IM-1 Orbit Determination:

A Comparison of Mission Deliveries vs Post-Flight Trajectory Reconstruction

AAS 24-282

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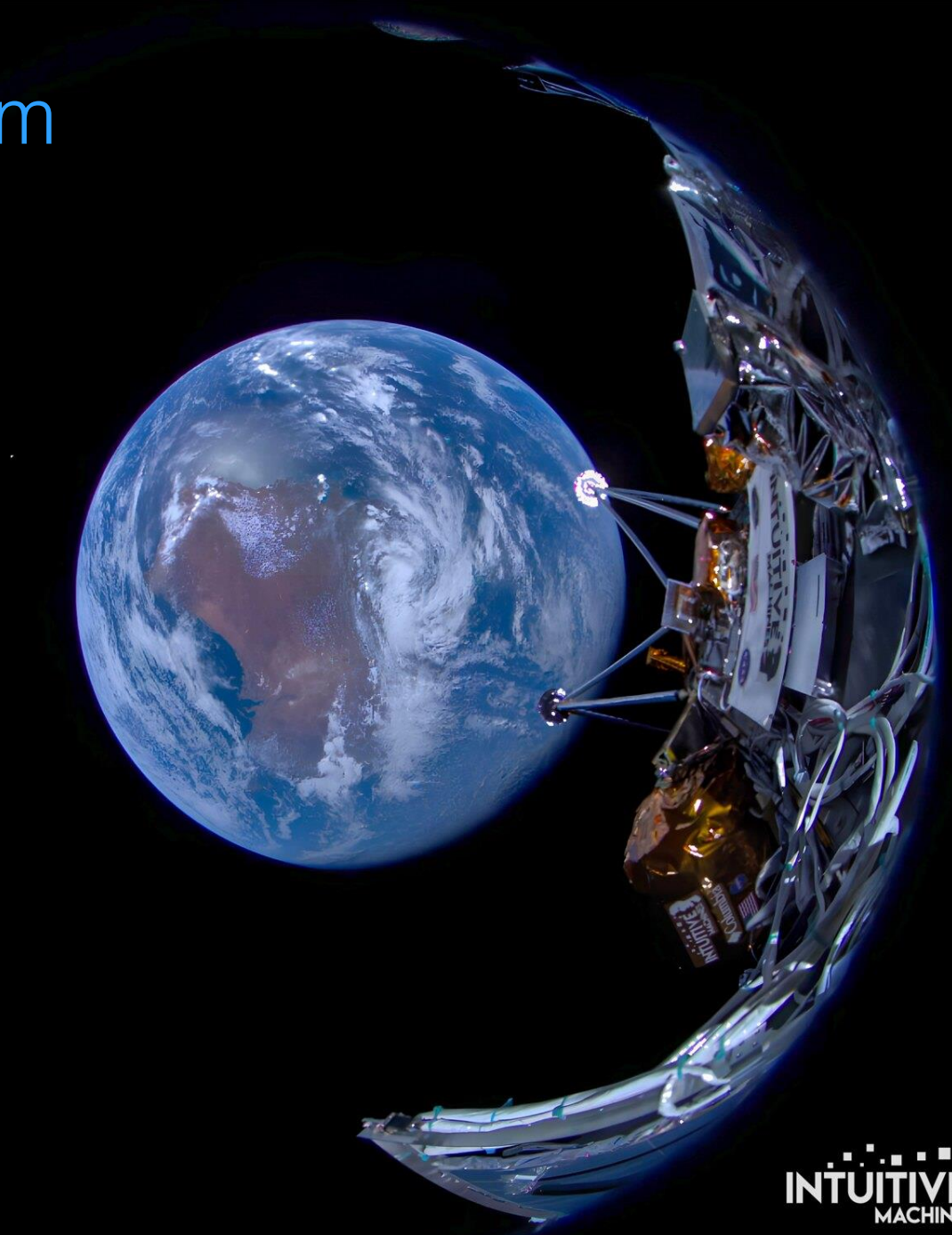
IM-1 Ground Navigation Team

INTUITIVE MACHINES

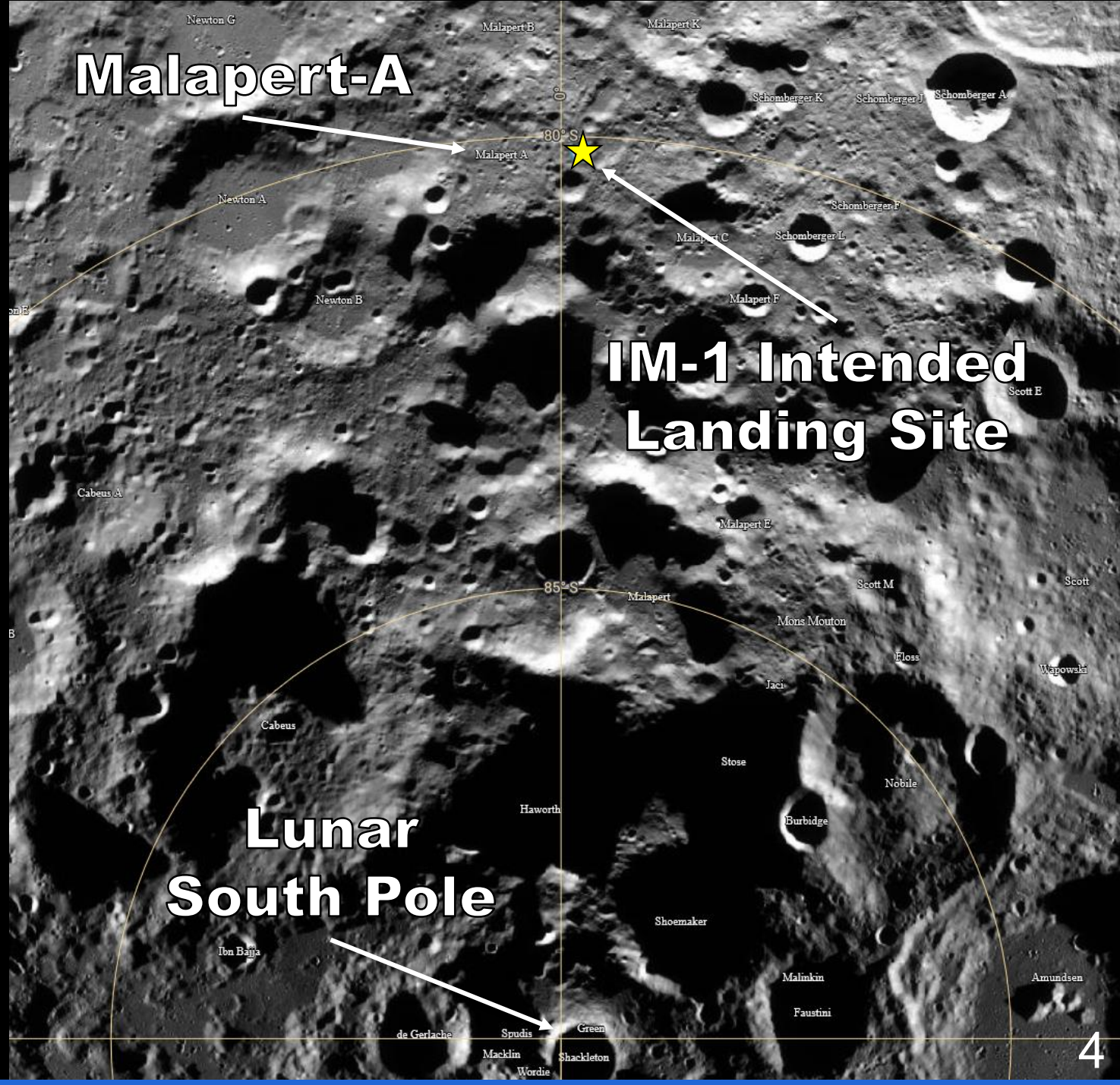
KINETX AEROSPACE



IM-1 MISSION OVERVIEW

IM-1 Landing Site

- The IM-1 mission was a lunar exploration mission with the goal of soft landing on the south pole of the Moon



IM-1 Landing Site

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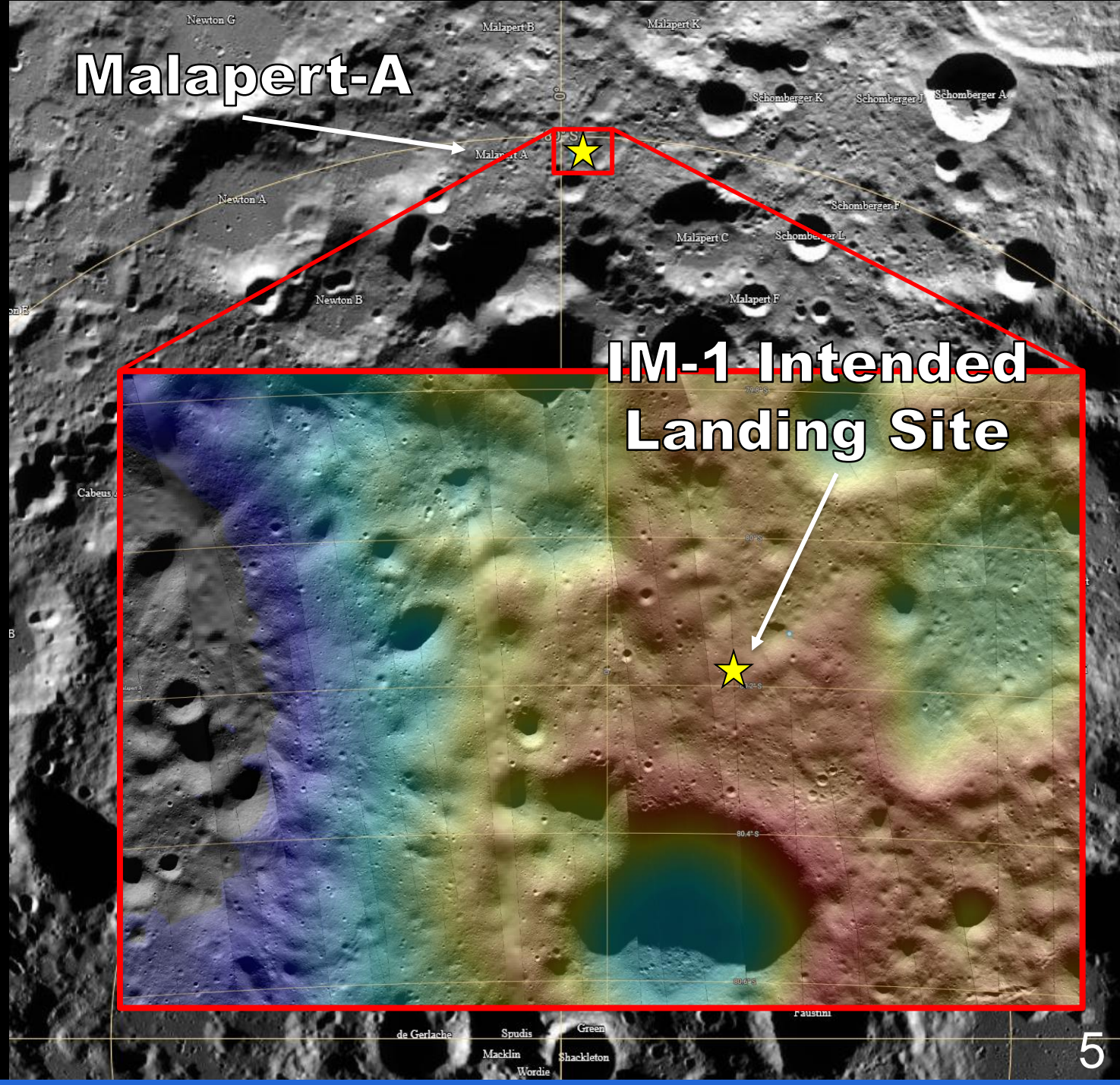
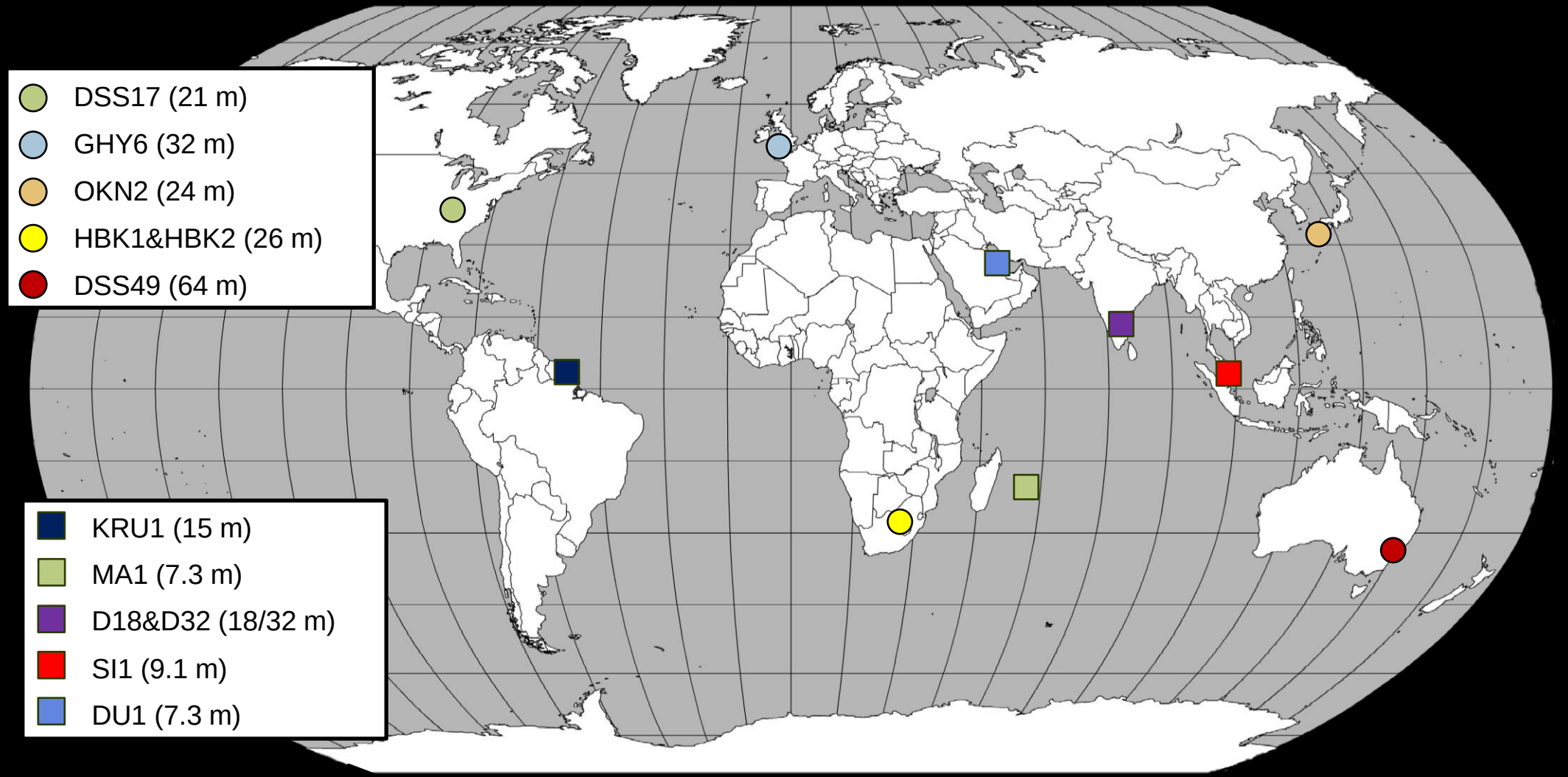
- The Malapert-A landing site was chosen for its flat terrain, view of Earth, and <80°S latitude

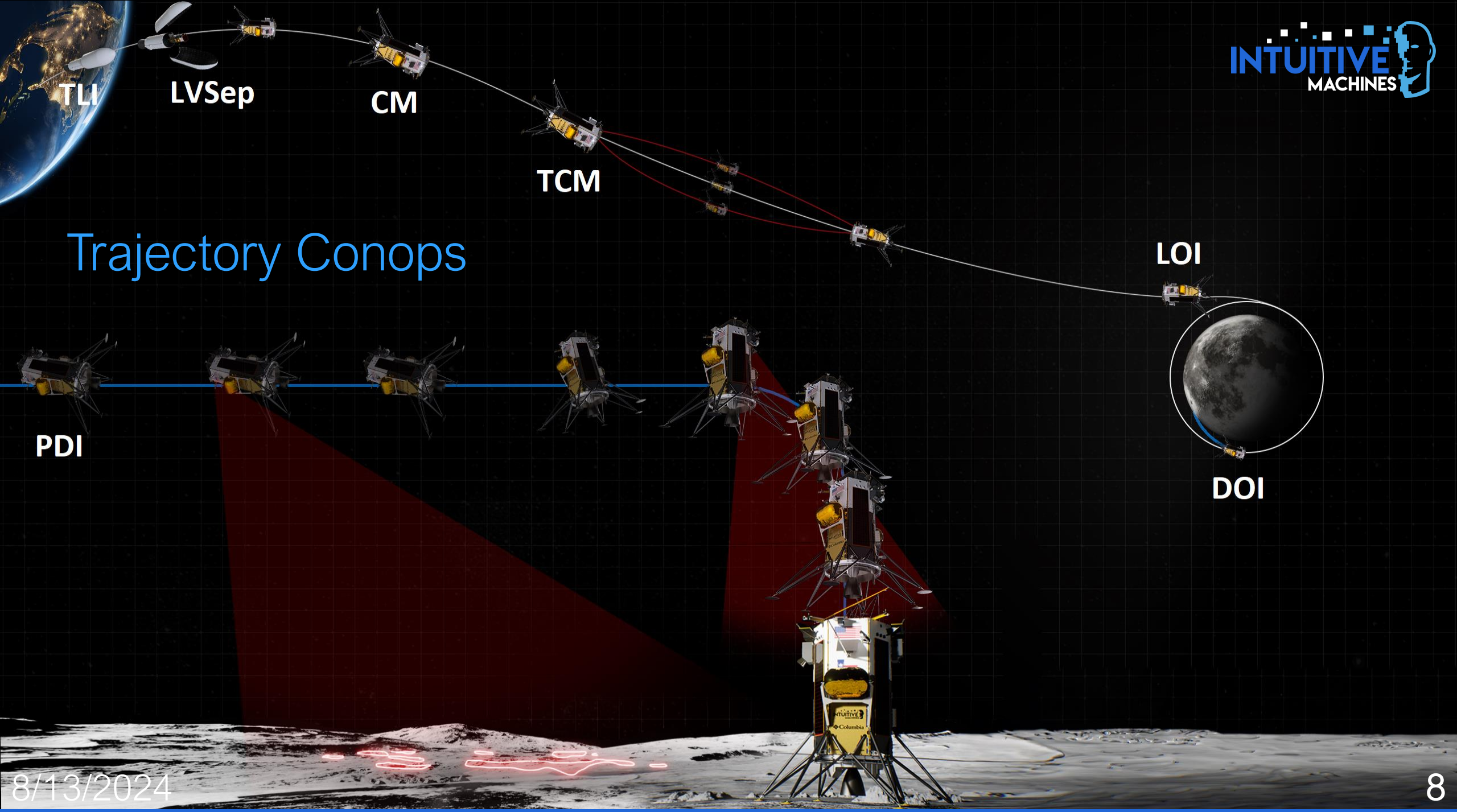


IM-1 Spacecraft – Odysseus aka Odie

- Hexagonal cylinder with six landing legs – 3.9 m tall
- IM's proprietary gimbaled LOX and LCH4 VR900 main engine
- Helium cold-gas RCS
- Three 700 W PV arrays for power
- GNC: two optical cameras, two star trackers, two LRFs, and two IMUs
- Comms: two transponders, two transmitters, and four low-gain & one high-gain antenna

IM-1's Lunar TT&C Network (LTN)





Trajectory Conops

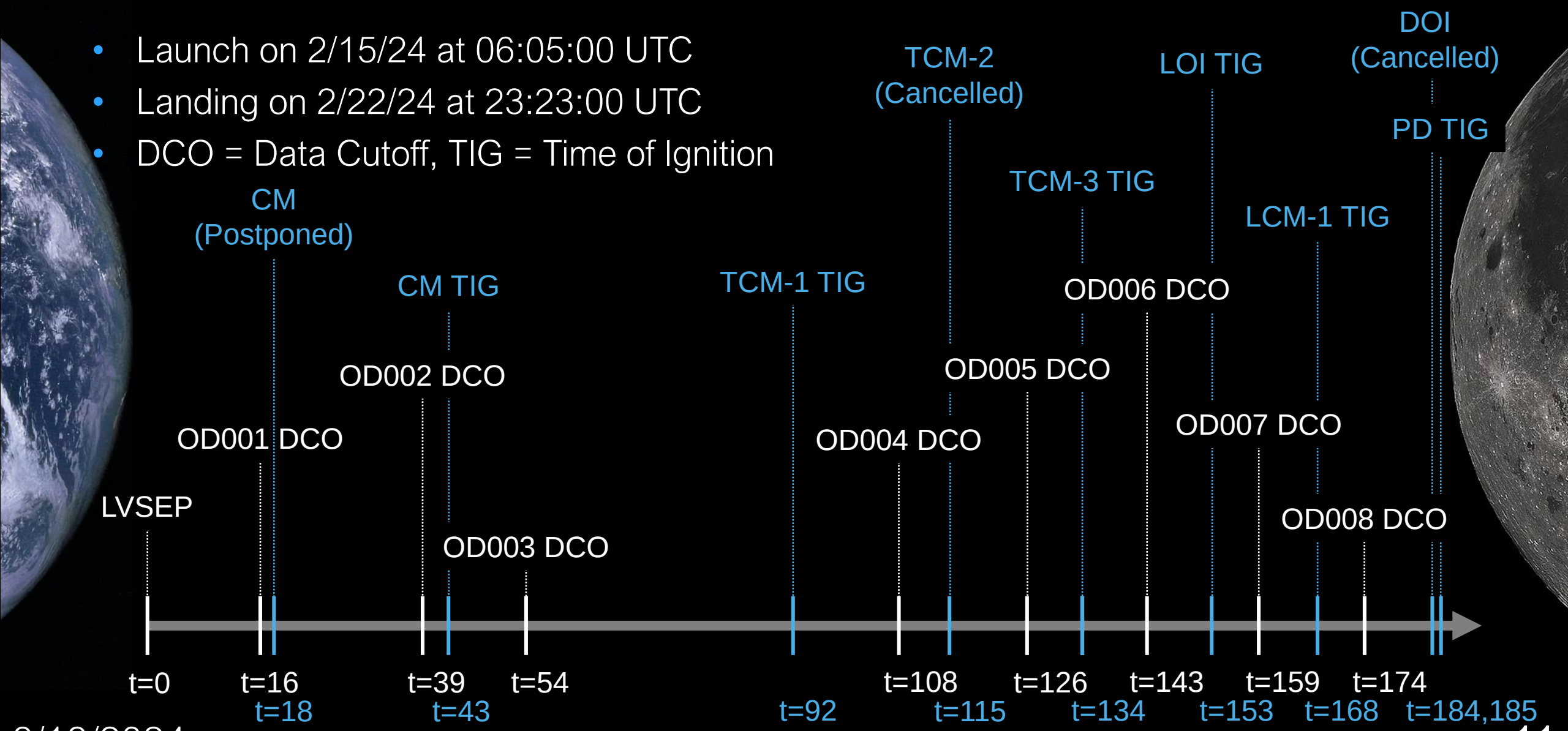
IM-1 OPERATIONAL ORBIT DETERMINATION (OD)

Operational OD Overview

- IM-1's Navigation Team was responsible for navigating Odie from LVSEP to the start of Powered Descent
- This was done with using 2way Range, 2way Doppler, and 3way Doppler
- The nominal plan was to receive continuous tracking data
  - Operational difficulties resulted in less than continuous tracking data
- The nominal plan was to use both GMAT's Batch filter and KinetX's filter Mirage to provide OD solutions
  - GMAT is NASA Goddard's General Mission Analysis Tool
  - Operational difficulties resulted in Mirage being the sole mission filter

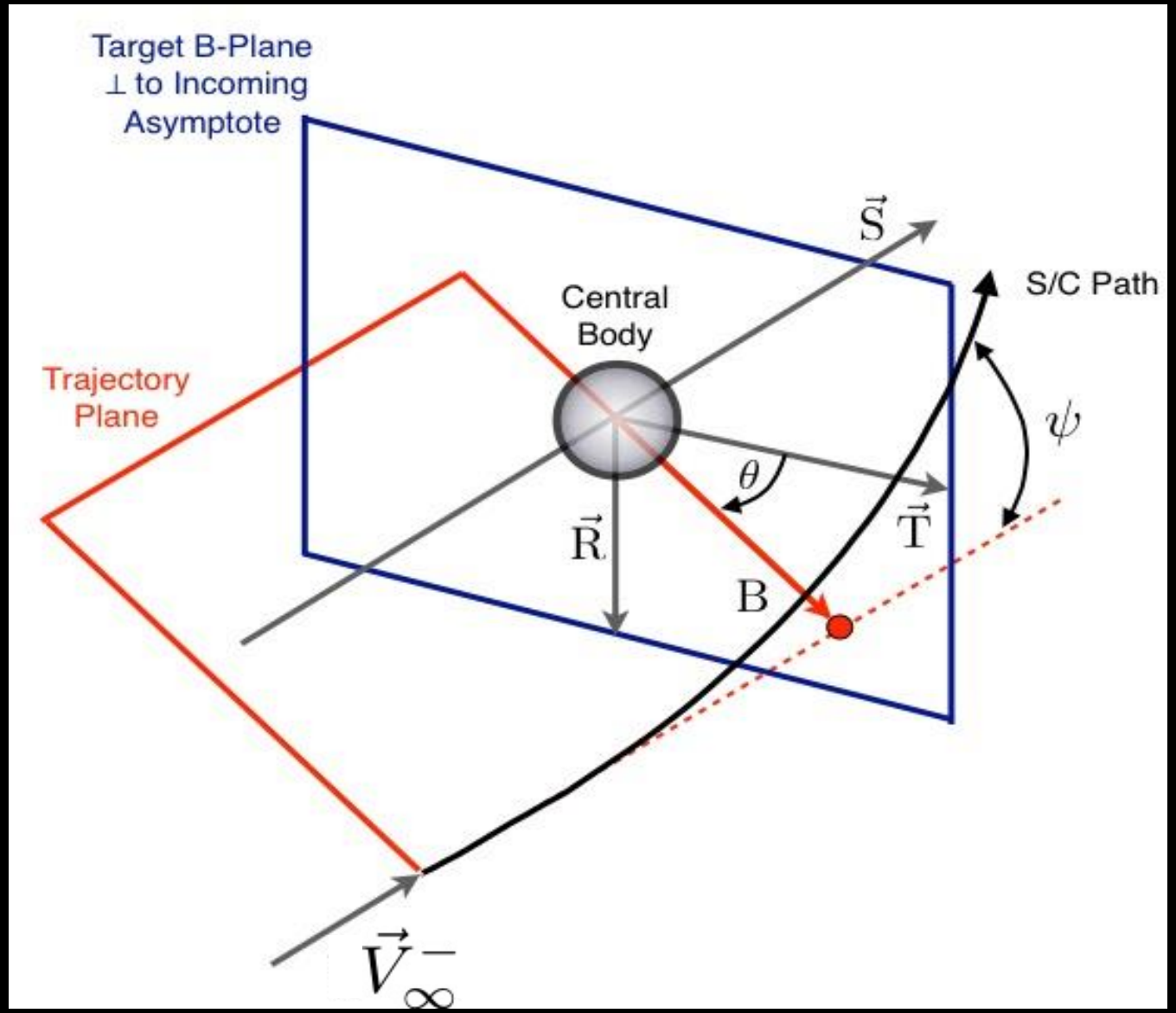
Mission Timeline in Hours from Launch

- Launch on 2/15/24 at 06:05:00 UTC
- Landing on 2/22/24 at 23:23:00 UTC
- DCO = Data Cutoff, TIG = Time of Ignition

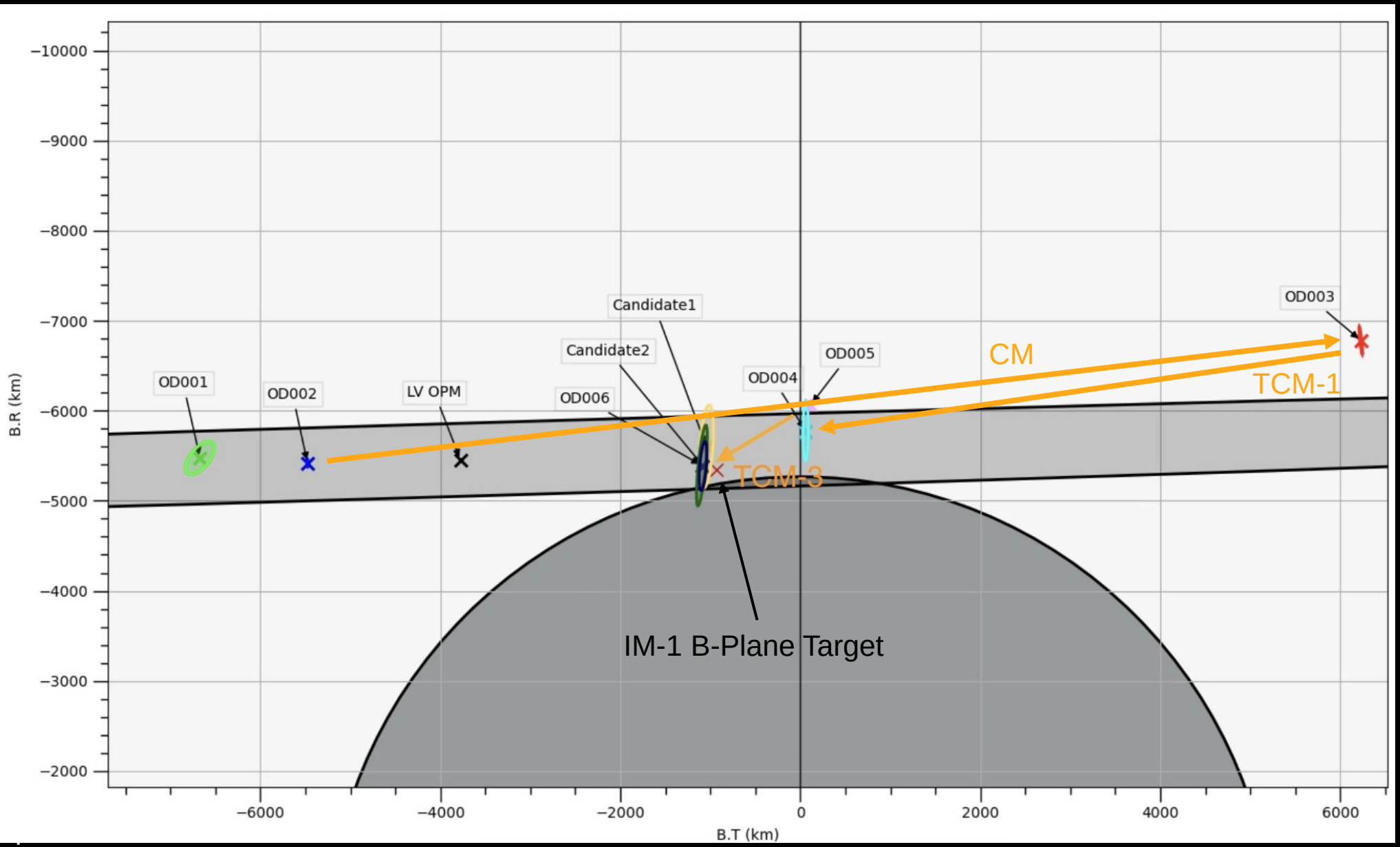


What is the B-Plane?

- Planar coordinate system that passes through central body
  - $\hat{S}$ = unit vector in the direction of $\vec{V}_\infty^-$
  - $\hat{T}$ = Lies in equatorial plane of central body normal to $\hat{S}$
  - $\hat{R} = \hat{S} \times \hat{T}$
- Intuitive way to visualize how your spacecraft is going to flyby the body
- **B** vector points to where the spacecraft pierces the B-Plane



Lunar Transit via the B-Plane



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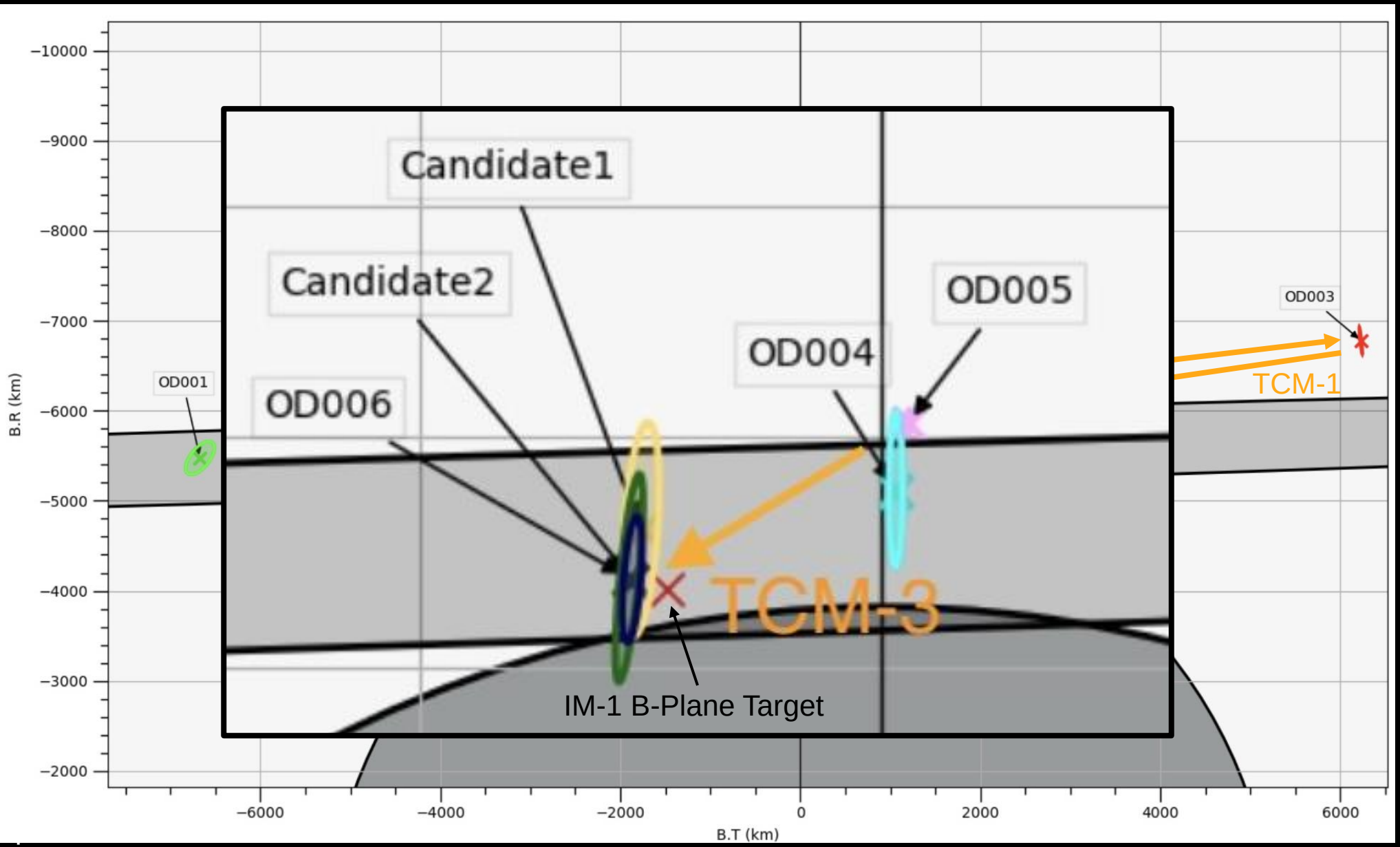
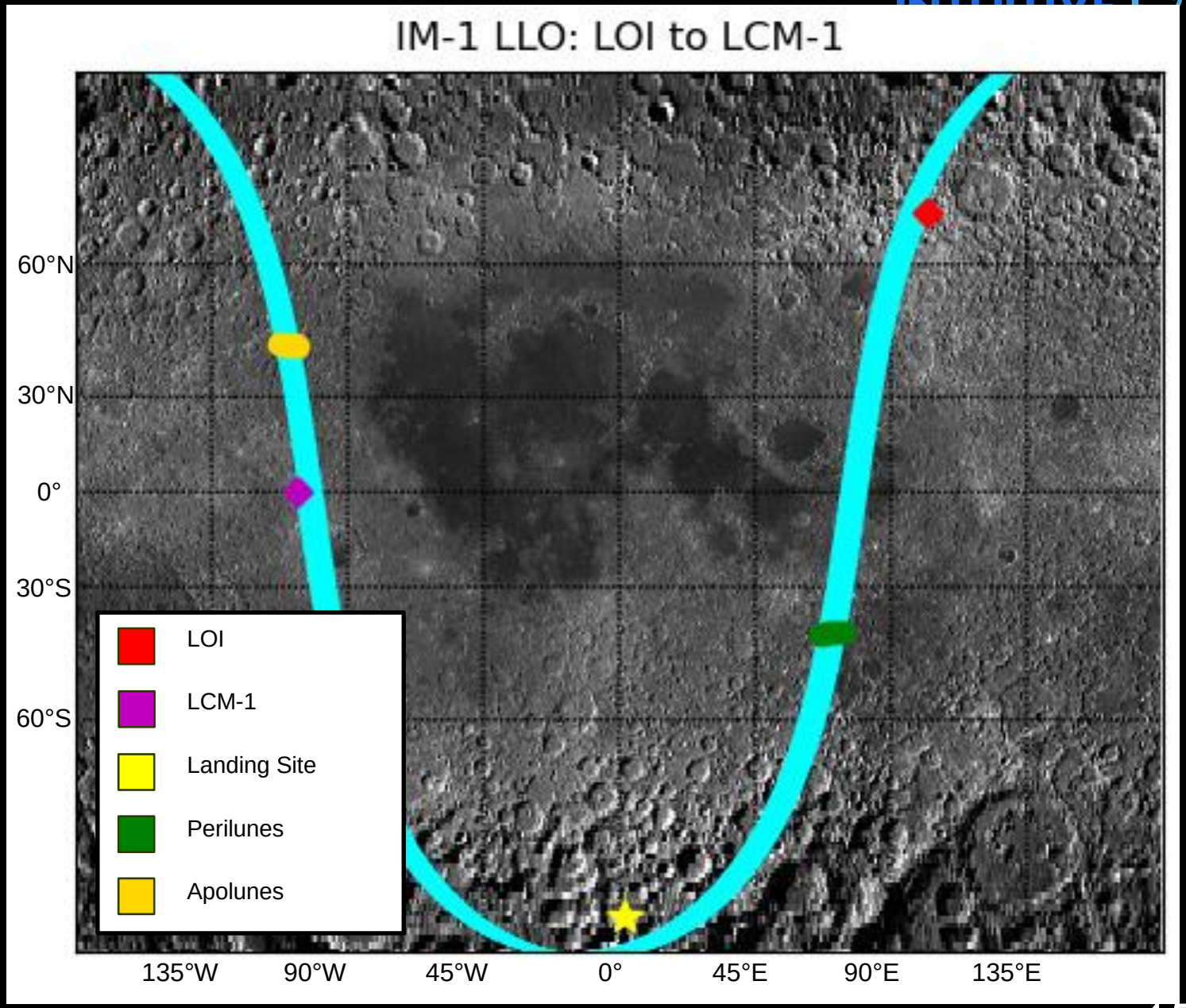


OD007

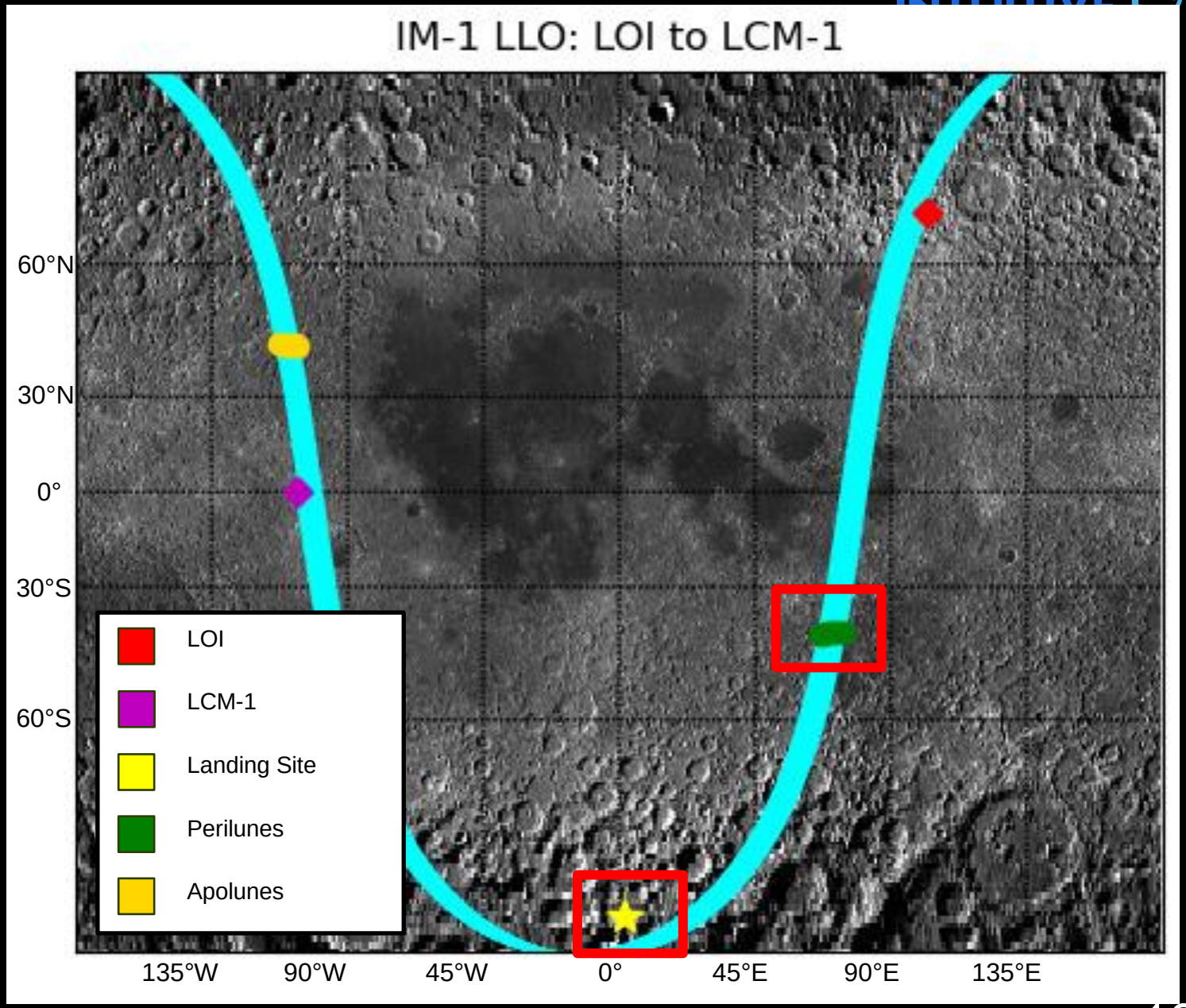
- LOI was an 827 m/s maneuver that put Odie into lunar orbit



OD007

- LOI was an 827 m/s maneuver that put Odie into lunar orbit

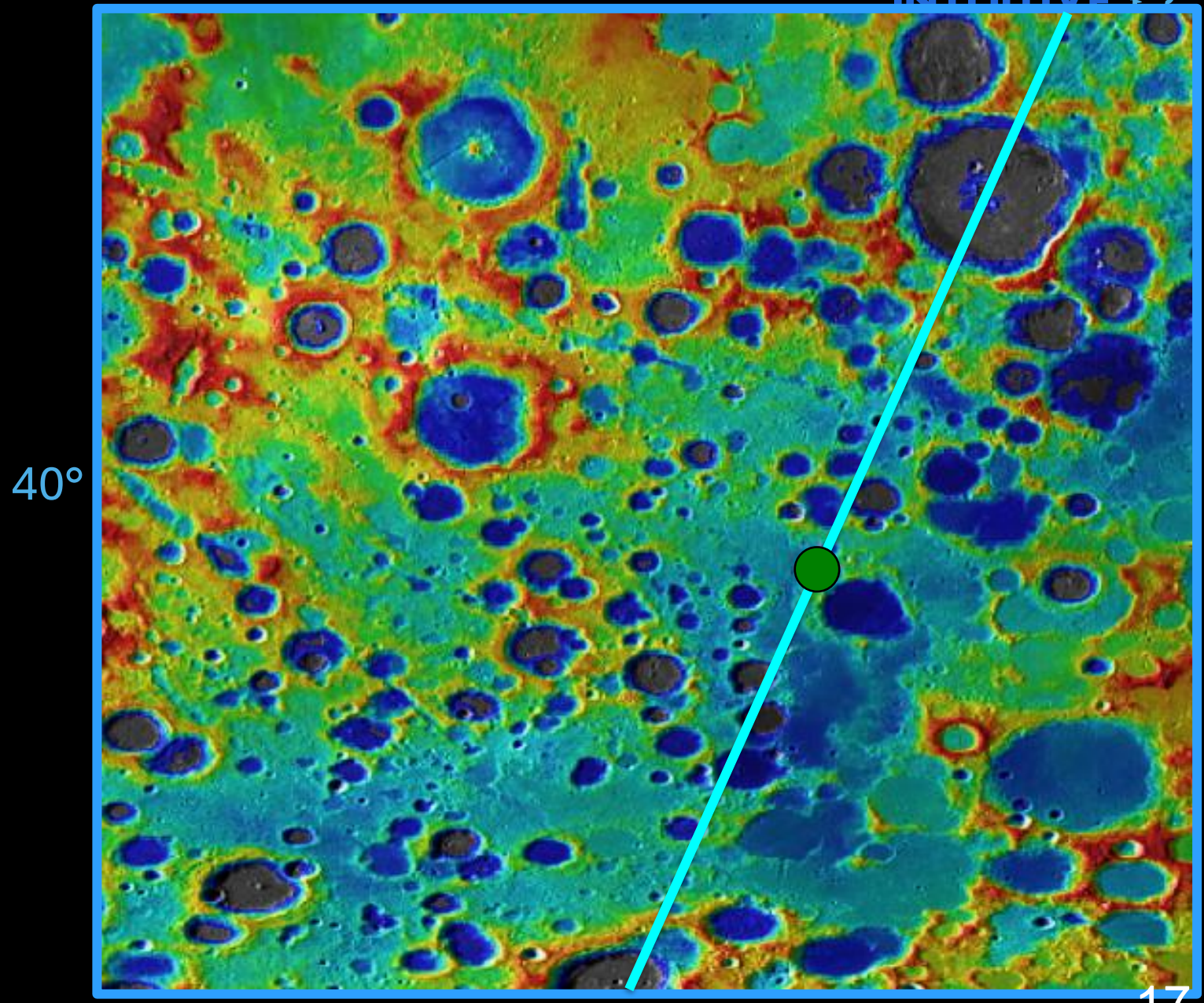
- OD007 indicated a low perilune and an inclination error



OD007

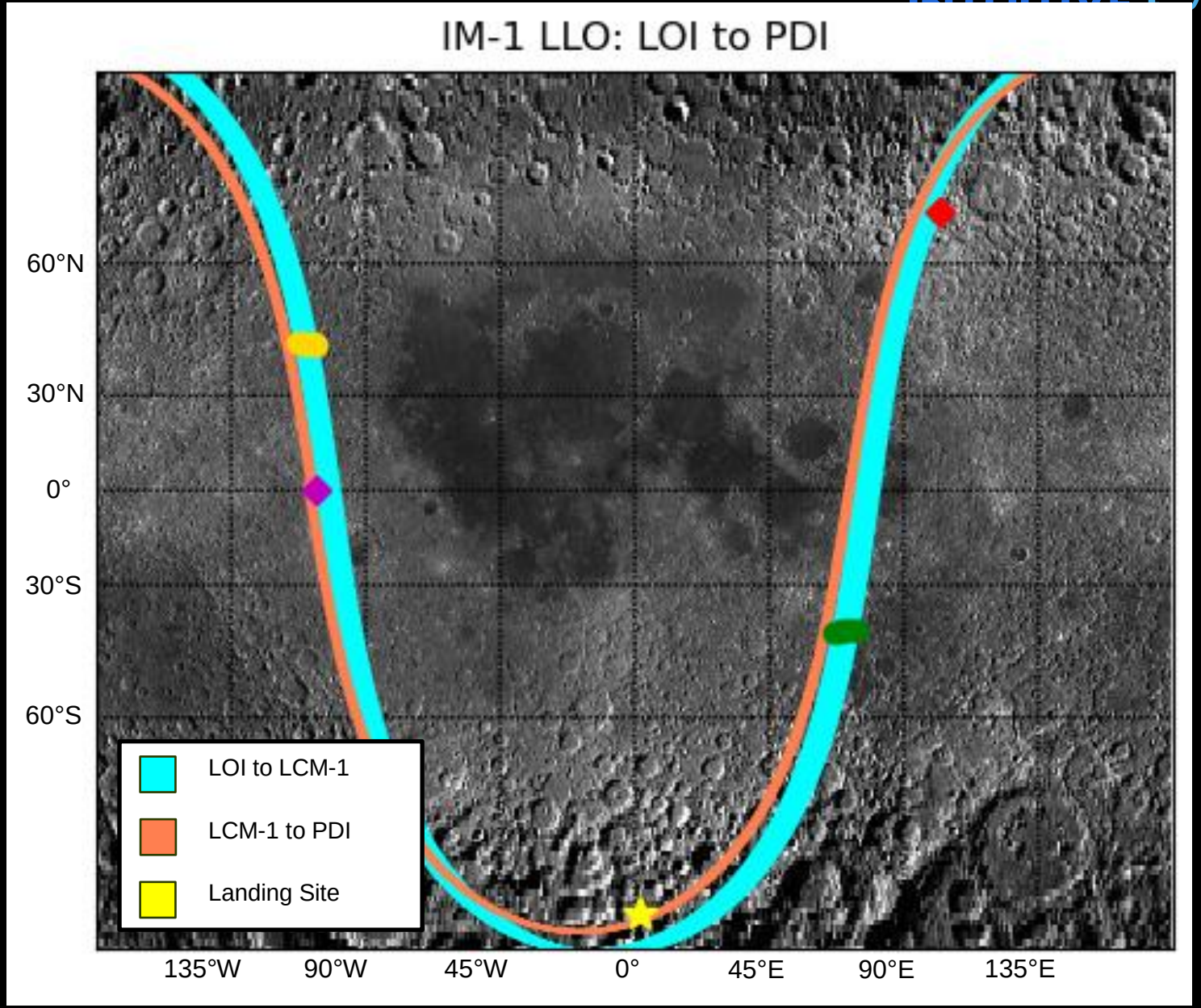
- Odie had an estimated perilune value of 1738.2 km post LOI
  - Located near 74.33°E and 42.13°S

- Lunar topography has an altitude of approx -500m at this location wrt the reference radius of the Moon



OD008

- LCM-1 was planned to target PDI 2 hours after the nominal PDI Epoch
- Raised perilune alt and corrected orbital inclination
- Replaced the DOI maneuver



OD008

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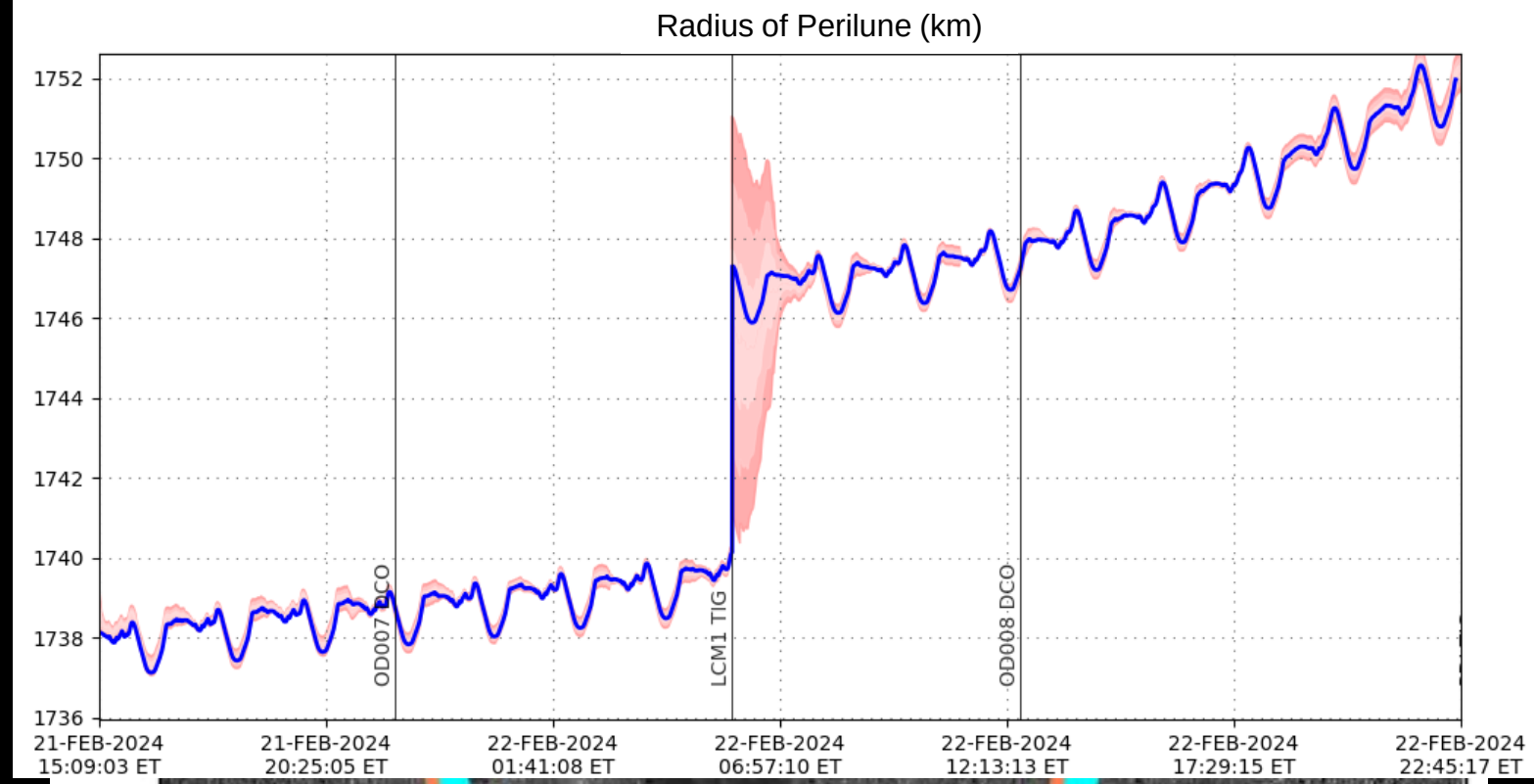
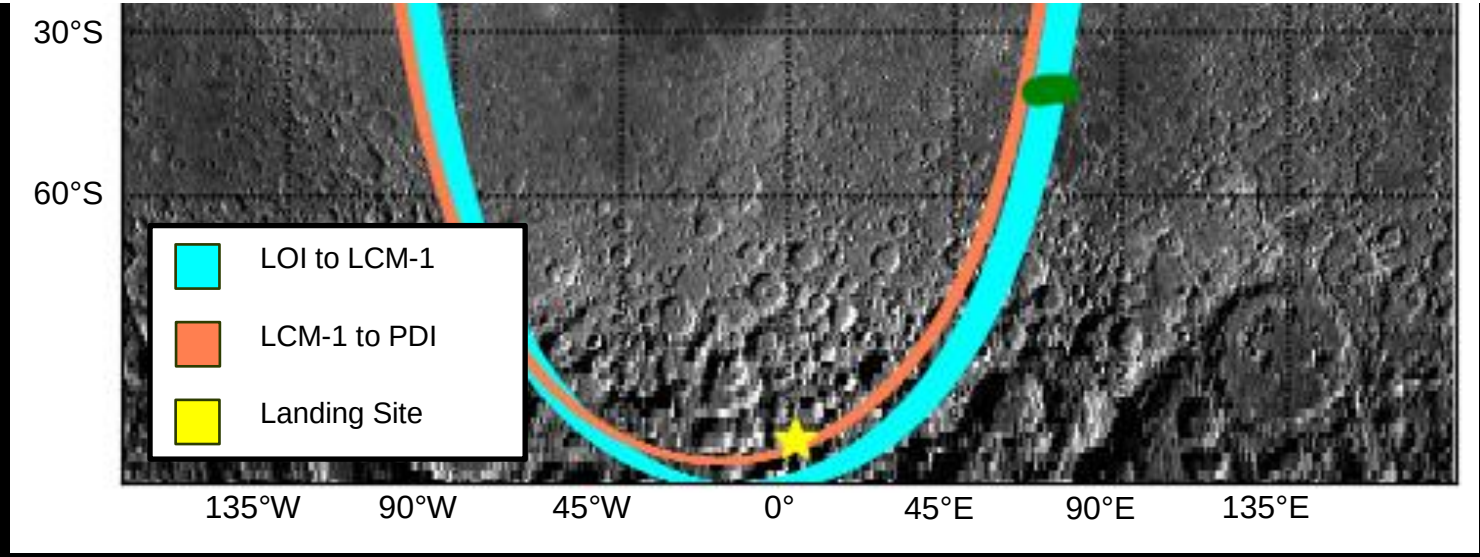
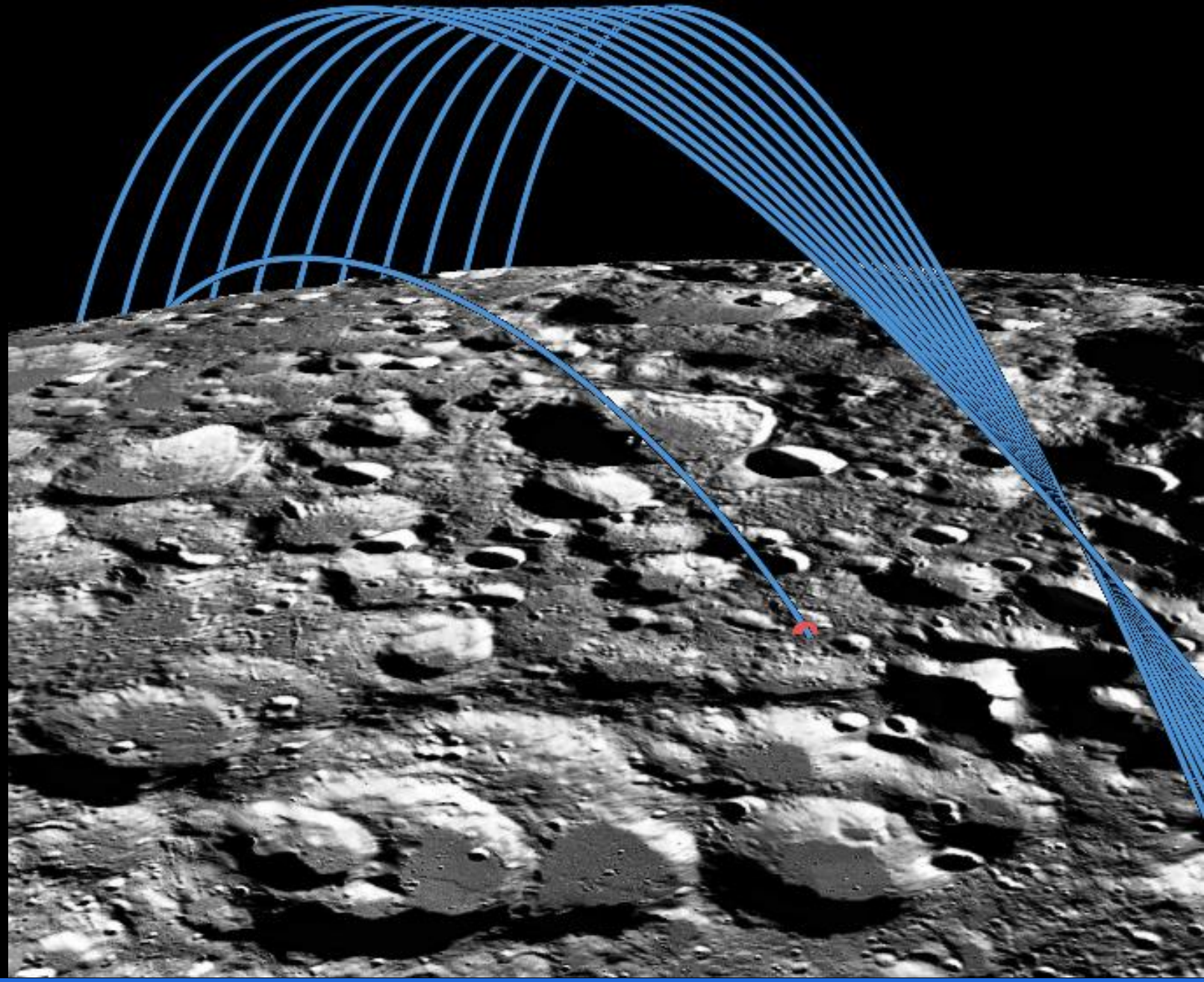




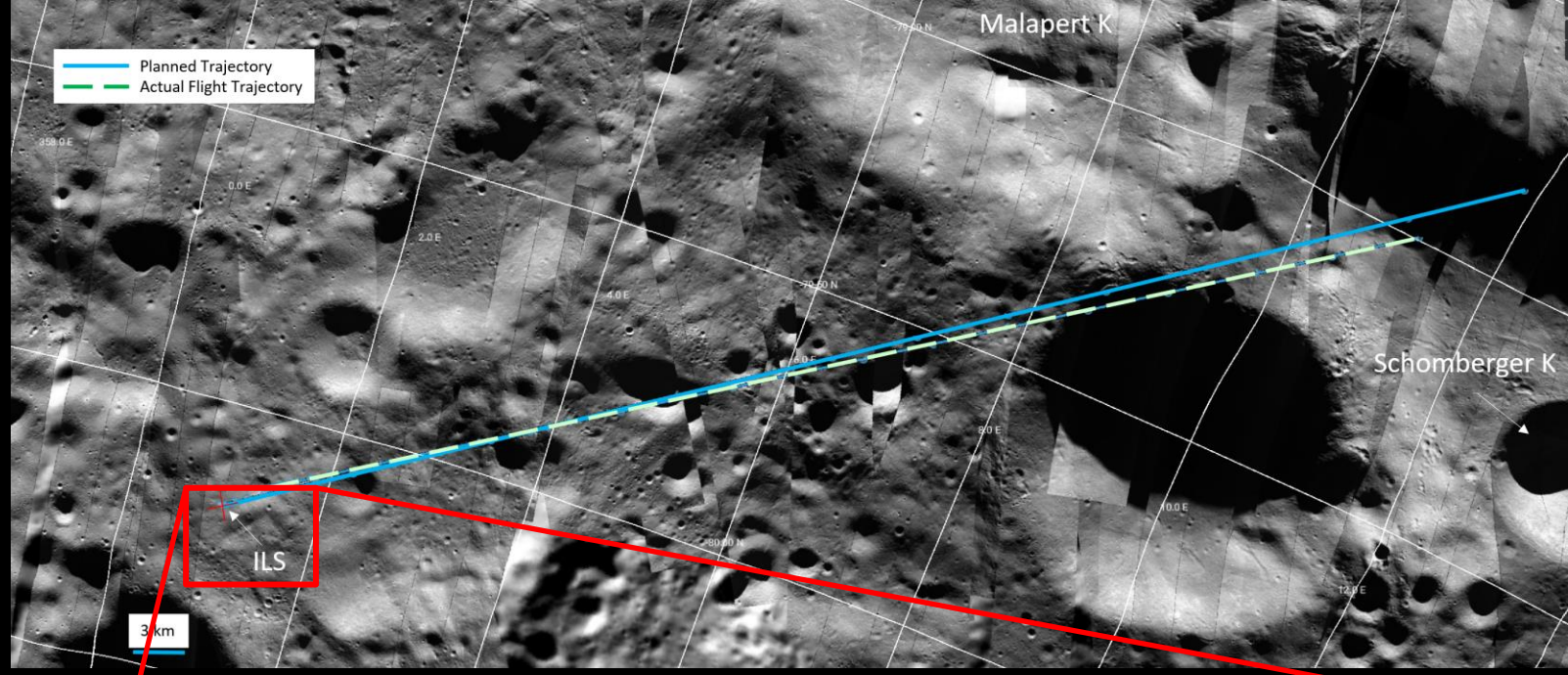
PDI and Landing

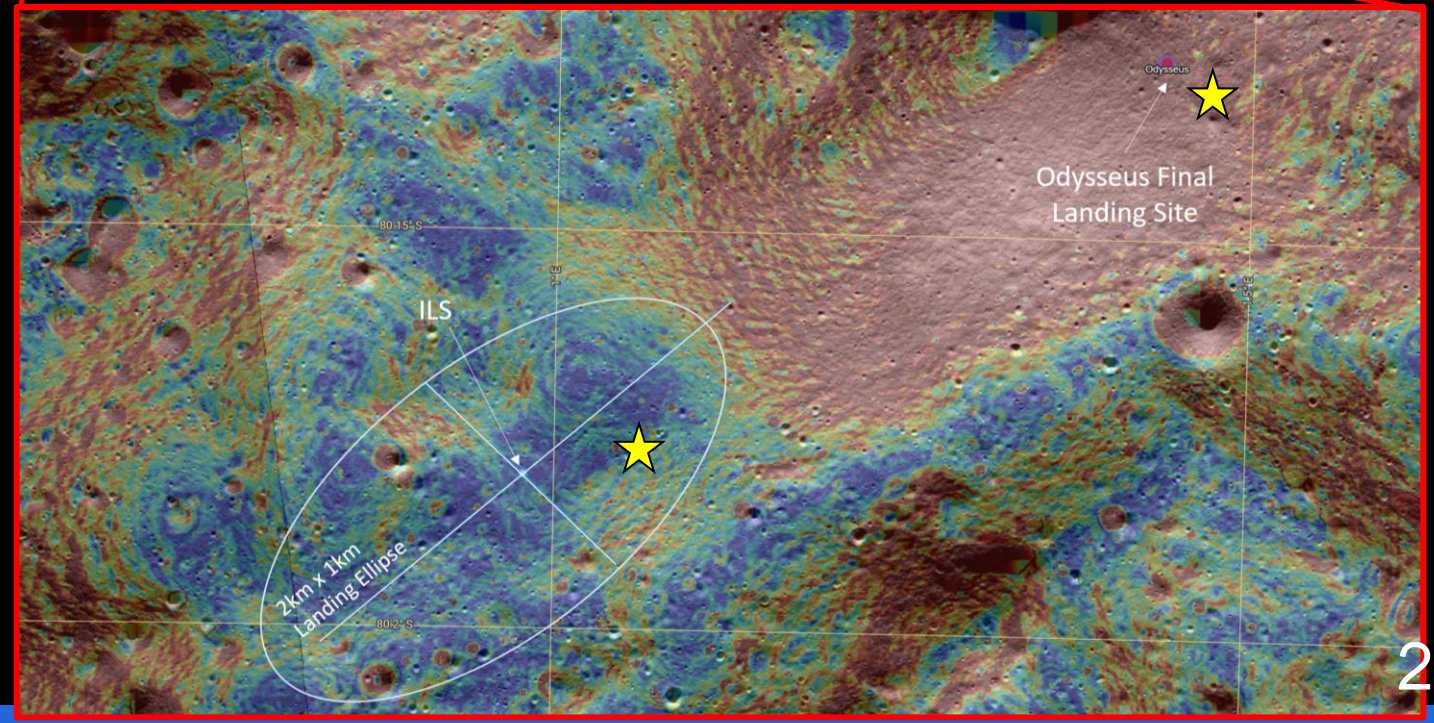
- The autonomous powered descent maneuver was successful



PDI and Landing

- The autonomous powered descent maneuver was successful
- Landed 3 km short of the intended landing site
- Surface ops lasted 174 hrs after landing





Conclusion

- IM successfully landed Odie near the south pole of the Moon and completed all science objectives
- IM-1 implemented several new technologies, worked through the difficulties that come with innovation, and learned invaluable lessons for future missions
- Read the paper for more information on…
  - Mission Events
  - IM's Lunar TT&C Network Performance
  - Filter Setup
  - Operational OD Difficulties
  - Best Estimated Trajectory

Questions?

Other IM-1 Papers at this Conference:

- AAS-24-340: IM-1 Pre-mission Landing Site Evaluation
- AAS 24-350: Maneuver Planning and Analysis with Copernicus for the IM-1 Mission