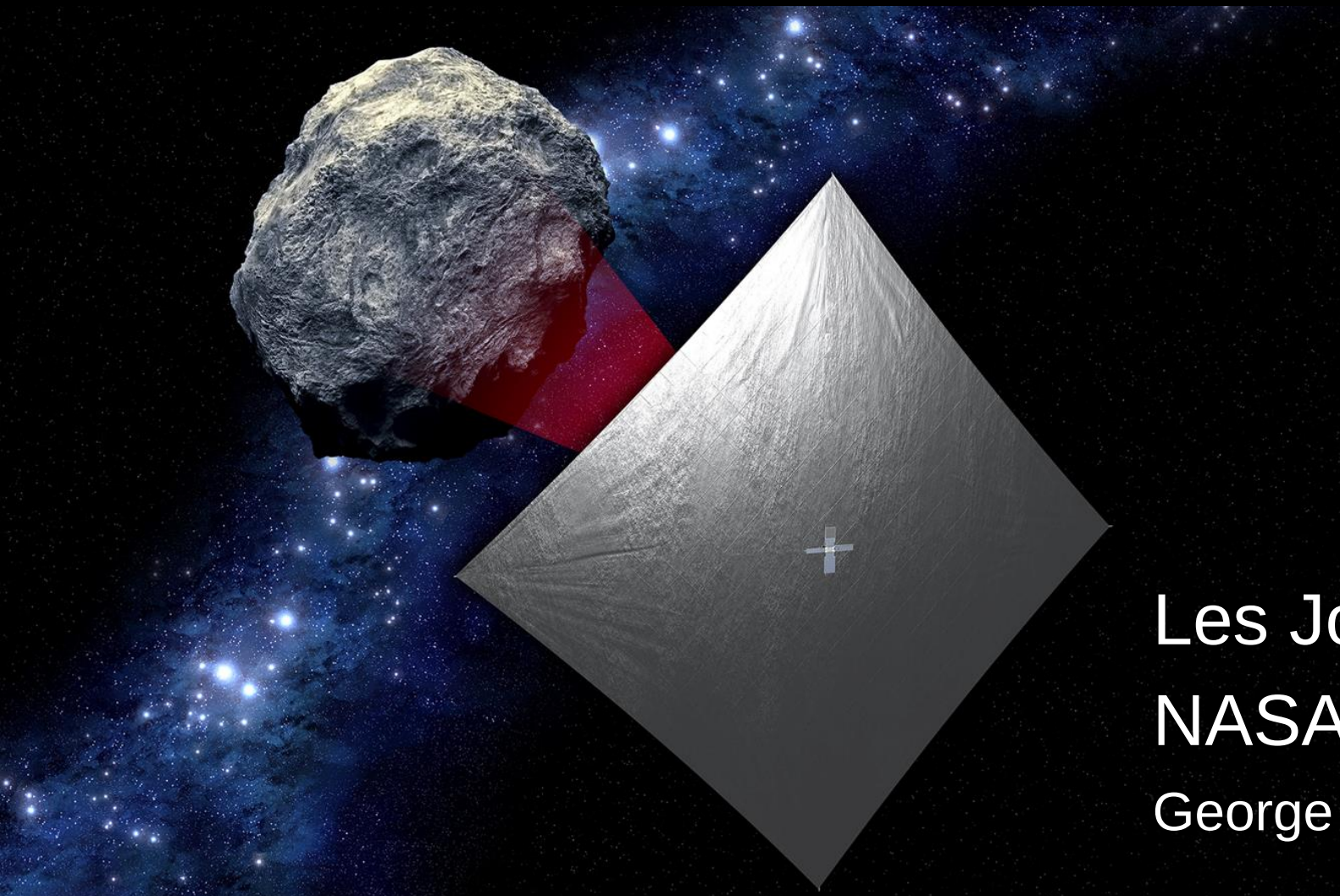
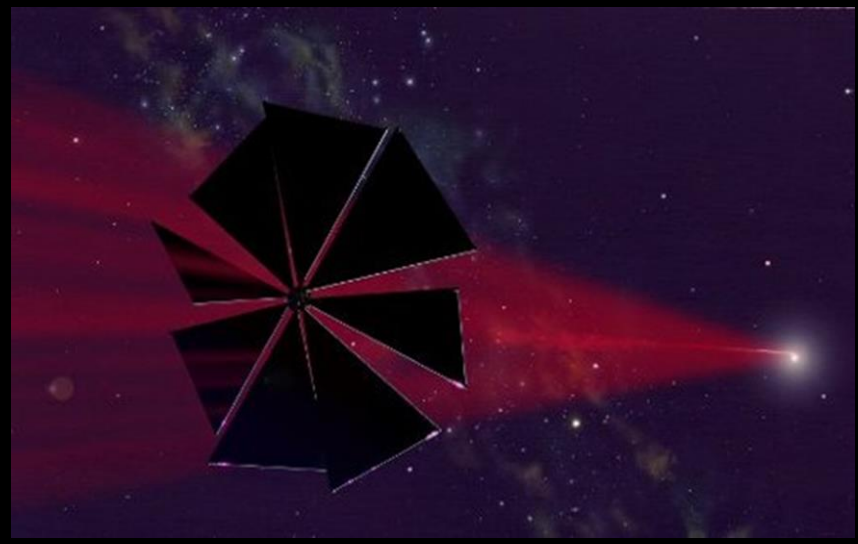
Solar Sails



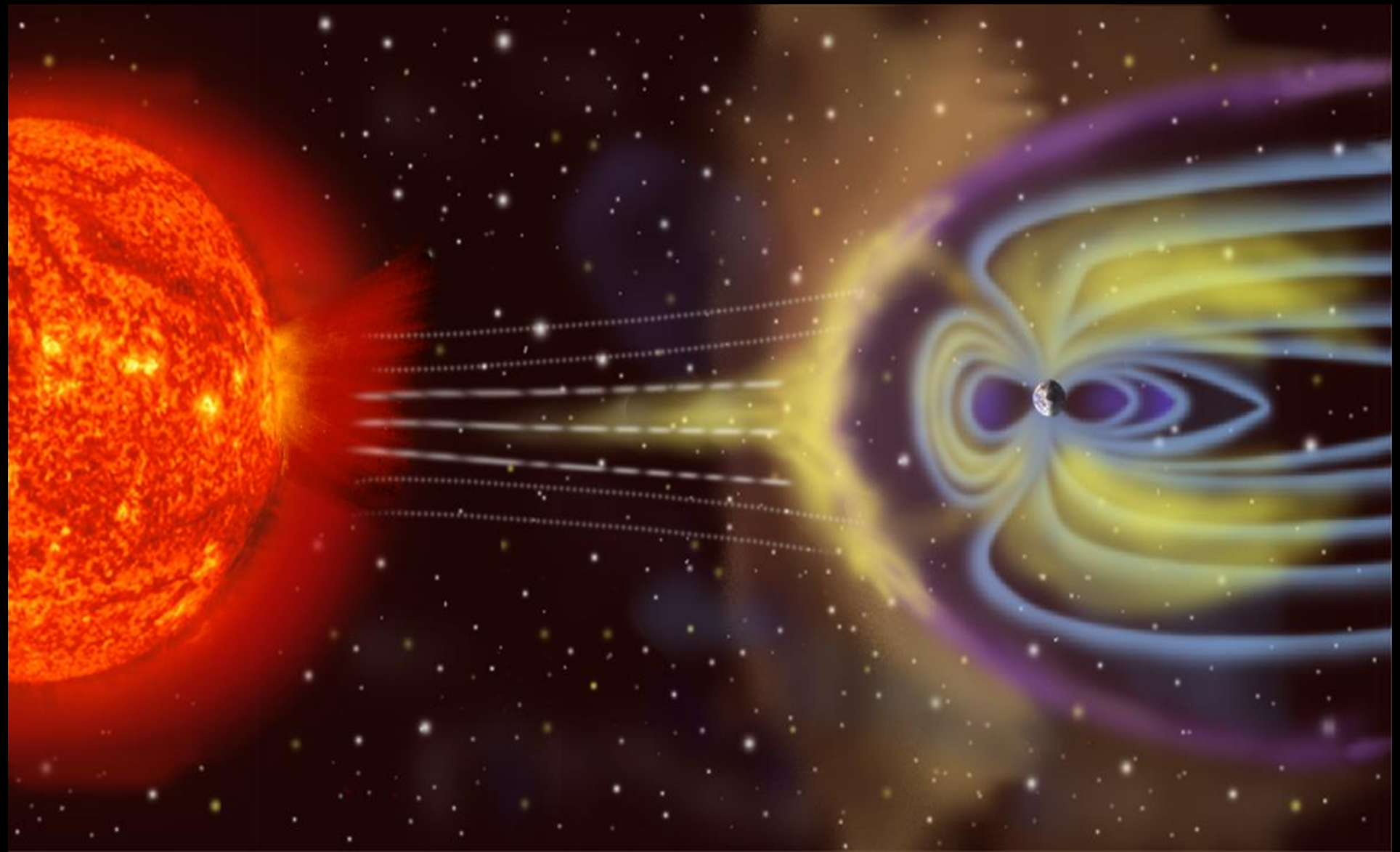


Les Johnson
NASA
George C. Marshall Space Flight Center

We tend to think of space as being

big and empty…

Space Is NOT Empty. Can we use the environments of space to our advantage?

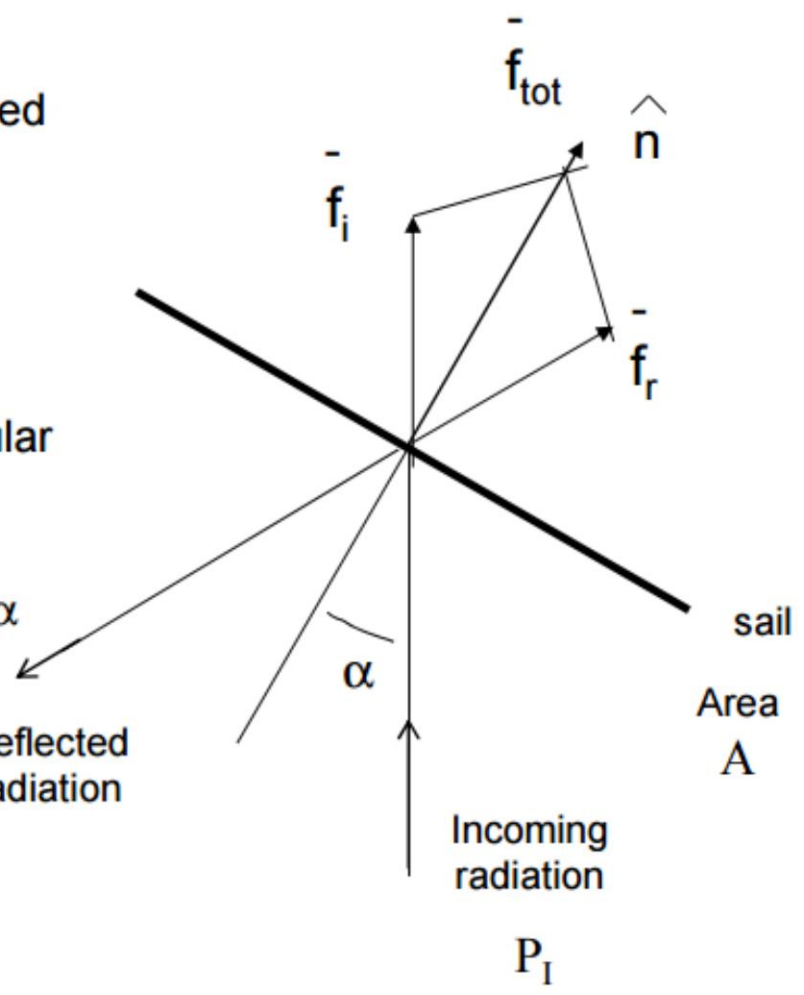


Just As Sailing Ships Can Use the Momentum of the Wind

Spacecraft Can Use the Momentum of Sunlight

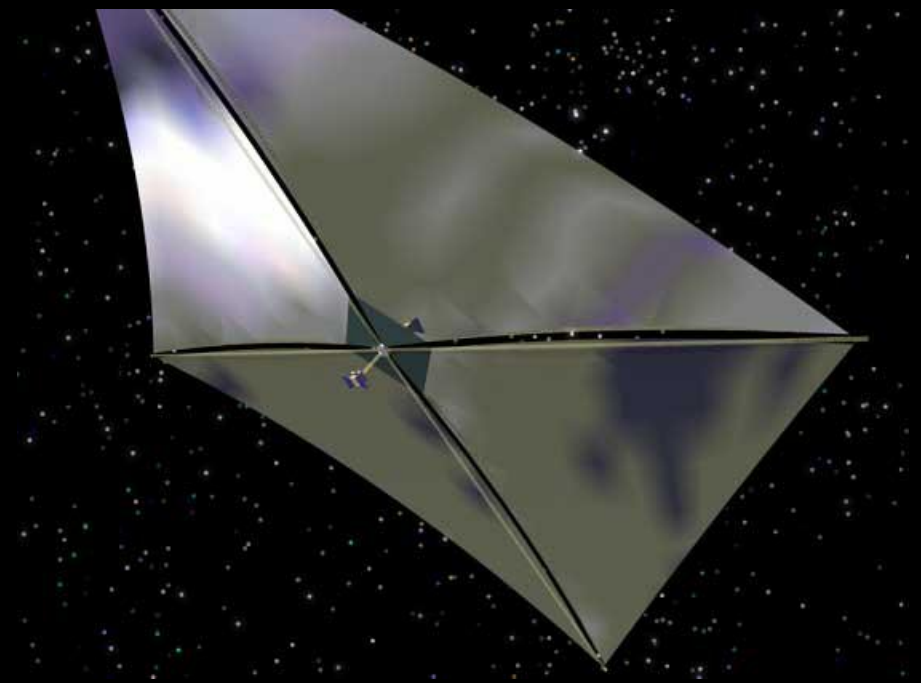
Photons Have Momentum

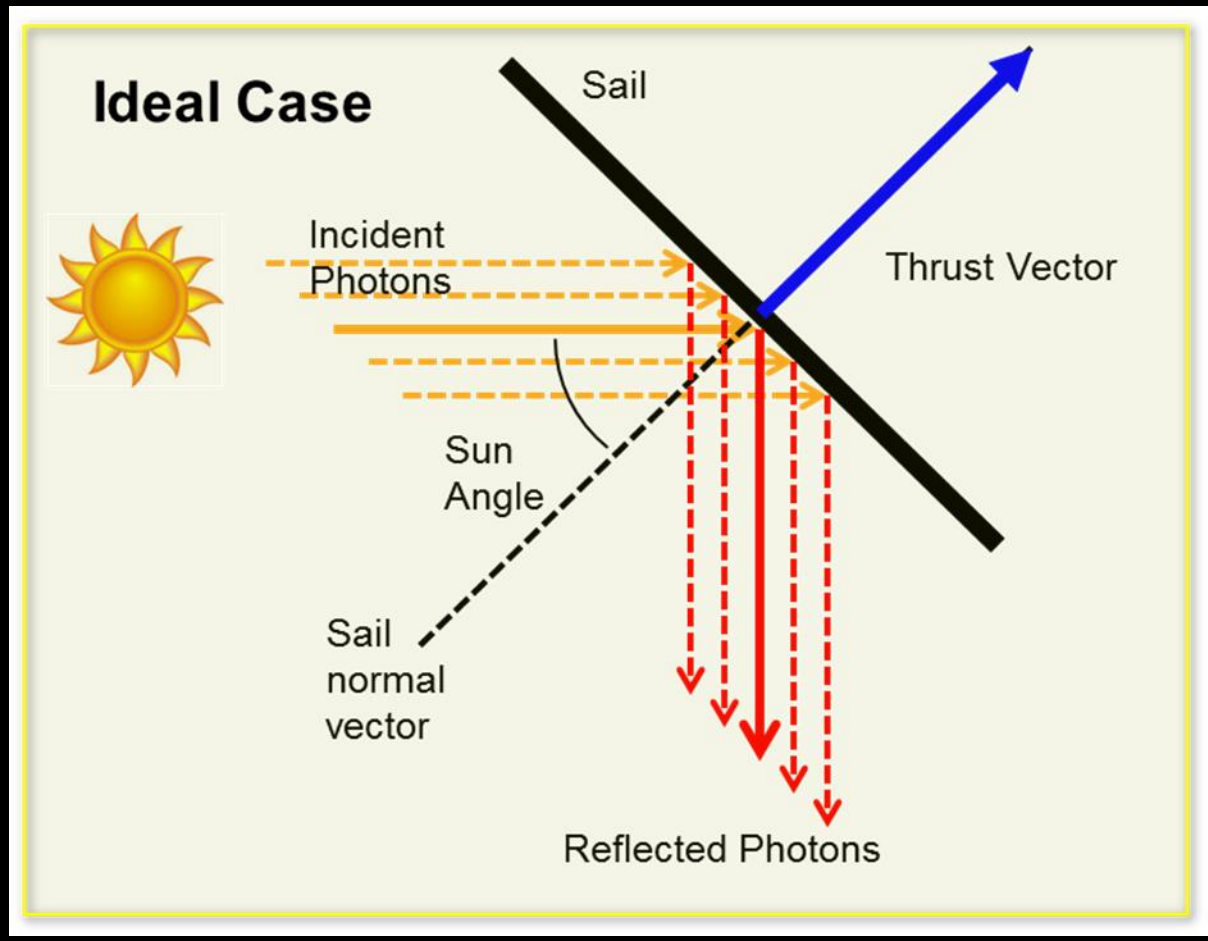
- **Photons carry Momentum**
  - $\rho = h\nu/c$
    - h = Planck's, ν = frequency, c = speed of light
- **Force generated on Reflective Surface**
  - Resultant force approximately perpendicular to surface
    - The bigger the surface, the more the force
  - Can "steer" sail by changing pitch angle α
- **Small, but potentially Constant Acceleration**
  - Potentially unlimited "delta V"
  - Allows some otherwise impossible orbits



Yes we can! With solar sails…

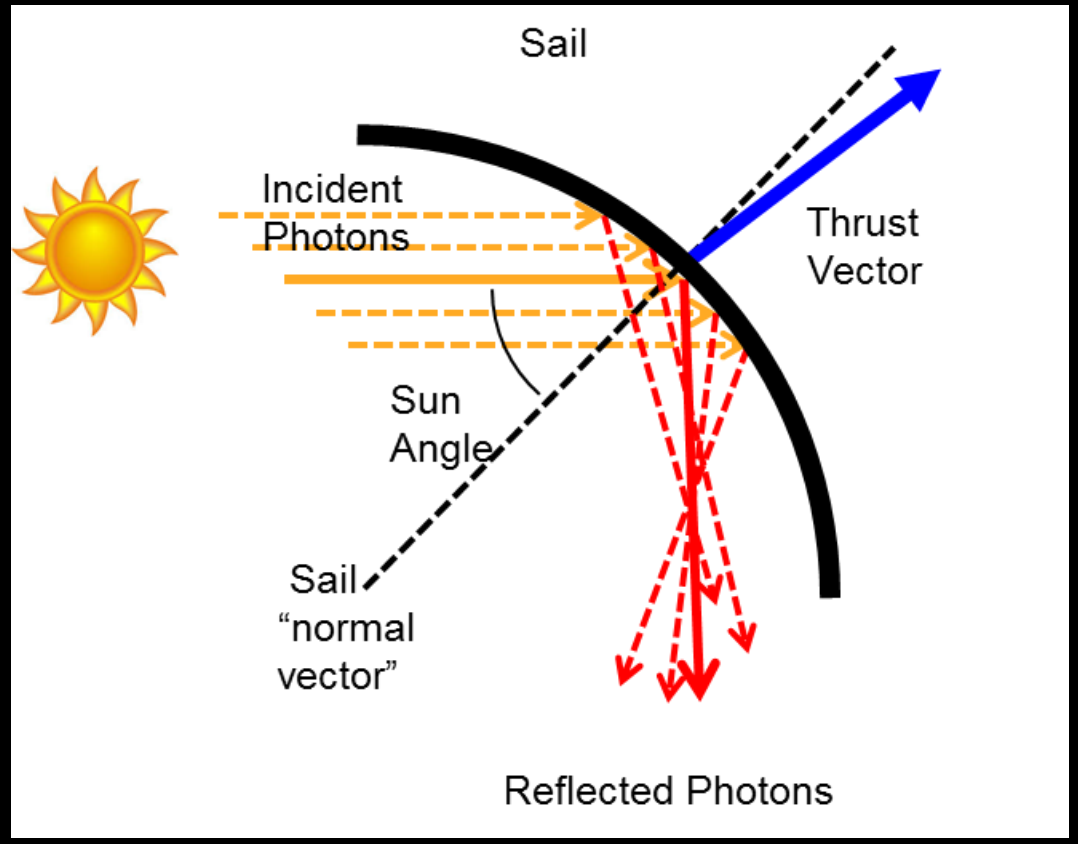
Solar sails use photon “pressure” or force on thin, lightweight, reflective sheets to produce thrust.

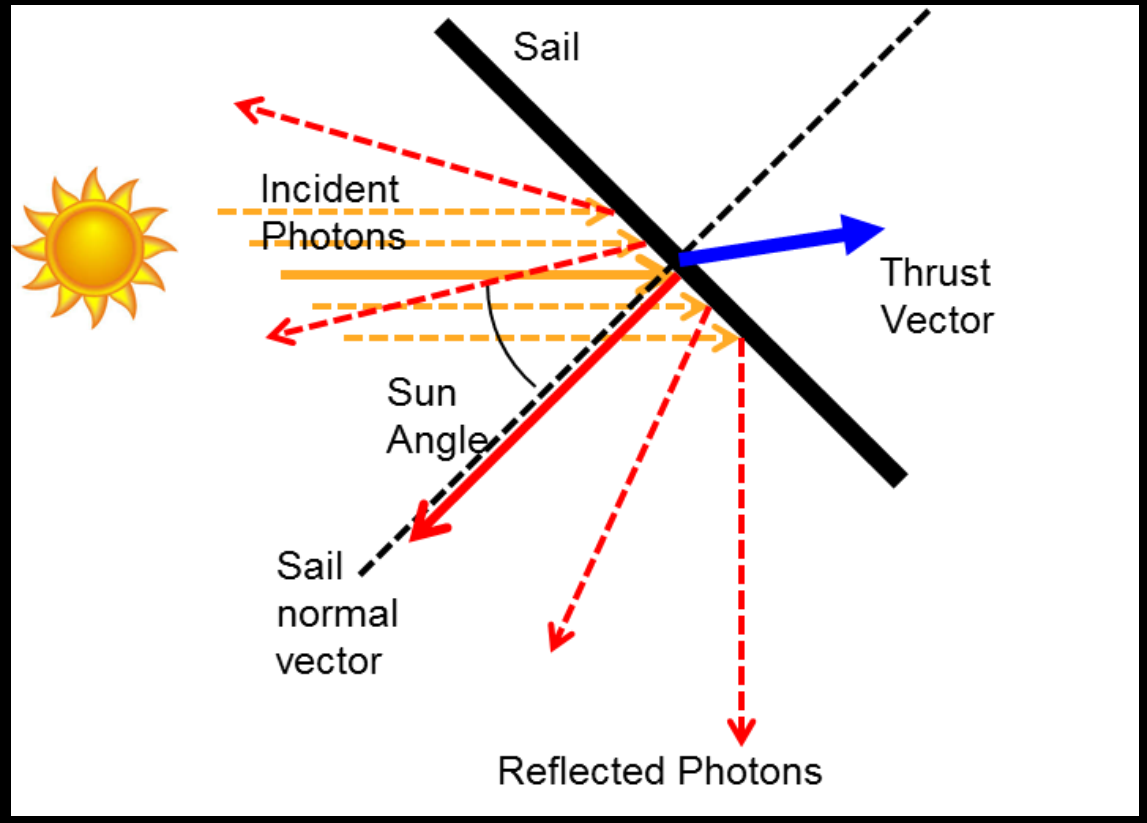




Real Solar Sails Are Not “Ideal”

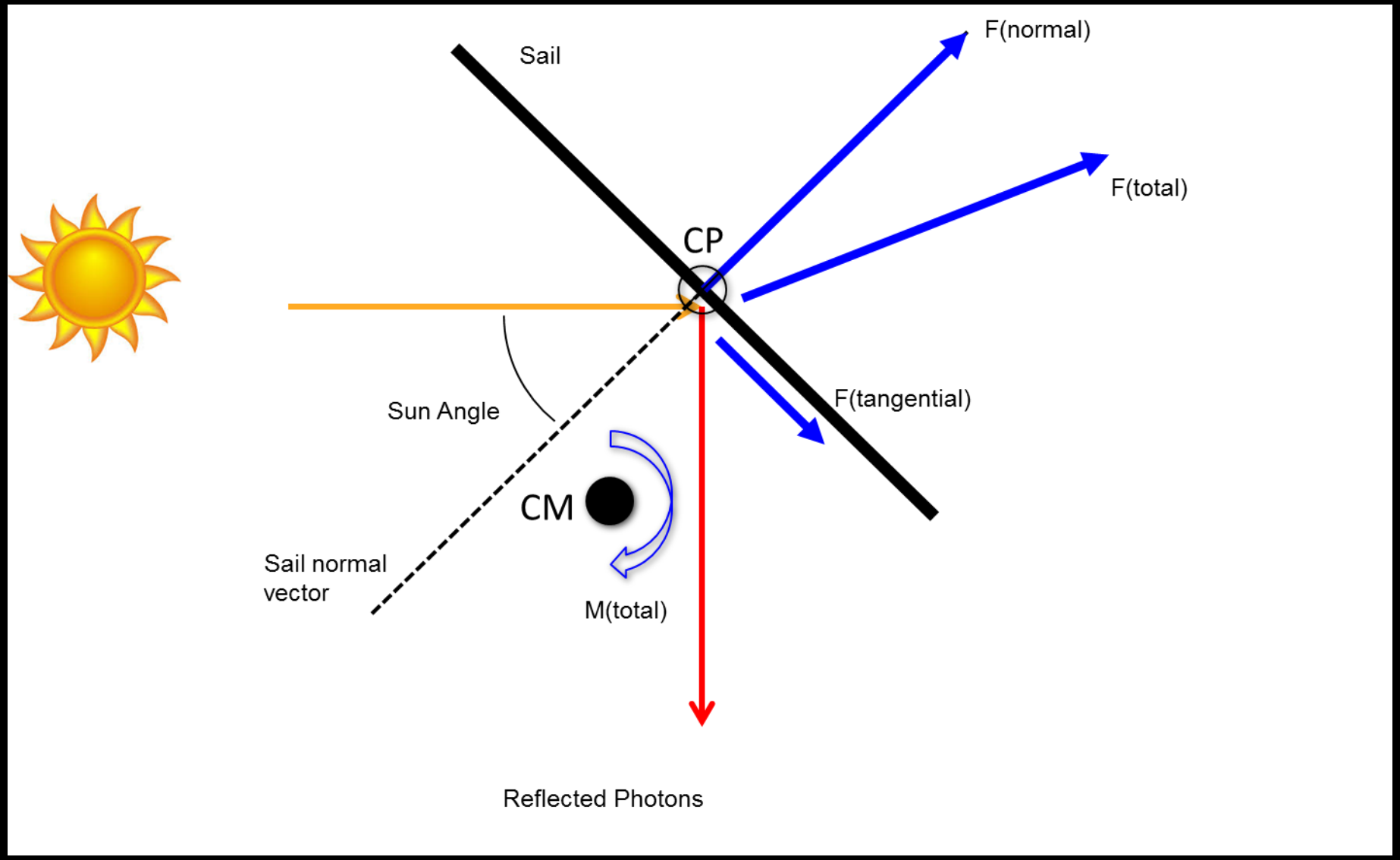
Billowed Quadrant





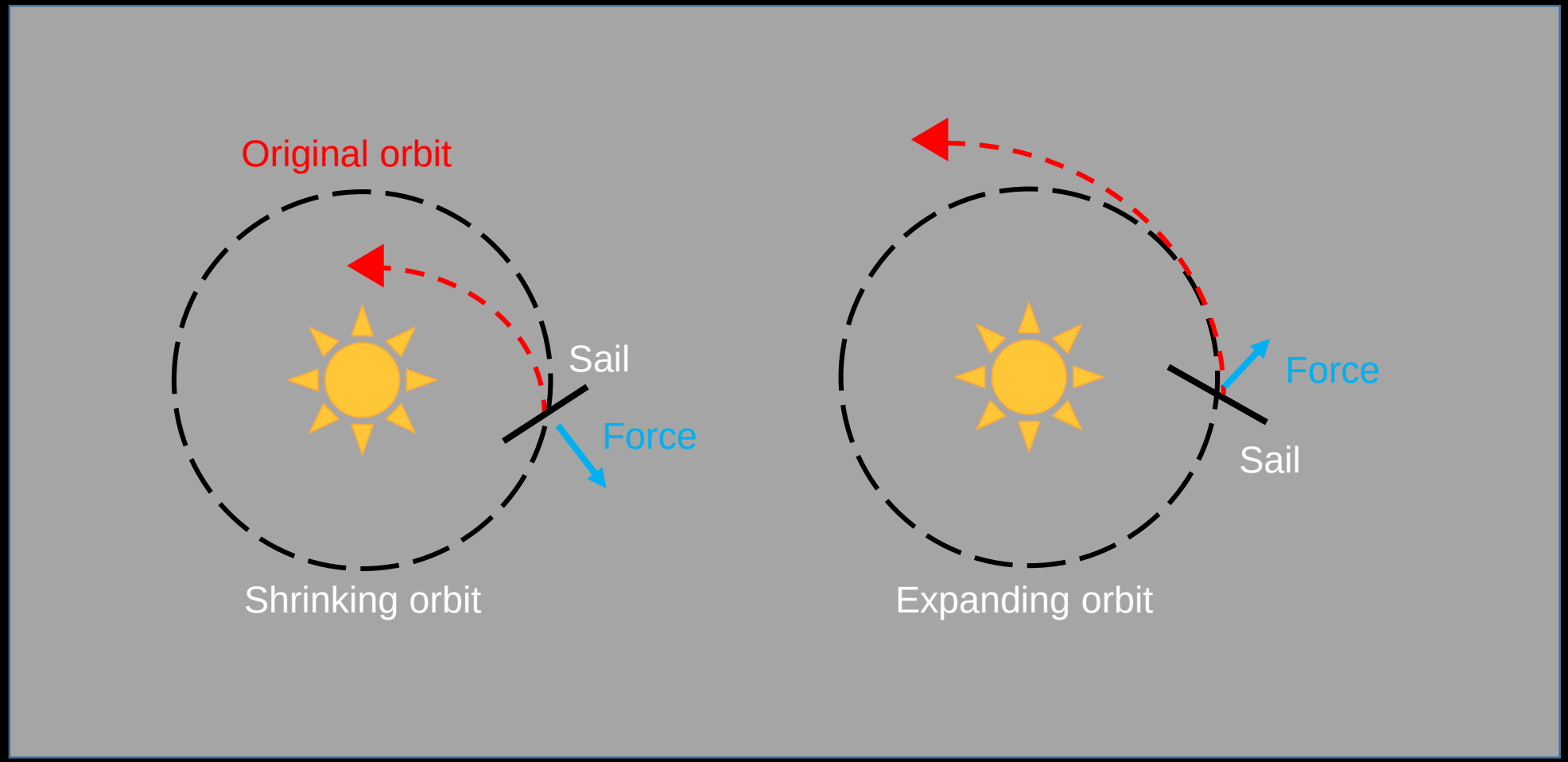
Diffuse Reflection

Thrust Vector Components



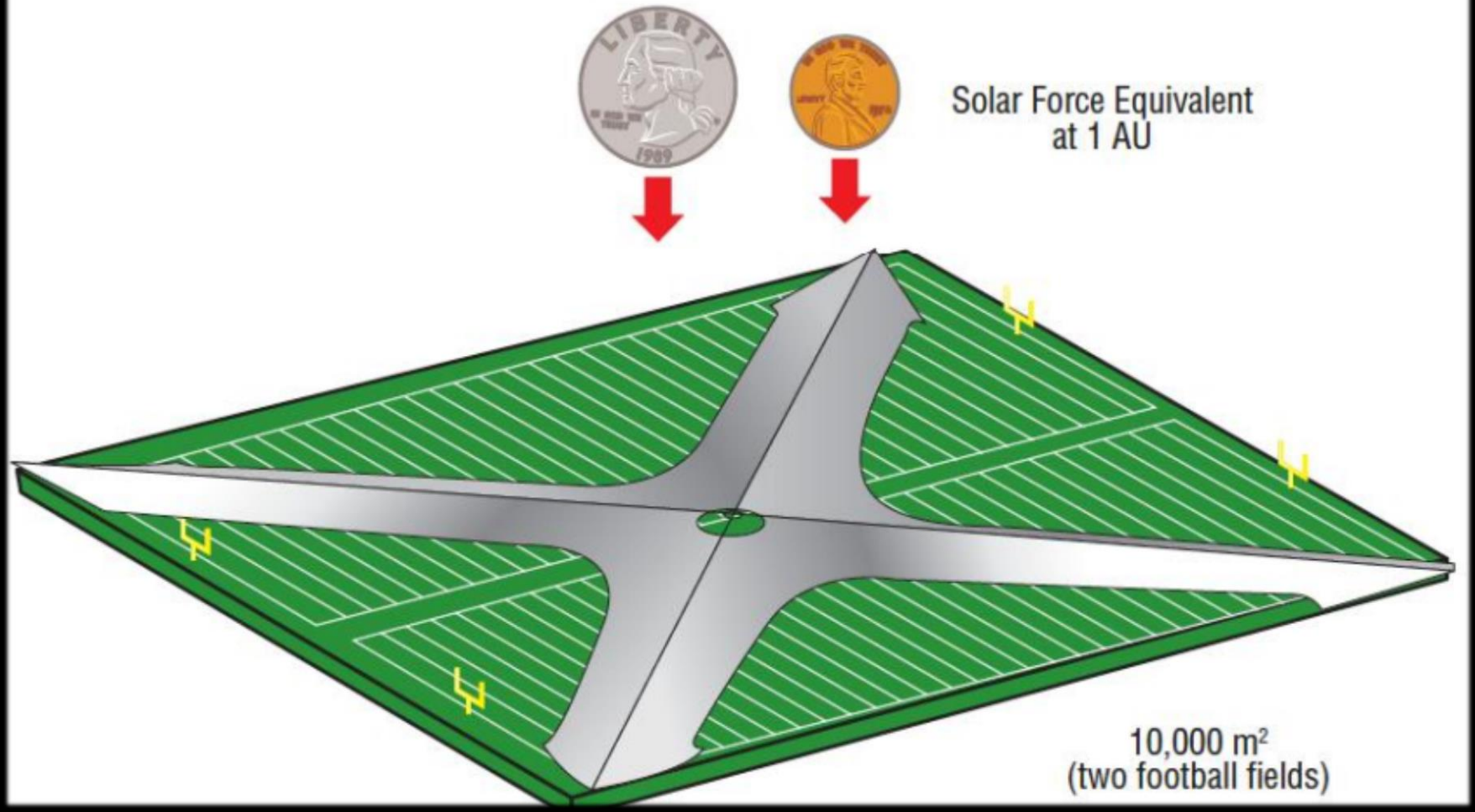
Solar Sail Trajectory Control

- Solar Radiation Pressure allows inward or outward Spiral



Solar Sails Experience **VERY** Small Forces

- **Force on a 100 m x 100 m square sail:**



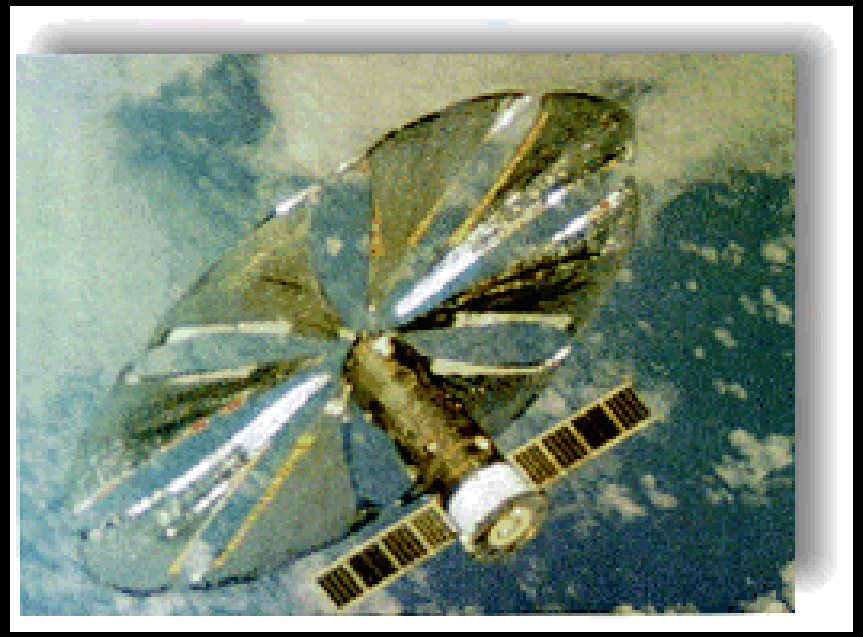
Echo II 1964

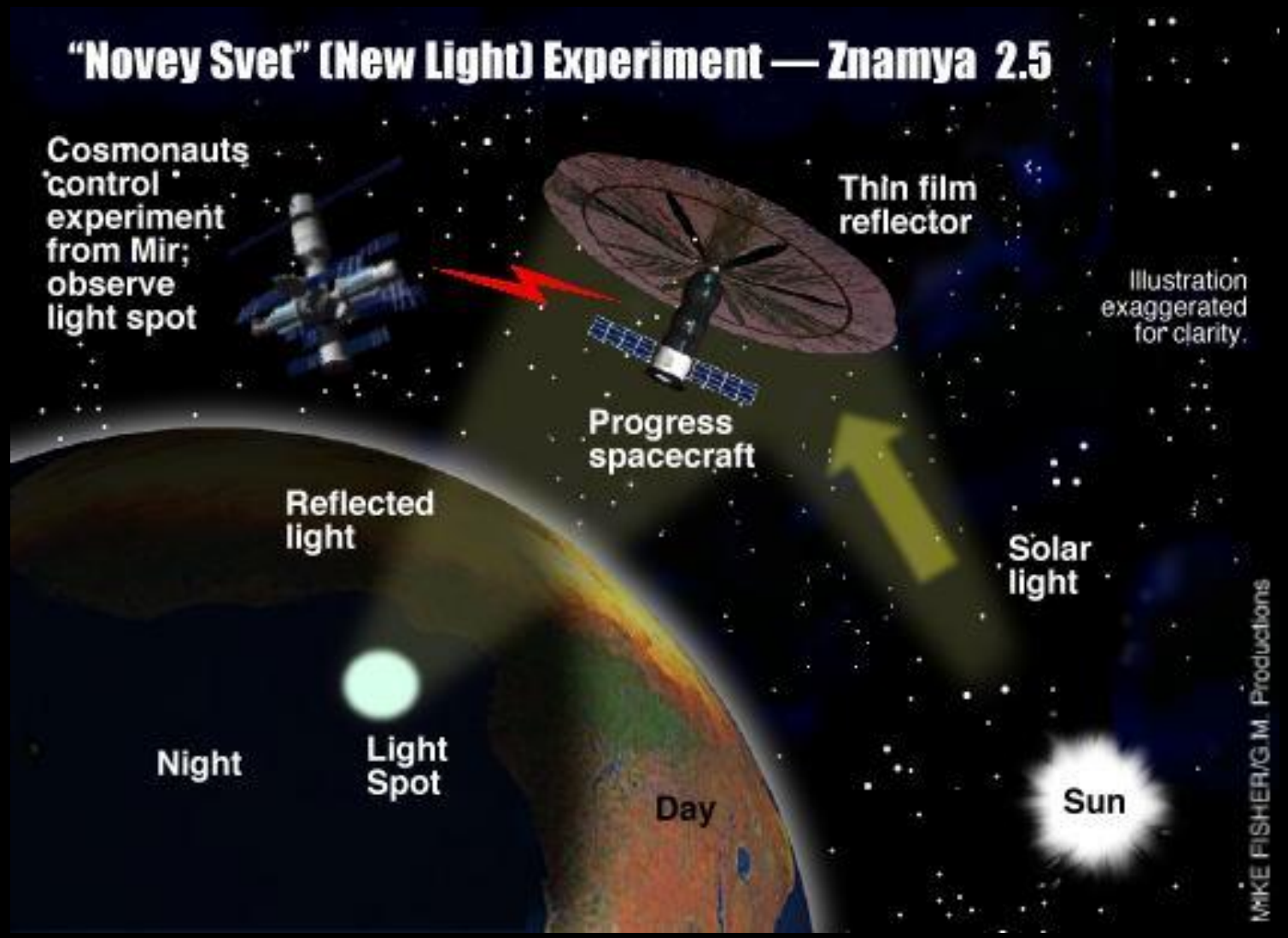
Solar thrust effect on spacecraft orbit

When folded, the satellite was packed into the 41-inch diameter canister shown in the foreground.

- **135-foot rigidized inflatable balloon satellite**
- **laminated Mylar plastic and aluminum**
- **placed in near-polar Orbit**
- **passive communications experiment by NASA on January 25, 1964**

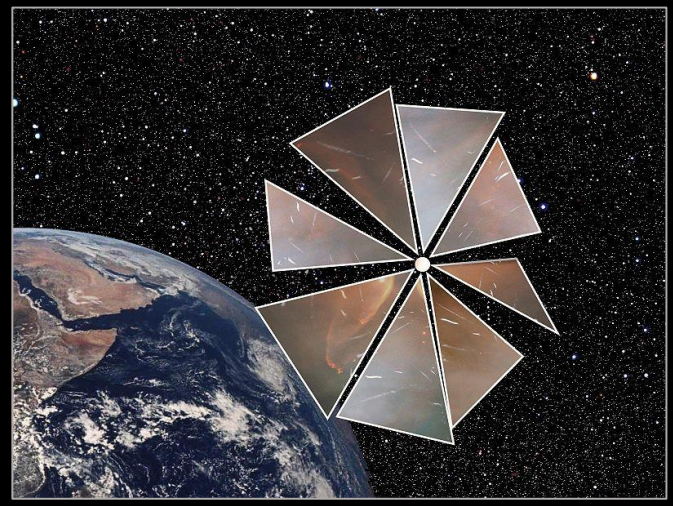
Znamya (Space Mirror)

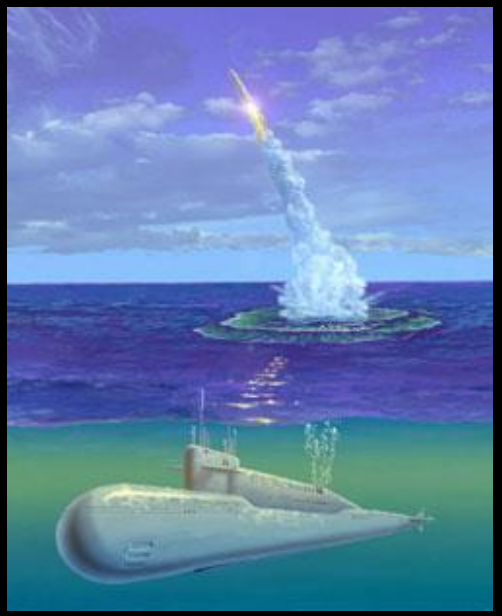




The Planetary Society's Cosmos-1 (2005)

- 100 kg spacecraft
- 8 triangular sail blades deployed from a central hub after launch by the inflating of structural tubes.
  - Sail blades were each 15 m long
  - Total surface area of 600 m^2
- Launched in 2005 from a Russian Volna Rocket from a Russian Delta III submarine in the Barents Sea.





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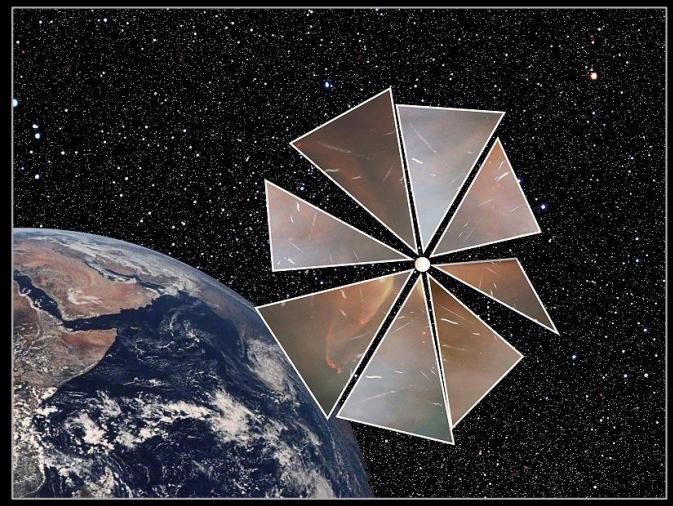
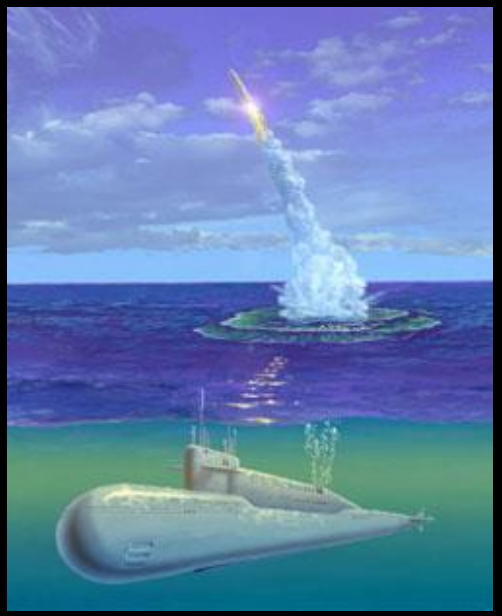
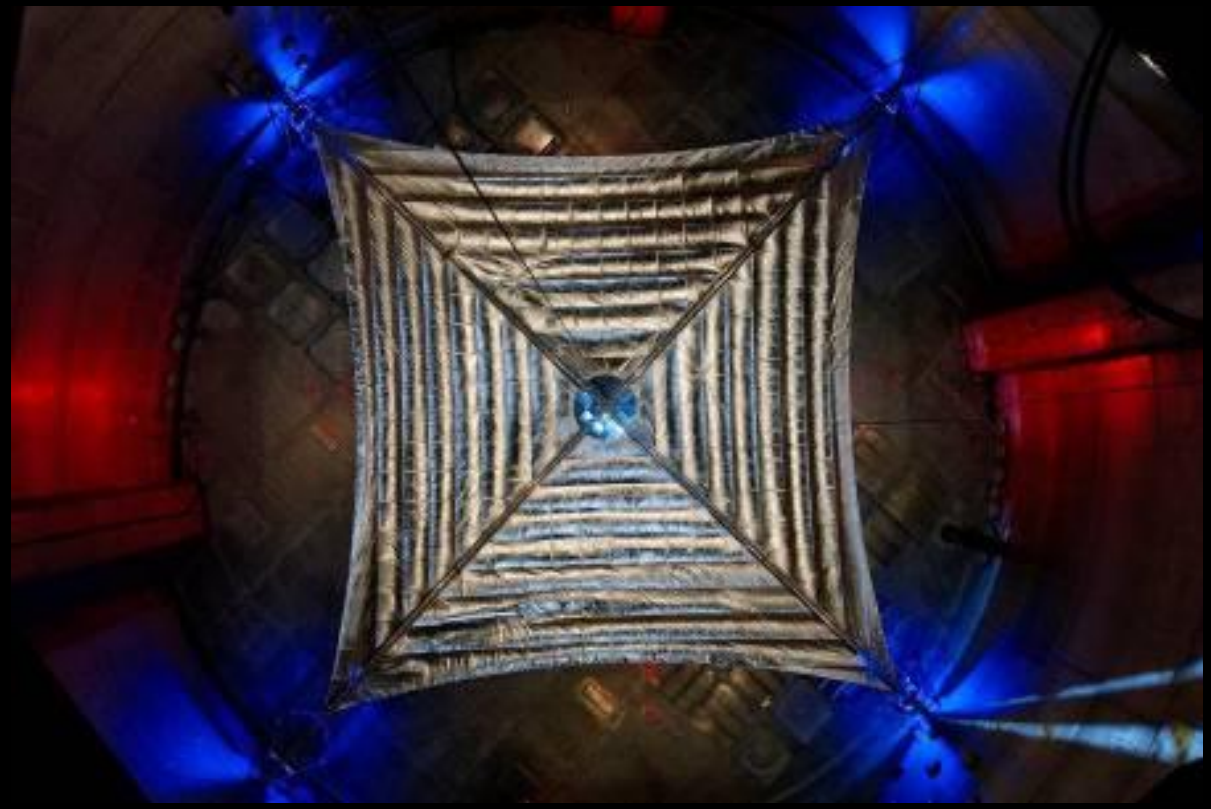
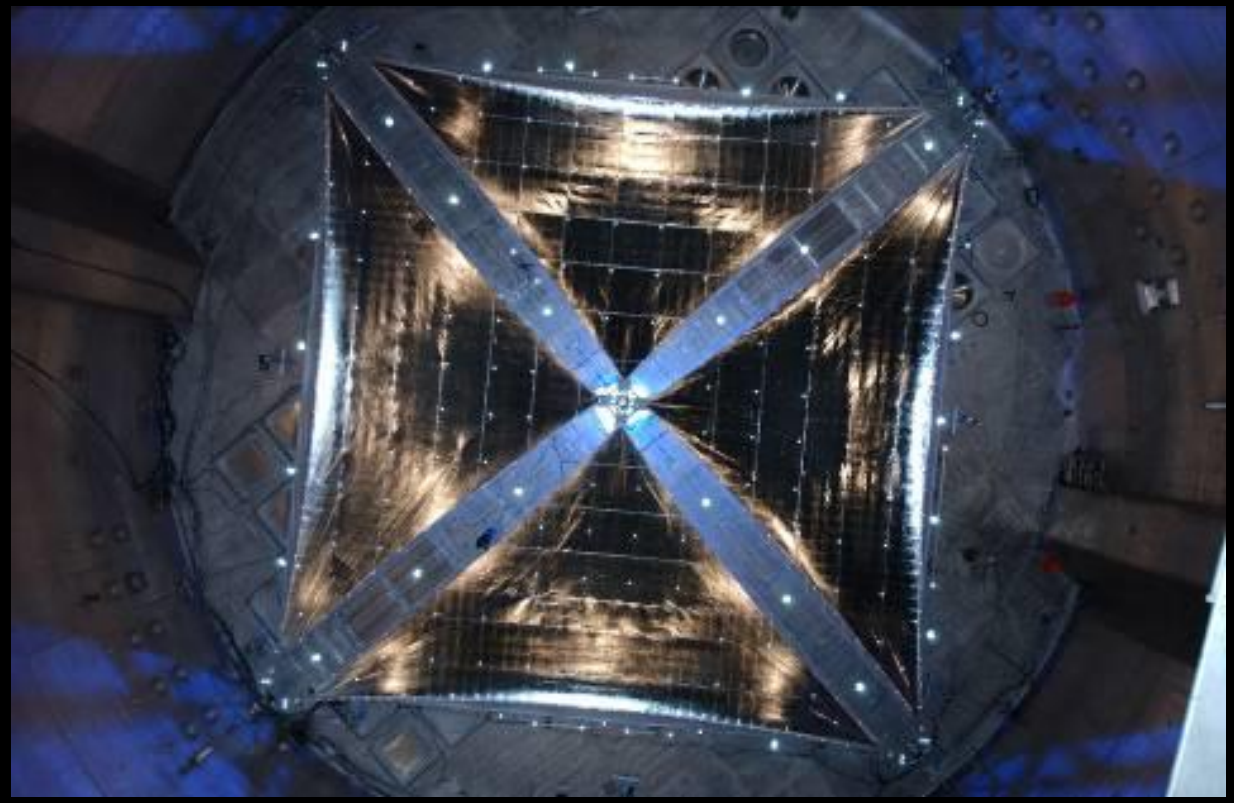
Rocket Failed.





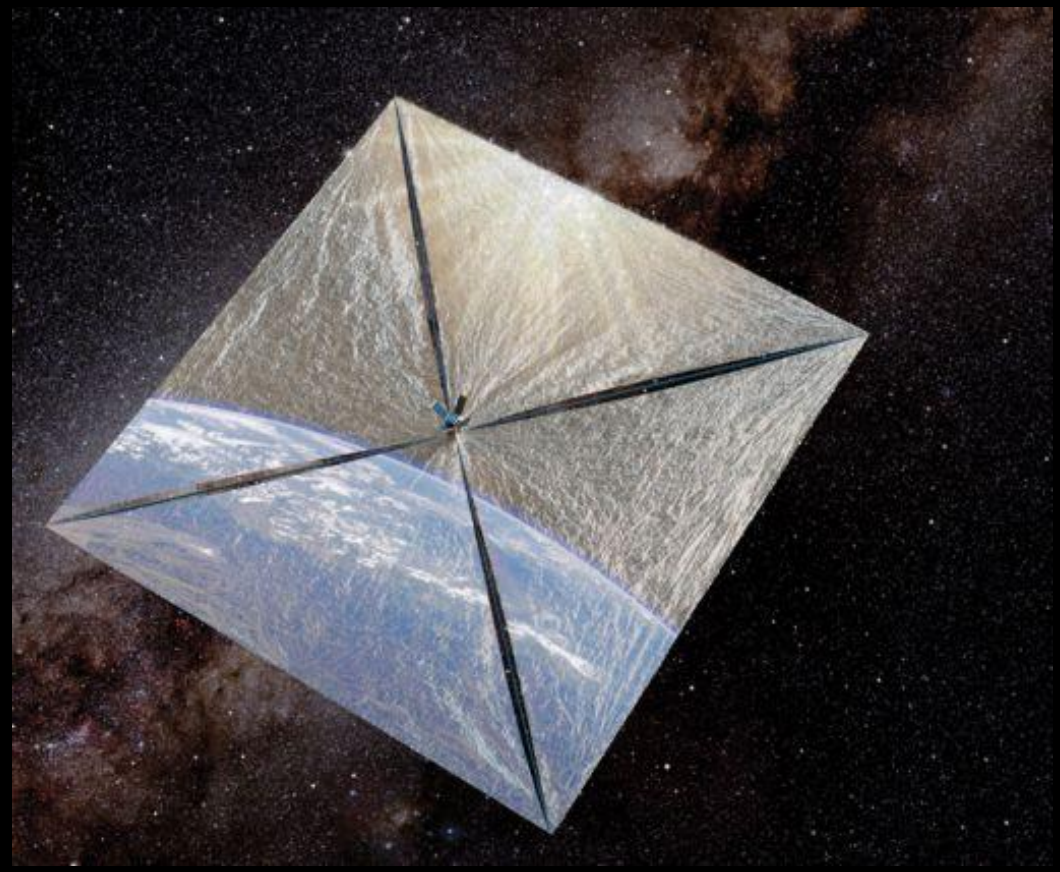
NASA Ground Tested Solar Sails in the Mid-2000's





NASA Space Technology Demo (2009)

- Planned to be a space flight demonstration of the solar sail
- developed and tested as part of the ground sail test program



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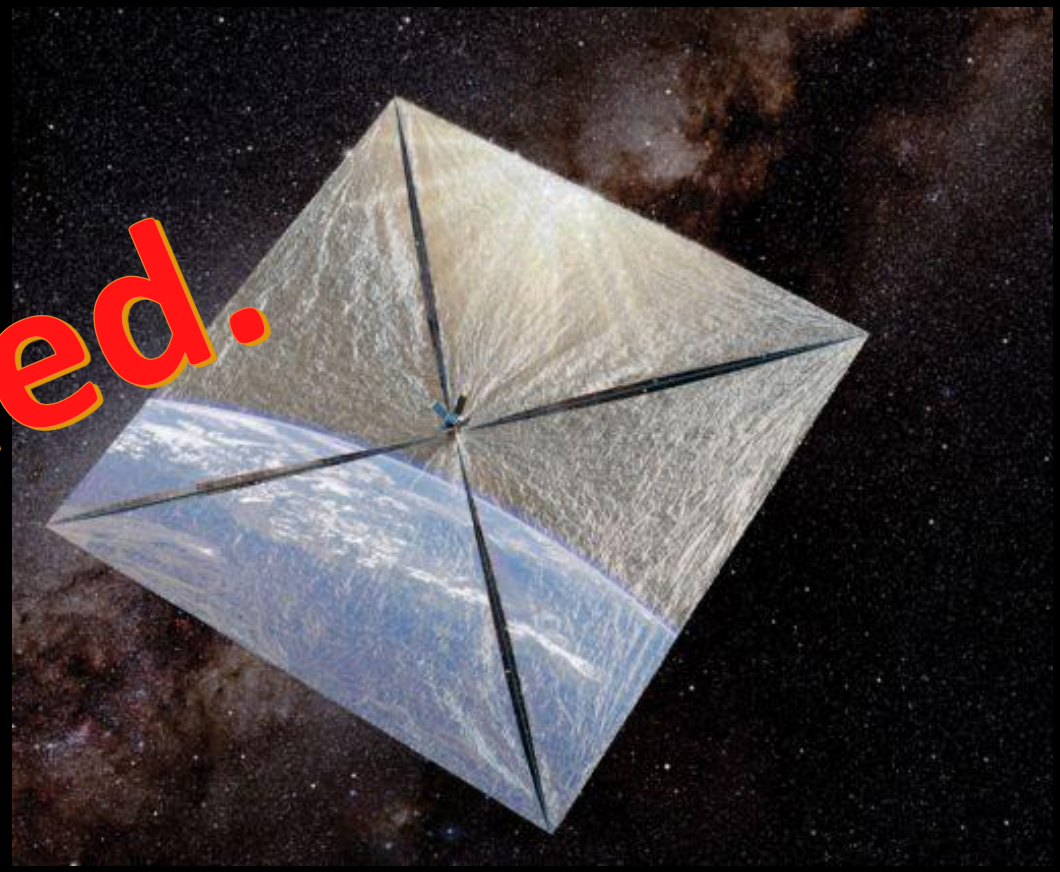
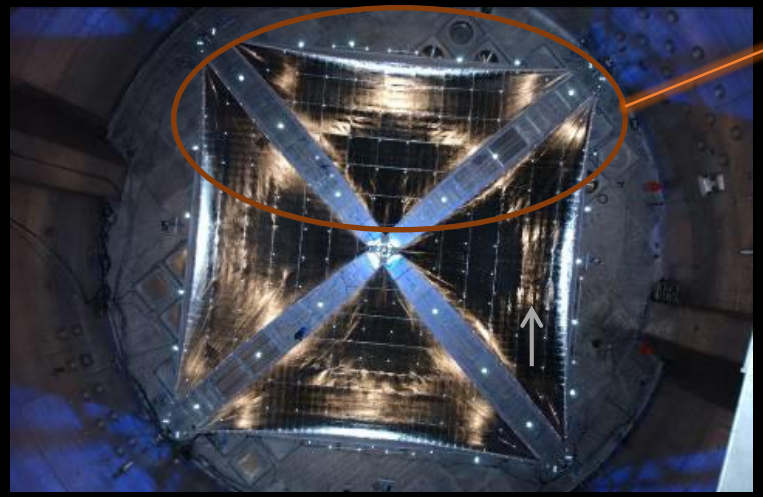
Canceled.

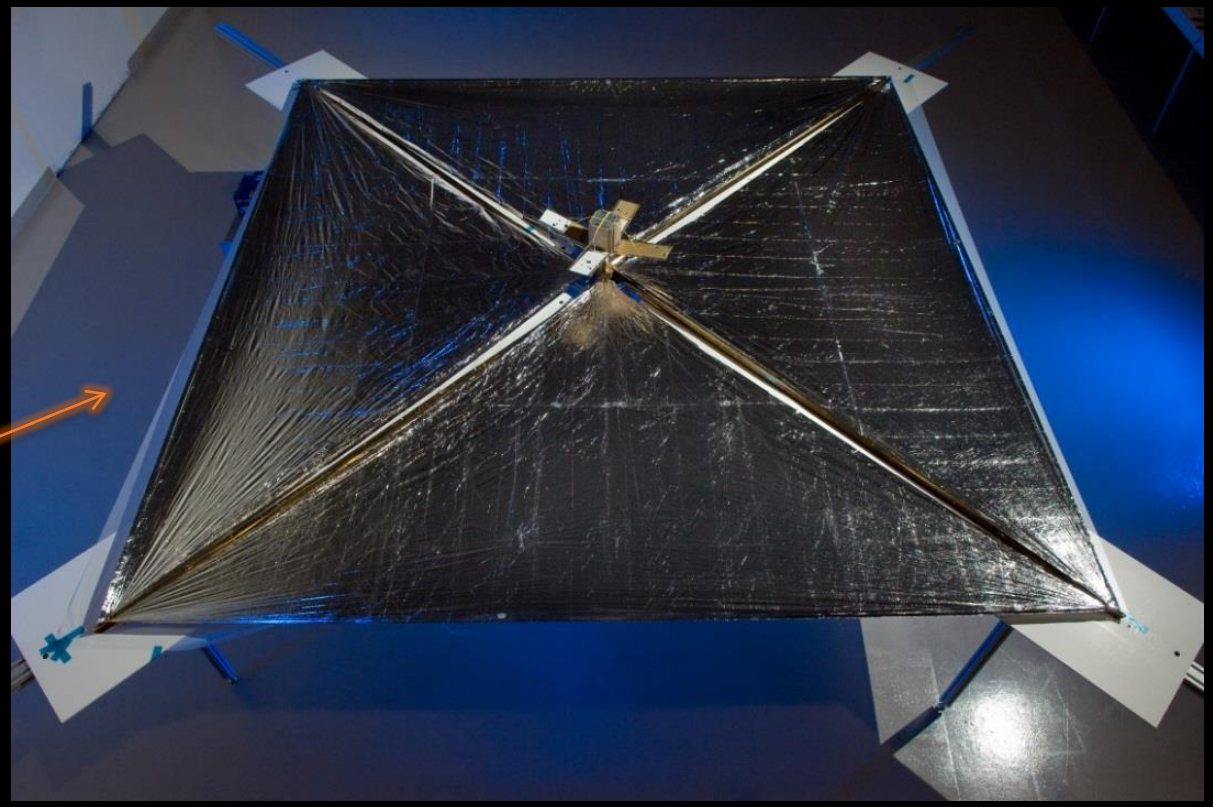


NanoSail-D Demonstration Solar Sail

Mission Description:

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

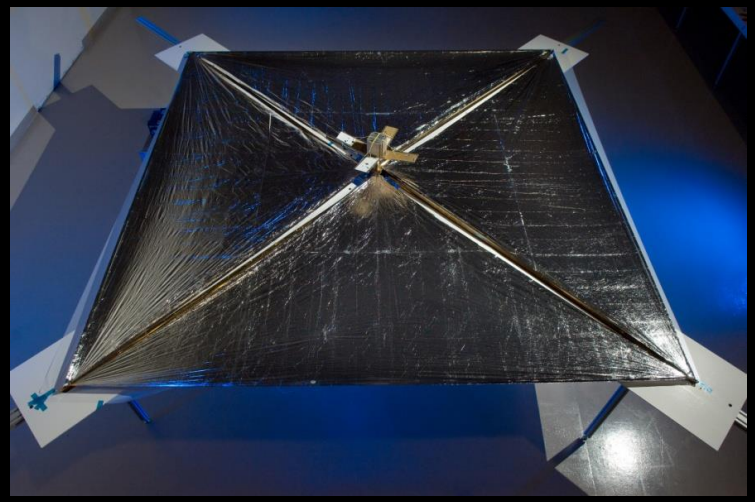




NanoSail-D1 Flight (2008)

Launch:

- Falcon-1, flight 3
- Kwajalein, Missile Range
- Primary payload: Air Force PnPSat



NanoSail-D1 Flight (2008)

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- Falcon-1, flight 3
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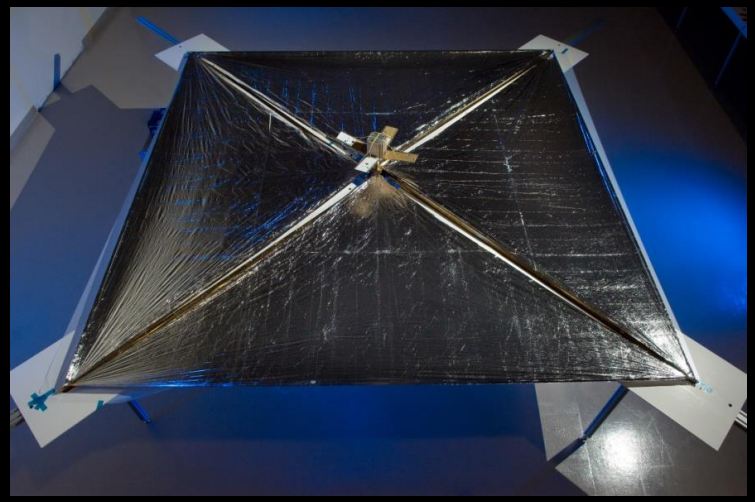
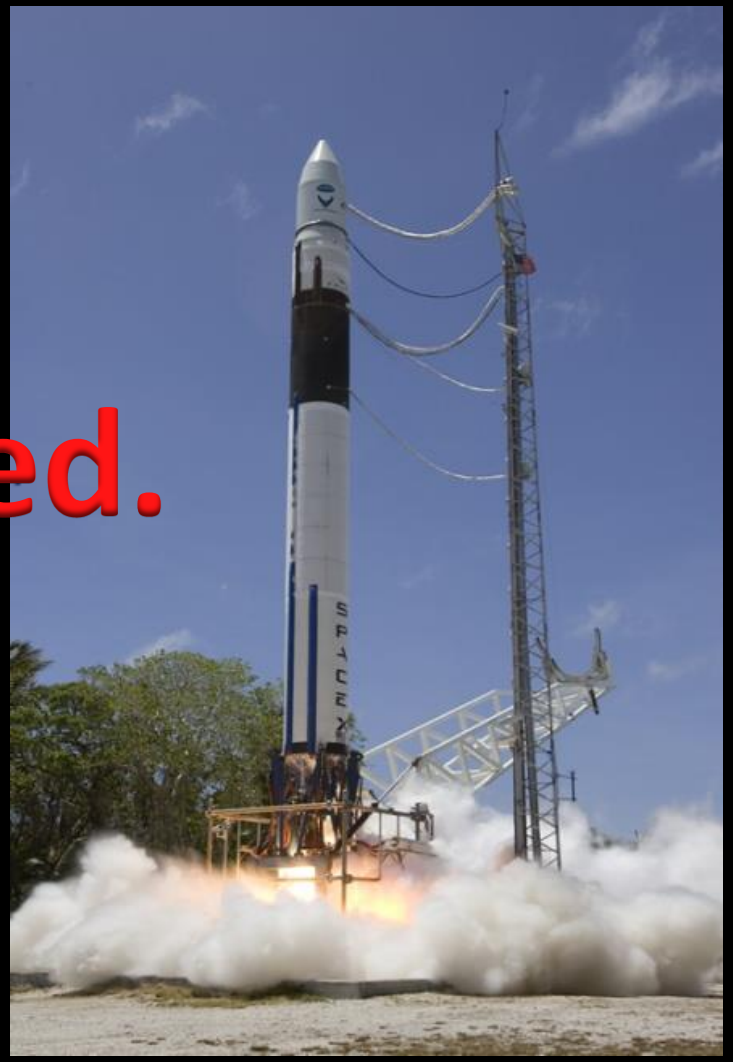




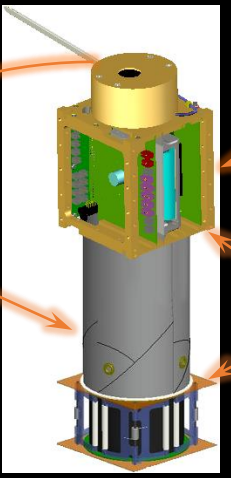
NanoSail-D2 Mission Configuration (2010)

3U CubeSat: 10 cm X 10 cm X 34 cm

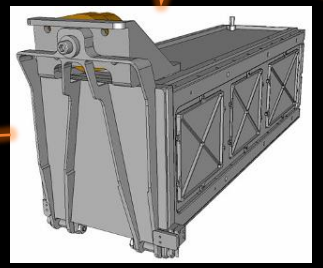
- Deployed CP-1 sail: 10 m^2 Sail Area (3.16 m side length)
- 2.2 m Elgiloy Trac Booms
- UHF and S-Band communications

Boom & Sail Spool (ManTech SRS)

Spacecraft Bus (Ames Research Center)



Bus interfaces Actuation Electronics (MSFC/UAH)



PPOD Deployer (Cal-Poly)

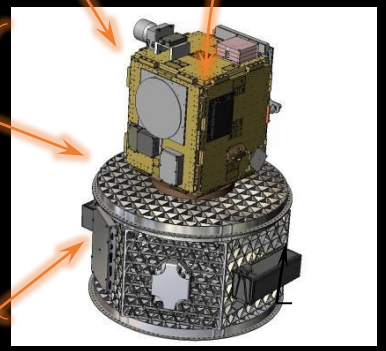
NanoSail-D (Aluminum Closeout Panels Not Shown)

Nanosail-D2 in Orbit August 19 2011 01h 19m 28s UT
Clay Center Observatory at Dexter and Southfield Schools
42.307404N, -71.13722W (WGS84)
www.claycenter.org Focal length:12,200mm,
Aperture = 640mm Ritchey-Chretien
Contact: Ron Dantowitz (rondantowitz@gmail.com)

AFRL Satellite (Trailblazer)

HSV-1

Adapter

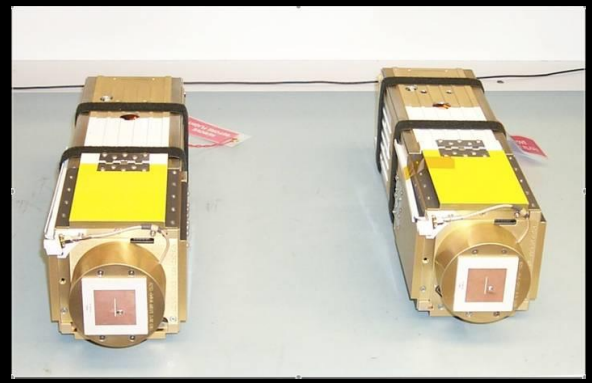


PreSat (ARC)

NanoSail-D (MSFC)

Ride Share Adapter (Space Access Technology)

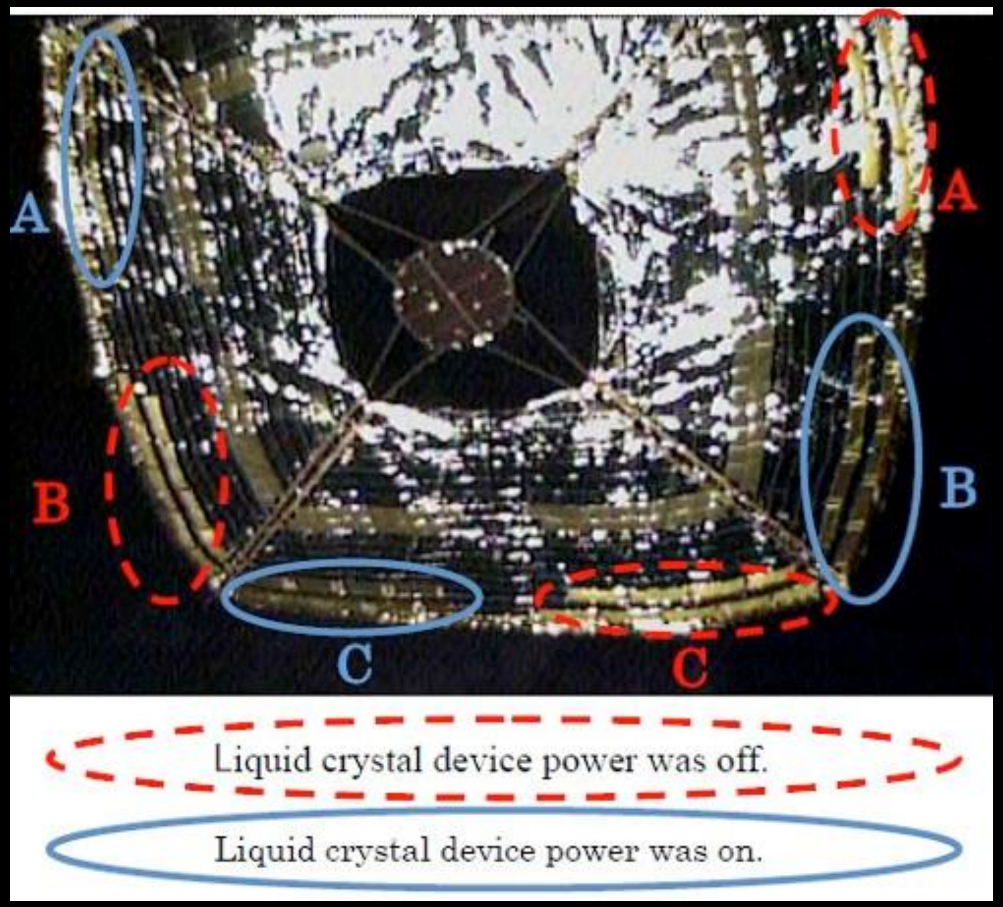
Stowed Configuration



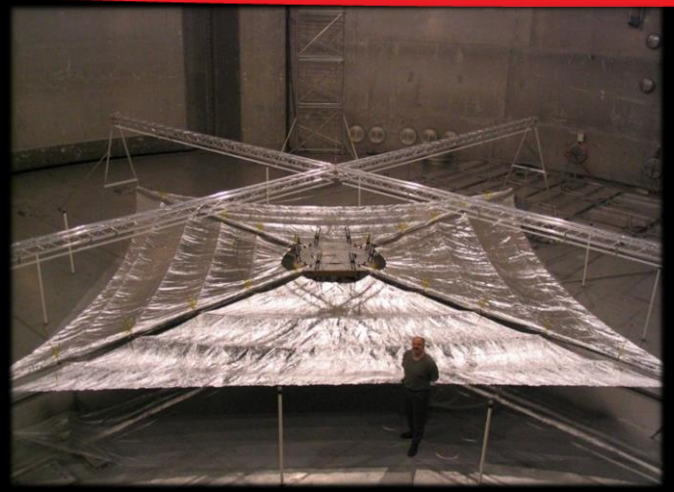
NSD-002

NSD-001

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



Sunjammer Solar Sail Demonstration Mission



83 m^2 ISP L'Garde Solar Sail 2004

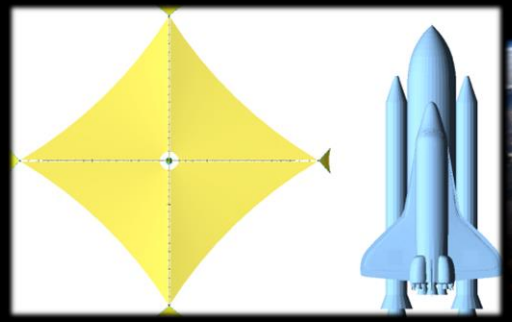
318 m^2 ISP L'Garde Solar Sail 2005

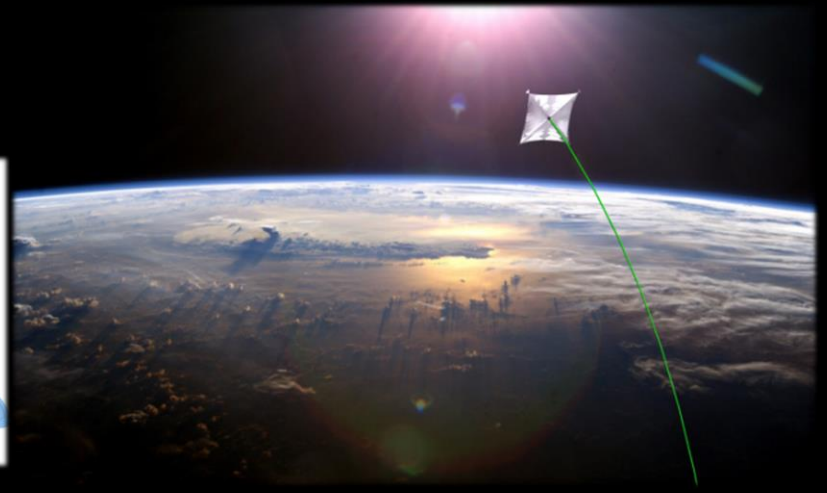
Design Heritage:

- Cold Rigidization Boom Technology
- Distributed Load Design
- Aluminized Sun Side
- High Emissivity Eclipse Surface
- Beam Tip Vane Control
- Spreader System Design

Design Features:

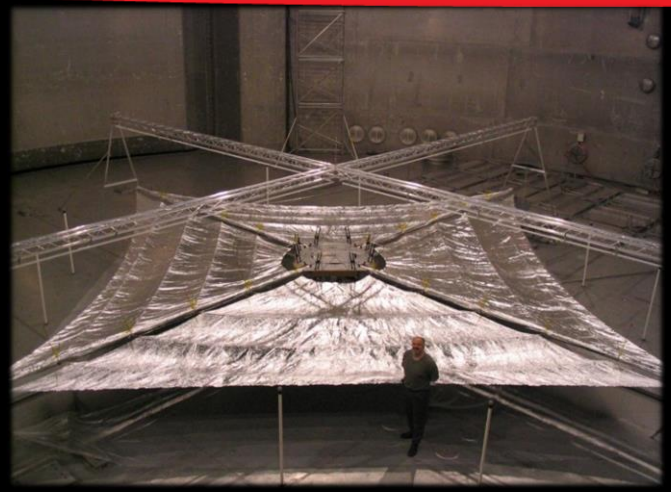
- High density packagability
- Controlled linear deployment
- Structural scalability
- Propellantless operation
- Meets current needs





1200 m^2 L'Garde Sunjammer Launch 2015

Sunjammer Solar Sail Demonstration Mission



83 m² ISP L'Garde Solar Sail
2004

18 m² ISP L'Garde Solar Sail
2005

Canceled.

Design Heritage:

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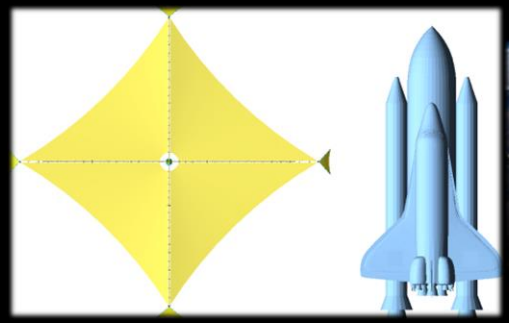
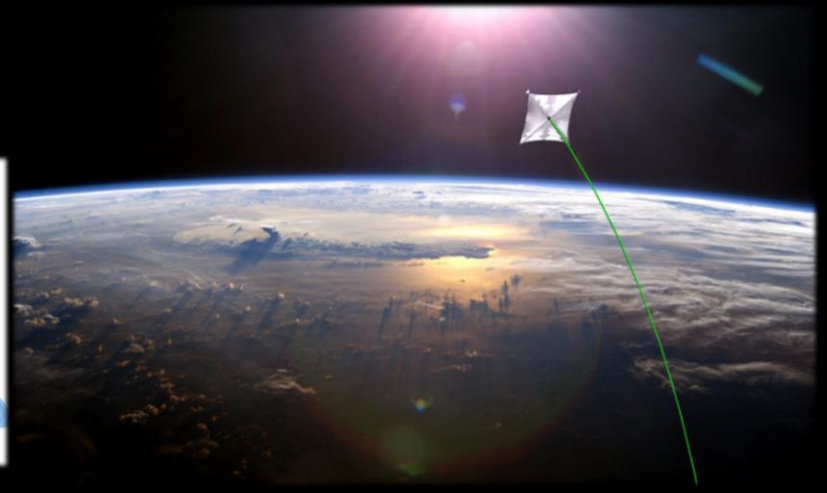
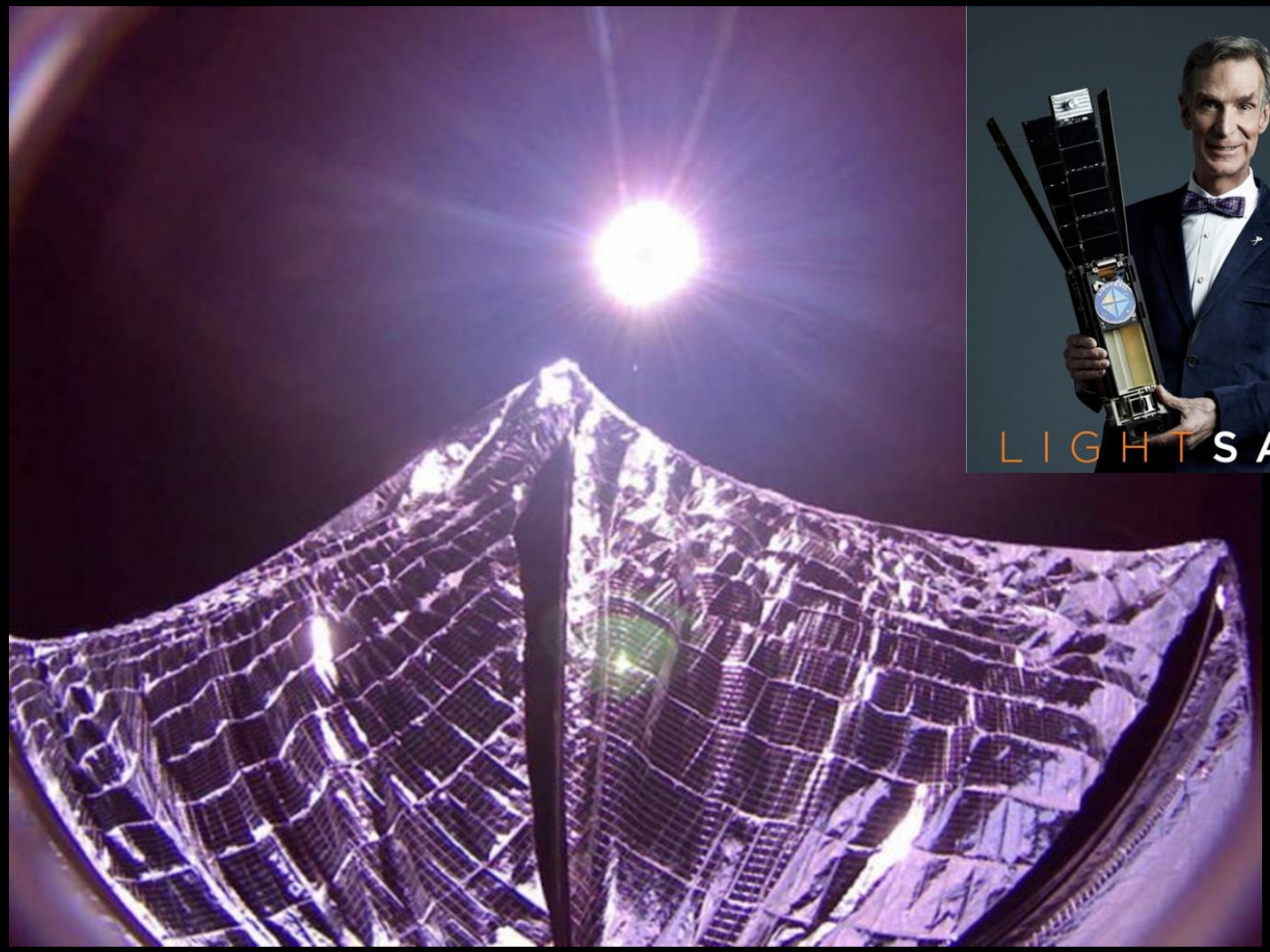




1200 m² L'Garde Sunjammer Launch
2015

Lightsail-A
(The Planetary Society)



- **32 m^2**
- **No active ‘sailing’**
- **3U CubeSat**

Flew successfully in 2015

LightSail-B to fly in 2018

University of Surrey's InflateSail (2017)

InflateSail is an inflatable, rigidizable sail for flight in Low Earth Orbit:

- 3U CubeSat with deployed sail area of 10 m^2
- Sail supported by bistable booms
- Inflation is driven by Cool Gas Generators (CGG): low system mass, long lifespan

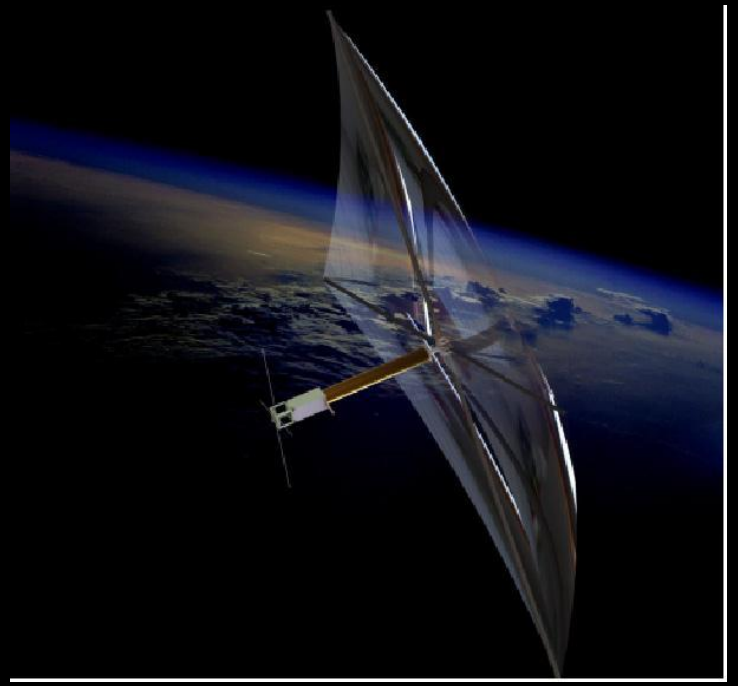


***Fig. 1**: InflateSail design concept*

***Fig. 2**: 80 mg CGG* George C. Marshall Space Flight Center

SURREY SPACE CENTRE

CGG technologies COOL GAS GENERATOR

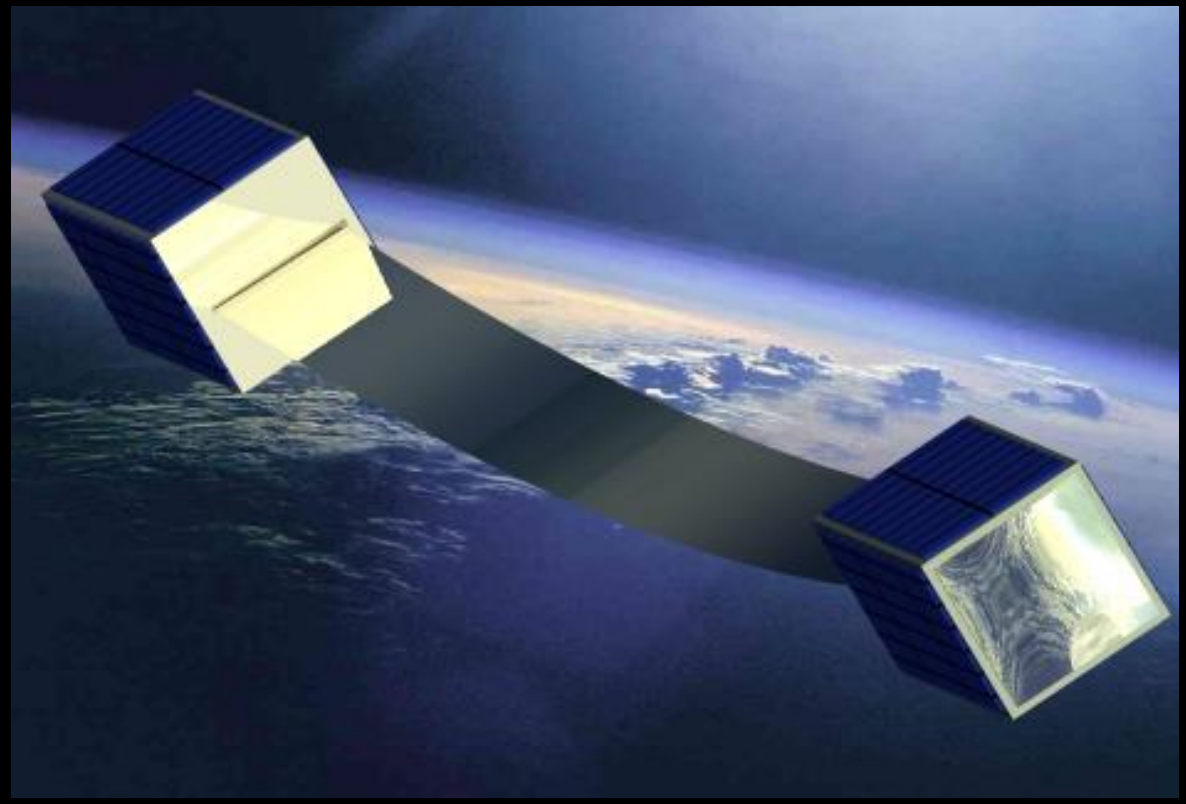
ASTRIUM AN EADS COMPANY

UNIVERSITY OF CAMBRIDGE

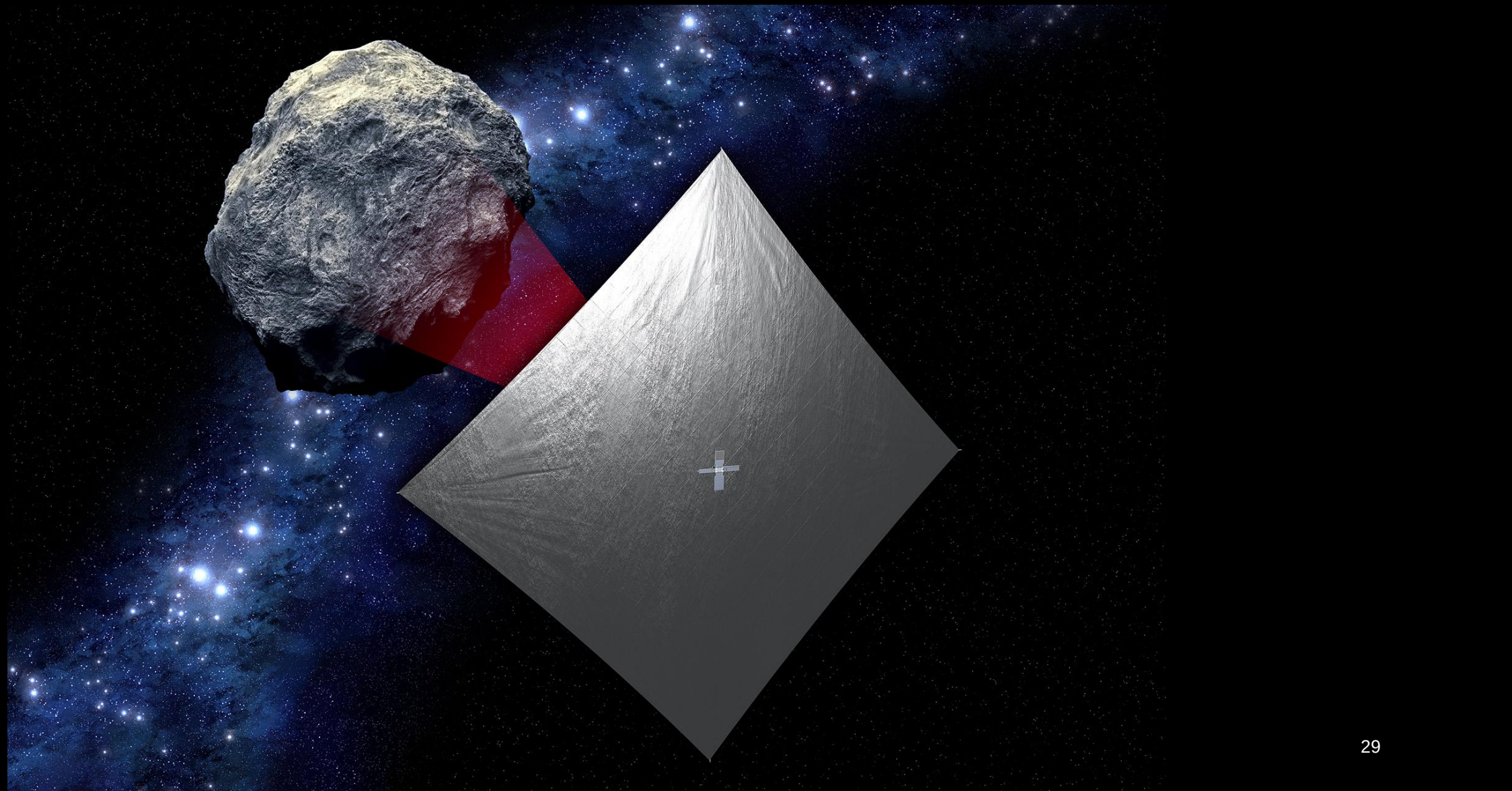
Cubesail CubeSat Solar Sail Propulsion Demonstration

- The University of Illinois at Urbana-Champaign (UIUC), working with NASA MSFC, NSF, and CU Aerospace, built the flight hardware for a CubeSat-based 20 m^2 solar sail orbit raising demonstration mission

- Manifested for 2018 launch



Near Earth Asteroid (NEA) Scout



NASA's Near Earth Asteroid Scout

The Near Earth Asteroid Scout Will:

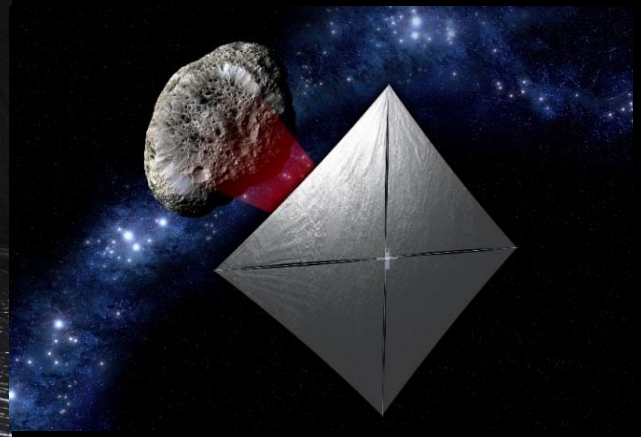
- Image/characterize a NEA during a slow flyby
- Demonstrate a low cost asteroid reconnaissance capability

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

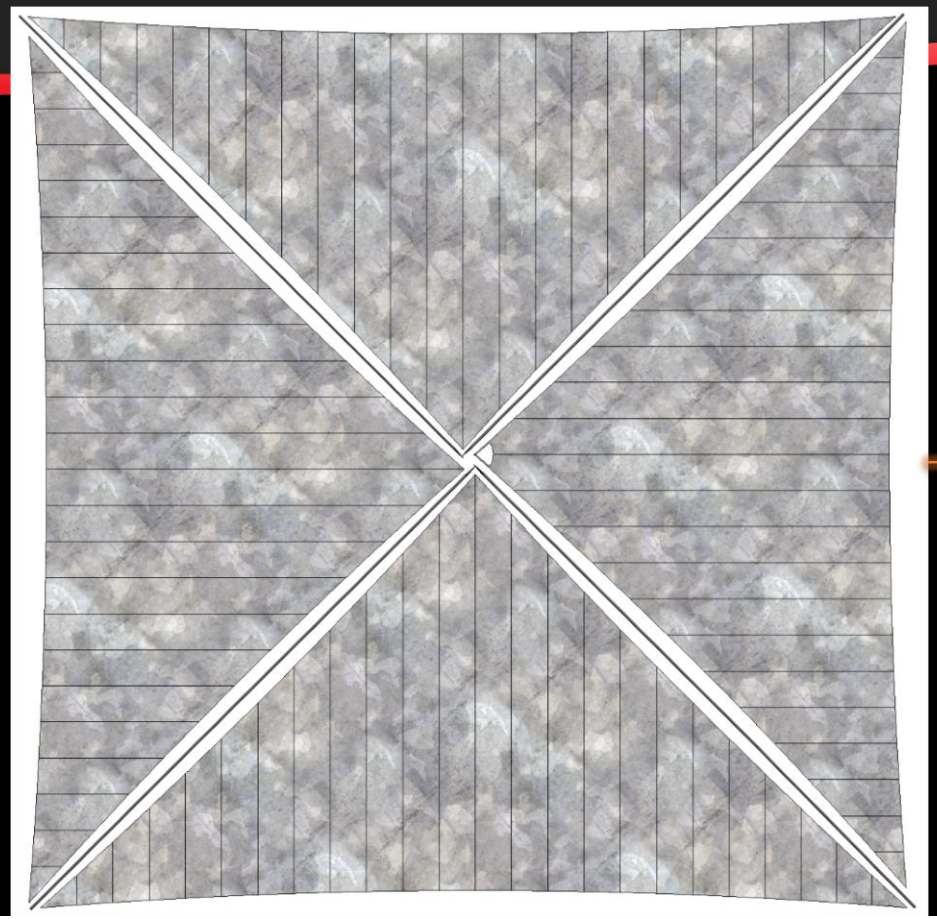
Solar Sail Propulsion System Characteristics

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



NEA Scout Approximate Scale

Deployed Solar Sail



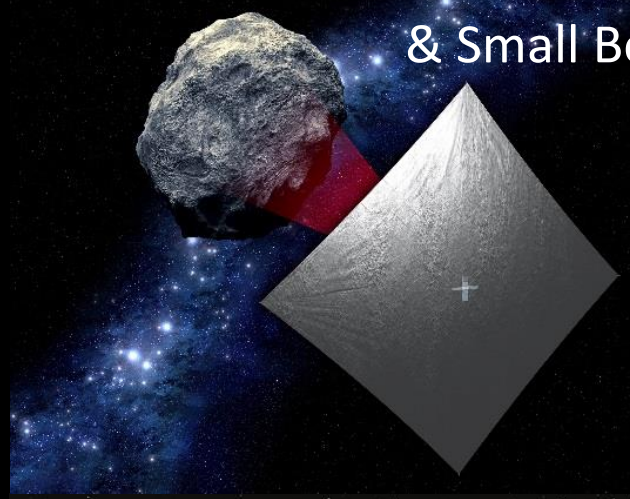
School Bus

6U Stowed Flight System

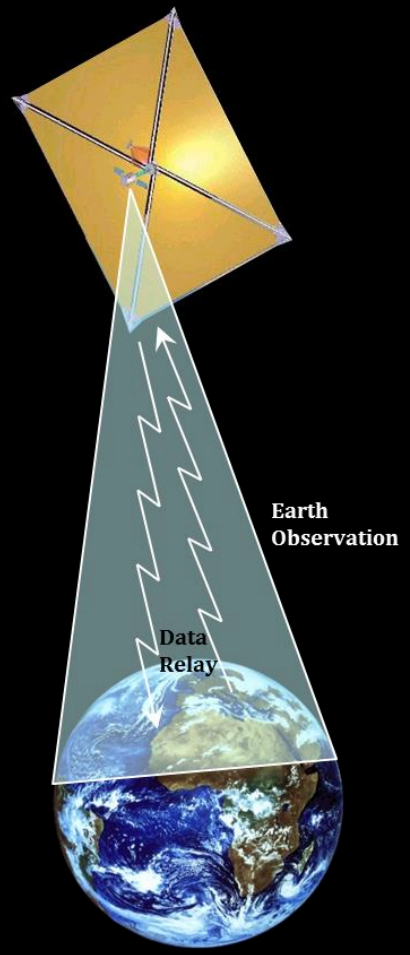
Folded, spooled and packaged in here

Potential Solar Sail Applications
(A Partial List!)

NEA Reconnaissance & Small Body Science

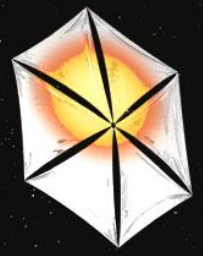


Earth Pole Sitting

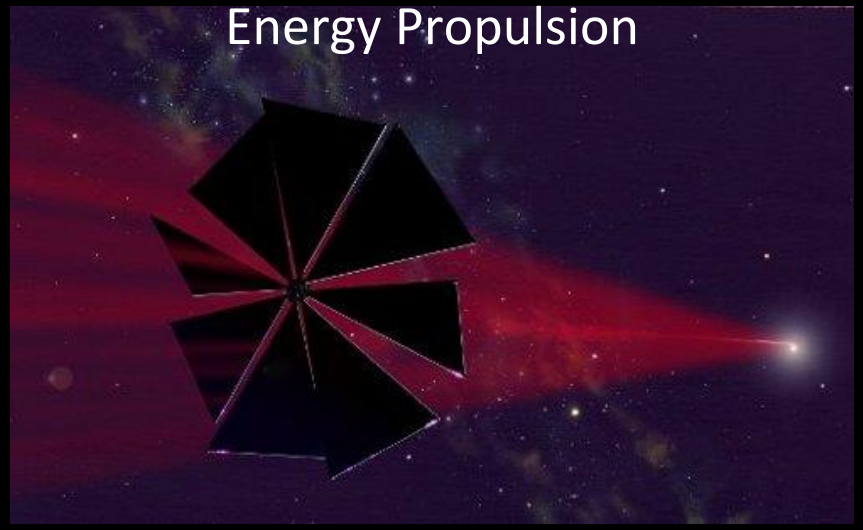


Rapid Outer Solar System Exploration and Escape

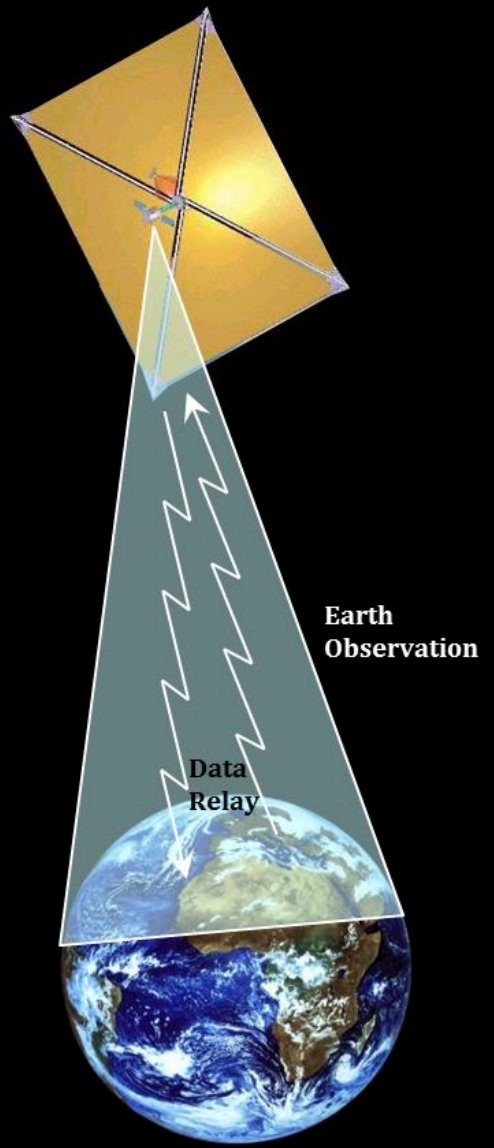
Heliophysics & Out of the Ecliptic Science



Toward Higher Performance Beamed Energy Propulsion

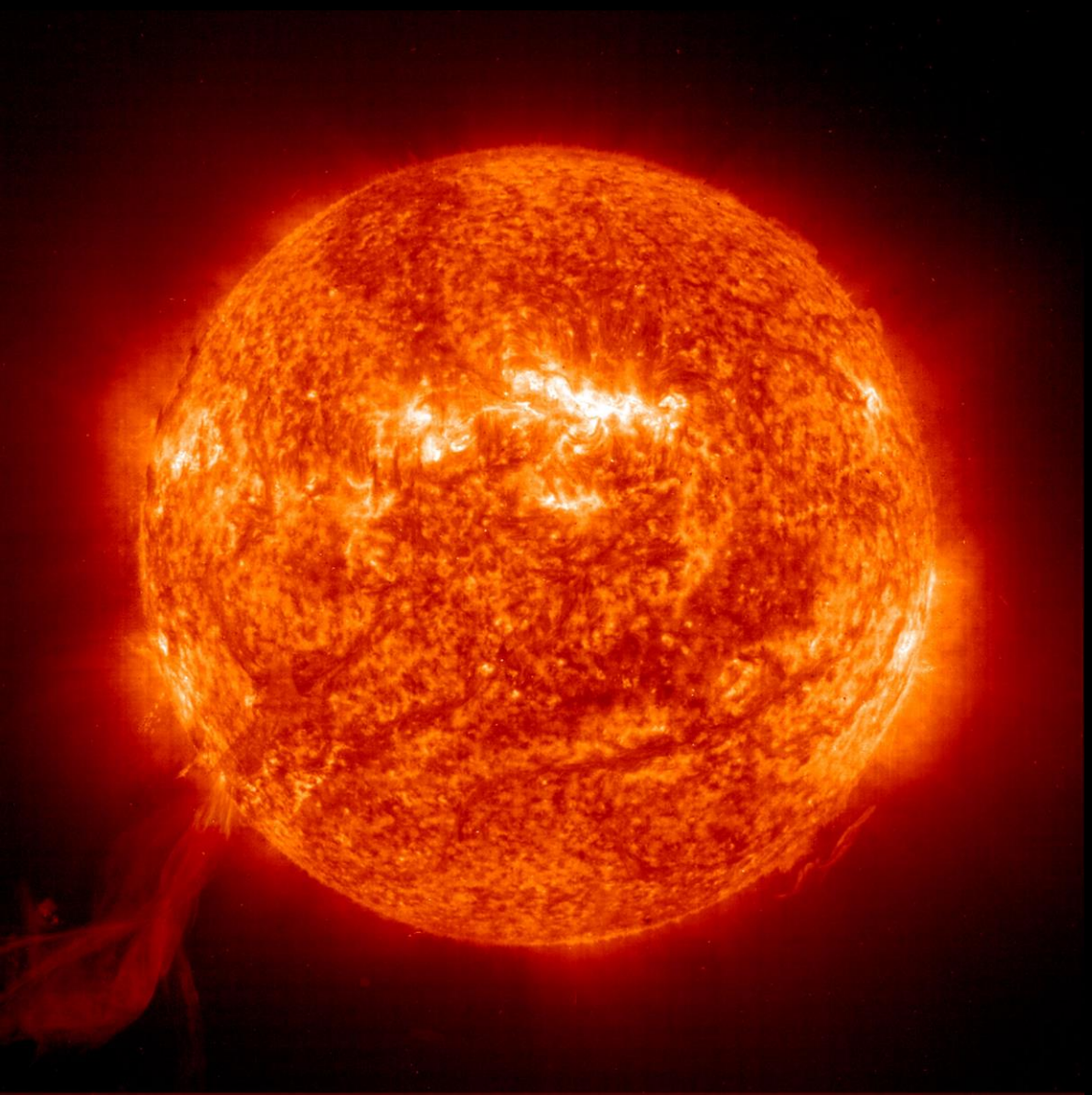


Possible Future Mission
Continuous Polar Observations



- Sailcraft over the polar regions of the Earth
- Sail tilted so the light pressure from the sunlight reflecting from it is exactly equal and opposite to the gravity pull of the Earth.

Possible Future Mission
Imaging the Solar Poles



- Leaving the ecliptic plane to image the Sun's poles is extremely propulsion intensive
- Solar sails can be used to "crank" a spacecraft's inclination from the ecliptic plane to a solar polar orbit

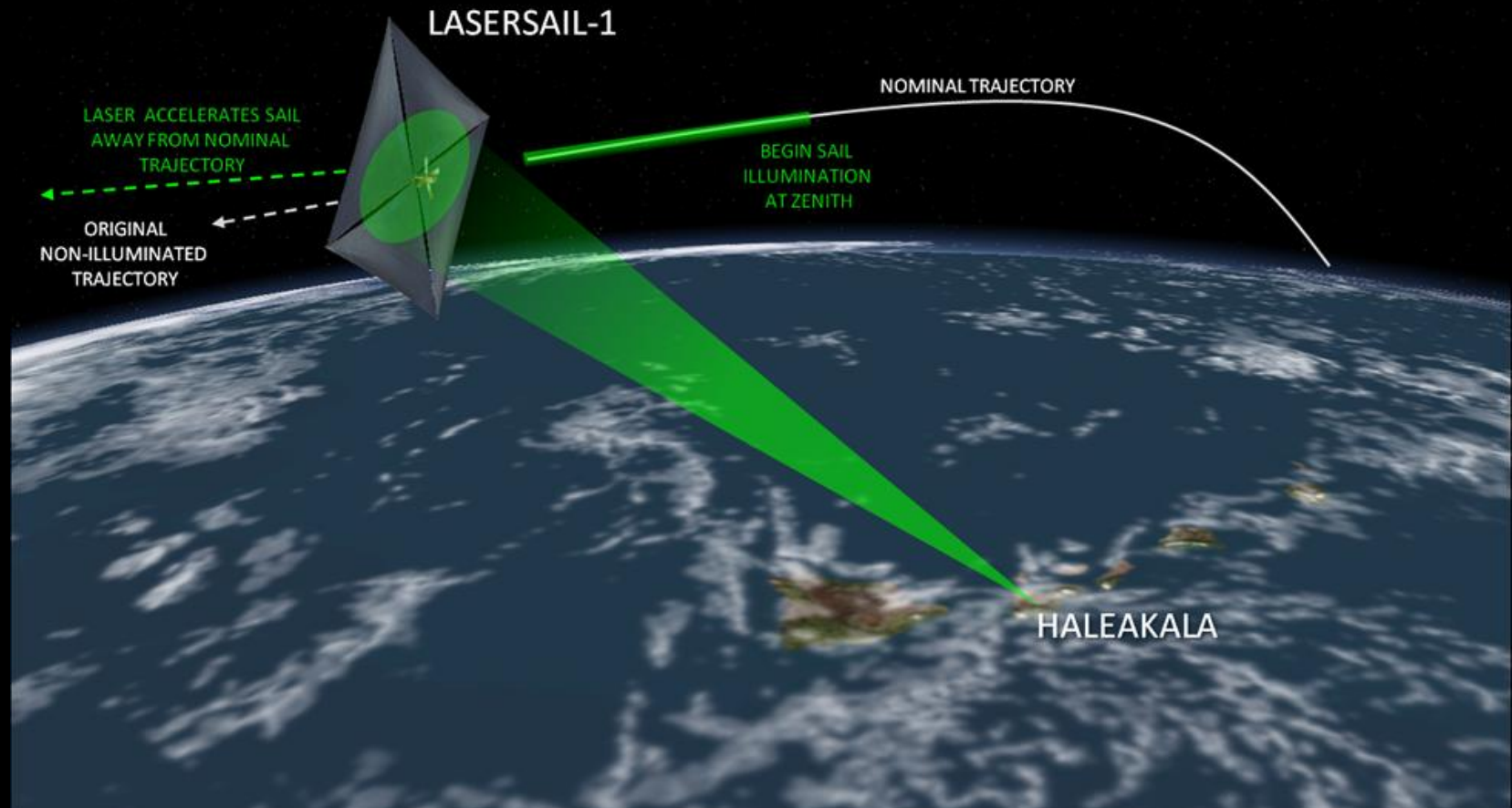
Possible Future Mission
Interstellar Medium Exploration

Deploy a large (>10,000 m^2) solar sail near the sun to enable travel 4X - 5X faster than Voyager

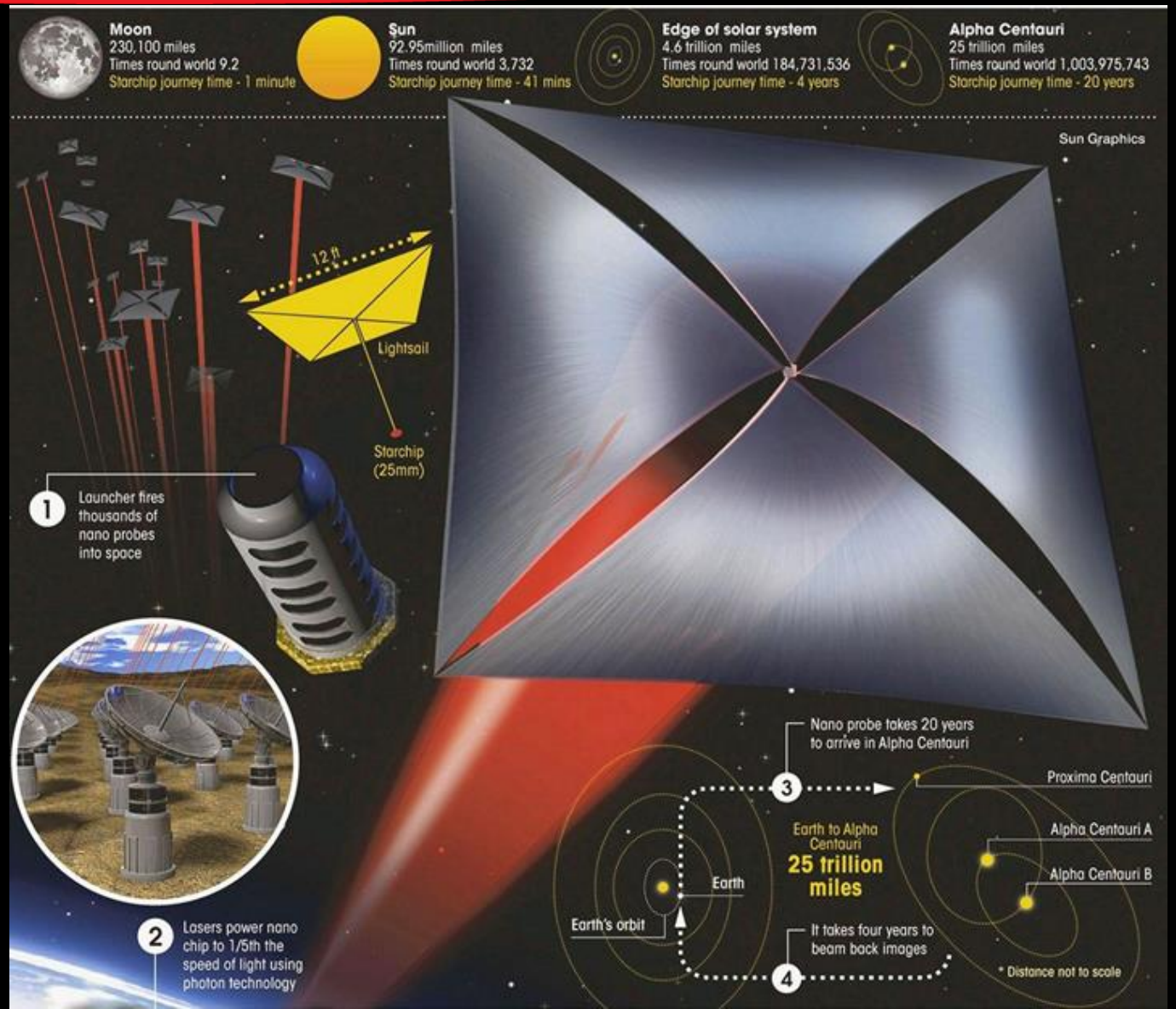
Goal: Reach 250 Astronomical Units within 20 years of launch

Laser Sailing: The Next **Big** Step

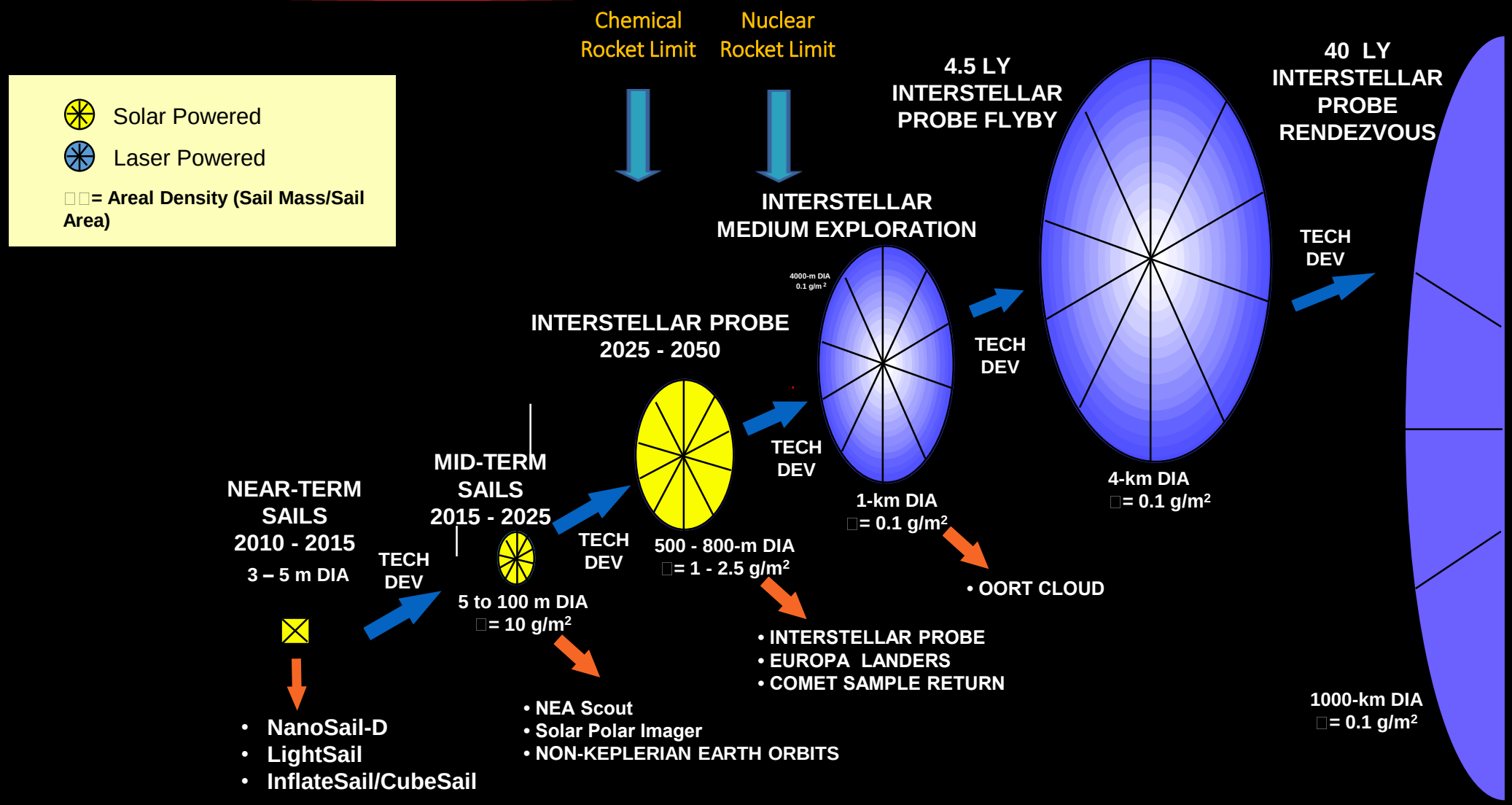
Ground to space laser illumination of a solar sail to impart measurable ΔV



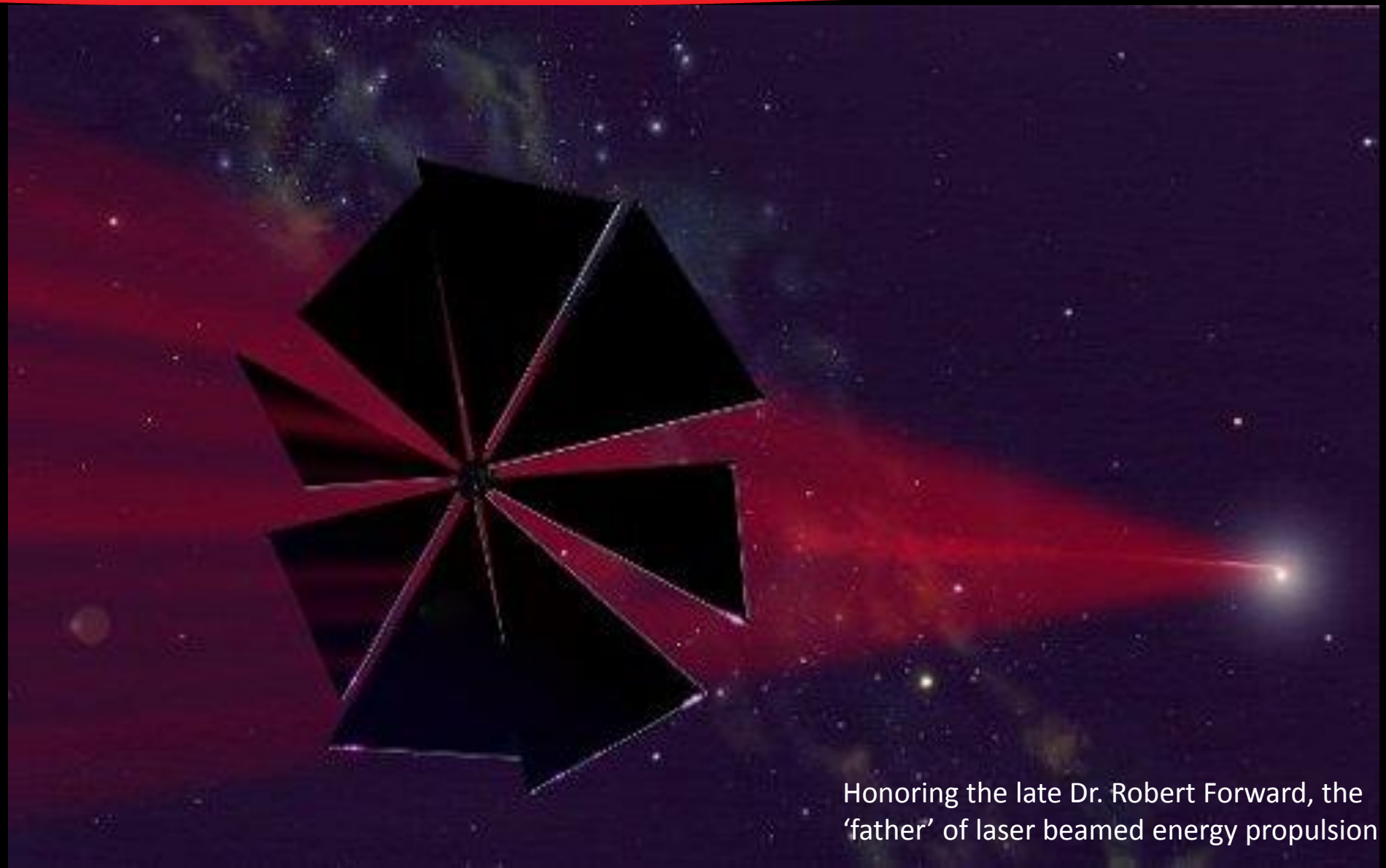
What about Breakthrough Starshot?



My Real Motive…



Solar Sails: A Step Toward the Stars



Honoring the late Dr. Robert Forward, the ‘father’ of laser beamed energy propulsion