The Solar Cruiser Mission: Demonstrating Large Solar Sails for Deep Space Missions

Les Johnson*, Frank M. Curran**, Richard W. Dissly***, and Andrew F. Heaton*

* NASA Marshall Space Flight Center
** MZBlue Aerospace
*** Ball Aerospace
Solar sails use photon “pressure” or force on thin, lightweight, reflective sheets to produce thrust.
Solar Sail Missions Flown (as of October 2019)

- **NanoSail-D** (2010)
  - NASA
  - Earth Orbit
  - Deployment Only
  - 3U CubeSat
  - 10 m²

- **IKAROS** (2010)
  - JAXA
  - Interplanetary
  - Full Flight
  - 315 kg Smallsat
  - 196 m²

- **LightSail-1** (2015)
  - The Planetary Society
  - Earth Orbit
  - Deployment Only
  - 3U CubeSat
  - 32 m²

- **CanX-7** (2016)
  - Canada
  - Earth Orbit
  - Deployment Only
  - 3U CubeSat
  - <10 m²

- **InflateSail** (2017)
  - EU/Univ. of Surrey
  - Earth Orbit
  - Deployment Only
  - 3U CubeSat
  - 10 m²
Current and Planned Solar Sail Missions

**CU Aerospace (2018)**
Univ. Illinois / NASA

- **Earth Orbit**
- **Full Flight**
- **In Orbit; Not yet deployed**
- **3U CubeSat**
- **20 m²**

**LightSail-2 (2019)**
The Planetary Society

- **Earth Orbit**
- **Full Flight**
- **In Orbit; Successful**
- **3U CubeSat**
- **32 m²**

**Near Earth Asteroid Scout (2020)**
NASA

- **Interplanetary**
- **Full Flight**
- **6U CubeSat**
- **86 m²**

**Solar Cruiser (2024)**
NASA

- **L-1**
- **Full Flight**
- **90 Kg Spacecraft**
- **>1200 m²**
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 (20cm X 10cm X 30 cm)
- ~86 m² solar sail propulsion system
- Manifested for launch on the Space Launch System (Artemis 1 / 2020)
- 1 AU maximum distance from Earth

Leverages: combined experiences of MSFC and JPL with support from GSFC, JSC, & LaRC

Target Reconnaissance with medium field imaging
Shape, spin, and local environment

Close Proximity Imaging
Local scale morphology, terrain properties, landing site survey
NEA Scout Full Scale EDU Sail Deployment
Solar Cruiser may launch as a secondary payload on the NASA IMAP mission in October, 2024. It then cruises past the Sun-Earth L1 point, demonstrating station keeping at an artificial equilibrium point.
**Solar Cruiser**

**Solar Sail Technology Investment Heritage**

- **LightSail 1 (The Planetary Society)**
  - 32 m² sail
  - Successful flight in 2015

- **LightSail 2 (The Planetary Society)**
  - 32 m² sail (NanoSail heritage design)
  - Successful flight in 2019

- **MSFC NanoSail-D**
  - 10 m² sail (made using parts left over from 400 m² demonstrator)
  - Successful flight 2010

- **SMD In-Space Propulsion Technology Project**
  - 400 m² solar sail demonstrator

- **HEOMD Near-Earth Asteroid Scout**
  - 86 m² solar sail
  - 2-year mission to an asteroid
  - Manifested on Artemis 1 (2020)

- **HEOMD Near-Earth Asteroid Scout**
  - 86 m², 2-year mission to an asteroid
  - Flight Unit Deployment Test (2014 - 2018)

- **In 2021, JWST will deploy 5 layers (772 m²) of thin film material traceable to Solar Cruiser (NeXolve)**

- **Reflective Control Devices (RCDs)**
  - NASA STMD Early Career Faculty STRA (2012)

- **Lightweight Integrate Solar Array (LISA)**
  - thin-film power generation
  - MSFC TIPS, STMD ECI & SSTP (2012-2021)

- **Roccor Composite Boom Technology**
  - Phase I & II SBIR (2018 – 2020)

- **NeXolve Large Sail Fabrication Automation**
  - Phase I & II SBIR (2019 – 2021)
Key Feature: The Solar Sail

- Reflectivity Control Devices (RCDs) for sailcraft attitude control
- Composite TRAC booms with excellent strength/weight ratio and thermal stability
- Embedded photovoltaics for additional power
- Passively stable design
- Scalable to future missions like SPI
Key Feature: PELE Coronagraph

PELE instrument (Polarization and Energetics in Line Emission) will provide space-based coronal imaging of both linear polarization states, combined with Doppler velocimetry, for a capability that is readily extensible to future missions.

The PELE coronagraph occults the solar disk down to $R_{\odot}=1.1$, enabling observations of magnetic structure in CME triggering regions.
Ball Sailcraft Concept

Star trackers (2x), mounted to stationary interior of spool

LGA Patch (1 of 2)

Spool for Solar Sail Deployment

Solar Sail Boom Deployer

AMT

PELE

PELE Aperture

TRAC Booms

Solar Array
# Solar Cruiser Operations Plan

<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Time Since Launch (days)</th>
<th>Duration (days)</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch and Commissioning</td>
<td>L+0 to L+28</td>
<td>28</td>
<td>Assess spacecraft functionality</td>
</tr>
<tr>
<td>Coronagraph Checkout</td>
<td>L+29 to L+53</td>
<td>24</td>
<td>Test and operate coronagraph</td>
</tr>
<tr>
<td>Sail Deploy and Checkout</td>
<td>L+54 to L+61</td>
<td>7</td>
<td>Deploy and Assess Sail</td>
</tr>
<tr>
<td>Sailcraft Cruise</td>
<td>L+62 to L+221</td>
<td>160</td>
<td>Use sail to fly to sub-L1</td>
</tr>
<tr>
<td>Sub-L1 Halo Orbit</td>
<td>L+222 to L+283</td>
<td>62</td>
<td>Operate coronograph on the sailcraft</td>
</tr>
<tr>
<td>Leave Ecliptic Plane</td>
<td>L+284 to L+365</td>
<td>92</td>
<td>Demonstrate heliocentric plane change</td>
</tr>
<tr>
<td>Science Enhancement</td>
<td>L+366 to L+ 730</td>
<td>365</td>
<td>Use coronograph to obtain science data</td>
</tr>
</tbody>
</table>
Science Enhancement Option

After the Baseline mission, *Solar Cruiser* proposes a 1-year SEO to observe the solar corona from vantage points off the Sun-Earth Line.

The sailcraft will cruise to 5 degrees Earth-trailing, where it will station-keep for 4 months for coronal observations.
WHY SOLAR SAILS?  Solar Storm Warning
WHY SOLAR SAILS?  Earth Pole Sitters

- Continual coverage of the polar regions
- Altitudes ranging from 0.75 million km to 3.5 million km, depending on sail performance and inclination chosen
WHY SOLAR SAILS? High Inclination Solar Science

Part of trajectory below Ecliptic Identified by dashed curve

1. Launch 5-24-18 $C_3 = 0.25 \text{ km}^2/\text{s}^2$
2. Start of Sail Phase 6-3-18
3. Start of Cranking Phase 12-19-18
4. End of Cranking Phase 2-5-25
5. Start of Science Operations 3-2-25
Questions?