National Aeronautics and
Space Administration

Digital Proving Ground: VIPER Rover Simulator (RSIM)

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14 November 2024

VIPER Mission

Lunar south pole

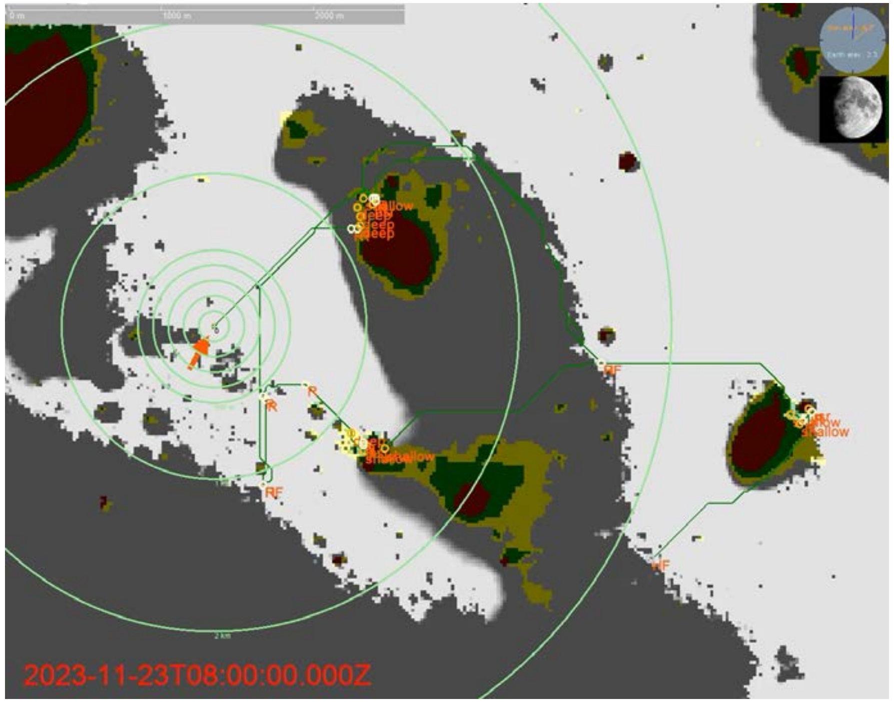
- Commercial launch and landing
- 100+ day mission (including extended survival periods)
- Up to 20 km total drive

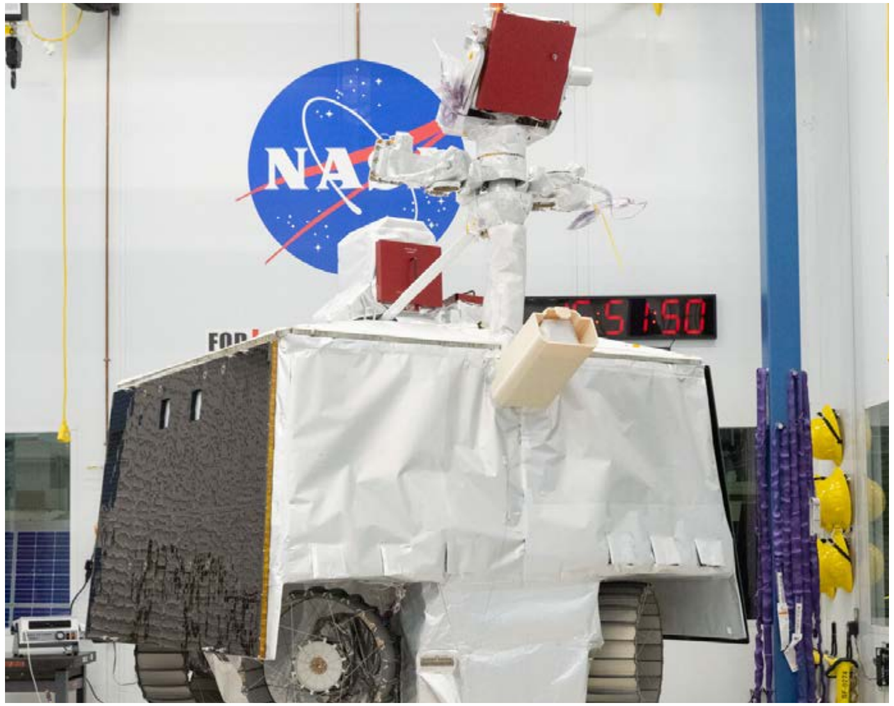
Science objectives

- Characterize distribution and physical state of volatiles (water ice, etc)
- Provide data to evaluate the potential for lunar in-situ resource utilization

Unique challenges

- Dynamic environment: light + shadows
- Real-time mission ops and science
- Prospecting & "speed made good"





VIPER's Digital Proving Ground Needs

Mission Design

- VIPER is a new type of robotic mission with interactive science
- Dynamic lunar environment, high ops cadence, traverse focus
- ConOps and OpsCon required iterative development (many cycles)

Flight Software

- Agile software engineering required continuous integration & testing
- Rapid technology development required prototyping environment
- Some Requirements V&V could only be done in simulation

Mission Operations

- Agile ops development required rapid prototyping and iteration
- New ops constructs (e.g., "Drive Team") and ops products (procedures, flight rules, etc) required iterative refinement via simulation
- Effective mission ops training is exceptionally important given short mission duration and highly uncertain lunar surface environment

VIPER “RSIM”

1. High-quality lunar lighting

- Direct/indirect sun, “Earth-shine”, rover lights
- Coherent backscatter (“opposition effect”)

2. High-fidelity camera models

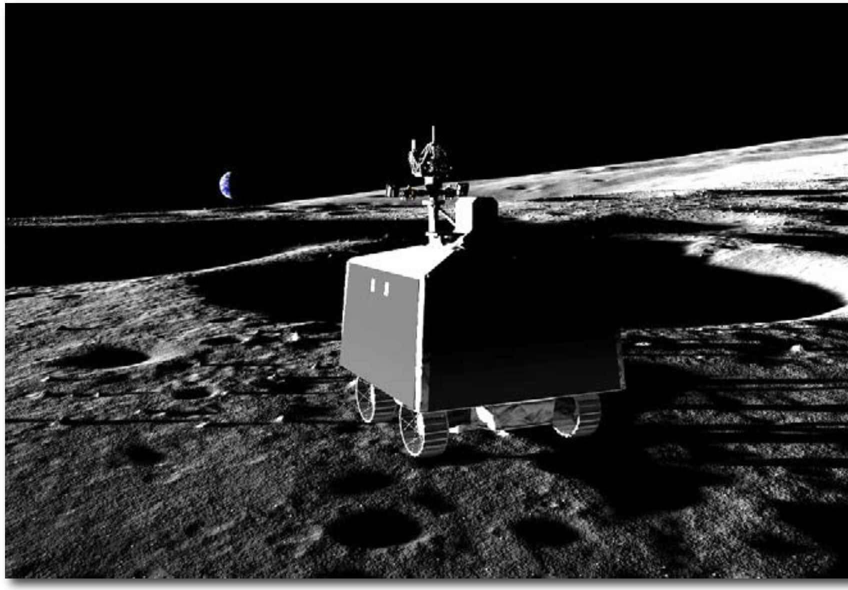
- Exposure, distortion, flare, fixed pattern noise, pixel defects, bit depth, read noise, etc.
- Tuned using NASA Ames “Lunar Lab” tests with camera/light EDUs

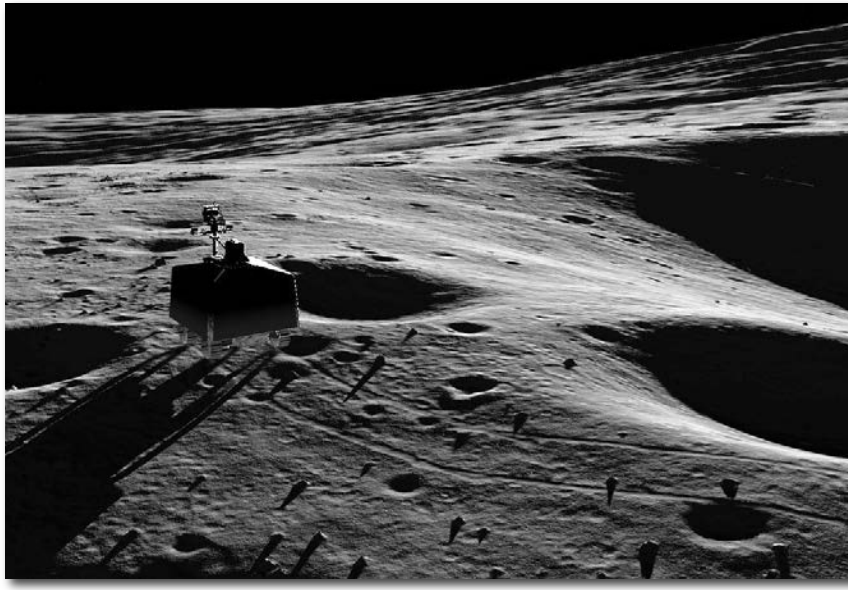
3. Real-time slip modeling

- Driving on unconsolidated soil
- Tuned using NASA Glenn “SLOPE” tests with mobility EDU

4. High-resolution lunar terrain models

- 1 m/pix DEM (photoclinometry, many images)
- 4 cm/pix synthetic DEM (science-based)





1. High-Quality Lunar Lighting

NASA Ames "Lunar Lab"

- High-fidelity surface appearance testbed
- Highlands: 12 tons of LHS-1 simulant in a 4x20 meter sandbox
- Mare: 8 tons of JSC-1A simulant in a 4x4 meter sandbox
- Terrain can be shaped and dusted to mimic micro-meteorite surface texture

Experimental setup

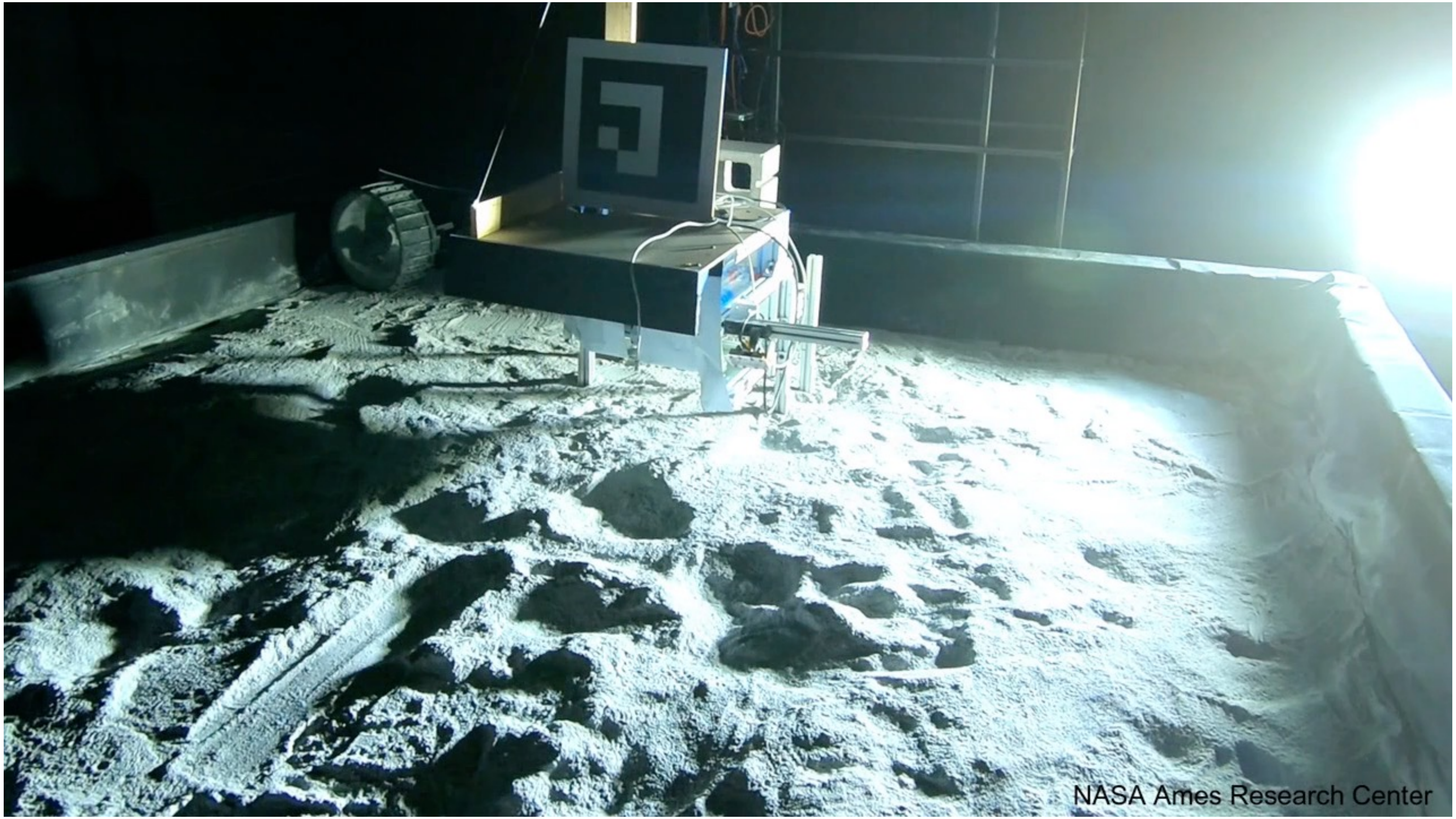
- Sun simulators for lunar polar lighting
- Sliding gantry provides non-contact data collection for optical sensors
- High accuracy (survey grade) lidar and positioning system for ground truthing

Simulated polar lighting on LHS-1 terrain

Appearance of VIPER rover wheel and tracks

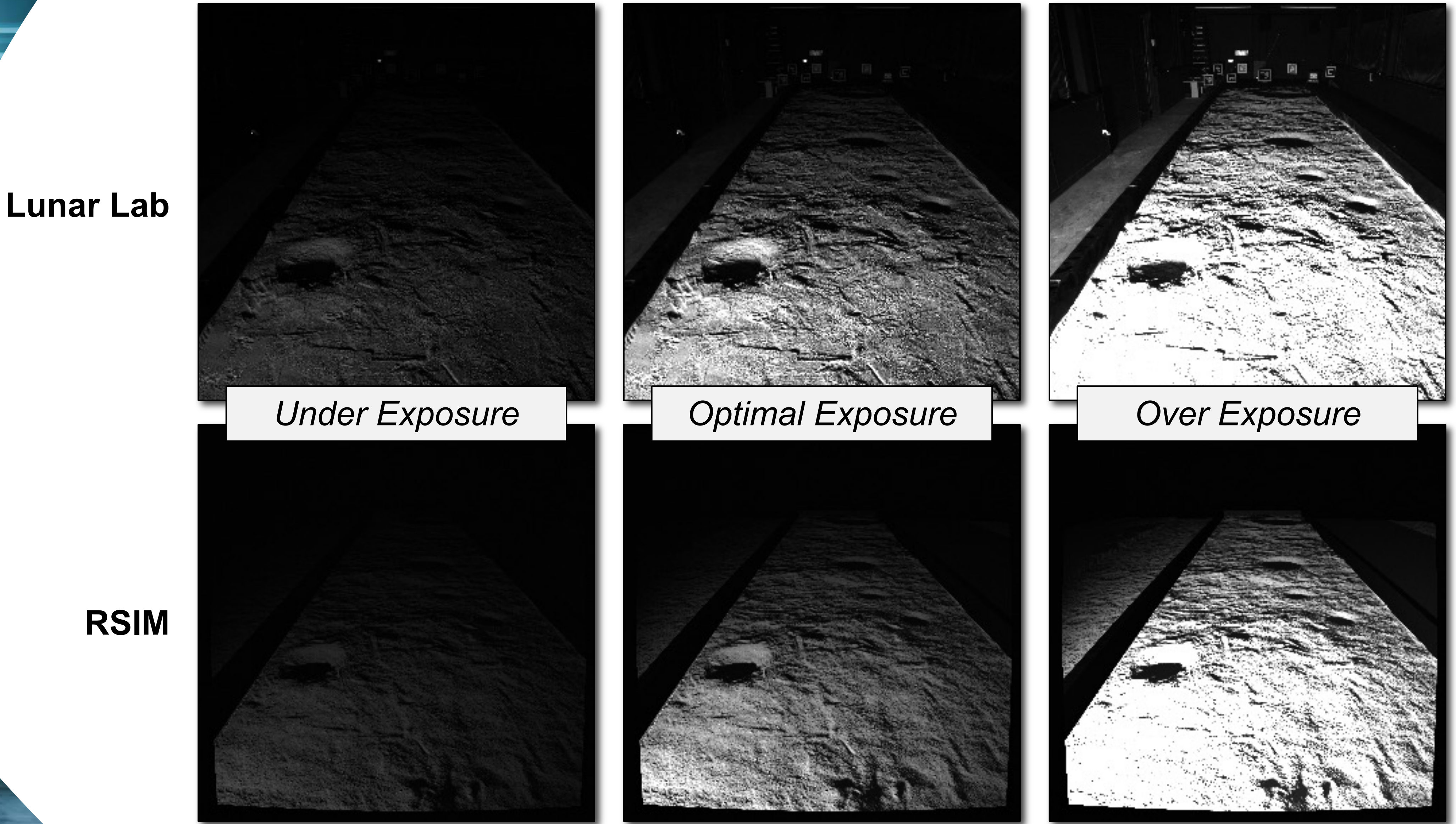
Sliding gantry over LHS-1 terrain

1. High-Quality Lunar Lighting



4m x 19m sandbox with 19 tons of LHS-1 lunar regolith simulant

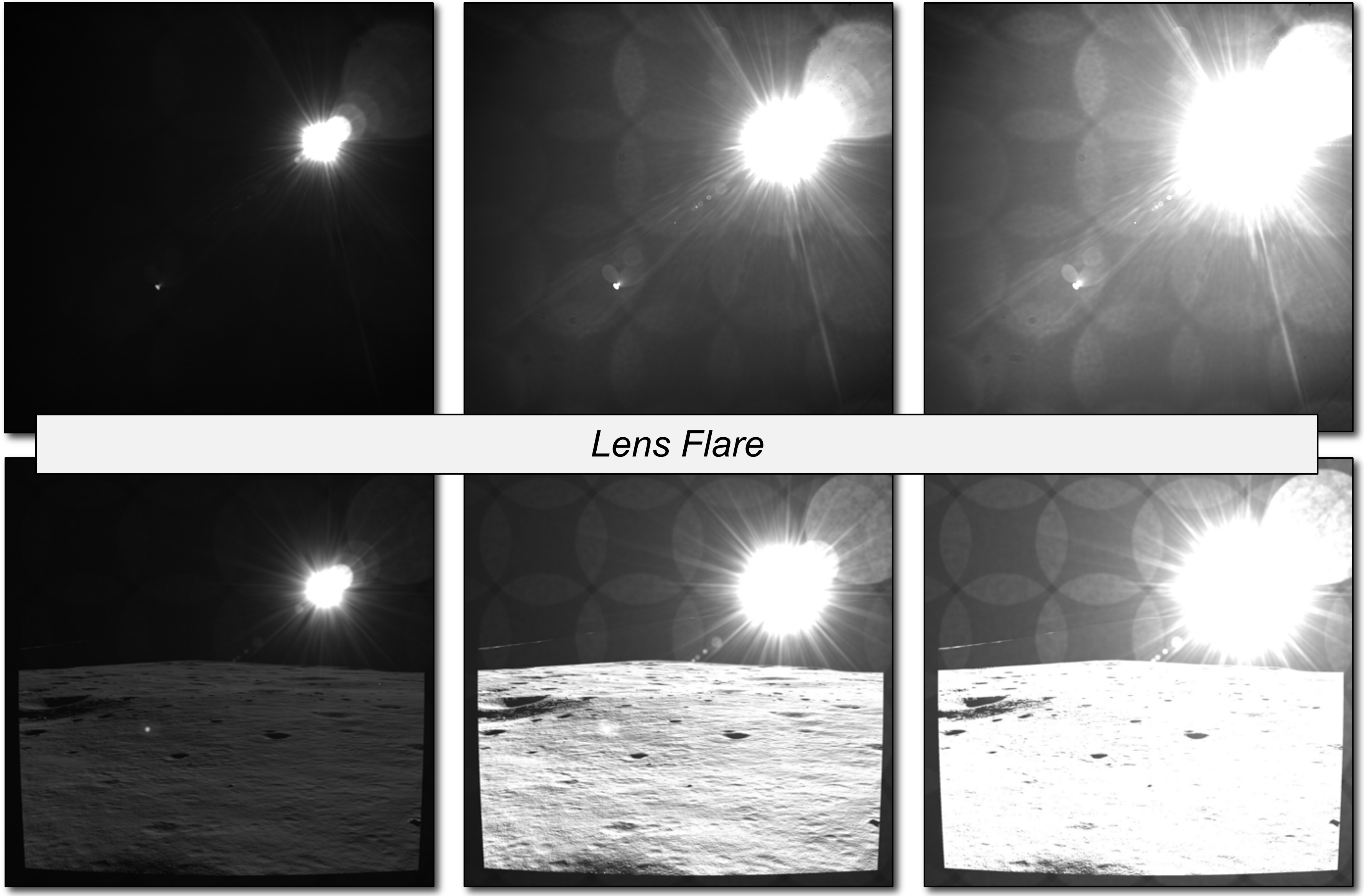
2. High-fidelity Camera Models



2. High-fidelity Camera Models

Lunar Lab

RSIM



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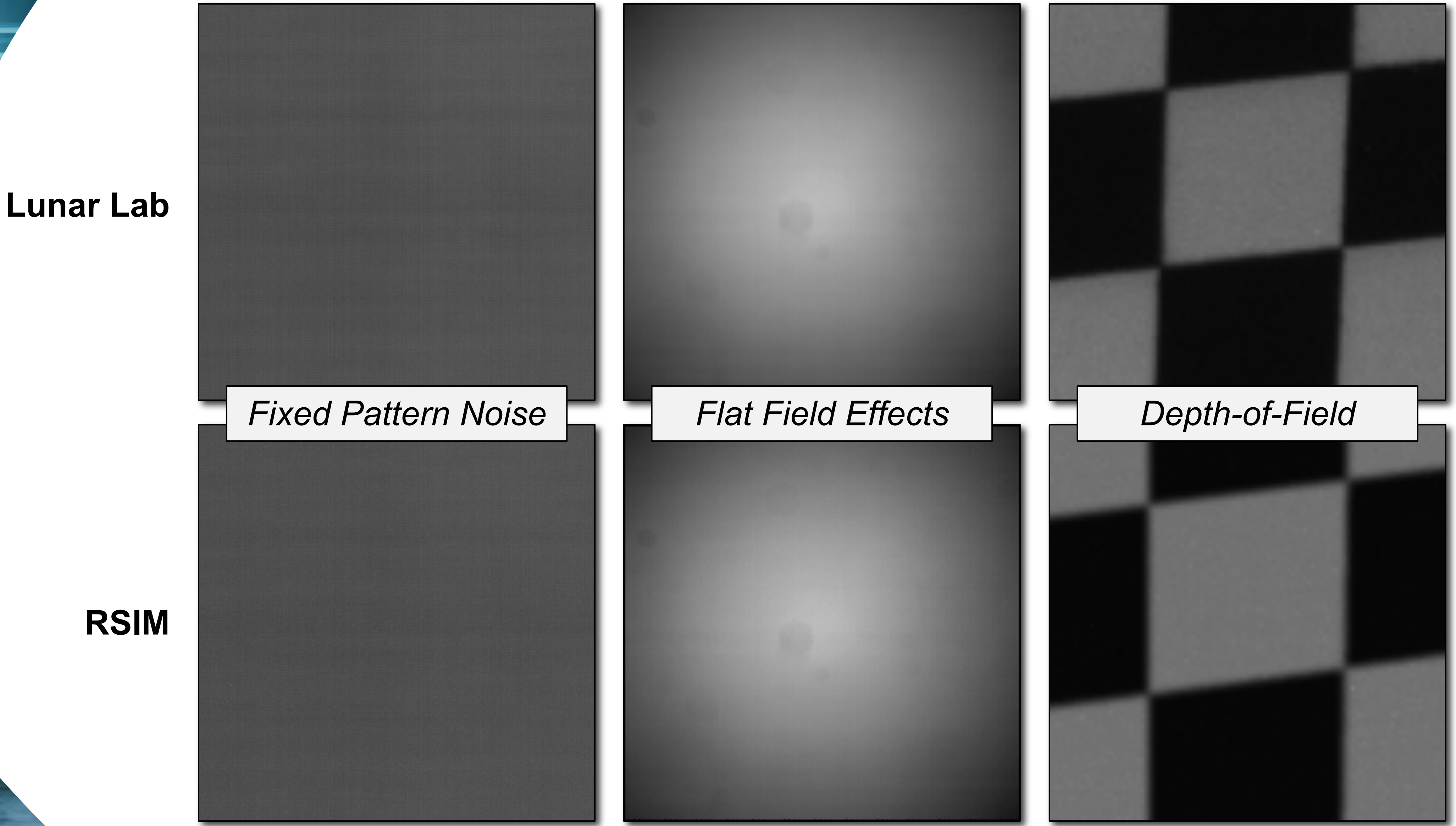


3. Real-time Slip Modeling

RSIM Rover Physics

- Approximate terramechanics of driving on unconsolidated soil
- Slip compliance and friction modulated on a per-wheel basis to account for compaction and rocks

SLOPE Lab (GRC)

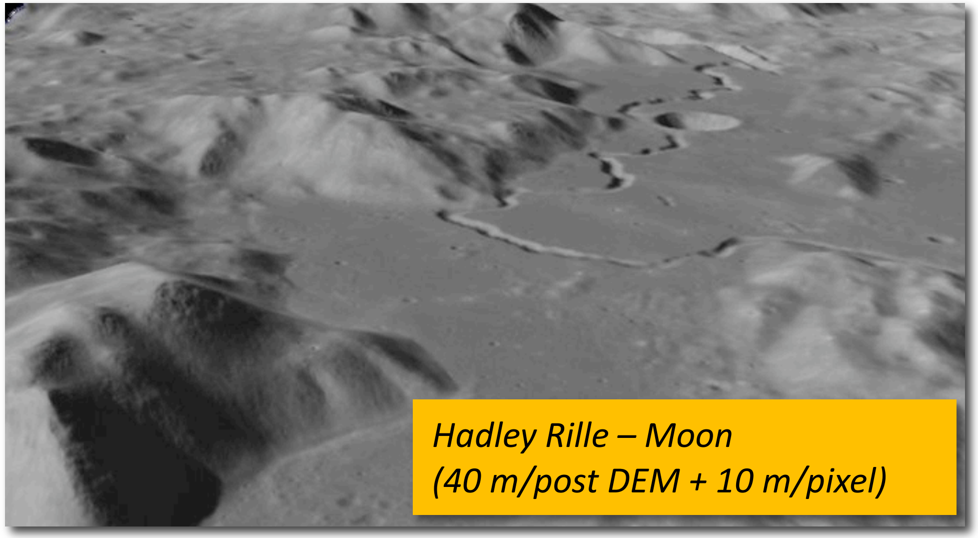
4. High-resolution Terrain Models

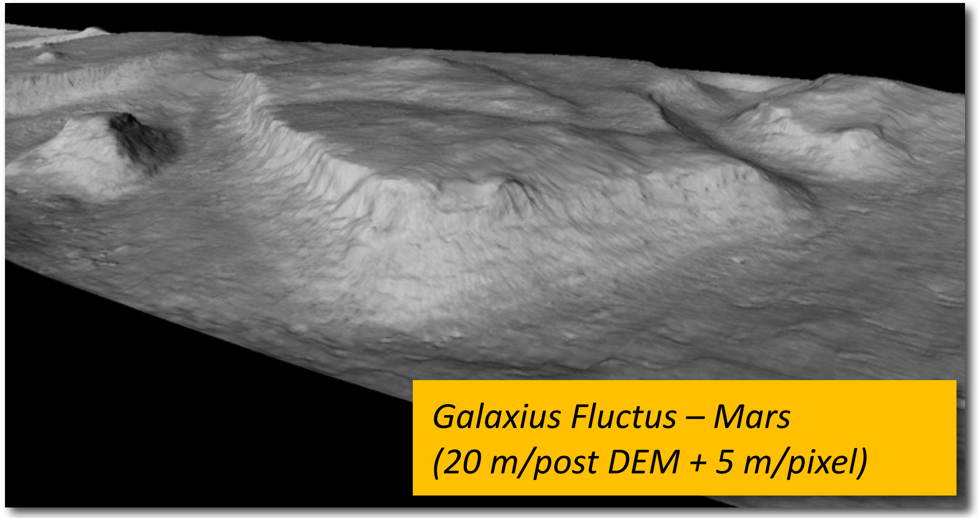
Ames Stereo Pipeline

- Command-line photogrammetry tools (including bundle adjustment, albedo reconstruction, etc.)
- C++ code hosted on GitHub (Apache 2 license)
- Linux and macOS binaries
  stereopipeline.readthedocs.io

Planetary data

- Apollo Metric Camera
- LRO Camera (LROC-NA)
- Mars High Resolution Imaging Science Experiment (HiRISE)
- Mars Orbiter Camera (MOC)
- MRO Context Camera (CTX)


Hadley Rille – Moon
(40 m/post DEM + 10 m/pixel)


Galaxius Fluctus – Mars
(20 m/post DEM + 5 m/pixel)

Lunar Digital Elevation Models (DEM)

Ames Stereo Pipeline

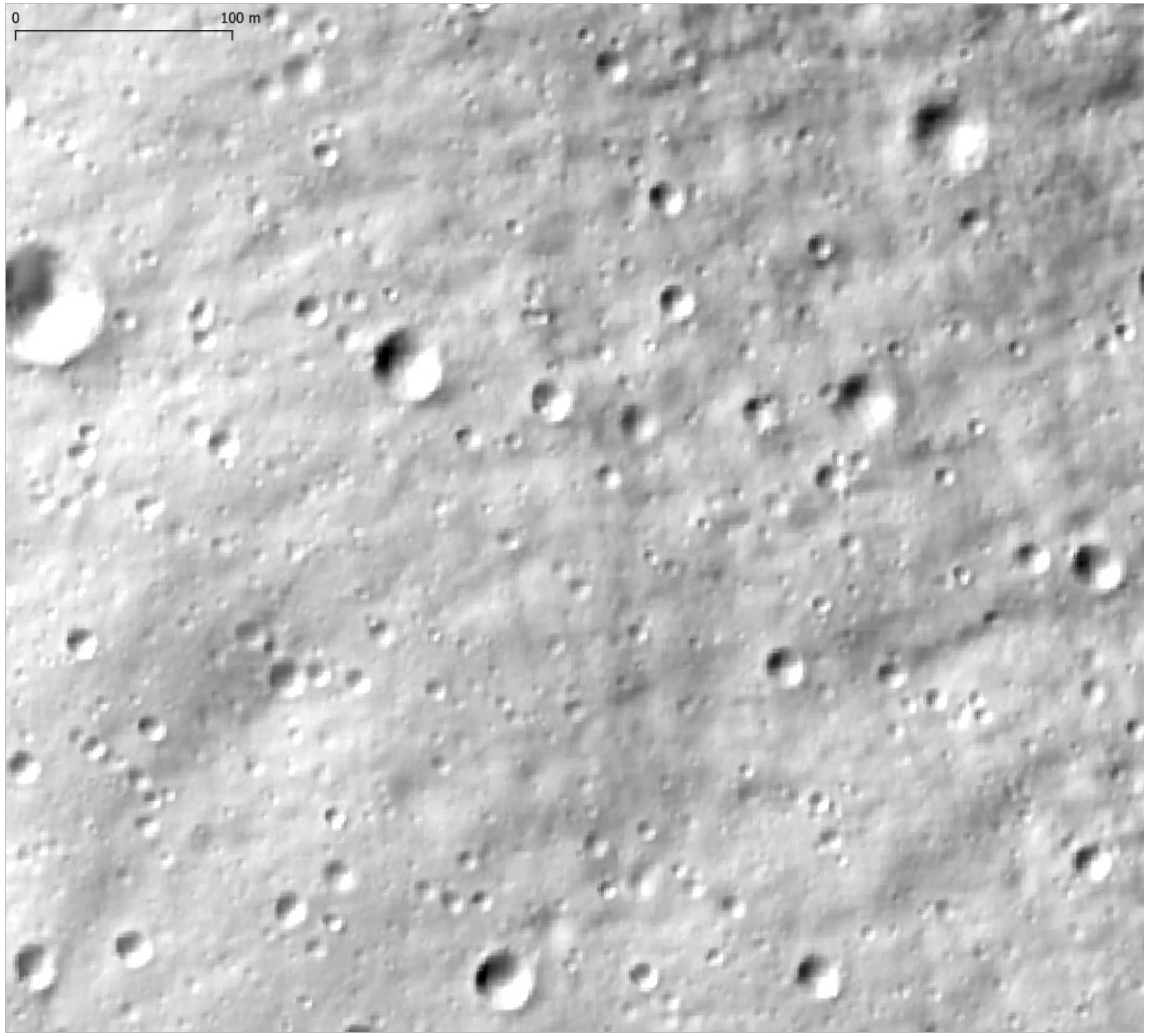
- LRO laser altimeter (LOLA) yields DEMs with **5 m/pixel** (mostly interpolated)
- Combine with long baseline stereo images (LROC-NA) yields DEMs with **3 m/pixel**

DEM based on LRO LOLA (5 m/pixel)

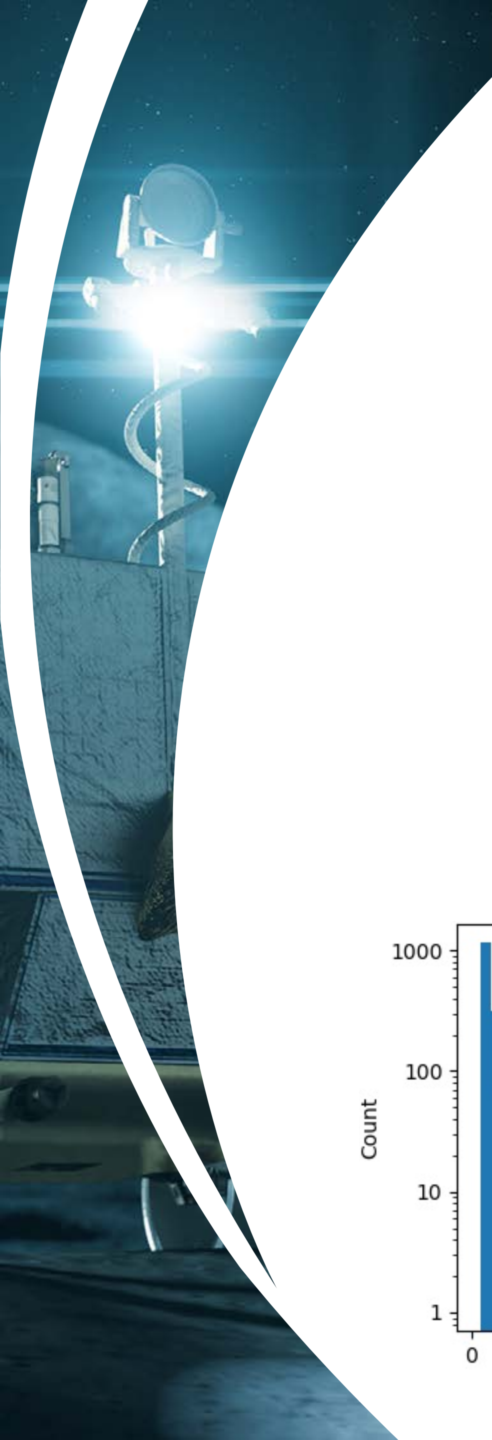
Lunar Digital Elevation Models (DEM)

Ames Stereo Pipeline

- **Photoclinometry** ("shape from shading")
- Estimate slope of each pixel from its shading in multiple images
- Combine dozens (or hundreds!) of images to model lunar surface at **1 m/pixel**



Ames Stereo Pipeline photoclinometry (1 m/pixel)



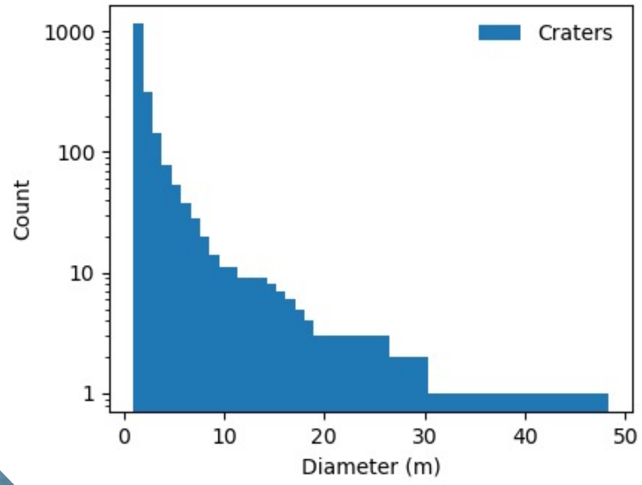
VIPER Synthetic Terrain Tools

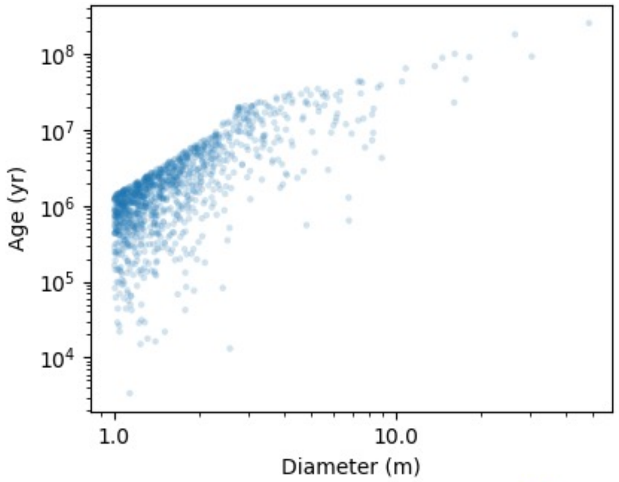
Objective

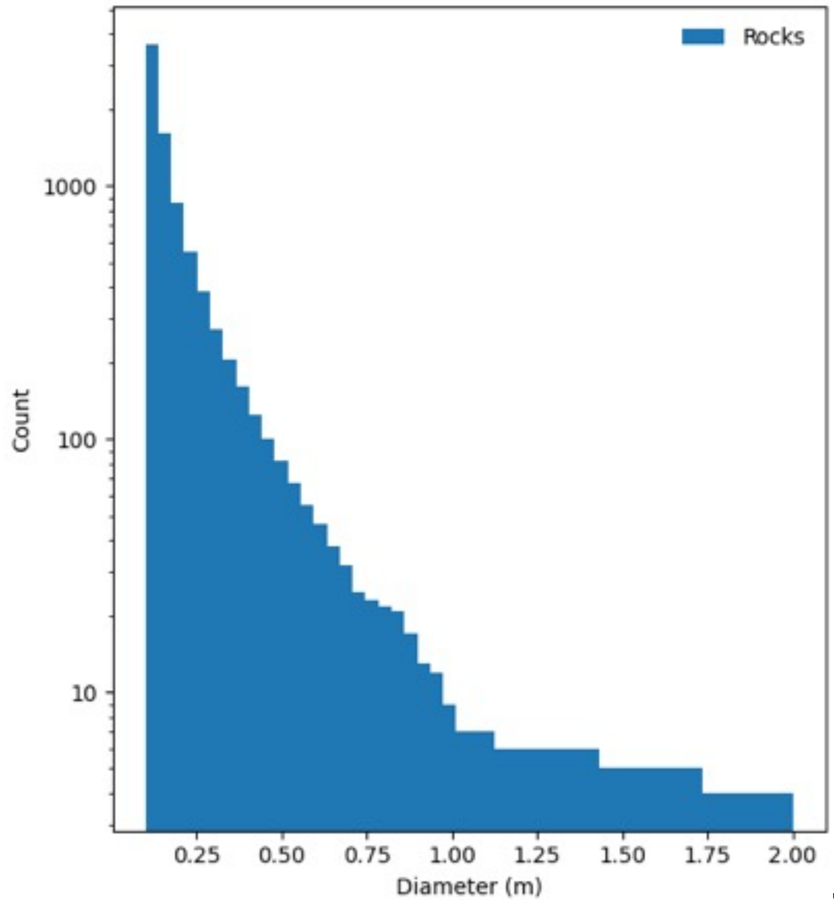
- Produce **scientifically plausible,** very high-resolution (**4 cm/pixel**) DEMs

Approach

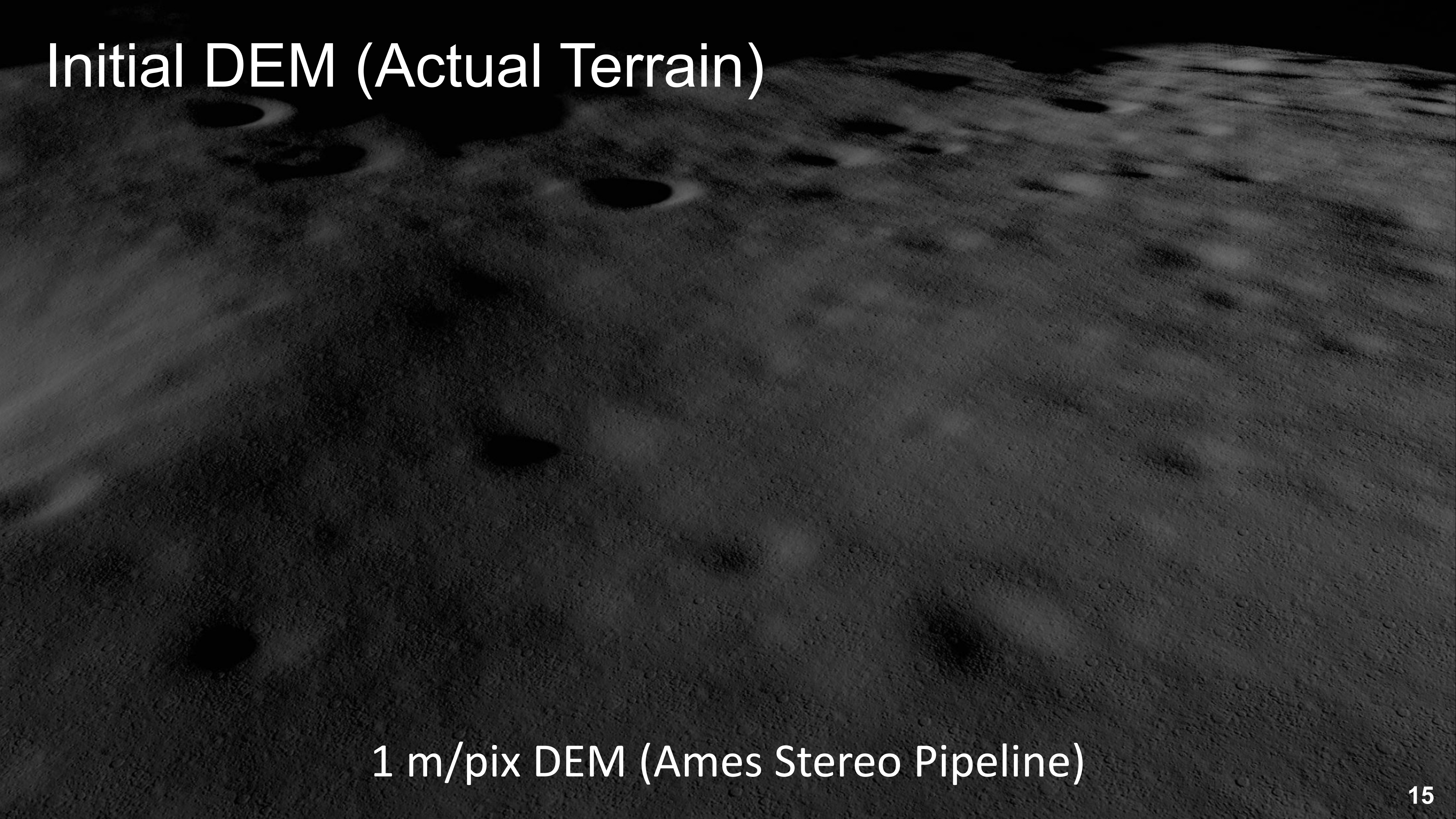
- Begin with lunar DEM (e.g., 1 m/pixel)
- Up-scale DEM via fractal synthesis
- Add synthetic craters and rocks based on size-frequency distribution studies
- Apply age effects (e.g., crater shape)





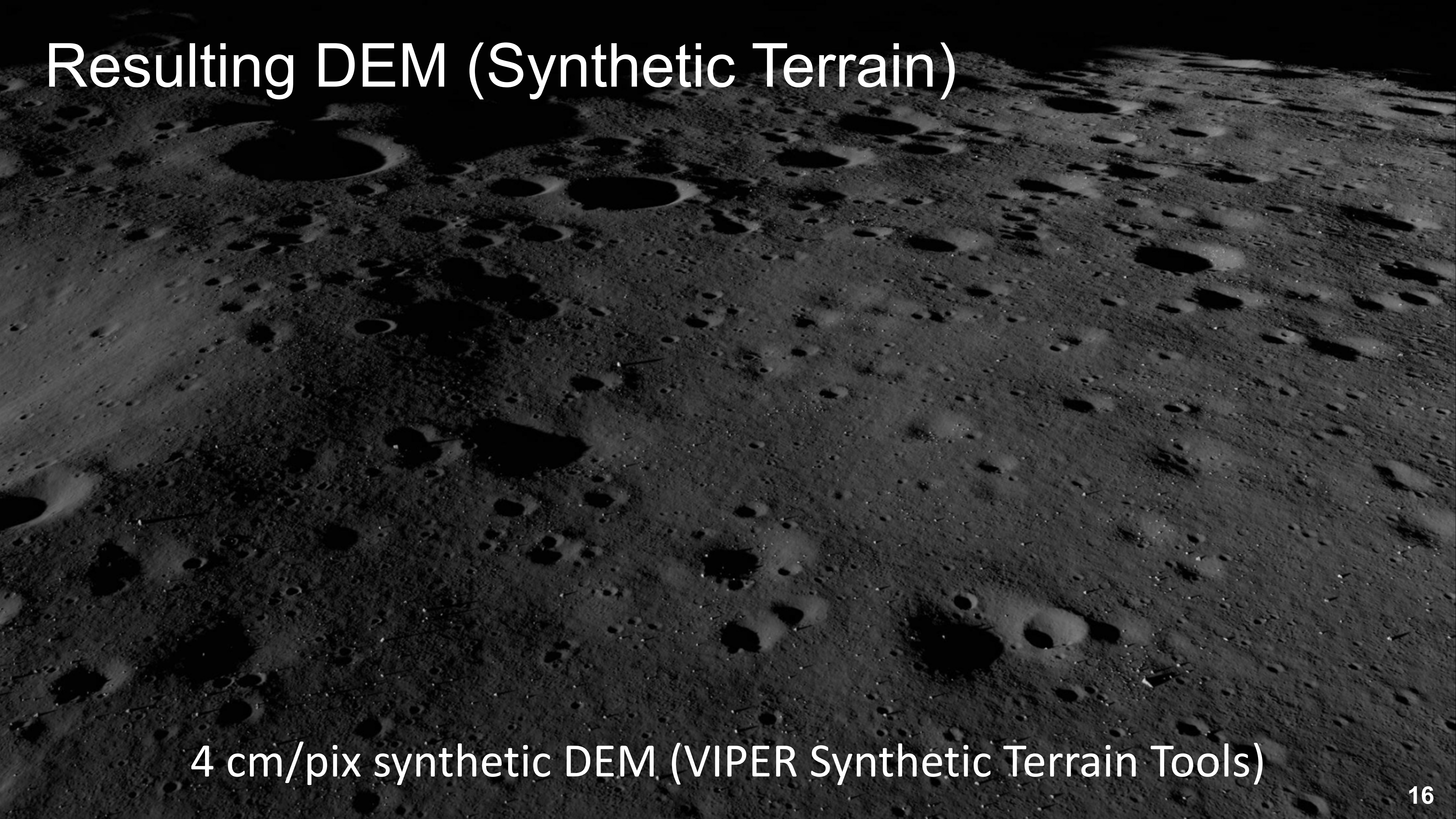


Initial DEM (Actual Terrain)



1 m/pix DEM (Ames Stereo Pipeline)

Resulting DEM (Synthetic Terrain)



4 cm/pix synthetic DEM (VIPER Synthetic Terrain Tools)

Real-time lunar surface simulation (VIPER RSIM)

Example Use Cases

Software Development

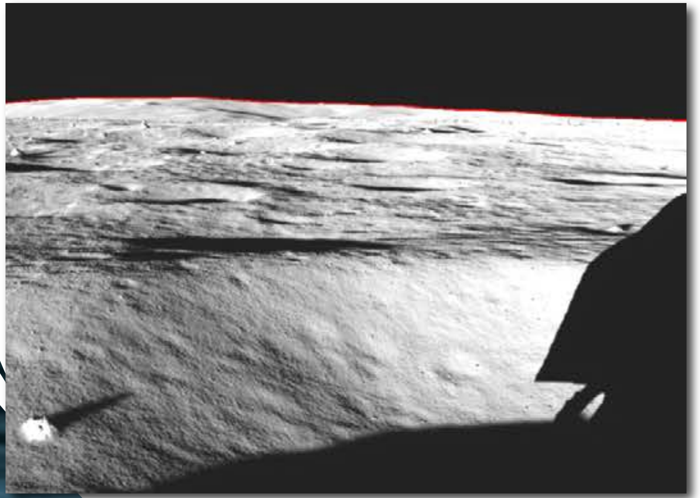
- Automated terrain hazard mapping (supports tactical motion planning)
- Visual odometry (relative localization)

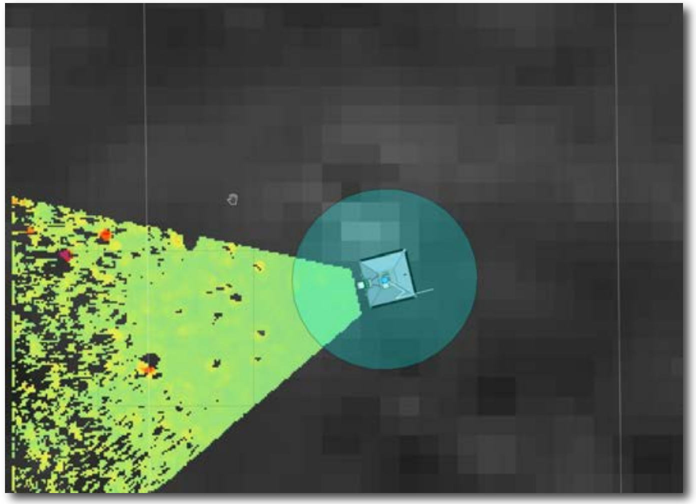
Mission Operations Development

- VERVE: Rover driving operator interface (primary command tool)

Mission Operations Training

- High-fidelity integrated ops sims (ERTs, ORTs, Rehearsals)

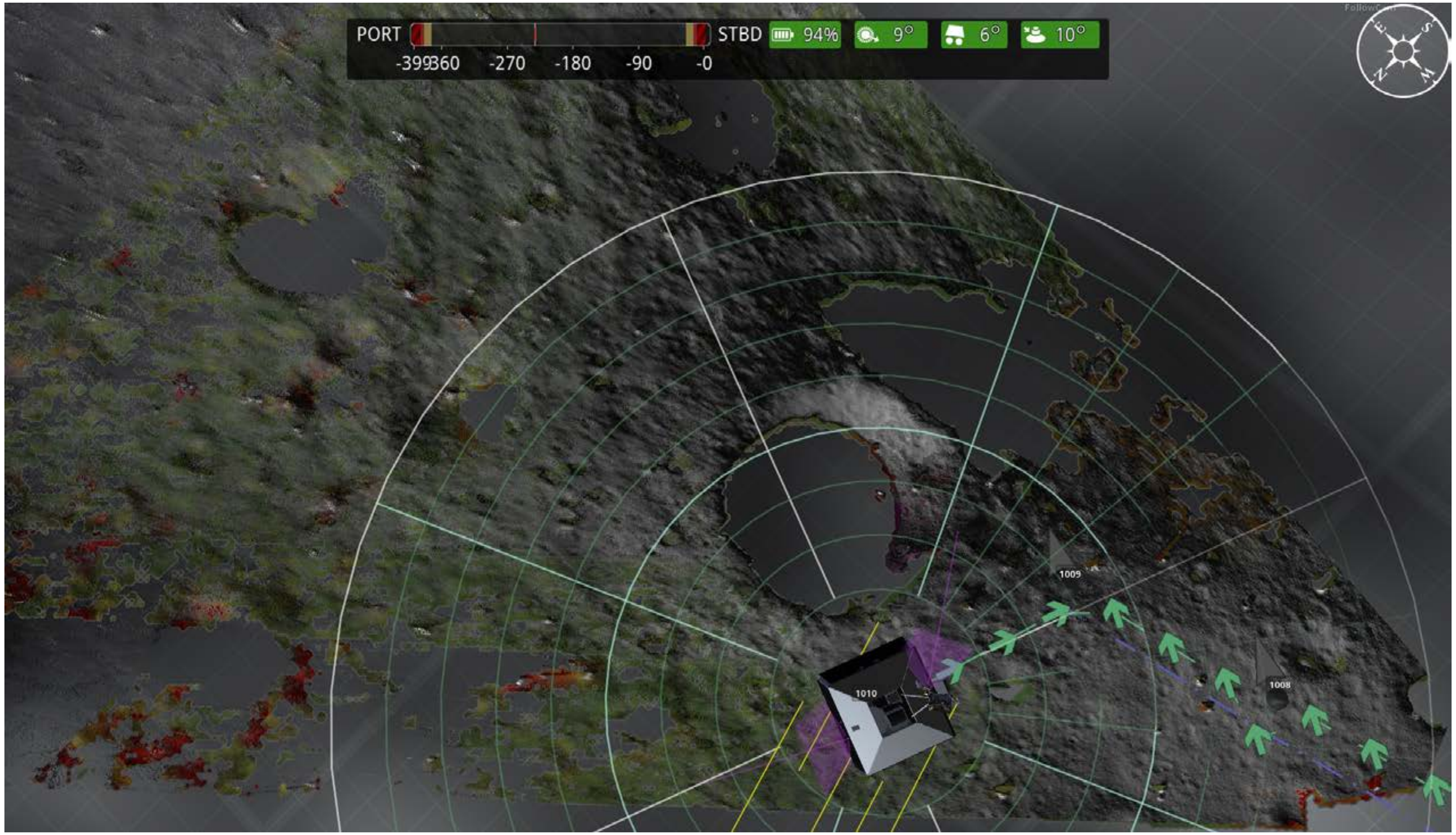




Terrain Hazard Mapping

- Assess geometric hazards (slopes and abrupt height differences) that present traversability risks or exceed rover mobility performance

3D point clouds



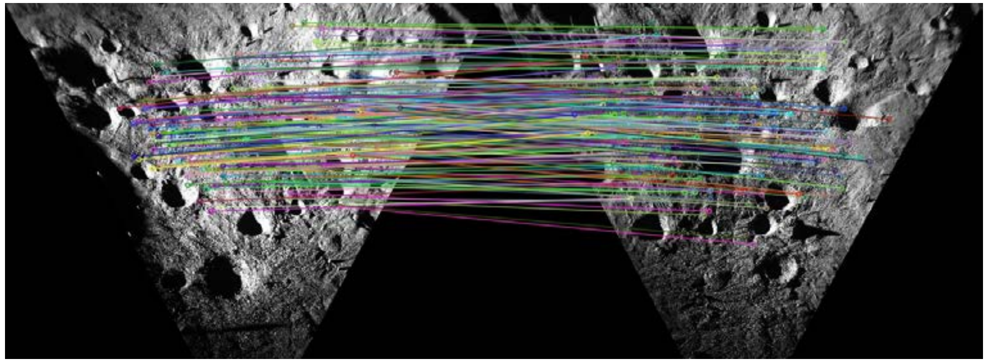
Terrain Hazard Mapping

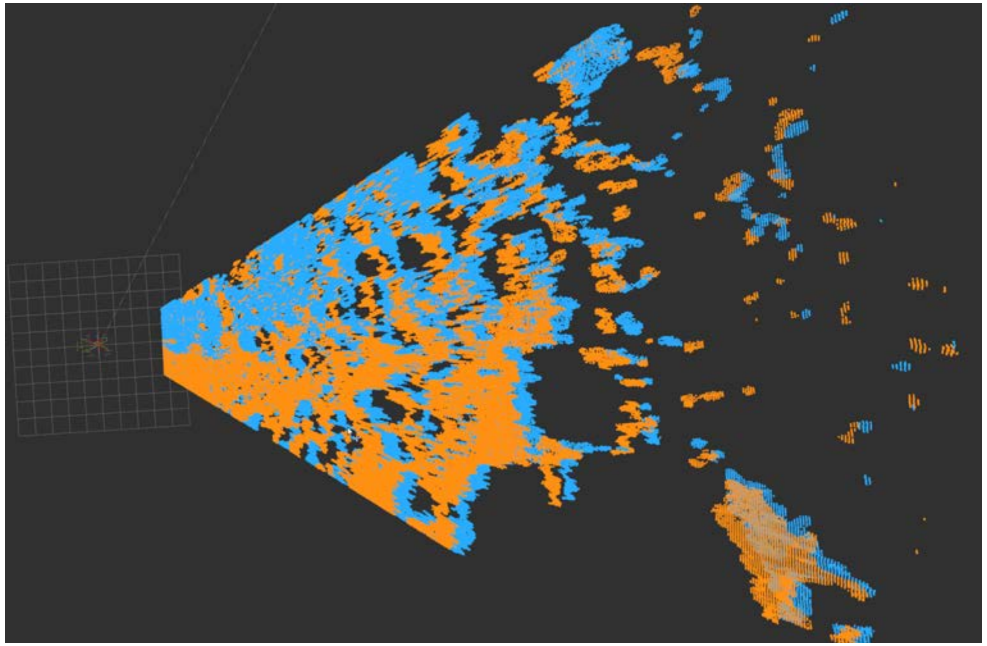
- Assess geometric hazards (slopes and abrupt height differences) that present traversability risks or exceed rover mobility performance

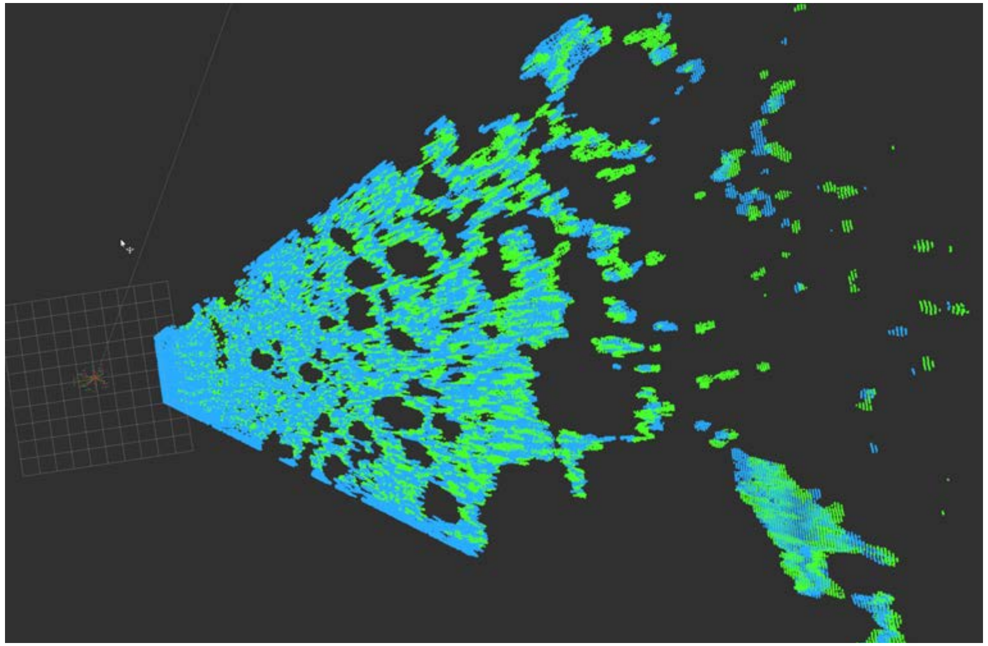
Risk classes

Visual Odometry

- Match 2D images and 3D points from different rover positions to estimate the relationships between rover positions over time
- Helps correct relative pose estimate errors due to wheel slip

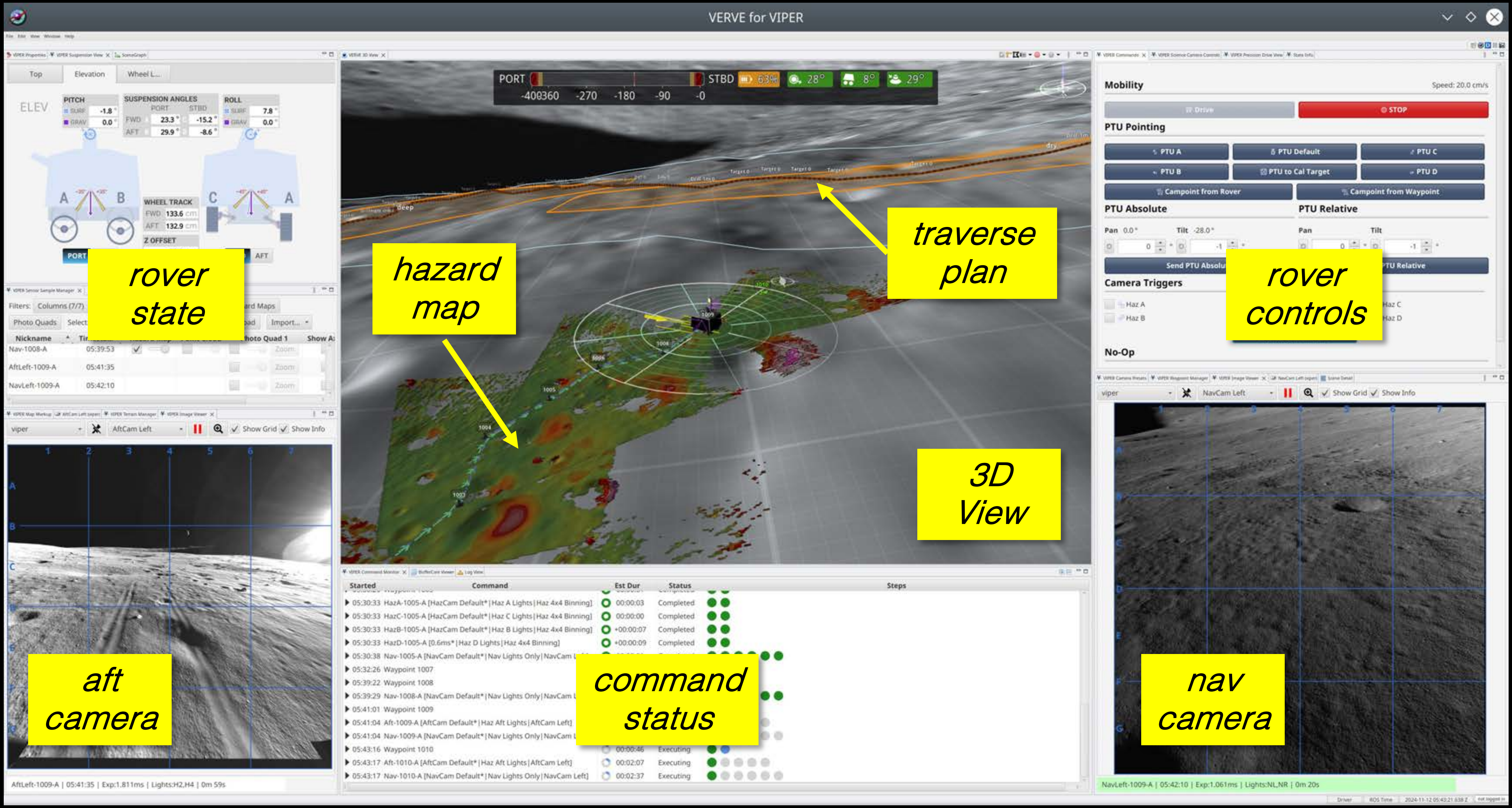




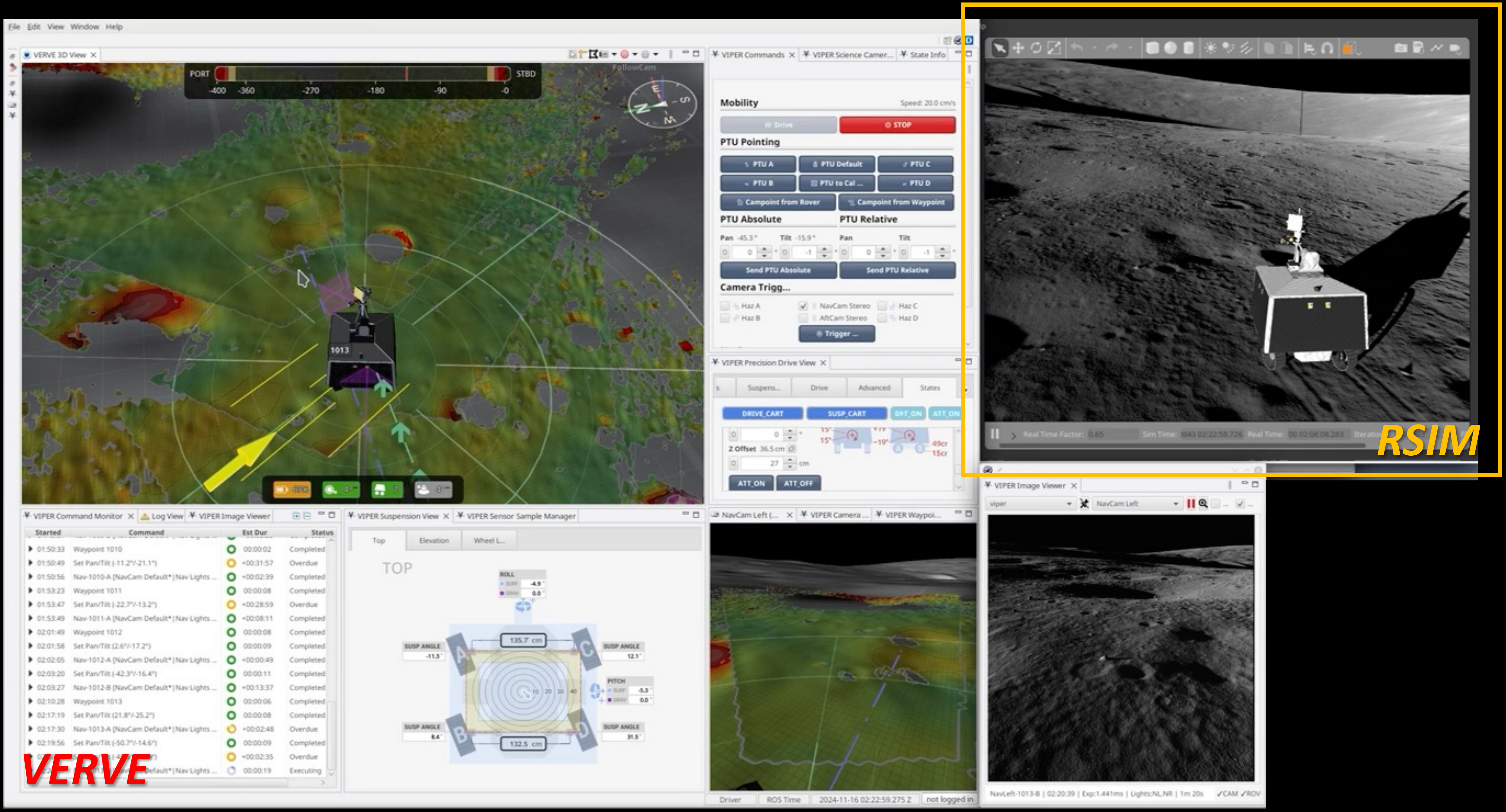


Mission Operations Training

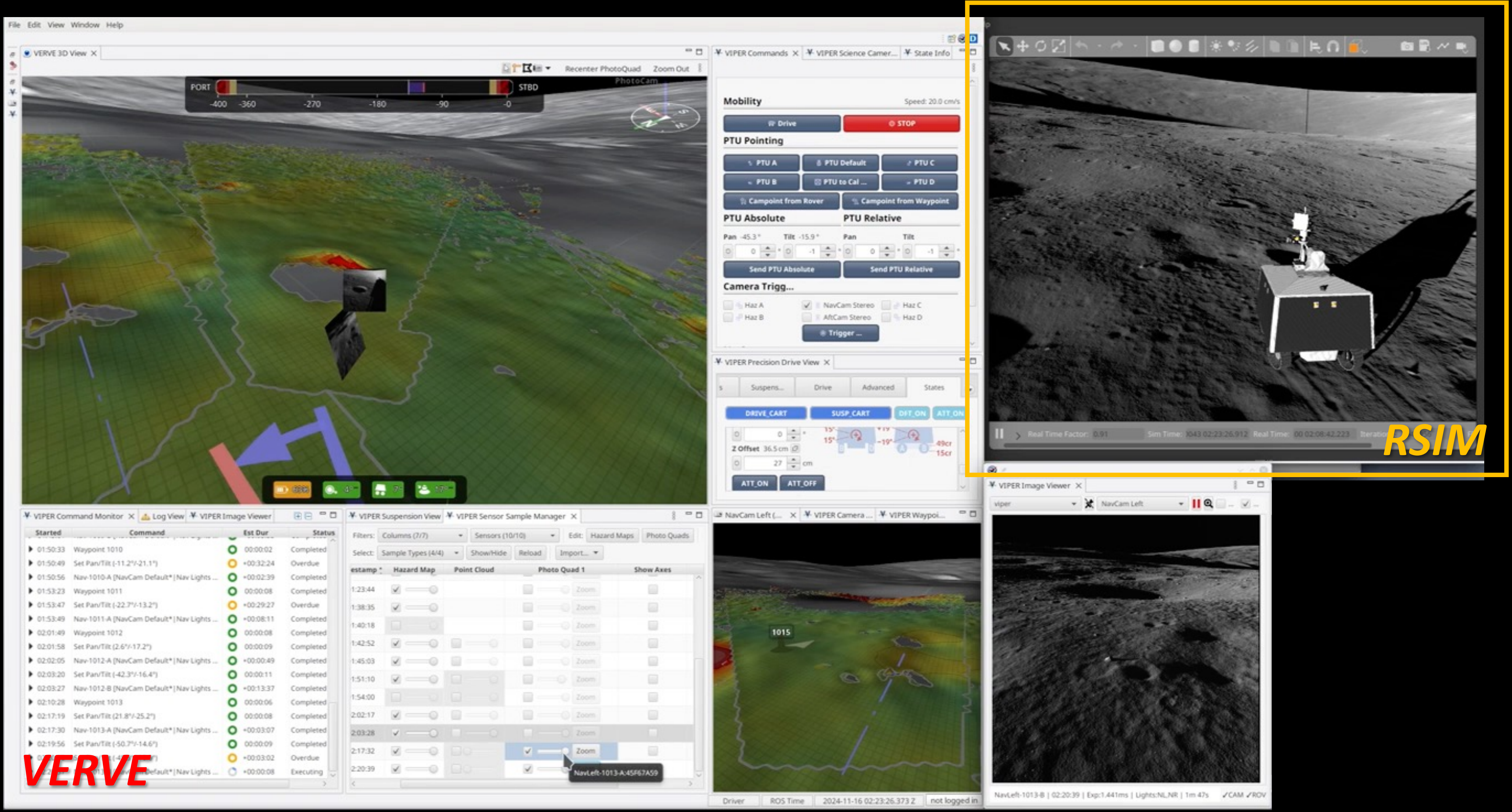
Rover Driving Interface (VERVE)



VERVE + RSIM (Assess terrain + place waypoint)



VERVE + RSIM (Refine waypoint + drive)



For additional information:

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