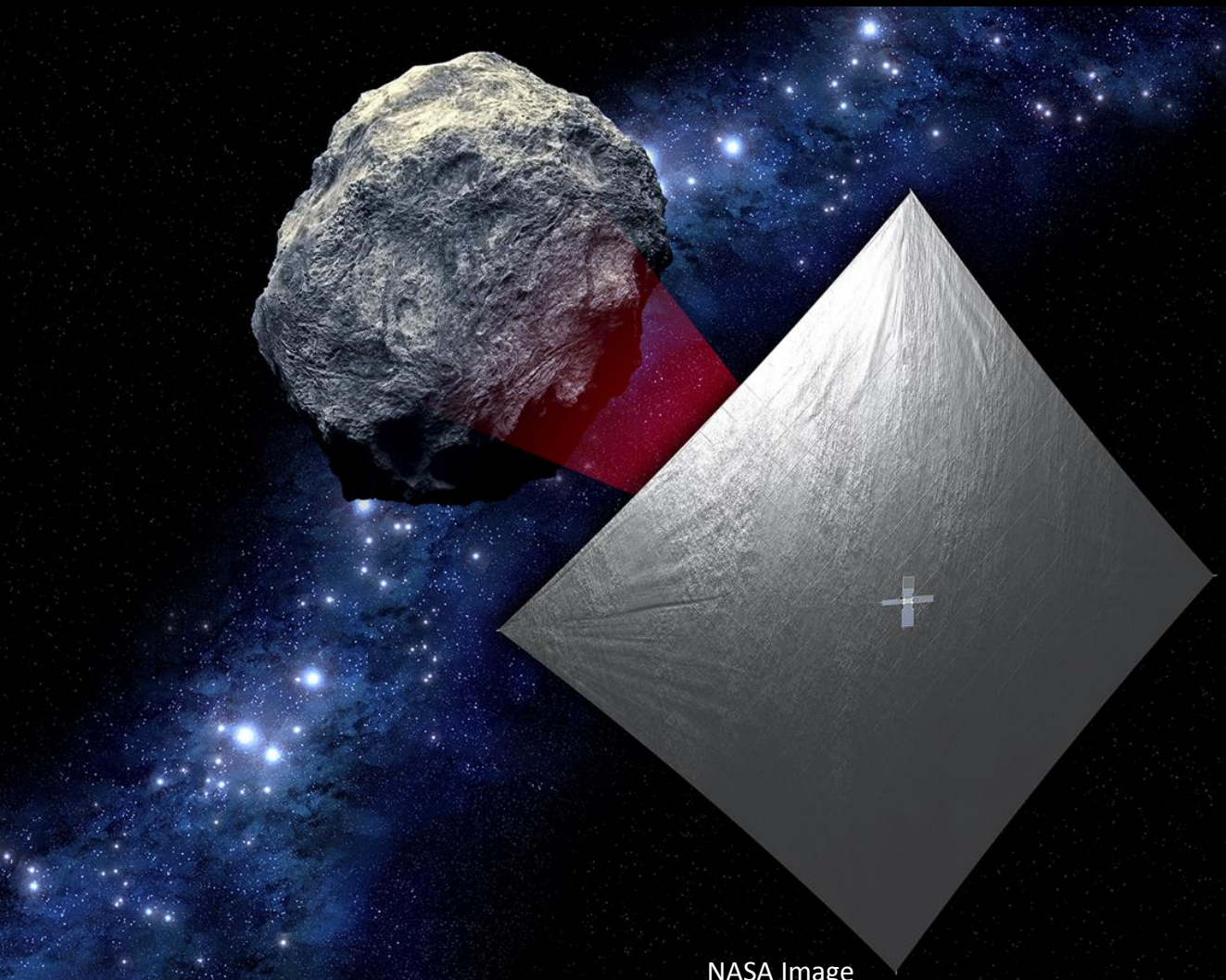
Solar Sails



NASA Image

Les Johnson
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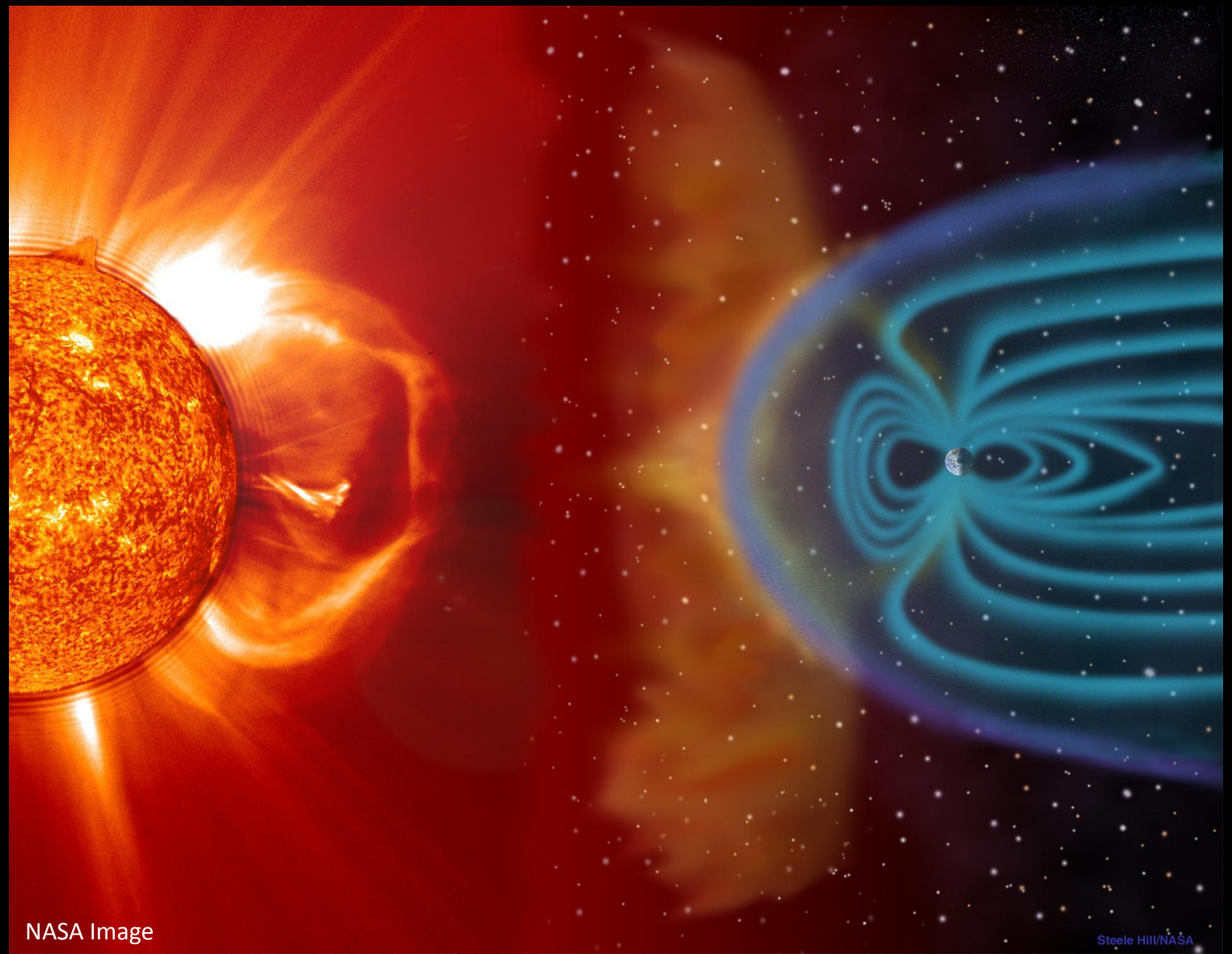
We tend to think of space as being

big and empty…

NASA Image

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

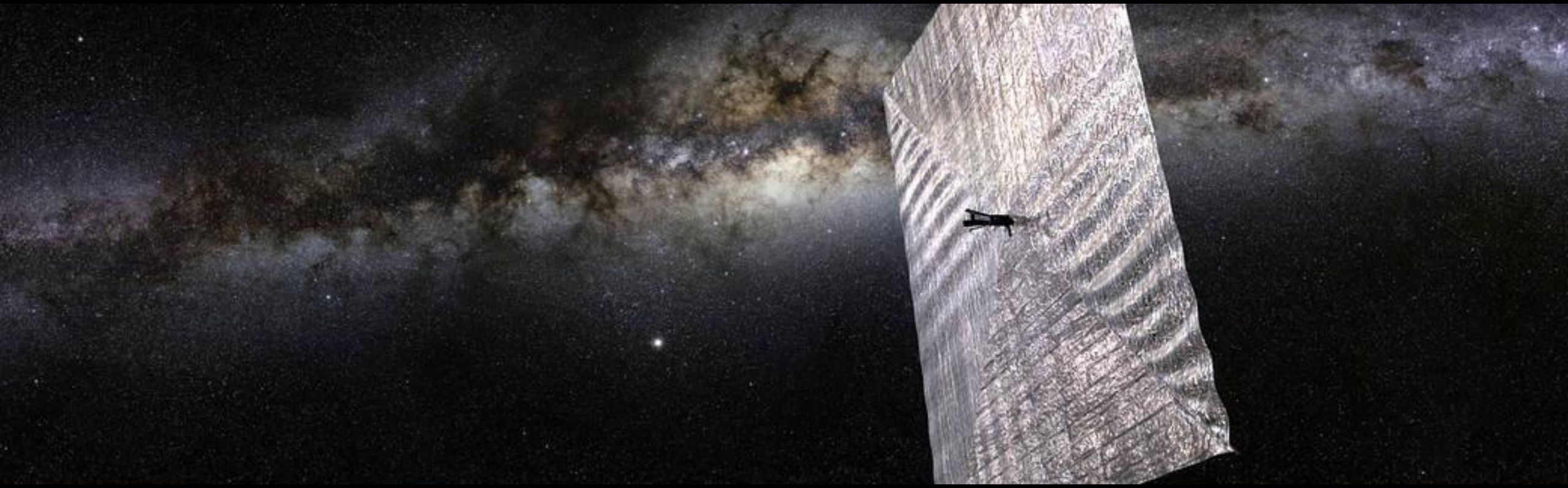


NASA Image

Just As Sailing Ships Can Use the Momentum of the Wind

U.S. Navy Image

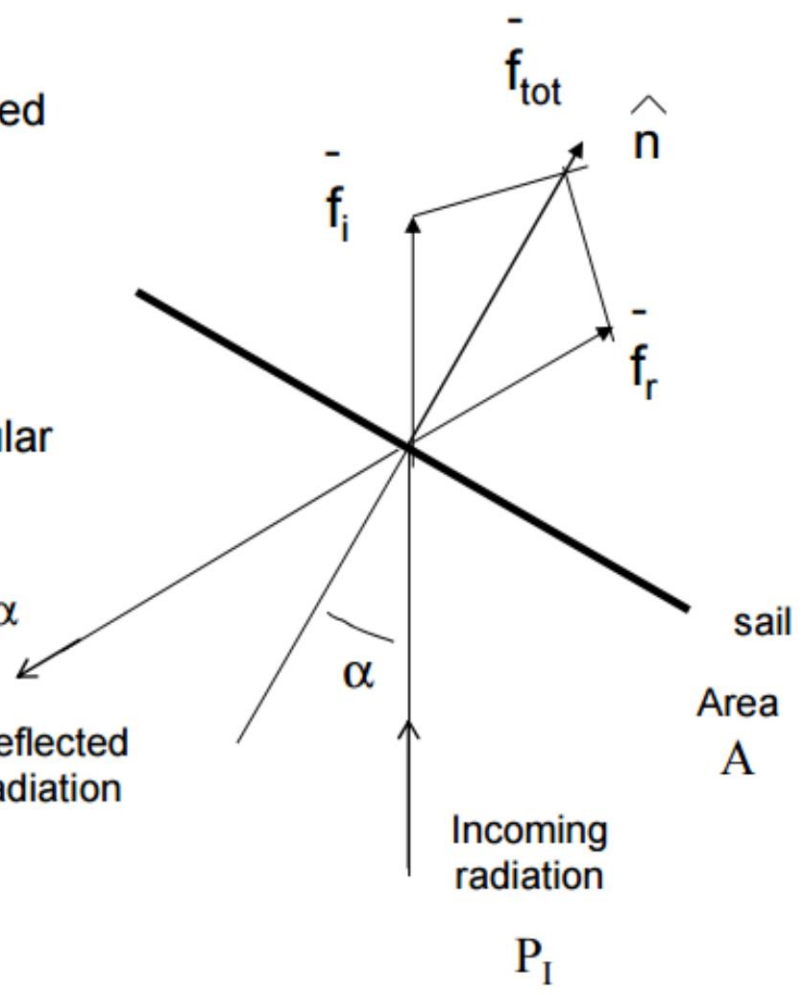
Spacecraft Can Use the Momentum of Sunlight



NASA Image

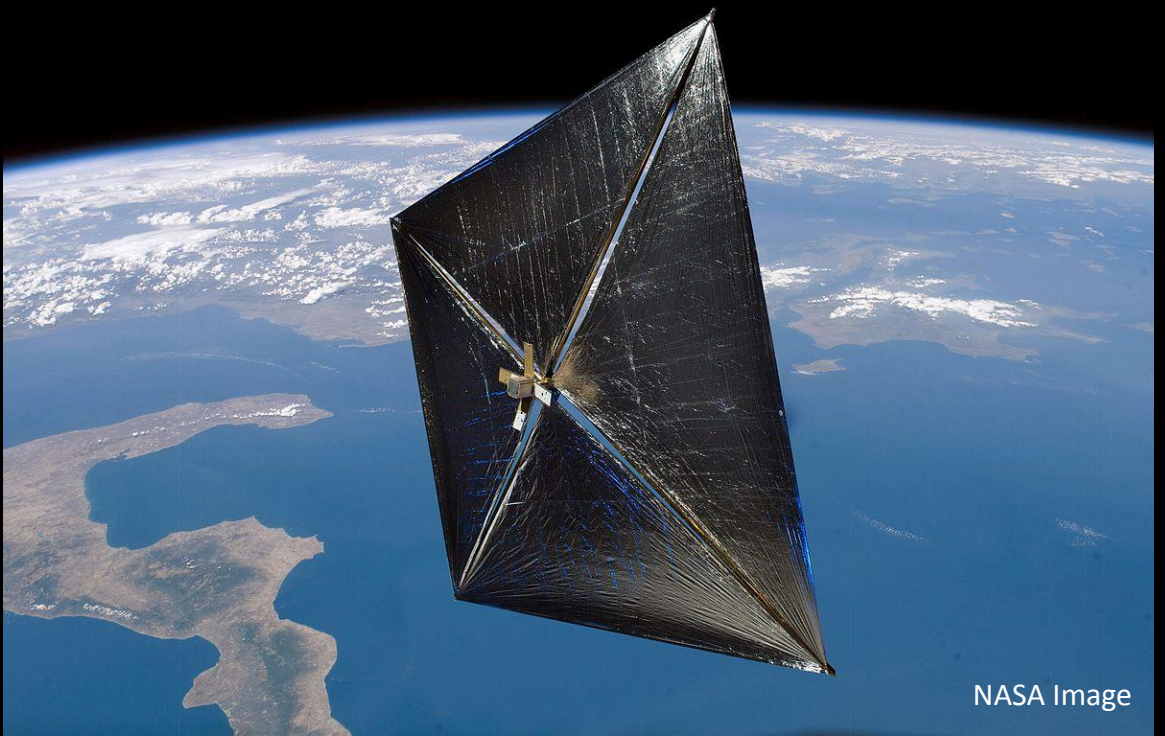
Photons Have Momentum

- **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

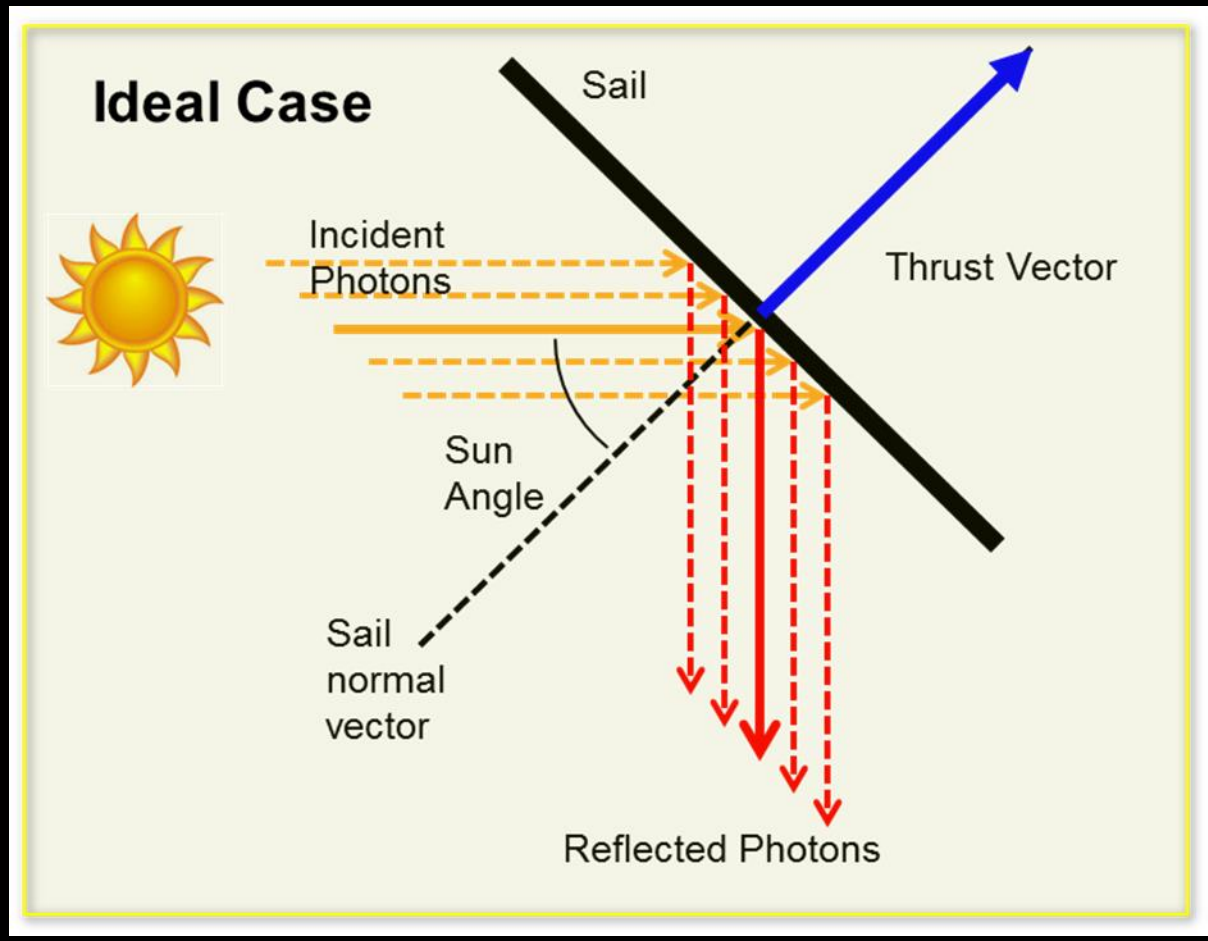


Yes we can! With solar sails…

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

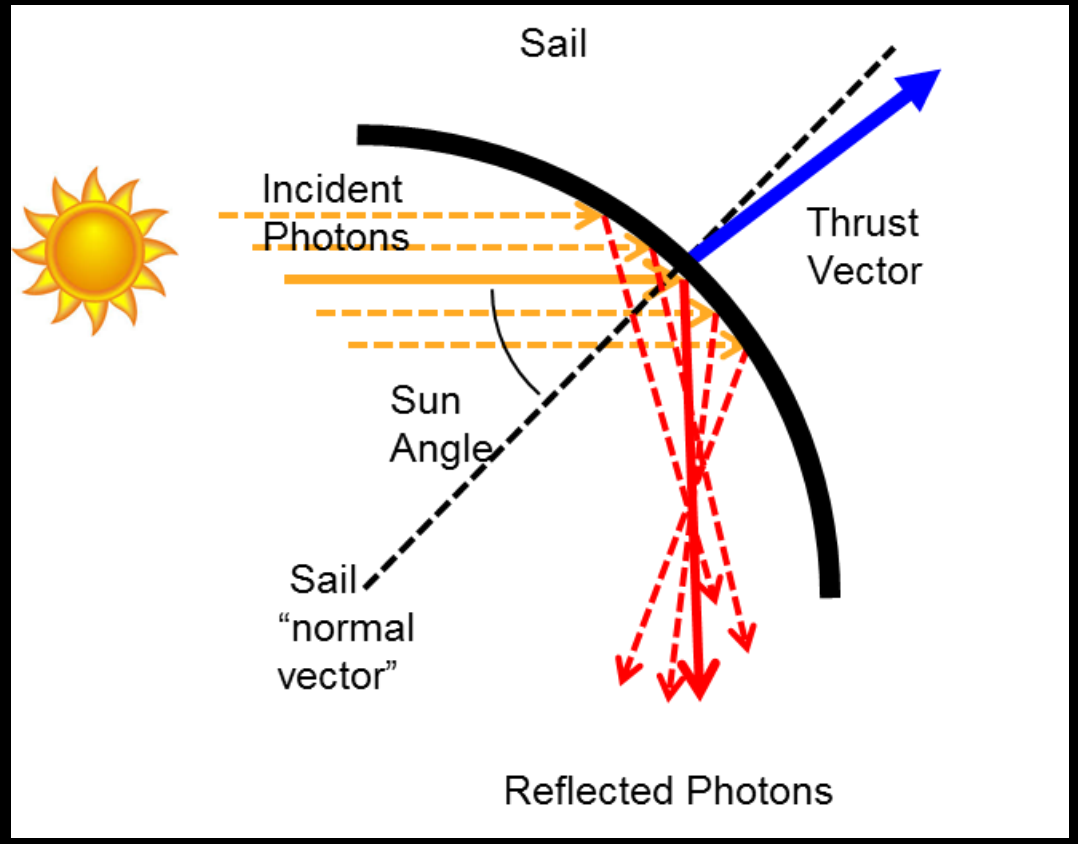


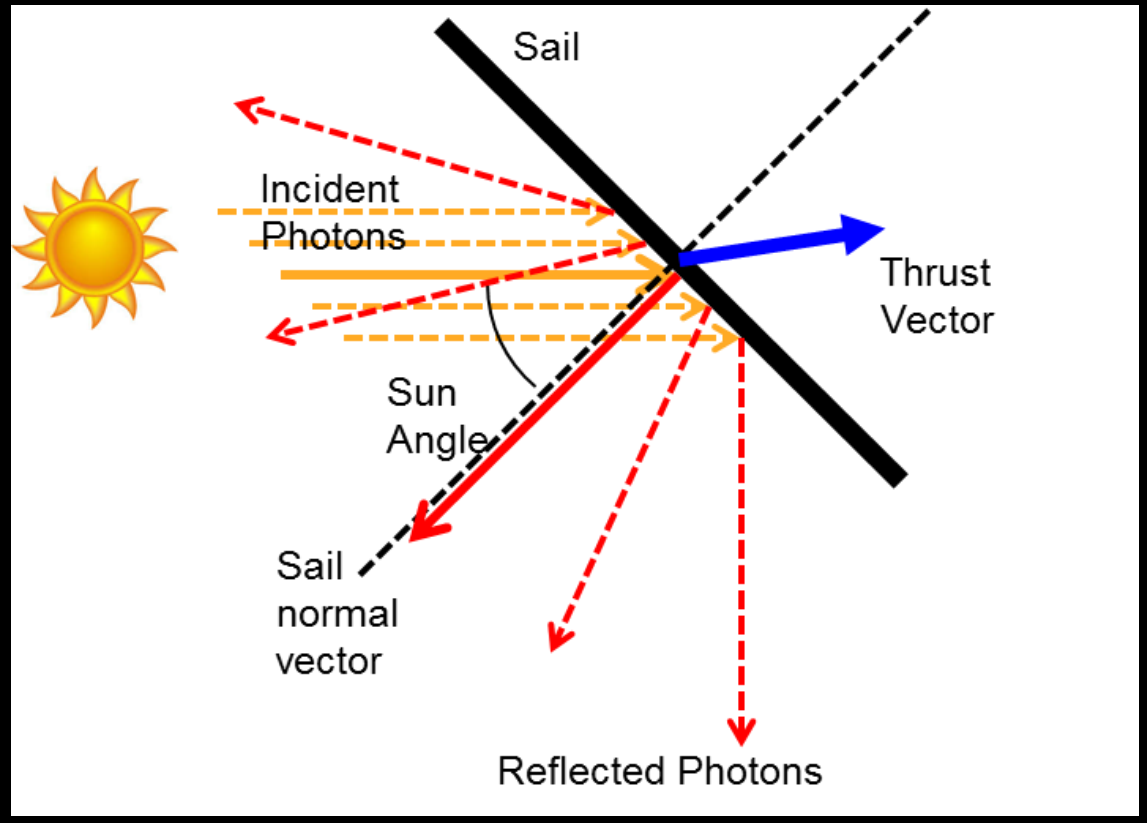
NASA Image



Real Solar Sails Are Not “Ideal”

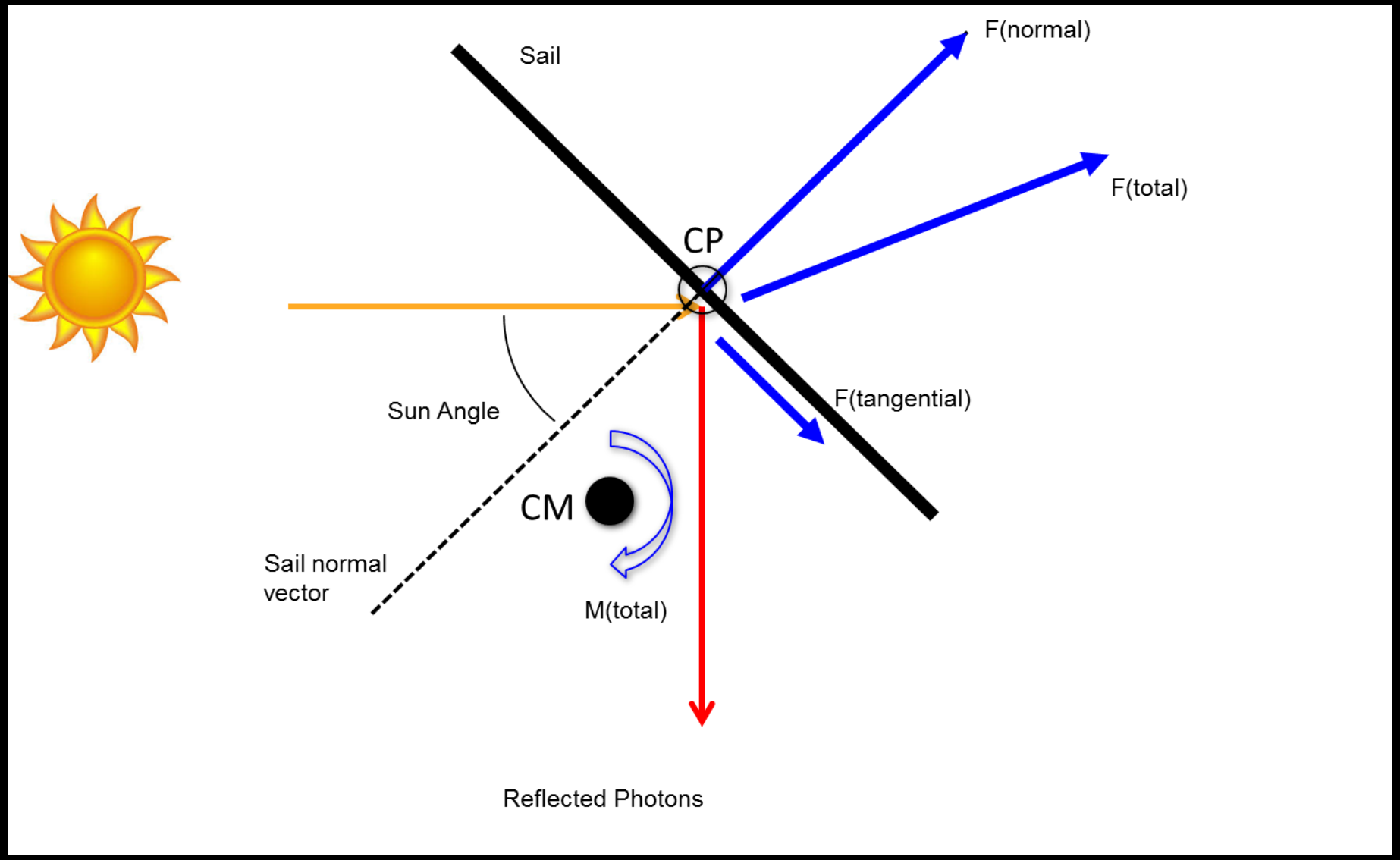
Billowed Quadrant





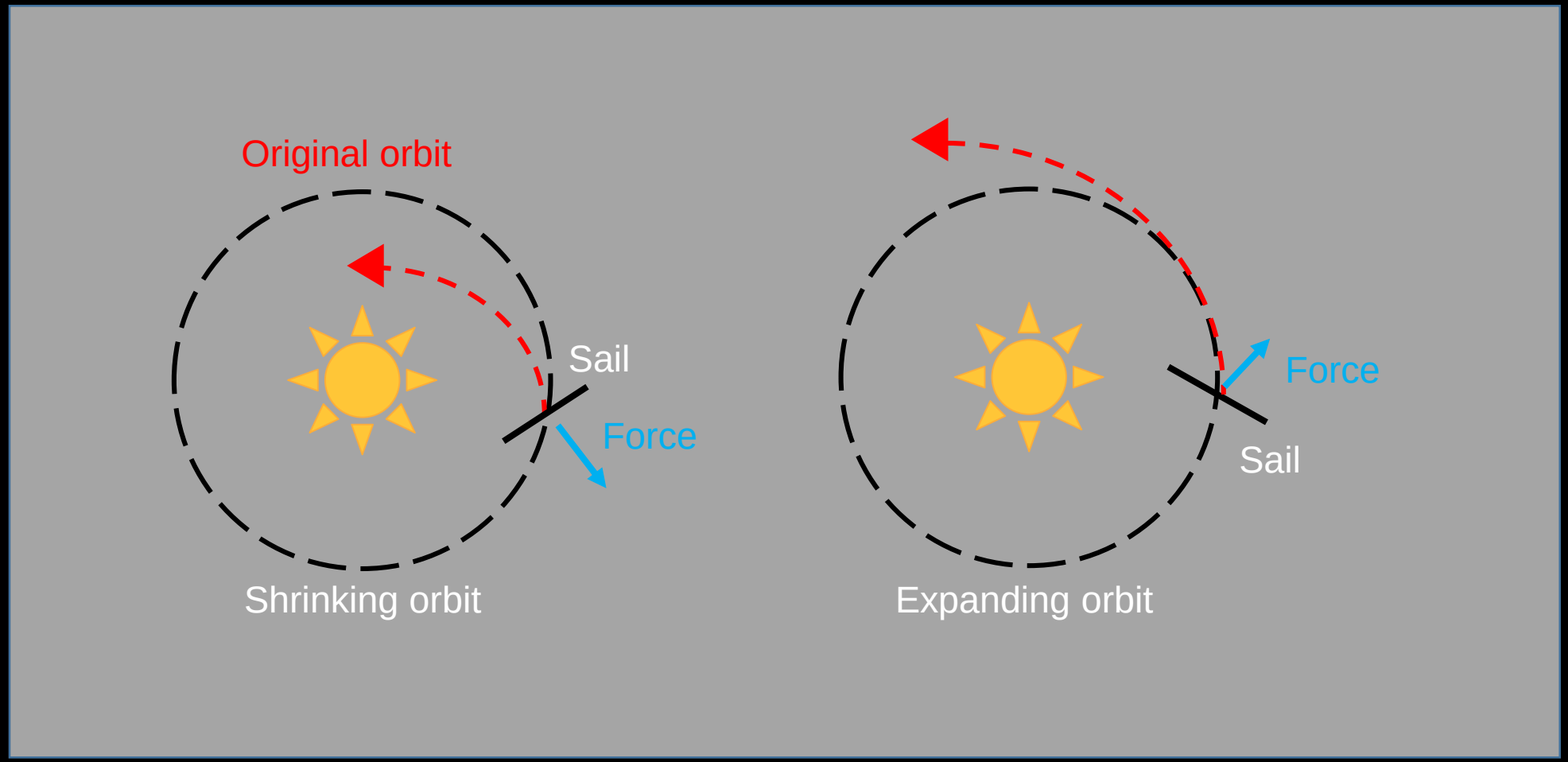
Diffuse Reflection

Thrust Vector Components



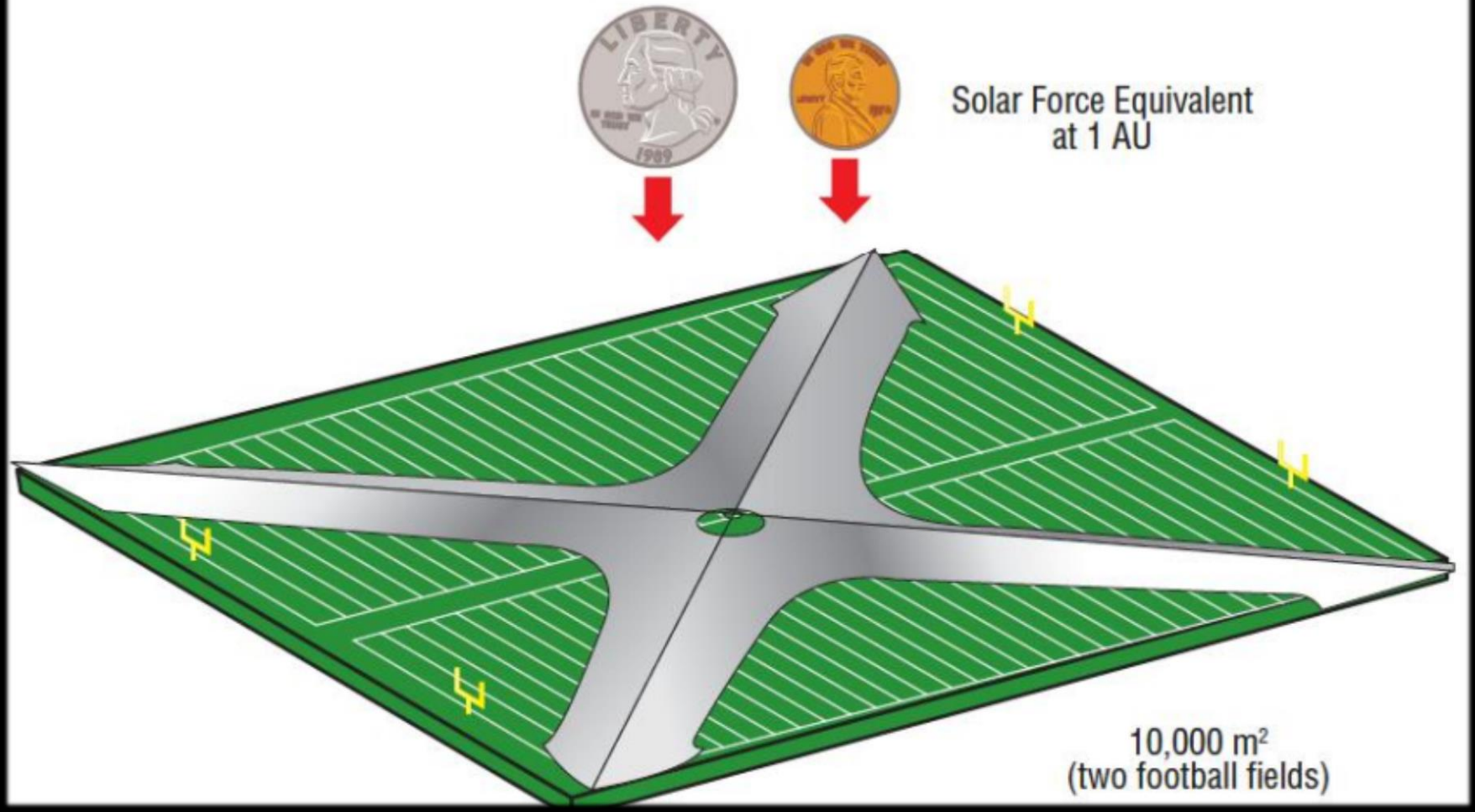
Solar Sail Trajectory Control

- 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

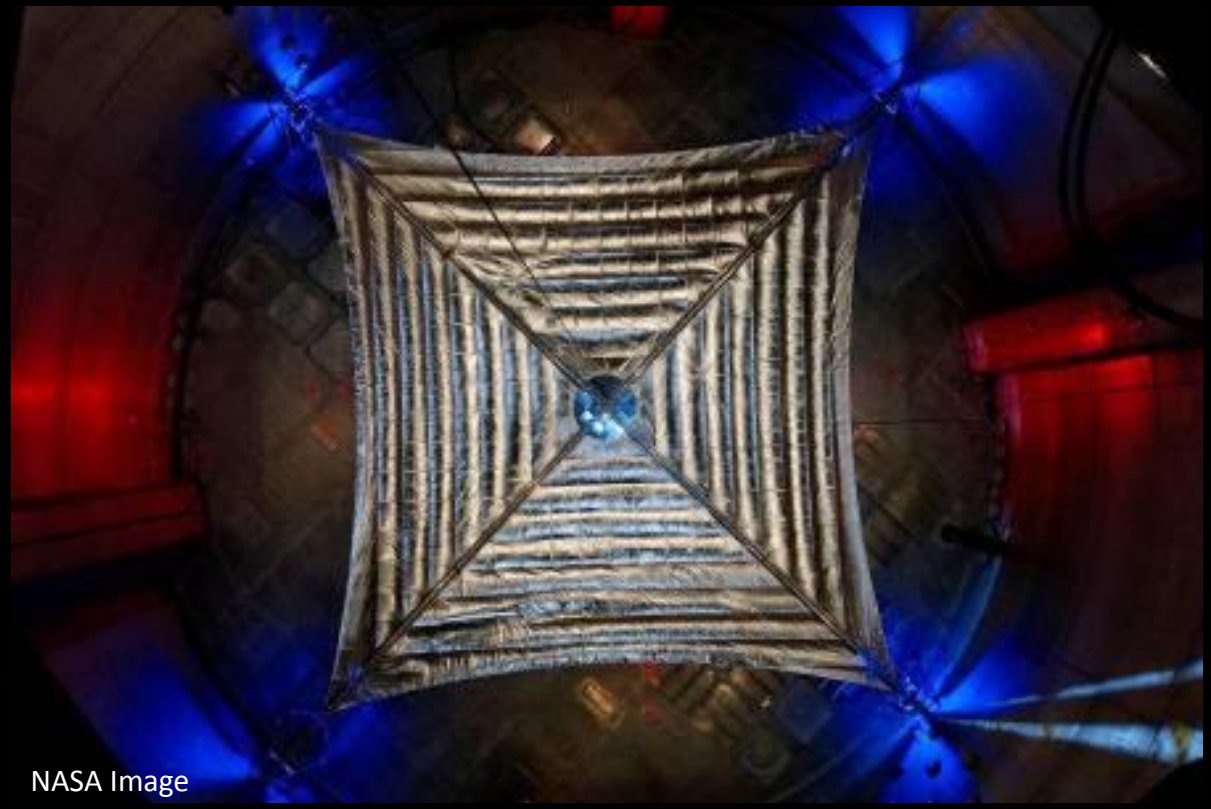
NASA Image

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

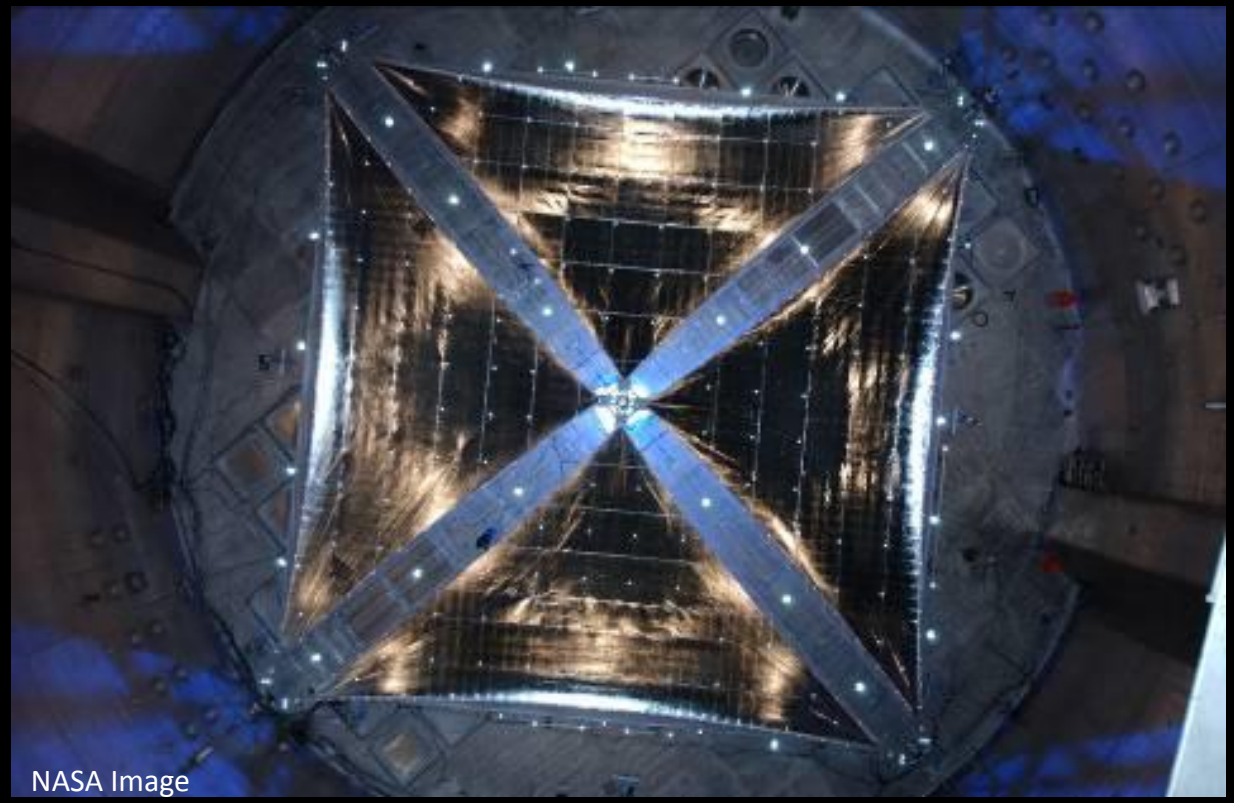
- **135-foot rigidized inflatable balloon satellite**
- **laminated Mylar plastic and aluminum**
- **placed in near-polar Orbit**
- **passive communications experiment by NASA on January 25, 1964**

NASA Image

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



NASA Image

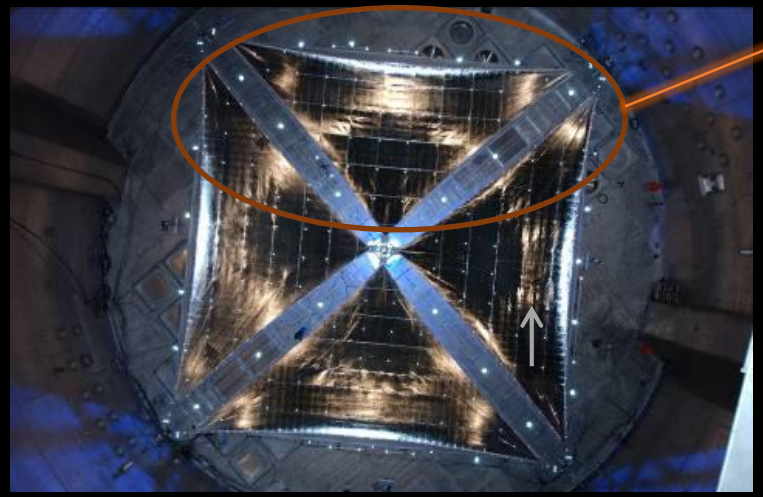


NASA Image

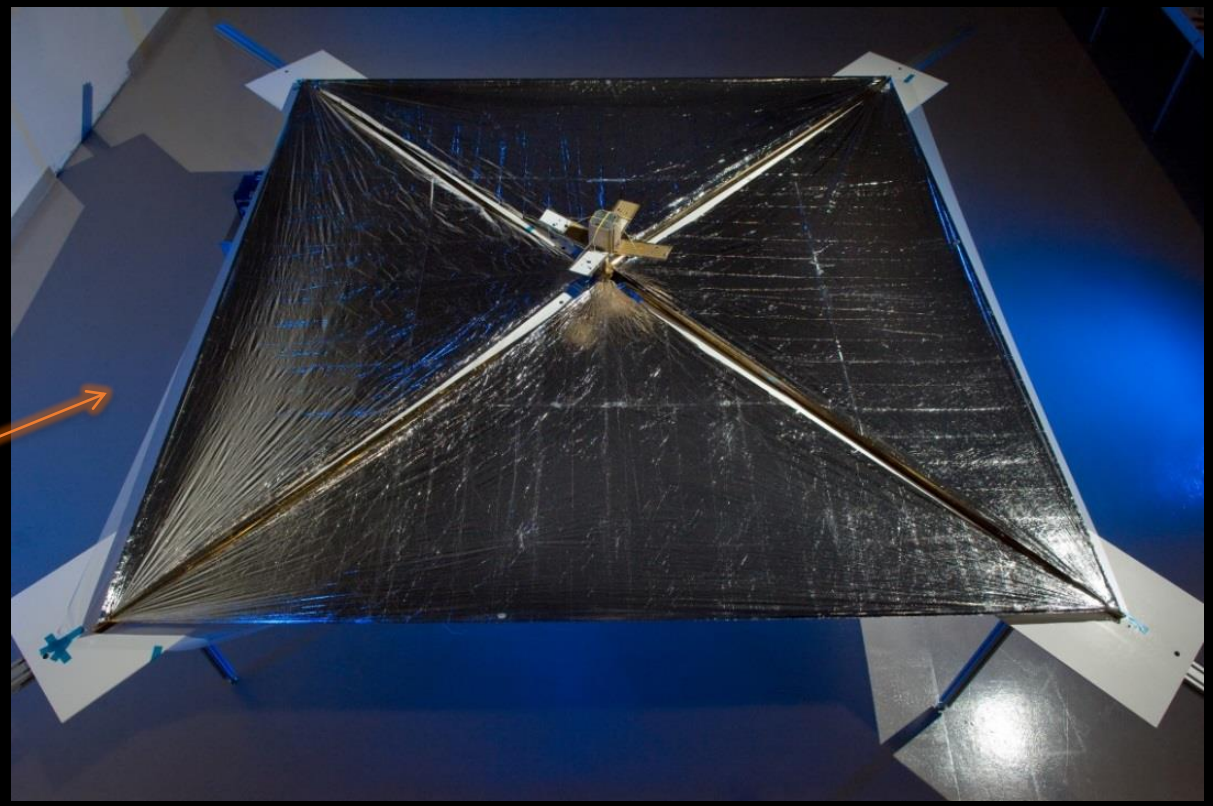
NanoSail-D Demonstration Solar Sail

Mission Description:

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



NASA Image



NASA Image

Lightsail-A
(The Planetary Society)

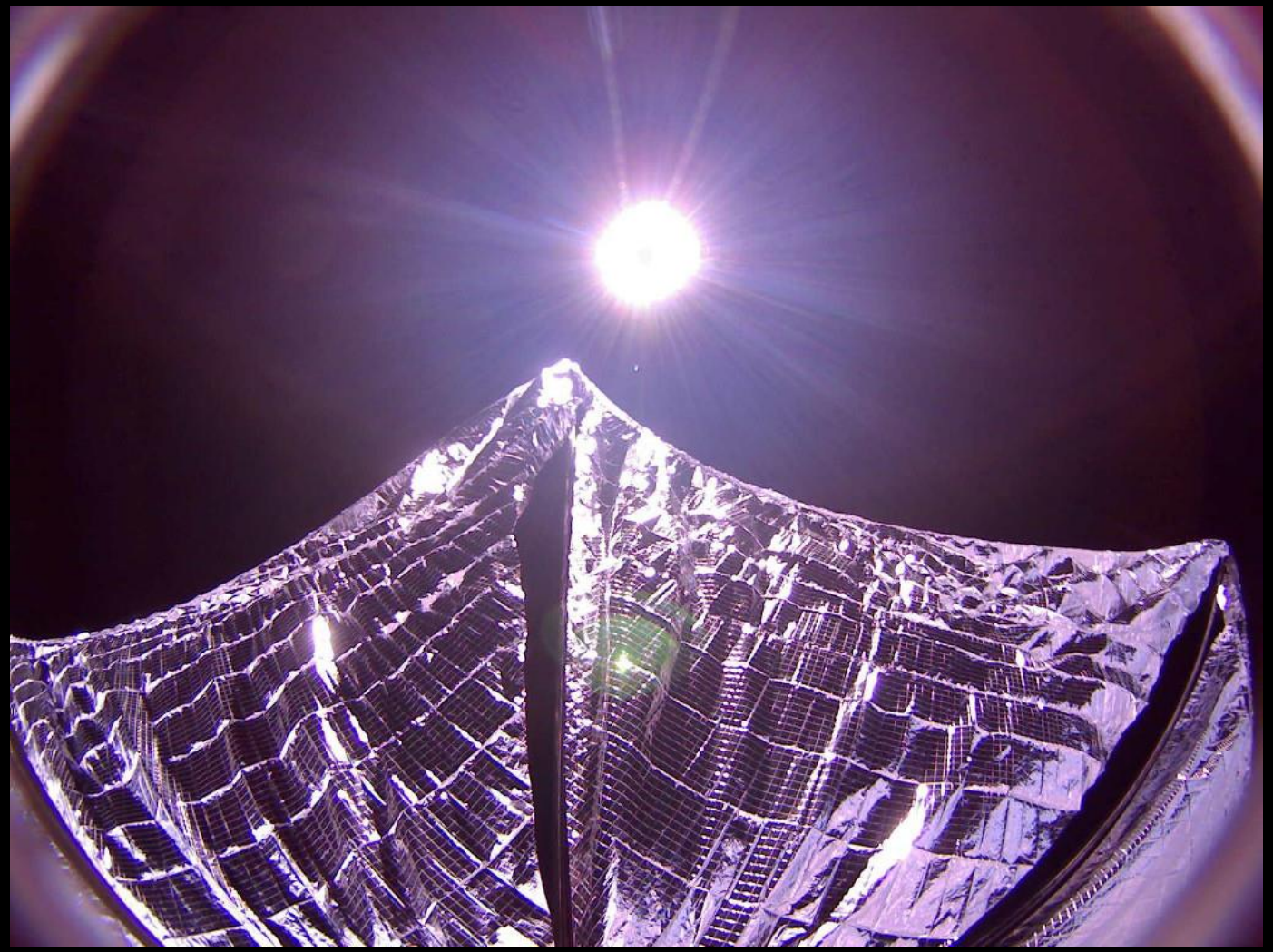


Image Courtesy of The Planetary Society

- **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

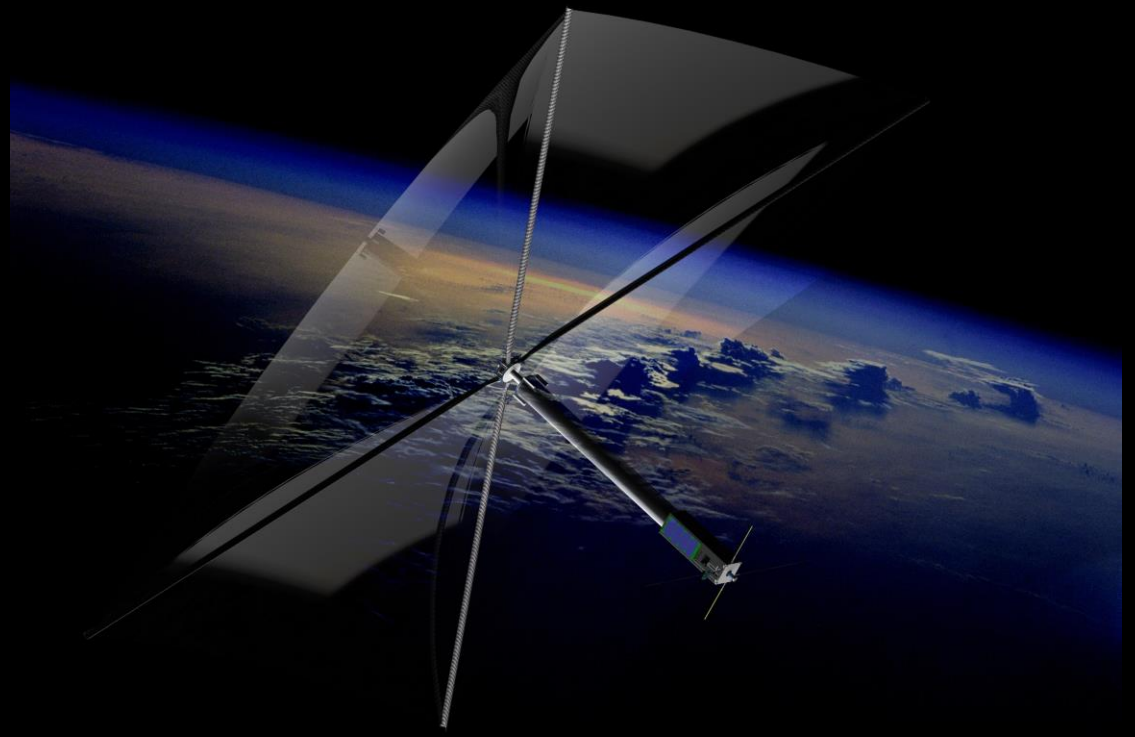


Image Courtesy of The University of Surrey

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

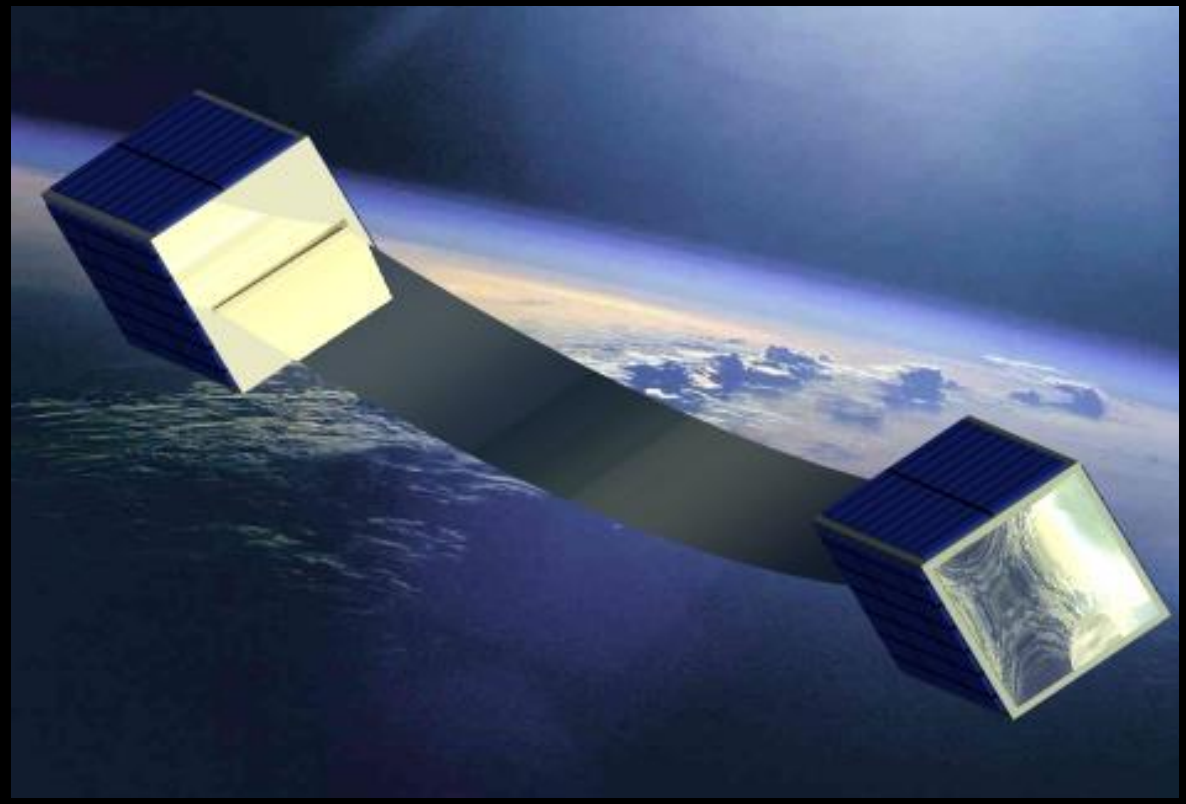
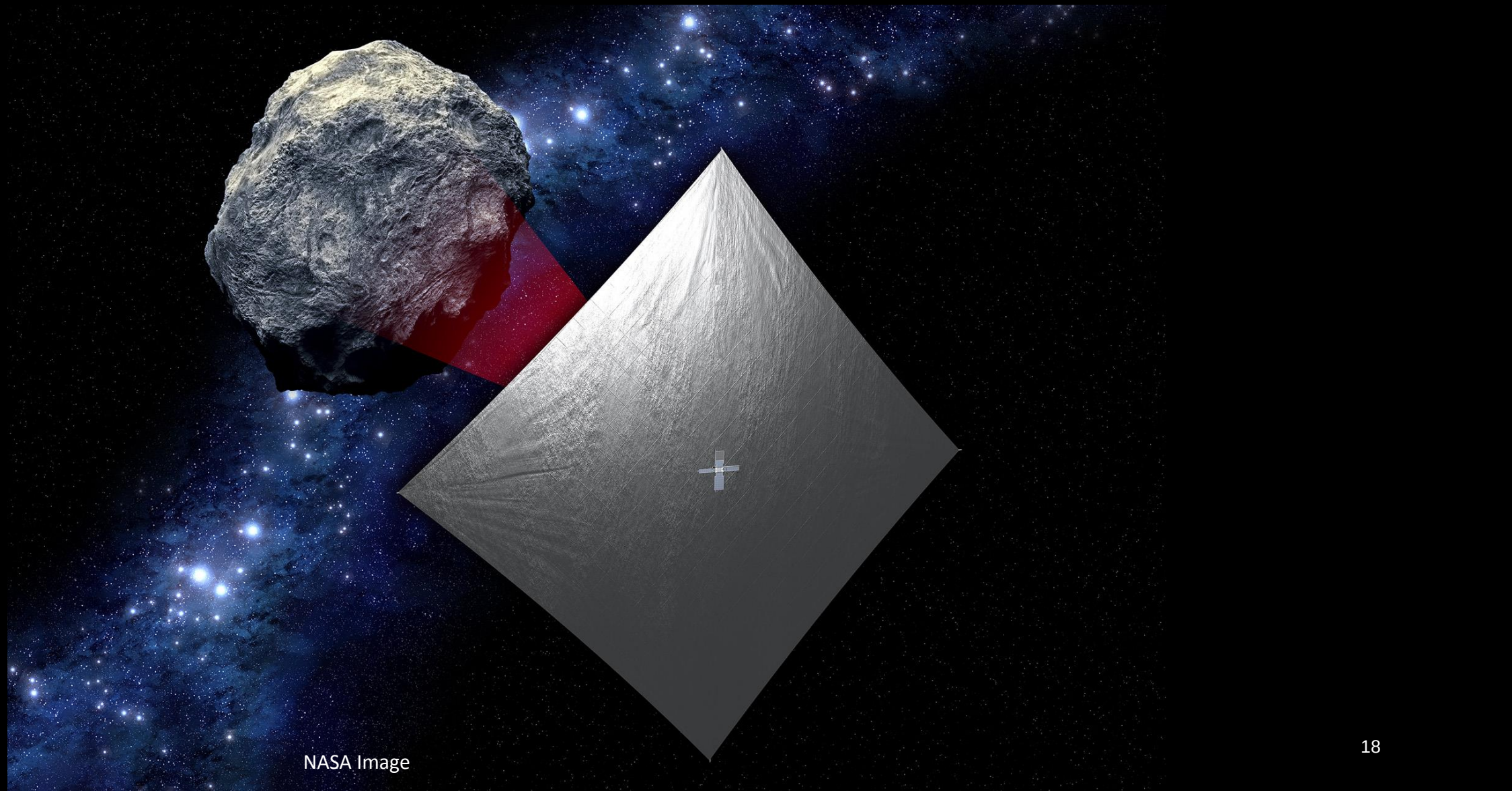


Image Courtesy of CU Aerospace

Near Earth Asteroid (NEA) Scout



NASA Image

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

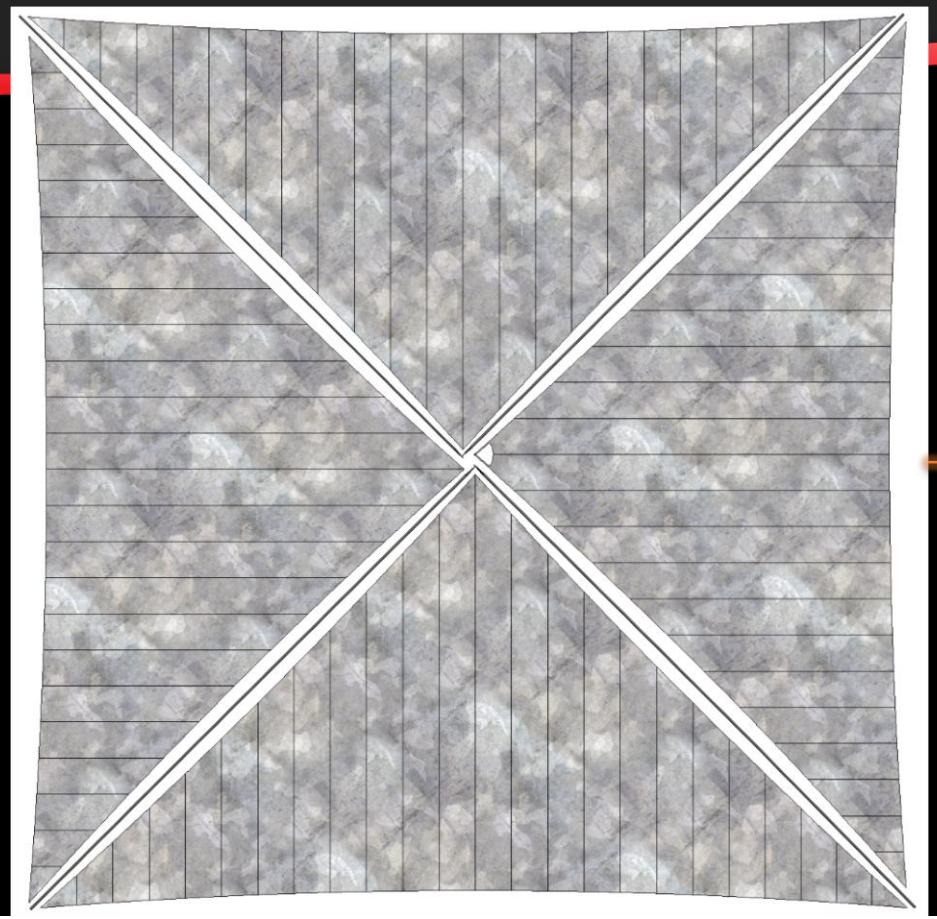
Solar Sail Propulsion System Characteristics

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

NASA Image

NEA Scout Approximate Scale

Deployed Solar Sail



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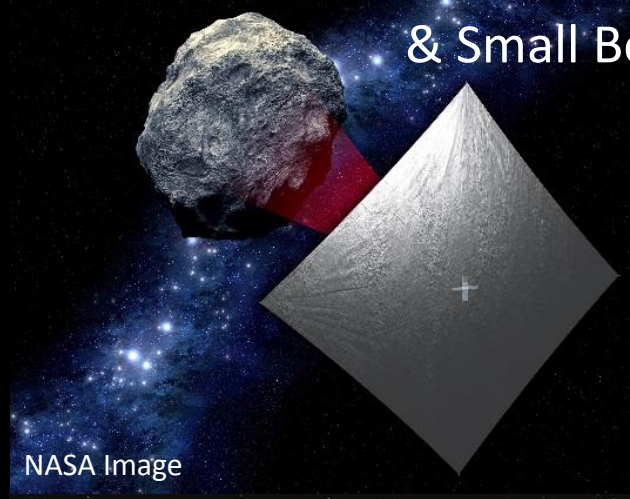
6U Stowed Flight System

School Bus

Public Domain Image

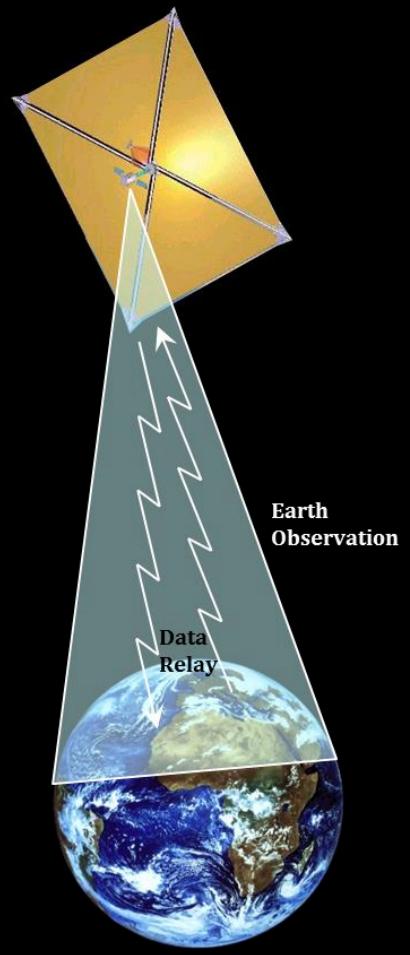
Potential Solar Sail Applications
(A Partial List!)

NEA Reconnaissance & Small Body Science



NASA Image

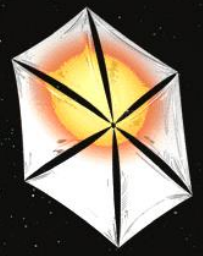
Earth Pole Sitting



NASA Image

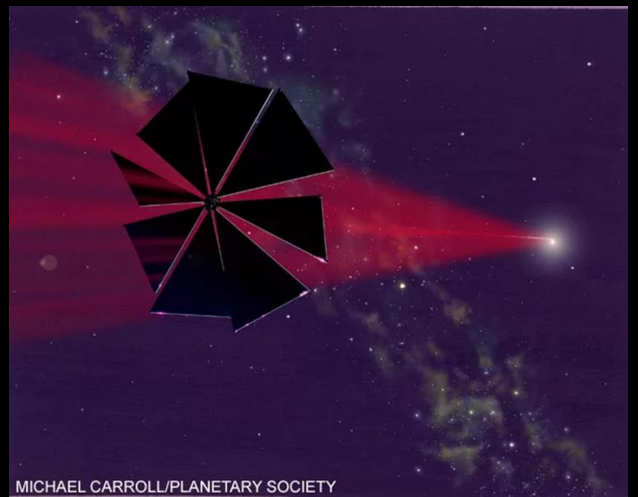
Rapid Outer Solar System Exploration and Escape

Heliophysics & Out of the Ecliptic Science



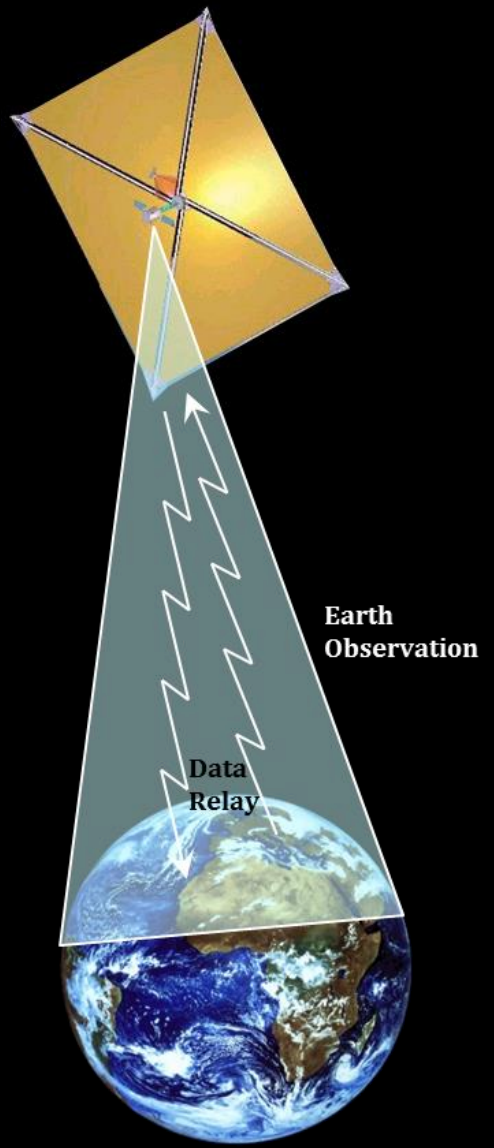
NASA Image

Toward Higher Performance Beamed Energy Propulsion



MICHAEL CARROLL/PLANETARY SOCIETY

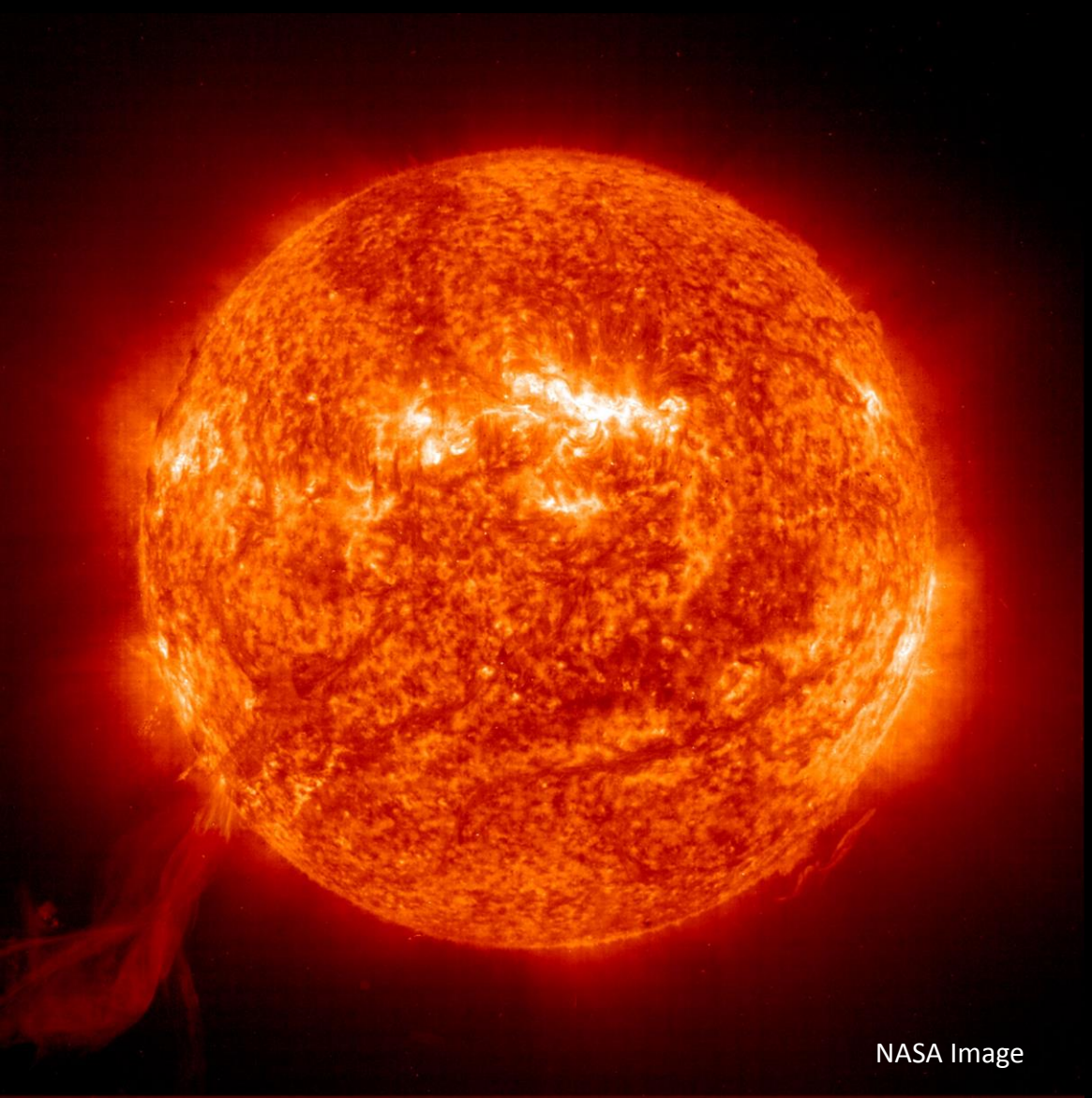
Possible Future Mission
Continuous Polar Observations



NASA Image

- 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



NASA Image

- 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

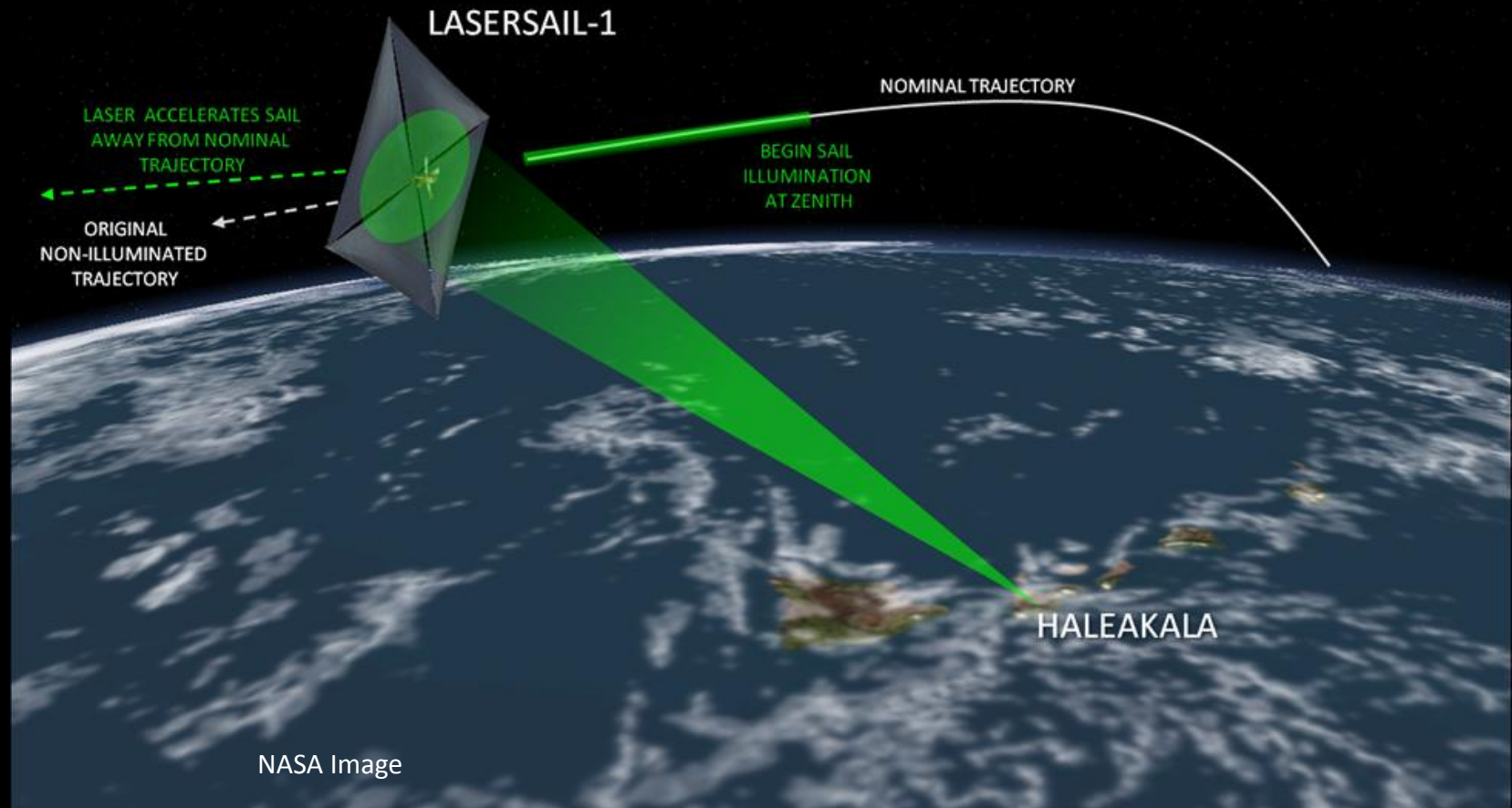
Deploy a large (>10,000 m^2) solar sail near the sun to enable travel 4X - 5X faster than Voyager

Goal: Reach 250 Astronomical Units within 20 years of launch

NASA Image

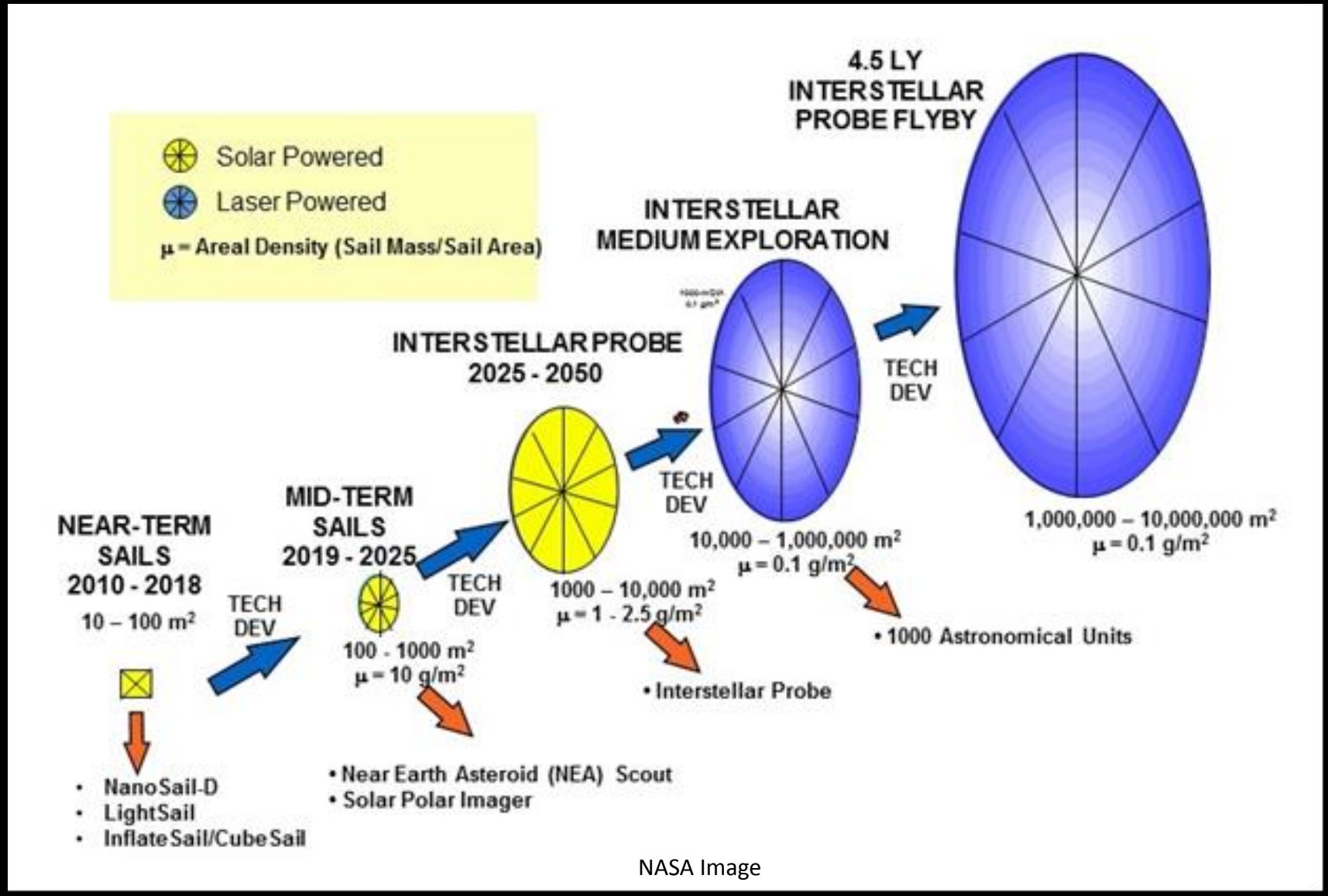
Laser Sailing: The Next **Big** Step

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



NASA Image

My Real Motive…



NASA Image

Solar Sails: A Step Toward the Stars