Jet Propulsion Laboratory
California Institute of Technology

Lunar Flashlight Mission Overview

Daniel Grebow, Stefano Campagnola,
Robert Haw, Theodore Sweetser

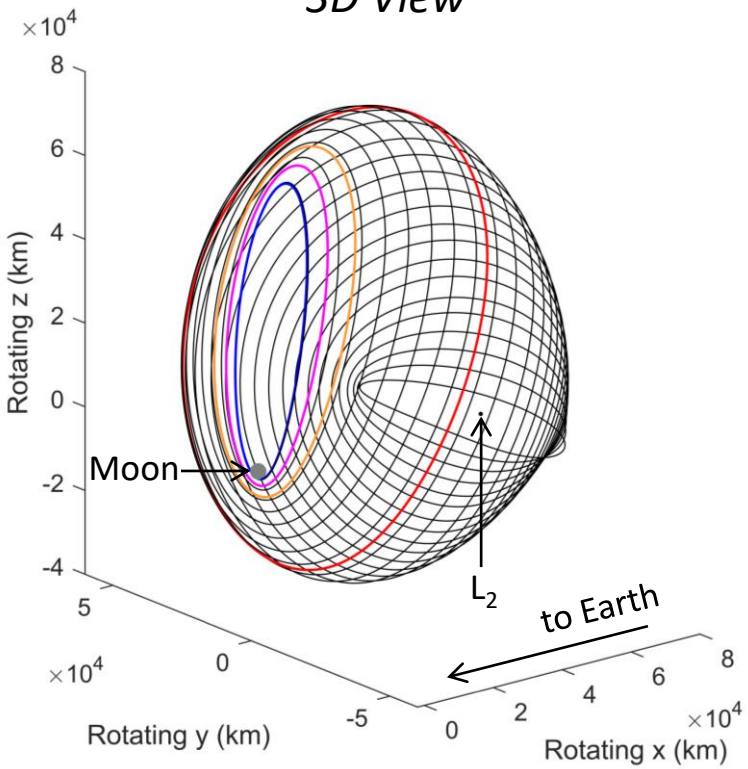
Lunar Flashlight

- One of several CubeSats launching with Artemis I
- Objective: determine the presence and abundance of water ice in cold traps at the south pole by shining lasers into shaded regions and measuring surface reflection
- Science orbit is a northern Near-Rectilinear Halo Orbit (NRHO)

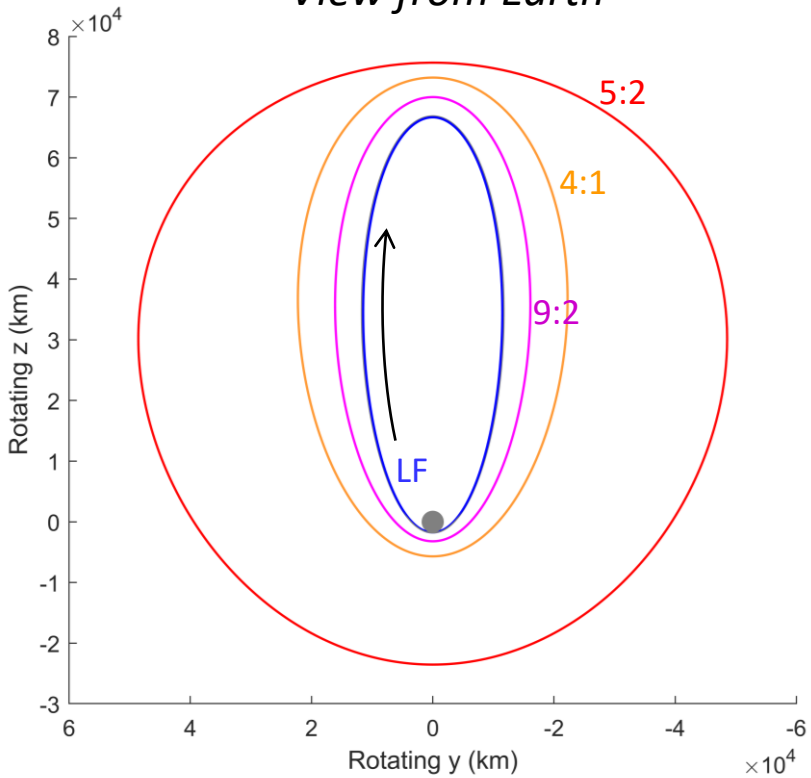
Video credit: NASA/Goddard Space Flight Center

Earth-Moon L_2 Northern Halo Orbit Family
CR3BP

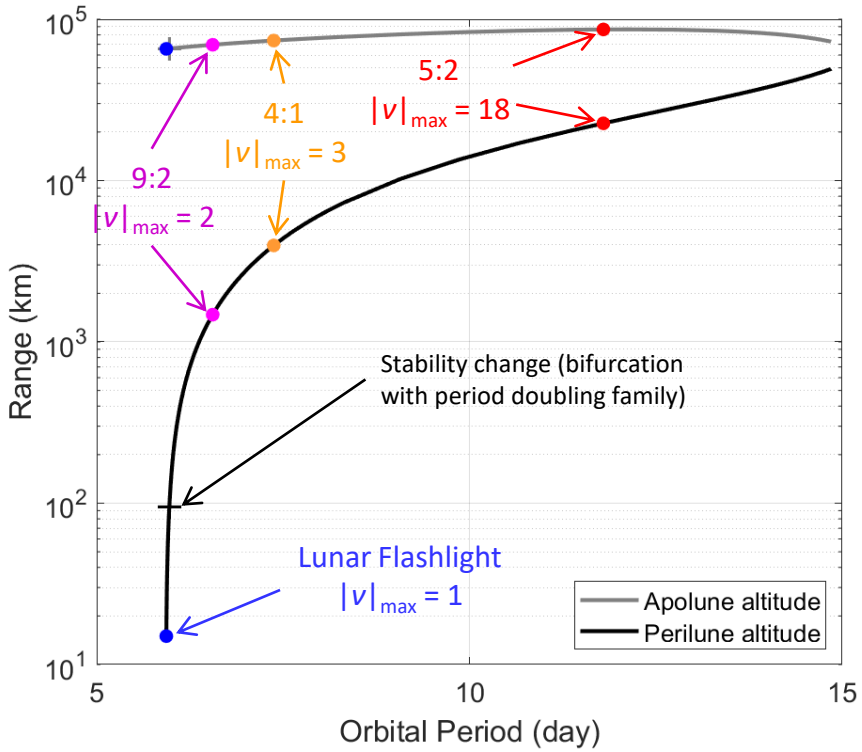
3D View



View from Earth



Apse Altitude vs. Orbital Period



Spacecraft always has direct line-of-sight with Earth, orbital direction of motion is clockwise as viewed from Earth, views above are in Moon-centered Earth-Moon-rotating coordinates.

Transitioning NRHO to Full Ephemeris Model

Variables:

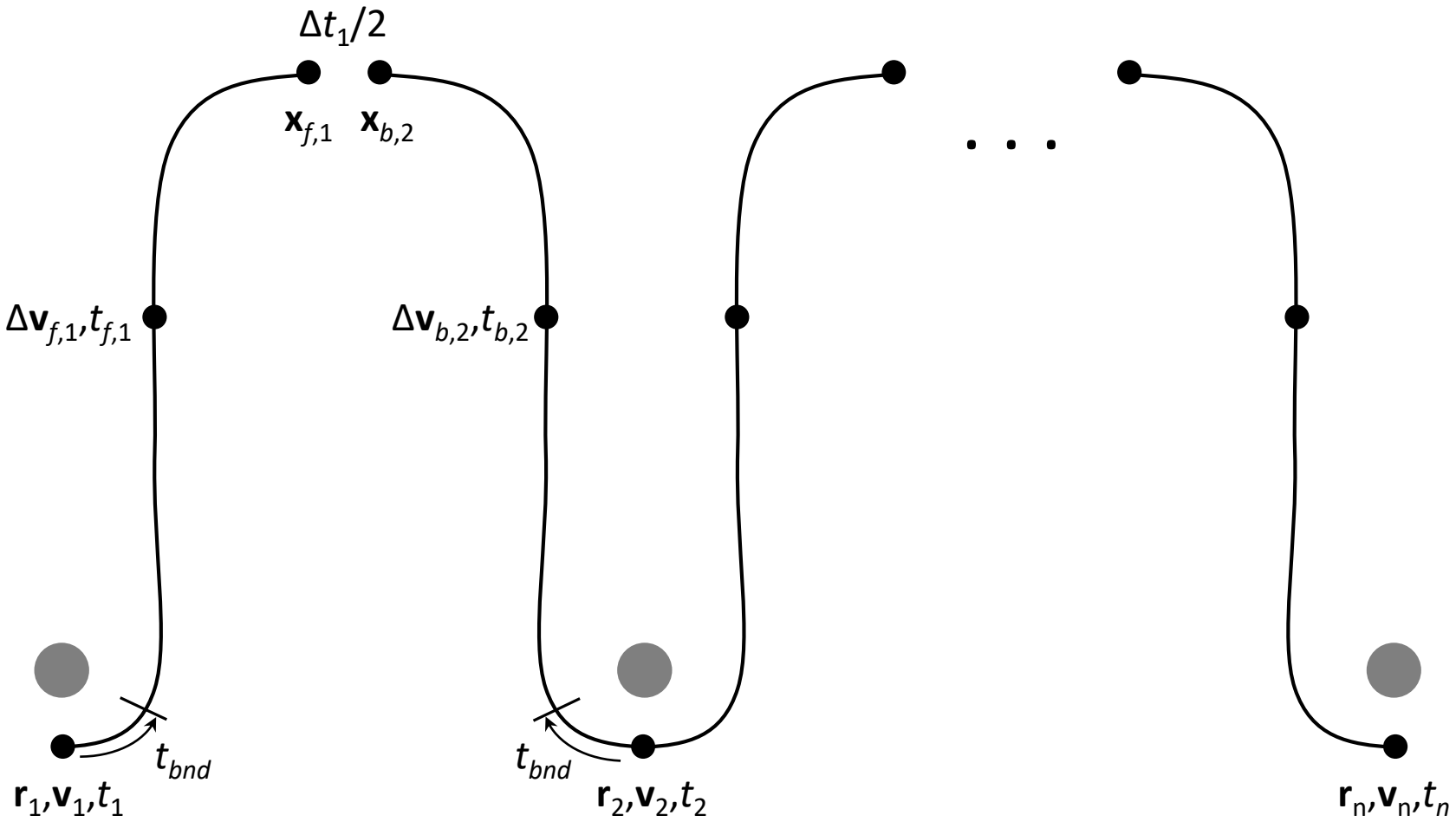
$$\mathbf{r}_i \, , \, \mathbf{v}_i \, , \, t_i$$
$$\Delta\mathbf{v}_{f,i} \, , \, t_{f,i}$$
$$\Delta\mathbf{v}_{b,i+1} \, , \, t_{b,i+1}$$

Constraints:

$$\mathbf{x}_{b,i+1} - \mathbf{x}_{f,i} = 0$$
$$\mathbf{r}_i \cdot \mathbf{v}_i = 0$$
$$r_{low} \le \|\mathbf{r}_i\| \le r_{upp}$$
$$t_i + t_{bnd} \le t_{f,i} \le t_i + \Delta t_i/2$$
$$t_{i+1} - \Delta t_i/2 \le t_{b,i+1} \le t_{i+1} - t_{bnd}$$

Objective:

$$\min J = \sum \|\Delta\mathbf{v}_{f,i}\|^2 + \|\Delta\mathbf{v}_{b,i+1}\|^2$$



Initial guess for $\mathbf{r}_i$, $\mathbf{v}_i$, t_i from CR3BP periodic orbit

ARTEMIS I

The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport

1 LAUNCH
SLS and Orion lift off from pad 39B at Kennedy Space Center

2 JETTISON ROCKET BOOSTERS
Solid rocket boosters separate

3 JETTISON LAUNCH ABORT SYSTEM (LAS)
The LAS is no longer needed, Orion could safely abort

4 CORE STAGE MAIN ENGINE CUT OFF (MECO) and separation

5 ENTER EARTH ORBIT
Perform the perigee raise maneuver

6 EARTH ORBIT
Systems check and solar panel adjustments

7 TRANS LUNAR INJECTION (TLI) BURN
Burn lasts for approximately 20 minutes

8 INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION
The ICPS has committed Orion to TLI

9 OUTBOUND TRANSIT
Requires several attitude maneuvers

A B C D
CUBESATS DEPLOY
ICPS deploys 13 CubeSats total

10 OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS
As necessary adjust trajectory for Lunar flyby to DRO

11 OUTBOUND POWERED FLYBY (OPF)
62 miles from the Moon; targets DRO insertion

Heliocentric Disposal precludes re-contact

12 ORBIT INSERTION
Enter Distant Retrograde Orbit for next 6-23 days

13 DISTANT RETROGRADE ORBIT (DRO)
Orbit Maintenance burns and solar panel adjustments; 38,000 nmi from the surface of the Moon

14 DRO DEPARTURE
Leave DRO and start return to Earth

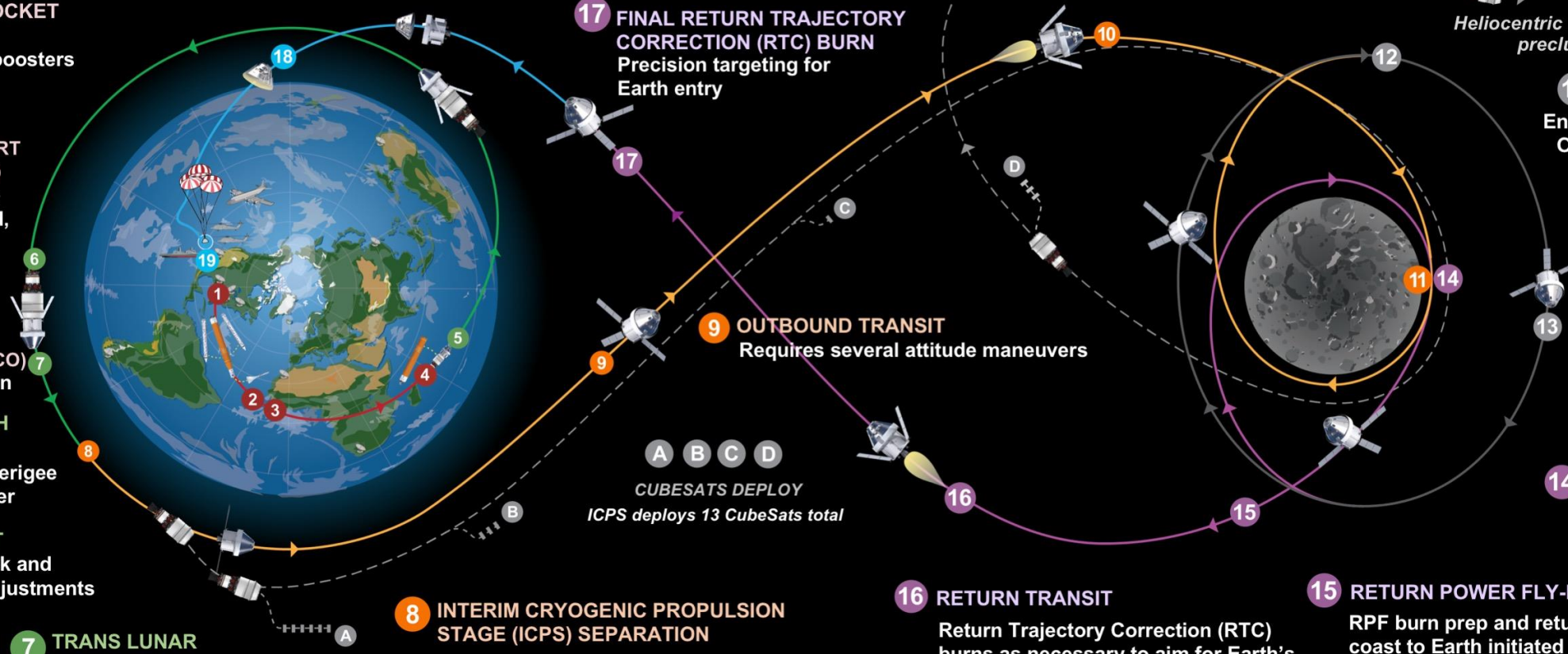
15 RETURN POWER FLY-BY (RPF)
RPF burn prep and return coast to Earth initiated

16 RETURN TRANSIT
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time 3-11 days

17 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN
Precision targeting for Earth entry

18 ENTRY INTERFACE (EI)
Enter Earth's atmosphere

19 SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ships



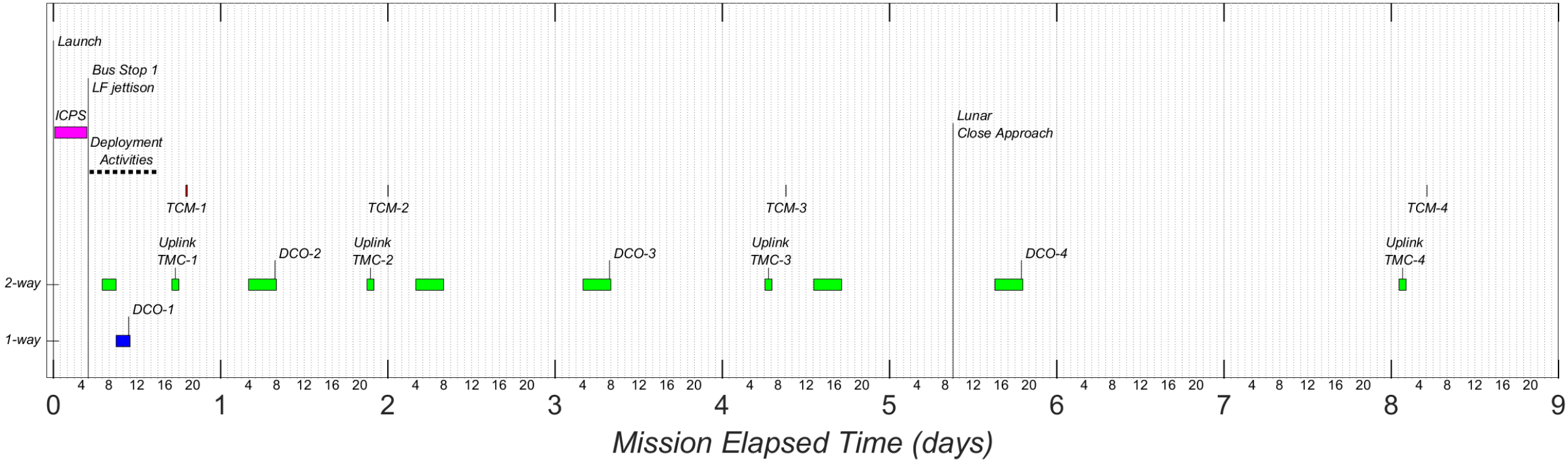
ARTEMIS

Image credit: NASA

ARTEMIS I

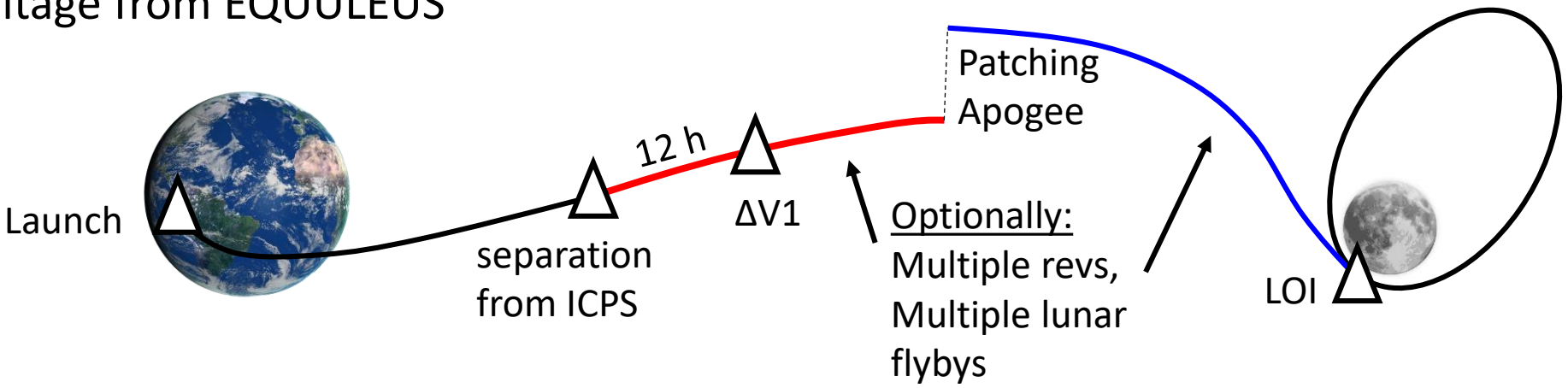
Total distance traveled: 1.3 million miles – Mission duration: 26-42 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

Post-Launch Notional ConOps

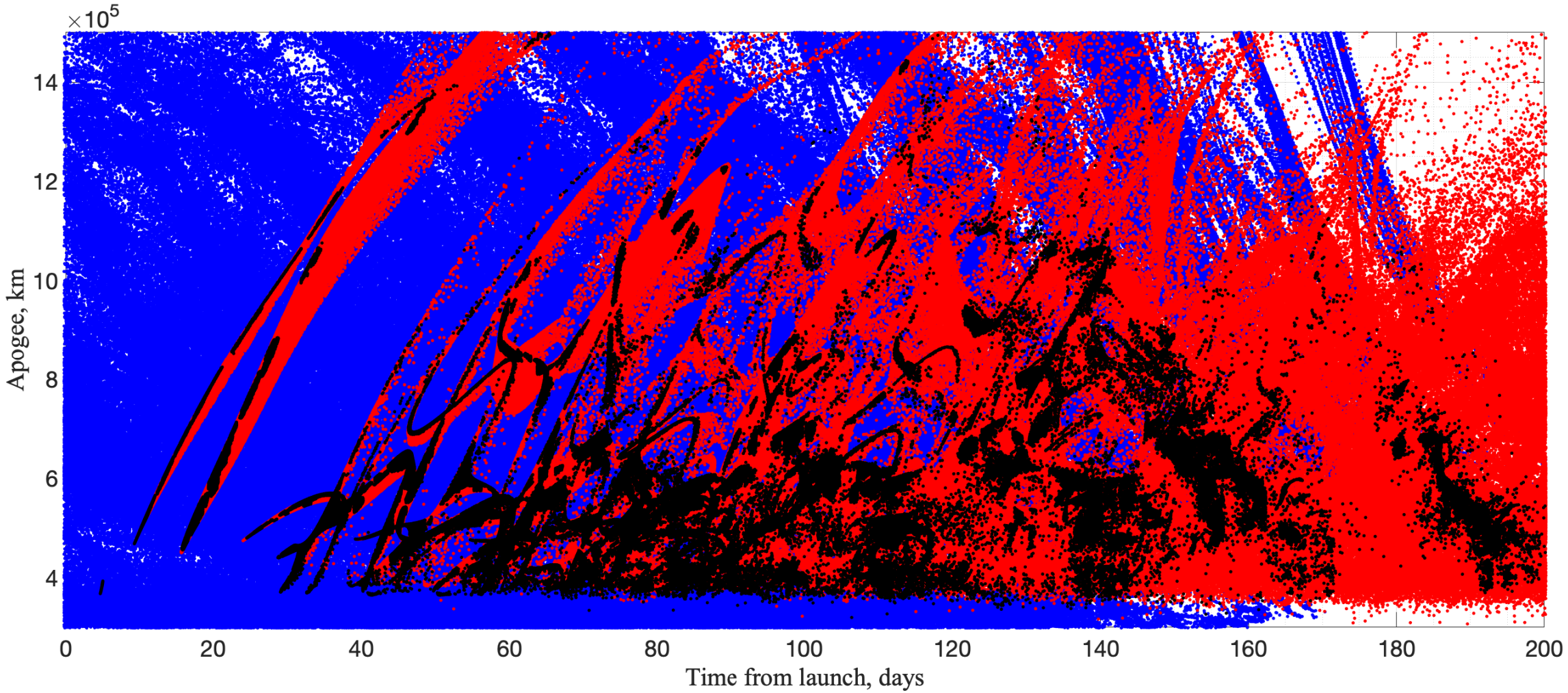


Transfer trajectory – design approach

- Create database of trajectories, propagated forward from interim cryogenic propulsion stage (ICPS) separation and backward from Lunar Orbit Insertion (LOI)
  - NASA's Advanced Concepts Organization delivered Oct 2019 ICPS post-disposal states ranging 11/6/2020 – 10/14/2021
  - From data selected Aug 14, 2021 as 'notional' launch for study
- Patch trajectories with similar states at apogees, optimize
- This robust approach is adaptable for automation, which is critical for LF due to the need to compute one or more different solutions per launch day
- Heritage from EQUULEUS

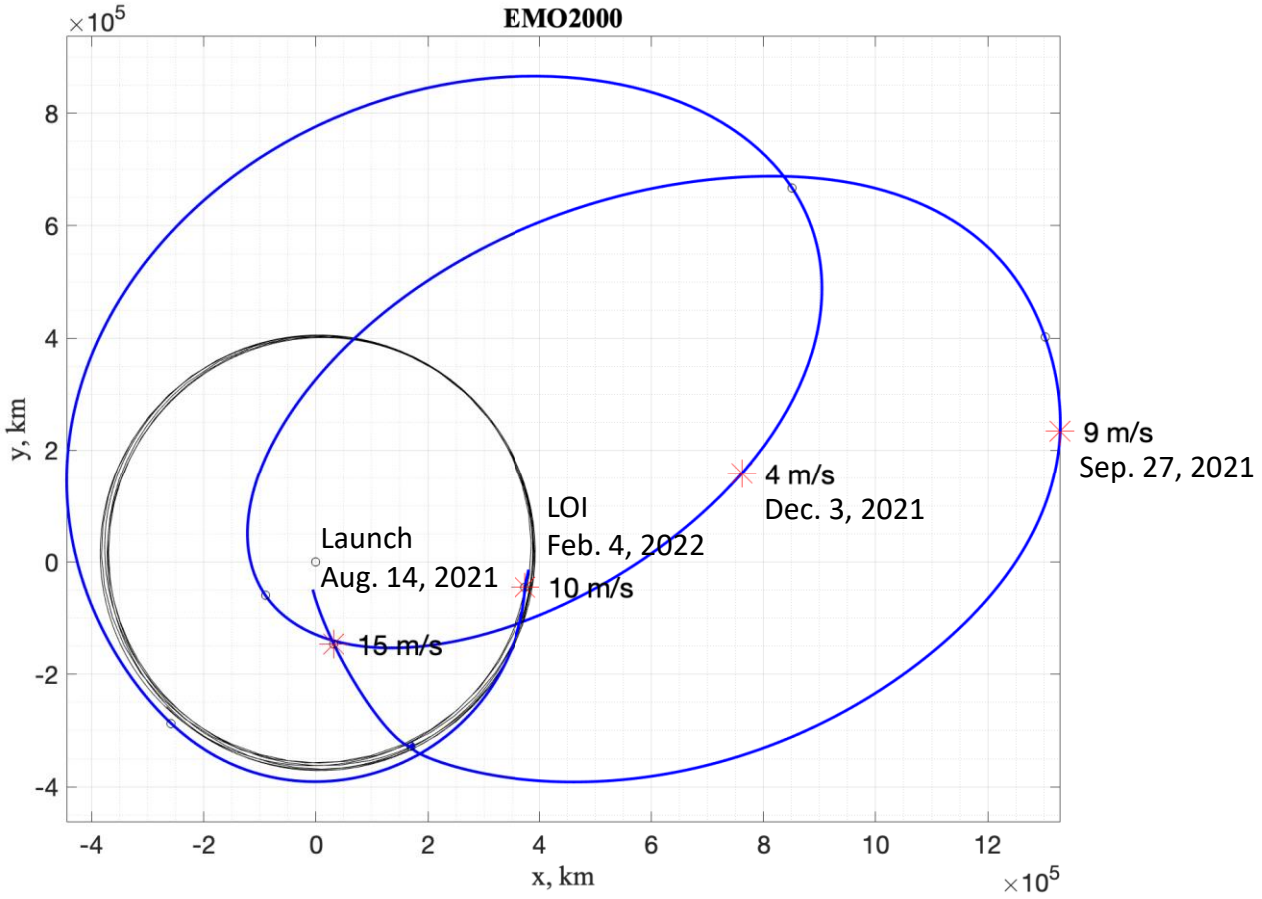


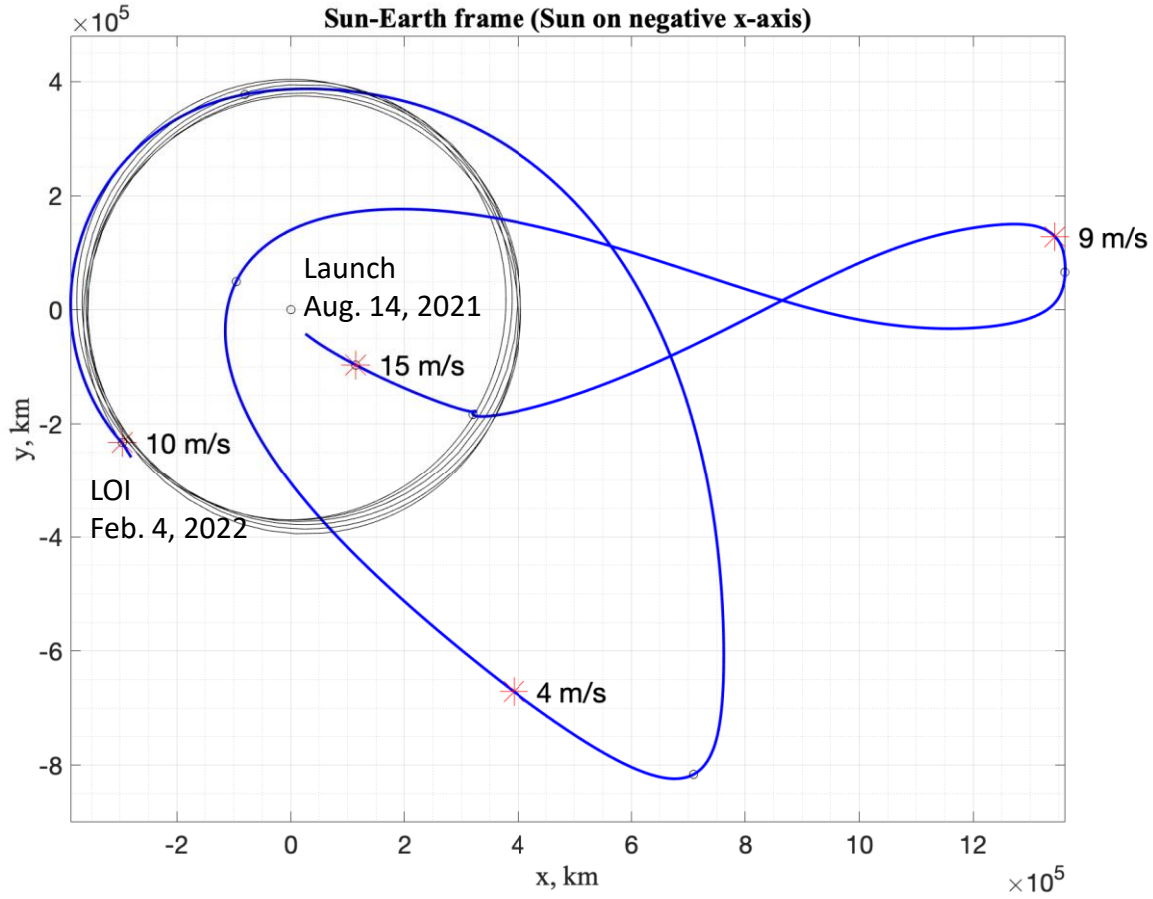
Patching databases
for notional launch on Aug 14, 8 pm UTC



Notional Lunar Flashlight Transfer

Flight time: 173 days

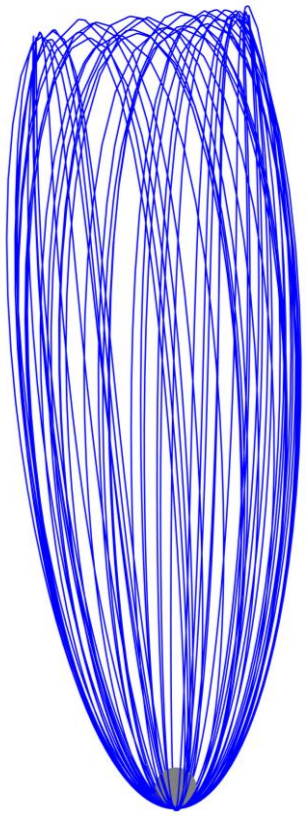




Notional Lunar Flashlight Science Orbit

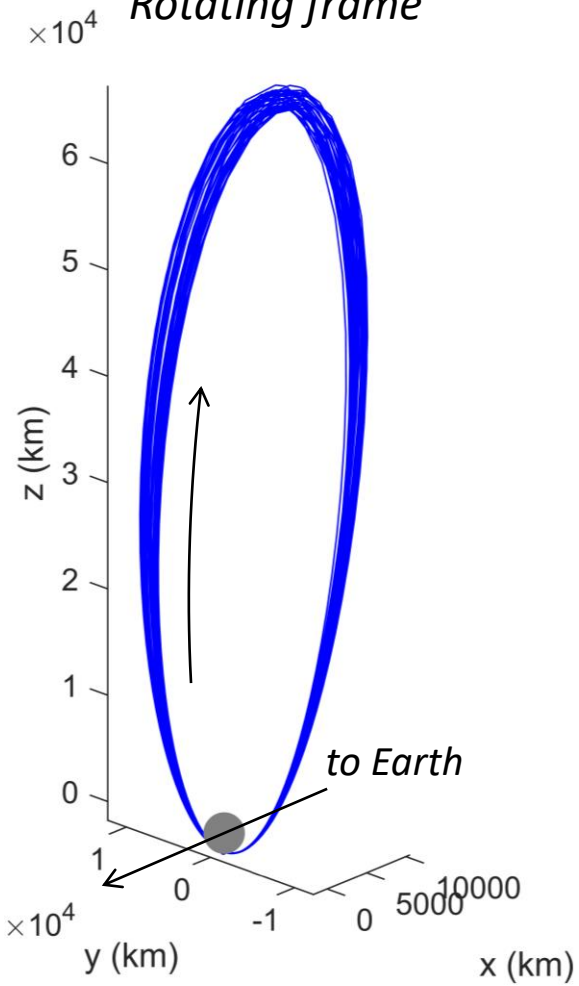
60-day nominal science orbit duration, or 10 close approaches

Inertial frame

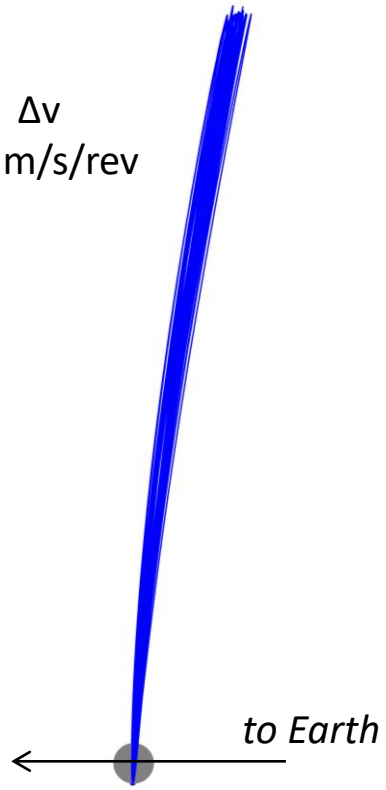


Orbital Period
5.7-6.1 days

Earth-Moon Rotating frame

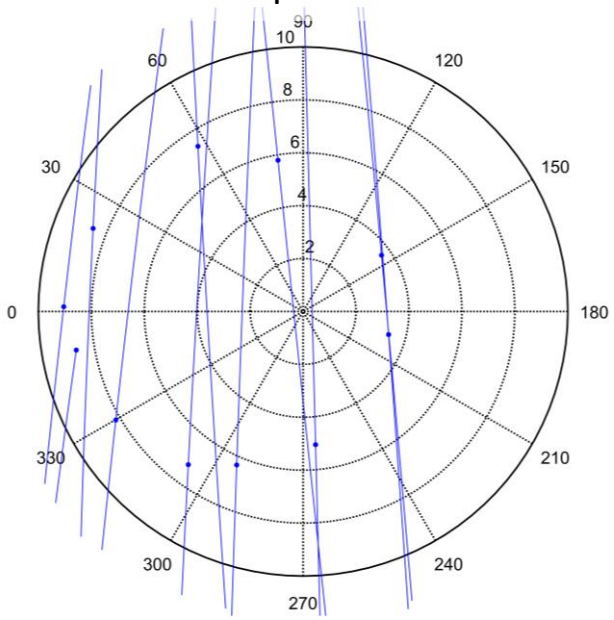


Rotating frame Side view

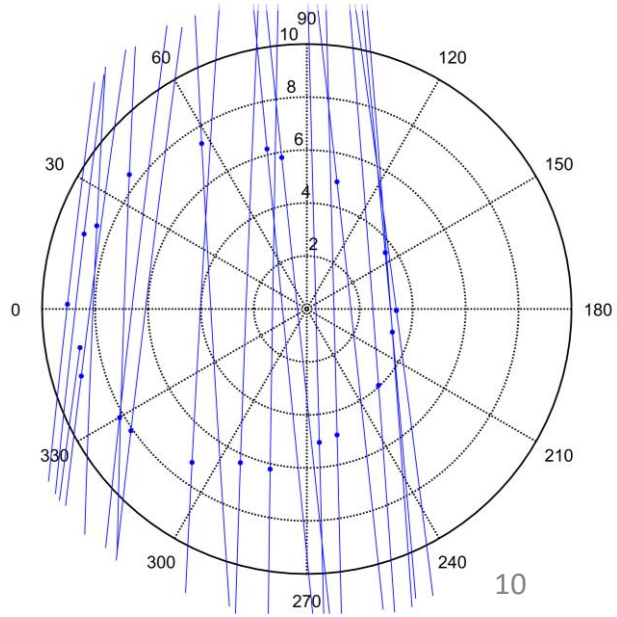


Perilune altitude
15 km ± 0.5 km

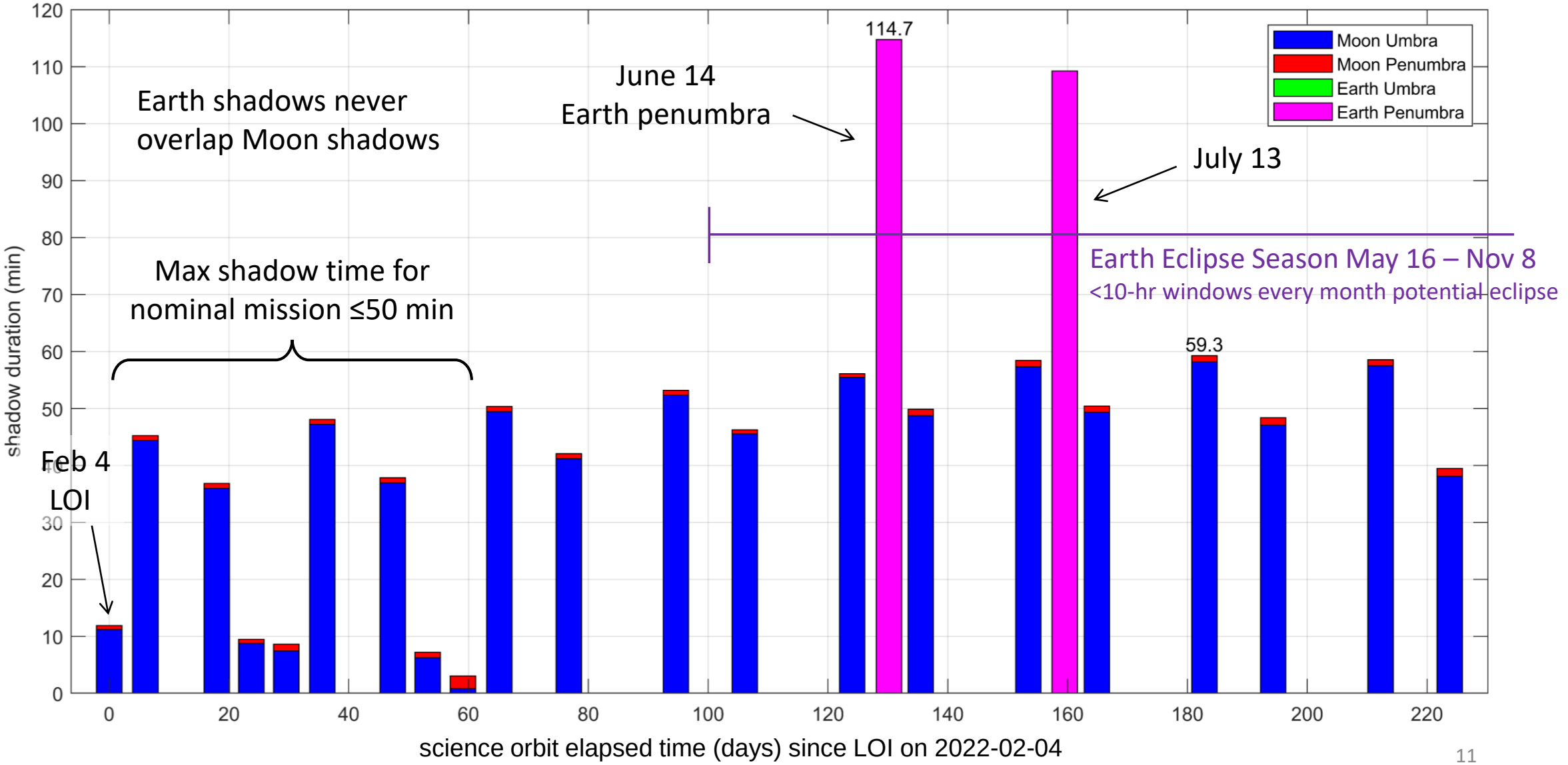
10 passes



20 passes



Shadow Times for Notional Science Orbit



Mission Duration & ΔV Budget

- Total mission duration (< 8-month requirement): **7.8 months**
- Total notional ΔV: **87 m/s**
- ΔV uncertainty 1-sigma assumed at 25% of each maneuver allocation

	Notional Reference ΔV (m/s)	Mission Design Allocation ΔV (m/s)	1-sigma (m/s)
TCMs lunar targeting	15	20	5
DSMs	13	50	12.5
LOI	10	12	3
Science maintenance	7	10	2.5
Total (uncertainty RSSed)	45	92	14
Total + 3-sigma	87	134	N/A

Total spacecraft ΔV capability: ~300 m/s