

National Aeronautics and
Space Administration



Digital Proving Ground: VIPER Rover Simulator (RSIM)

Terry Fong

VIPER Deputy Rover Manager
NASA Ames Research Center

14 November 2024

VIPER Mission

Lunar south pole

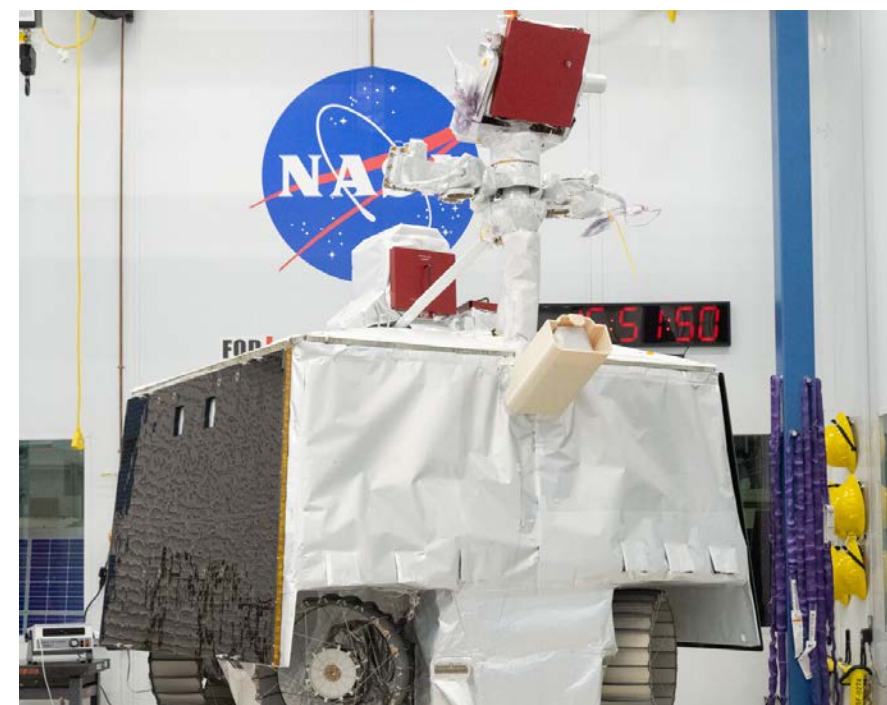
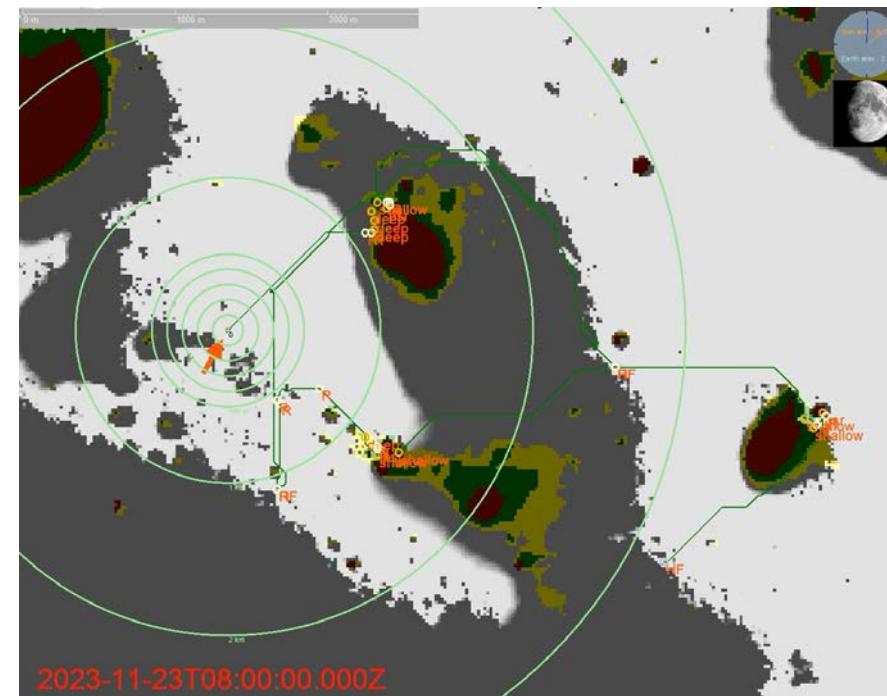
- Commercial launch and landing
- 100+ day mission (including extended survival periods)
- Up to 20 km total drive

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

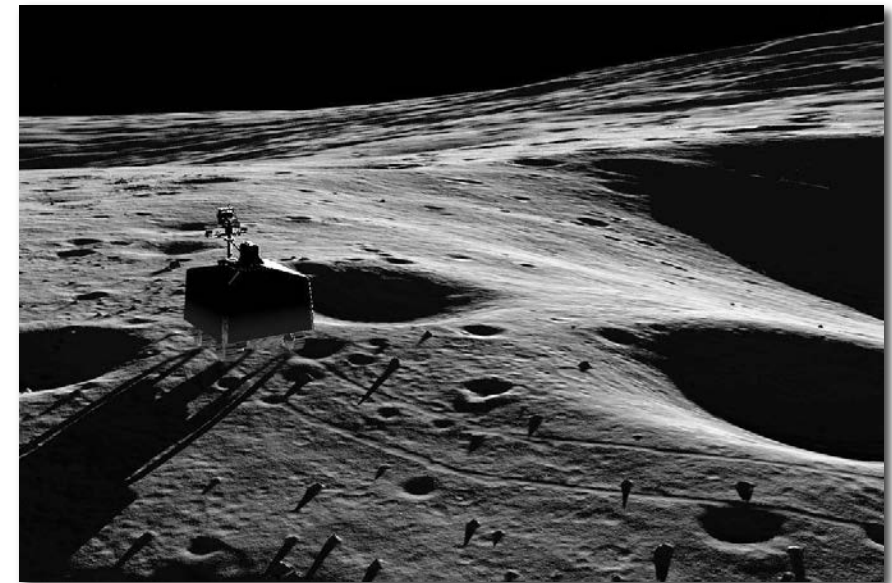
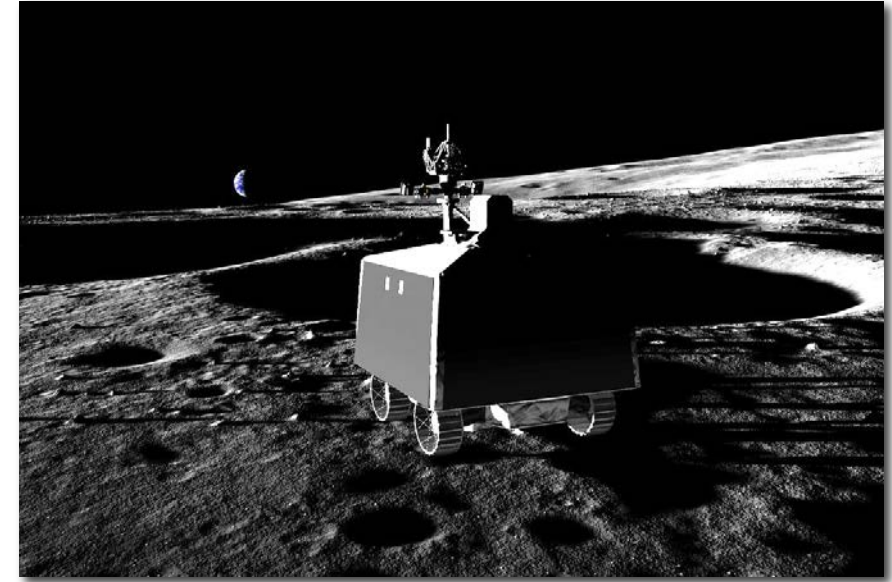
- Exposure, distortion, flare, fixed pattern noise, pixel defects, bit depth, read noise, etc.
- Tuned using NASA Ames “Lunar Lab” tests with camera/light EDUs

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

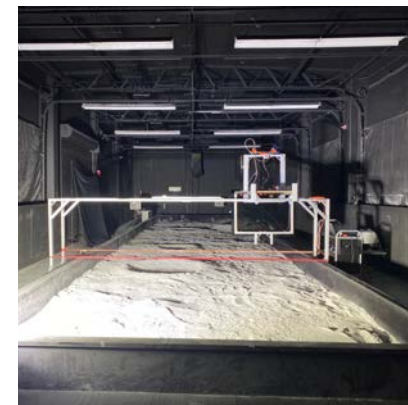
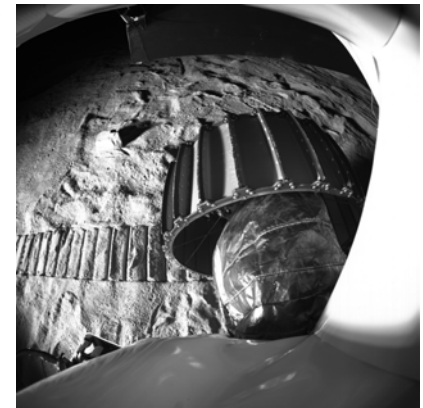
Experimental setup

- 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



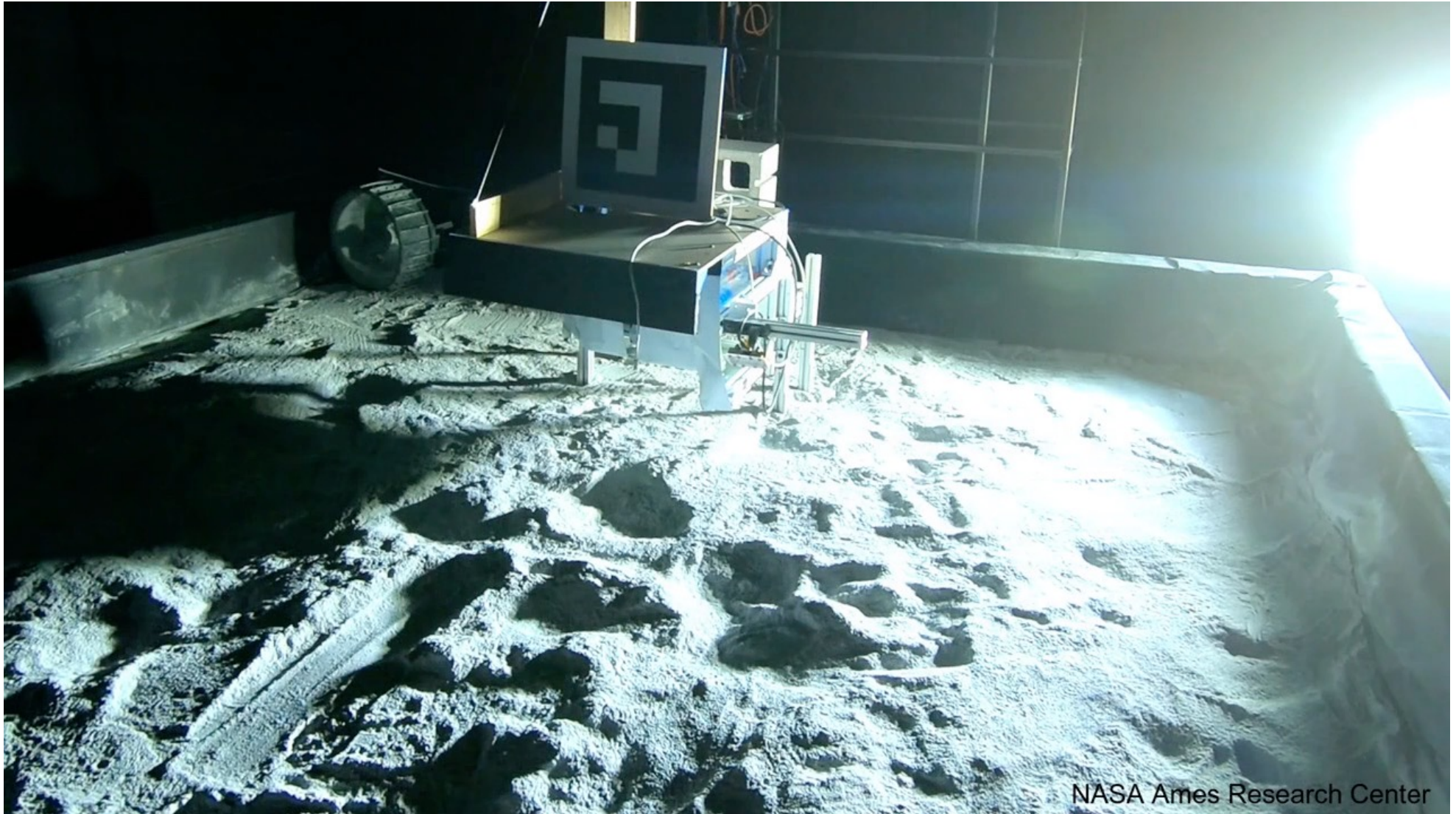
Simulated polar lighting on LHS-1 terrain

*Appearance of
VIPER rover wheel
and tracks*



*Sliding gantry over
LHS-1 terrain*

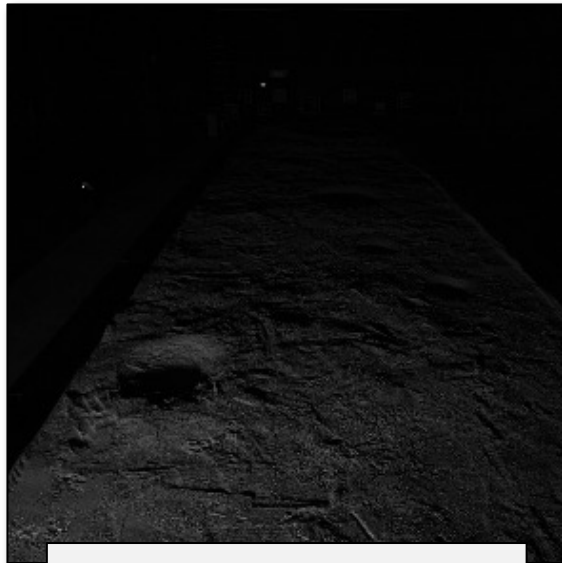
1. High-Quality Lunar Lighting



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

2. High-fidelity Camera Models

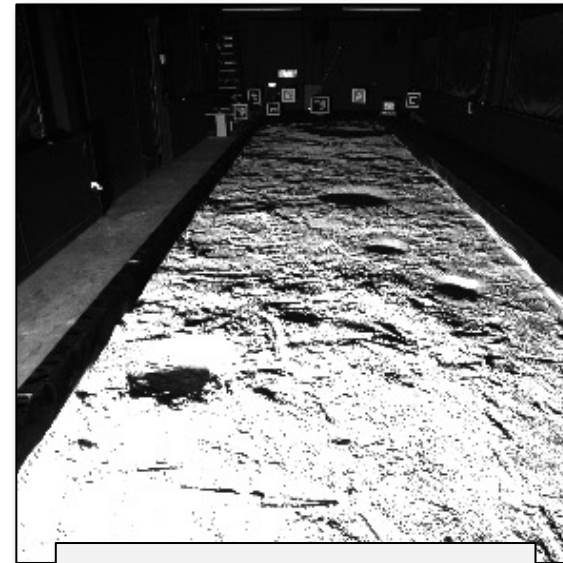
Lunar Lab



Under Exposure

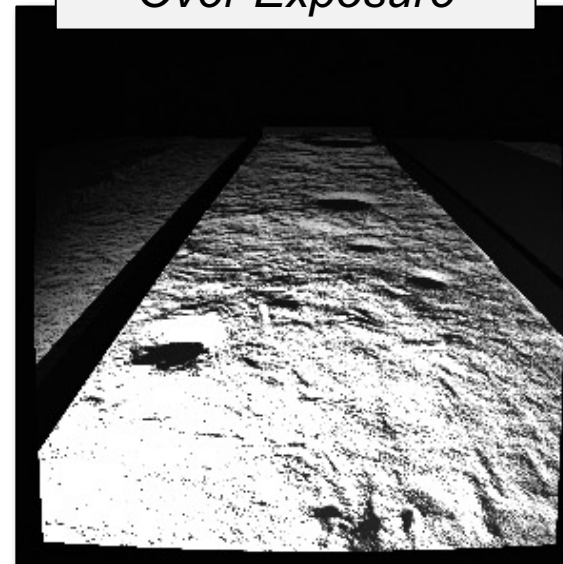


Optimal Exposure



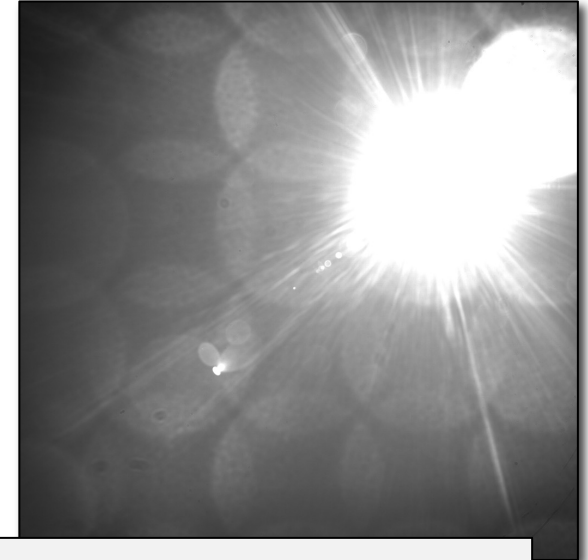
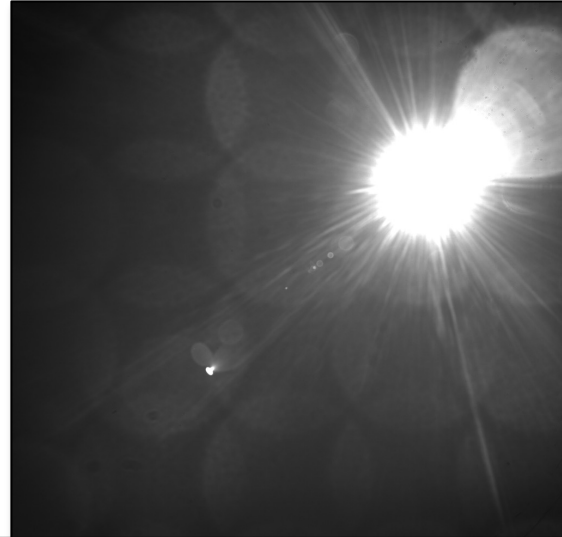
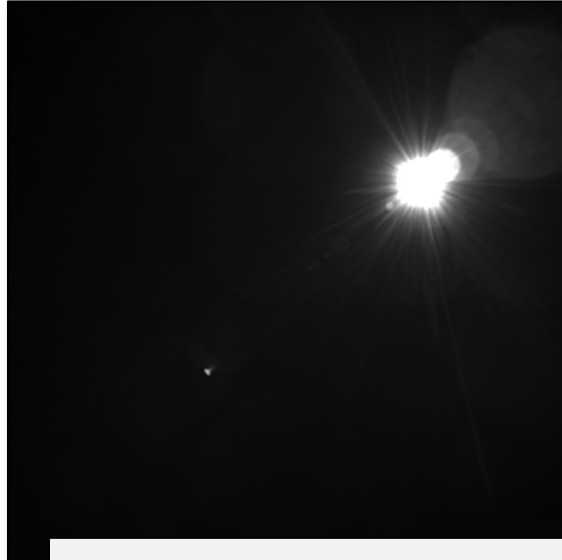
Over Exposure

RSIM



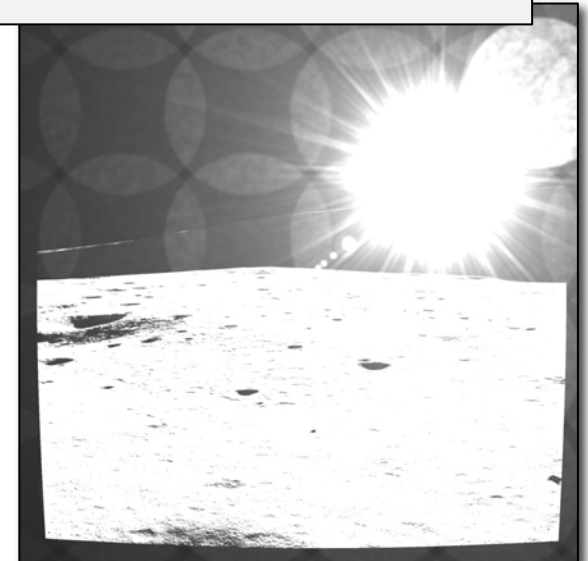
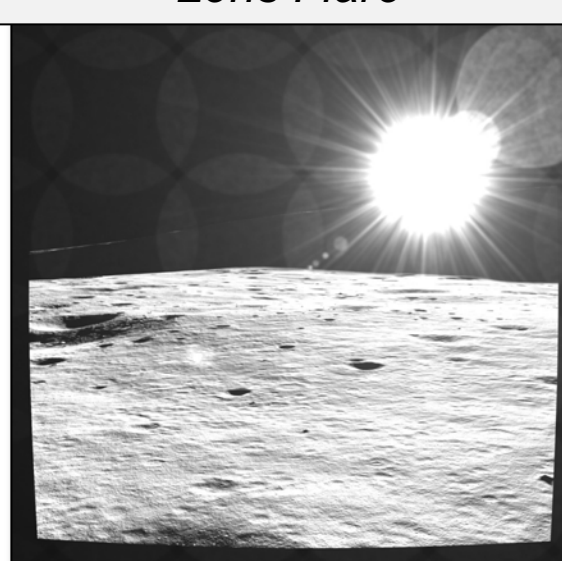
2. High-fidelity Camera Models

Lunar Lab



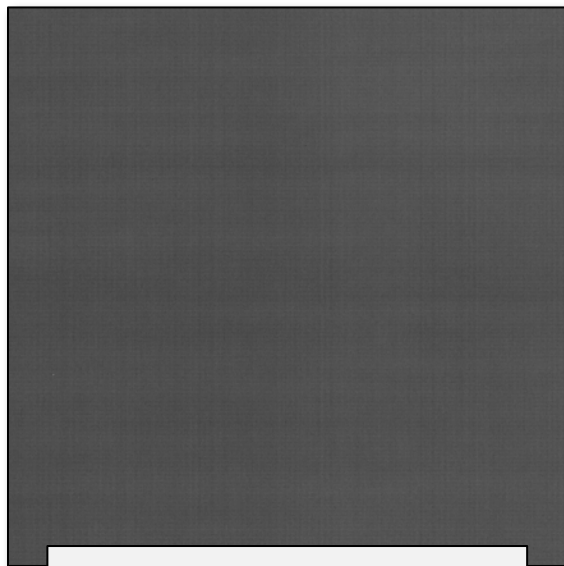
Lens Flare

RSIM

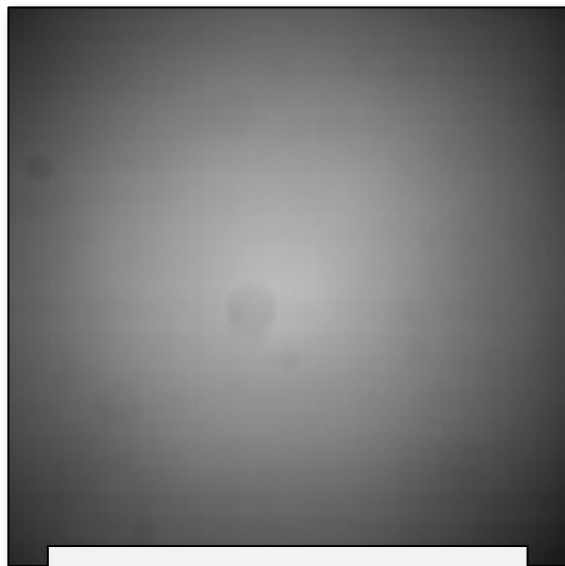


2. High-fidelity Camera Models

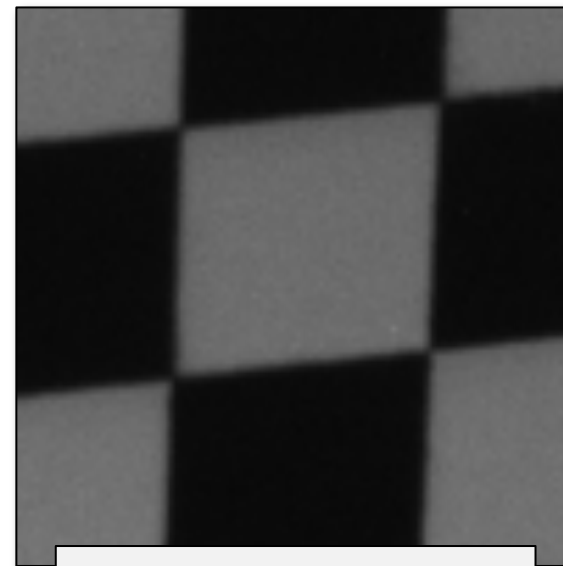
Lunar Lab



Fixed Pattern Noise

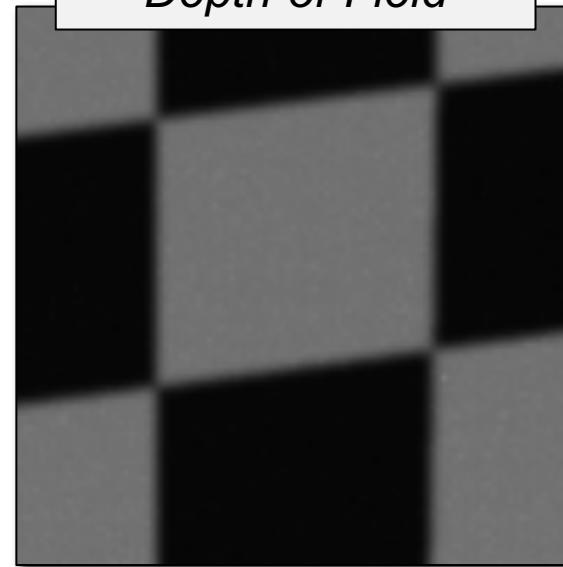
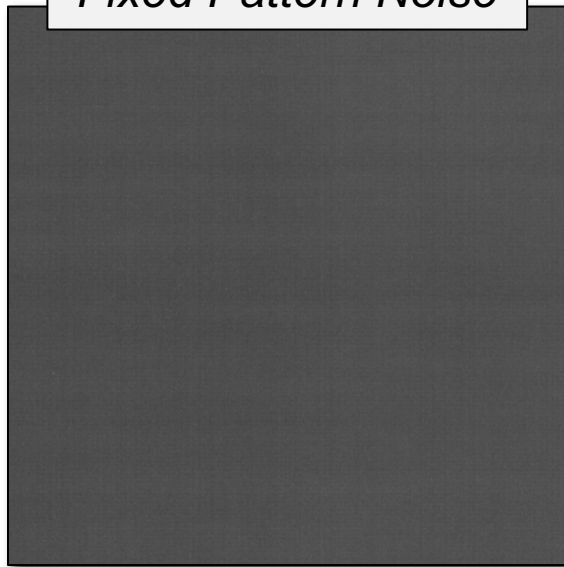


Flat Field Effects



Depth-of-Field

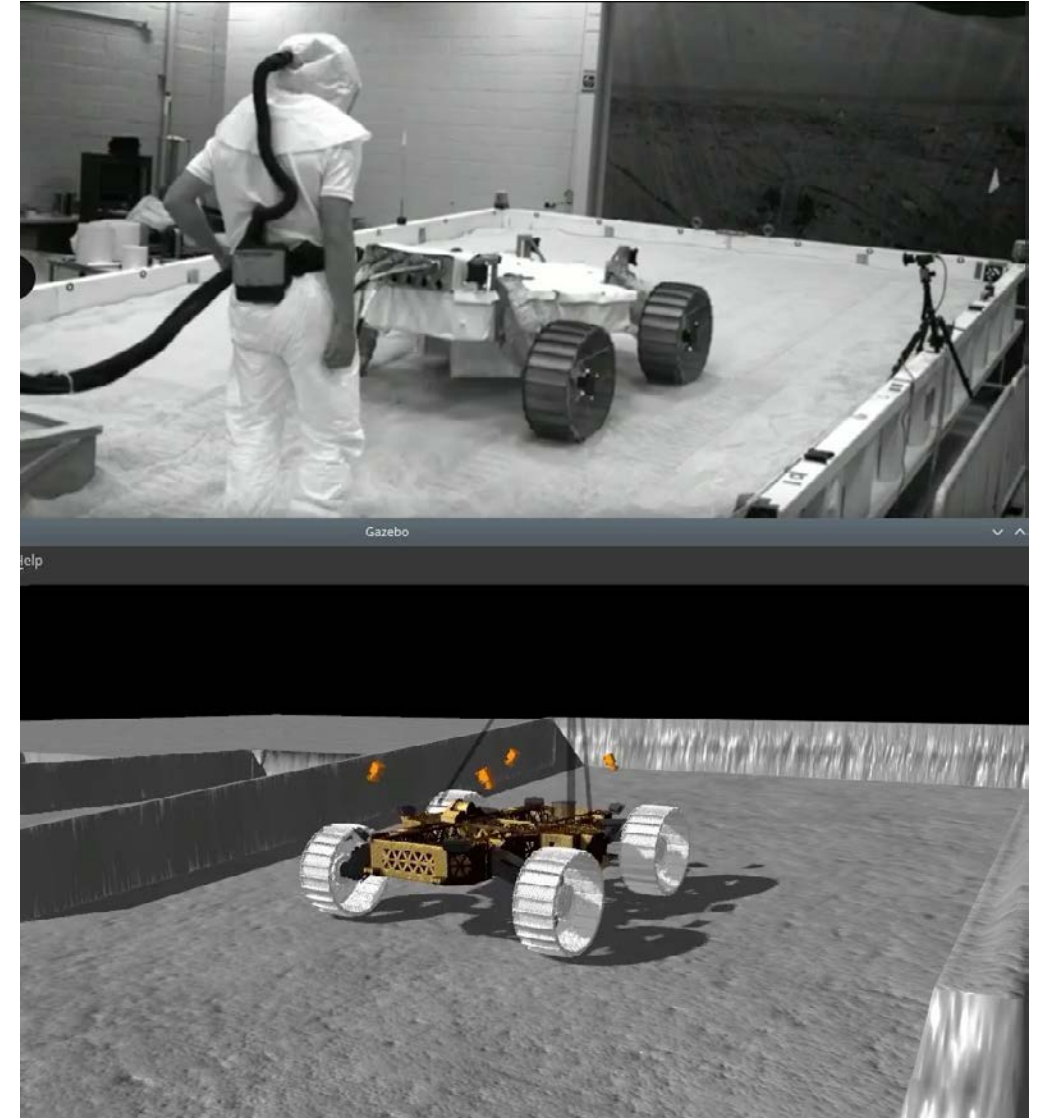
RSIM



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



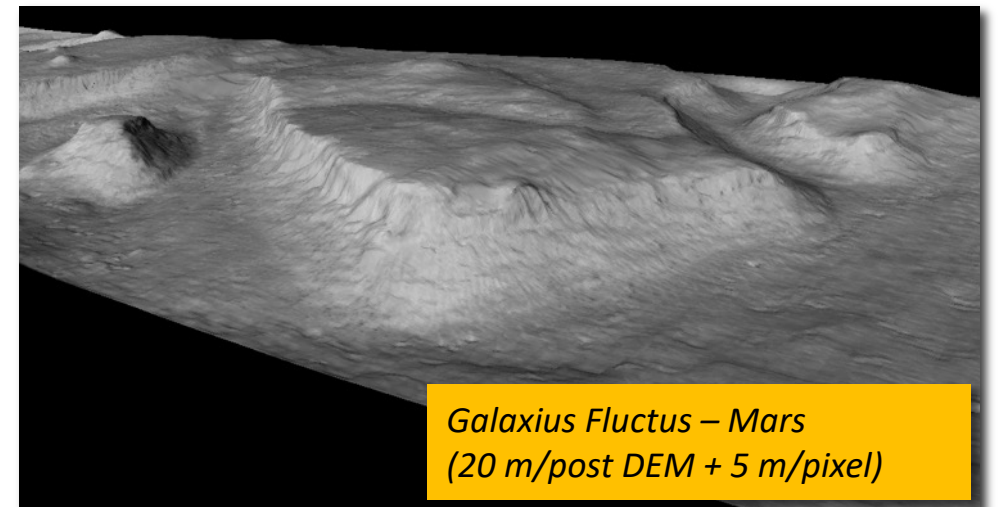
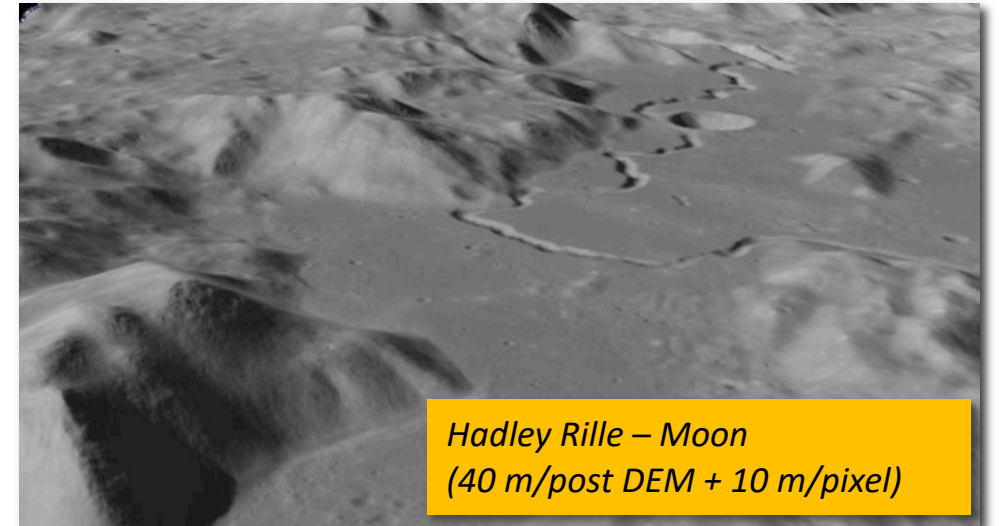
4. High-resolution Terrain Models

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)



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)

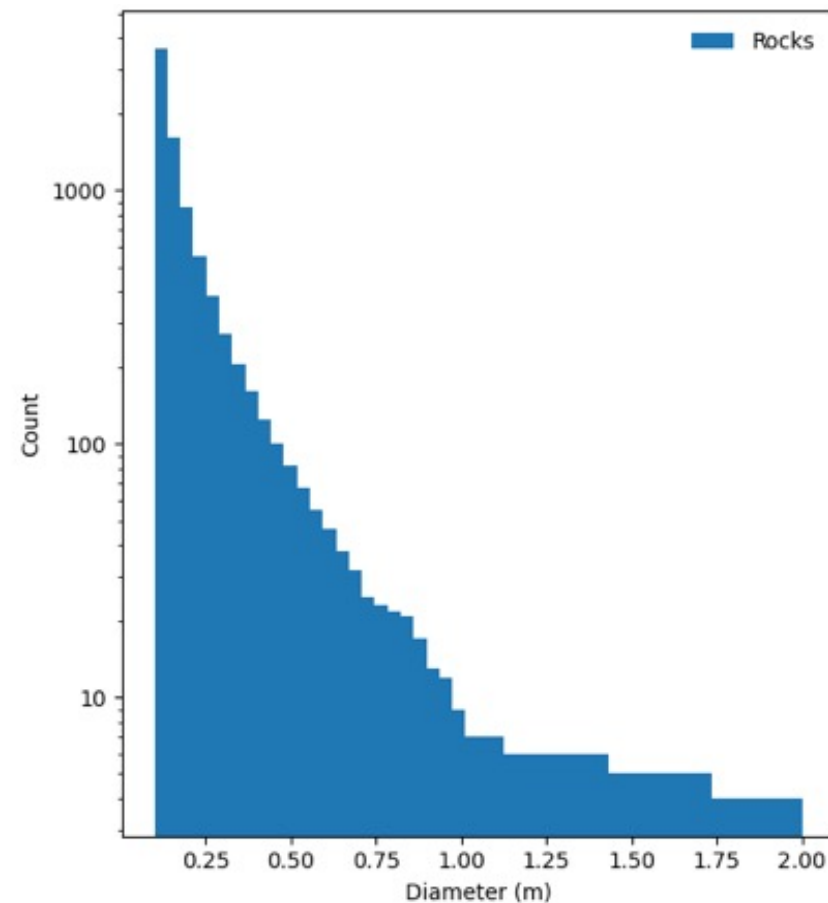
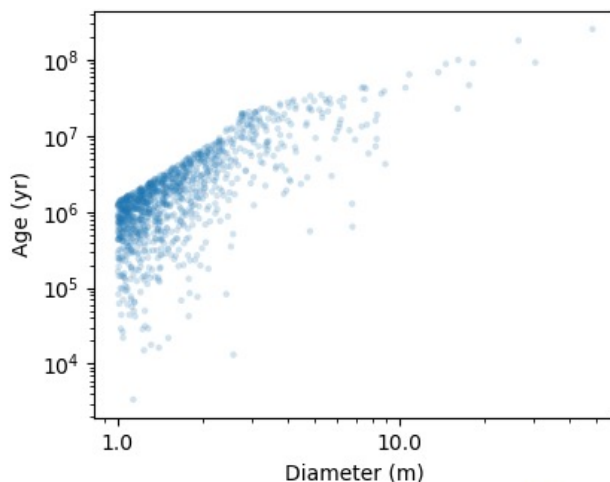
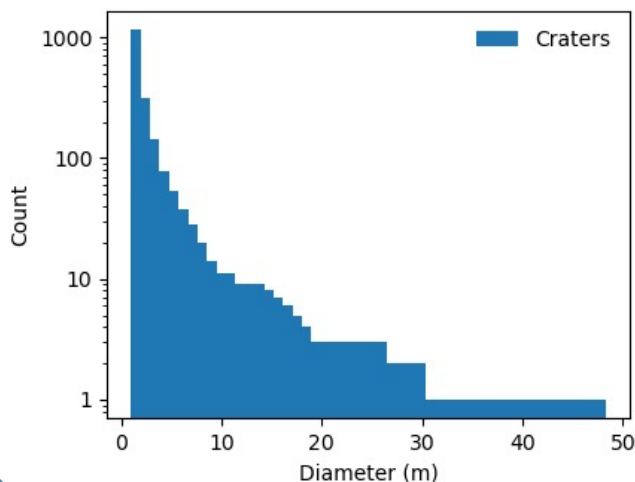
VIPER Synthetic Terrain Tools

Objective

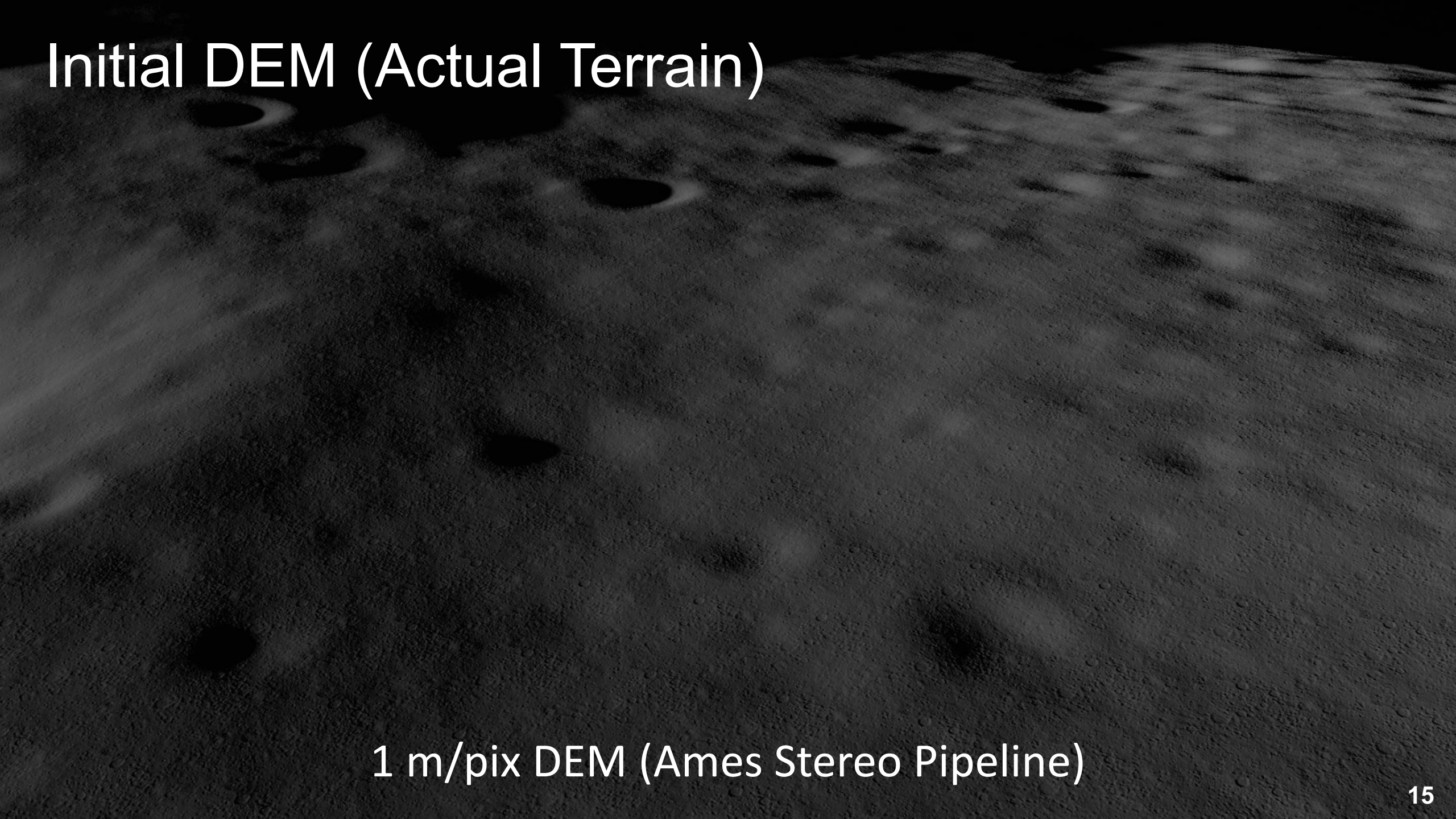
- Produce **scientifically plausible**, very high-resolution (**4 cm/pixel**) DEMs

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)

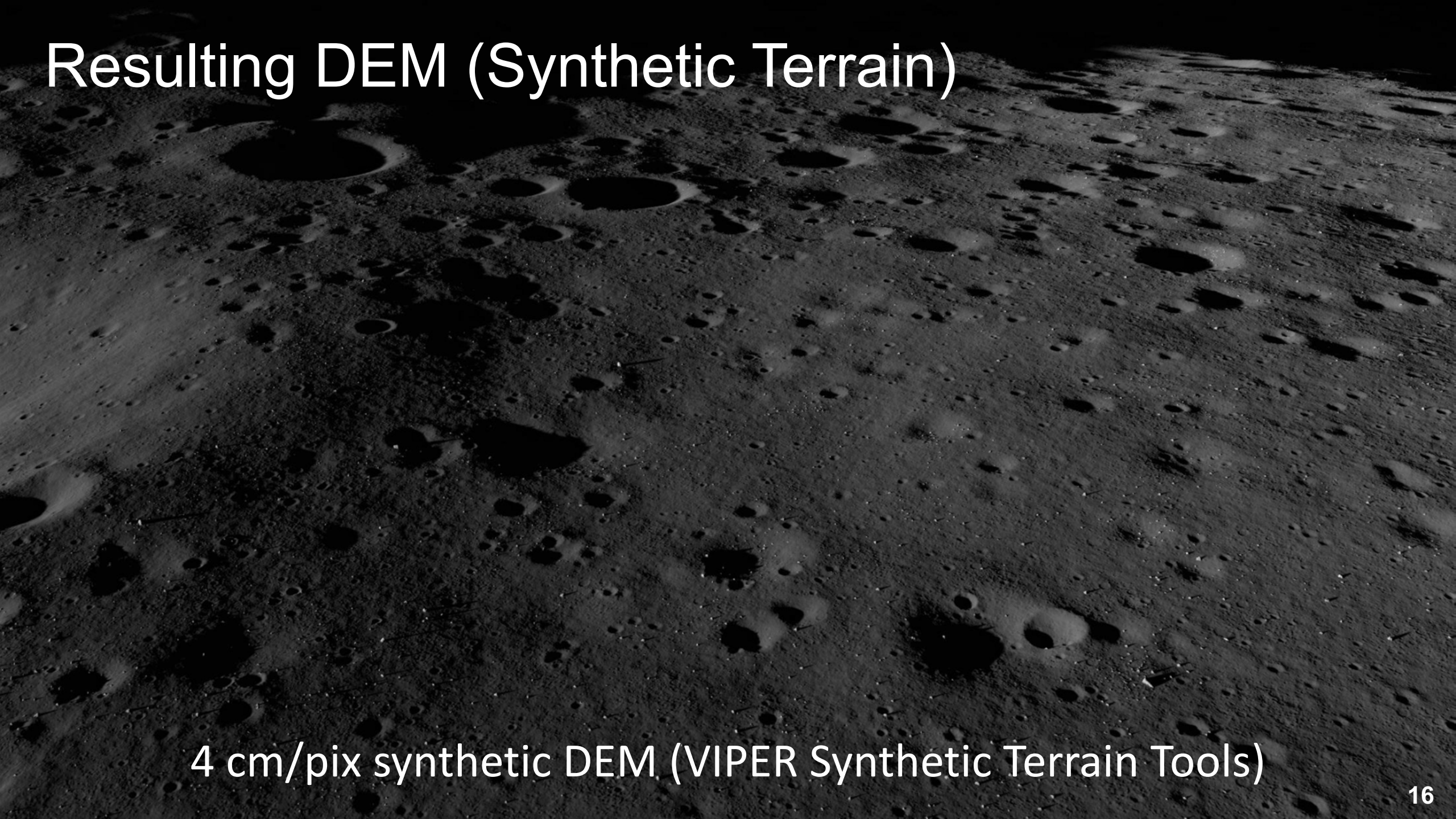


Initial DEM (Actual Terrain)



1 m/pix DEM (Ames Stereo Pipeline)

Resulting DEM (Synthetic Terrain)

A grayscale synthetic Digital Elevation Model (DEM) of a lunar surface. The terrain is covered with numerous craters of various sizes, from small pits to large, deep basins. The lighting creates strong shadows, emphasizing the three-dimensional nature of the craters and the ruggedness of the surface. The overall appearance is a high-resolution, detailed representation of a planetary landscape.

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



Real-time lunar surface simulation (VIPER RSIM)

Example Use Cases

Software Development

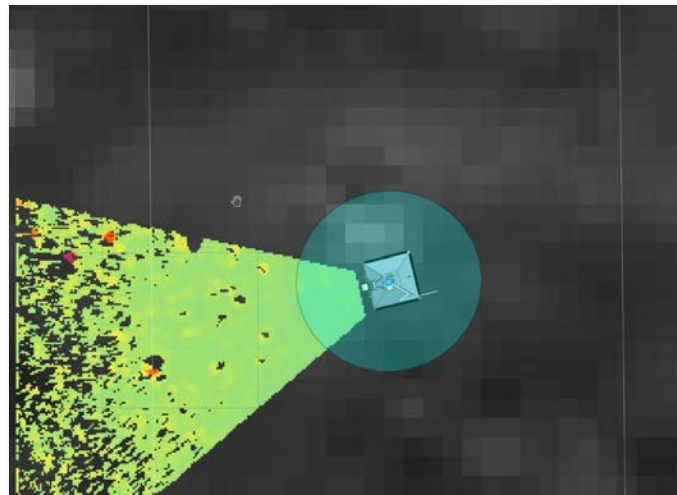
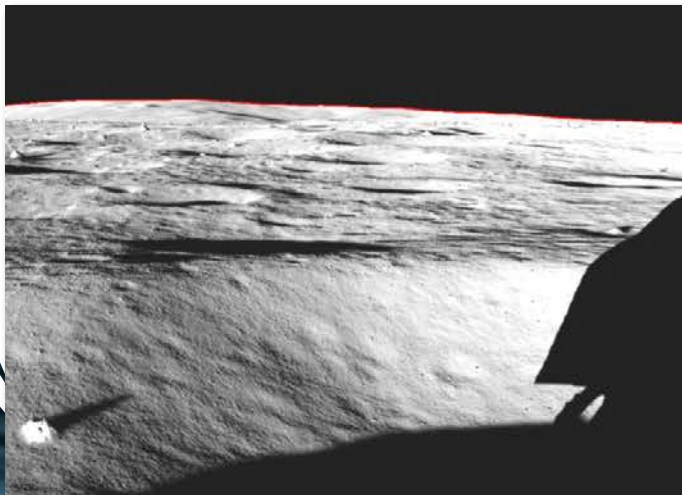
- Automated terrain hazard mapping (supports tactical motion planning)
- Visual odometry (relative localization)

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

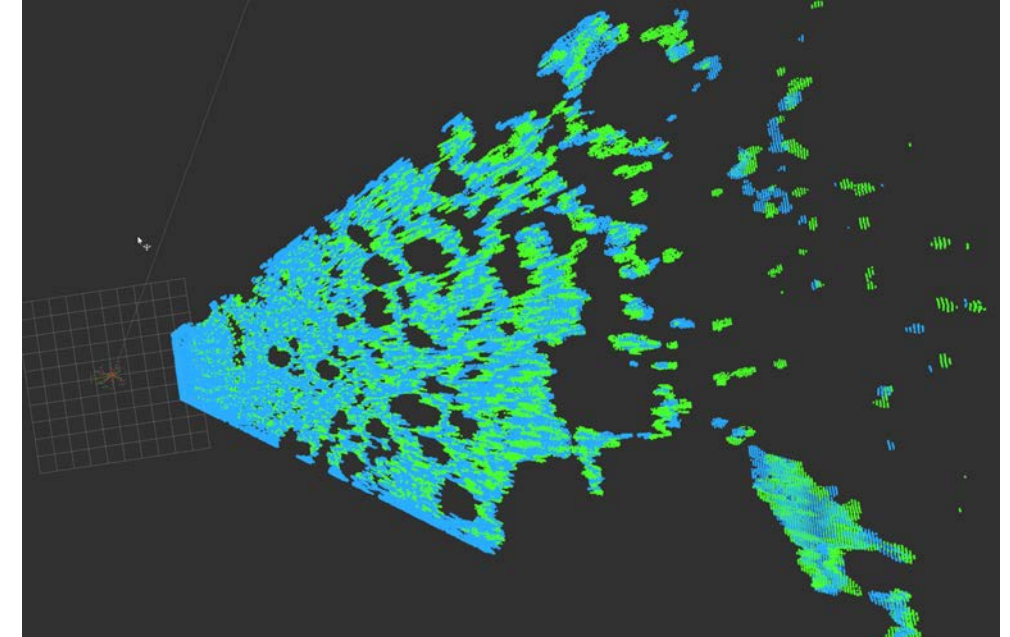
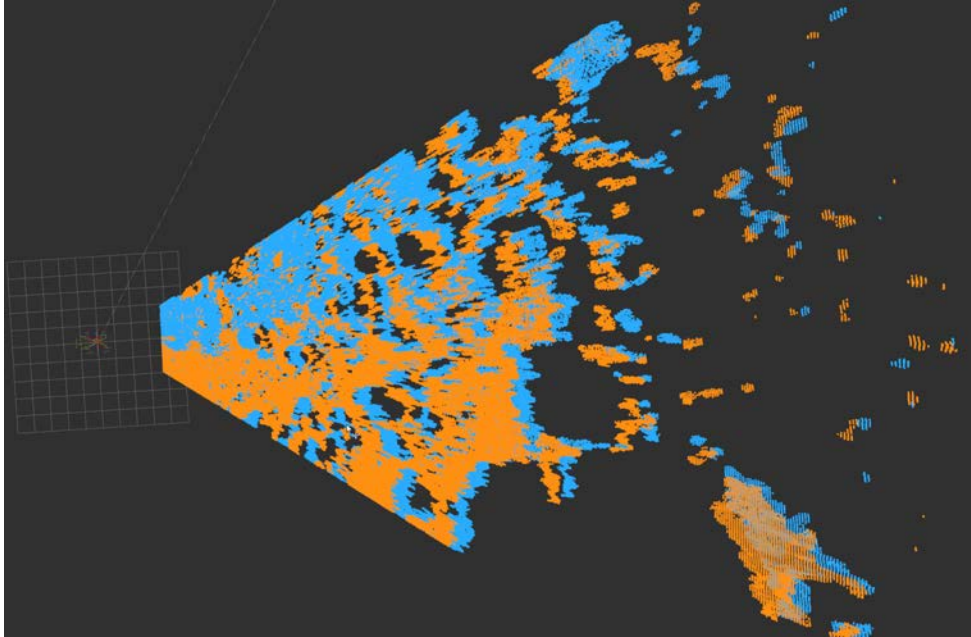
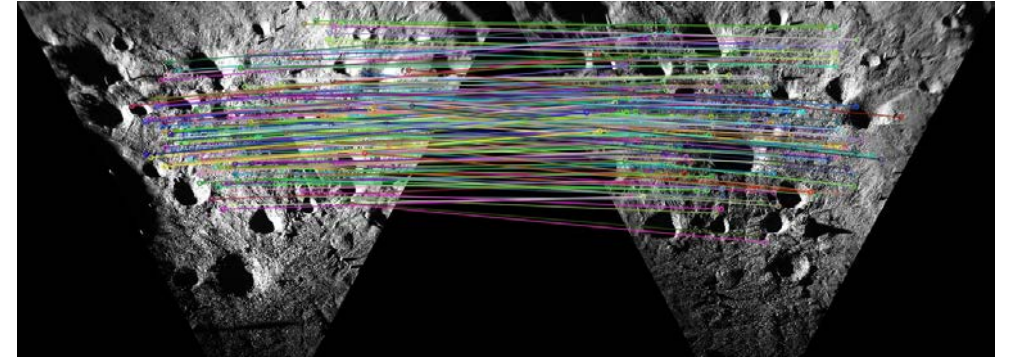
- Assess geometric hazards (slopes and abrupt height differences) that present traversability risks or exceed rover mobility performance

**Risk
classes**



Visual Odometry

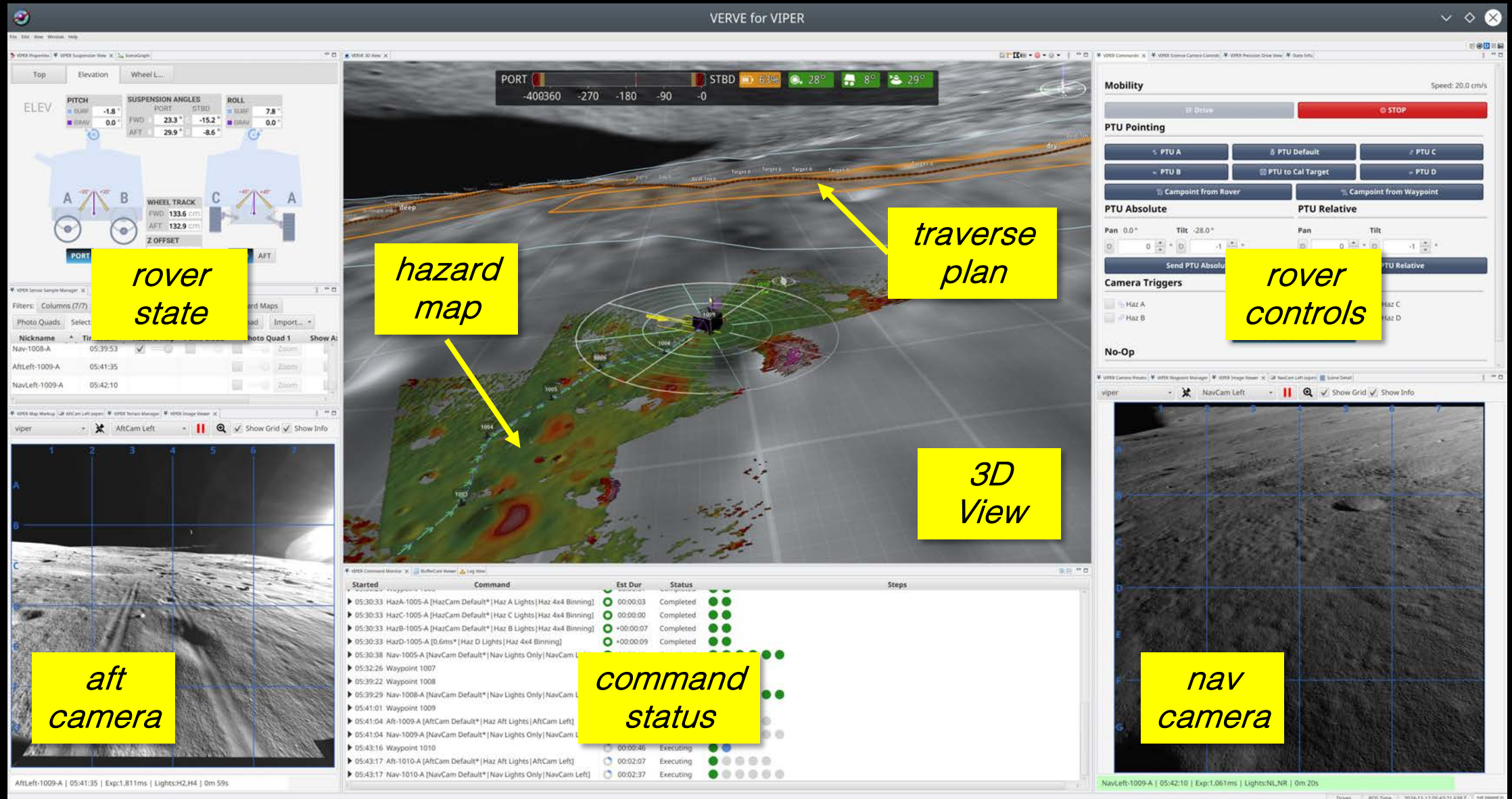
- Match 2D images and 3D points from different rover positions to estimate the relationships between rover positions over time
- Helps correct relative pose estimate errors due to wheel slip



Mission Operations Training



Rover Driving Interface (VERVE)



VERVE + RSIM (Assess terrain + place waypoint)

VERVE 3D View



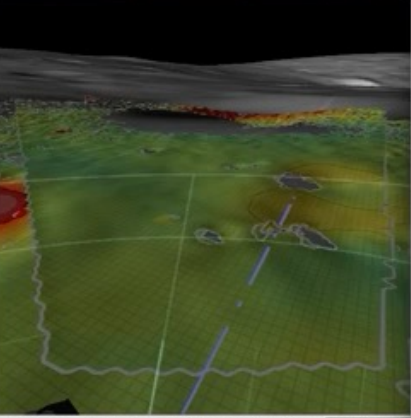
VERVE Command Monitor

Started	Command	Est Dur	Status
01:50:33	Waypoint 1010	00:00:02	Completed
01:50:49	Set Pan/Tilt (-11.2°/-21.1°)	+00:31:57	Overdue
01:50:56	Nav-1010-A [NavCam Default*] Nav Lights ...	+00:02:39	Completed
01:53:23	Waypoint 1011	00:00:08	Completed
01:53:47	Set Pan/Tilt (-22.7°/-13.2°)	+00:28:59	Overdue
01:53:49	Nav-1011-A [NavCam Default*] Nav Lights ...	+00:08:11	Completed
02:01:49	Waypoint 1012	00:00:08	Completed
02:01:58	Set Pan/Tilt (2.6°/-17.2°)	00:00:09	Completed
02:02:05	Nav-1012-A [NavCam Default*] Nav Lights ...	+00:00:49	Completed
02:03:20	Set Pan/Tilt (-42.3°/-16.4°)	00:00:11	Completed
02:03:27	Nav-1012-B [NavCam Default*] Nav Lights ...	+00:13:37	Completed
02:10:28	Waypoint 1013	00:00:06	Completed
02:17:19	Set Pan/Tilt (21.8°/-25.2°)	00:00:08	Completed
02:17:30	Nav-1013-A [NavCam Default*] Nav Lights ...	+00:02:48	Overdue
02:19:56	Set Pan/Tilt (-50.7°/-14.6°)	00:00:09	Completed
02:20:19	Nav-1013-B [NavCam Default*] Nav Lights ...	+00:02:35	Overdue
02:20:19	Executing	00:00:19	Executing

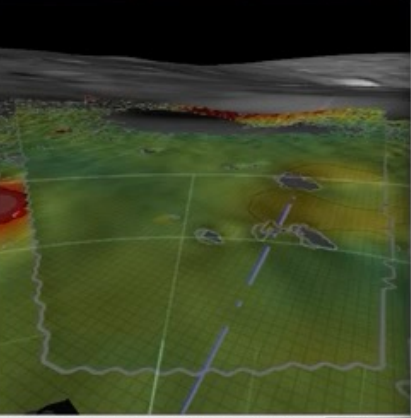
VERVE Suspension View



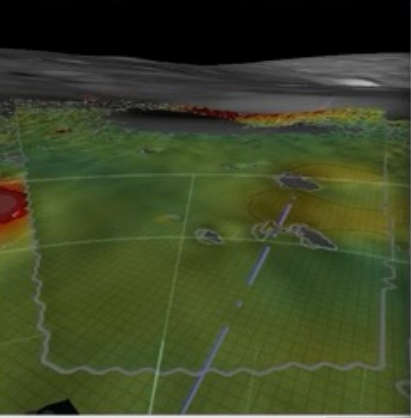
VERVE Image Viewer



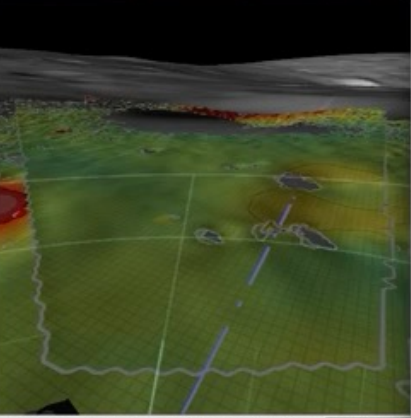
VERVE Sensor Sample Manager



VERVE Waypoint...



VERVE Camera...



VERVE Precision Drive View

DRIVE_CART

SUSP_CART

DFT_ON

ATT_ON

DRIVE_CART

SUSP_CART

DFT_ON

ATT_ON

VERVE Mobility

Drive

STOP

PTU A

PTU Default

PTU C

PTU B

PTU to Cal ...

PTU D

Campoint from Rover

Campoint from Waypoint

PTU Absolute

PTU Relative

Pan

Tilt

Pan

Tilt

Send PTU Absolute

Send PTU Relative

Camera Trigg...

Haz A

Haz B

Haz C

Haz D

NavCam Stereo

AltCam Stereo

Trigger ...

VERVE Image Viewer

NavCam Left

NavCam Right

NavCam Front

NavCam Back

NavCam Top

NavCam Bottom

NavCam Left

NavCam Right

NavCam Front

NavCam Back

NavCam Top

NavCam Bottom

NavCam Left

NavCam Right

NavCam Front

NavCam Back

NavCam Top

NavCam Bottom

RSIM



VERVE

24

VERVE + RSIM (Refine waypoint + drive)

The image displays the Verve and RSIM software interface, which is used for planning and controlling a rover mission. The interface is divided into several panels:

- VERVE 3D View:** A 3D terrain map showing the rover's path and waypoints. The map is color-coded by elevation, with green for lower areas and yellow/red for higher areas. A scale bar at the top indicates distances from -400 to 0 meters.
- VERVE Command Monitor:** A table showing the execution status of various commands. The table has columns for 'Started', 'Command', 'Est Dur', and 'Status'.
- VERVE Sensor Sample Manager:** A table showing the status of various sensors. The table has columns for 'Filters', 'Columns (7/7)', 'Sensors (10/10)', 'Edit', 'Hazard Maps', and 'Photo Quads'.
- VERVE Precision Drive View:** A panel showing the rover's current position and orientation. It includes a 'DRIVE_CART' button and a 'SUSP_CART' button. The 'Z Offset' is set to 36.5 cm.
- VERVE Image Viewer:** A panel showing the rover's camera feed. The feed shows the rover's perspective of the terrain, with a scale bar at the bottom indicating distances from 0 to 100 meters.
- RSIM:** A panel showing the rover's current position and orientation. It includes a 'DRIVE_CART' button and a 'SUSP_CART' button. The 'Z Offset' is set to 36.5 cm.

The Verve logo is visible in the bottom left corner of the interface.

For additional information:

Terry Fong

VIPER Deputy Rover Manager

NASA Ames Research Center

terry.fong@nasa.gov

+1.650.604.1349

