
Deployed by FastSat Spacecraft

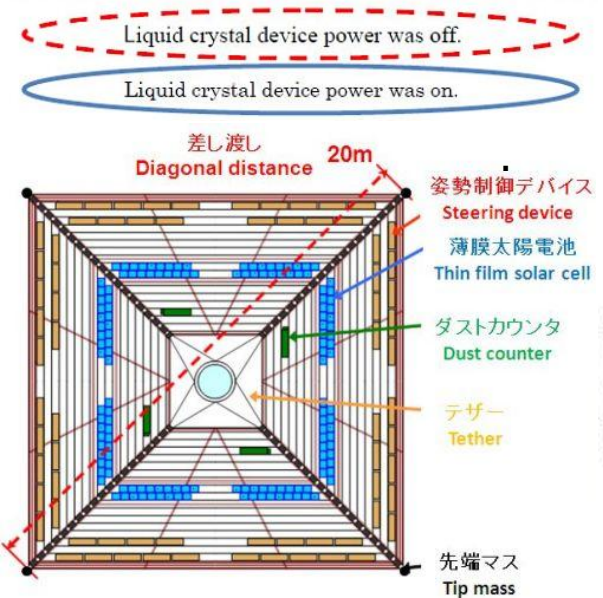


- 3U Cubesat: 10cm X 10cm X 34cm
- Deployed CP-1 sail:10 m^2 Sail Area (3.16 m side length)
- 2.2 m Elgiloy Trac Booms
- UHF & S-Band communications
- Permanent Magnet Passive Stabilization

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

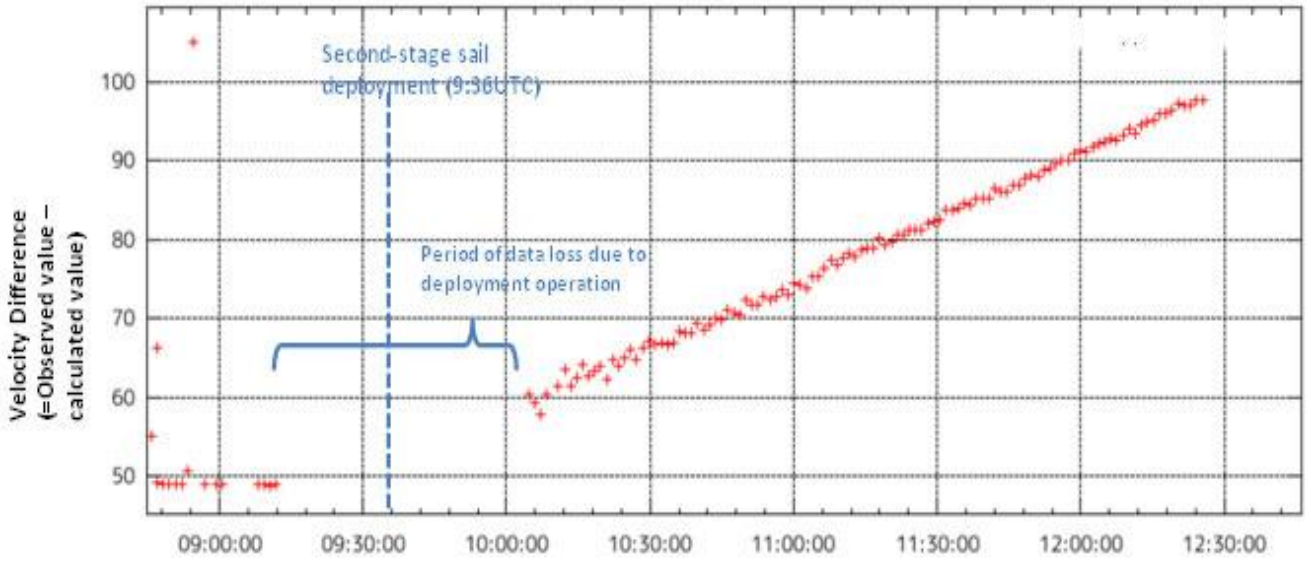




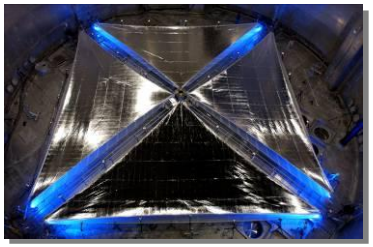


- IKAROS was launched on May 21, 2010
- The Japan Aerospace Exploration Agency (JAXA) began to deploy the solar sail on June 3.
- IKAROS has demonstrated deployment of a solar sailcraft, acceleration by photon pressure and attitude control
  - Deployment was by centrifugal force
  - Sail membrane is 7.5 mm thick

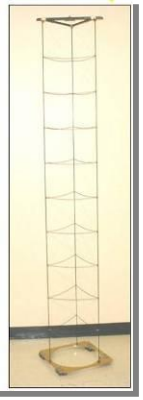
Configuration / Body Diam.	1.6 m x Height 0.8 m (Cylinder shape)
Configuration / Membrane	Square 14 m and diagonal 20 m
Weight	Mass at liftoff: about 310 kg



TRL Assessment Methodology

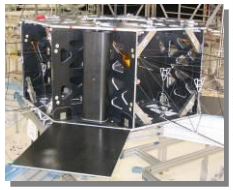


ATK 20M System

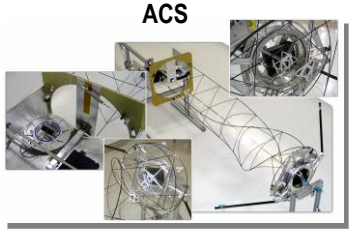


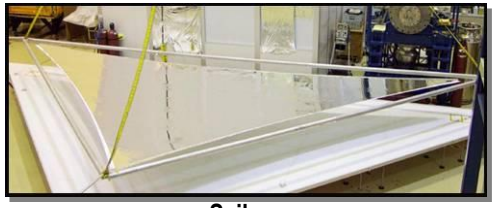
Masts

Central Structure



ACS





Sails

System	Subsystems	Components
ATK 20M Quadrant	Sails	Materials & Coating
		Deployment Sequencers
		Grounding Straps
		Compliant Border
	Masts	Battens
		Longerons
		Diagonals
		Corner Group
		Halyards
		Lanyards
		Deployment Motors
	ACS	Translating Masses
		Motors/ Control Mechanisms
		Spreader Bars
		Mast Tip Mechanism
		Control Wiring
		Software
	Central Structure	Carrier Assembly
		Doors & Actuators
		S/C Interface
		Sail Drum

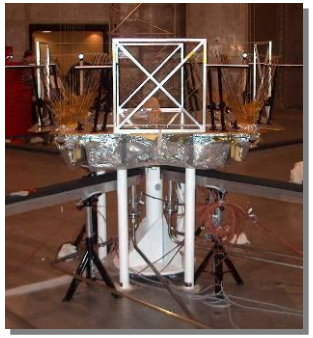
ACS
Central Structure
Sails
Masts/Beams
ATK
L'Garde

Identify Solar Sail Major Subsystems → Identify Subsystem Components → Assess Component/ Subsystem TRL (3-5) → Assess System TRL (6)

L'Garde 20M System

Beams

Central Structure

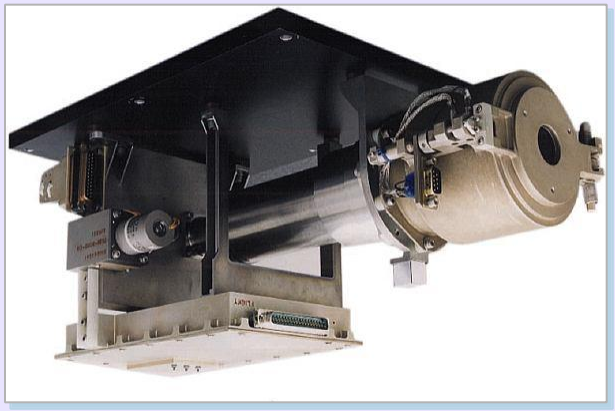


ACS

Sails

System	Subsystems	Components
L'Garde 20M System	Sails	Materials & Coatings
		Integrated Ripstop
		Grounding Straps
		Stripped Net
	Beams	Boom & Rigidization System
		Inflation Subsystem
		Heater Wires
		Insulation
		End Caps
		Spreader System & Rings
		Cat's Cradle
	ACS	Tip Vanes
		Vane Cant Mechanism
		Vane Rotation Mechanism
		Control Wiring
		Software
	Central Structure	Carrier Assembly
		Doors & Actuators
		S/C Interface

NEO Spacecraft Camera: NEAR MultiSpectral Imager



NEAR multispectral imaging system (MSI)

- Consists of optical system and passively cooled Si CCD focal plane unit.
- Designed to take images at various wavelengths of 433 Eros from orbit and fly by of 253 Mathilde
- Also provides optical navigation for spacecraft

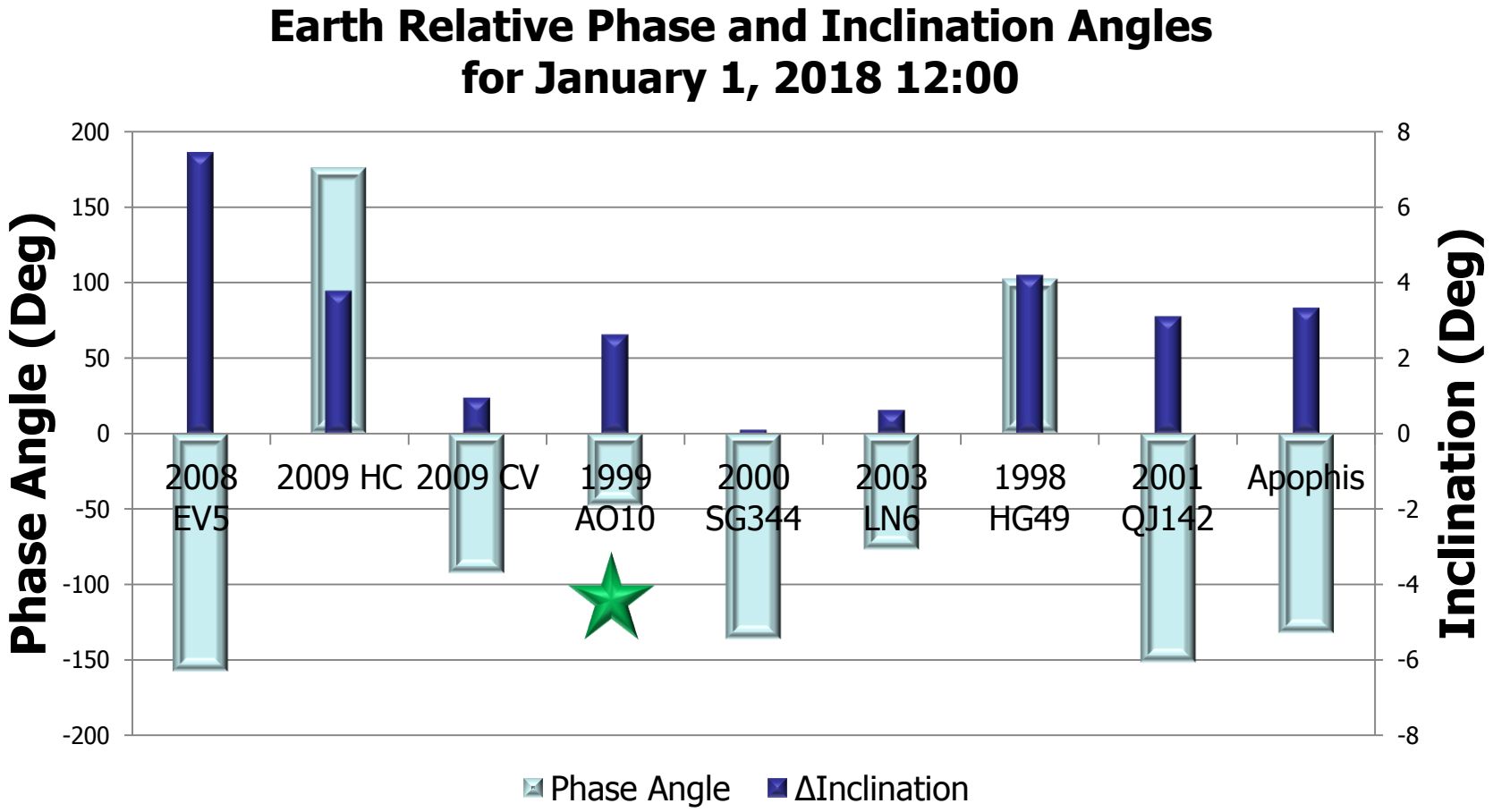
Scientific objectives:

- Map asteroid morphology and surface composition
- Determine overall size, shape, and spin characteristics.

Specifications:

Mass: Camera head 5.05 kg; Supporting electronics, 4.5 kg
Power: Camera head 2.16W; Electronics, 10.86 W
Detector: Si CCD; Thompson-CSF TH7866
Field of view: 2.25° X 2.9°, in 244 X 537 pixels = 3.9 X 5.1 km from 100-km distance
Resolution: 9.5 X 16.1 m from 100-km distance
Exposure time: to 999 ms in 25-ms increments, manual or automatic
Wavelength range: 400-1100 nm
Filter wavelengths: 1 broadband filter, 7 spectral filters at 450, 550, 760, 900, 950, 1000, and 1050 nm
Data Character: 12-bit data, with three-tiered compression menu.

First Asteroid Selection

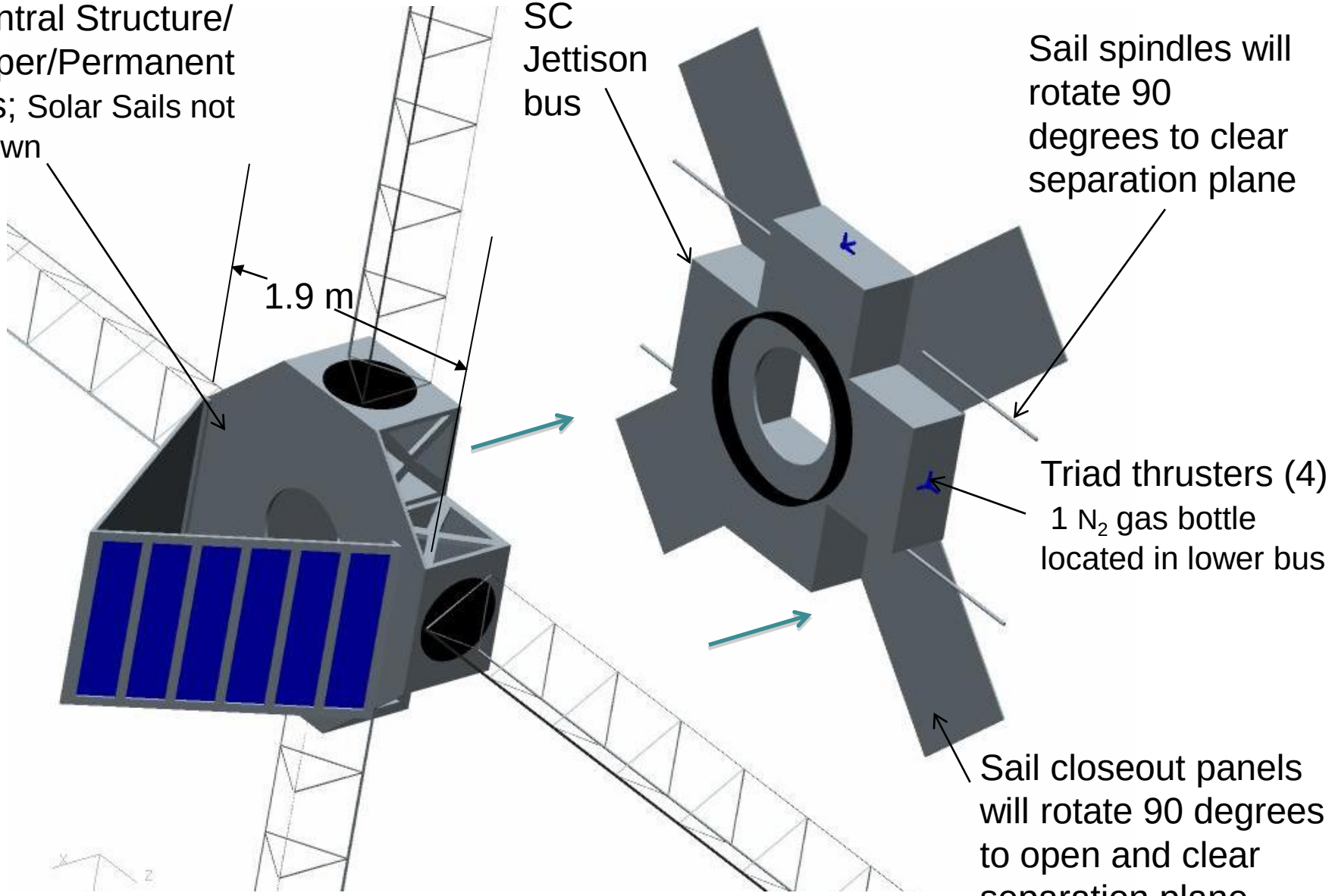


Long Term Mission Results

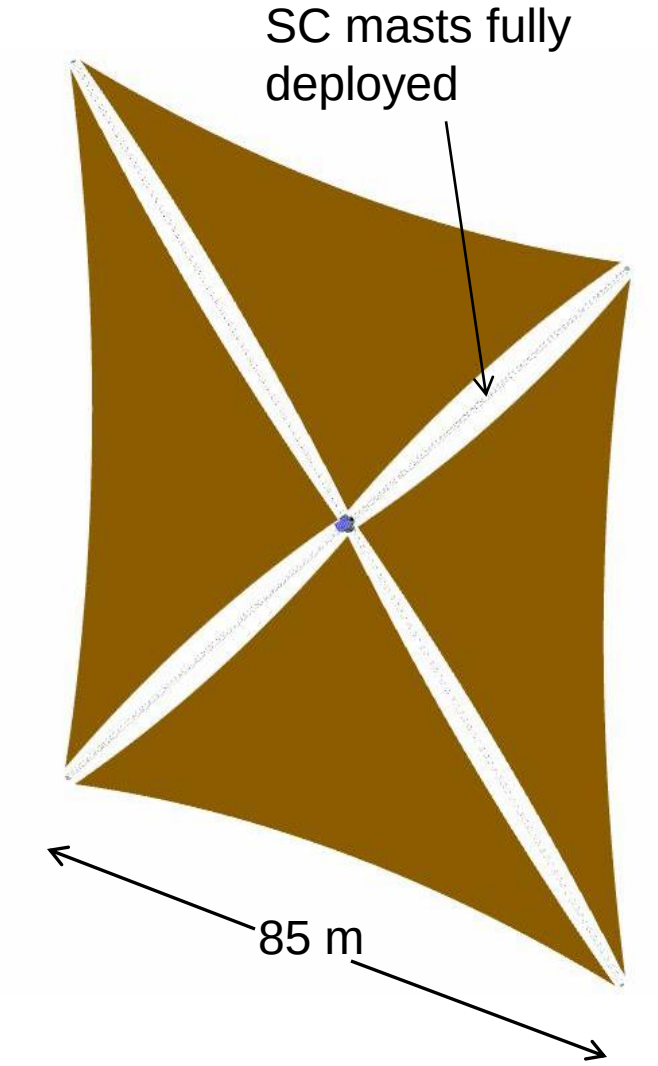
- **Time of Transfer (Rough Estimate)**
  - From Earth to 1999 AO10 1.54 Years
  - Observation 35 Days
  - From 1999 AO10 to Apophis 2.5 Years (Conservative)
  - Observation 30 Days
  - From Apophis to 2001 QJ142 1.7 Years (Conservative)
  - Observation 30 Days

- **Total Time of Flight ~6 Years**
  - As observation time increases, the optimal selection of asteroids change
  - With refinement, total time will decrease

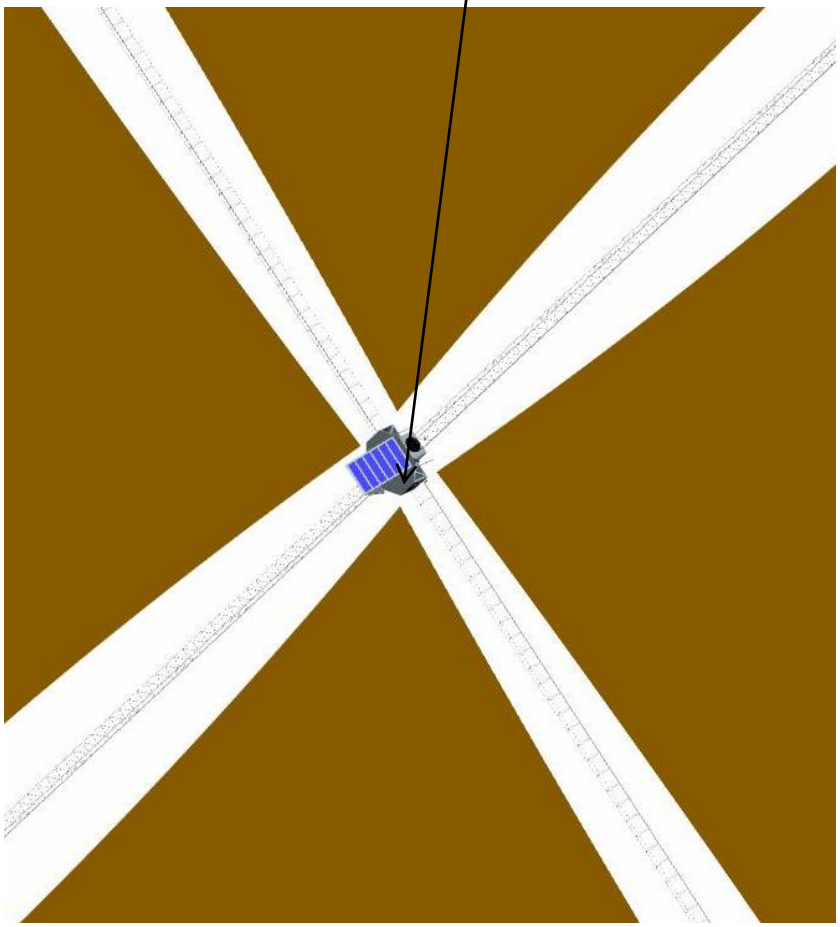
NEO SC Lower Bus Jettison



NEO Solar Sail SC Deployment



Close-up forward view of SC bus with masts extended



Ground Rules and Assumptions

1. The NAFCOM (NASA/Air Force Cost Model) was used to estimate the Solar Sail spacecraft costs herein.
2. Messenger was used as the analogy.
3. Cost estimate was based on ATK Solar Sail system ground demonstrators
4. Technical data and mass properties were supplied by the Solar Sail proposal team.
5. All Costs are estimated in Fiscal Year (FY) 2011 dollars in millions based on NASA Inflation tables.
6. System Test Hardware Costs represent proto-flight approach. All applicable system integration (wrap) costs represent the wrap cost for one test unit.
7. Costs associated with the DDT&E effort encompass the period from the beginning of full scale development through factory checkout of test vehicle.
8. Individual subsystem totals contain all hardware costs and engineering and manufacturing labor costs charged to that subsystem.
9. Fee is calculated at 10% of the spacecraft.
10. Program Support (Level One PM, SE&I, and S&MA) cost are calculated at 20% of the spacecraft.
11. Vehicle Integration costs are calculated at four percent of the spacecraft.
12. Reserves are set at 30%.
13. Launch and operation cost are not included.

Spacecraft Costs (2011$ in Millions)

WBS ITEM	DDT&E	Flight Unit	Total
Subsystem Level	36.1	40.7	76.8
Structures	7.5	1.5	9.0
Electrical Power	2.3	1.9	4.2
Communications	6.2	3.7	9.9
Command & Data Handling	1.8	1.2	3.0
Guidance & Navigation	4.6	2.4	7.0
Reaction Control	1.7	3.3	5.0
Camera	2.0	1.7	3.7
Sail Propulsion System	10.0	25.0	35.0
System Level	13.7	7.6	21.3
Integration, Assembly & Checkout	0.5	1.0	1.5
Systems Test Operations	1.5	0.0	1.5
Ground Support Equipment	4.0	0.0	4.0
Systems Engineering & Integration	3.9	4.4	8.3
Program Management	2.0	2.2	4.2
Launch & On-Orbit Support	1.8	0	1.8
Subtotal	49.8	48.3	98.1
Vehicle Integration	2.0	1.9	3.9
Fee	5.2	5.0	10.2
Program Support	11.4	11.1	22.5
Sub-total	68.4	66.3	134.7
Reserves (30%)	20.5	19.9	40.4
TOTAL	89.0	86.2	175.2