



# DRAFT

## Asteroid Redirect Crewed Mission Nominal Design and Performance

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- 2010 Presidential announcement:
  - The U.S. intends to launch a human mission to an asteroid.
- Early studies showed that Near Earth Asteroid (NEA) missions required:
  - Significant increase in payload to orbit mass
  - Improved technology for long duration spaceflight
    - Near or fully closed loop environmental control
    - Overall improvements in system reliability [to reduce required spares]



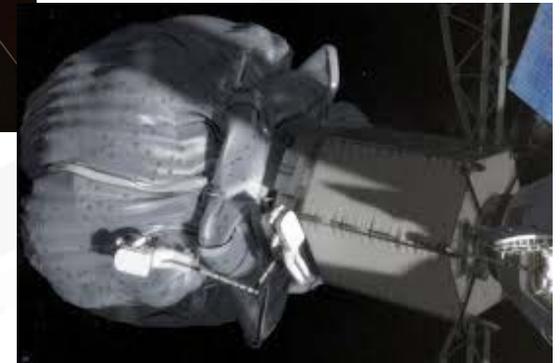
- Keck Institute of Space Studies (KISS) study
  - Robotic spacecraft redirect a NEA to the Earth-Moon vicinity
  - Short duration crewed mission to the captured asteroid.
- Asteroid Redirect Mission (ARM) study
  - Robotic asteroid rendezvous, capture
  - Redirect to Earth-Moon vicinity
  - Earth-Moon destination: Distant Retrograde Orbit (DRO)
  - -----
  - Asteroid Robotic Redirect Mission (ARRM)
  - Asteroid Redirect Crewed Mission (ARCM)

# Mission Overview



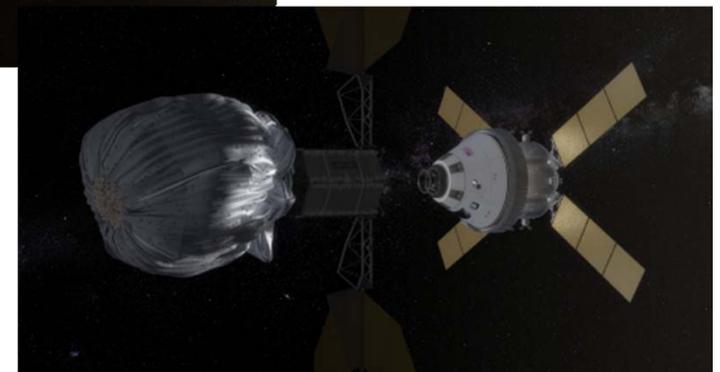
- **ARRM**

- ARV - SEP/Chem.
- Rendezvous/  
Redirect
- Delivers NEA to  
DRO



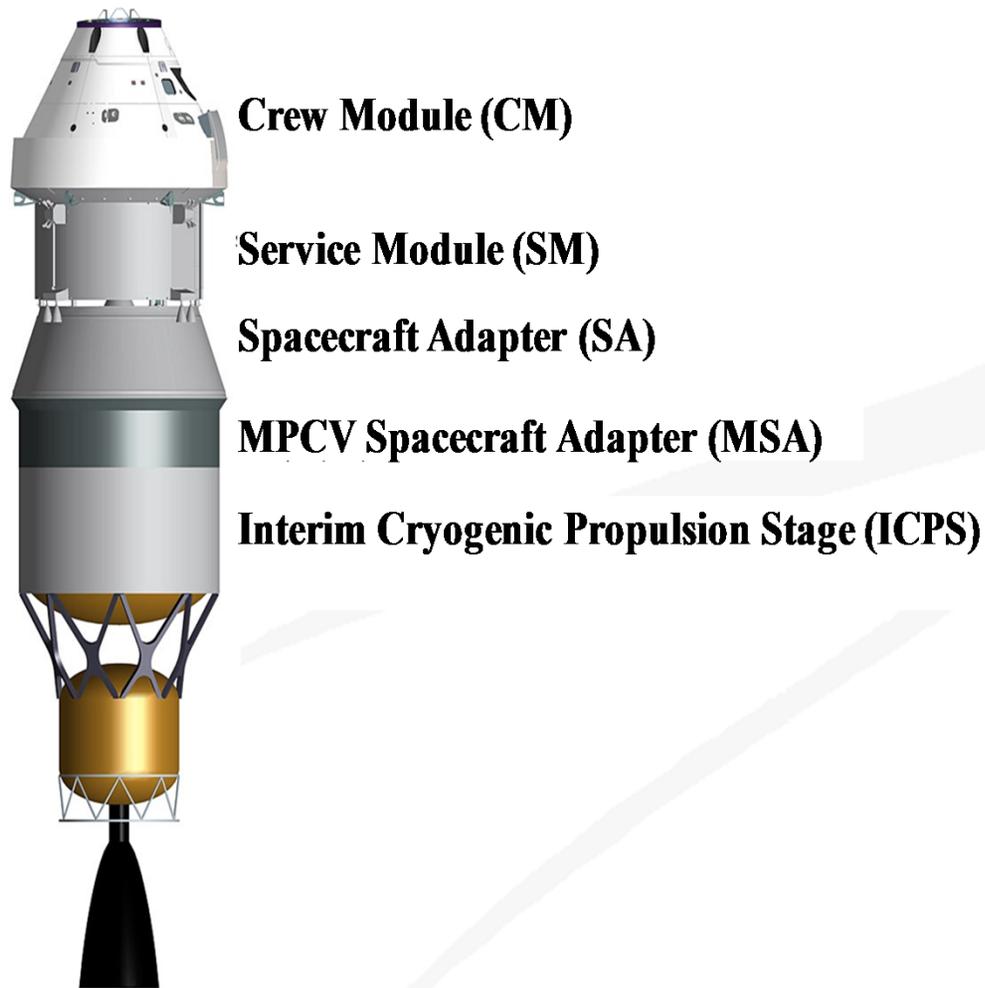
- **ARCM**

- Orion rendezvous  
with ARV/NEA
- 2 EVAs
- Return





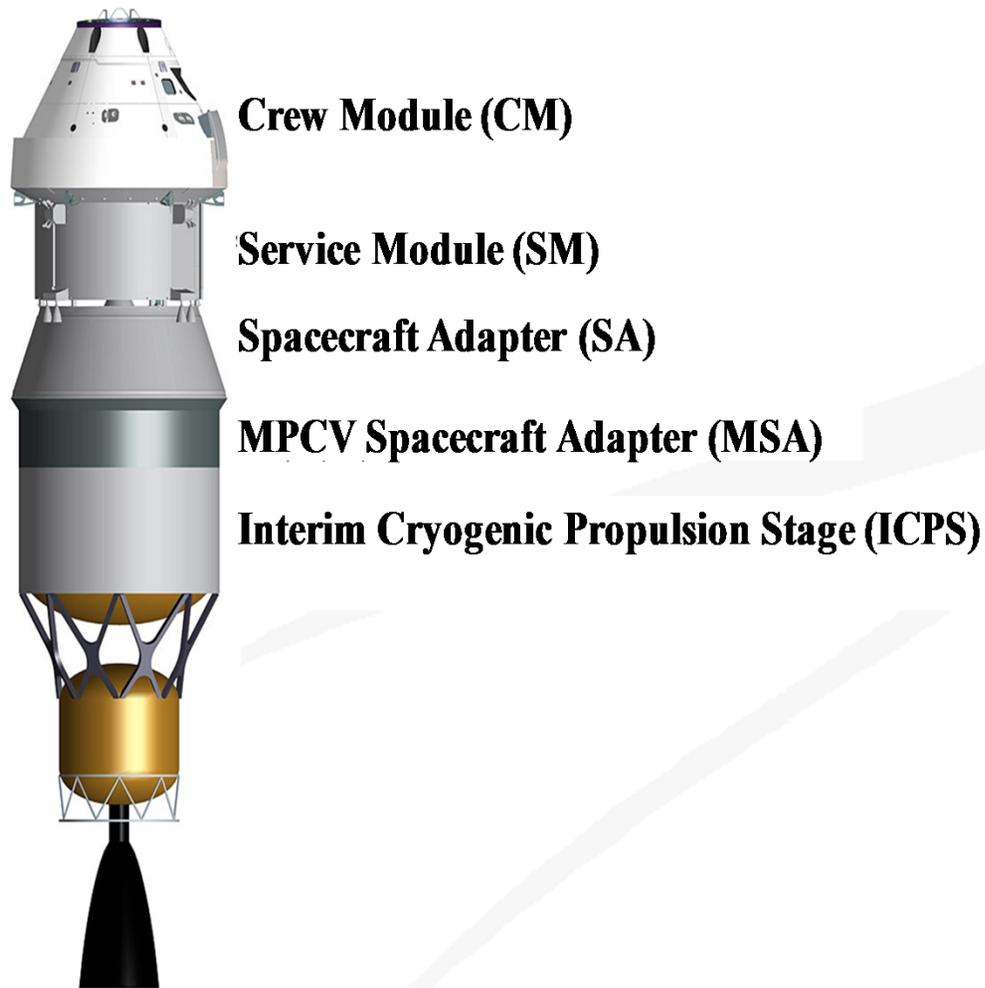
- General environmental considerations: radiation, plasma, thermal, micrometeoroid, orbital debris
- Trajectory focus on gravity
  - Earth: GGMO2C (GRACE mission)
  - Moon: LP150Q for Moon
  - Sun/other: Point mass
  - Used in Constellation Program



## SLS

- Launch to MECO
- ICPS upper stage
  - Perigee raise maneuver PRM
  - TLI (partial)
  - $\Delta V = 2,900$  m/s
    - 41 m/s PRM
    - 80 m/s TLI finite burn losses

# Vehicle Characteristics



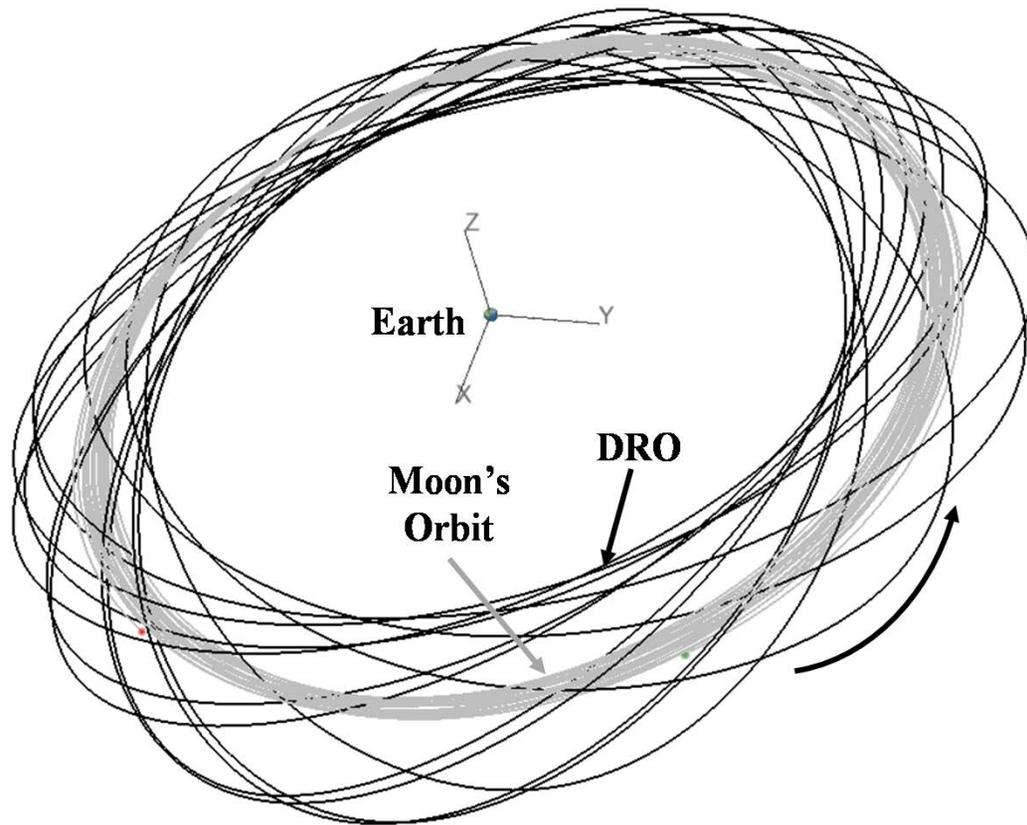
## Orion

- Crew size: 2
- 30 day max mission
- TLI participation
- All post-TLI maneuvers
- $\Delta V = 1,168 \text{ m/s}$ 
  - 24,092 kg w/ 500 kg prop/dry mass switch
- $I_{sp} = 315.1 \text{ s}$

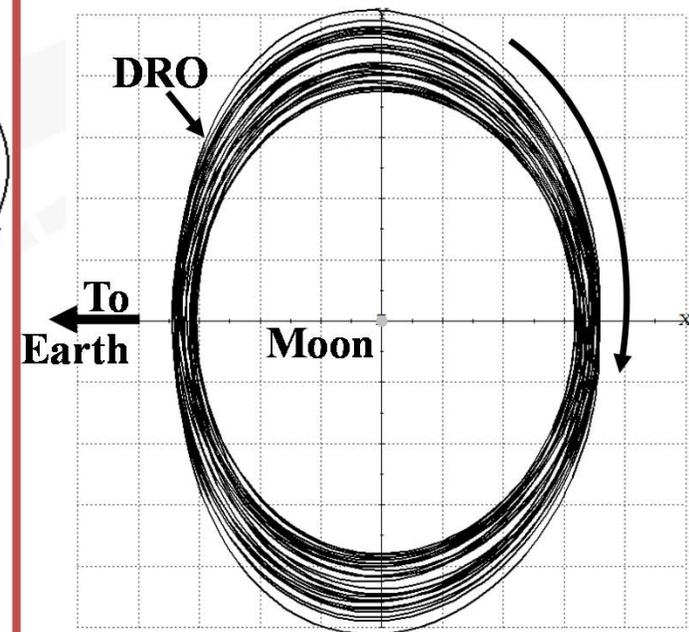
# ARV Storage Orbit



- DRO – Stable in CR3BP (no orbit maintenance required)
- 70,000 km amplitude



**Inertial (ECLIPJ2000) Earth-Centered Frame**

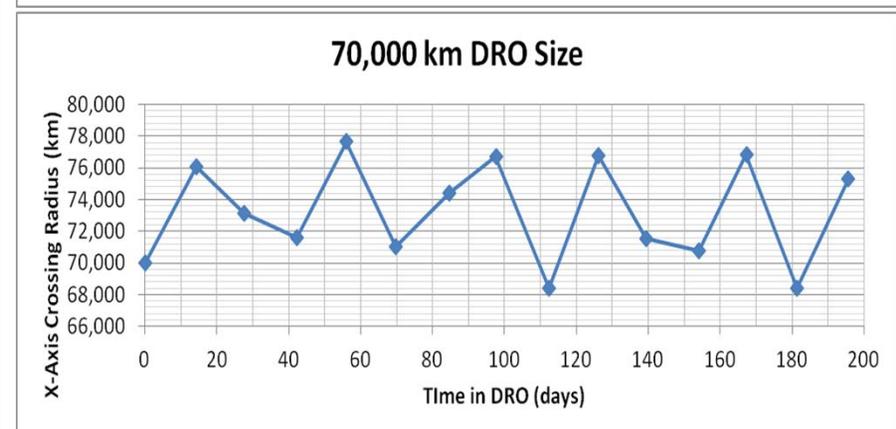
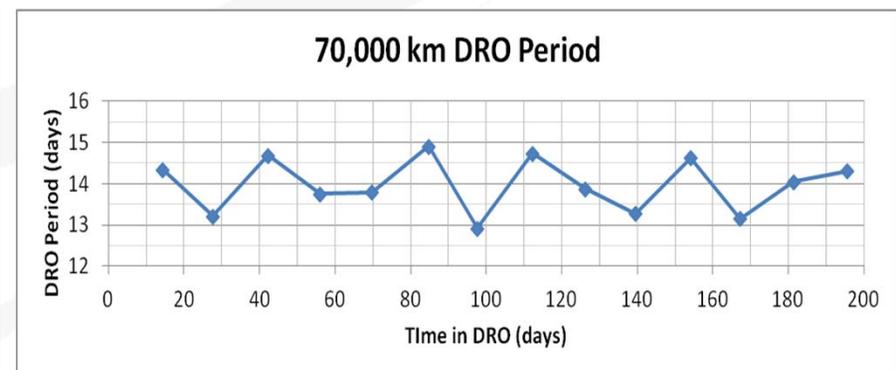
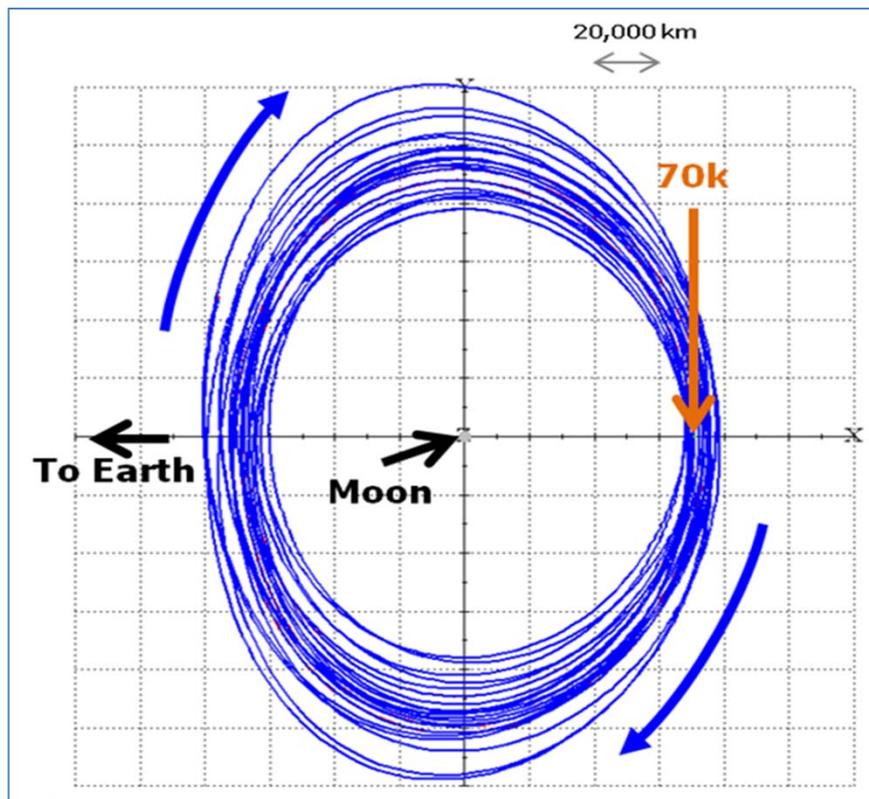


**Earth-Moon Rotating Frame**

# ARV Storage Orbit



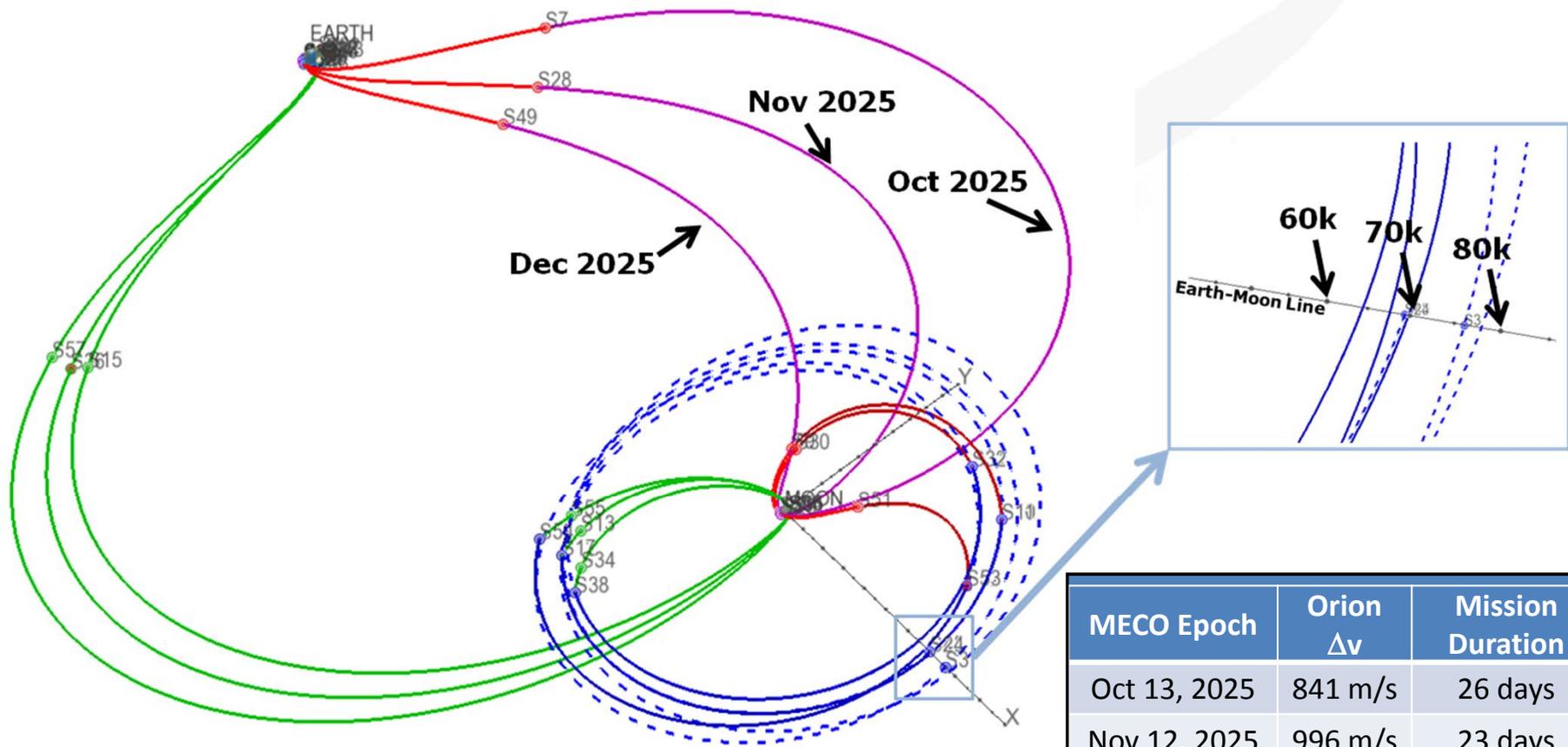
- 13-15 day period
- X-axis crossing variation from 68,000 – 78,000 km
- 2/1 resonance with Moon orbital period (enhanced launch opportunities)



# ARV Storage Orbit



- Consecutive example monthly missions to a DRO
- Maximizes launch opportunity
- Minimizes  $\Delta v$  given Orion mission duration constraints (i.e., < 30 days)



MECO Epoch	Orion $\Delta v$	Mission Duration
Oct 13, 2025	841 m/s	26 days
Nov 12, 2025	996 m/s	23 days
Dec 12, 2025	957 m/s	21 days

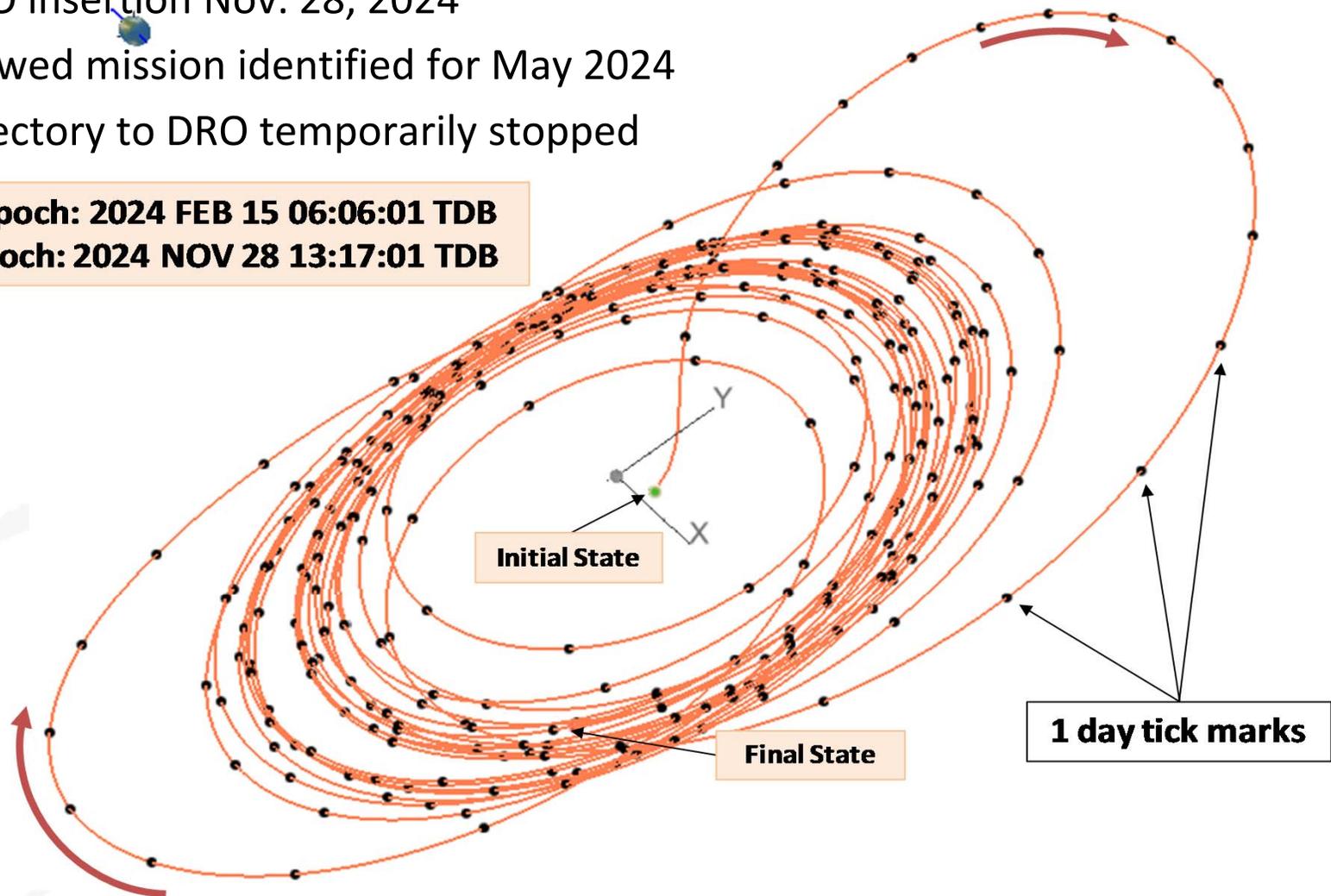
Earth-Moon rotating frame

# Reference Nominal Mission



- Asteroid Redirect Vehicle (ARV) enters Earth-Moon space on Feb. 15, 2024
- Final DRO insertion Nov. 28, 2024
- Early crewed mission identified for May 2024
- ARV trajectory to DRO temporarily stopped

**Initial epoch: 2024 FEB 15 06:06:01 TDB**  
**Final epoch: 2024 NOV 28 13:17:01 TDB**



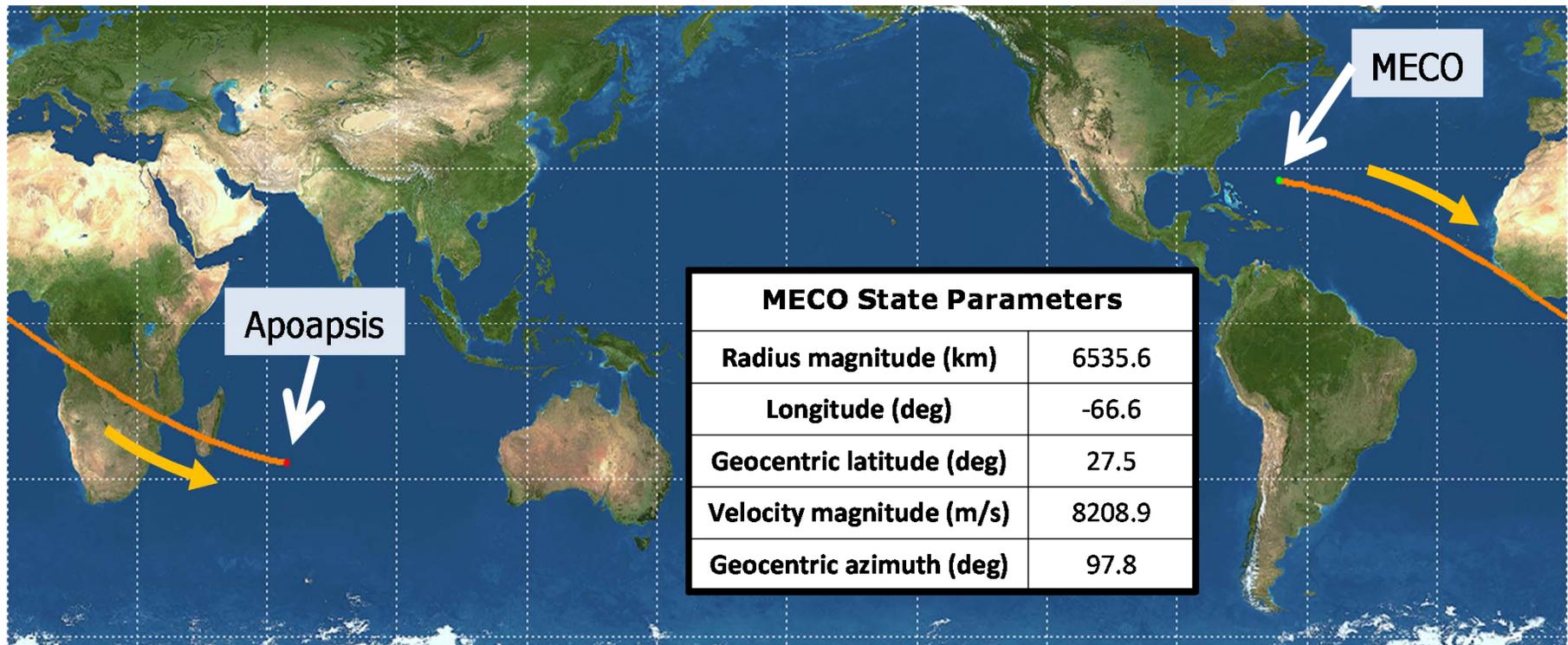
*Earth-Moon rotating frame*

*ARV trajectory courtesy JPL. Data file 2009BDToDRO-3-LASSO.bsp*

# Reference Nominal Mission - MECO



- Launch to MECO with SLS (MECO state provided by MSFC)
- Reference mission begins post MECO (1,806 x 41 km)
  - MECO occurs May 16, 2024 15:31:58\*

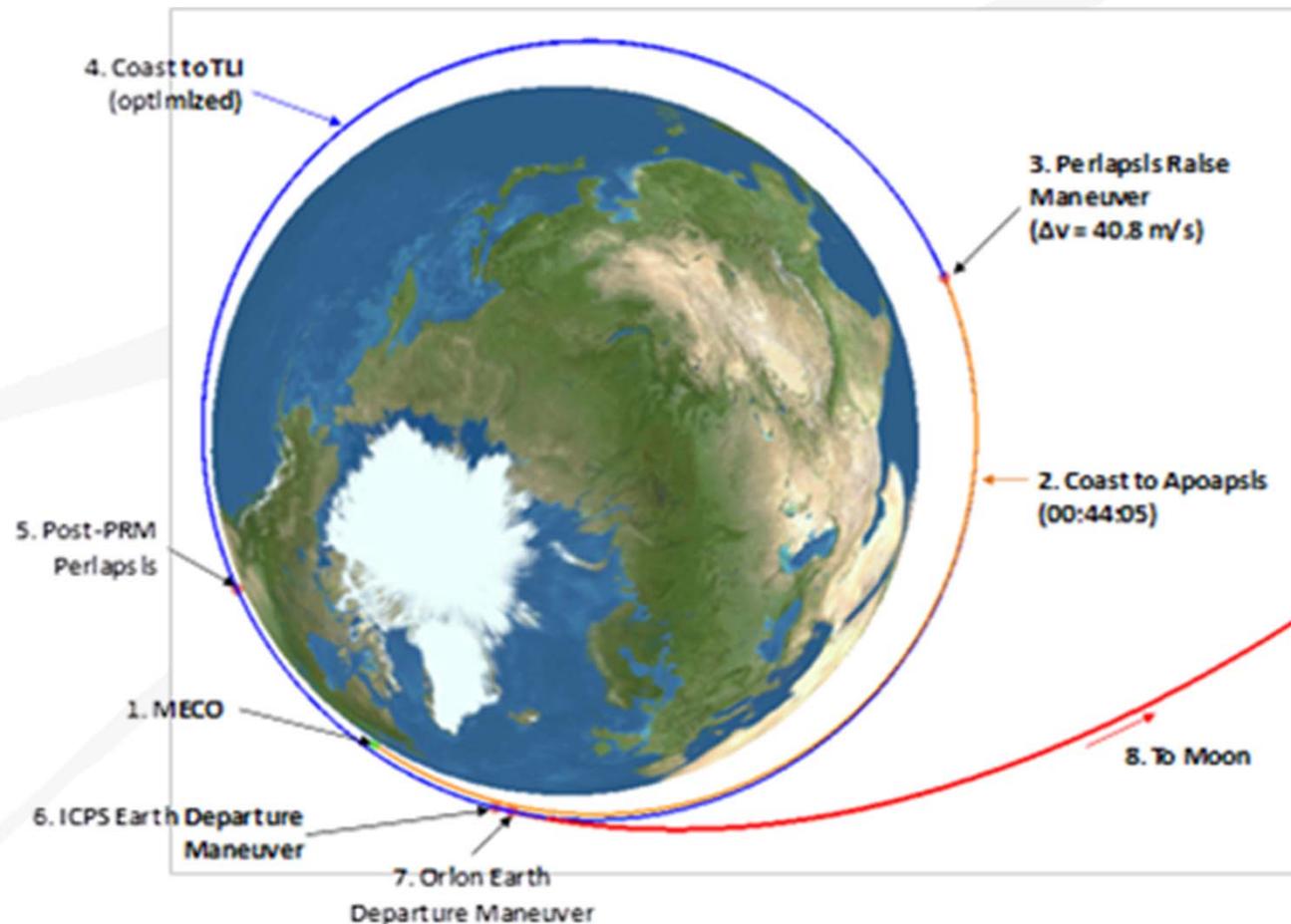


\* Barycentric Dynamical Time (TDB)

# Reference Nominal Mission – Departure Sequence



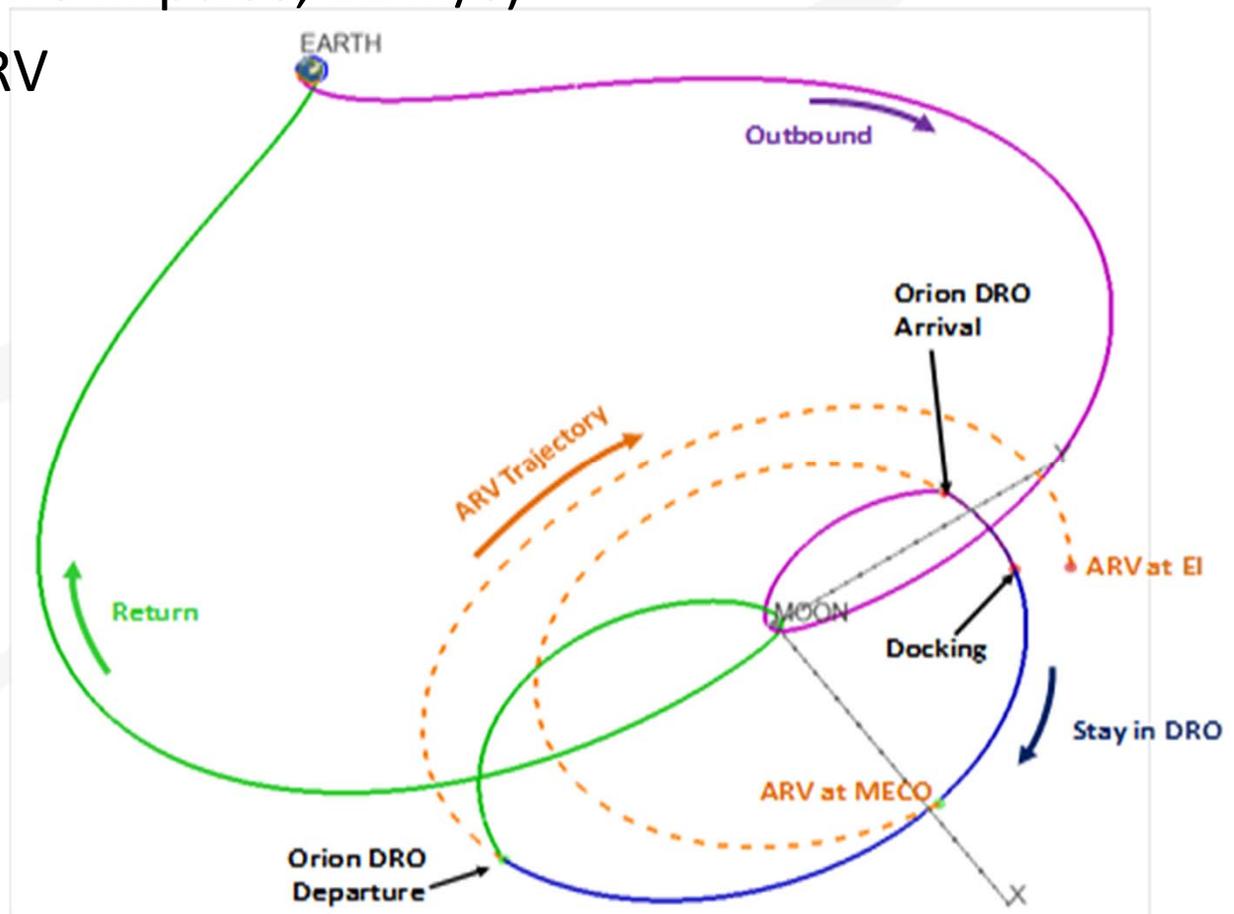
- Post MECO state (near perigee) propagated to apogee (~45 min)
- PRM raises perigee from 41 to 185 km (41 m/s)
- ICPS Earth departure maneuver
- Orion Earth departure maneuver to powered Lunar Gravity Assist (LGA) target



# Reference Nominal Mission – TLI to EI

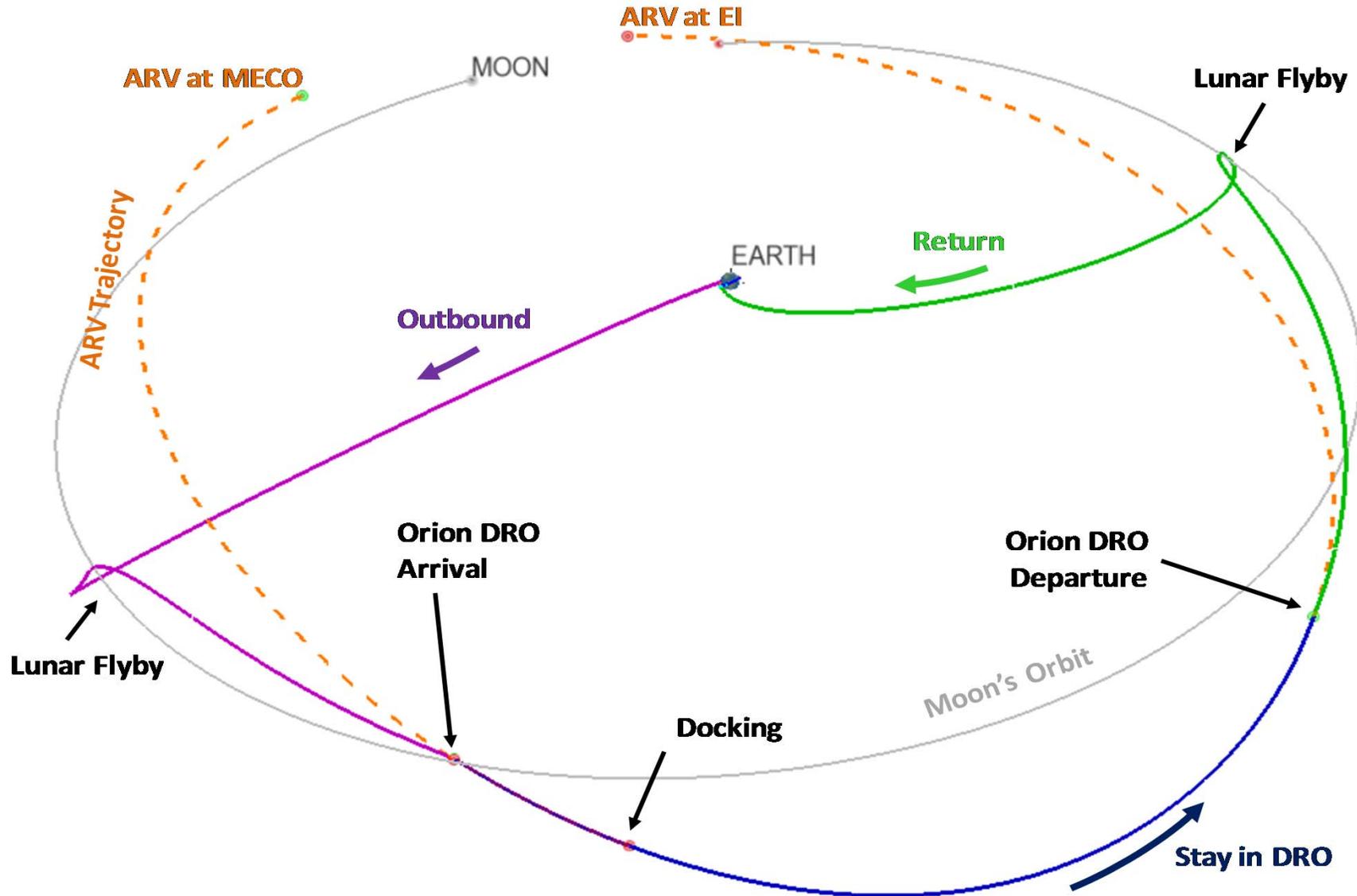


- Powered outbound LGA at Moon (100 km min altitude)
- LGA to DRO arrival (insertion)
- 1 day rendezvous (two impulse, 11 m/s)
- 5 days docked to ARV
  - 1 day contingency
- 2 EVAs
- DRO departure
  - Targets return LGA
- Powered LGA to EI



*Earth-Moon rotating pulsating frame*

# Reference Nominal Mission – TLI to EI

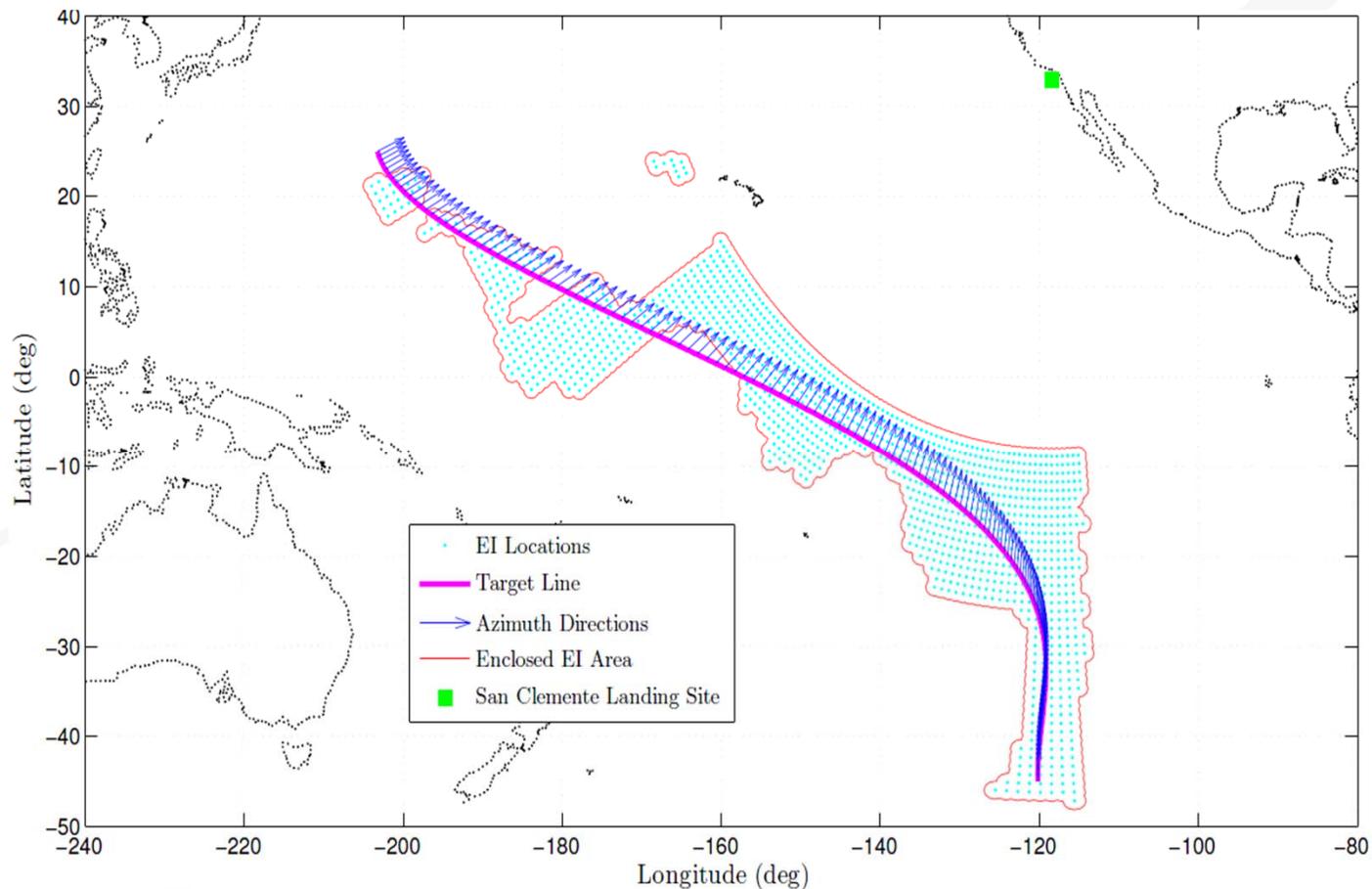


*Inertial J2000 Earth-centered frame*

# Reference Nominal Mission – EI Target



- Post LGA to EI
- Target line placed Orion of the coast of San Clemente, CA
- 2 m/s budget for Orion Service Module disposal



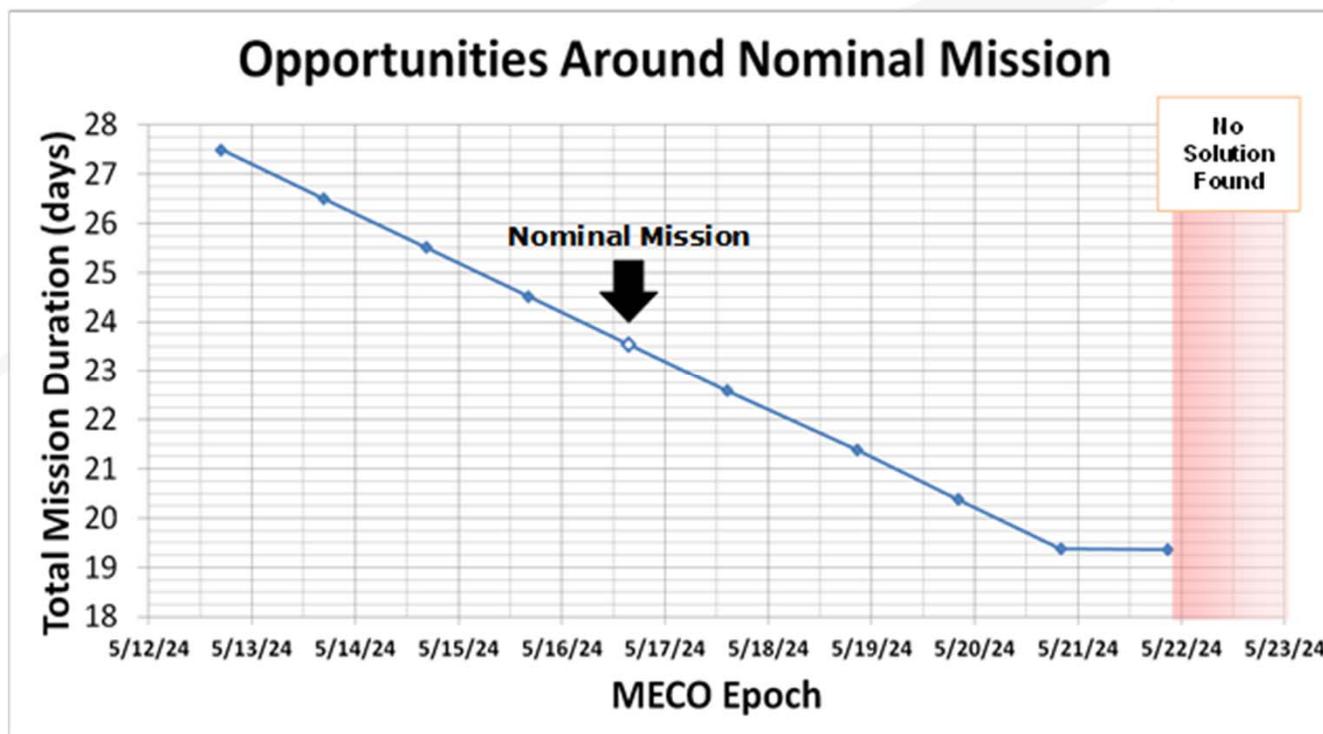


<b>MECO: 2024-May-16 15:31:58 TDB</b>		
<b>Event</b>	<b>Timeline (DD:HH:MM:SS from MECO)</b>	<b>SM <math>\Delta v</math> Maneuver Magnitude (m/s)</b>
MECO	00:00:00:00	
Perigee Raise Maneuver (PRM)	00:00:44:05	41
ICPS TLI	00:03:34:35	2779
Orion TLI	00:03:35:05	28
Outbound LGA	06:12:55:05	241
DRO Arrival	08:10:59:24	242
Rendezvous Start	08:10:59:24	5.7
Rendezvous Completion - Docking	09:10:59:24	5.4
DRO Departure	14:10:59:24	146
Return LGA	18:10:01:36	497
EI	23:13:43:24	

# Reference Nominal Mission – Mission Availability



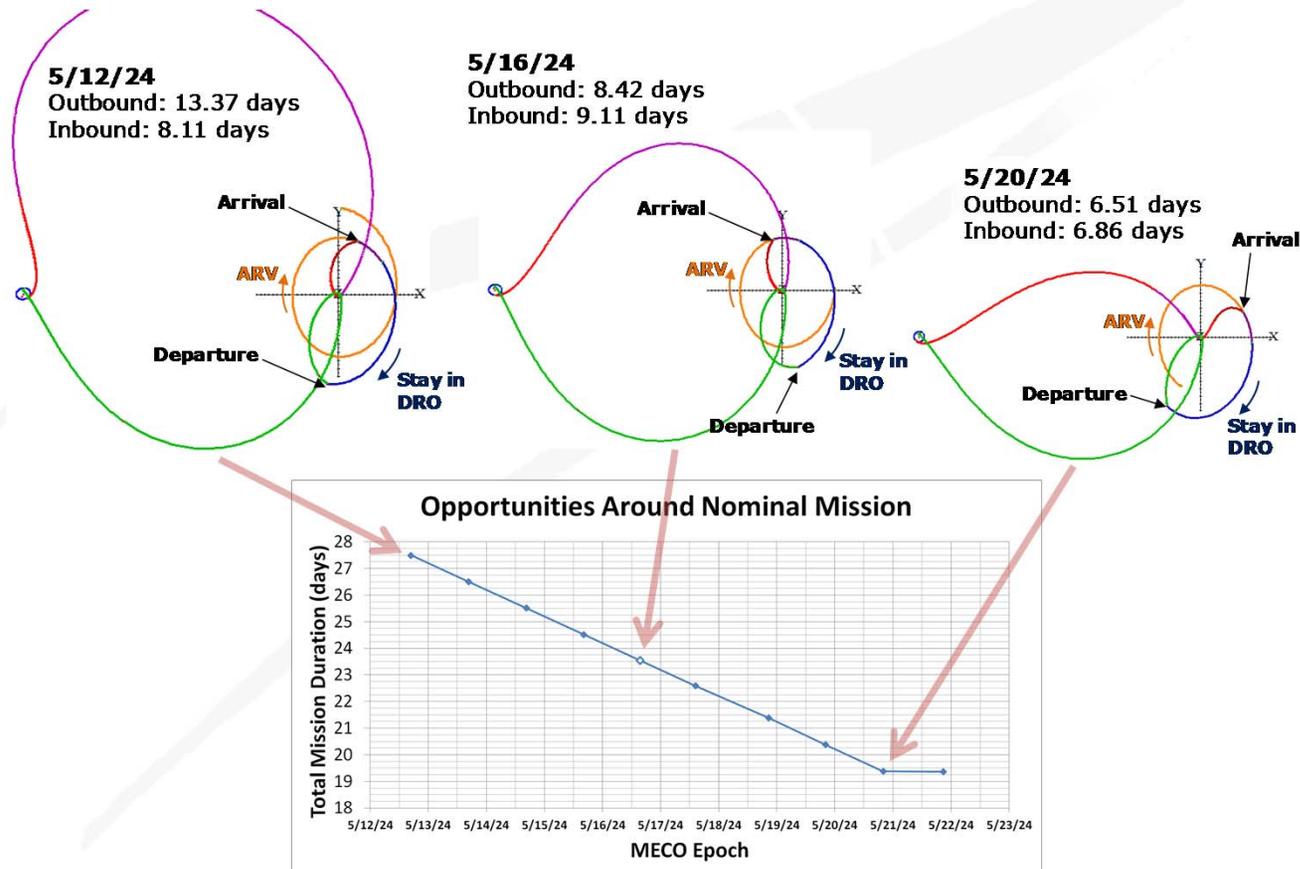
- Determine mission availability prior to and after nominal date
- Missions assessed before and after nominal mission using same assumptions
- Total mission duration minimized, using all available Orion propellant



# Reference Nominal Mission – Mission Availability



- Missions reflecting early, nominal and late mission opportunity
- Outbound and inbound flight times are adjusted for favorable DRO insertion and departure
- For shorter flight time cases, the trajectory switches to a different solution family with a posigrade lunar flyby on the outbound phase



# Conclusion



- A nominal crewed mission (ARCM) can be performed that will allow a crew to rendezvous with an awaiting ARV/asteroid in a moon-centered DRO. The 23.6-day overall mission time, accessing all of the available usable  $\Delta v$  (1168 m/s), is within the Orion active vehicle duration limit prescribed for a crew of 2. The use of two powered LGAs reduces the  $\Delta v$  cost for Orion, thus enabling the mission. The overall mission plan originally targeted a crewed rendezvous mission with the ARV/asteroid after the ARV had settled into a final DRO. However, this study showed that the ARV/asteroid redirect mission trajectory could be interrupted, several months earlier, for about 24 days, in order to conduct an ARCM.