

National Aeronautics and Space Administration

Solar Sail Propulsion – Ready for SmallSat Mission Implementation

Les Johnson, Chief Technologist

MSFC, ST01

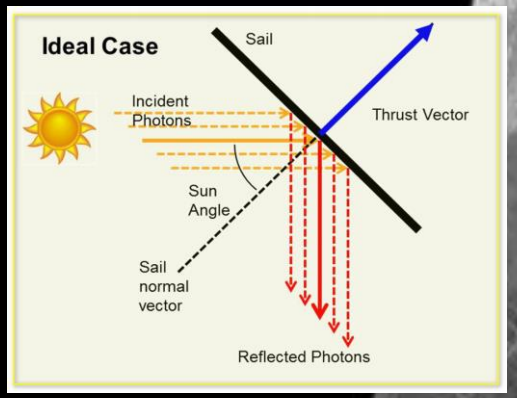
11/4/2024

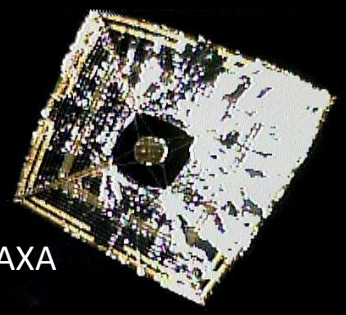
Solar Sail Propulsion

- Produce thrust with sunlight pressure or on thin, lightweight, reflective sheets

- Will never run out of fuel, allowing space missions to new locations

- Low mass & volume, high ΔV propulsion

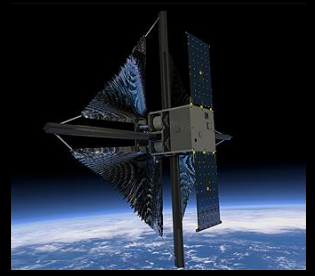




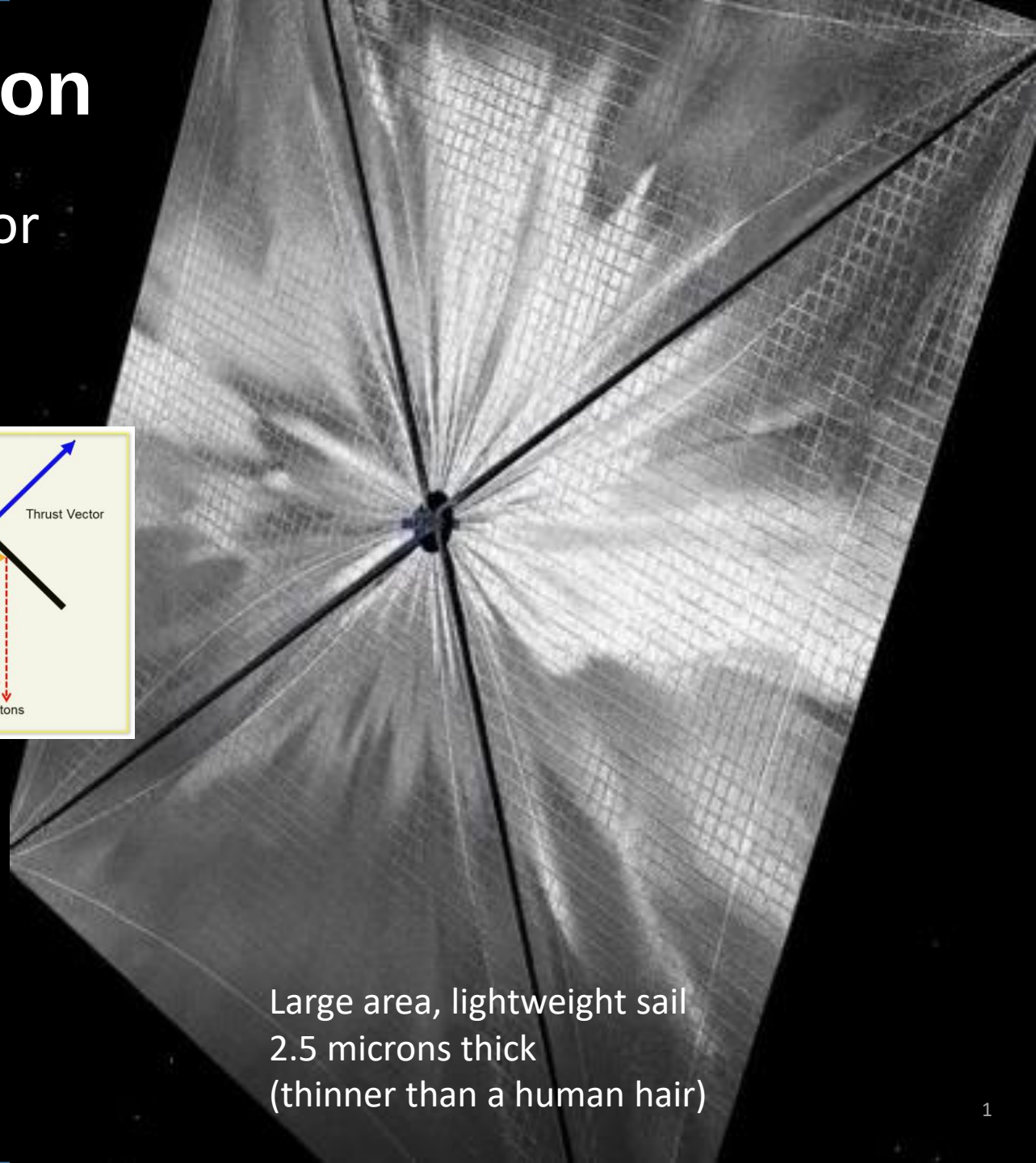
JAXA



The Planetary Society



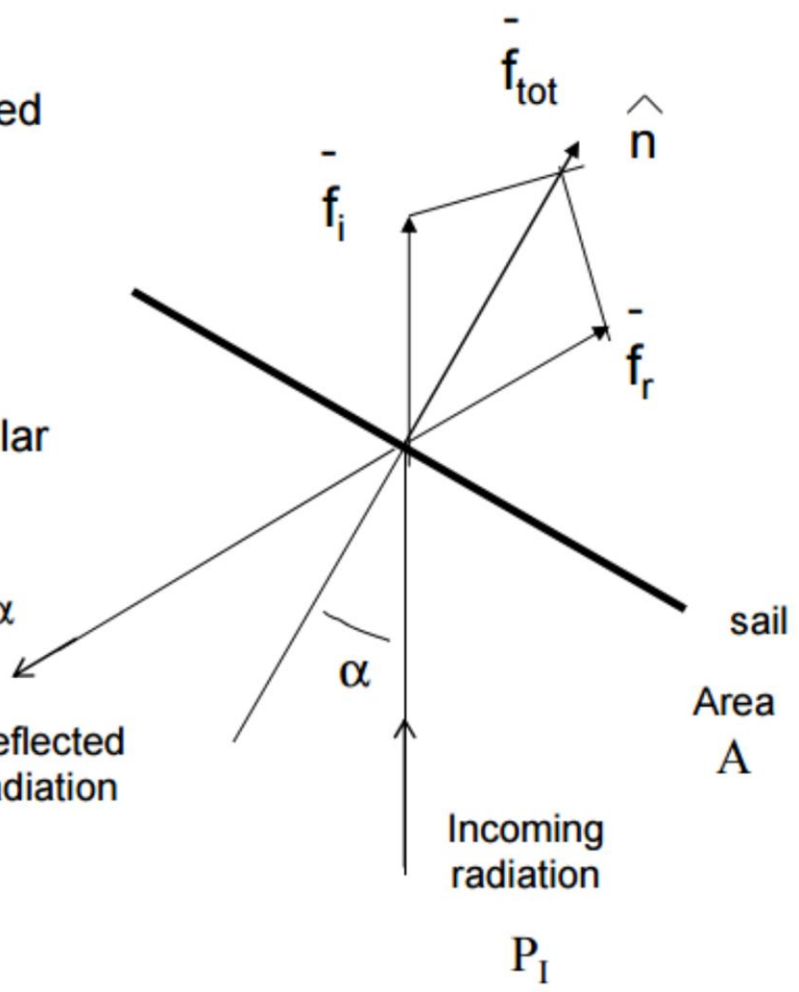
NASA



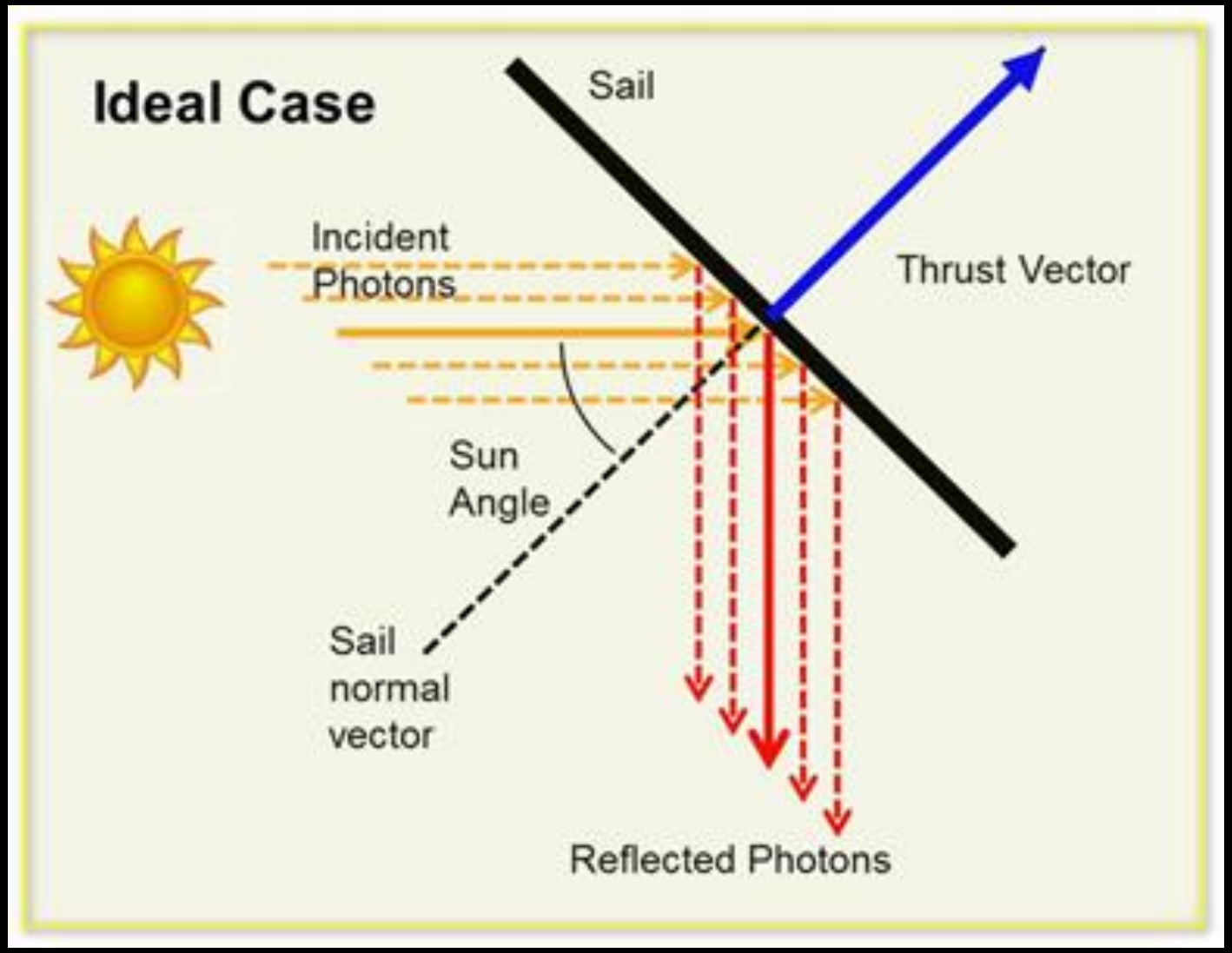
Large area, lightweight sail
2.5 microns thick
(thinner than a human hair)

Photons Have Momentum
Which Can Be Imparted to the Solar Sail

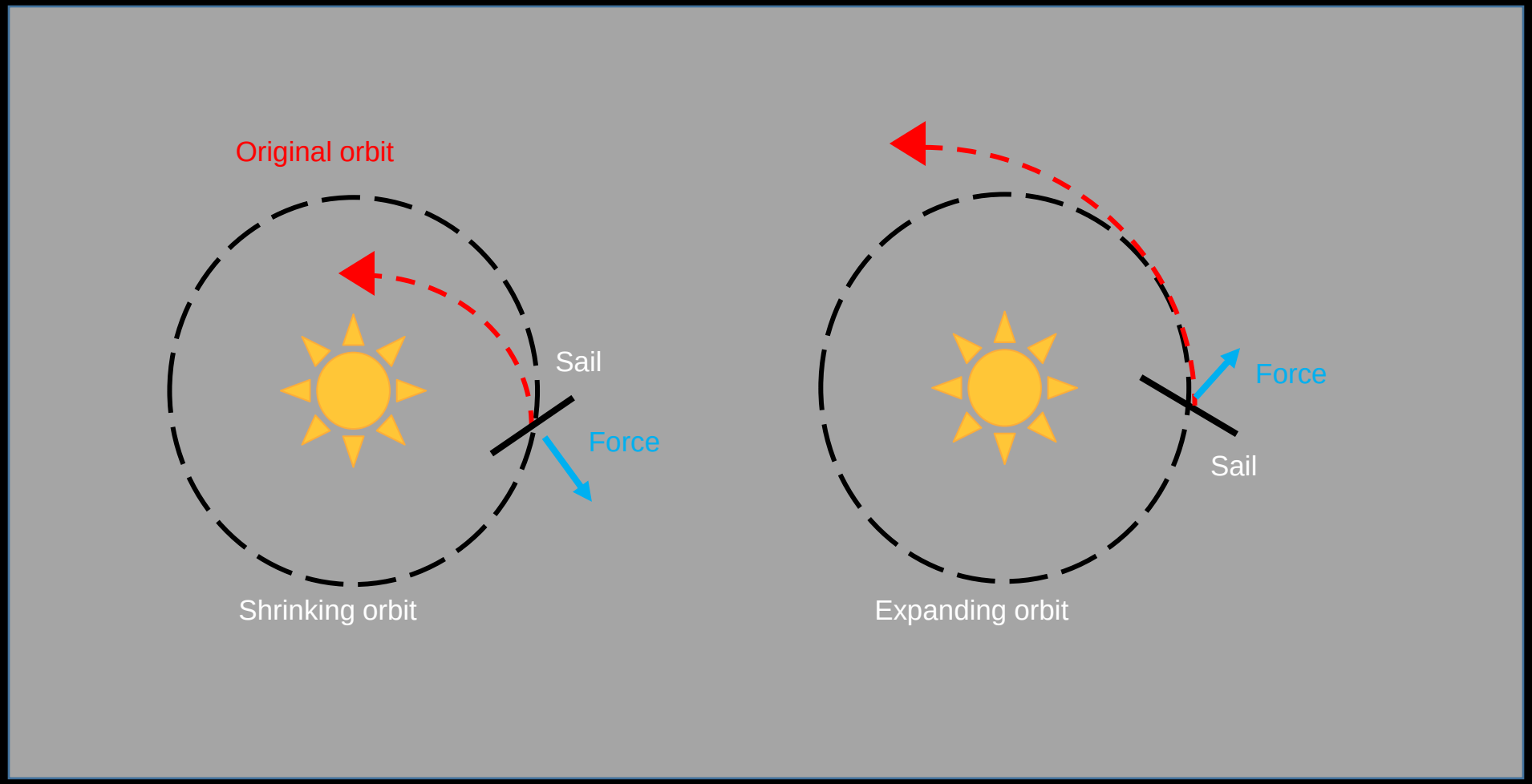
- **Photons carry Momentum**
  - $\rho = h\nu/c$
    - h = Planck's, ν = frequency, c = speed of light
- **Force generated on Reflective Surface**
  - Resultant force approximately perpendicular to surface
    - The bigger the surface, the more the force
  - Can "steer" sail by changing pitch angle α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



Tip/Tilt the Sail to Control Thrust Vector



Solar Sail Trajectory Control

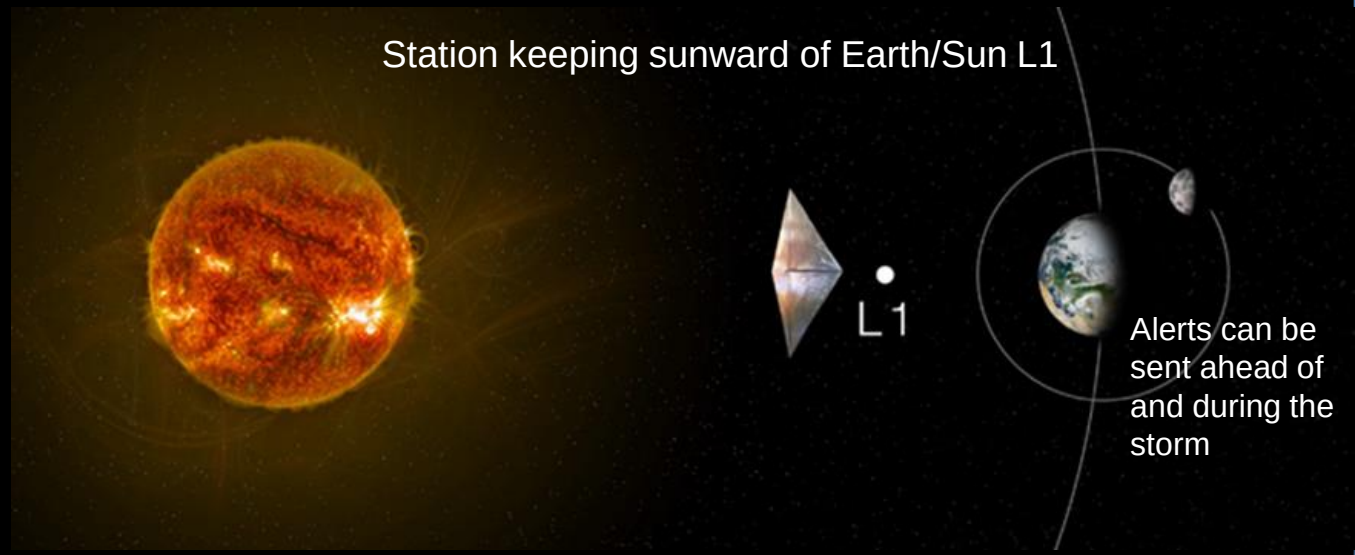


Commonly Used Solar Sail Figure of Merit (FOM)
Characteristic Acceleration (Ac)

- Characteristic Acceleration (Ac): acceleration experienced at 1 AU with the sail normal to the Sun.
- With 9.08 $\mu N/m^2$ radiation pressure at 1 AU
- The instantaneous acceleration will be larger or smaller than the Ac when the sail operates at distances other than 1 AU

Solar Sails Enable Earlier Warning of Space Weather Events

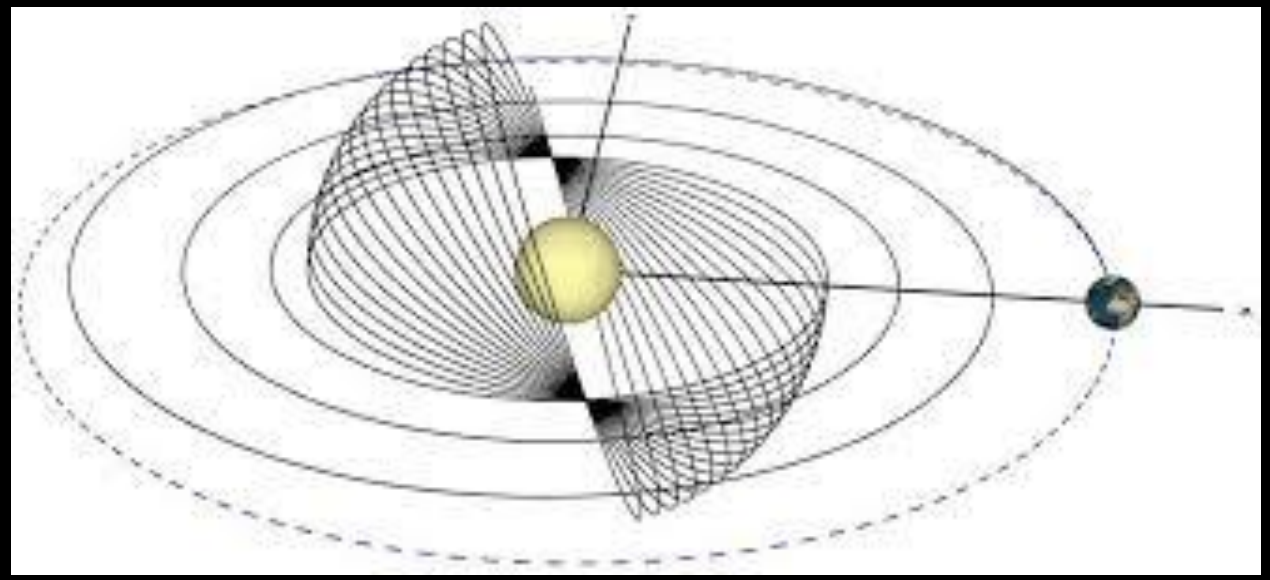
- Space Weather (solar storms) can overload the power grid and cause blackouts, knock out satellites, and poses health risks to astronauts traveling beyond Earth
- Solar Sails will enable NOAA and NASA to provide increase solar storm warning times
- NOAA submitted this need as a priority in the NOAA Decadal Survey inputs and #1 priority to STMD Technology Prioritization Survey



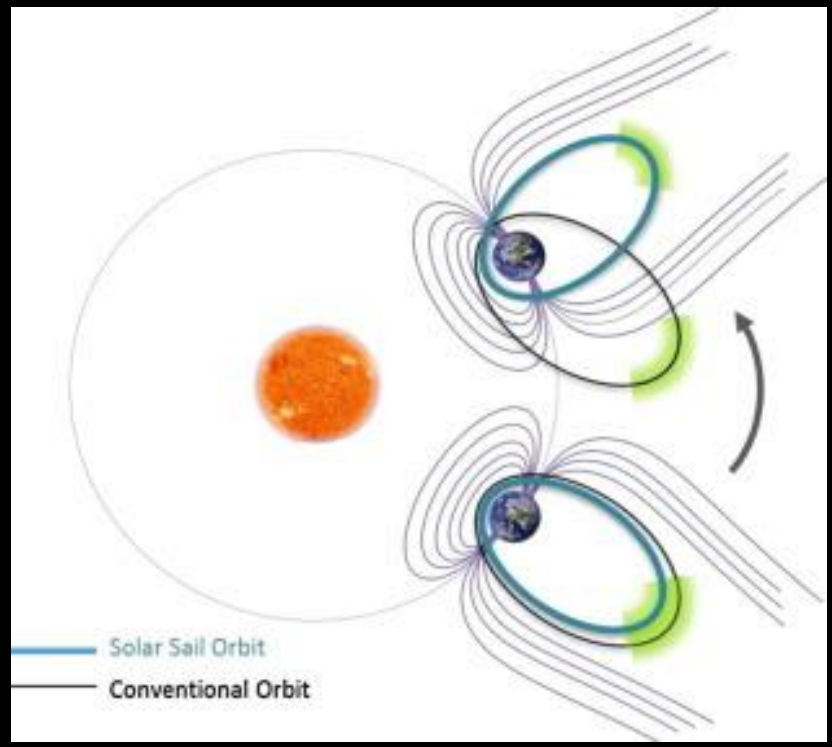
Solar Sails Enable up to 50% Increased Warning Time for Solar Storms

Large area, lightweight sail
2.5 microns thick
(thinner than a human hair)

Solar Sails Enable High Priority Science Missions in the Heliophysics Decadal Survey



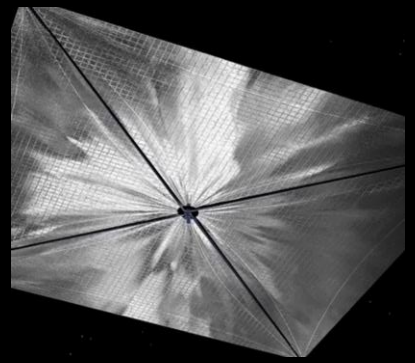
- Propel a science spacecraft out of the ecliptic plane to a solar polar orbit (very difficult or impossible to achieve chemically)

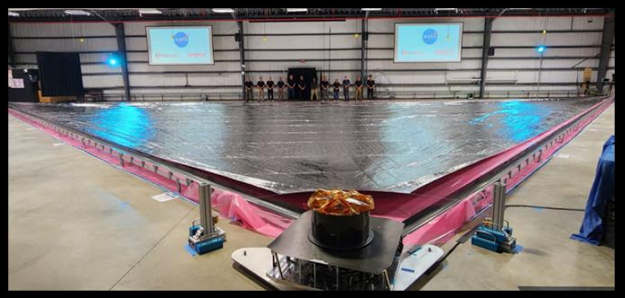


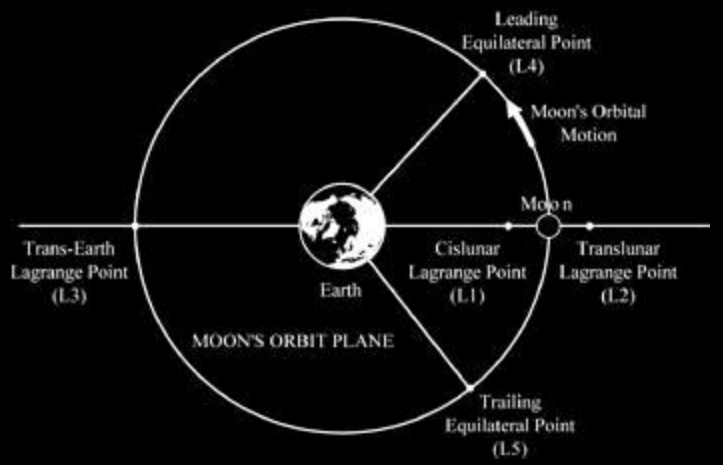
- Propel a spacecraft to remain in the Earth's magnetotail (behind the Earth; opposite the sun)

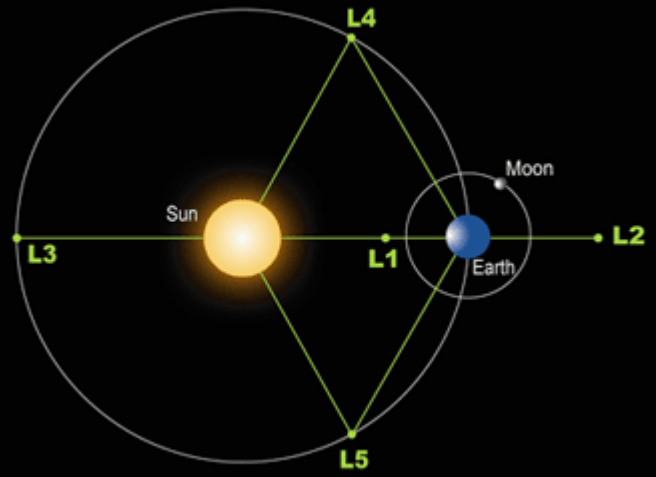
Solar Sail Propulsion Enables Missions to Multiple Destinations -1

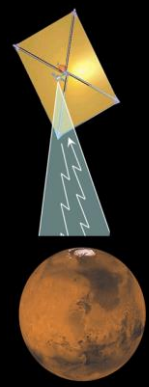
Once demonstrated (anywhere beyond GEO),the solar sail system can be used on other spacecraft to propel them for widely diverse mission applications and payloads.

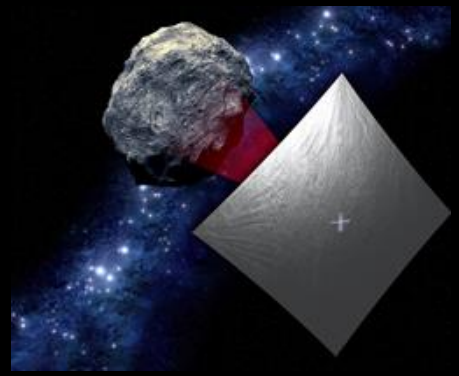








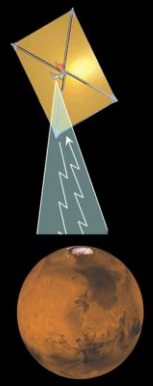




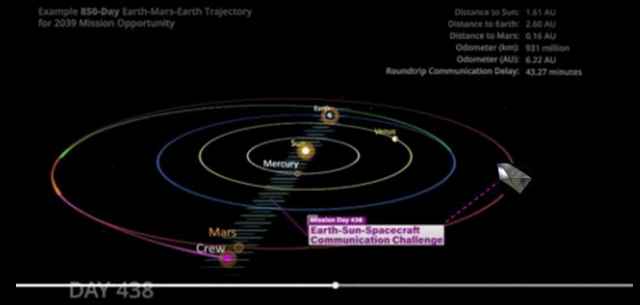
Solar Sail Propulsion Enables Missions to Multiple Destinations - 2



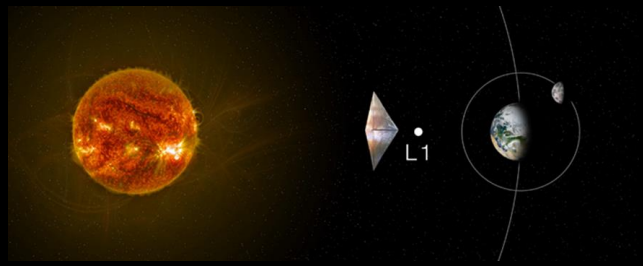
Provide near-continuous viewing of any lunar hemisphere for enhance communications, position, navigation, and timing (PNT)



Enables Mars pole sitting spacecraft, providing continuous line of sight and communications above Martian pole(s) to the associated hemisphere.



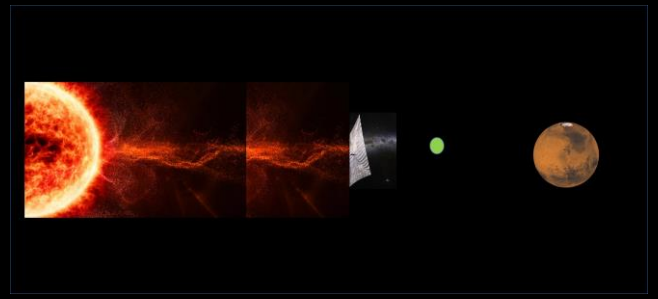
Solar propelled communication satellite can reposition itself at-will, leading or trailing Mars (or Earth) orbit to provide continuous line-of-sight between Mars and Earth -- without the use of propellant.



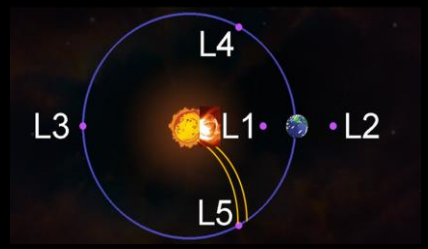
Station keeping sub L1 (Sun/Earth) to provide up to 50% increased warning time for solar storms in cis-lunar space

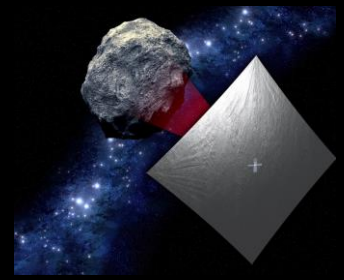


Maneuvering at-will in cis-lunar space, between LaGrange points, Gateway, and other orbits without depleting propellant

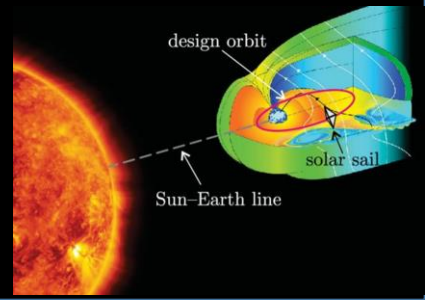


Optimal station keeping for increased warning times of solar storms at Mars

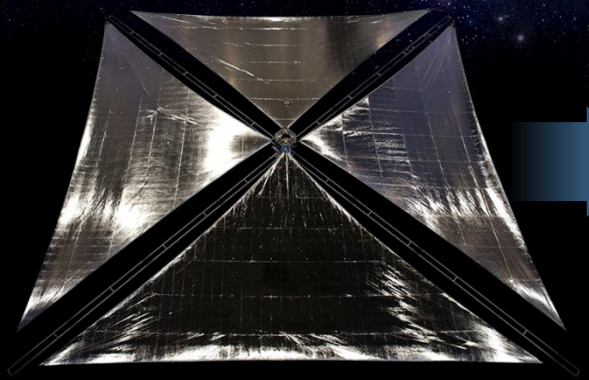




Enables new destinations and orbits for science and exploration of the solar system



Team Has Two Decades of NASA Solar Sail Development Experience Increasing Solar Sail Capabilities

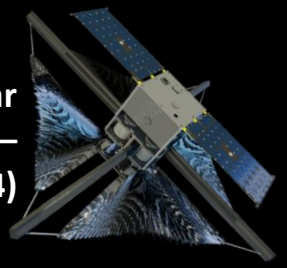


Solar Sail Ground Demonstrators [MSFC] (400 m^2 - 2004)

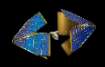


NanoSail–D [MSFC] (10 m^2 – 2010)

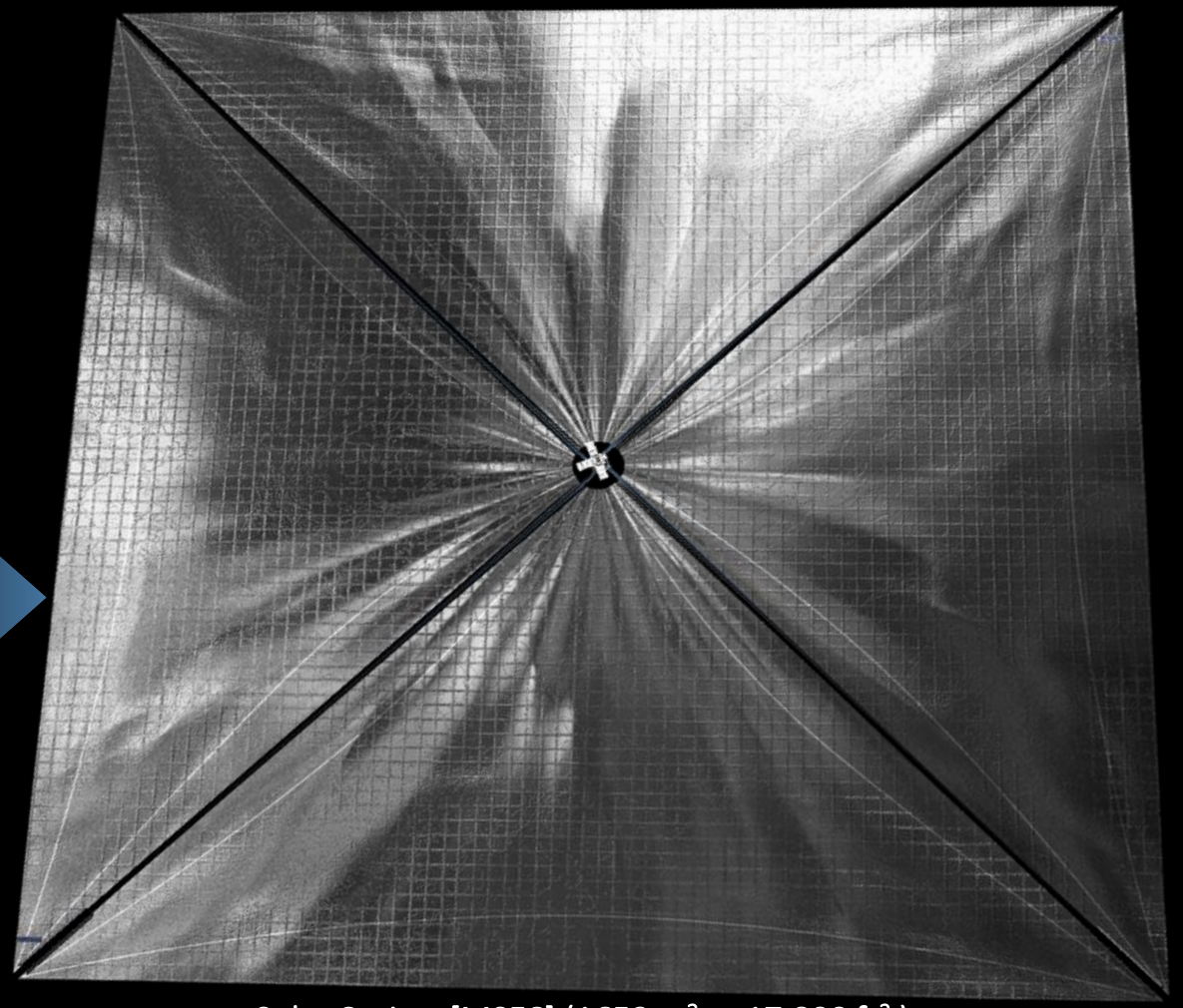
Near-Earth Asteroid Scout [MSFC] (86 m^2 or 925 ft^2 - 2022)



Advanced Composite Solar Sail System [LaRC] (80 m^2 – 2024)



Lightweight Integrated Solar Array & anTenna [MSFC] (2024)



Solar Cruiser [MSFC] (1653 m^2 - ~17,800 ft^2)
Larger than an Olympic swimming pool

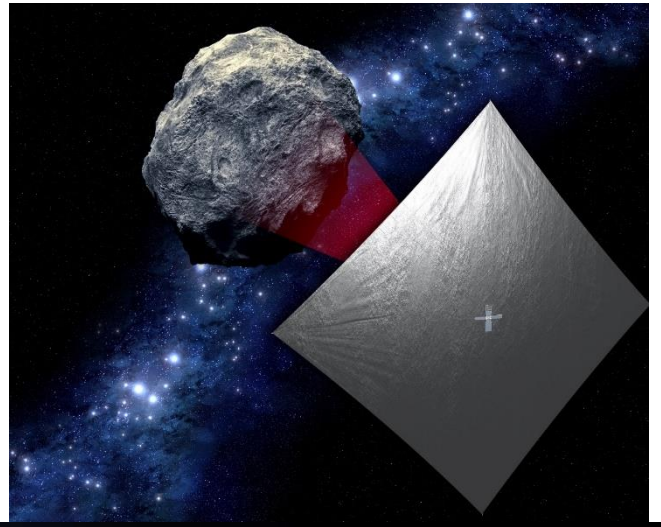
Near Earth Asteroid Scout
Launched: Status *Unknown*

Goals

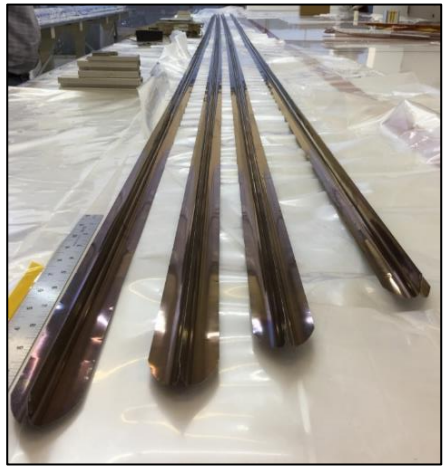
- First long duration (> 2 years) interplanetary science mission using solar sail propulsion

Key Spacecraft & Mission Parameters

- 6U cubesat (8” X 4” X 12”)
- 86 m^2 (925 ft^2) solar sail propulsion system
- Launched November 16 with Artemis 1
- Unable to make radio contact (as of this time)

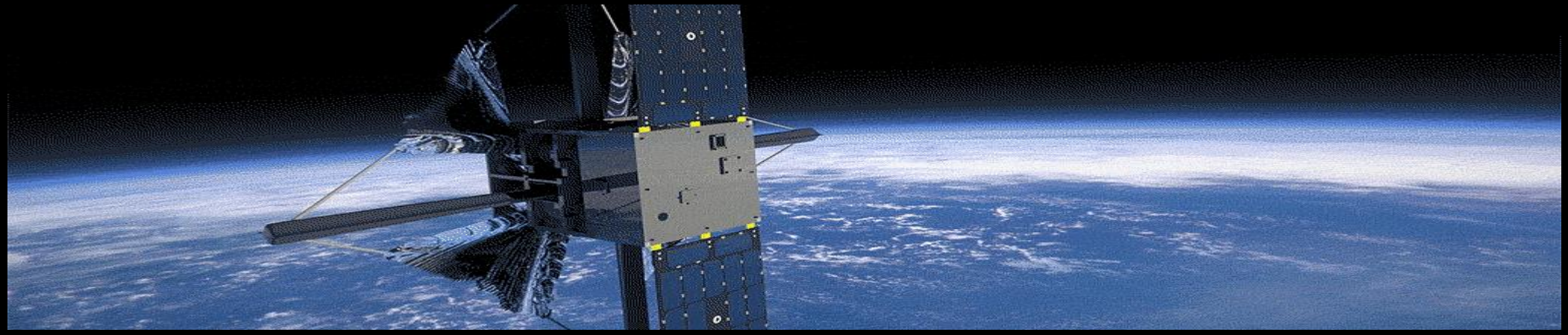








LaRC Advanced Composite Solar Sail System (ACS3)



Objectives:

- Demonstrate successful deployment of the composite boom as well as sail packing and deployment systems in low-Earth orbit
- Evaluate the efficacy of the shape and design of the solar sail
- Characterize the thrust functionality of the sail as the spacecraft gradually changes orbit
- Appx. 81 m^2





Images Courtesy of NASA's Langley Research Center

Solar Cruiser Technology Demonstration Mission – Overview

Mission

Solar Cruiser to mature solar sail propulsion technology to enable near-term, compelling space missions for Heliophysics and NASA.

Mission Technology Goals

Demonstrate solar sail propulsion technology to enable near- and mid-term Heliophysics science missions up to and including high solar inclination orbits, sub-L1 halo orbits, non-Keplerian solar and other planetary orbits

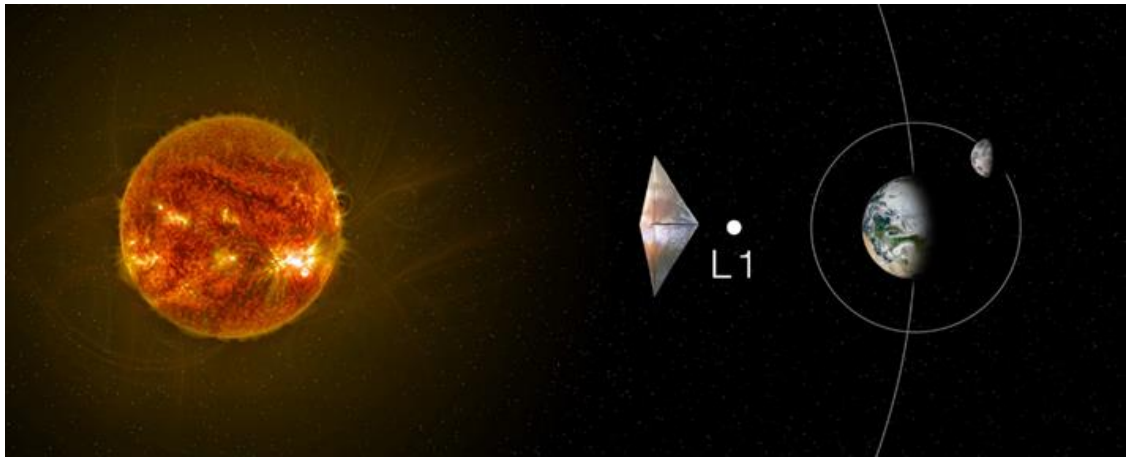
- Increased Space Weather warning times
- Sustained in-situ measurements within the Earth's magnetotail
- High inclination solar orbital observations

Status

- Completed PDR and was scheduled for February 2025 Launch
- Project was not confirmed at KDP-C due primarily to schedule concerns
- Funding received to achieve TRL-6 by January 2024

Project Reformulation

- NASA working with stakeholders to reformulate and continue the project with launch possible as early as 2028



Technical Details

Solar Sail

- Deployed Area: ~17,800 ft^2 (1653 m^2)
- Fabric: 2.5 micron thick Colorless Polyimide-1
- Composite Boom Lengths (X4): 97 ft (29.5 m) each

Payload

- 2.5 kg context camera

Destination

- Non-Keplerian sub-L1 halo orbit

Launch

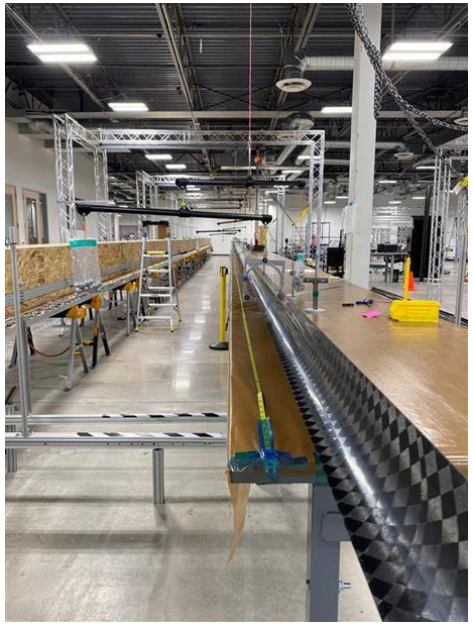
- Secondary payload on ESPA Grande

Total Cost to complete

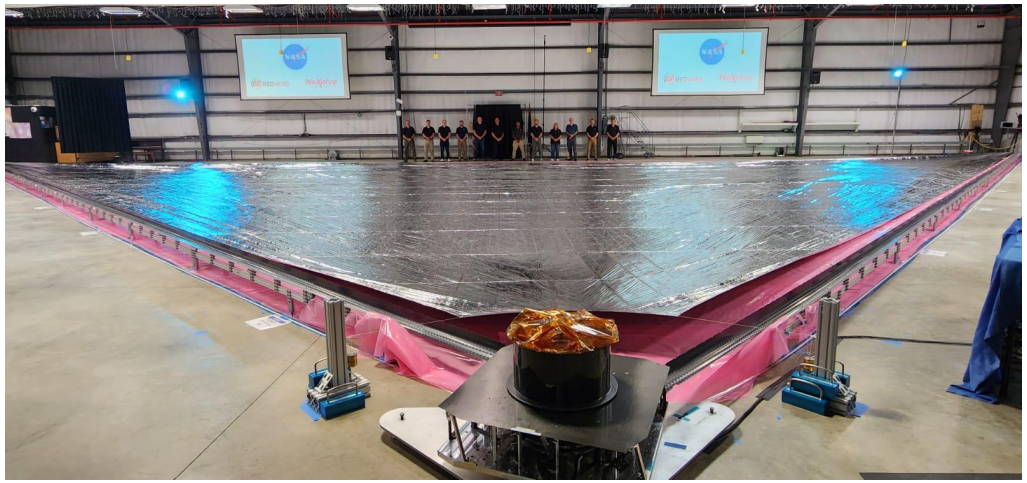
- $65M

Prototype Quadrant Deployed and Tested

- Full-scale quadrant Prototype deployment testing complete



SQ Deployment
Test Design layout in MSFC Activities Center



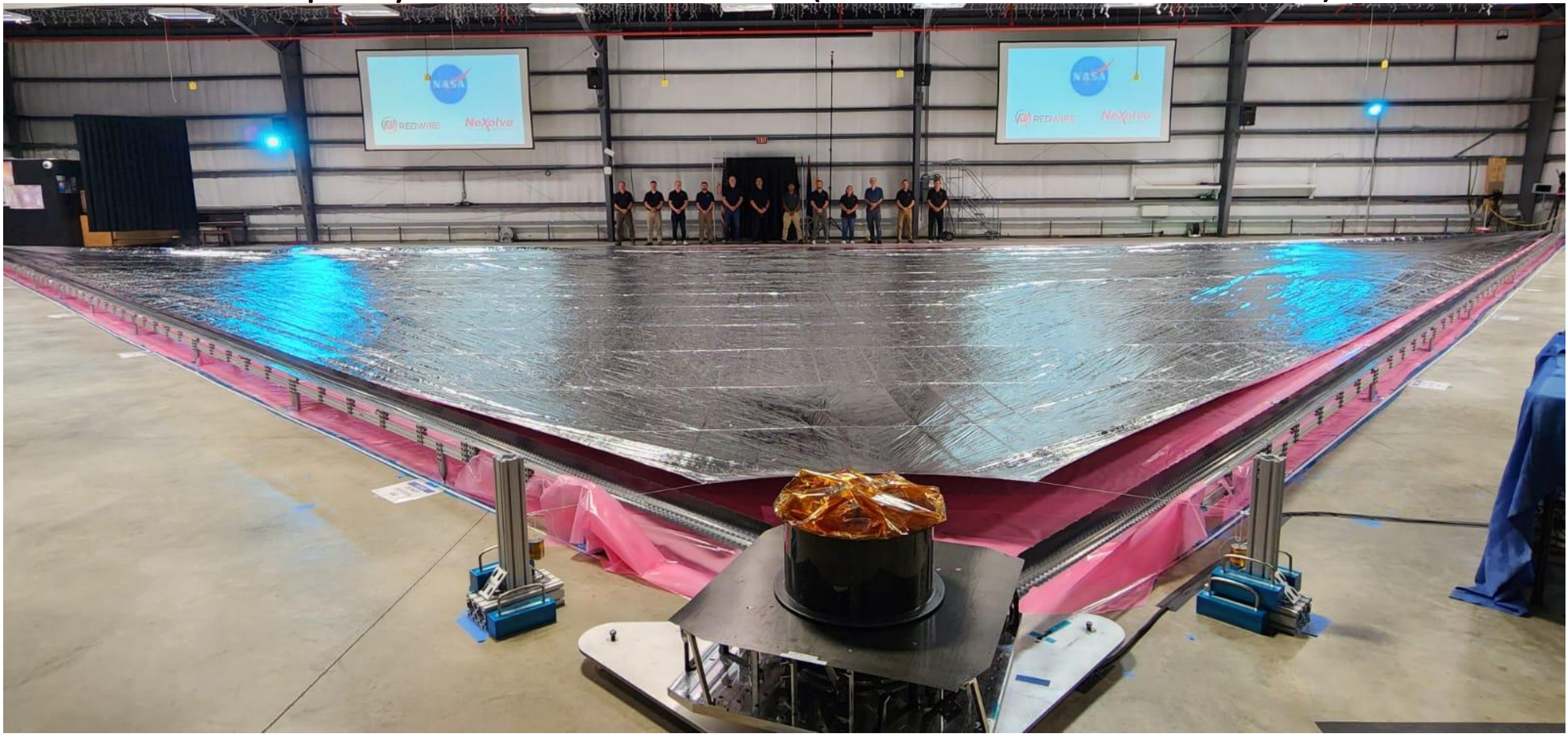
Prototype Sail Quadrant (SQ) Manufacturing





Prototype single quadrant hardware:
1 full-scale SQ
2 full-scale TRAC booms
1 full-scale Sail Deployment Mechanism

Prototype Solar Sail Quadrant Deployed and Tested (~4700 ft^2 / 440 m^2)



TRL-6 Achieved January 2024



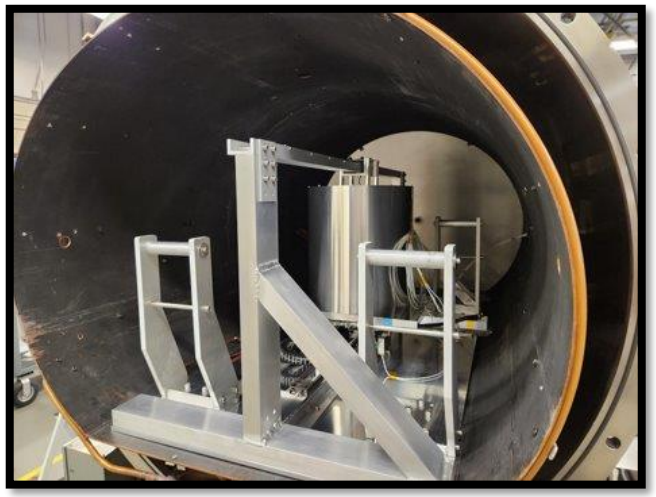
TRL-6 single quadrant (~410 m^2) hardware demonstrated:
1 full-scale sail quadrant
2 full-scale TRAC booms
1 full-scale Sail Deployment Mechanism

Solar Cruiser -- Continues Solar Sail technology maturation activities
Solar Sail System TRL-6 Completed January 2024

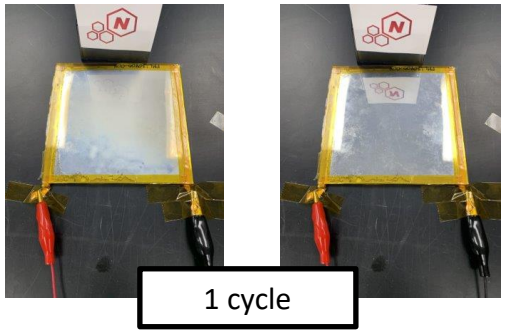
AMT Design Life Verification Test (DLVT) -- COMPLETE

- Ambient testing successfully COMPLETE (1088 cycles).
- 181 hot translations and 181 cold translations COMPLETE with no issues

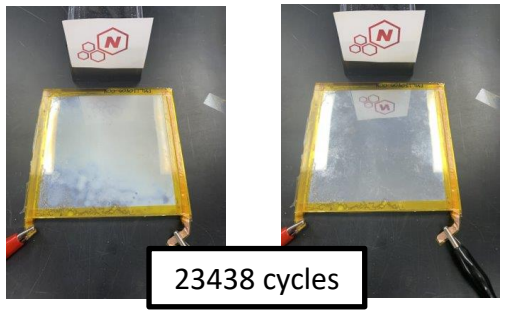
RIGHT: Test article placed in TVAC chamber (8/14)



RCD – mature to TRL5

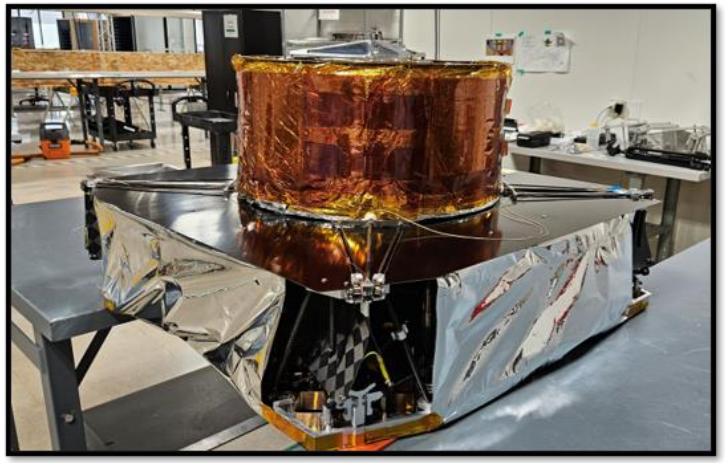


- Cycles the RCDs on for 16 hours and off for 8 hours.
- This cycle was repeated over the course of 26 days.

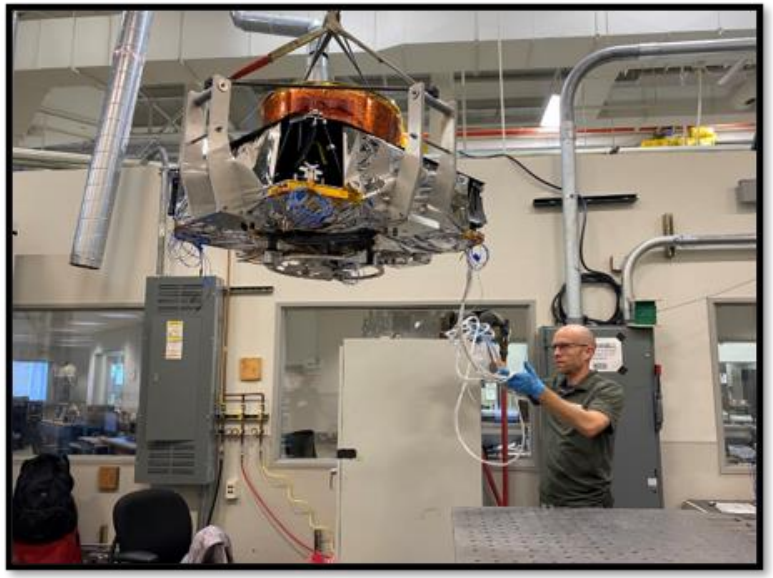


Proposal for TRL6 testing in work

Solar Sail System – mature to TRL 6

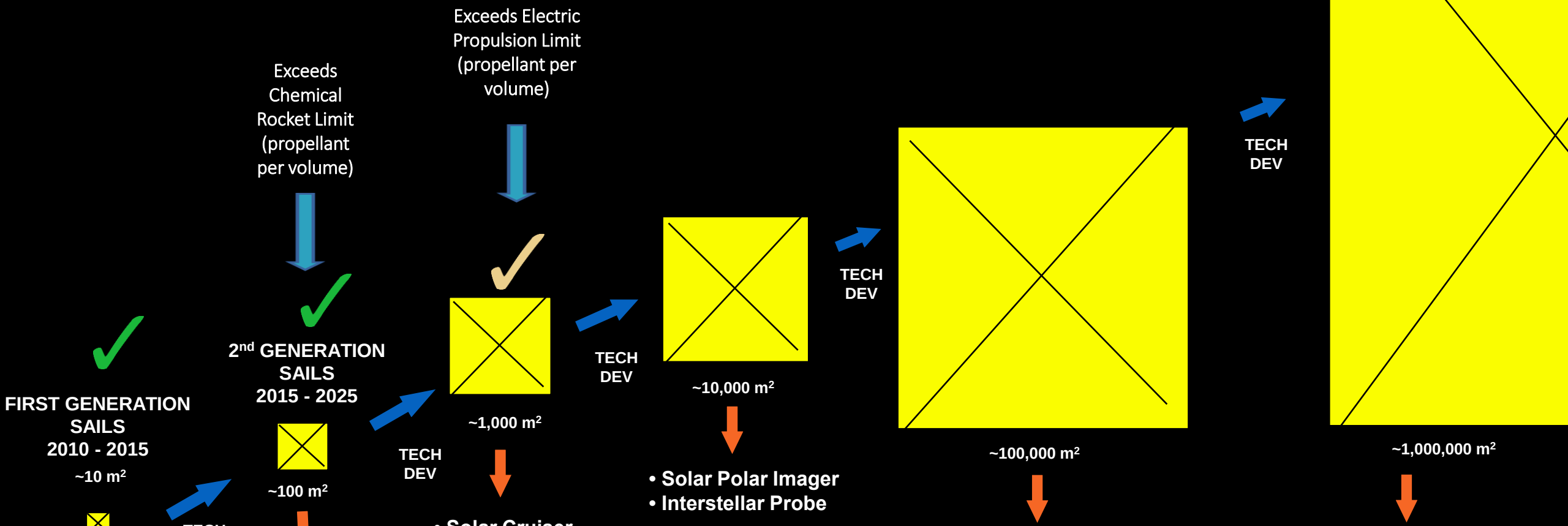


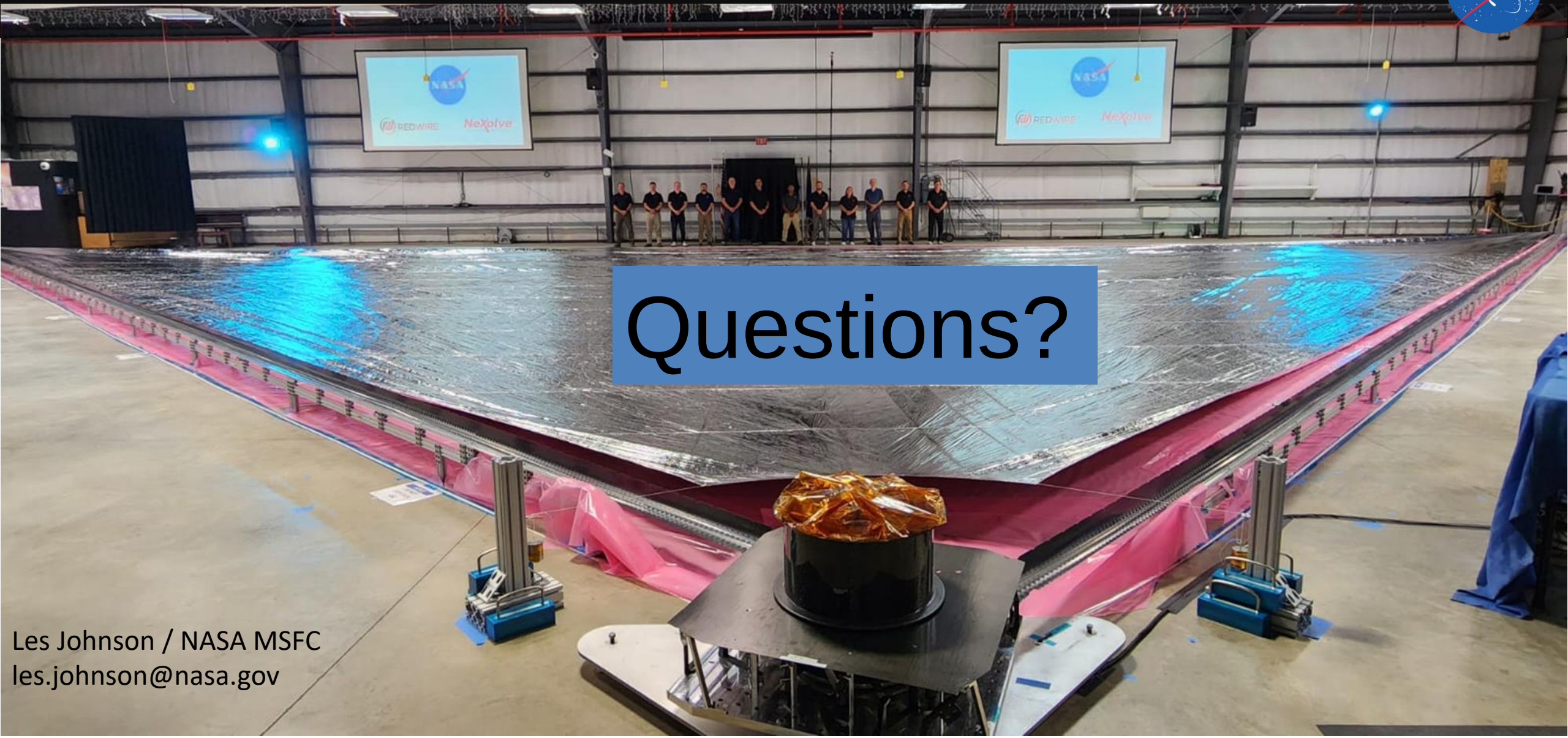
- System fully assembled
- System passed all final check outs
- System completed vibration testing with no issues
- System completed thermal only cycle testing with no issues
- TVAC scheduled for 12/4



SSS post-vibration testing

Solar Sail Technology Plan (Originally Created in 2004)





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