Sailing on Sunlight - Solar Sails for Exploring the Solar System and Beyond



Les Johnson

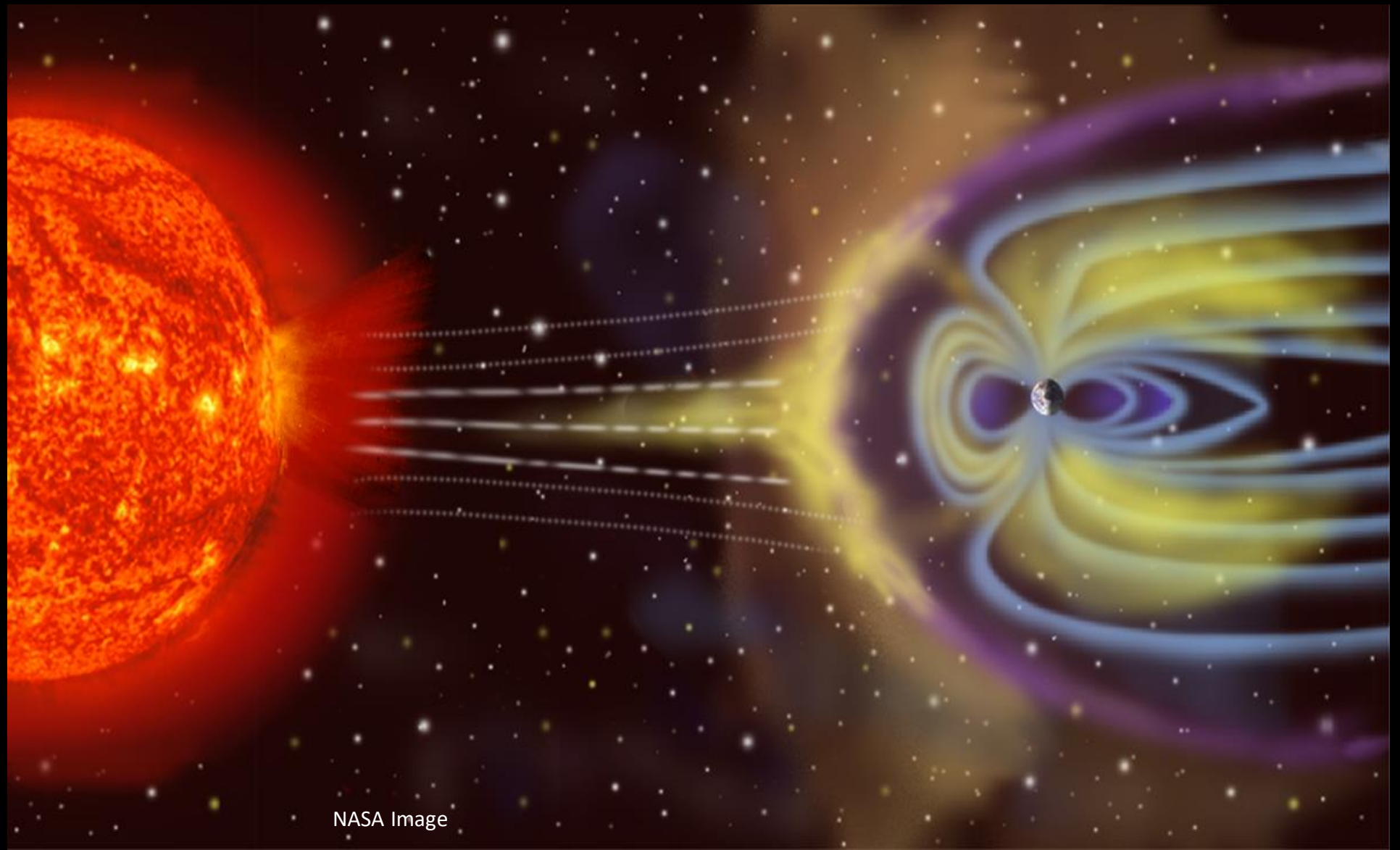
NASA
George C. Marshall Space Flight Center

We tend to think of space as being



NASA Image

Space Is NOT Empty. We can use the environments of space to our advantage



NASA Image

Just As Sailing Ships Can Use the Momentum of the Wind

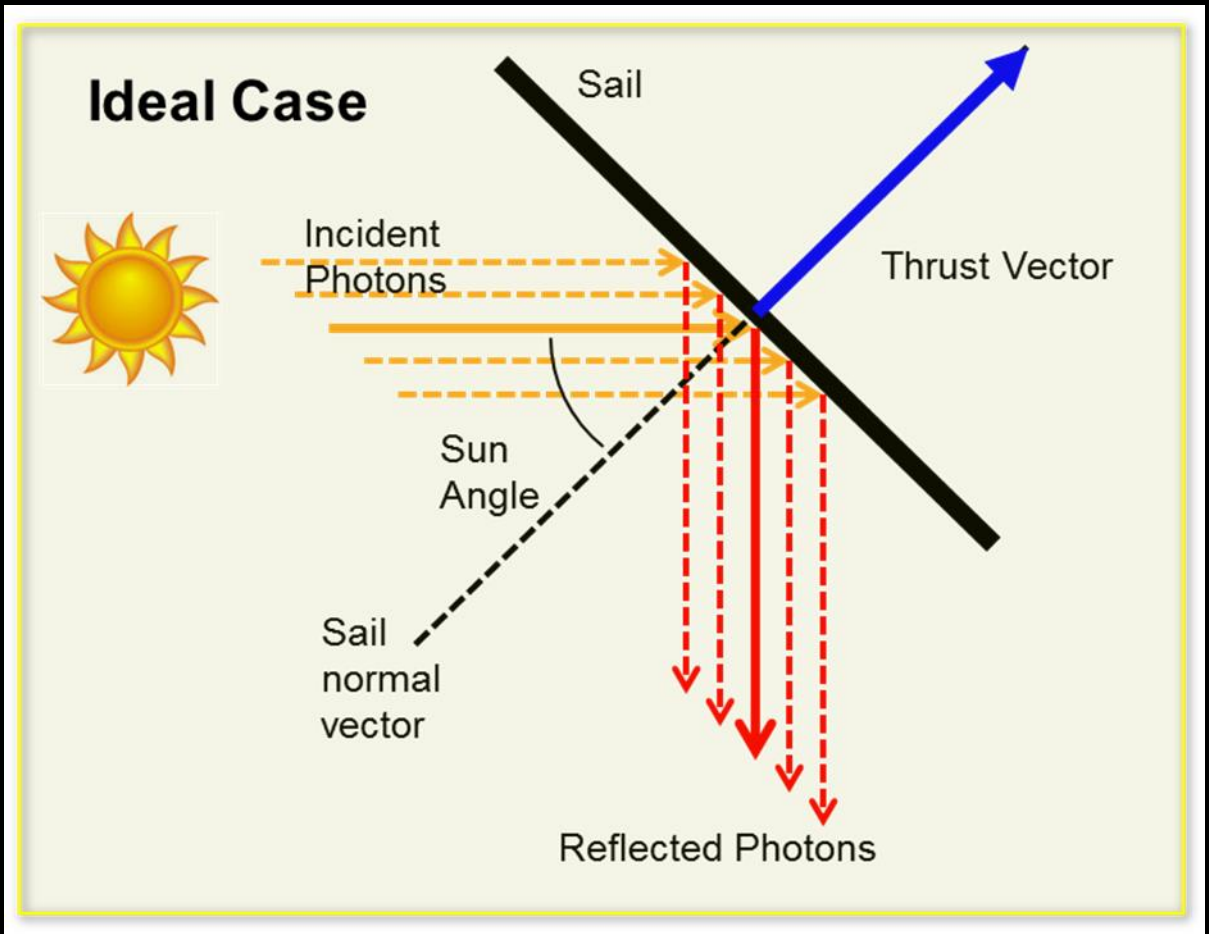


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Solar Sails Derive Propulsion By Reflecting Photons

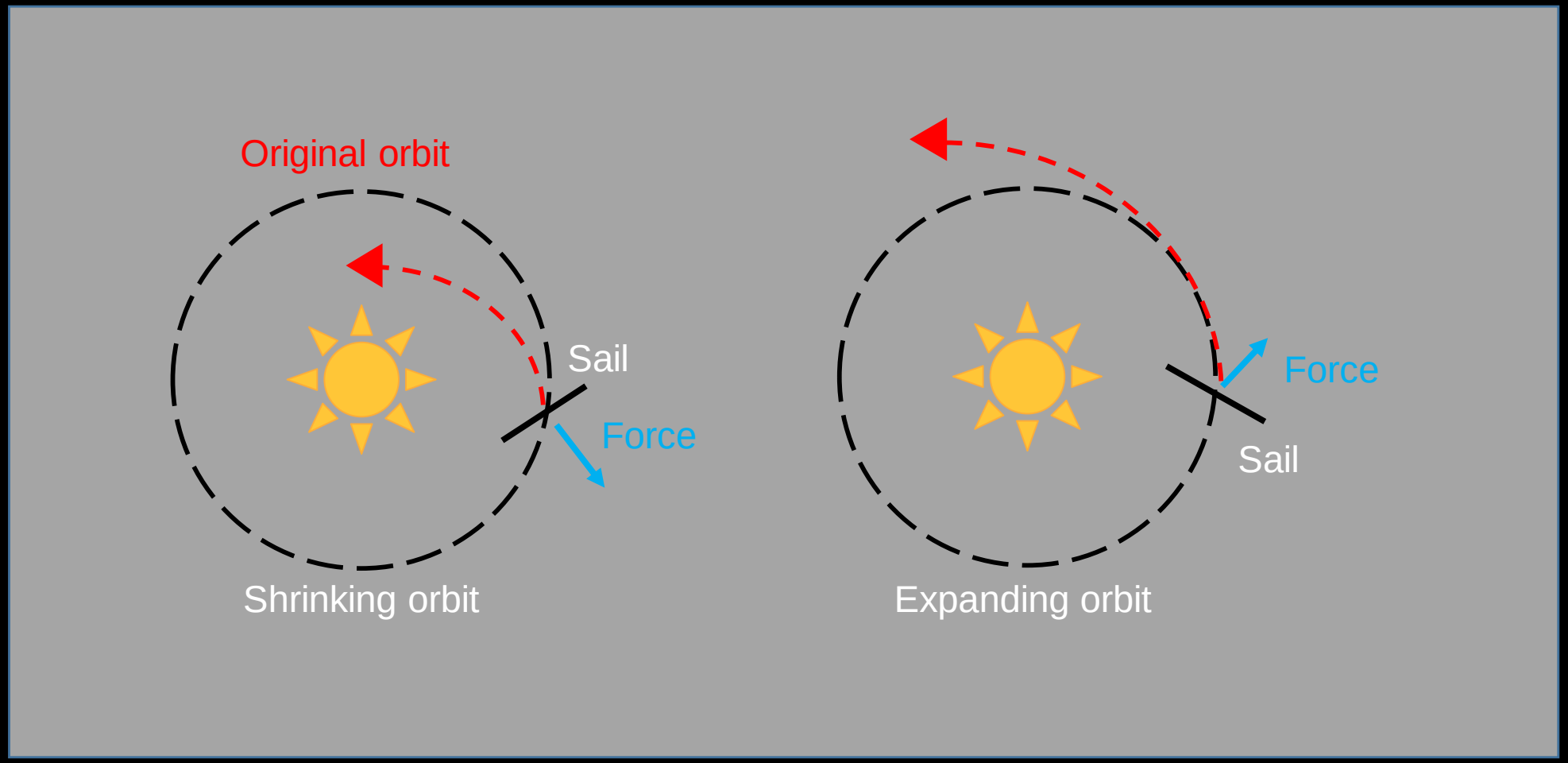
Solar sails use photon “pressure” or force on thin, lightweight, reflective sheets to produce thrust.


NASA Image

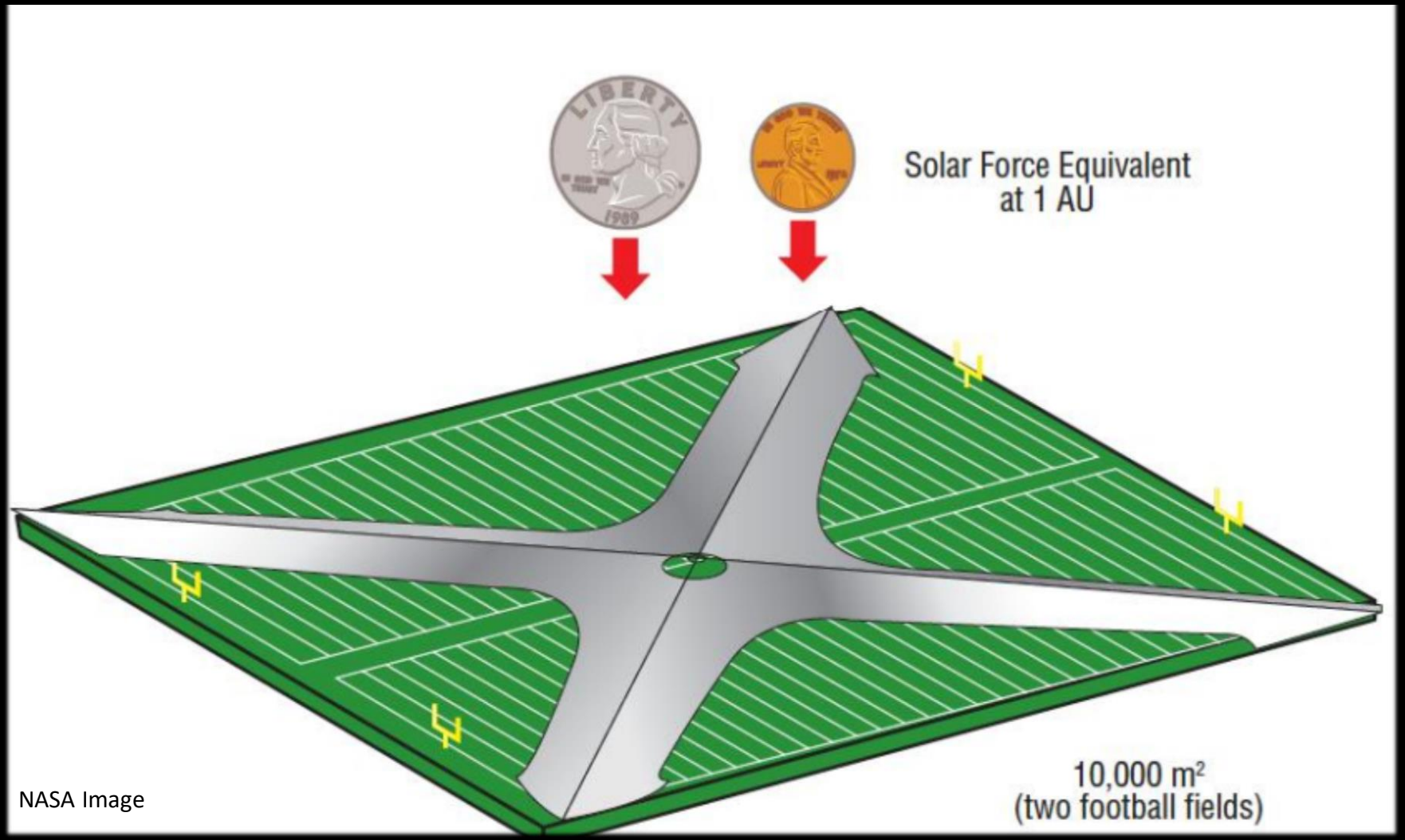


Solar Sail Trajectory Control

Sunlight Pressure allows inward or outward spiral toward or away from the sun

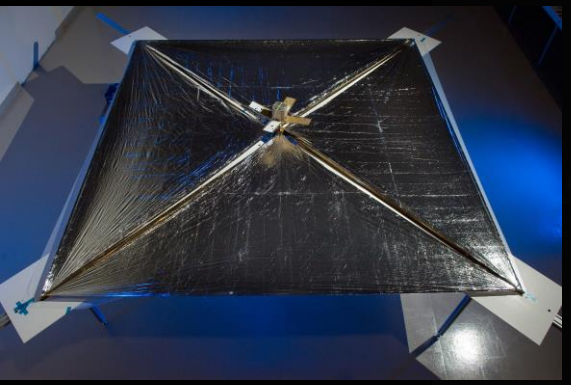


Solar Sails Experience **VERY** Small Forces



NASA Image

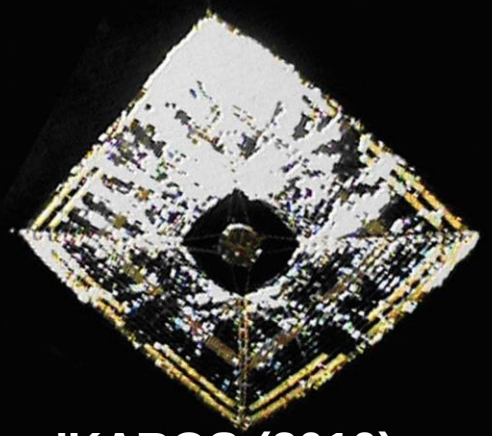
Solar Sail Missions Flown



NanoSail-D (2010)
NASA

Earth Orbit
Deployment Only

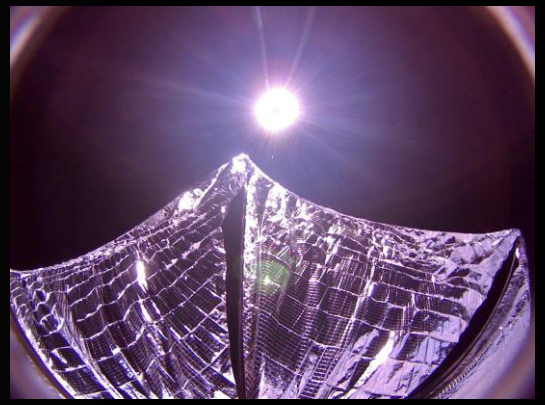
3U CubeSat
100 ft²



IKAROS (2010)
JAXA

Interplanetary
Full Flight

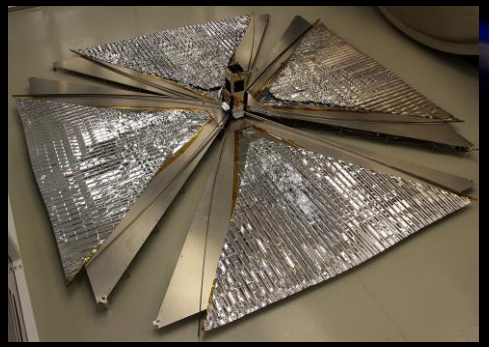
315 kg Smallsat
2109 ft²



LightSail-1 & 2
(2015/2019)
The Planetary Society

Earth Orbit
Deployment / Flight

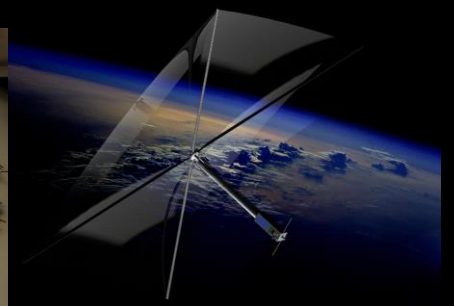
3U CubeSat
345 ft²



CanX-7 (2016)
Canada

Earth Orbit
Deployment Only

3U CubeSat
<100 ft²

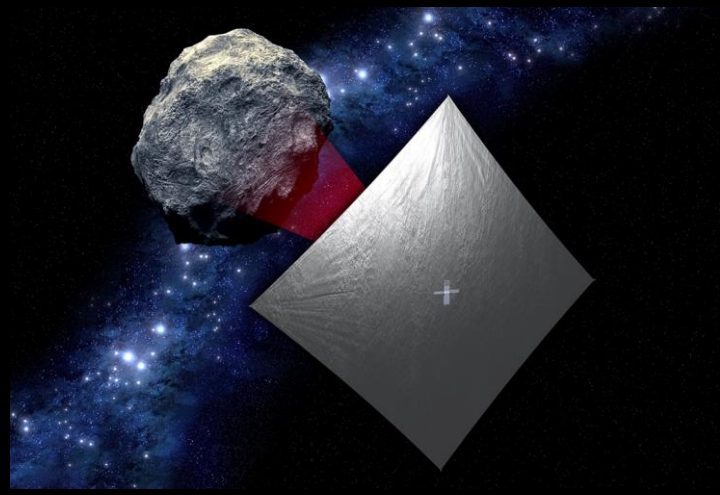


InflateSail (2017)
EU/Univ. of Surrey

Earth Orbit
Deployment Only

3U CubeSat
100 ft²

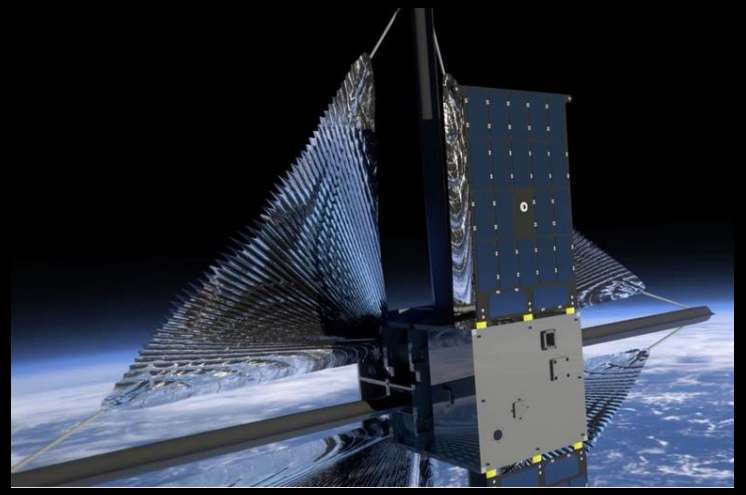
Planned Solar Sail Missions



Near Earth Asteroid Scout (2021) NASA

Interplanetary
Full Flight

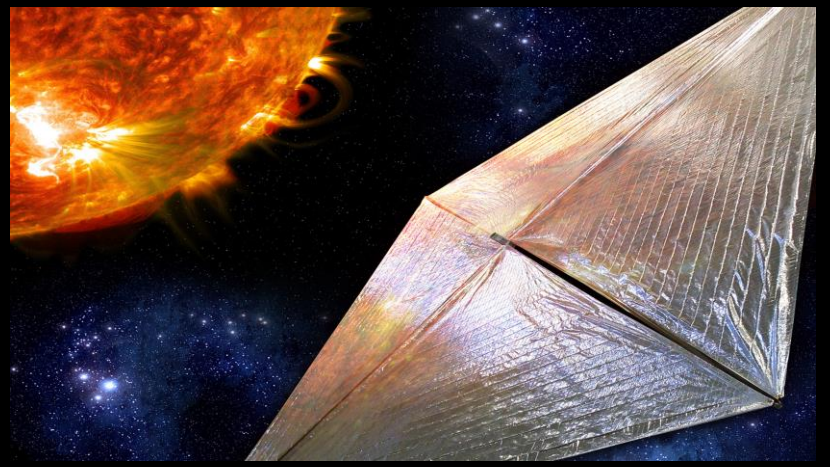
6U CubeSat
925 ft^2



Advanced Composite Solar Sail System (2022) NASA

Earth Orbit
Full Flight

12U CubeSat
796 ft^2



Solar Cruiser (2025) NASA

Interplanetary
Full Flight

100 kg spacecraft
17,793 ft^2

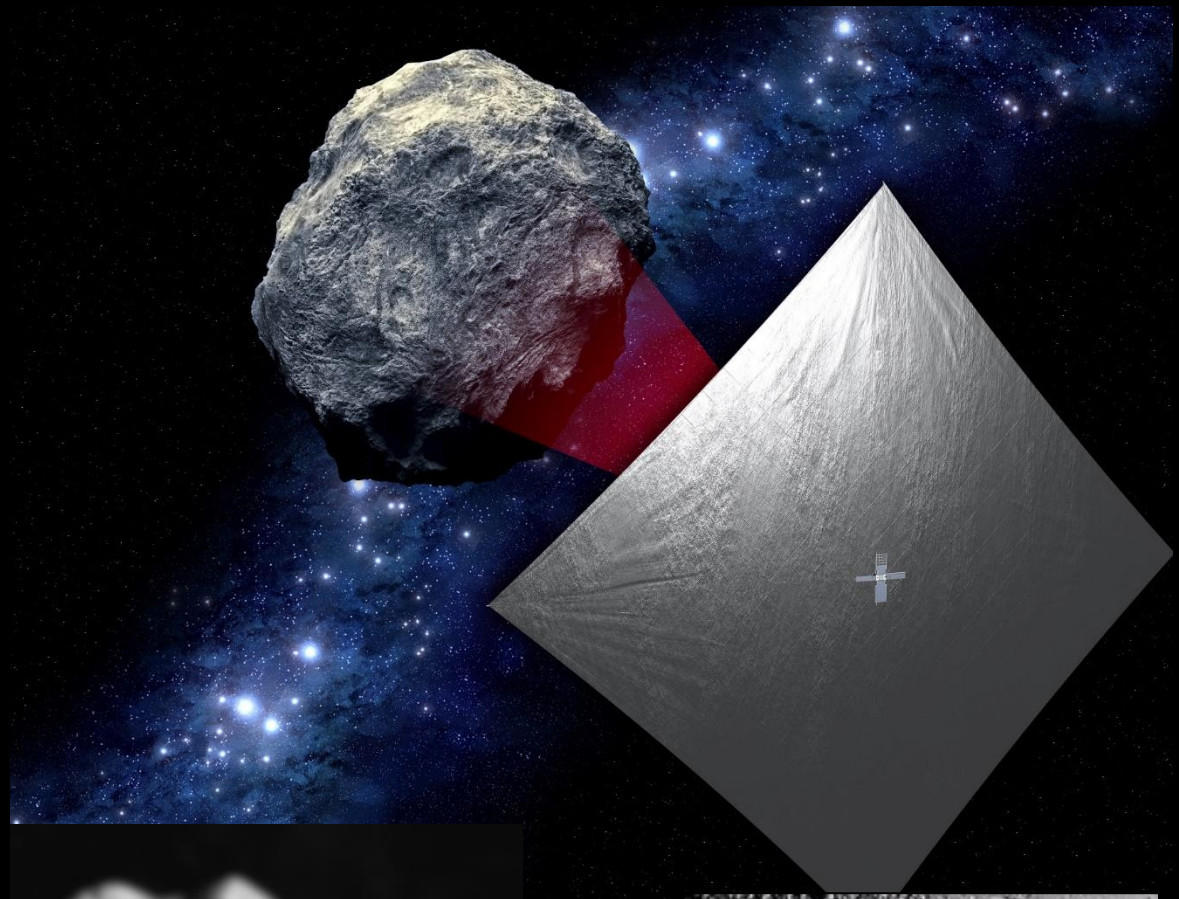
Near Earth Asteroid Scout

GOALS

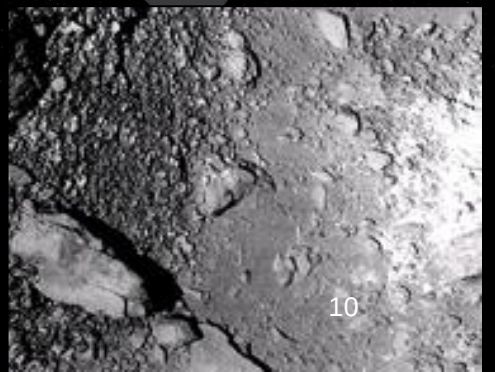
- First interplanetary mission using solar sail propulsion
- Characterize a Near Earth Asteroid for possible future human visits

Key Spacecraft & Mission Parameters

- 6U cubesat (8” X 4” X 12”)
- 925 ft^2 solar sail propulsion system
- Manifested for launch on the Space Launch System (Artemis 1 / 2021)
- 1 AU maximum distance from Earth

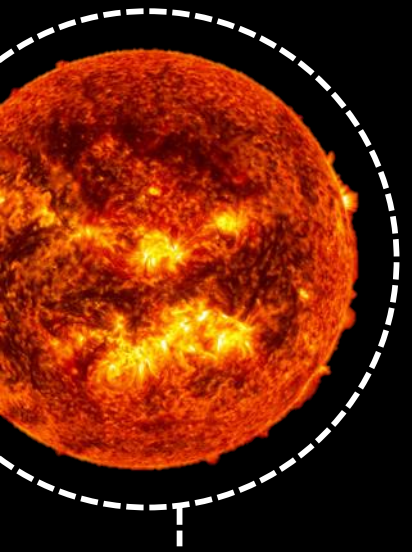






NEA Scout is one of 13 Secondary Payloads on Artemis 1

SMALLSATS TO BE DEPLOYED FROM THE ORION STAGE ADAPTER



SUN

- CuSP (Southwest Research Institute)

MOON

- Lunar Flashlight (NASA)
- Lunar IceCube (Morehead State University)
- LunaH-Map (Arizona State University)
- OMOTENASHI (JAXA)
- LunIR (Lockheed Martin)
- EQUULEUS (JAXA)





EARTH-MOON

- ArgoMoon (ESA/ASI)

ASTEROID

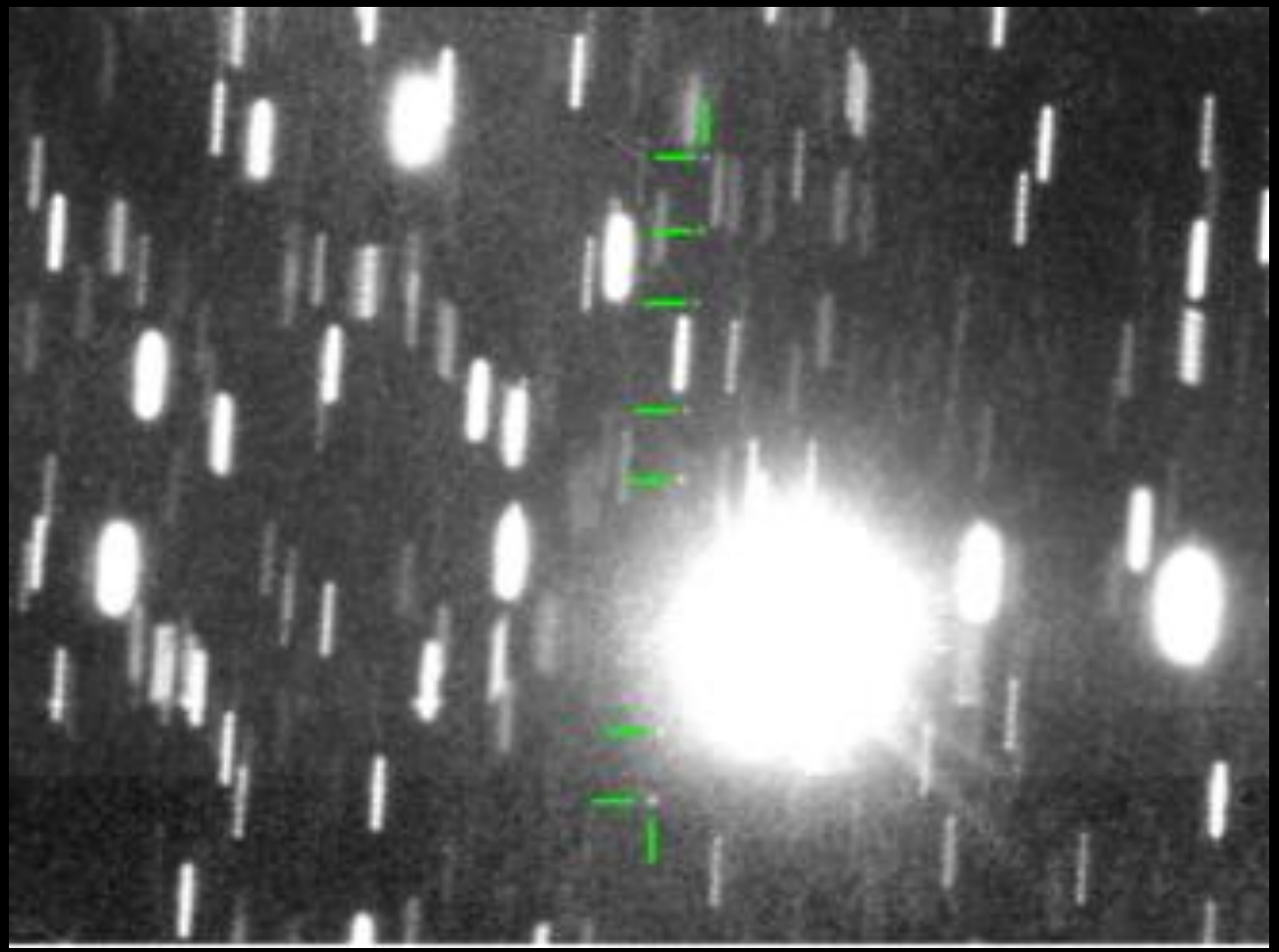


- NEA Scout (NASA)

…AND MORE

- Biosentinel (NASA)
- Cislunar Explorers (Cornell University)
- CU-E^3 (University of Colorado Boulder)
- Team Miles (Miles Space)

NEA Scout
Candidate Asteroid: 1991 VG

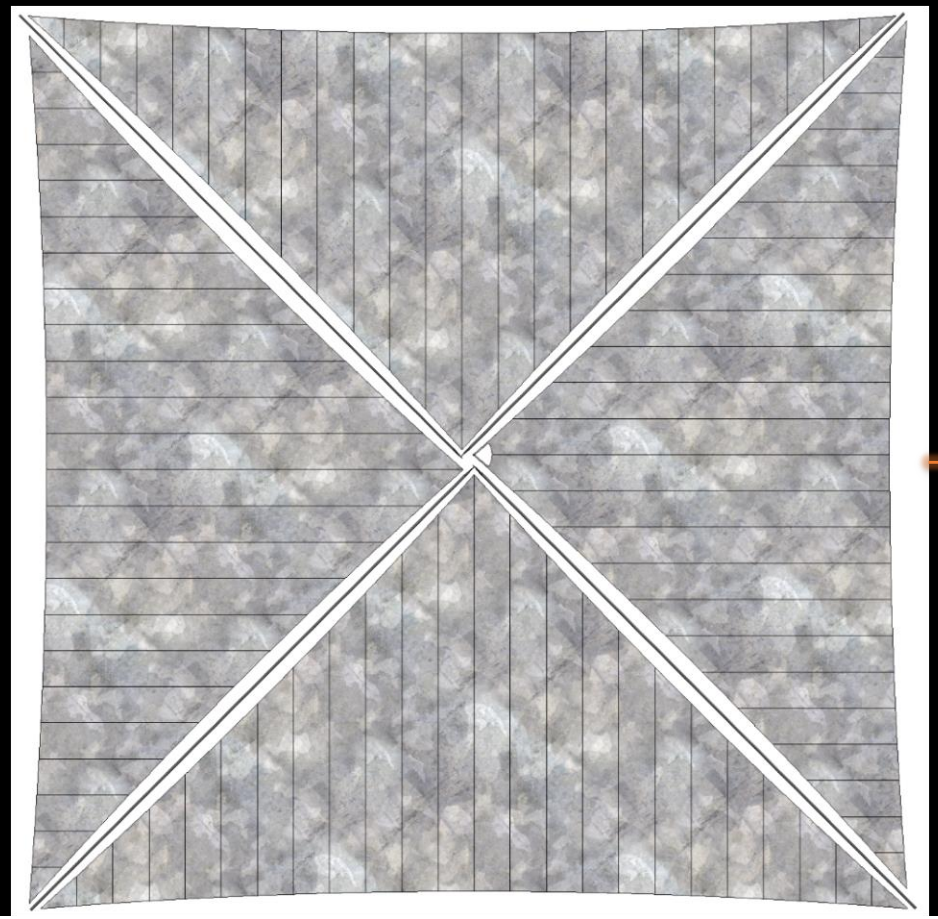


NASA Image

- Diameter ~ 5 -12 meters
- Rotation period between a few minutes and less than 1 hour
- Unlikely to have a companion
- Unlikely to retain an exosphere or dust cloud
  - Solar radiation pressure sweeps dust on timescales of hours or day

925 ft^2 Solar Sail (NEA Scout)

Deployed Solar Sail



School Bus

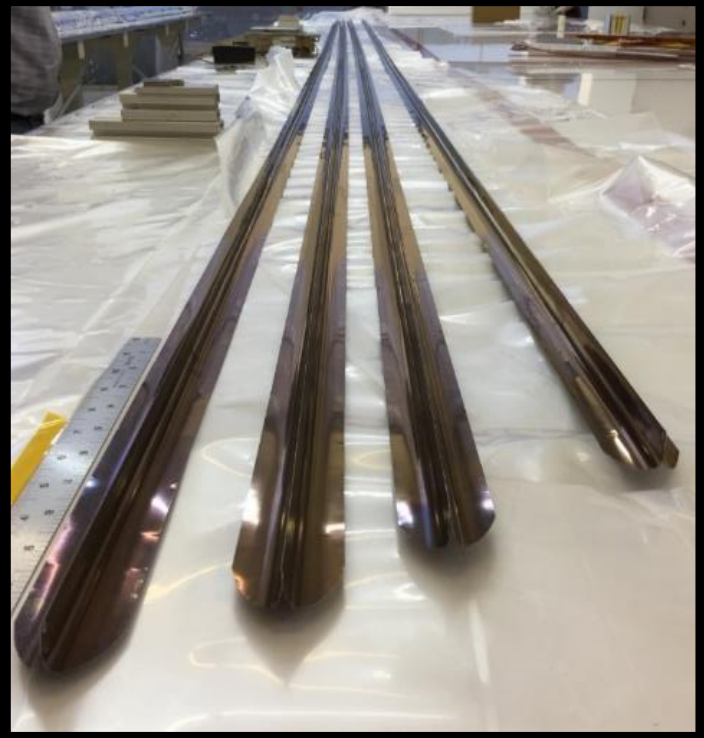


Spacecraft



Folded, spooled and packaged in here

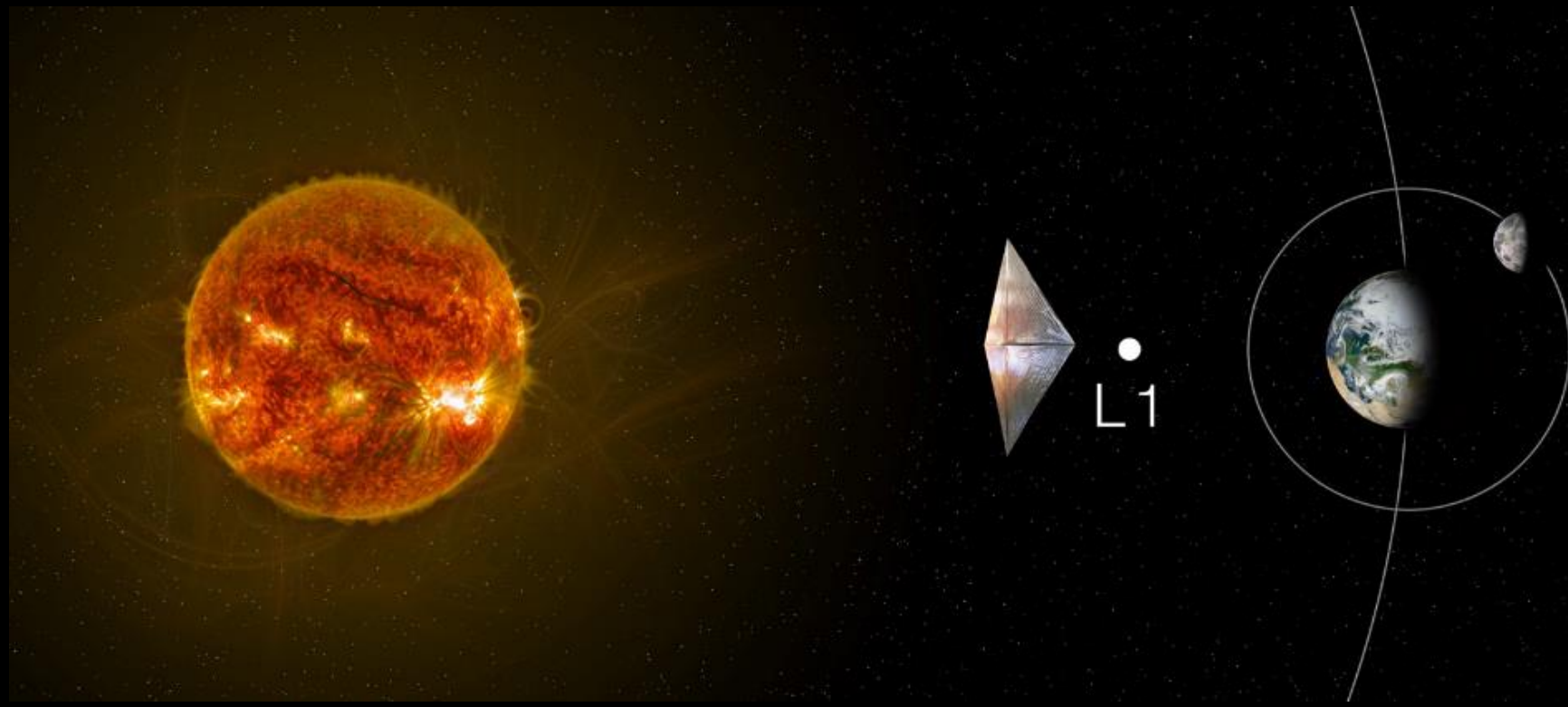
NEA Scout Flight Sail Testing



24 foot booms

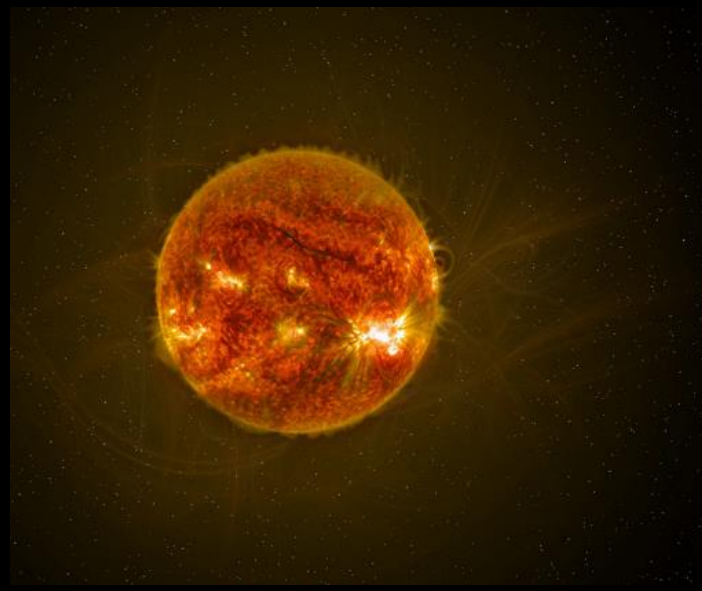


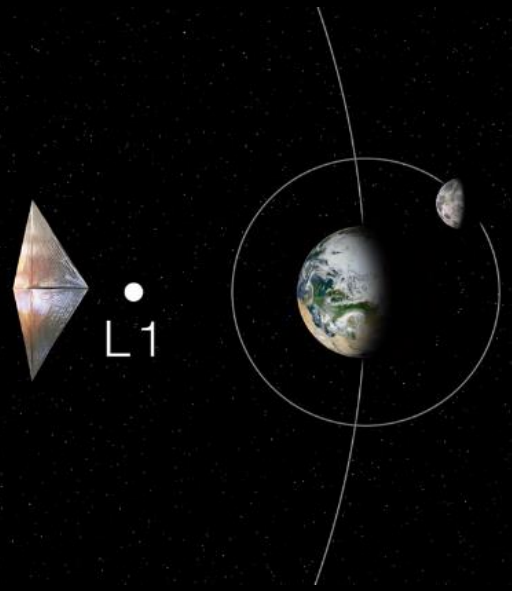
Solar Cruiser Mission Overview

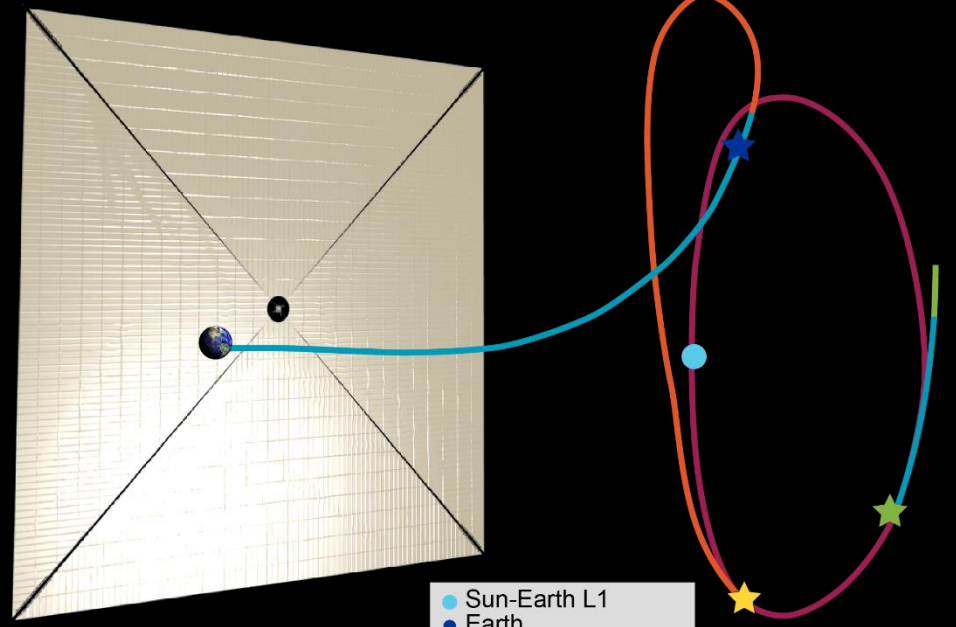


Solar Cruiser will launch as a secondary payload on the NASA IMAP mission in 2025. Using a solar sail, it will cruise toward the sun and demonstrate the ability of a solar sail to remain stationary along a line from the Sun to the Earth for long periods of time.

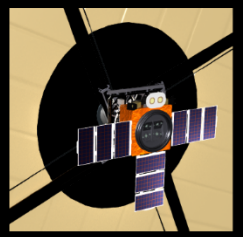
Solar Cruiser Will Demonstrate Solar Sail Propulsion Enabling Novel Orbits and Destinations

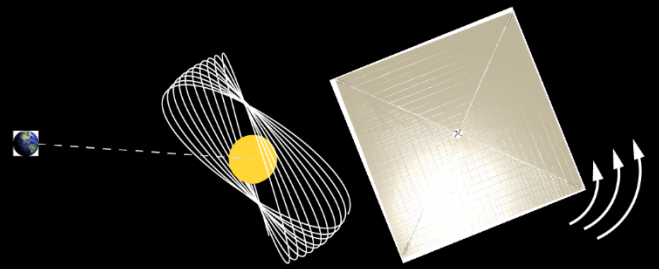






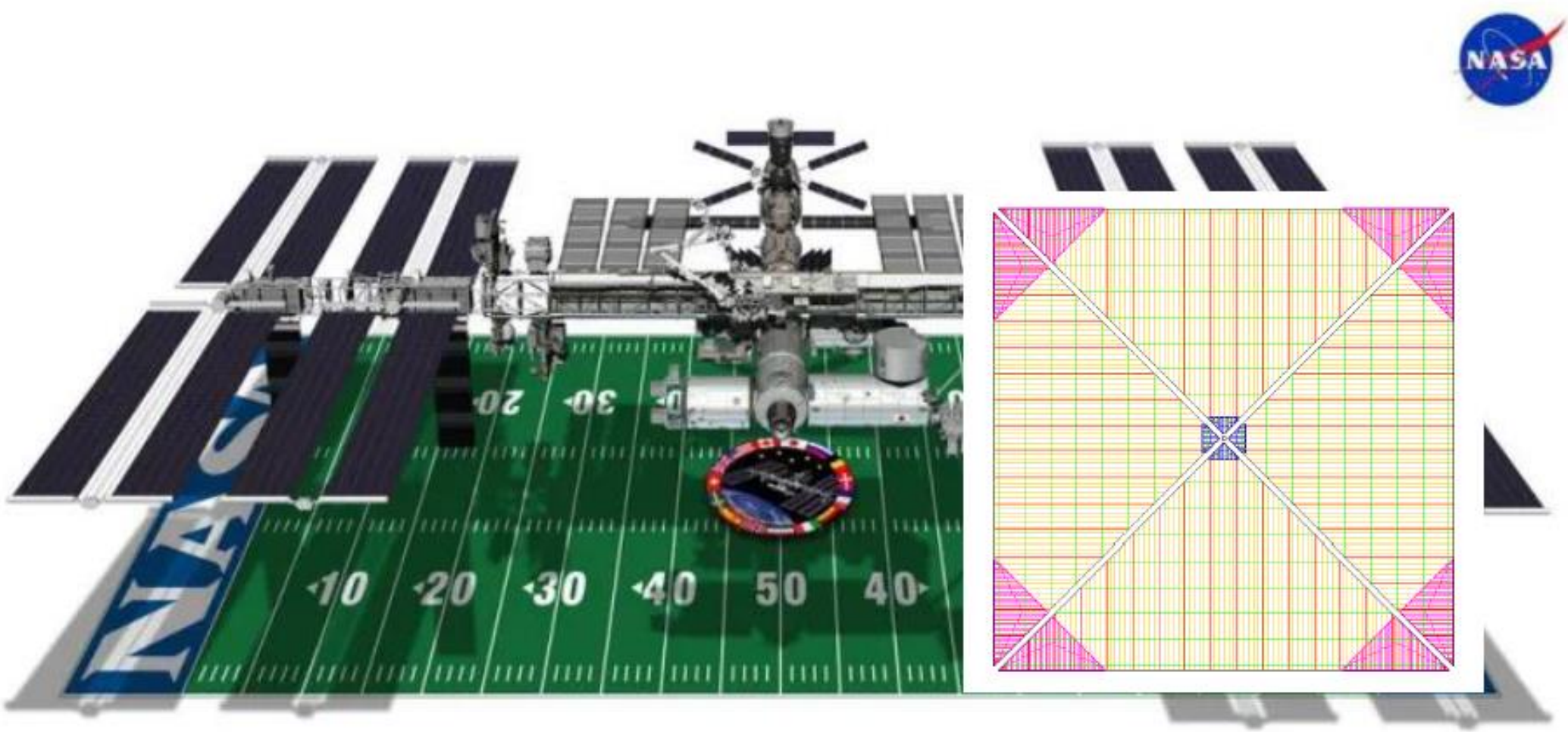






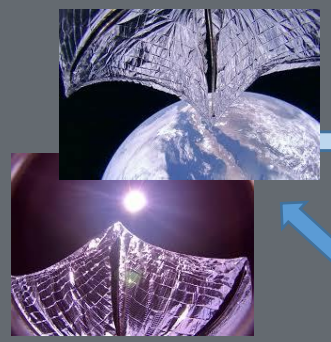
2 days	20 days	44 days	45 days	228 days	258 days	265 days	282 days	312 days
L+2 days *LEOP*	18 days *Checkout*	24 days *Ballistic Transfer*	1 day *Solar Sail Deployment*	183 days *Sailcraft Characterization, Transfer, and Station Keeping*	30 days *Inclination Change*	7 days *Roll Demonstration*	17 days *Decommissioning*	30 days *Funded Schedule Margin*

Solar Cruiser: 1/3 the size of a football field



Sail Developments Leading to Solar Cruiser

Solar Cruiser Team Members Have Been Involved In Each Of These Maturation Efforts



LightSail 1 & 2 (The Planetary Society)



NASA Near-Earth Asteroid Scout





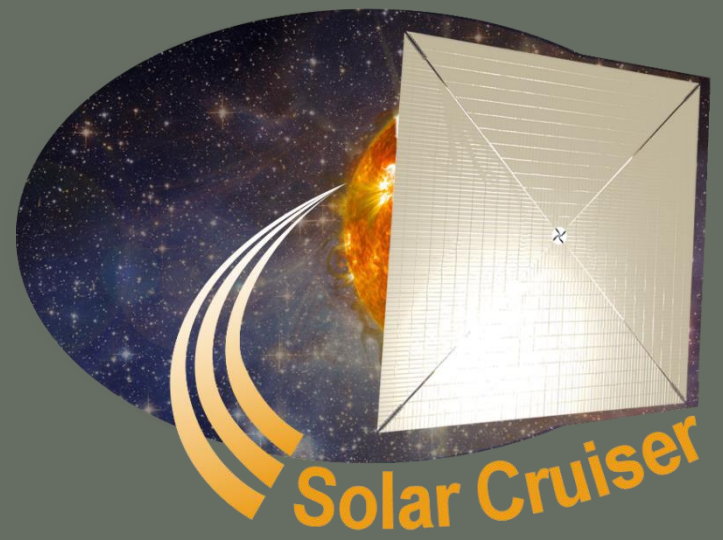
NASA 400 m^2 Ground Tests



NASA MSFC NanoSail – D



NASA Near-Earth Asteroid Scout



Integration of Small Spacecraft

Solar Sail System Design

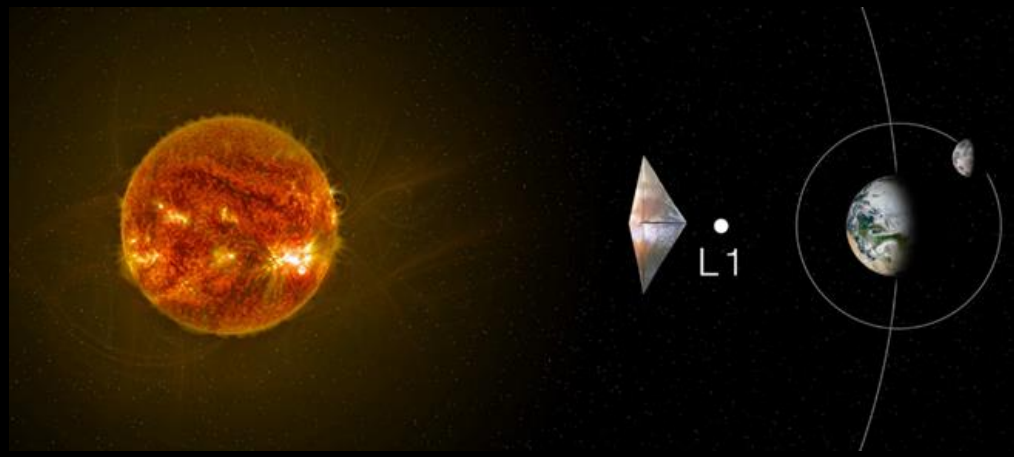
Sail Software

Composite Booms Sail Deployer

Sail Membrane Fabrication

Sail Context Camera

Solar Cruiser *Immediately Enables Solar Science* and Solar Storm Monitoring



Space Weather Applications:

- Increase the warning times by up to 50% for solar storms, benefiting Earth power utilities and spacecraft operators.
- Directly benefits human exploration beyond Earth orbit

Severe Sun Storm Threatens Utilities
By MATTHEW L. WALD
New York Times (1857-Current file); Jun 6, 1991; ProQuest Historical Newspapers The New York Times (1851 - 2001)
pg. A16

Severe Sun Storm Threatens Utilities

By MATTHEW L. WALD

A severe disturbance of the Earth's magnetic field, caused by temporary changes in solar activity, began on Tuesday night, threatening electric

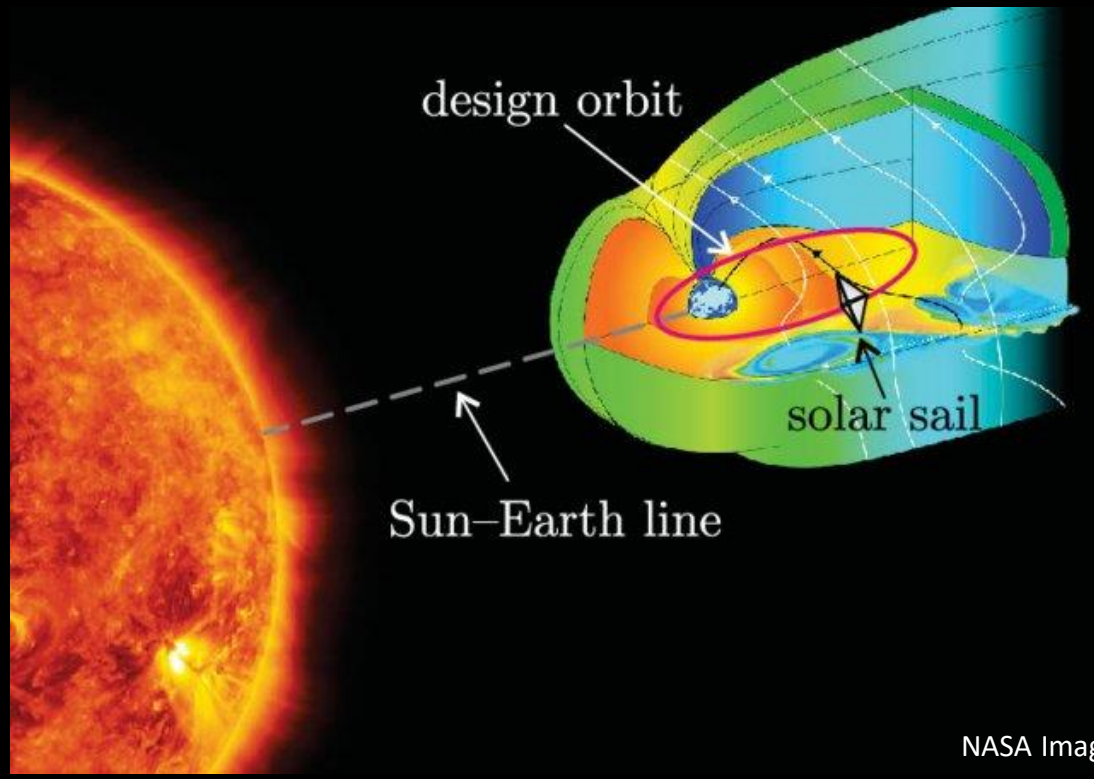
ment Services Center, in Boulder, Colo.

Electric utilities in the northern United States and in Canada are concerned because the solar activity changes the shape of the earth's mag-

blackouts could result. Presumably, after a warning from the probe, utilities would try to reduce demand and send less power over long distances, relying more on local generators.

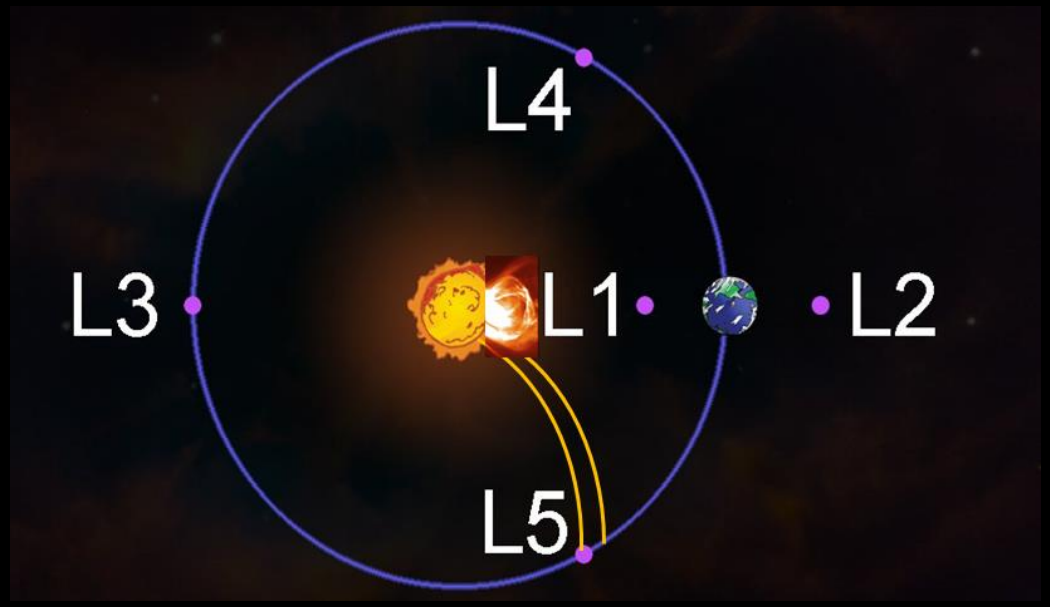
Immediately Enables Sustained Sampling of the Earth's Magnetotail

- Using multiple sailcraft, the entire geomagnetic tail could be populated by particle and field instruments that can remain there for long periods of time



NASA Image

Immediately Enables Sustained Solar Observations Off the Sun-to-Earth Line

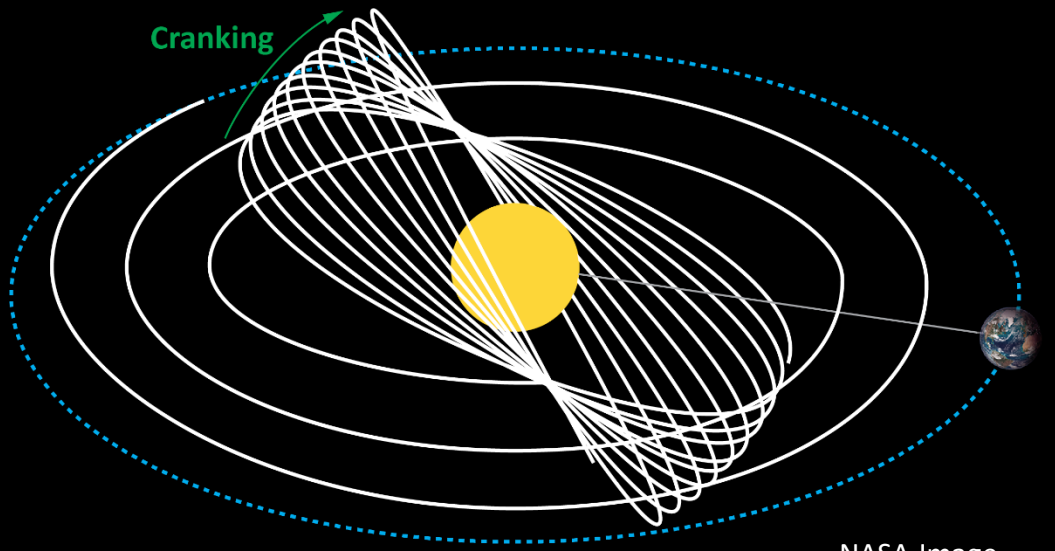


Observations enabled include imaging coronal mass ejections (CMEs) between the sun and Earth and in-situ measurements of solar wind streams in the vicinity of L5 before they rotate into Earth

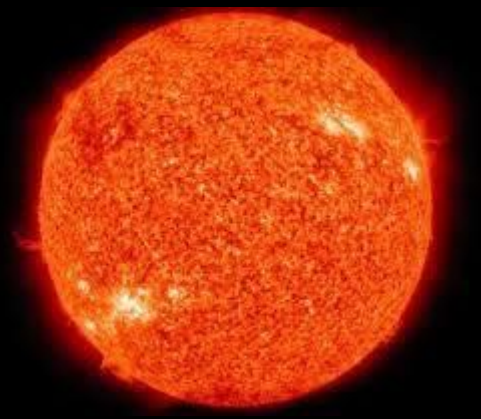
- Long term station keeping and flexible repositioning to be responsive to changing solar conditions

Immediately Enables SmallSat Missions for Studying High Solar Latitudes

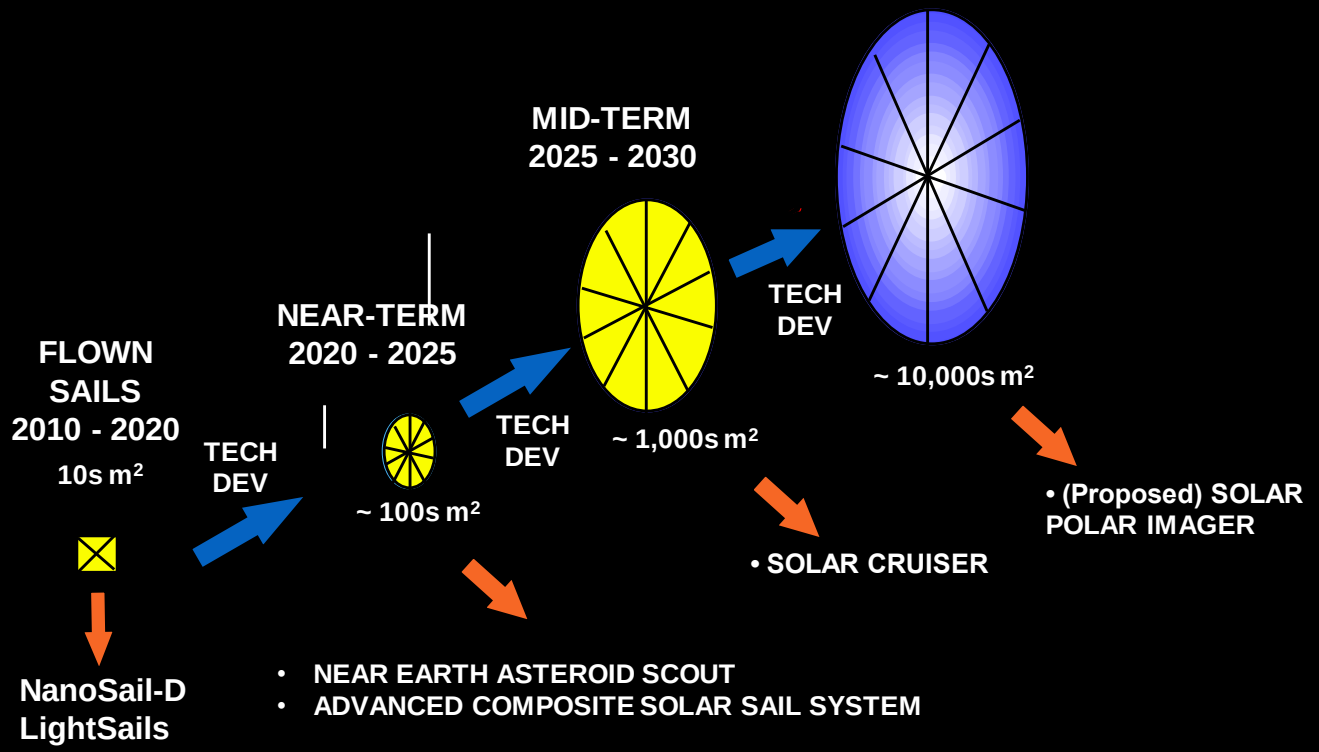
- A Solar Cruiser-class sailcraft (*without scaling)* can image the Sun at high latitudes – something not easily accomplished using rockets



NASA Image

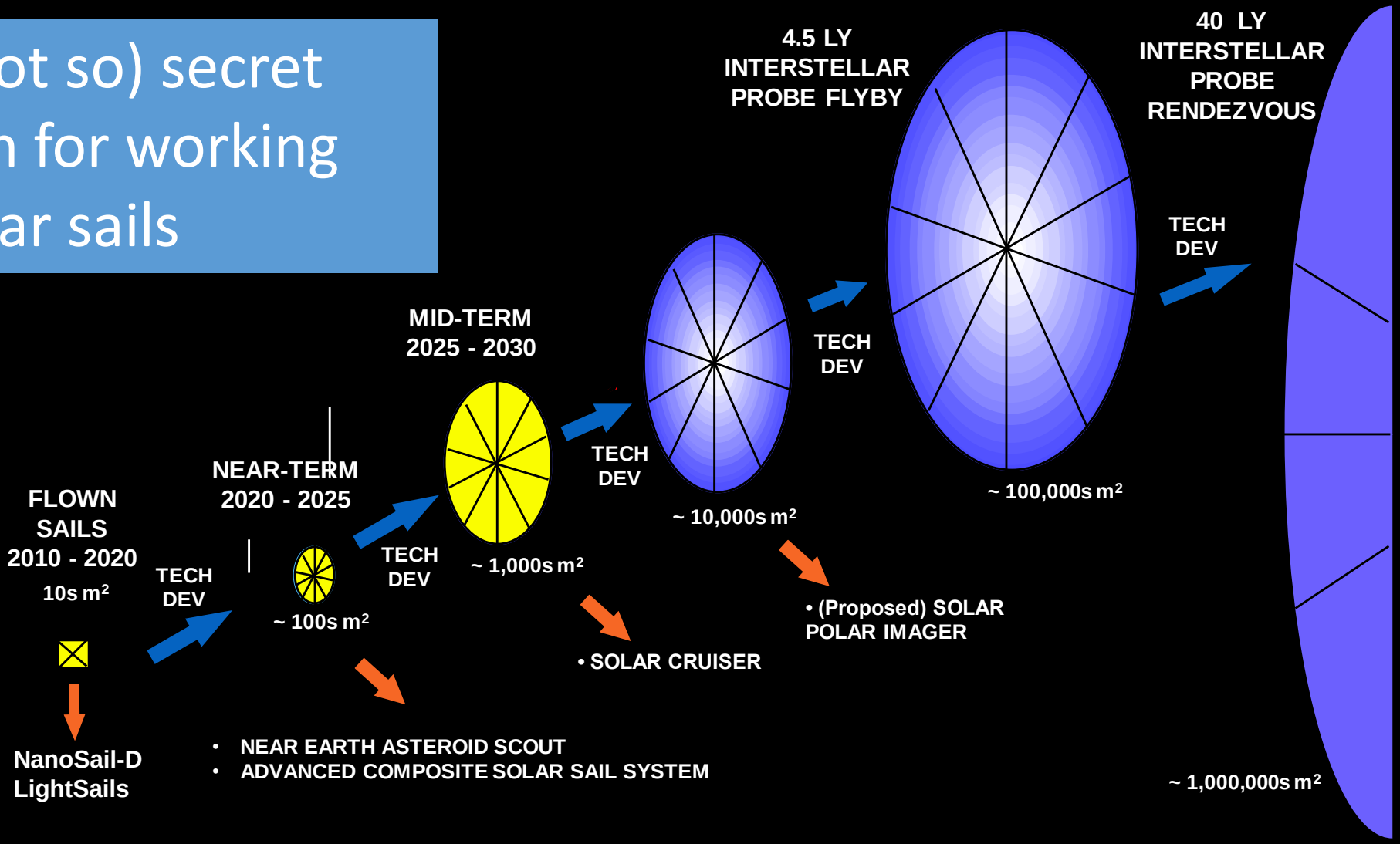


Evolution of Solar Sail Propulsion



Evolution of Solar Sail Propulsion Toward Interstellar Travel

My (not so) secret reason for working on solar sails



Sailing on Sunlight - Solar Sails for Exploring the Solar System and Beyond



Les Johnson
les.johnson@nasa.gov