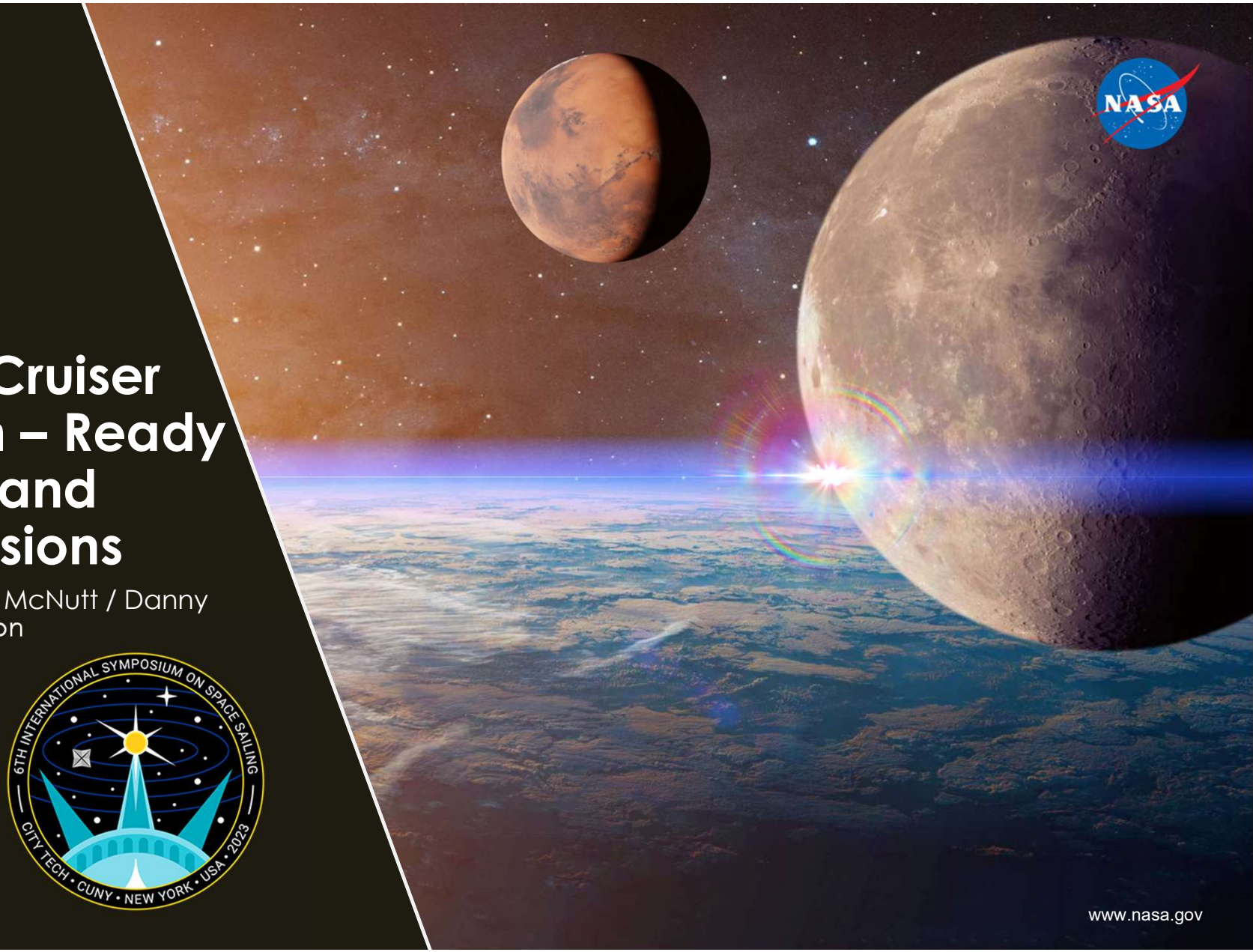
National Aeronautics and
Space Administration

The NASA Solar Cruiser Solar Sail System – Ready for Heliophysics and Deep Space Missions

Les Johnson / Carlos Diaz / Leslie McNutt / Danny Tyler / Darren Wallace / Jeff Wilson

NASA MSFC

March 28, 2023



Solar Cruiser Technology Demonstration Mission (as currently defined)

Mission
Mature solar sail propulsion technology to enable near-term, compelling space missions for NASA and the nation.

Mission Technology Goals
Demonstrate solar sail propulsion technology to enable near- and mid-term missions in cis-lunar space, sun-L1 halo orbits, non-Keplerian and other planetary orbits

- Maneuver without regret capability in the Earth/Moon system
- Space Domain Awareness
- Increased Space Weather warning times
- Sustained in-situ measurements within the Earth's magnetotail
- High inclination solar orbital observations

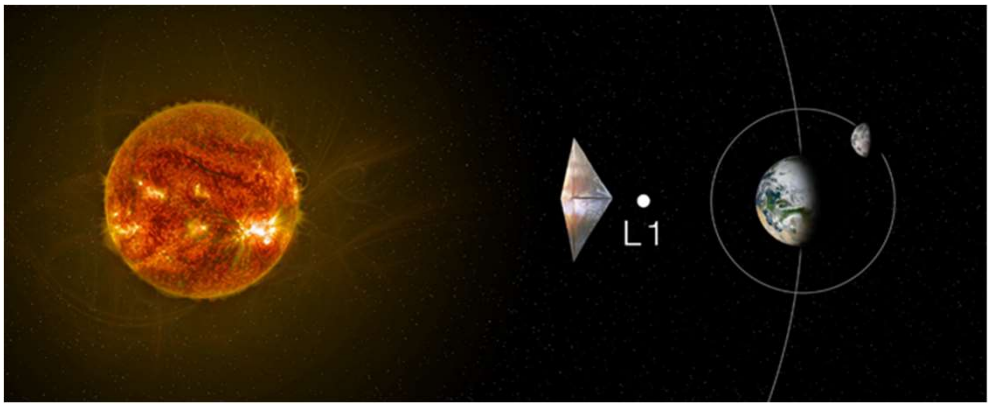
The Team
NASA MSFC: Project Management, ADCS Software, MDNav, Mission Operations

Ball Aerospace: Sailcraft Bus & Sailcraft I&T

Redwire: Solar Sail System

Purdue & Univ. Alabama: Student Collaborations

Completed PDR and was scheduled for February 2025 Launch



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
- Can accommodate 5 – 10 kg without significant changes

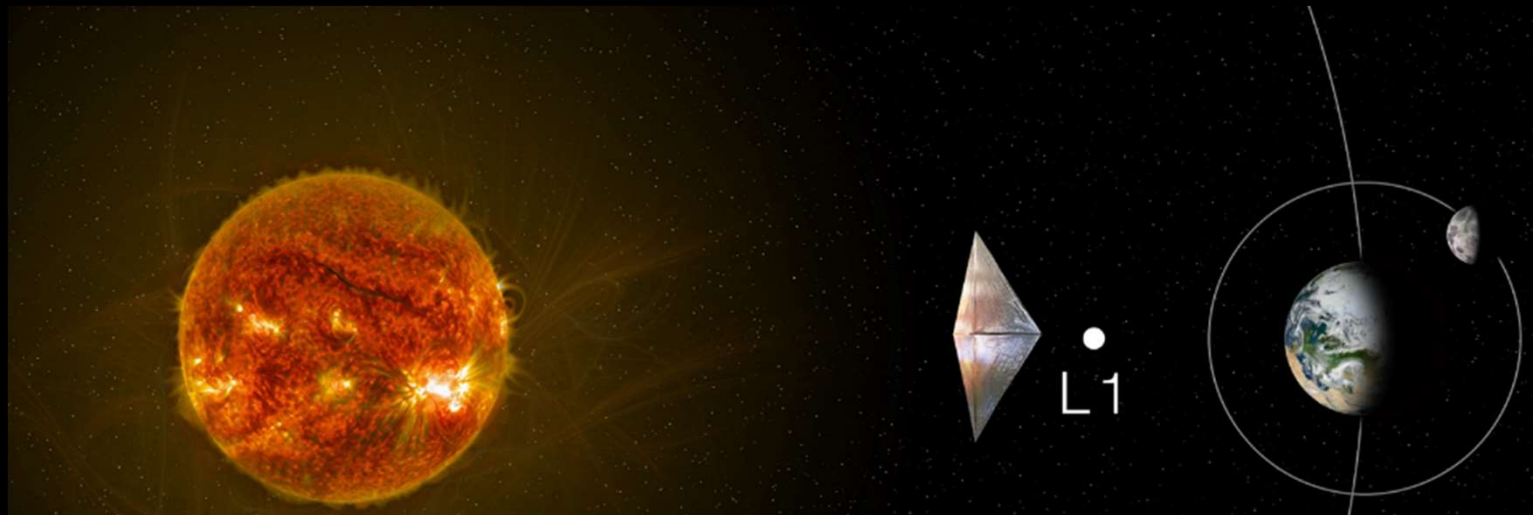
Destination

- Non-Keplerian sub-L1 halo orbit

Launch

- Secondary payload on ESPA Grande on Falcon 9 with IMAP mission

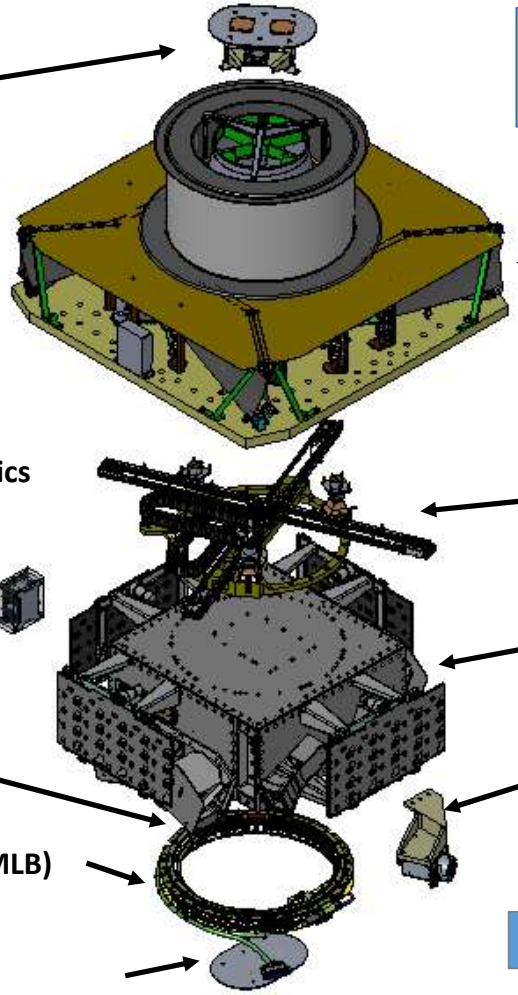
Solar Cruiser Mission Overview



Solar Cruiser was to launch as a secondary payload on the NASA IMAP mission in 2025. Using a solar sail, it would have cruised 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.

Due to a technical problem with the spacecraft and insufficient schedule margin to accommodate required changes, the mission was not confirmed for flight.

Solar Cruiser Flight and Technology Systems



Total System Mass: 111 kg
Designed for ESPA Grande

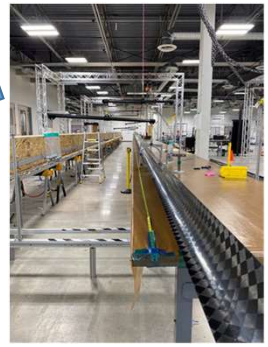
Solar Sail Technology System: Booms, Sail Deployment Mechanism, and Quadrants

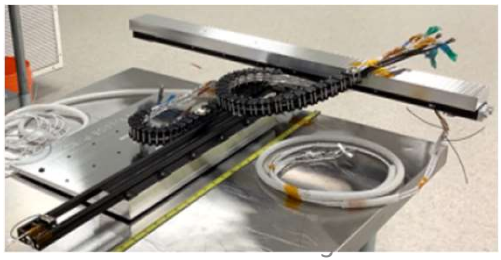
Technology System Active Mass Translator

Sailcraft Bus

Context Camera

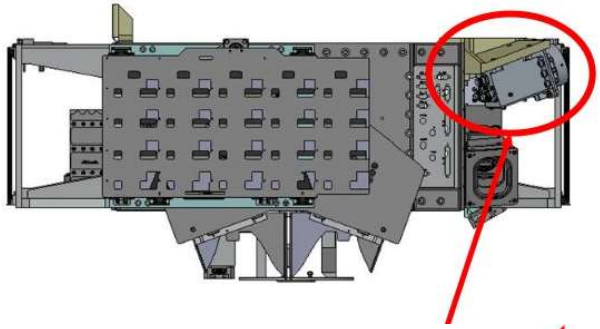
SSADCS Software

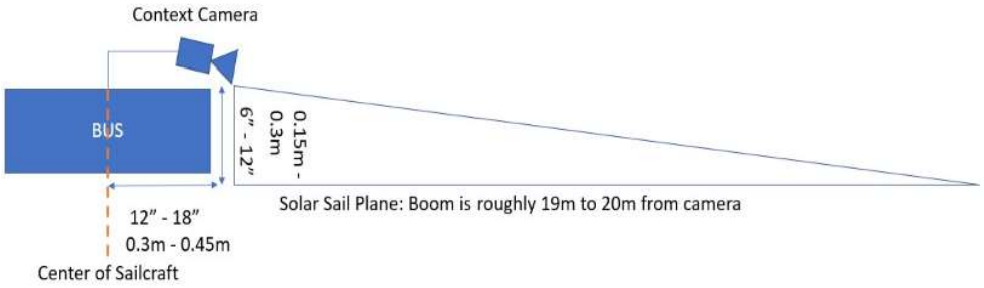


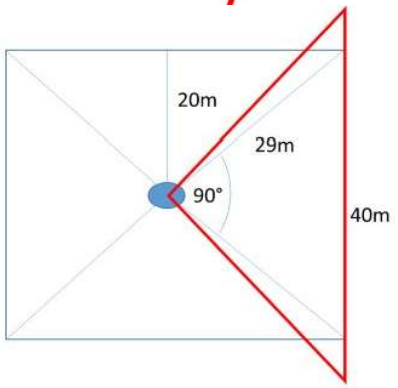


Current Solar Cruiser Payload

- Current capability allows for a payload capability of a context camera which could be replaced with an alternate instrument
  - Mass – 2.5 kg
  - View angle
  - Power – 5/12V
  - Data – SpaceWire interface; 10 Gb storage; up to 64 kbps downlink
- Additional capability (mass, power, volume) can be negotiated based on sail performance stakeholder needs

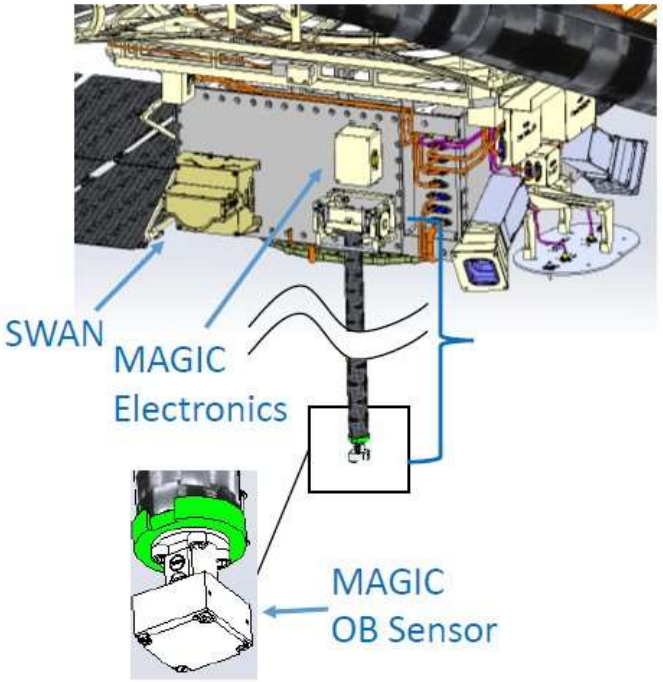






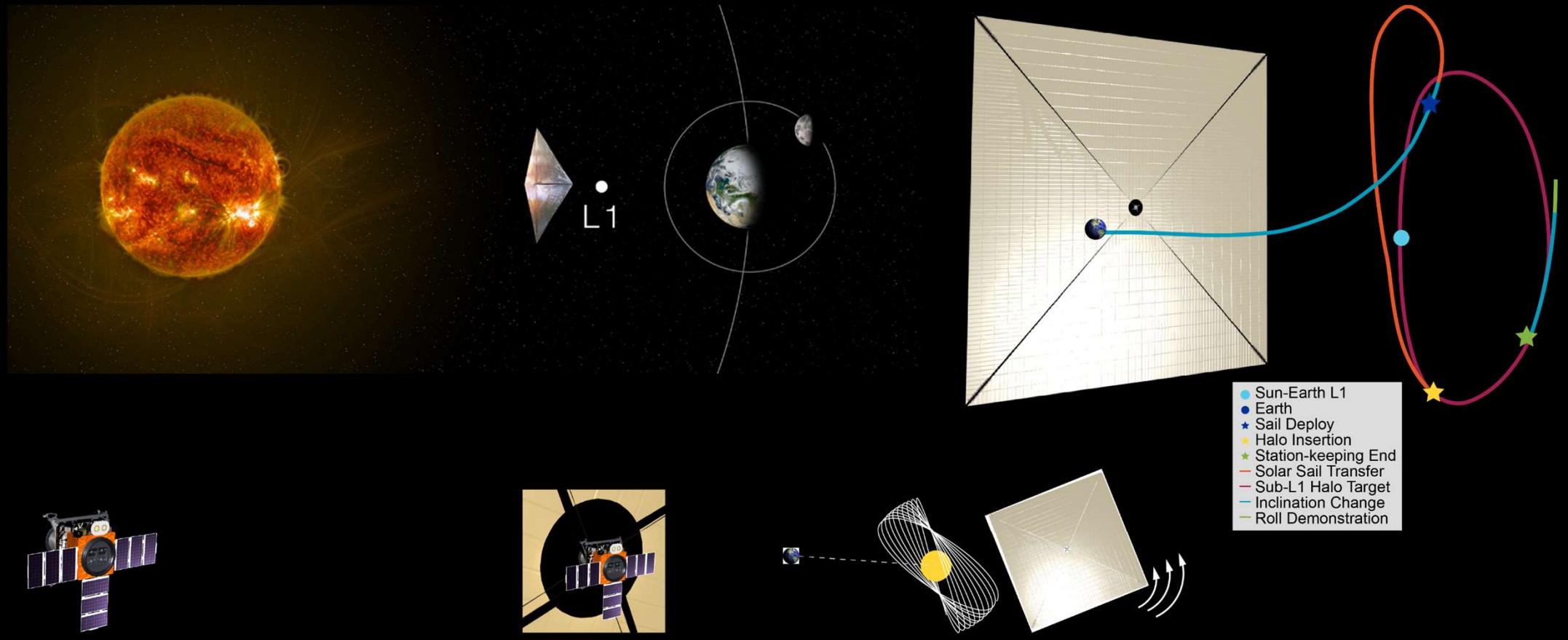
Solar Cruiser Can Accommodate A Magnetometer and Particle Sensor

- Over the course of the NOAA Magic Swan study, the team investigated the feasibility of flying relevant instruments (MAGIC & potentially SWAN) on Solar Cruiser.
  Direction given during the study shifted the focus to MAGIC-only accommodation, to:
  1. Characterize if a solar sail has any influence on the data of a magnetometer instrument (MAGIC) and quantify those effects.
  2. Prove Feasibility of accommodating similar Solar Weather instruments onto a Solar Sail mission.
  - *Secondary Goal:* Attempt to obtain scientifically meaningful data from MAGIC (and possibly SWAN).
- Technical Out brief Review package has full accommodation detail and was submitted to NOAA on 12/04/2020.
  - This package focuses primarily on feasibility of MAGIC accommodation and some technical detail on more demanding items.
  - Technical accommodation information for many less demanding items (Mounting Design, ADCS, Structural, Thermal, etc.) omitted.



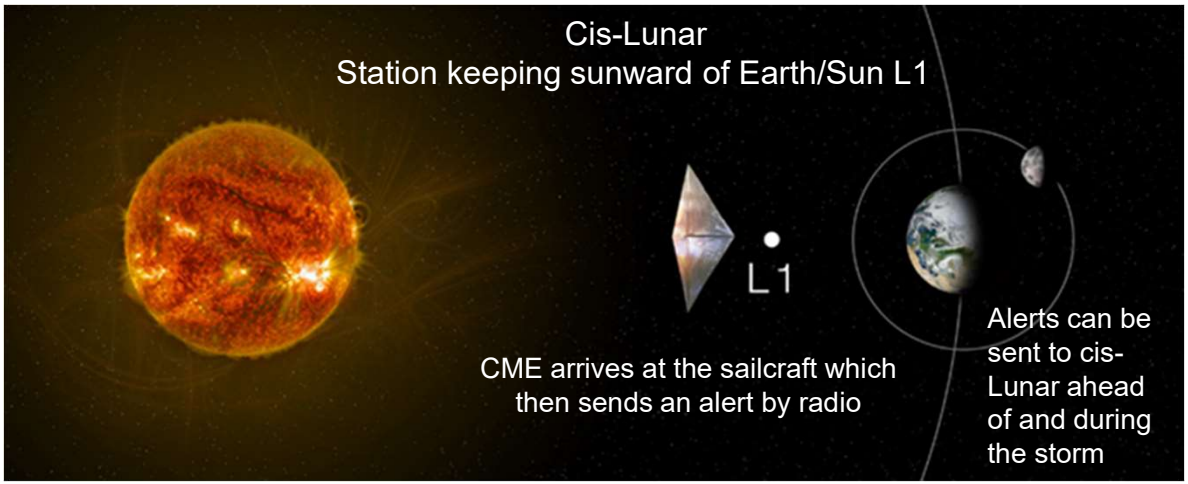
Note: At the time of this study, Solar Cruiser had 3x Solar Panels

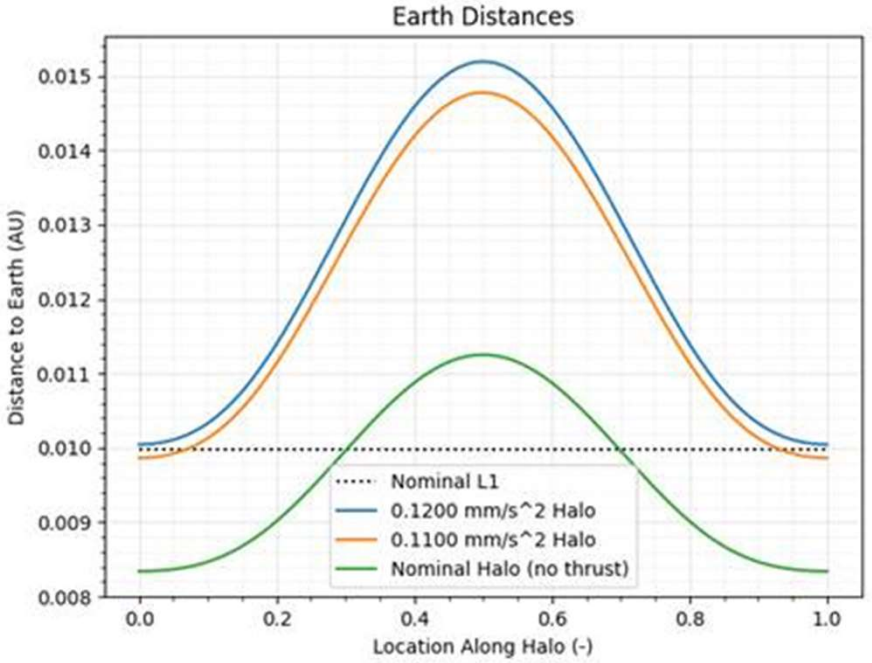
Solar Cruiser Will Demonstrate Solar Sail Propulsion Enabling Novel Orbits and Destinations



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*

Near-Term Sail Application: Advanced Warning of Solar Storms (Space Weather)

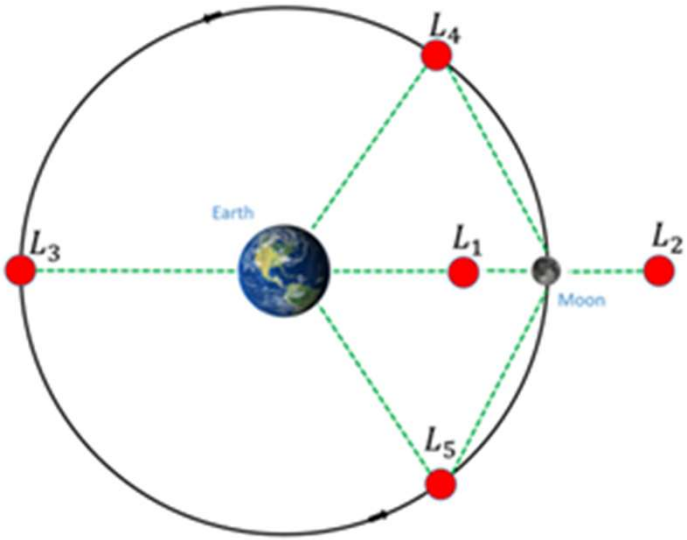




An instrumented sailcraft would increase solar storm warning times by 50% for both “typical” and “fast” Coronal Mass Ejections (CMEs) from ~55 min. to 83 min., and 20 min. to 30 min.

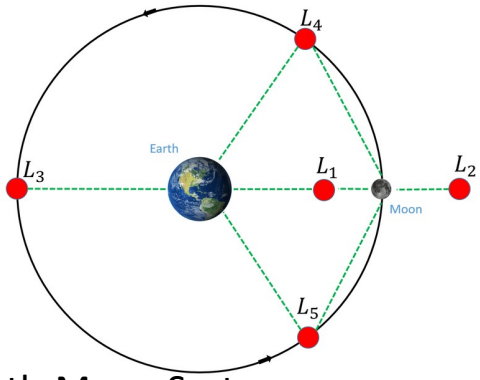
Near-Term Solar Sails in Cis-Lunar Space
Enhanced Communications, Position, Navigation, and Timing

- Enable station keeping in orbits that allow extended viewing of lunar hemispheric polar regions to enhance communication (between lunar surface assets and with Earth), position, navigation, and timing as well as surface observations and operations
- Enable near-continuous observation and communications *from lunar farside*
- Can cycle between lunar Lagrange points and the near-rectilinear halo orbit (Gateway) without propellant limit

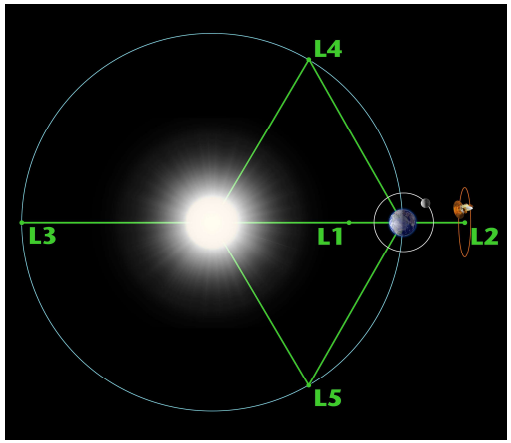


Can cycle between lunar Lagrange points and the near-rectilinear halo orbit (Gateway) with trip times of 4 – 6 days.

Near- Term Solar Sails Enable Space Domain Awareness and Continuous Maneuver Without Regret Capability in Cis-Lunar Space



Earth-Moon System



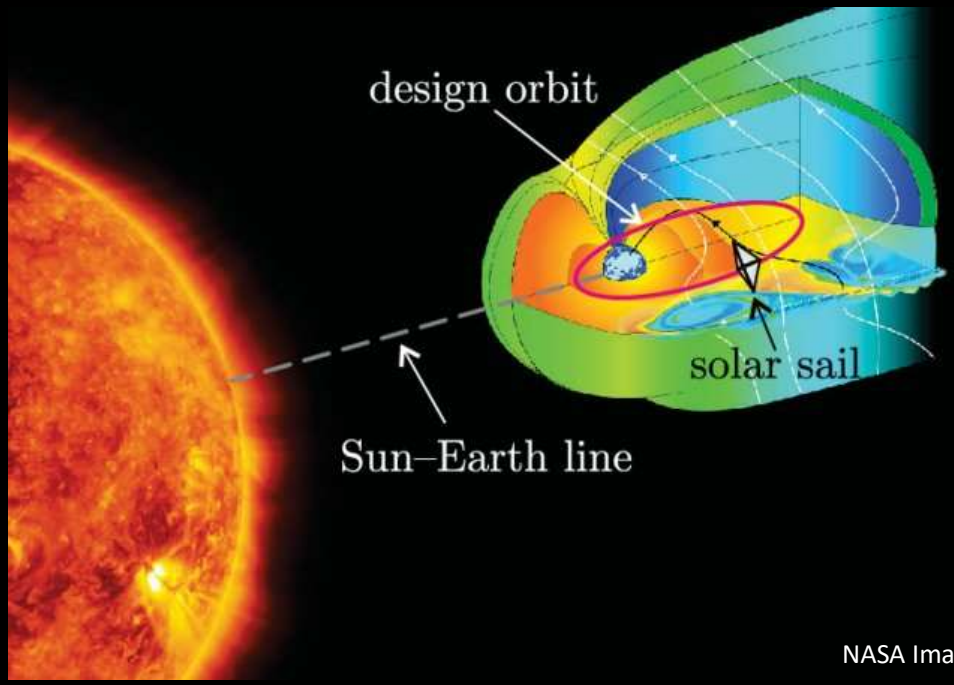
Sun-Earth System

- **Maneuver without regret among Sun-Earth and Earth-Moon Lagrange regions**
  - Logistics support – relocation of observers, communications
  - Provides flexible and unique observation locations, communication nodes, etc.
- ***Cycling between lunar Lagrange Points***
  - *4 to 6 day transfer times*
- **Near-rectilinear halo orbit (Gateway)**
- **Near-continuous lunar farside station keeping**
- **Near-continuous lunar pole observations**

Maneuvering capability in cis-lunar space is of interest to many agencies

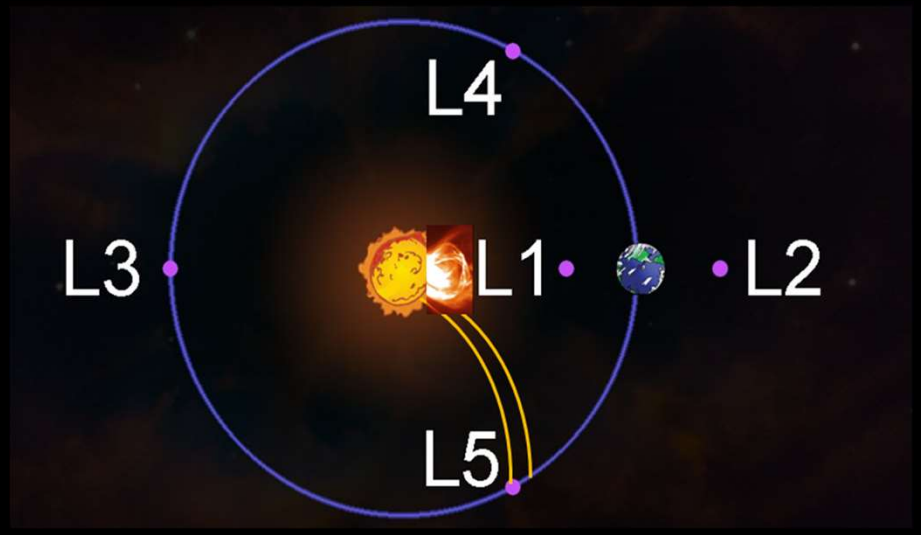
Immediately Enables Sustained Sampling of the Earth's Magnetotail

- 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

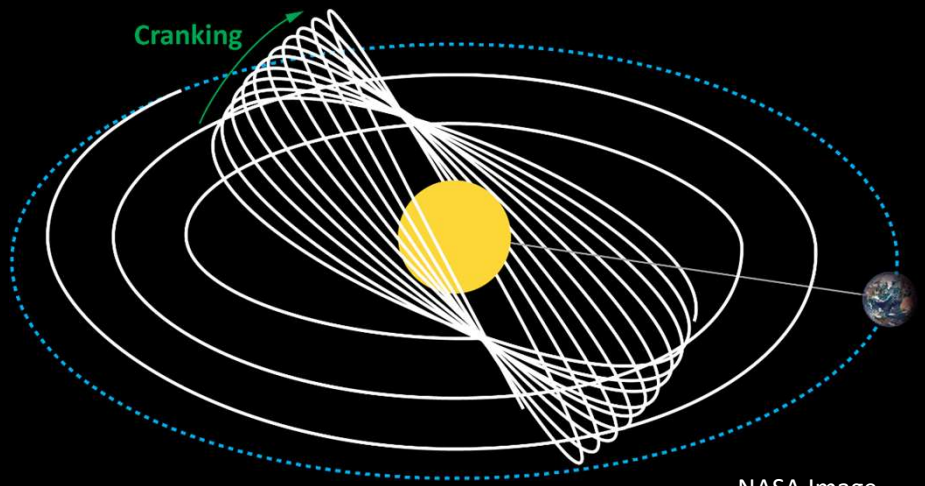


Observations enabled include imaging coronal mass ejections (CMEs) between the sun and Earth and in-situ measurements of solar wind streams in the vicinity of L5 before they rotate into Earth

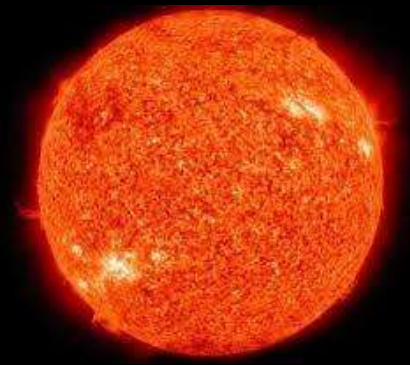
- Long term station keeping and flexible repositioning to be responsive to changing solar conditions

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

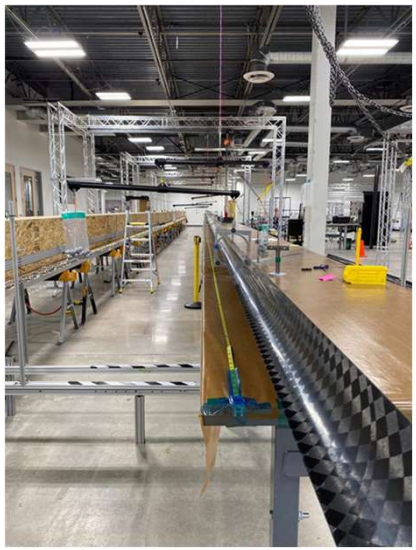


NASA Image

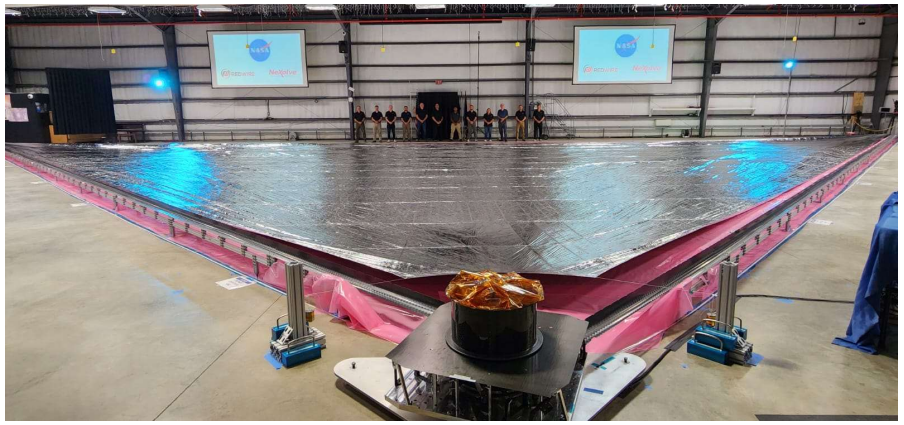


Prototype Quadrant Deployed and Tested

- 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

Solar Cruiser Project Status

- NASA Science Mission Directorate (SMD) did not confirm at KDP-C
  - Independent Standing Review Board (SRB) and MSFC Center Management Council recommended the project go forward to 2025 launch
  - SMD was concerned we could not meet schedule and had no alternative launch options
  - If funding is restored, 2028 launch opportunities can be met
  - $31M investment to-date in Solar Cruiser
- Other funding sources being sought
  - NOAA – possible LV contribution in 2028; providing funds in FY23 and FY24 to support project continuance
  - SMD – funding maturation of key technologies. $10 M secured since non-confirmation for FY23
  - Other NASA and other agencies – in discussion for funding

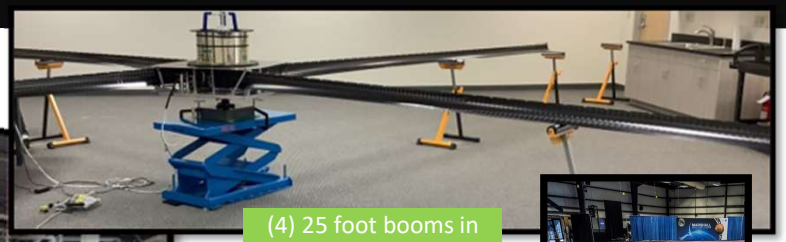
Solar Cruiser hardware status (images in following charts)

	Prototype	Flight Hardware (build timeline and delivery)
Solar Sail System		
Booms	COMPLETE -- (4) 25' prototype booms [used in ¼ scale deployment test], (2) 100' booms [used in full scale quadrant deployment test] IN PROGRESS -- (4) 100' prototype booms [(2) booms to be used in full scale quadrant deployment test Jan 2024]	
Sail Deployment Mechanism (SDM)	COMPLETE -- (1) Brassboard SMD [used in ¼ scale & full scale deployment test] IN PROGRESS -- (1) Prototype SDM [to be used for TRL-6 testing Jan 2024]	
Active Mass Translator (AMT)	COMPLETE -- (1) Brassboard AMT [used for environmental testing] IN PROGRESS -- (1) Prototype AMT [to be used for life testing Sept 2023]	
Sail Membrane	COMPLETE -- (1) 1/16th scale quadrant [used in ¼ scale deployment test], (1) full scale (4,450 ft^2) quadrant [used in full scale quadrant deployment test] IN PROGRESS -- (1) full scale (4,450 ft^2) quadrant [to be used in full scale quadrant deployment test Jan 2024]	FY23 – 25 (build and delivery of Full sail is 17,800 ft^2)
Sailcraft bus		
Iris Radio	N/A	FY23 (delivery of Flight Unit)
Avionics Unit, High-speed Data Recorder, Reaction Wheels, Batteries, Coarse Sun Sensors, Star Trackers	N/A	FY23 (delivery) ~$500K to fully fund hardware (funding needed mid FY23)

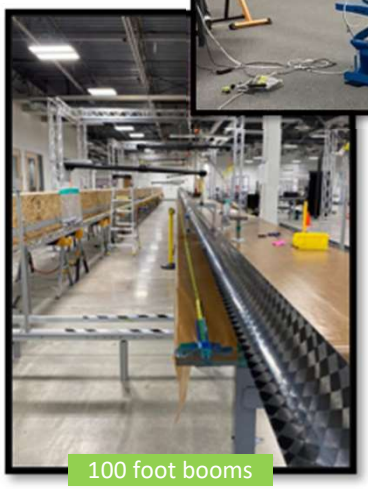
Fully funded
Partially funded

Solar Cruiser hardware status

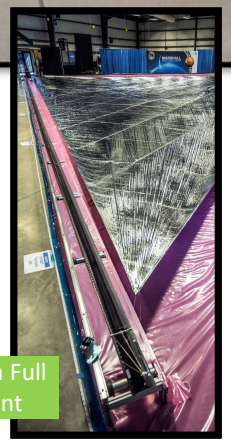
TRAC Booms



(4) 25 foot booms in Mini Deployment



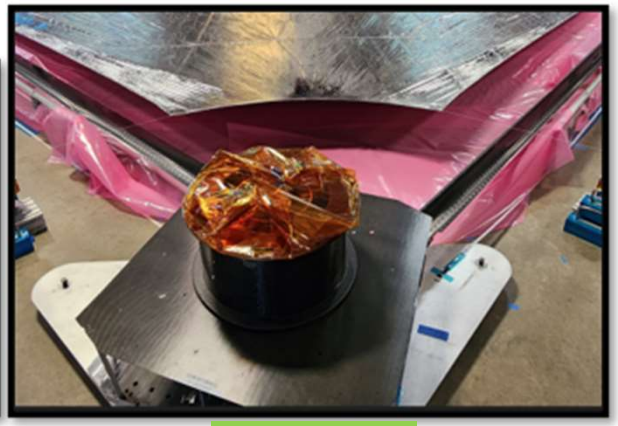
100 foot booms



100 foot booms in Full scale Deployment

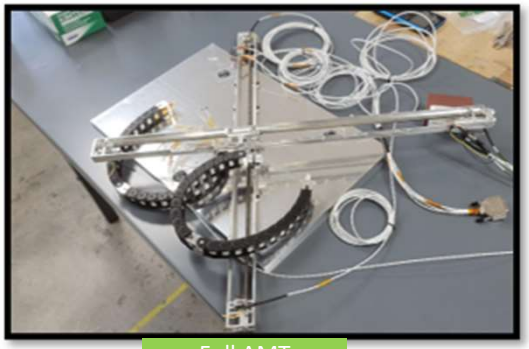
Sail Deployment Mechanism (SDM)

Mini Deployment

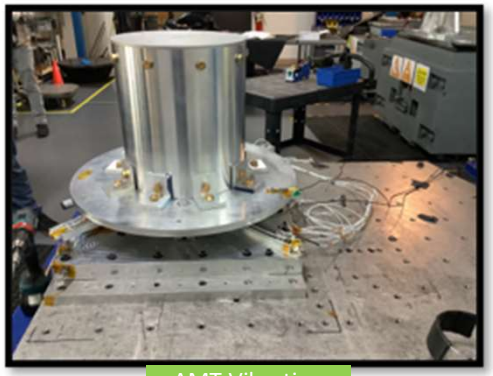


Full Deployment

Active Mass Translator



Full AMT



AMT Vibration Testing

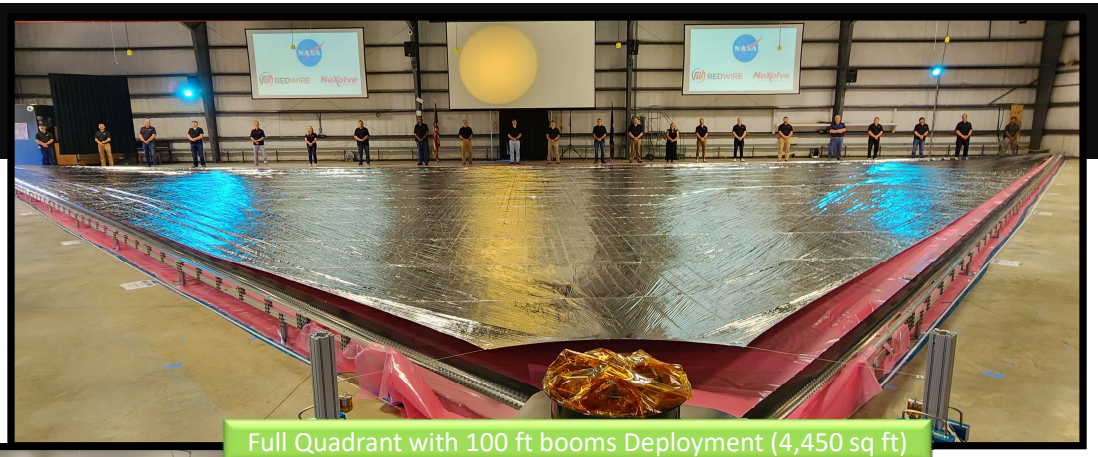
Sail Membrane

Spooled quadrant

Successful Ground Deployments

Several ground deployment testing complete including:

- One quadrant 250 sq ft^2 conducted over 5 separate deployments
- 4 quadrants of 1,100 ft^2
- One full quadrant of 4,450 ft^2



Full Quadrant with 100 ft booms Deployment (4,450 sq ft)

Four quadrant at 1/16th scale deployment (1,100 sq ft)

One quadrant at 1/16th scale deployment (250 sq ft)

In January 2024, the Solar Cruiser will perform another ground deployment. This deployment will be conducted after environmental testing including Vibration and TVAC.

The deployment will include Four 100 ft boom and only one quadrant of the sail membrane. The size of the deployment will be 4,450 ft^2.

Solar Cruiser
Collaborations & Partnerships

- **Solar Cruiser Project Team**
  - NASA MSFC (PM, system engineering, SSADCS GN&C)
  - Ball Aerospace (spacecraft bus, integration)
  - Redwire (solar sail system)
  - NeXolve (sail membrane)
  - NASA LaRC (supporting analysis)
- **NASA Science Mission Directorate, Heliophysics Division**
  - ~$40M invested between FY19 – FY23
- **Other NASA and Government Agencies**
  - Funding TBD
- **NOAA**
  - Contributing funding in FY23 & FY24
  - Contributing launch (2028)

National Aeronautics and
Space Administration

The NASA Solar Cruiser Solar Sail System – Ready for Heliophysics and Deep Space Missions

Les Johnson / Carlos Diaz / Leslie McNutt / Danny Tyler / Darren Wallace / Jeff Wilson

NASA MSFC

March 28, 2023