

The Space Weather Follow On – Lagrange 1 Mission

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The Space Weather Follow On - Lagrange 1 (SWFO-L1) Mission

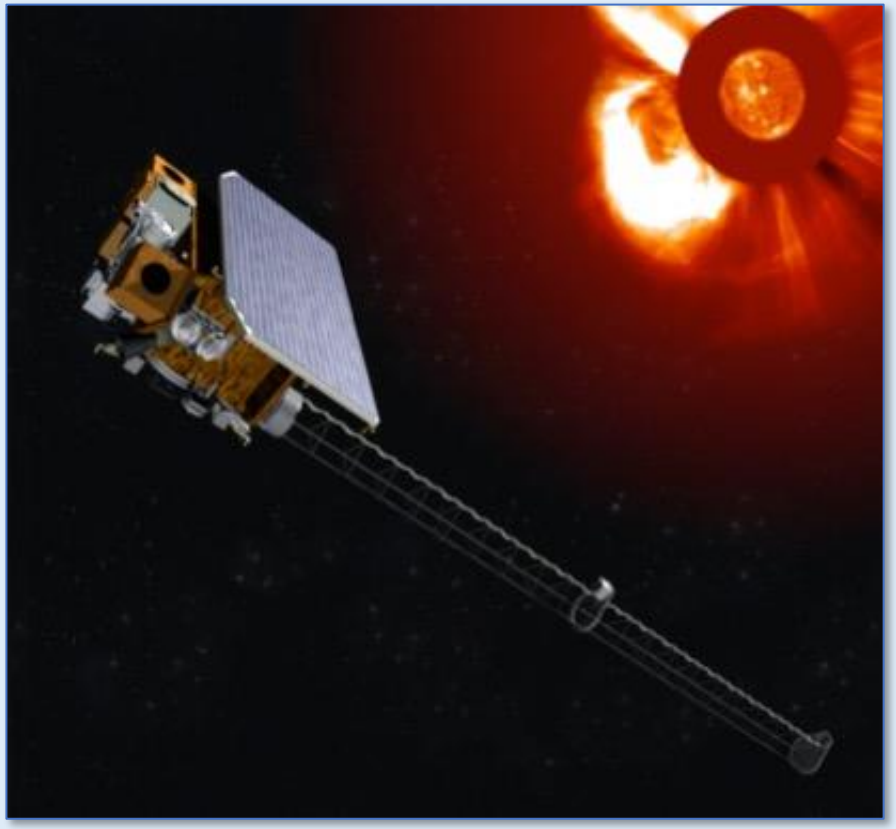
- The National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite and Data Information Service (NESDIS) established the Office of Space Weather Observations (SWO)
  - Critical data provided to the National Weather Service's (NWS) Space Weather Prediction Center
  - The Program and related NOAA activities are aligned with the National Space Weather Strategy and Action Plan
- The first SWO mission, SWFO-L1, will be positioned into a Sun-Earth L1 Lissajous orbit with the goal of providing continuous measurements of the space environment and observations of the Sun's outer atmosphere, and contributing to accurate forecasts of space weather disturbances.
- SWFO-L1 Flight Project is managed by NASA/GSFC
  - Acquisition and implementation assistance from NASA
  - The Goddard Navigation and Mission Design branch provides pre-launch analysis support, ground system development and testing, and operational support via Goddard's Flight Dynamics Facility (FDF)
  - Support spans launch and early orbit, transfer trajectory, orbit insertion, and initial stationkeeping until handover to the SWO NOAA Satellite Operations Facility (NSOF) who performs routine navigation and maneuver support
  - FDF provides backup services as required

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Spacecraft

- BAE, 3.75 m^2, ~390 kg, Sun-pointed, 3-axis stabilized
- Rideshare with NASA's Interstellar Mapping and Acceleration Probe (IMAP), NET Sept 23, 2025
- Compatible with the Secondary Payload Adapter (ESPA) Grande, which is used on the Air Force's Evolved Expendable Launch Vehicle (EELV)
- A 4-meter ring procured by NASA for the IMAP mission will be provided for integration

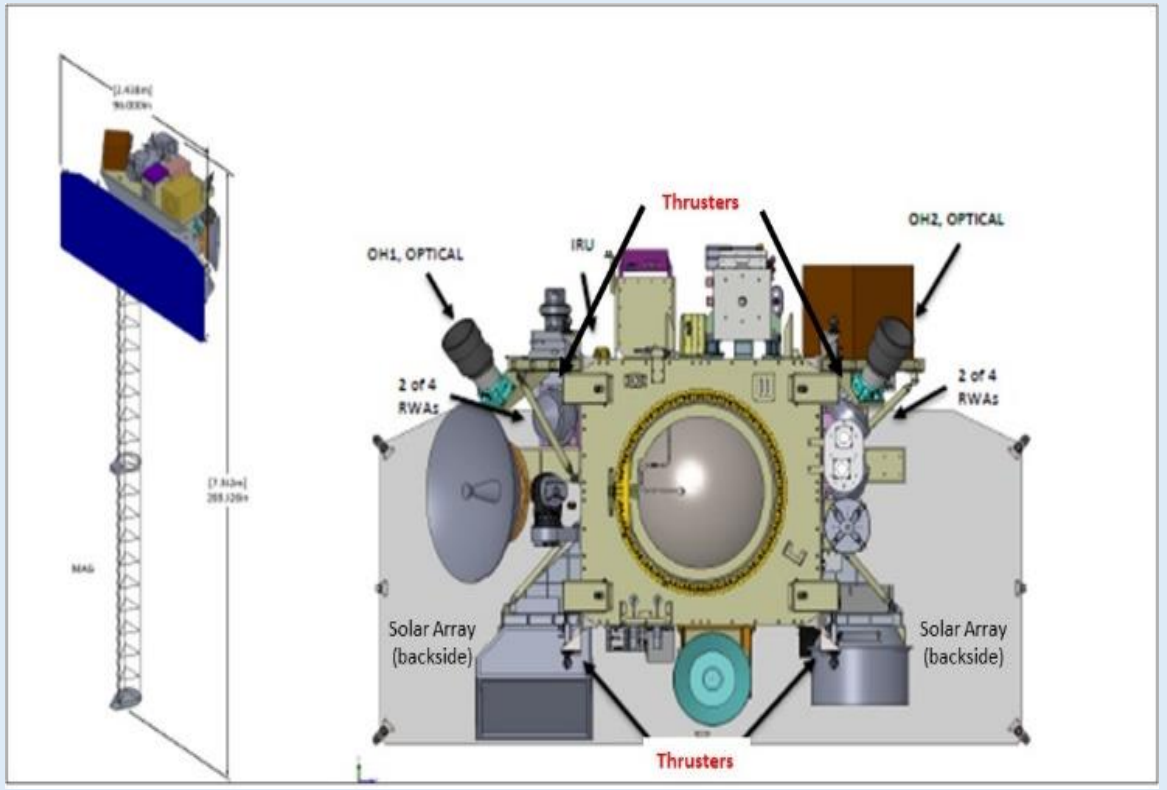


Instrumentation

- Compact Coronagraph-2 (CCOR-2) – Naval Research Laboratory (NRL)
- Solar Wind Plasma Sensor (SWiPS) – Southwest Research Institute (SwRI),
- Magnetometer (MAG) – SwRI/University of New Hampshire (UNH)
- Supra Thermal Ion Sensor (STIS) – University of California, Berkeley (UCB)

The Space Weather Follow On - Lagrange 1 (SWFO-L1) Mission

- SWFO-L1 propulsion system design, a simple monopropellant propulsion system
  - Four 5N thrusters, each canted by ~ 5 deg with respect to the spacecraft primary center line, the X axis
  - Provides for both translational and momentum management control during the entire mission duration
  - The propulsion system contains one diaphragm tank with hydrazine (N2H4) propellant and gaseous nitrogen (GN2) pressurant, operated in blowdown
  - The total initial thrust using the four thrusters at beginning of life is ~ 18.35 N and will drop to 5.87 N at the minimum pressure level
  - The amount of fuel used for the insertion maneuver takes approximately half of the 72 kg of fuel loaded at the time of launch

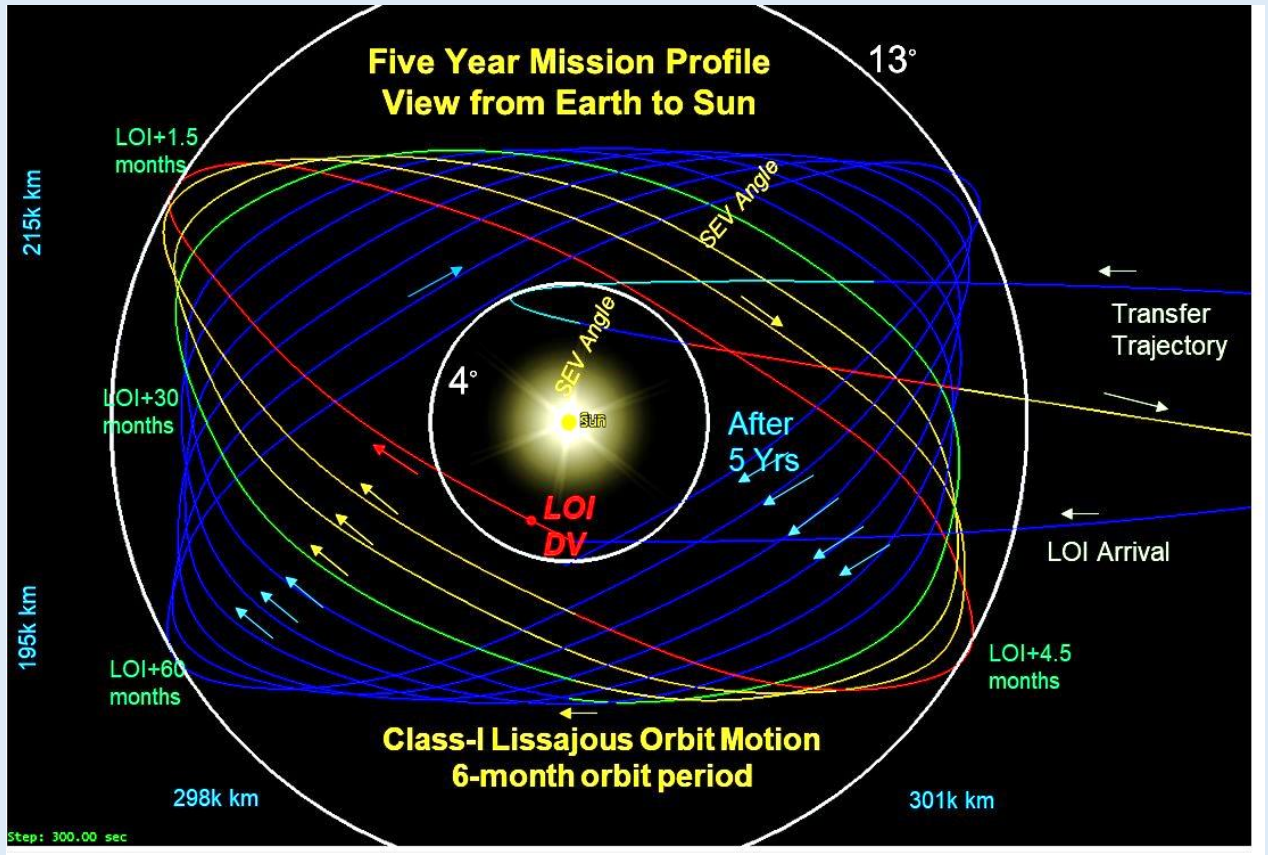


SWFO-L1 Bus and Propulsion Layout

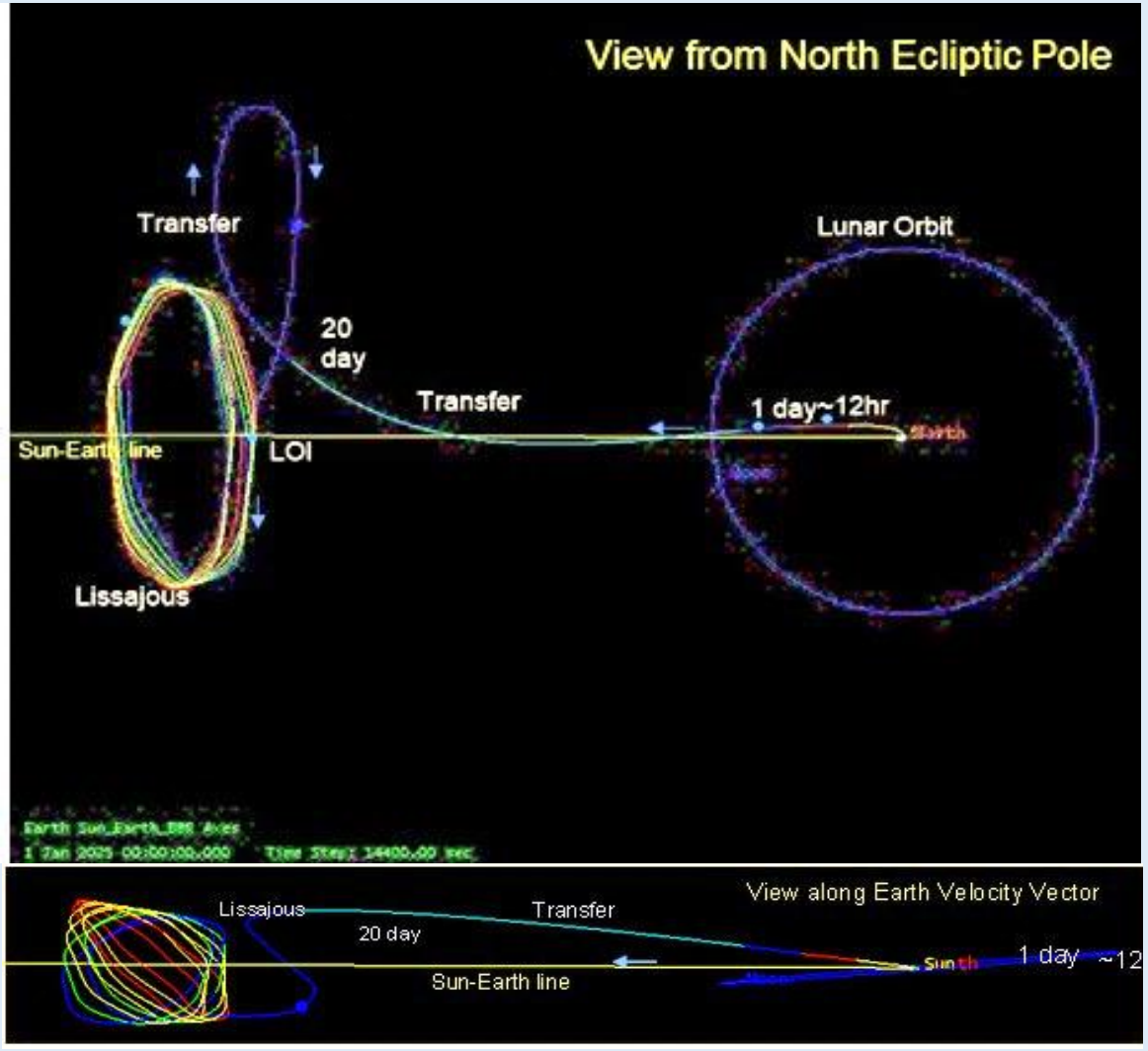
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Lissajous Orbit Selection

SWFO-L1 Lissajous Orbit as viewed from Earth in a Sun-Earth Rotating Frame



Viewed from above ecliptic plane



Launch Rideshare and Insertion DV and Fuel Budget

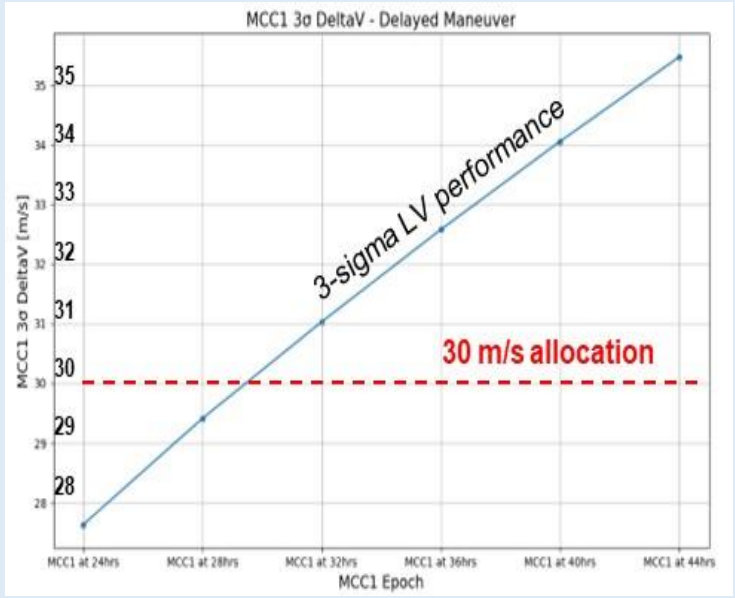
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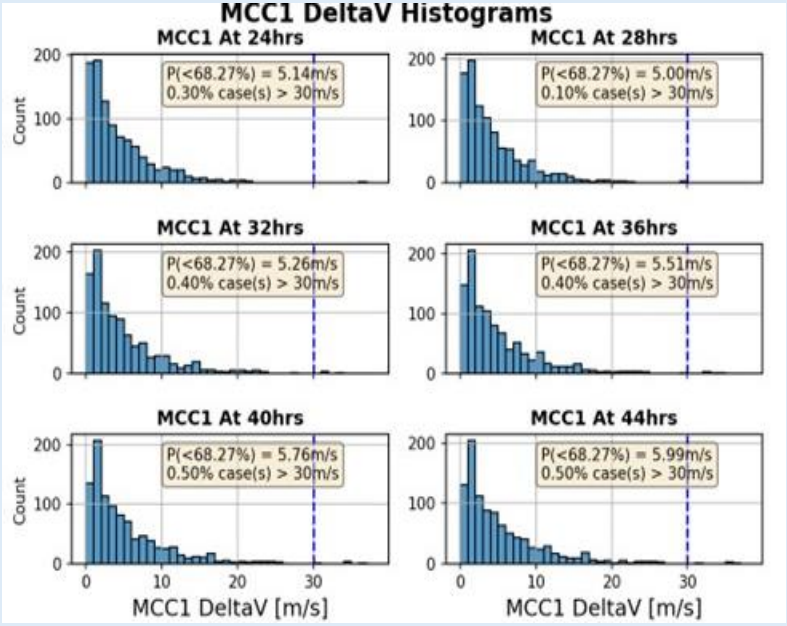
- Secondary spacecraft on the IMAP SpaceX Falcon-9 launch NET Sept 23, 2025
  - Launch window, launch C3, IMAP Class-I Lissajous design drives the SWFO-L1 transfer design, correction maneuvers to target the SWFO-L1 LOI requirements, and the selection of the Lissajous orbit
- SWFO-L1 maneuvers onto its own transfer trajectory to attain the Lissajous orbit insertion conditions chosen to minimize the Lissajous Orbit Insertion (LOI) DV

Delta-V Budget Assessment

Maneuver	Results (P<99.7%) [m/s]	Allocation [m/s]
MCC1	27.8	< 30
MCC2	3.7	< 5
LOI	156.5	< 160
Transfer Total (Statistical sum-per-iteration)	185.4	< 195
Stationkeeping (0-5 year)	21.8	< 22.5
Rephase	58	< 62
Stationkeeping (5-10 year)	21.8	< 22.5
EOM	1.0	<= 1
Mission Total	288.0	303

MCC1 Monte Carlo Delta-V Assessment



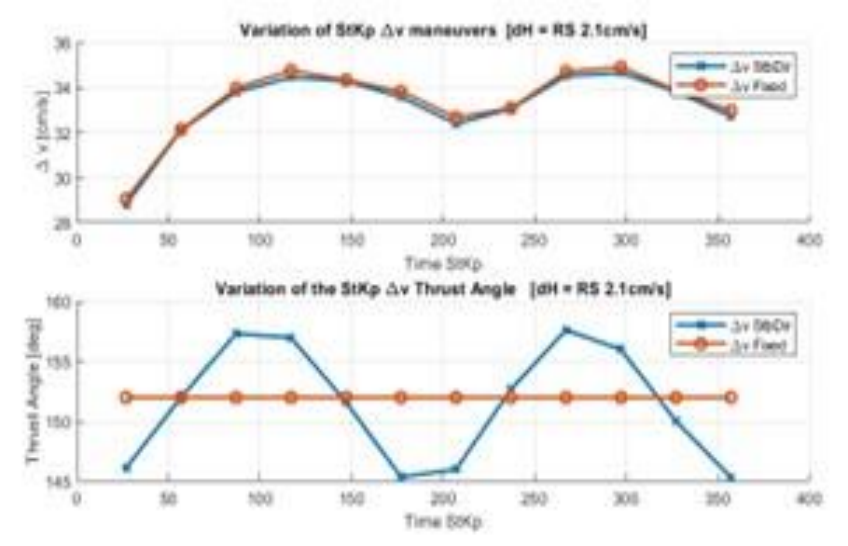


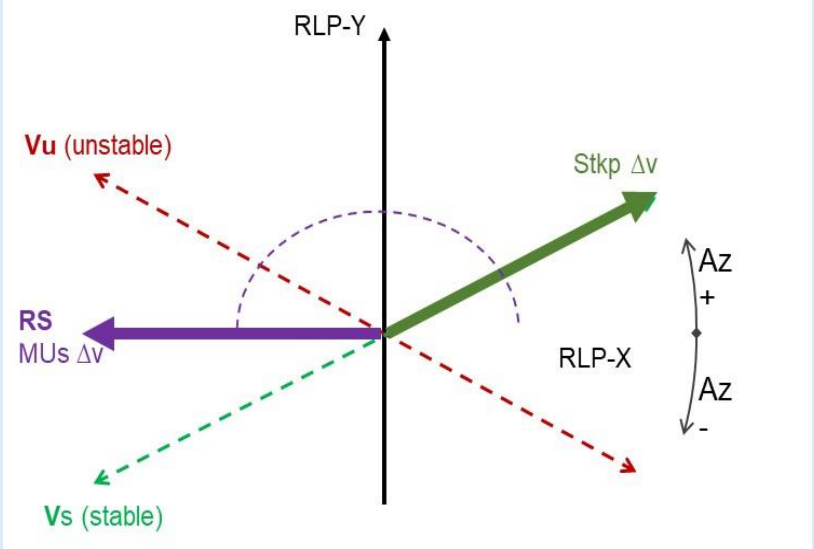
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Weekly Momentum Management Operations (Momentum Unloads (MUs))

- MU Residual 5.77 cm/s sunward DVs modeled in the nominal orbit integration
- Monthly SK DV of ~35 cm/s, larger than typically encountered for a Sun-Earth L1 mission
- An SK method was proposed that employed the residual MU DV in a direction dynamically more accommodating, e.g. the stable or unstable mode direction of a three-body dynamical system
- Investigation into this maneuver plan proved mathematically (dynamically) favorable and reduce SK DV to near zero, but alas, due to the need to slew SWFO-L1 using thrusters to achieve the proper attitude resulted in additional fuel
- "Stable mode" direction removes the added sunward MU perturbations, e.g. a SK DV in roughly the opposite direction of the MU residual DV, but dynamically situated

SWFO-L1 Stationkeeping DV and Geometry, Left Figure Showing Delta-Vs, Right Figure Showing DV, Stable and Unstable Directions in Rotating Frame



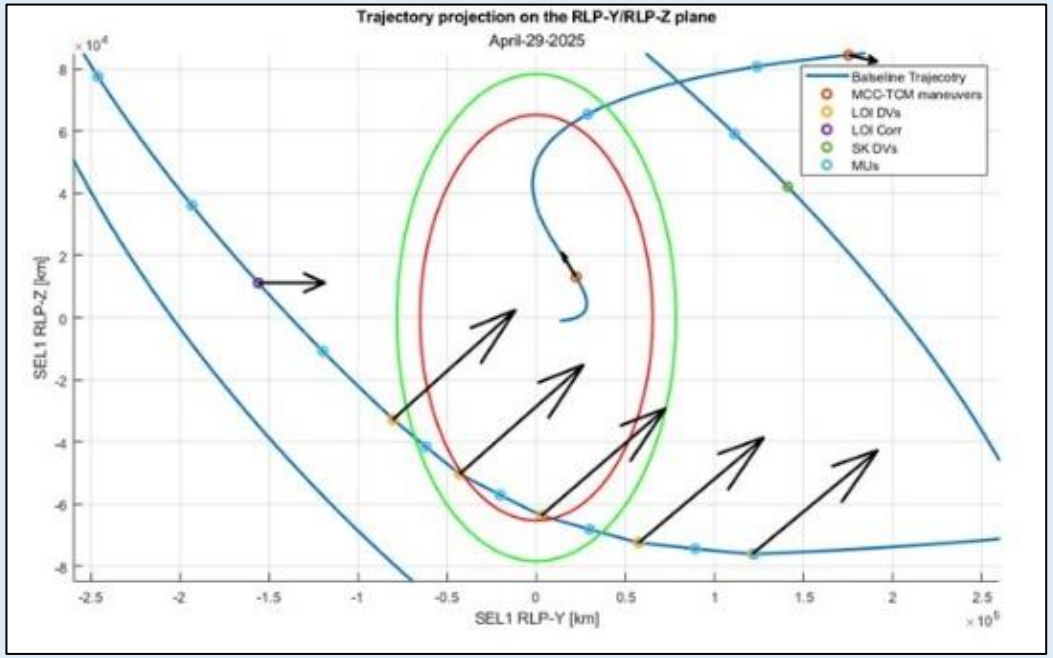


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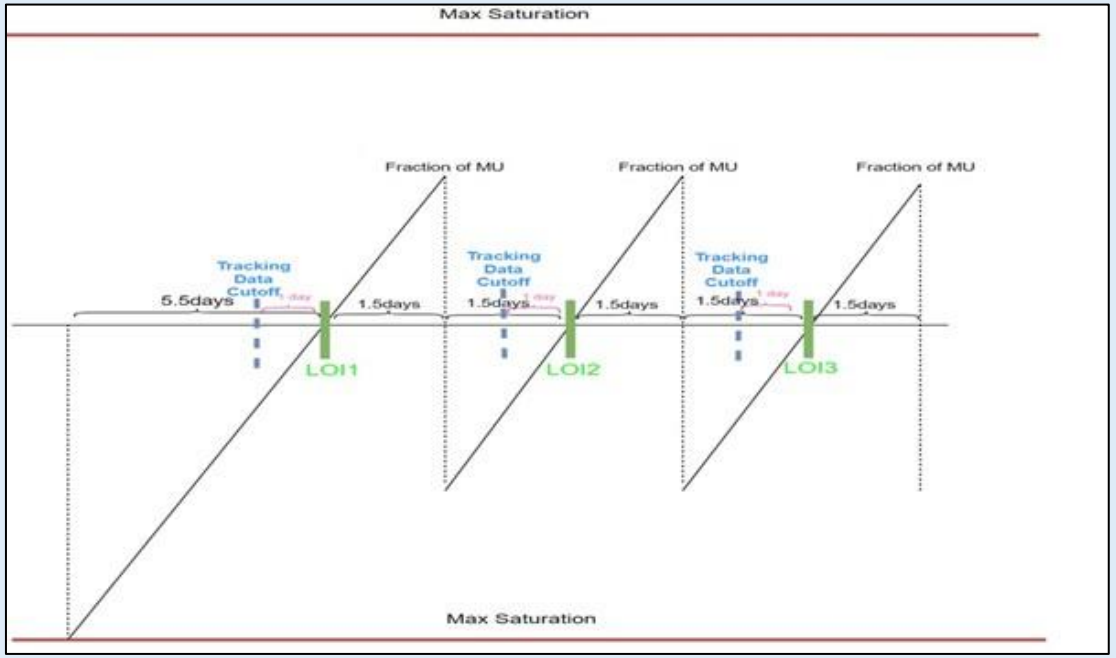
Lissajous Orbit Insertion (LOI) Considerations

- A nominal single LOI design would require a ~155 m/s maneuver performed over a ~90-minute duration
- Spacecraft design with respect to thermal and power constraints limits the duration of a single maneuver to less than 30 mins, including 10 min slew time to LOI attitude
- Requires maneuver design limit “large” maneuver to a maximum of 20 minutes, (19 min implemented)
- Results in a five segmented LOI over 15 days with DSN tracking between LOIs and required MU unloads between each LOI segment to attaining nominal wheel speed of zero, +/- 0.66 Nms at the next LOI maneuver

LOI Segmented maneuver directions



MU Schedule between LOI Segments

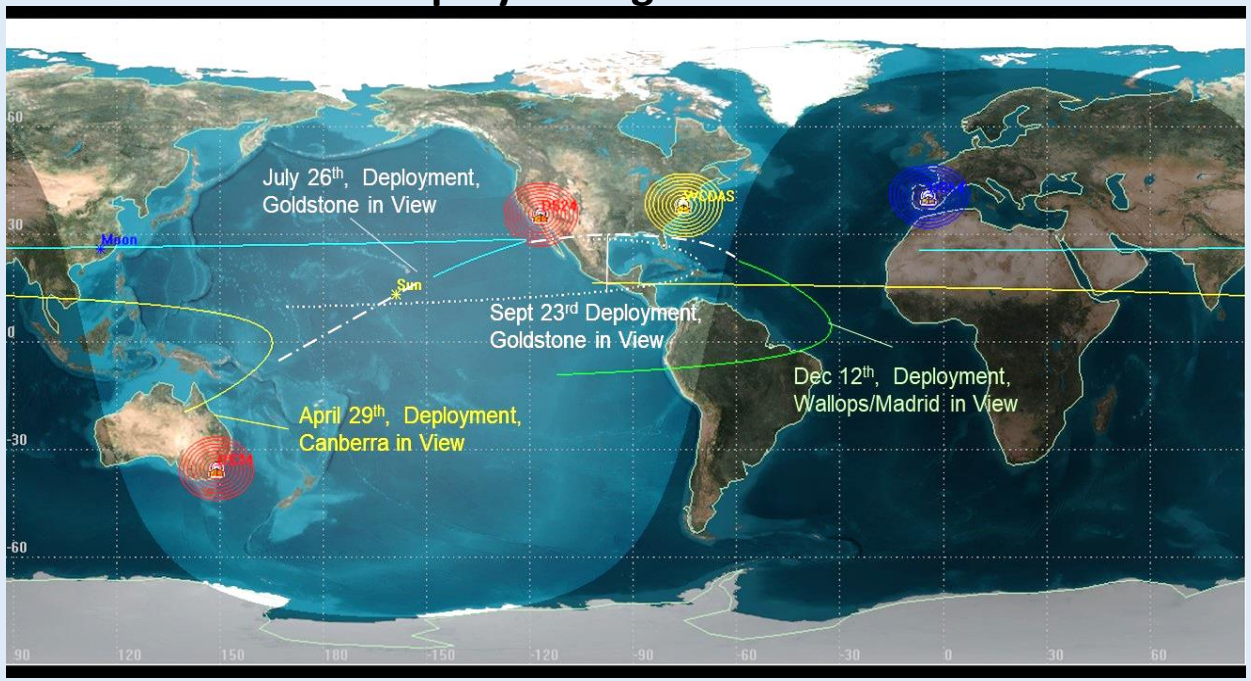


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SWFO Antenna Network (SAN)

- Routine S-band Range and Doppler tracking measurements using a combination of the new SWFO-L1 Antenna Network (SAN) and the Deep Space Network (DSN)
- SAN stations are located at the Wallops Command and Data Acquisition Station (WCDAS) site, with a Consolidated Backup at the West Virginia site (CBU)
- The challenge for SWFO-L1 comes from the use of DSN during launch and early operational support during the first week to support MCC1 and other critical spacecraft operations and checkouts, and from the use of the SAN
- Certification of the SAN stations used for tracking and orbit determination is required.
  - Performed by the Goddard FDF support team in cooperation with the SAN KBR (formerly Kellogg Brown & Root)
  - For SAN certification, the DSCOVR Sun Earth L1 orbiter mission has been used primarily to certify both range and Doppler measurements for the routine mission support

Post deployment ground track



Conclusion

The NASA Goddard Space Flight Center's (GSFC) Navigation and Mission Design Branch, code 595, is working with the GSFC SWFO-L1 project office and the NESDIS Office of Satellite and Product Operations (OSPO) to ensure a successful mission that continues the observation of the Sun and space weather

The SWFO-L1 mission support is challenging due spacecraft design and operations

- Launch vehicle rideshare impacts on mission design and maneuver timing
- Lissajous orbit size and orientation requirements needed to maintain minimum and maximum Sun-Earth-Spacecraft angles
- Momentum unload management operations: larger than normally experienced weekly residual DVs of 5.77 cm/s in the sunward direction
- Design of the LOI maneuver based on spacecraft design constraints and system dynamics
- Certifying the quantity and quality of tracking data measurements required for orbit determination using a newly developed SWFO-L1 Antenna Network.

SWFO-L1 Launch Opportunity, Sept 23 – Oct 13, 2025