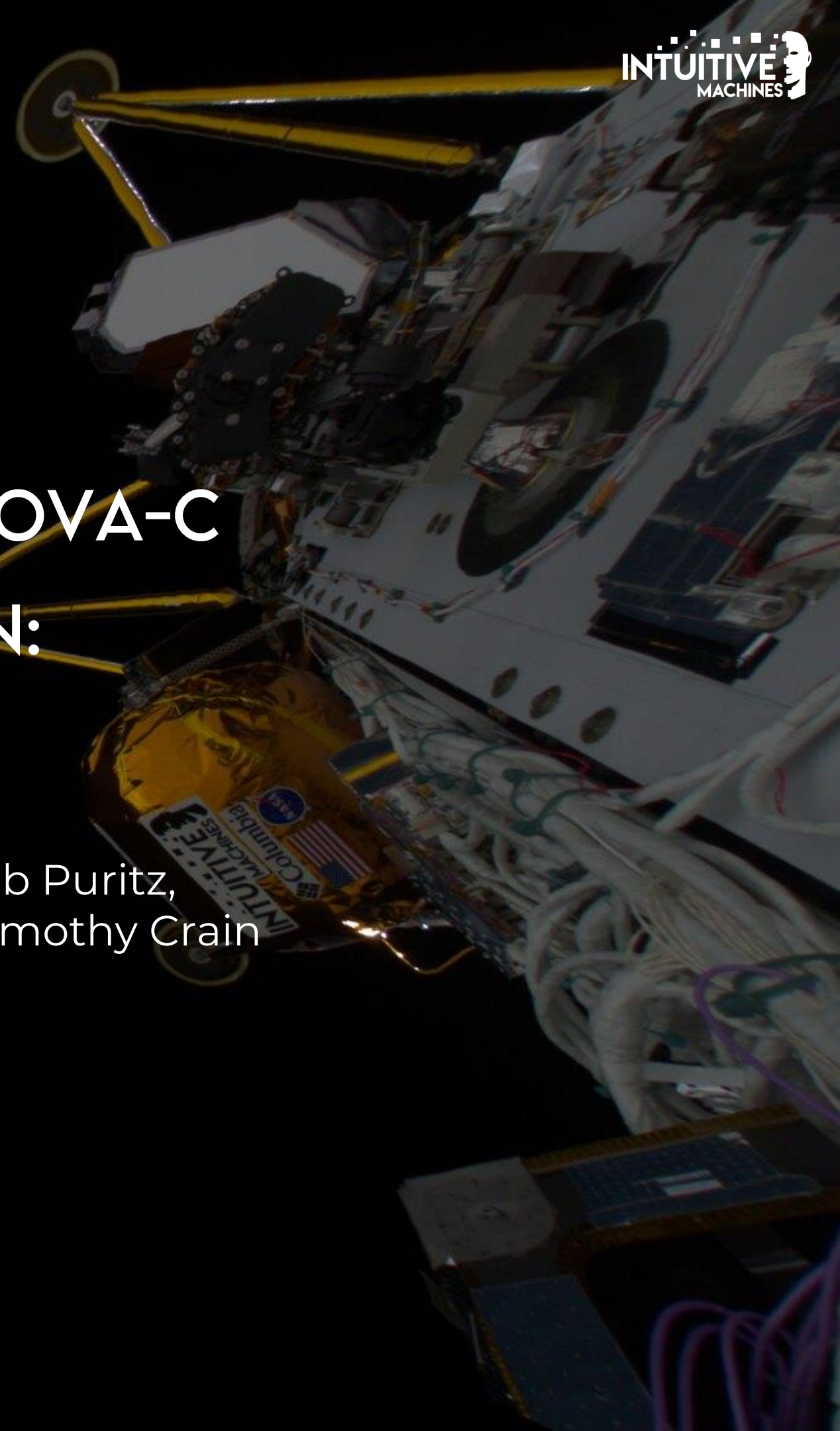




# SYNTHETIC LUNAR IMAGERY FOR NOVA-C SPACECRAFT OPTICAL NAVIGATION: IM-1, IM-2 MISSIONS AND BEYOND

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# AGENDA

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1. IM-1 and IM-2 Synthetic Imagery Process
2. IM-1 Imagery Comparisons
3. IM-2 Mission Deltas and Imagery Comparisons
4. Improvements for Future Missions
5. Questions

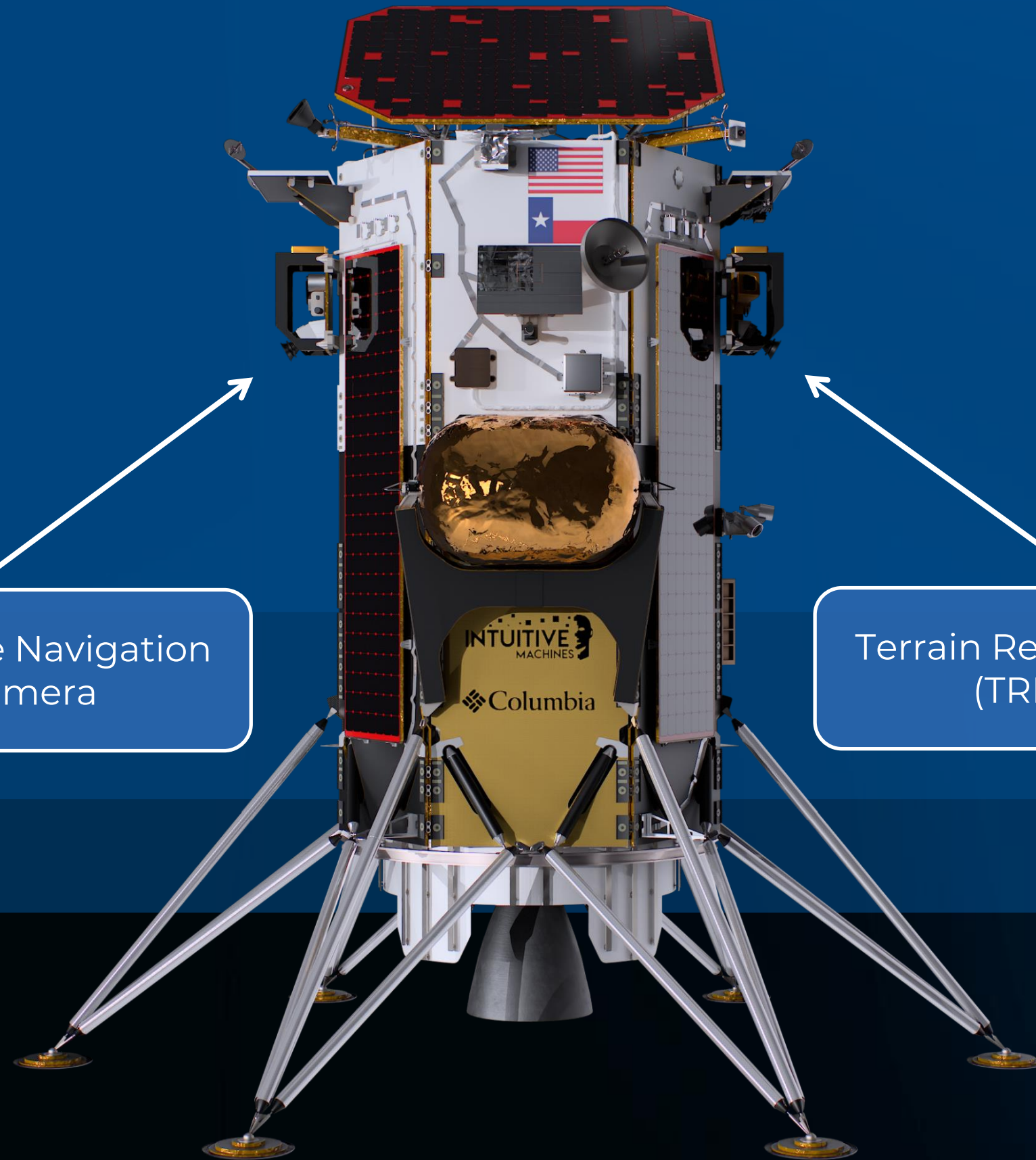
# NOVA-C NAVIGATION CAMERAS

## CAMERA SPECIFICATIONS

Parameter	TRN	HRN
Focal Length [mm]	6.5	16.2
Aperture Diameter [mm]	2.03	1.4
Aperture F#	F/8	F/5.2
Horizontal FOV [°]	47.35	19.96
Vertical FOV [°]	36.45	15.05
Diagonal FOV [°]	57.47	24.81
Sensor Size [pixels]	2592 × 1944	
Sensor Size [mm]	5.7 × 4.28	
Pixel Pitch [mm]	0.0022 × 0.0022	

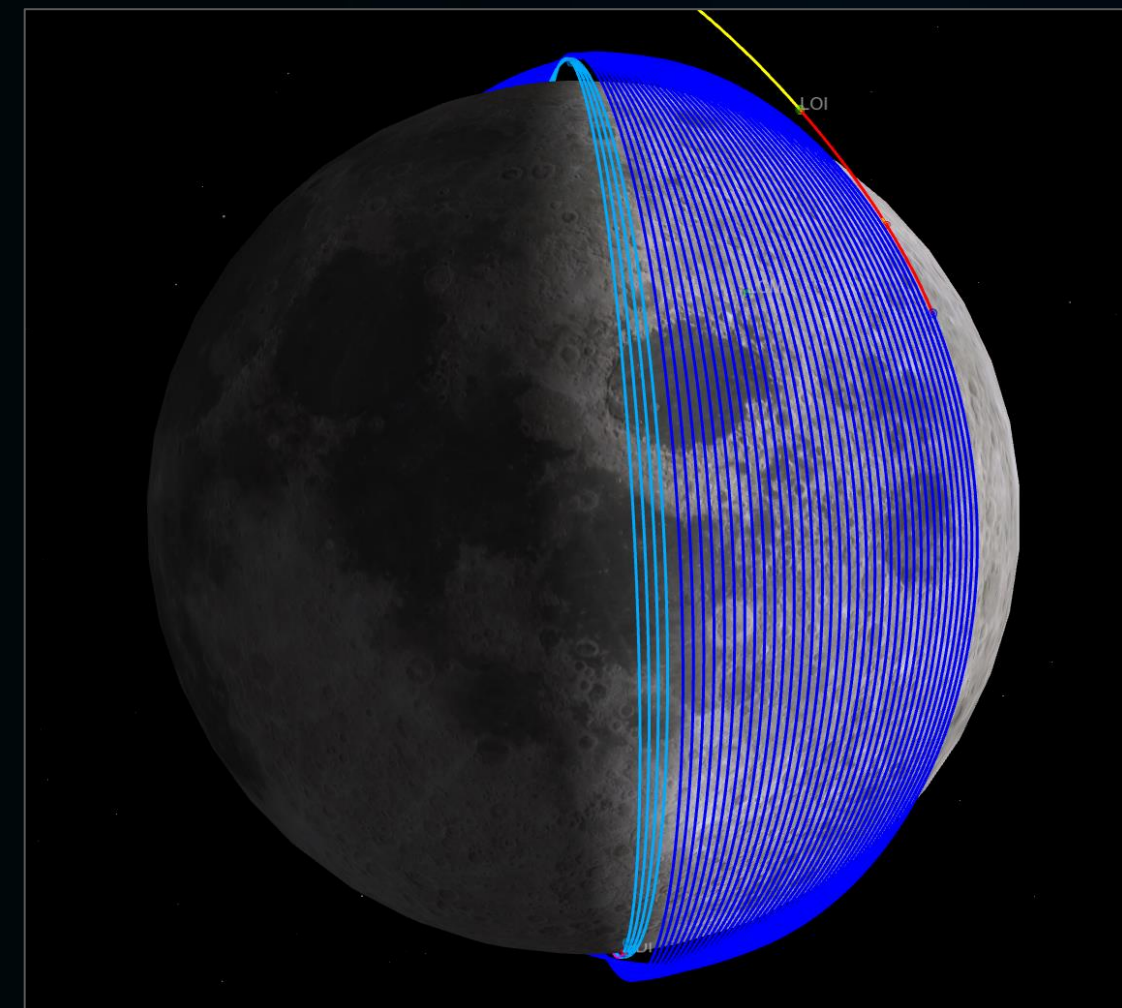
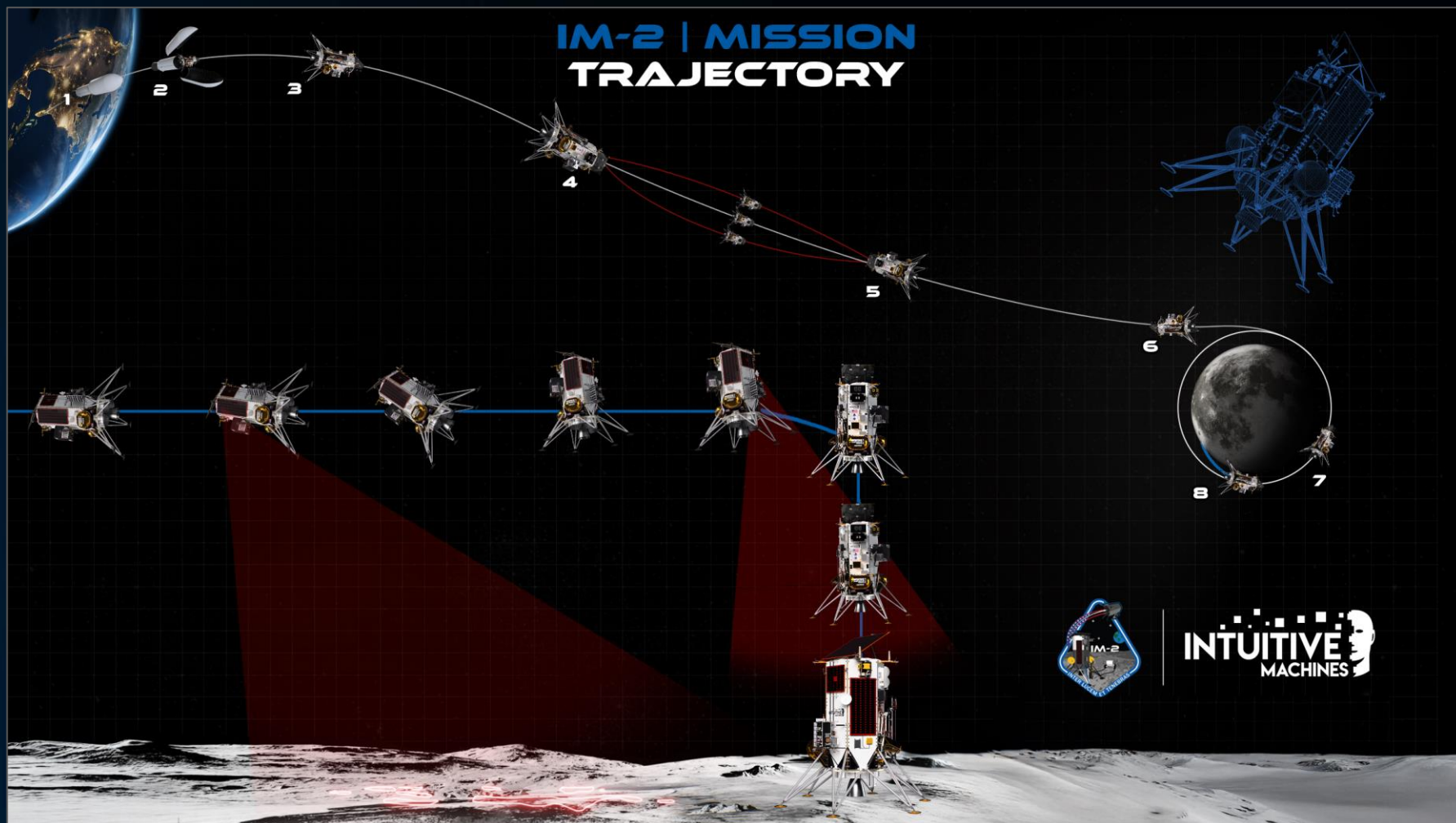
Hazard Relative Navigation (HRN) Camera

Terrain Relative Navigation (TRN) Camera

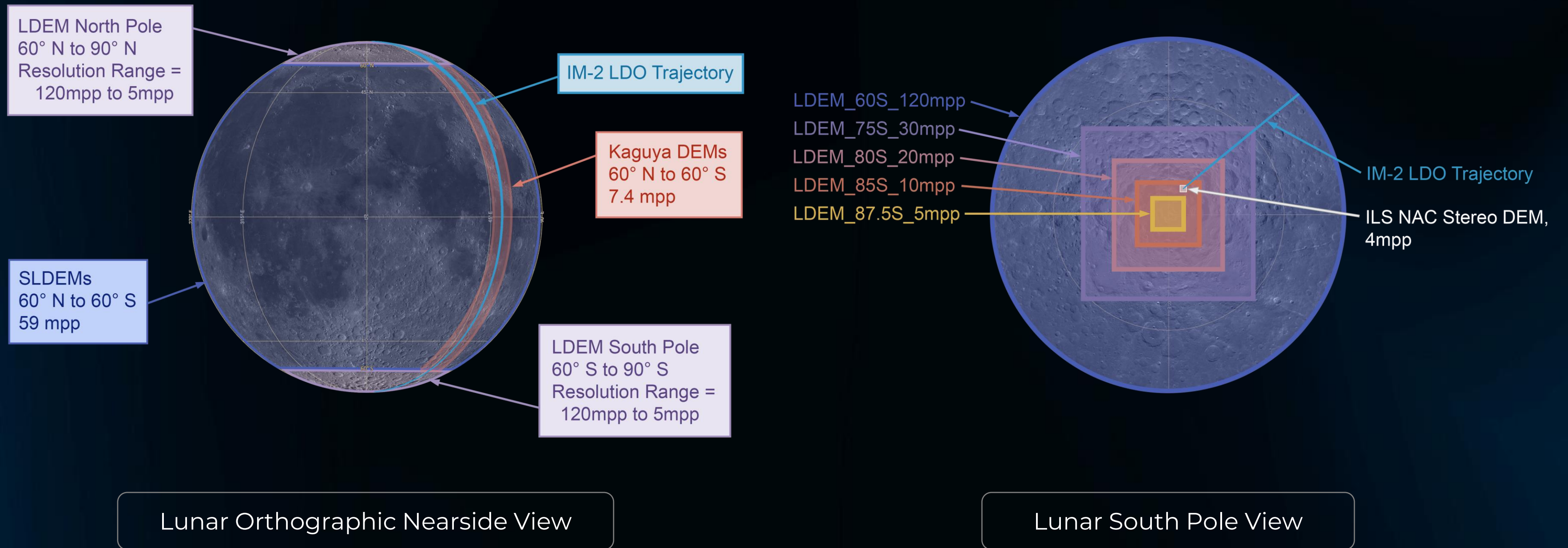


# IM-1 / IM-2 IMAGING PHASES

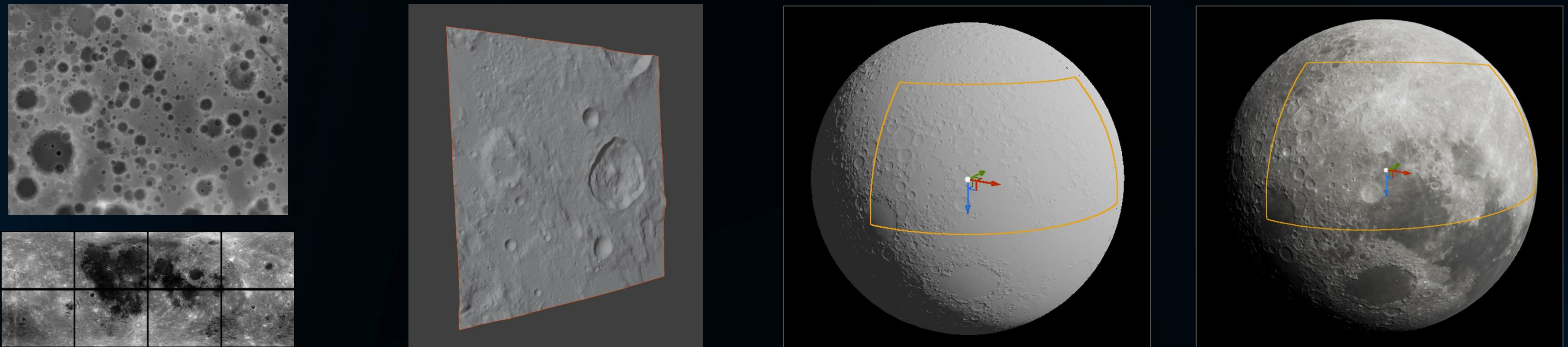
IMAGING PHASES	OPTICAL NAVIGATION SOFTWARE
Low Lunar Orbit (LLO)	Delta-POSITION (DPOS) and Line-Of-Sight-to-Surface (LOSS)
Lunar Descent Orbit (LDO)	DPOS and LOSS
Hazard Detection and Avoidance (HDA)	HDA



# IM-1 / IM-2 LUNAR DATA SOURCES



# SYNTHETIC IMAGERY PROCESS



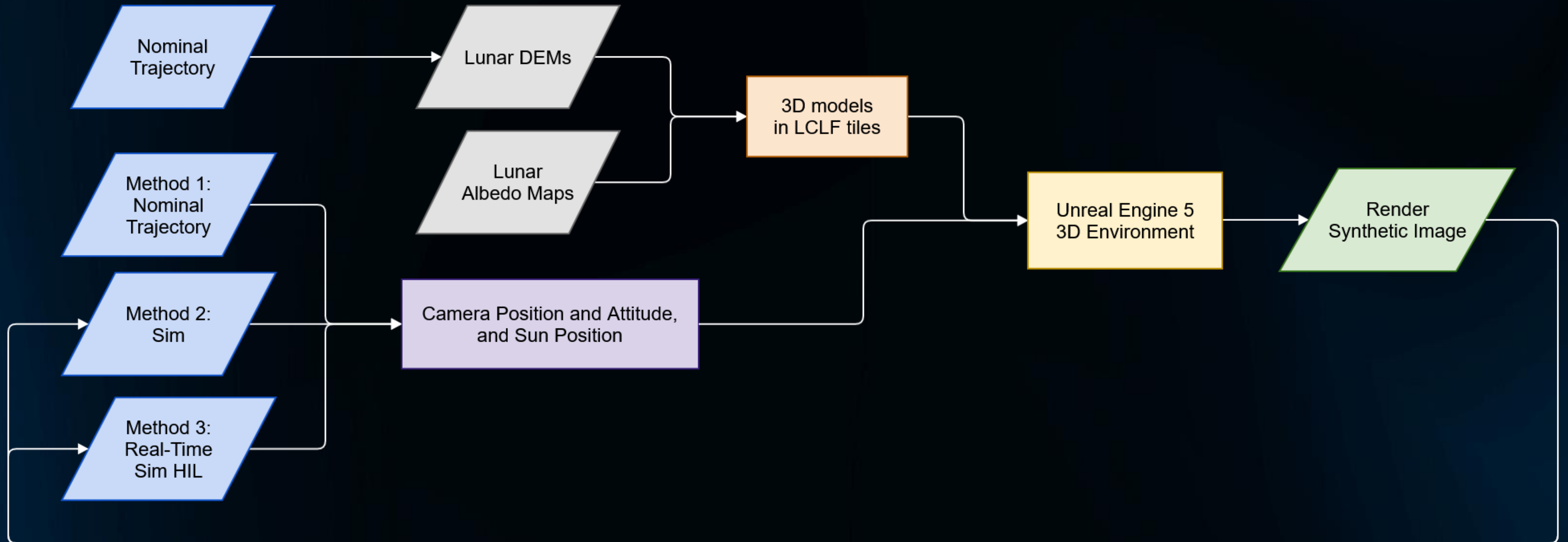
Lunar data sources:  
DEMs + albedo maps

3D models built using  
Blender Python + GDAL

3D models imported to  
Unreal Engine 5

Albedo map materials  
applied to 3D models

# RENDERING METHODS



# UP NEXT...

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1. IM-1 and IM-2 Synthetic Imagery Process
- 2. IM-1 Imagery Comparisons**
3. IM-2 Mission Deltas and Imagery Comparisons
4. Improvements for Future Missions
5. Questions

# IM-1 IMAGERY COMPARISON



IM-1 Mission TRN Image



Synthetic Image Recreation

# IM-1 IMAGERY COMPARISON



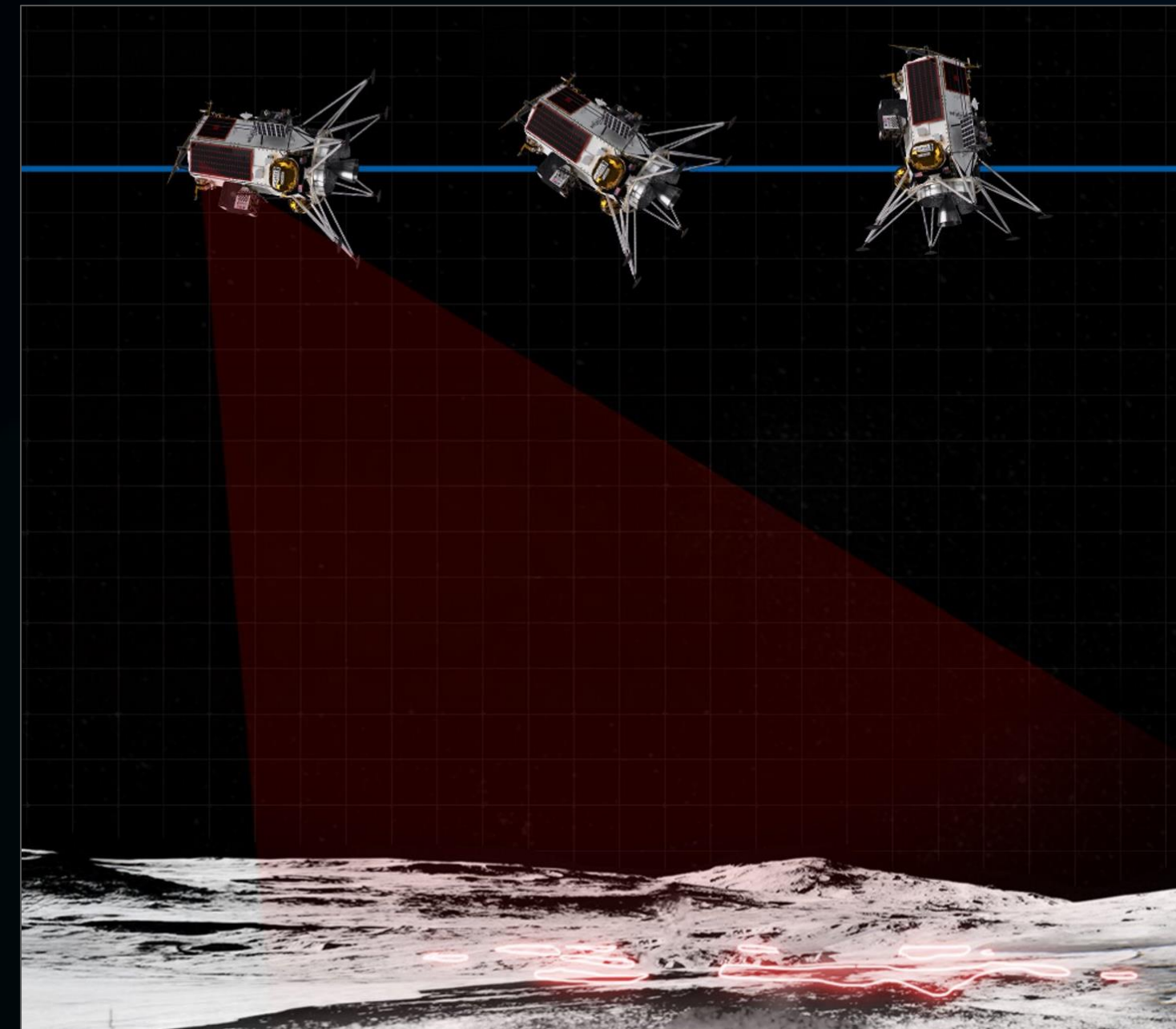
IM-1 Mission TRN Image



Synthetic Image Recreation

# IM-2 MISSION DELTAS

- Rendering with real-time sim HIL environment
- LOSS: new OpNav measurement on IM-2 Mission
- LOSS crater database
  - Generated by detecting craters in synthetic images
  - Stores craters as LCLF positions onboard
- During IM-2 Mission:
  - LOSS detects craters and matches to the database
  - Over 200 measurements accepted during LDO
  - Increases our confidence in synthetic imagery process



# IM-2 IMAGERY COMPARISON



IM-2 Mission HRN Image



Synthetic Image Recreation

# IM-2 IMAGERY COMPARISON



IM-2 Mission TRN Image



Synthetic Image Recreation

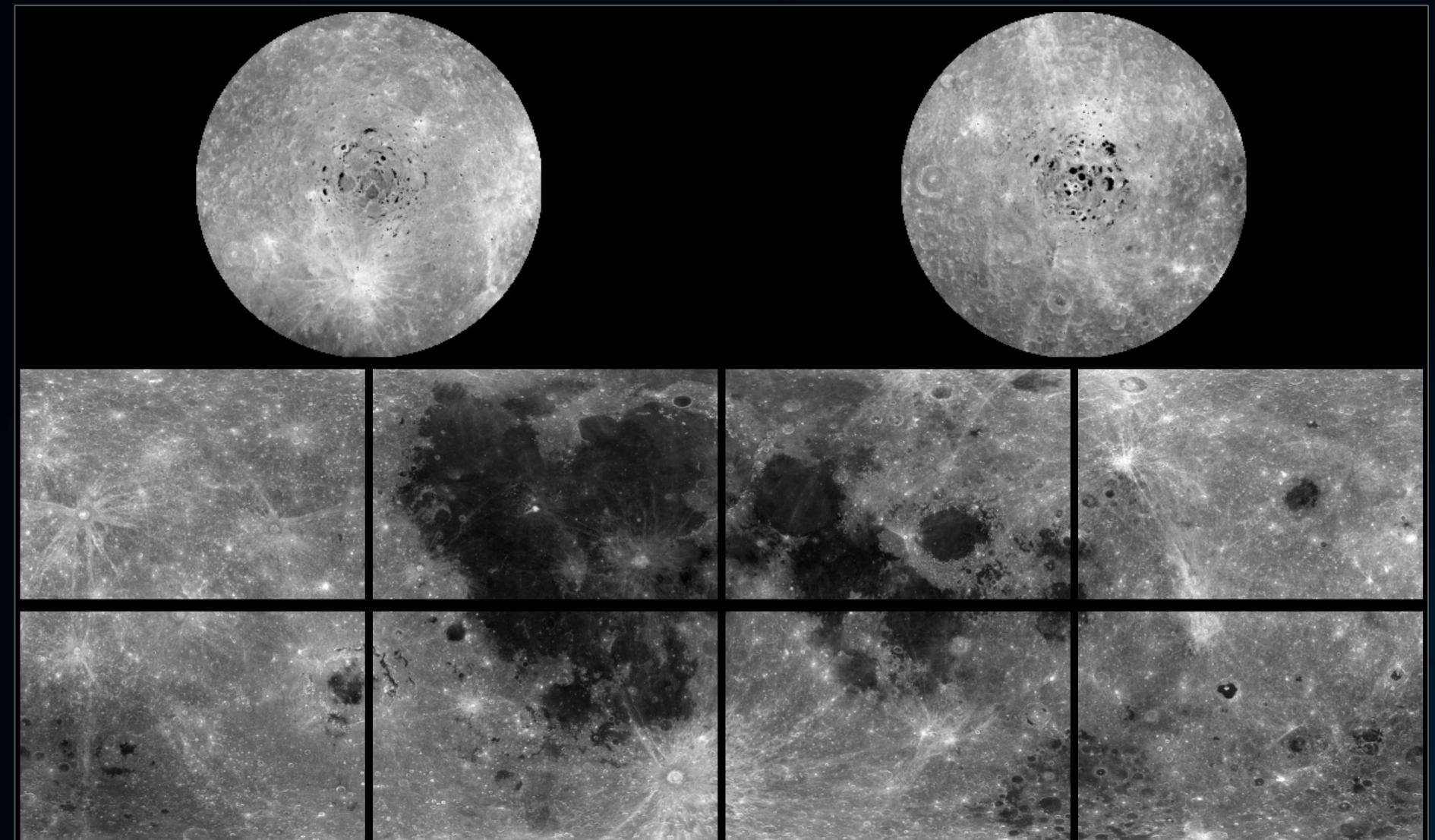
# ONGOING IMPROVEMENTS

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1. Albedo Maps
2. Lunar Reflectance Models
3. Lighting and Shadows
4. DEM Data Sources
5. Terrain for Low Altitude Imagery
6. Terrain Streaming Methods

# ALBEDO MAP SOURCE

- IM-1 / IM-2 albedo map
  - WAC Hapke Normalized Mosaic
  - 400 mpp resolution
  - Does not have polar regions
- New albedo map
  - WAC Empirically Normalized Mosaic Albedo Map
  - ~100 mpp resolution
  - Includes polar regions



LROC Team, [https://data.lroc.im-ldi.com/lroc/view\\_rdr/WAC\\_EMP](https://data.lroc.im-ldi.com/lroc/view_rdr/WAC_EMP)

# ALBEDO MAP COMPARISONS



Synthetic Image:  
Low-Res Albedo

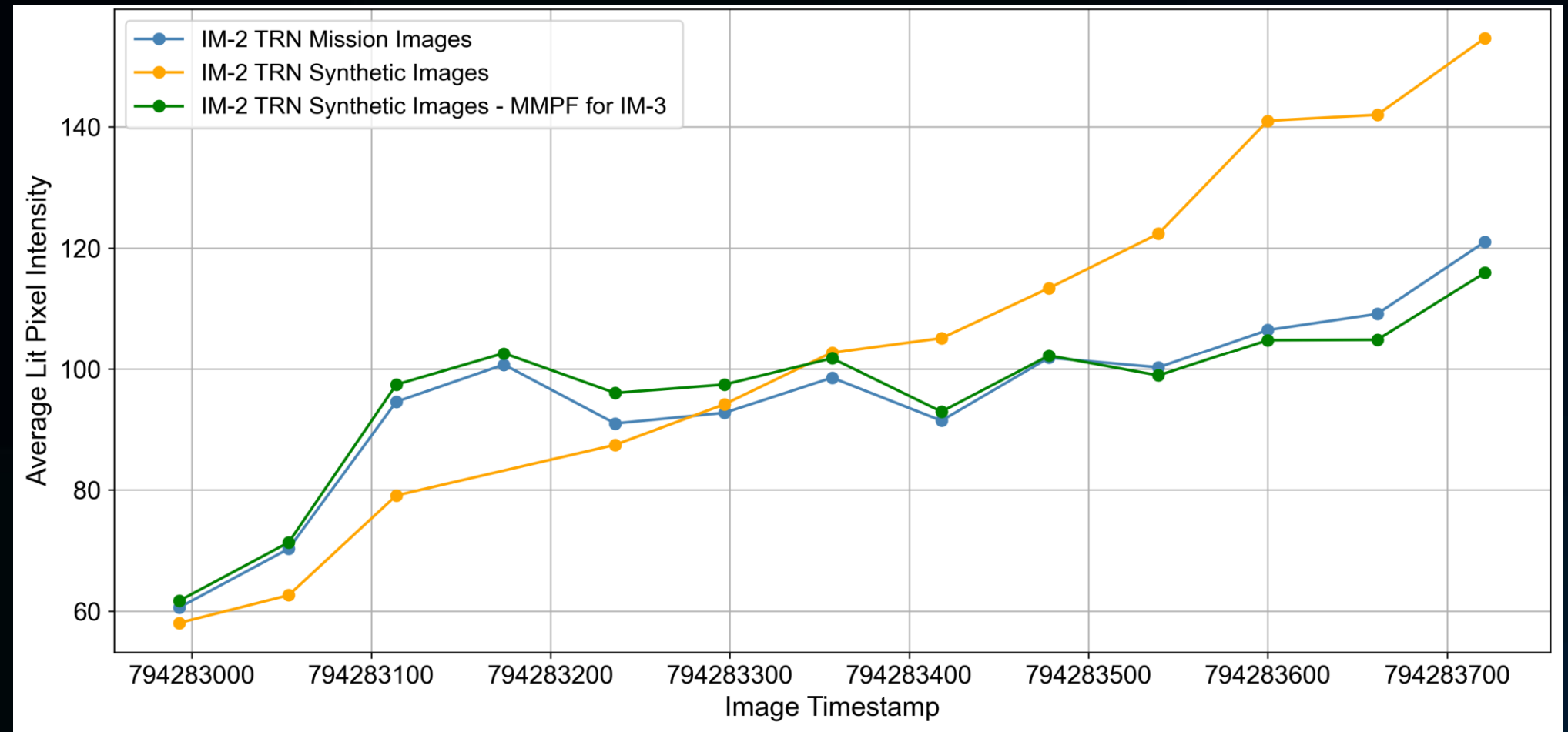
IM-2 Mission TRN Image

Synthetic Image:  
High-Res Albedo

# LUNAR REFLECTANCE MODELS

- Bidirectional Reflectance Distribution Function (BRDF) model called the “Mean Moon Photometric Function”
- Implemented using Unreal’s material editor in the High Level Shading Language (HLSL), layered with albedo maps

Synthetic Imagery BRDF Comparisons



Mature Highland Coefficients

Coefficient	Value
$B_0$	-1.480
$B_1$	-0.00008353
$B_2$	0.01296
$B_3$	-0.2378
$B_4$	0.5561
$B_5$	0.6637
$B_6$	-0.4399

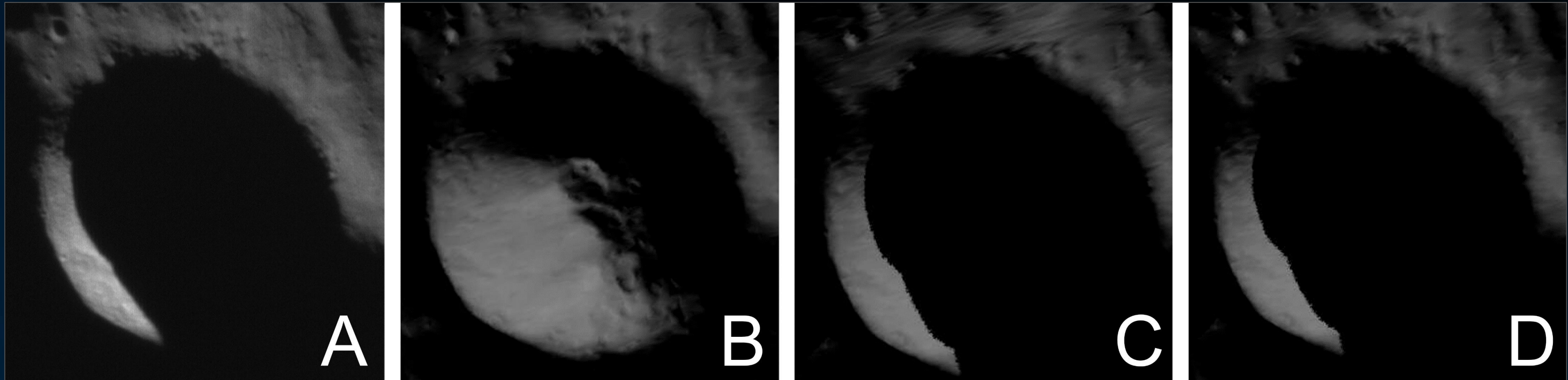
A. K. Boyd et al.,(2019)

Mean Moon Photometric Function

$$\frac{I}{F} = \frac{\cos(\iota)}{\cos(\iota) + \cos(\epsilon)} e^{B_0 + B_1 g^2 + B_2 g + B_3 g^{\frac{1}{2}} + B_4 \cos(\epsilon) + B_5 \cos(\iota) + B_6 \cos^2(\iota)}$$

A. K. Boyd et al., “LROC NAC Global Photometry: Terrain Types and Phase Curves” (2019)

# LIGHTING AND SHADOWS



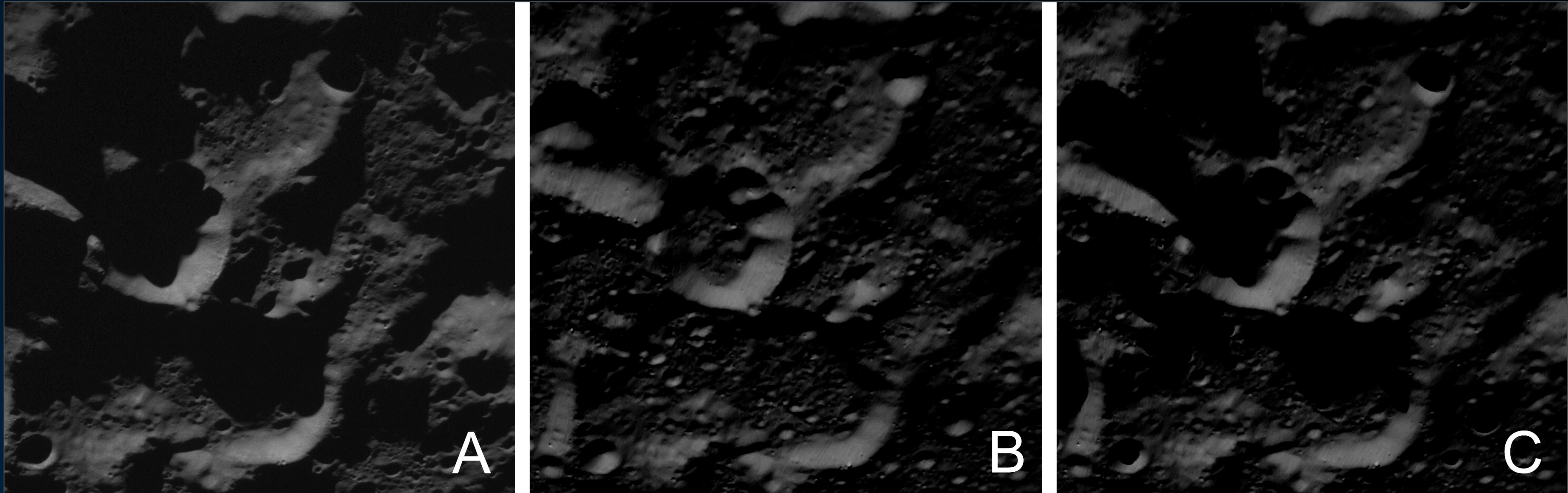
IM-2 Mission

UE 5.0 Render

UE 5.5 Render

UE 5.5 Render  
Custom Settings

# LIGHTING AND SHADOWS



IM-2 Mission

UE 5.0 Render

UE 5.5 Render  
Custom Settings

# CONCLUSION

- Synthetic imagery process critical to OpNav development and testing
- IM-2 mission had over 200 LOSS measurements
- IM-1 and IM-2 mission image comparisons
  - Strong visual correlations
  - Identified areas for improvements
- Ongoing improvements for IM-3 and future missions





# THANK YOU

Q&A

