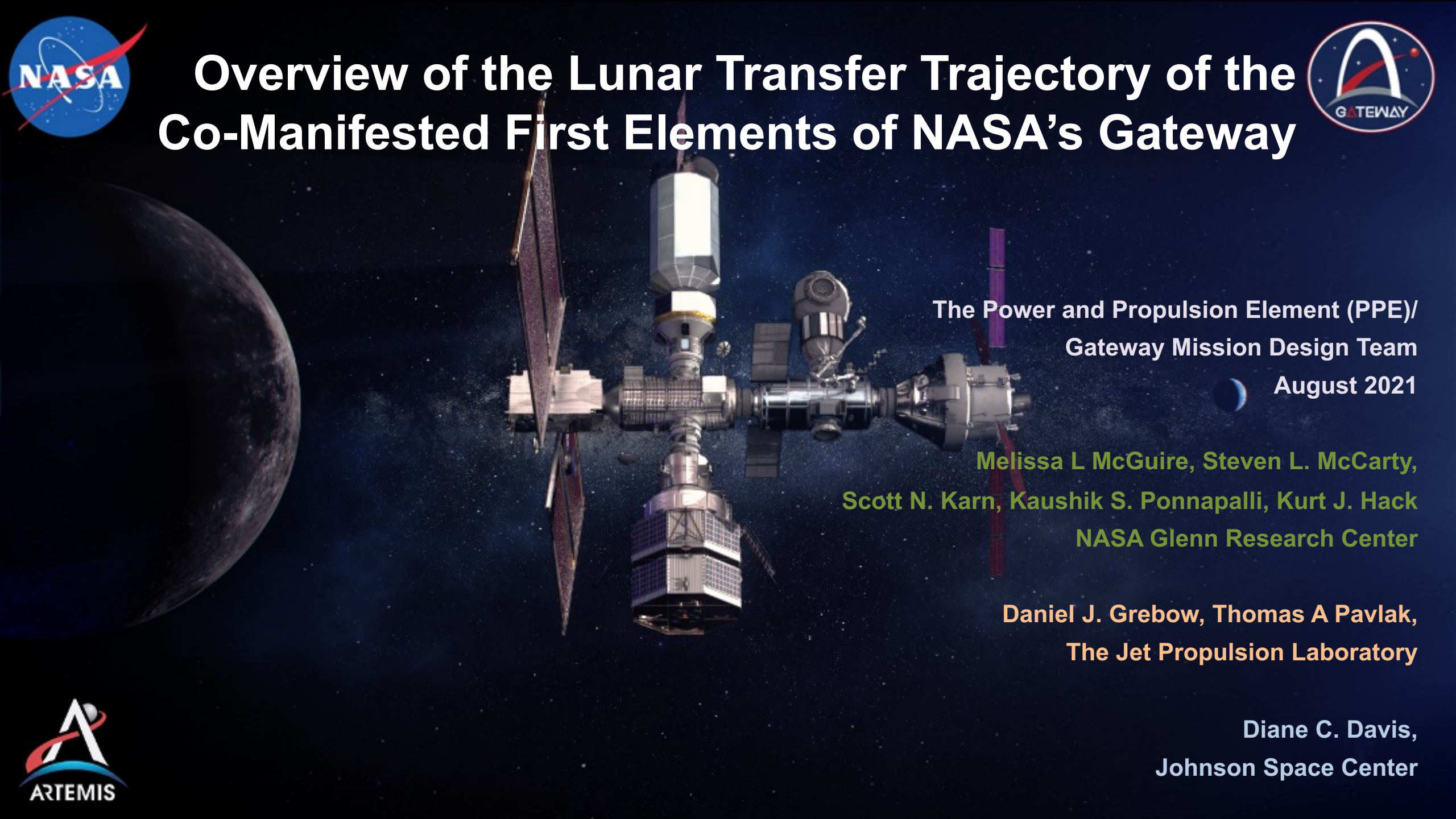
Overview of the Lunar Transfer Trajectory of the Co-Manifested First Elements of NASA's Gateway



The Power and Propulsion Element (PPE)/
Gateway Mission Design Team
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Melissa L McGuire, Steven L. McCarty,
Scott N. Karn, Kaushik S. Ponnapalli, Kurt J. Hack
NASA Glenn Research Center

Daniel J. Grebow, Thomas A Pavlak,
The Jet Propulsion Laboratory

Diane C. Davis,
Johnson Space Center

Background: Gateway

In March of 2017, NASA announced its next steps for exploration of destinations beyond LEO, landing first woman and next man on the moon with a goal of sustained human presence.

In order to move toward these next steps, the first phase of this exploration will involve the building of a Gateway in cislunar orbit.

The Gateway is envisioned as an outpost for lunar exploration and for explorations further away from Earth and eventually to Mars.

Notional Gateway Configuration (including Orion)*

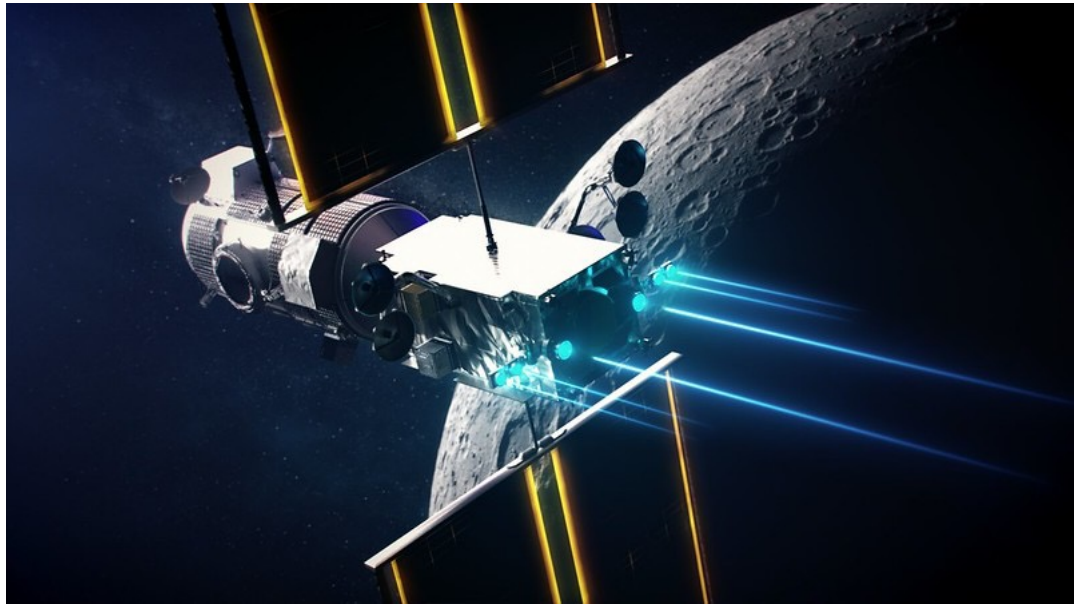
*https://www.nasa.gov/gateway

Background Co-Manifested Vehicle (CMV)

The first elements of the Gateway to be delivered are the Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO).

These two elements will launch together as the Co-Manifested Vehicle (CMV) on a single Falcon Heavy launch vehicle.

After being injected into a Medium Earth Orbit, the PPE Electric Propulsion (EP) system will be used to transfer the CMV to the Gateway's final destination: a Near Rectilinear Halo Orbit (NRHO) in cislunar space.

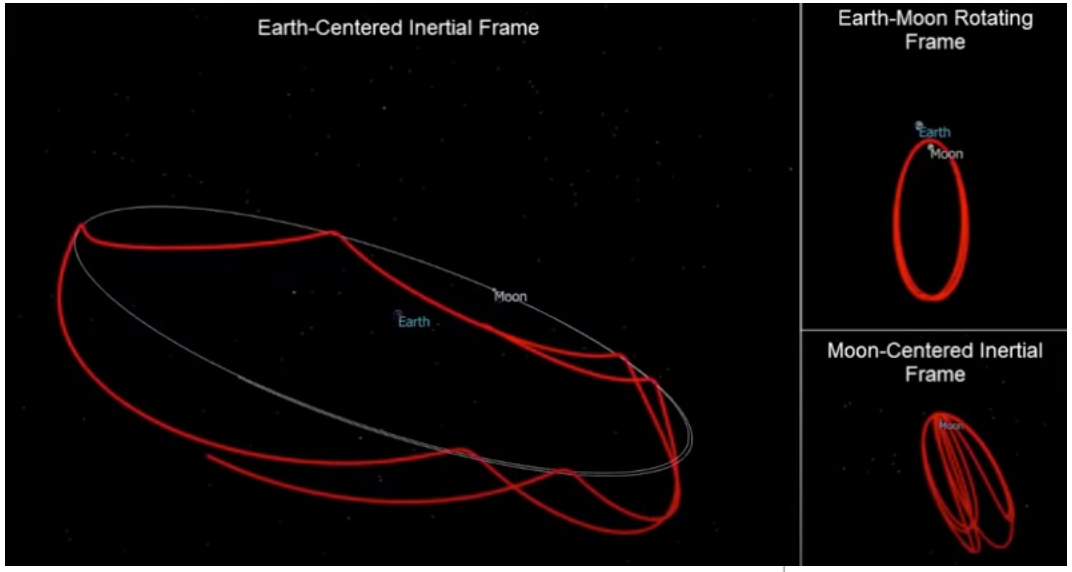


*https://www.flickr.com/photos/nasa2explore/albums/72157716027881092/with/50356331258/

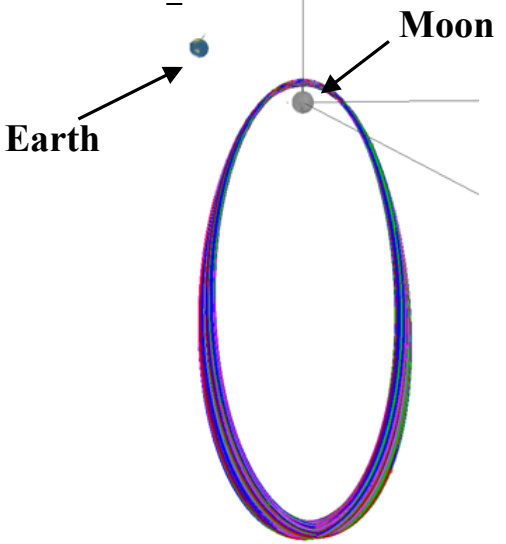
Destination Near Rectilinear Halo Orbit (NRHO)

- The lunar transit targets the Gateway reference NRHO

Description	L2 southern, 9:2 lunar synodic resonance
Average Period	6.56 days
Mean Perilune Radius	3,366 km
Mean Apolune Radius	71,100 km
Initial Epoch	January 2, 2020
Ephemeris Duration	15 years



NRHO visualization (D. Davis)
https://www.youtube.com/watch?v=X5O77OV9_ek



- [1]The White paper: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190030294.pdf

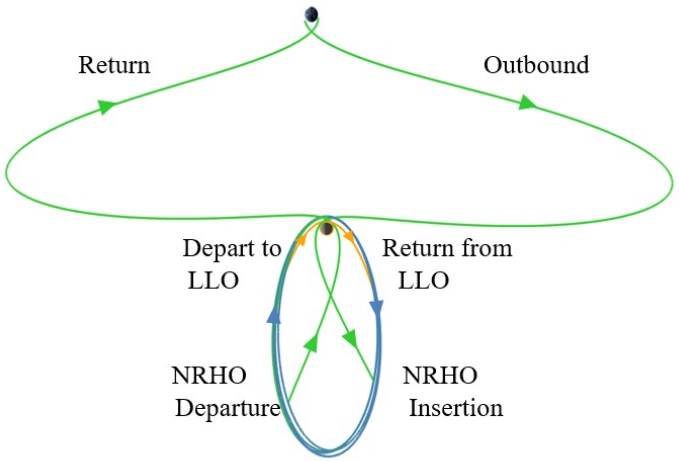
- The NAIF site for the NRHO SPK https://naif.jpl.nasa.gov/pub/naif/misc/MORE_PROJECTS/DSG/

1. Lee, D.E., "Gateway Destination Orbit Model: A Continuous 15 Year NRHO Reference Trajectory," NASA Johnson Space Center White Paper, August 20, 2019.

Introduction: Paths to NRHO

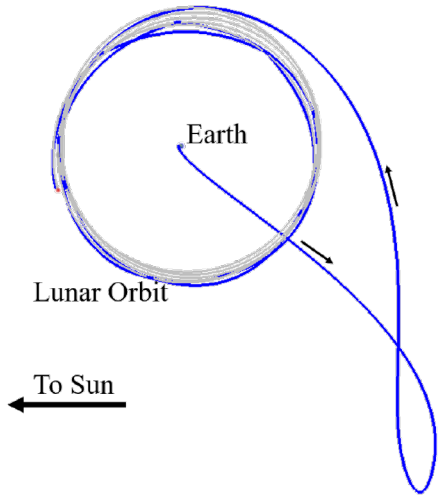
Direct TLI to NRHO (ex. Orion)

Time: 3-5 days
Propulsion: Chemical



Ballistic Lunar Transfer

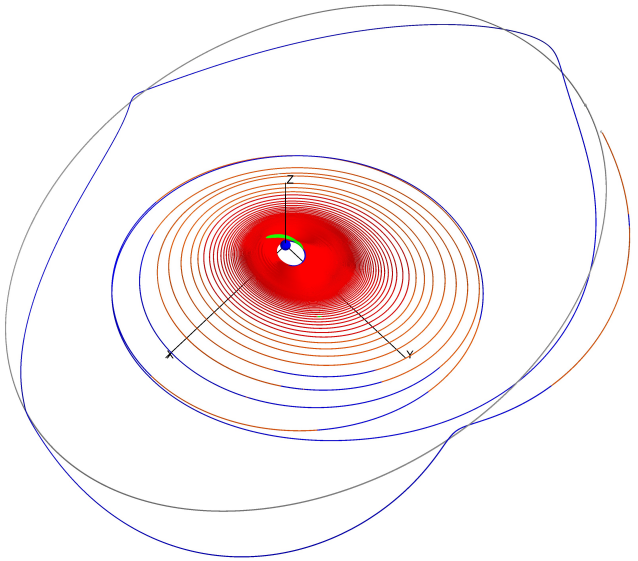
Time: 120-180 days
Propulsion: Chemical



Whitley, R., et al. "EARTH-MOON NEAR RECTILINEAR HALO AND BUTTERFLY ORBITS FOR LUNAR SURFACE EXPLORATION", 2018

Low Thrust Spiral (ex. CMV)

Time: 120-365 days
Propulsion: Electric

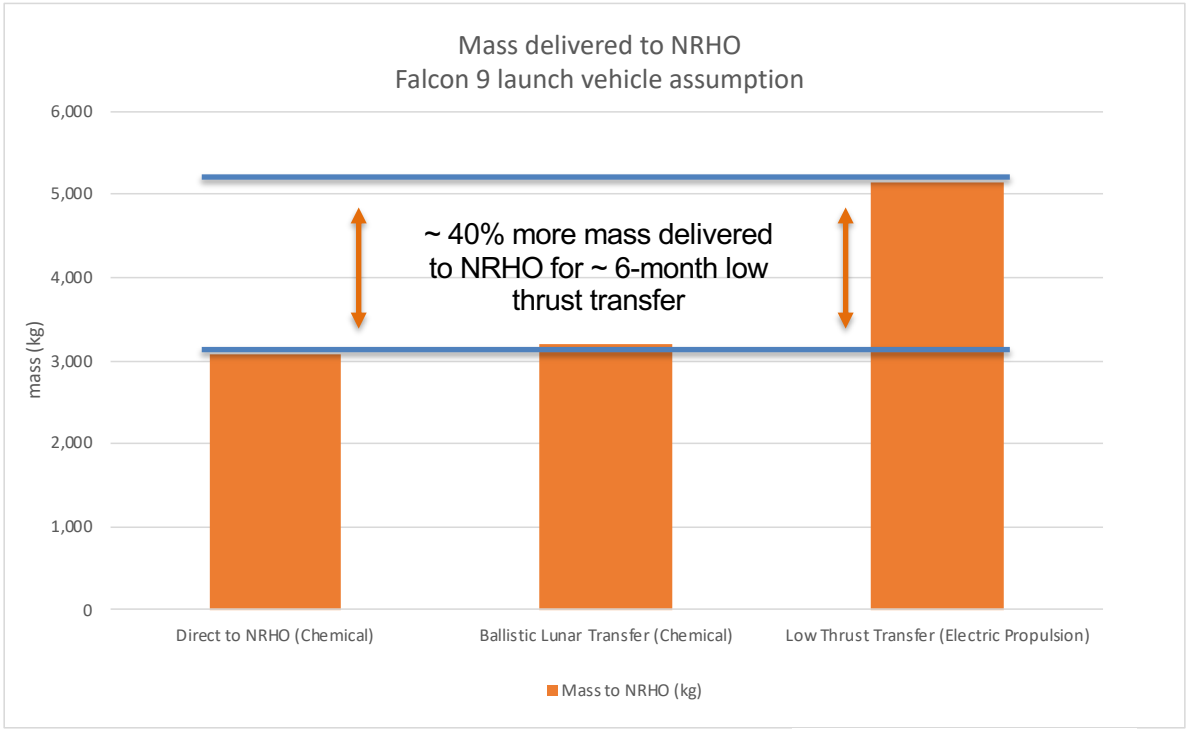


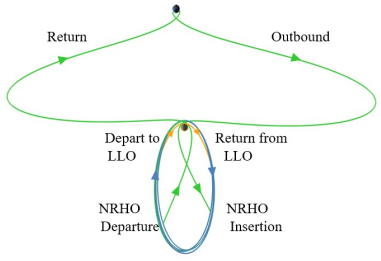
Power & Propulsion Element Electric Orbit Raise Design Reference Mission 3; January 2021

PPE-DOC-1038_PPE_HALO_DRM3_22Jan2021.docx

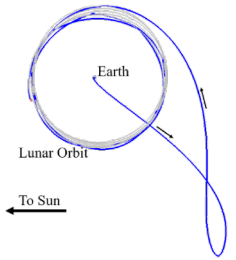
Mass Benefit of Electric Propulsion

- **The CMV mass exceeds the capability of any current launch vehicle to deliver direct to NRHO**
- **Electric propulsion is used to increase the mass delivery to the NRHO capability**
- **Example mass delivery to NRHO for each propulsion system and transfer option:**
  - Assume a publicly available Falcon 9 performance
  - **Direct** to NRHO uses the F9 to deliver the mass directly toward the moon
  - **BLT** uses the F9 to deliver the mass on a trajectory that takes advantage of the sun to raise the orbit to the NRHO
  - **Low Thrust Spiral Transfer** uses the efficient electric propulsion system to send the mass on a series of spirals about the earth to the NRHO
- **The low thrust spiral transfer trades time for additional mass delivered to its destination**

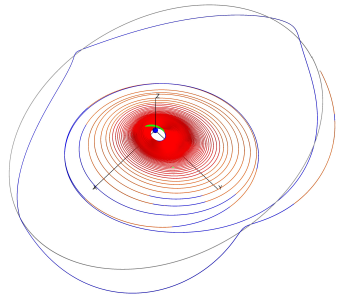




Direct TLI to NRHO (ex. Orion)



Ballistic Lunar Transfer

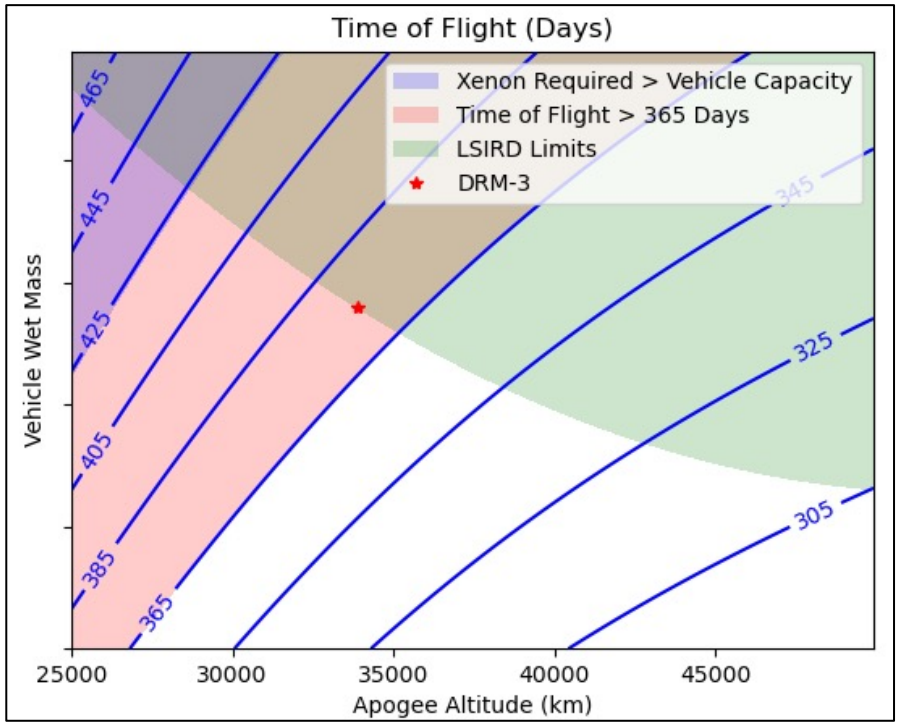


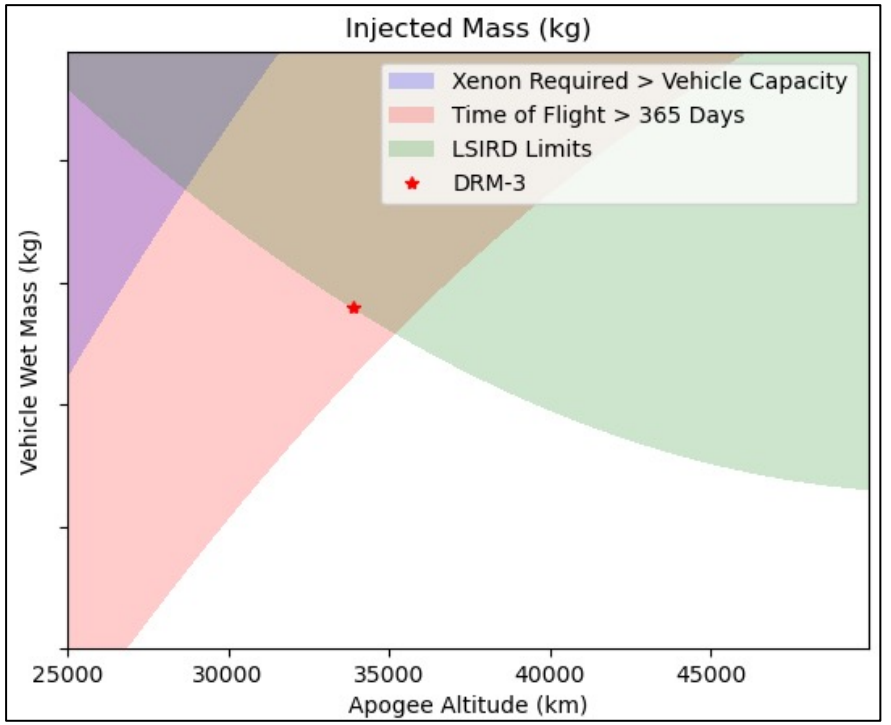
Low Thrust Spiral (ex. CMV)

Design Reference Mission 3 Overview

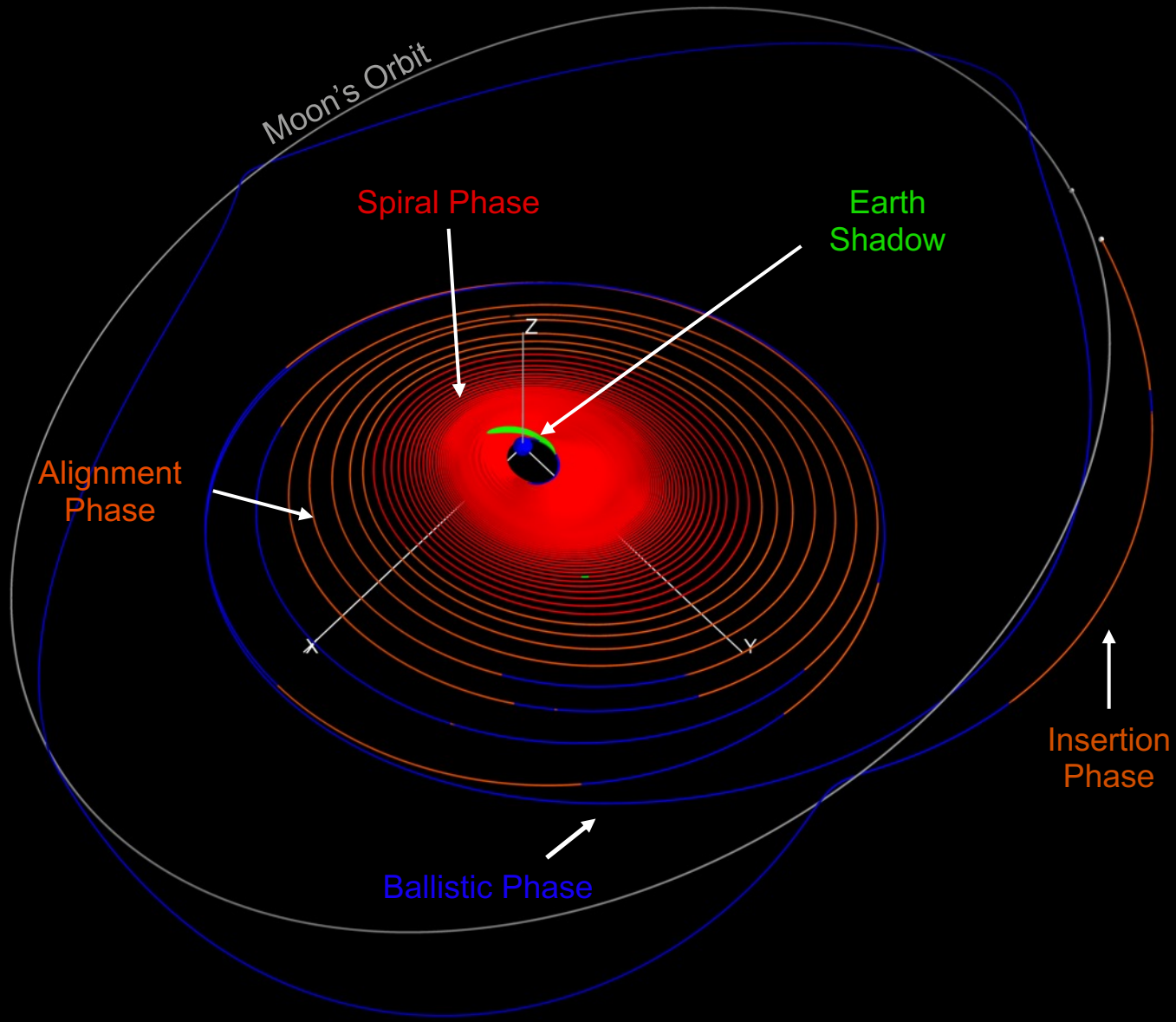
- **The low thrust transfer trip time and mass delivery depends upon the performance the launch vehicle, the on-board electric propulsion system, and the propellant capacity**
- **Increasing initial mass delivered by the launch vehicle requires lower starting orbits**
- **Lower starting orbits, and increased mass will require more time and propellant to deliver to NRHO**

- The green region is above the assumed launch vehicle performance capability
- The pink region indicates transfers where trip times exceed 365 days
- Purple region indicates transfers that exceed the assumed vehicle electric propulsion system propellant capacity





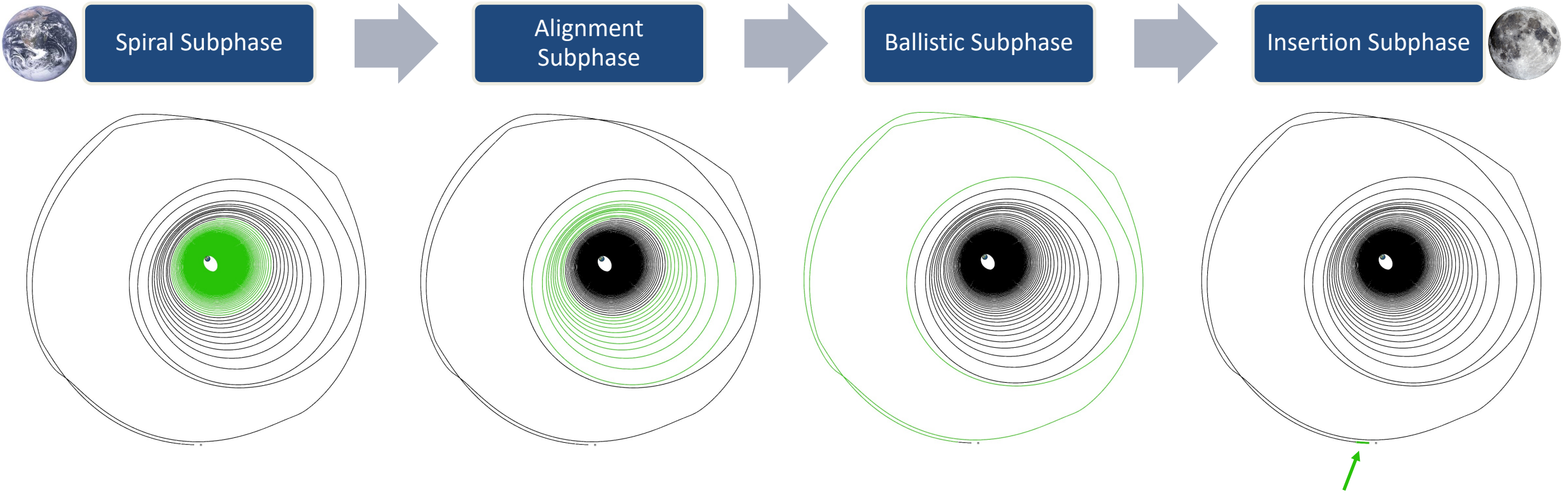
Design Reference Mission 3 Trajectory Phase Overview



Earth-Centered J2000 Inertial Frame

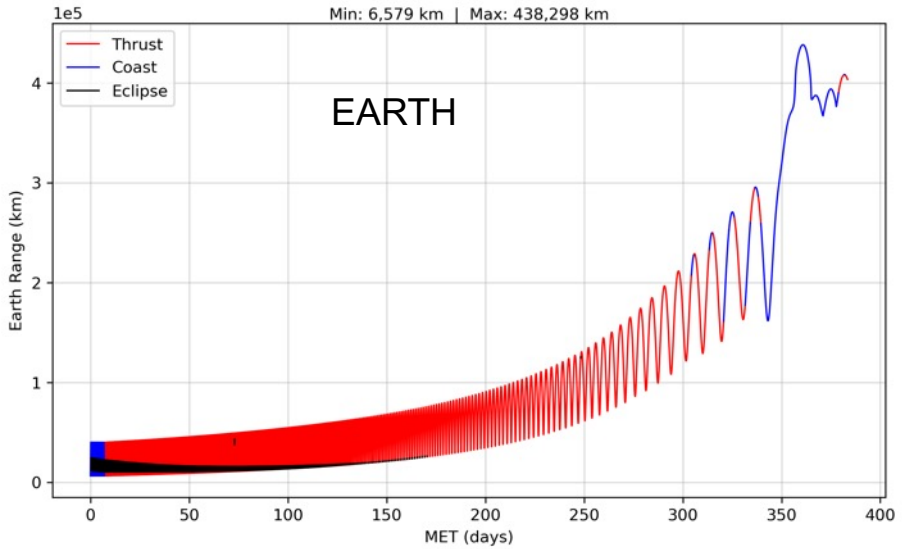
Lunar Transfer Trajectory Subphase Depiction

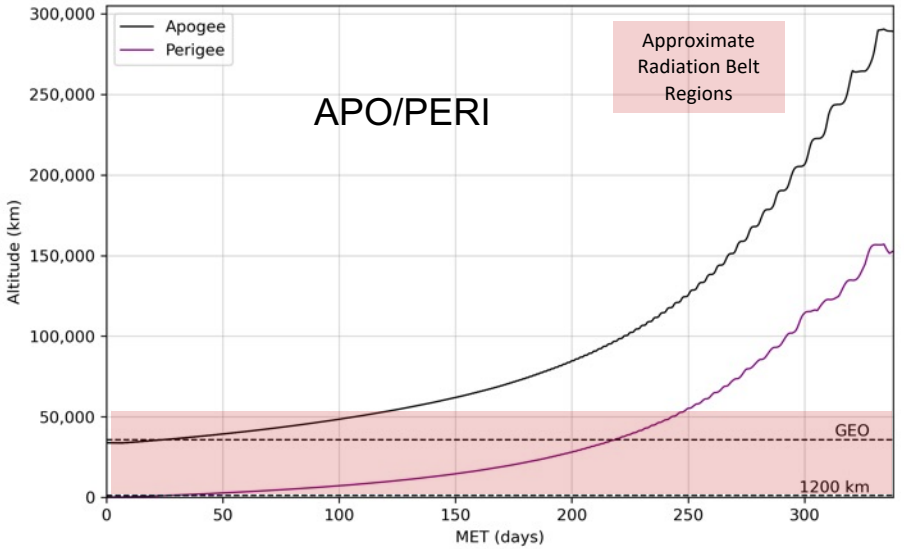
- **Break lunar transfer trajectory into four distinct subphases**
  - Additional scope, definitions and boundary conditions are defined by mission design and operations



DRM-3 Visualization

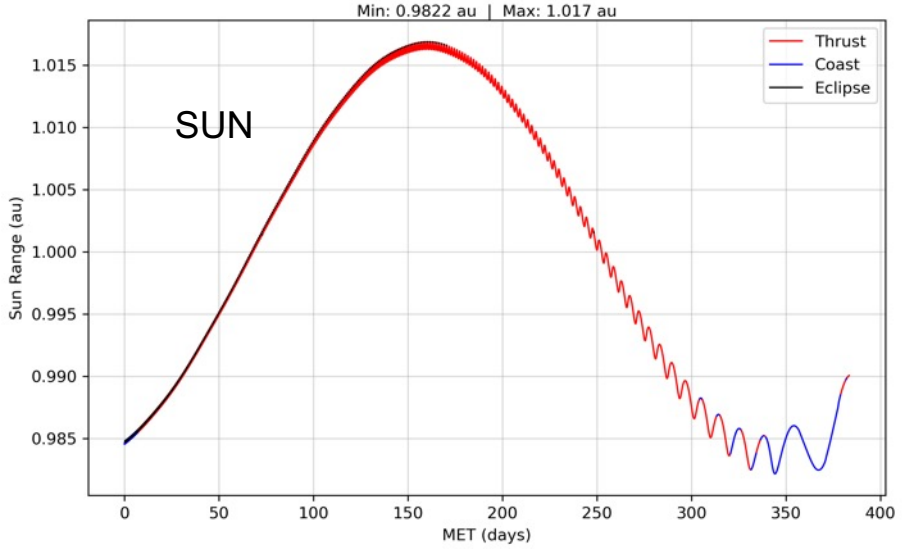
DRM-3 Range vs. Mission Elapsed Time

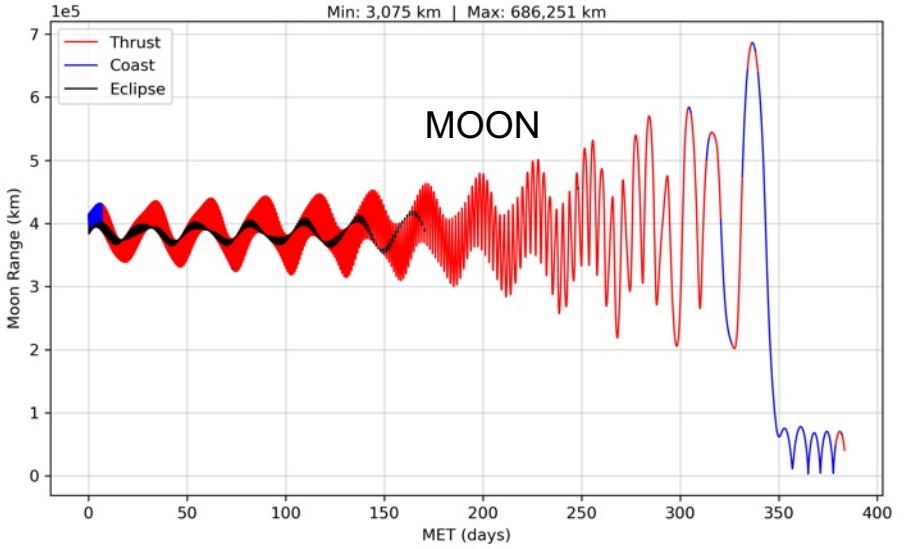




Time trajectory spends between 1,000-12,000km (Inner Van Allen Belt) and 13,000-60,000km (outer VAB)

Time in Belts (days)	MET until above Belts (days)
153	256





The total time of flight of DRM-3 is 383 days, where 319 days are spent thrusting and 64 days are spent coasting.

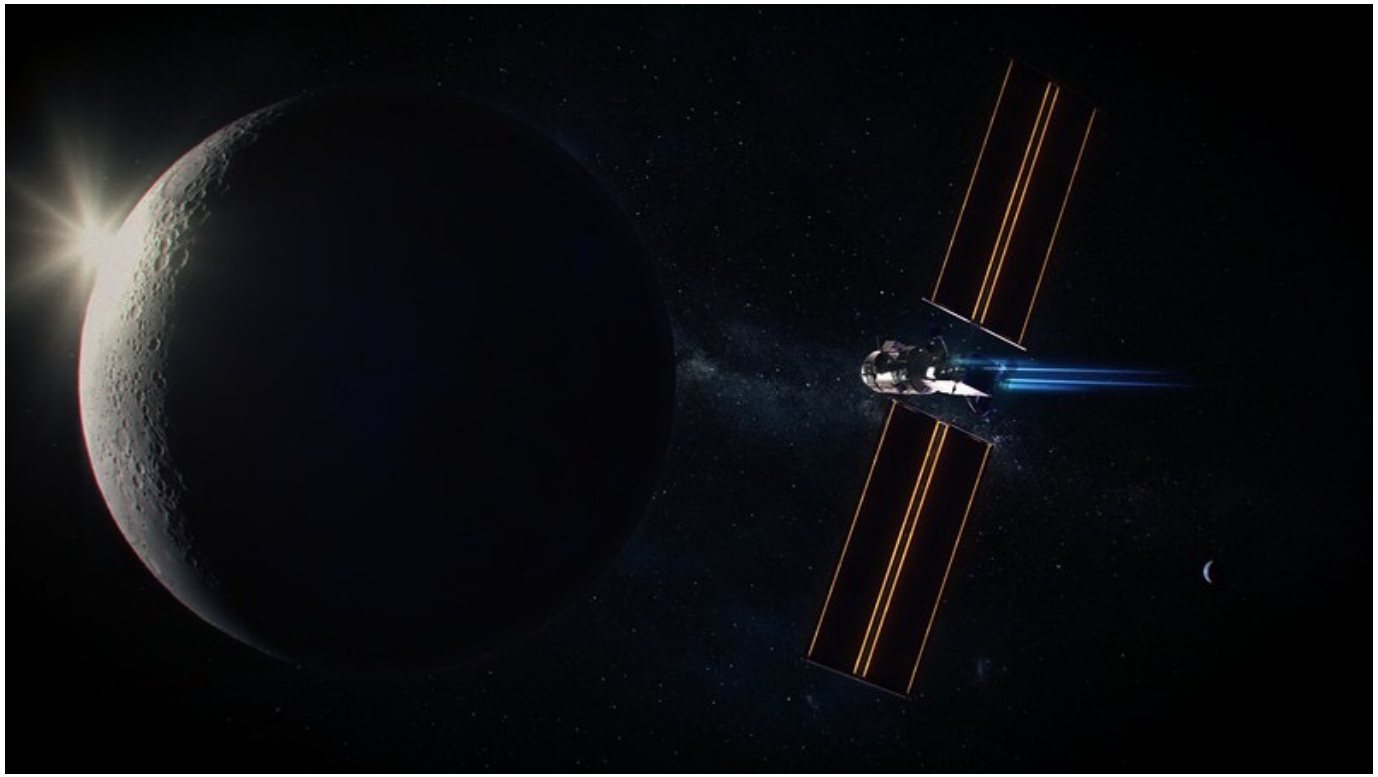
Red is thrust, Blue is coast

Conclusion

- The use of the highly efficient Solar Electric Propulsion system of the PPE enables the delivery of the PPE and HALO to the NRHO on a single launch

- The Design Reference Missions designed for the CMV's lunar transit trajectory are used by the CMV subsystem teams to make vehicle design decisions such as increasing Xe tank capacity, thermal system capacity, and reductions in mass

- When it flies, the CMV will represent an order of magnitude of higher power SEP and demonstrate capabilities to deliver greater payload masses to the moon than has been accomplished to date



This high-power electric propulsion technology PPE is on the path toward the high-power solar electric propulsion vehicles that will enable human exploration to Mars and previously impossible robotic exploration to the outer planets.

Acknowledgments

- The authors wish to thank their PPE and Gateway leadership across the agency for their constant support and encouragement

- We thank our families for their support and understanding of the hours we've been keeping and will continue to keep into the near future

- This presenter wishes to thank her outstanding team, without who's amazing work, none of this would be possible.


NASA