

NASA FOD – KARI Operations

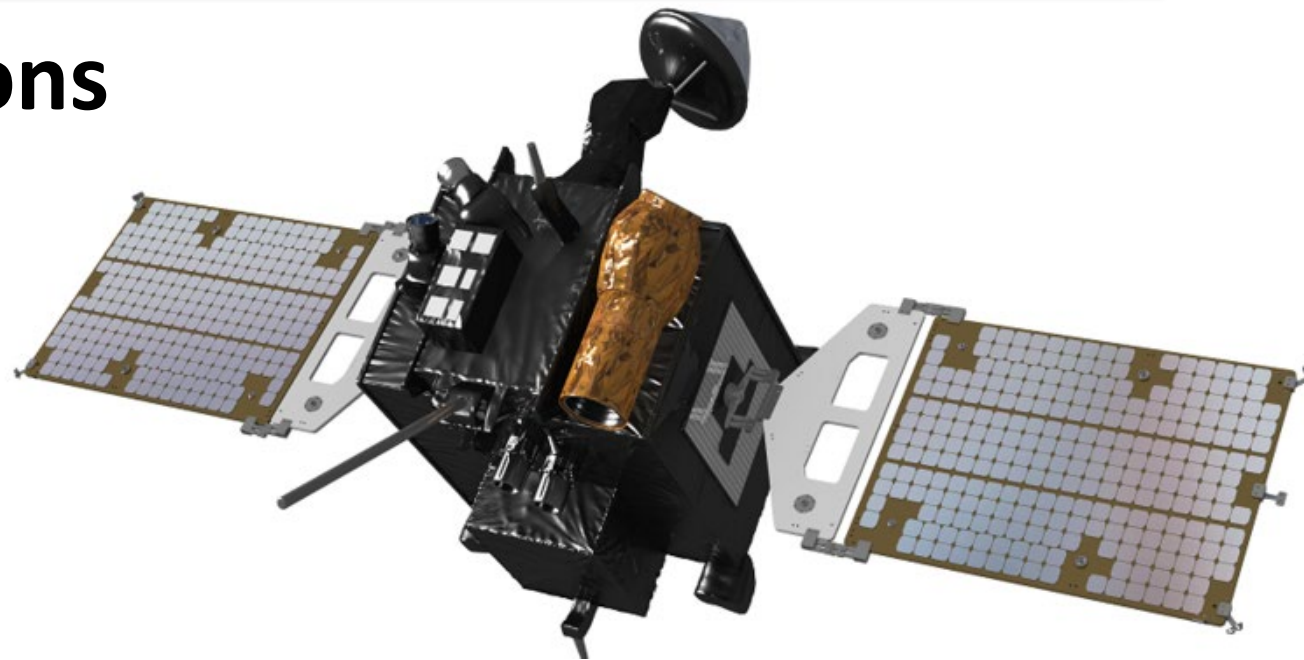
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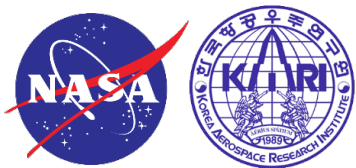


Table of Contents



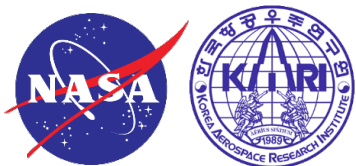
- Background
 - NASA/KARI Agreements
- KARI-NASA Joint Operations
 - Overview
 - Timeline
 - Pre-Flight Preparations
- Operational Support
 - Trajectory Operations
 - Conjunction Operations
- Benefits to the Artemis Program



Background



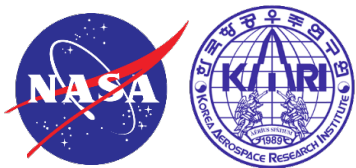
- In 2016, NASA and KARI entered into a cooperation agreement for the Korea Pathfinder Lunar Orbiter (KPLO) mission
 - NASA would provide mission design, tracking, and trajectory planning support for the KPLO Mission
 - KARI would place a NASA science instrument on the KPLO spacecraft
- NASA Science Instrument: ShadowCam
 - Selected by NASA in 2017
 - Operated by Arizona State University
- NASA Operations Support
 - Tracking and communication provided by Deep Space Network (DSN)
 - Operational support provided by NASA Flight Operations Directorate (FOD) at Johnson Space Center (JSC) in Houston, TX
 - » FOD is responsible for all Human Spaceflight at NASA
 - » KPLO Trajectory and navigation support is provided by the Artemis Flight Control Team in the NASA Mission Control Center (MCC-H)



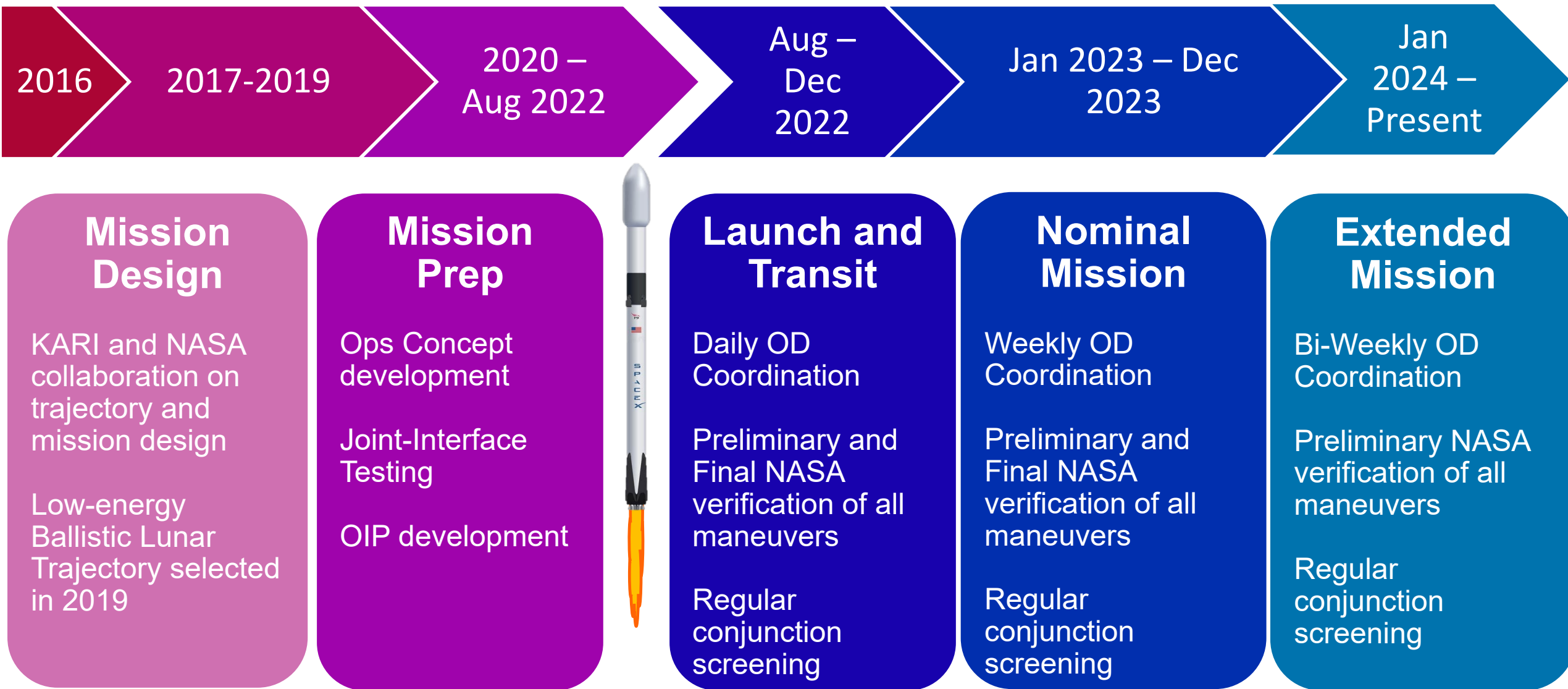
KARI-NASA Joint Operations

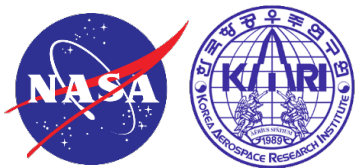


- KARI has full mission authority. KARI operates and troubleshoots the spacecraft, performs orbit determination (OD) and maneuver planning.
- NASA Support
 - **Nominal:** JSC's Mission Control Center (MCC) provides:
 - » Periodic verification of orbit determination and burn targeting
 - » Conjunction screening and risk assessments
 - » End-of-Mission Lunar disposal support, to protect historic sites or other lunar assets
 - **Contingency:** NASA supports off-nominal issues related to trajectory or OD tracking.
- Roles and Responsibilities and joint procedures are documented in a Joint OIP (Operational Integration Procedure) Document, trajectory priorities and operational objectives are documented in a KARI-authored constraints document



KARI-NASA Operations History

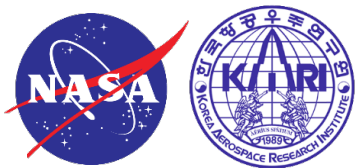




Pre-Flight Preparation



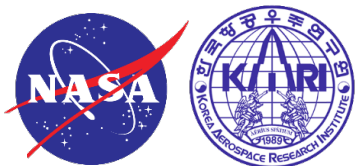
- NASA/KARI teams spent several years developing the Operational Plan and preparing for flight
 - Software Development
 - » Coordinated the force models and propagation settings used to model the KPLO trajectory to ensure consistency across both agencies
 - » Developed tools and software needed to support KPLO operations
 - Joint-Interface Tests
 - » April 2021 – Connectivity testing between Mission Control Centers
 - » May-Sep 2021 – Testing of operational procedures
 - » Dec 2021 – July 2022 – Operational Rehearsals
- Operations Interface Procedure (OIP)
 - Formally documents all aspects of the coordination between KARI and NASA JSC
 - Outlines when and how often NASA will provide verification of KARI trajectory planning
 - Specifies key details, propagation settings, and file formats for all deliveries between the agencies



Trajectory Operations



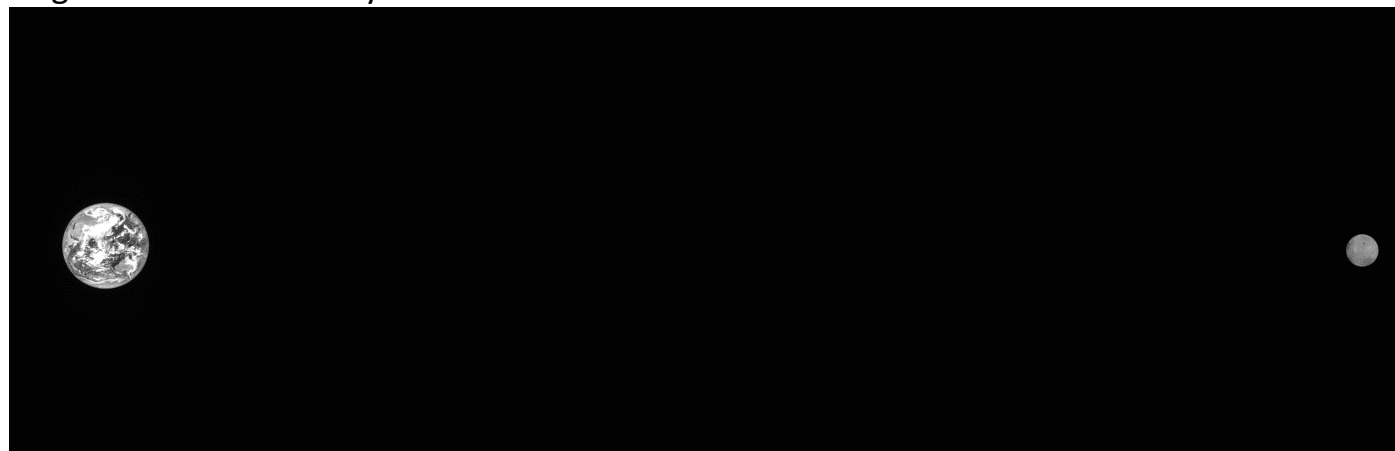
- KARI has full mission authority over the KPLO mission, and performs all spacecraft operations
 - Handles all telemetry and commanding
 - Performs Orbit Determination
 - Plans and executes all maneuvers
- NASA JSC performs periodic independent verification of Orbit Determination and Maneuver planning
 - Orbit Determination
 - » NASA uses it's Deep Space Network (DSN) tracking data to calculate an independent solution of KPLO's position and trajectory
 - » NASA compares this solution to the solution developed by the KARI team
 - » Generates a Comparison Report based on the Pass Criteria defined in the OIP
 - Maneuver Planning
 - » During Maneuver Planning, JSC uses Targeting Parameters defined by KARI to independently target all spacecraft maneuvers
 - » JSC generates a Comparison Report based on the Pass Criteria defined in the OIP
- If any verification fails, NASA and KARI will hold a telecon to troubleshoot and determine the source of the error



Contingency Operations: TCM-3

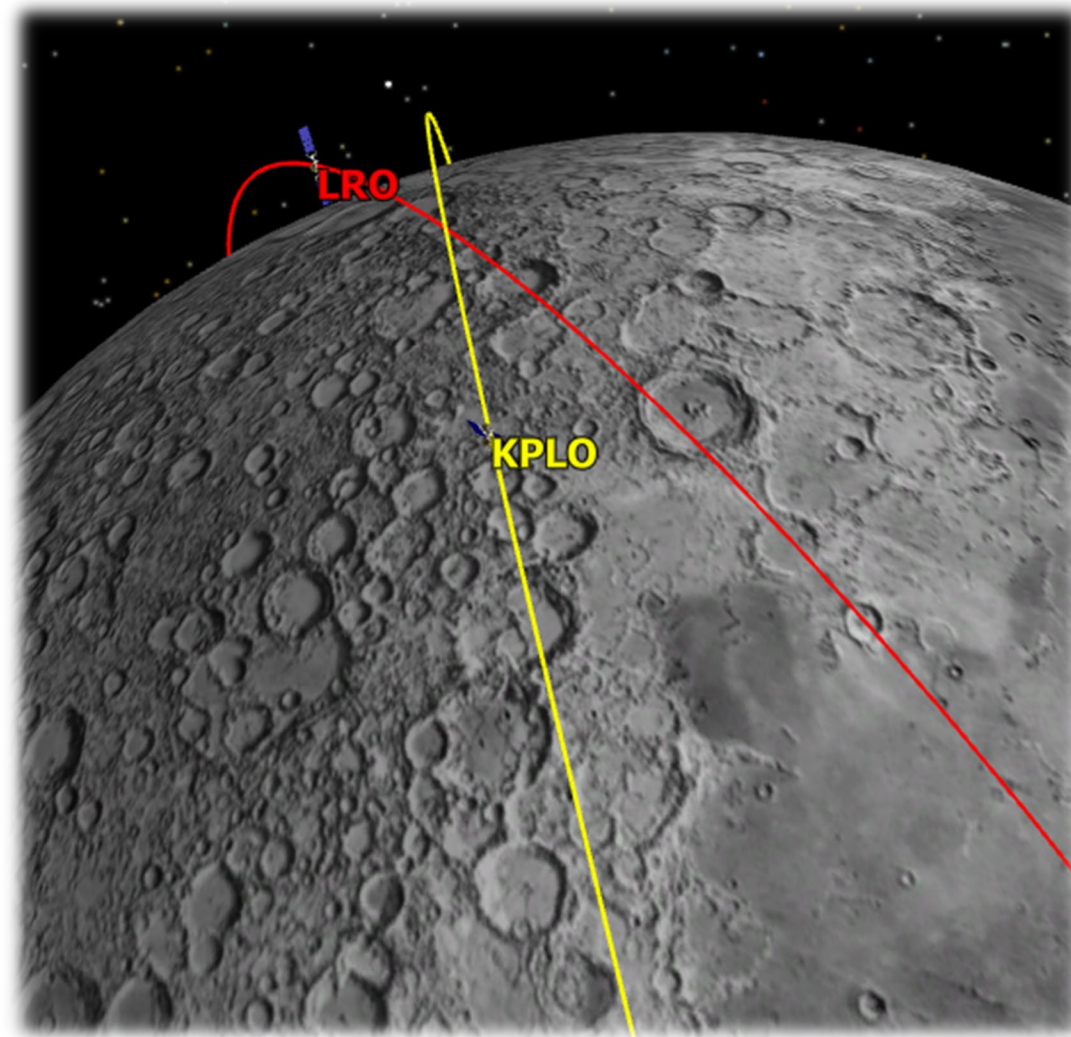


- **September 1st 2022:**
 - KPLO Flight Dynamics teams were preparing for TCM-3, the most important burn in the Ballistic Lunar Transfer
 - Less than 24 hours before the burn, KPLO suddenly entered into a SafeMode and performed an unplanned attitude maneuver
- **Recovery:**
 - KARI team successfully recovered the vehicle during the next communications pass
 - Nominal operations restored
- **Replanning:**
 - KARI/NASA teams quickly performed updated Orbit Determination on the next DSN Pass to understand the impacts to the trajectory
 - KARI updated the Maneuver Targeting for TCM-3
 - » Pushed back the burn 3 hours to allow time for retargeting
 - » NASA provided verification that the targets were good and successfully achieved a Lunar encounter
 - » ΔV of the maneuver decreased by 1%
- **Execution:**
 - KPLO successfully performed TCM-3 and set KPLO on an intercept path with the Moon
- **The KARI/NASA team successfully recovered, replanned, and executed the maneuver in just 24 hours**



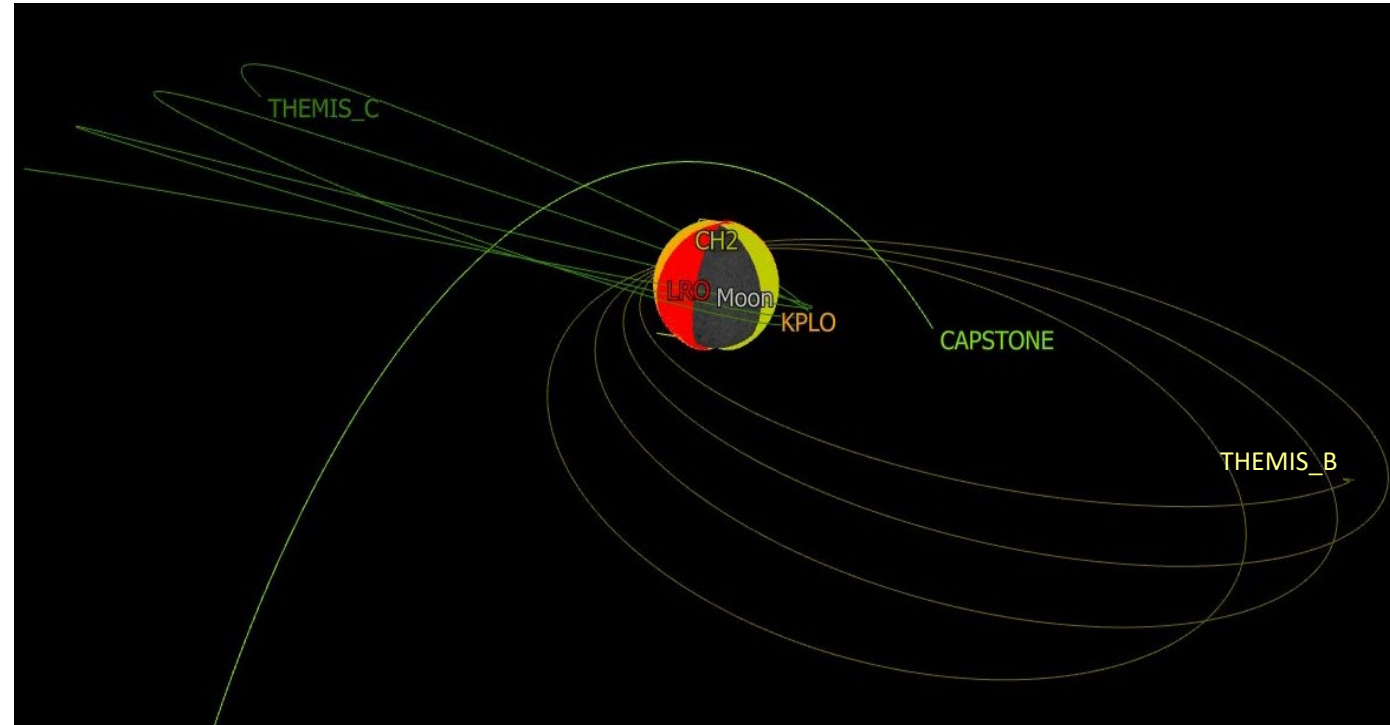
Conjunction Screening

- **Conjunction** – A close approach with another spacecraft that carries a potential risk of collision
- NASA and KARI Flight Dynamics teams are responsible for monitoring the KPLO trajectory for potential conjunctions and taking any necessary actions
- Conjunction screening for Lunar spacecraft is performed at NASA JPL using a system called MADCAP
 - Voluntary system to which International Spacecraft operators can submit their trajectories to screen against other spacecraft
 - Notifies spacecraft operators of upcoming conjunctions
- When a high concern conjunction is identified, NASA will calculate a Probability of Collision (P_c)
 - Utilized by KARI to determine if action is necessary for KPLO



Conjunction Screening

- As of June 2024, KPLO Flight Dynamics teams have analyzed **27** close approaches with other spacecraft
 - 24 with Lunar Orbiters in Low Lunar Orbit
 - » 15 with ISRO Chandrayaan-2
 - » 9 with NASA Lunar Reconnaissance Orbiter (LRO)
 - 3 with Lunar Landers
 - » 2 with Hakuto
 - » 1 with SLIM
- KPLO has performed 4 Collision Avoidance Maneuvers to mitigate collision risks





NASA Support Levels

NASA operational support for KPLO has slowly decreased through the mission as KARI has developed their expertise in flying the spacecraft

Launch + Lunar Transfer

Nominal Mission

Extended Mission

OD Verification: 1x / day

Maneuver targeting verification:
Prelim and Final

OD Verification: 1x / week

Maneuver targeting verification: Prelim and Final

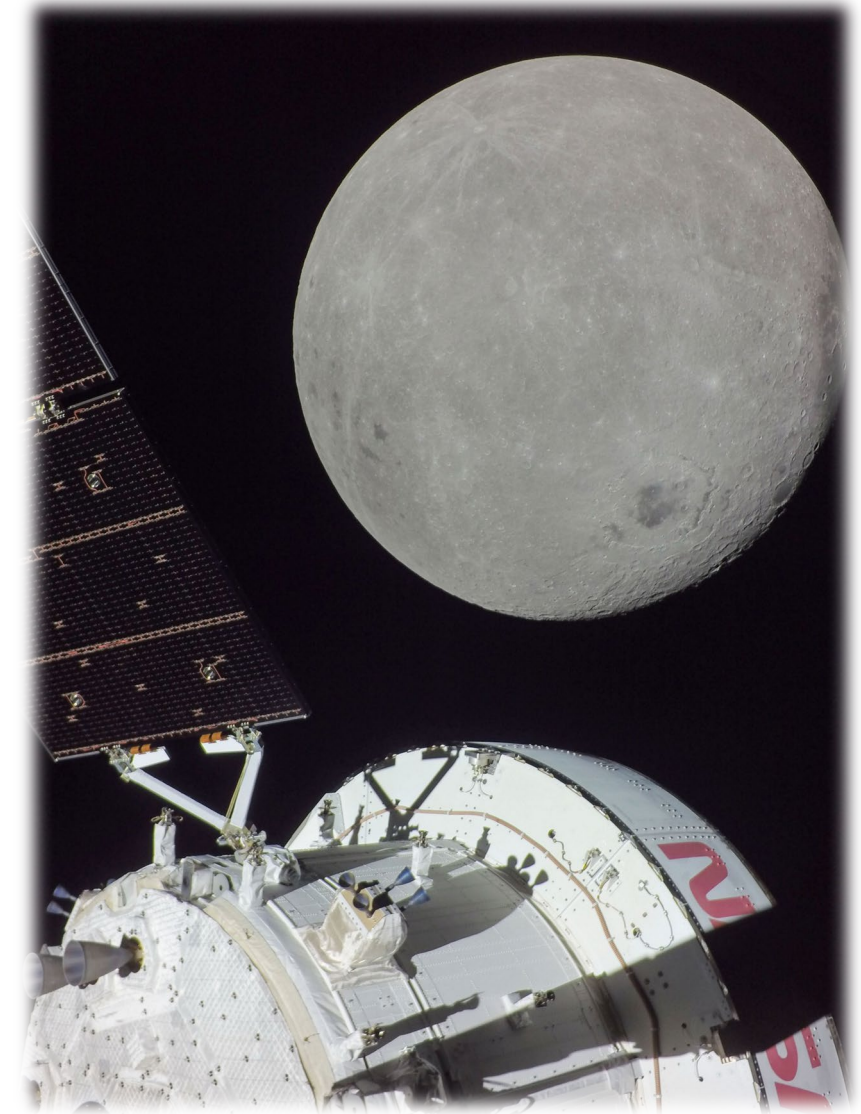
OD Verification: 1x / 2 weeks

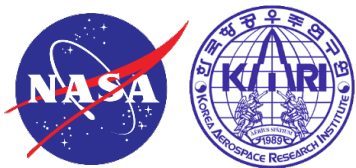
Maneuver targeting verification:
Prelim

KARI has gained lots of experience operating KPLO over the last 2 years, and NASA has full confidence in their independent operations capability

Benefits to the Artemis Program

- NASA will return humans to the surface of the Moon under the Artemis Program
 - Artemis II will be the first-time humans have flown beyond Low-Earth Orbit since 1972
- Data from ShadowCam and other KPLO instruments directly informing NASA decisions regarding Lunar exploration
- KPLO operations have provided valuable Lunar flight experience to NASA
 - Performed by the same Flight Control teams which fly the Artemis missions
 - Many lessons learned regarding tracking and modeling lunar trajectories
 - Extensive real-world testing experience for Artemis ground software
 - Conjunction screening experience with KPLO is informing future Artemis Program policies and ground rules





Backup

