

National Aeronautics and
Space Administration



Volatiles Investigating Polar Exploration Rover

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NASA Ames Research Center

29 April 2026

Just Two Decades Ago...

The Moon was a very different place from how we understand it today

Studied from the Earth, in-situ and with samples returned to Earth

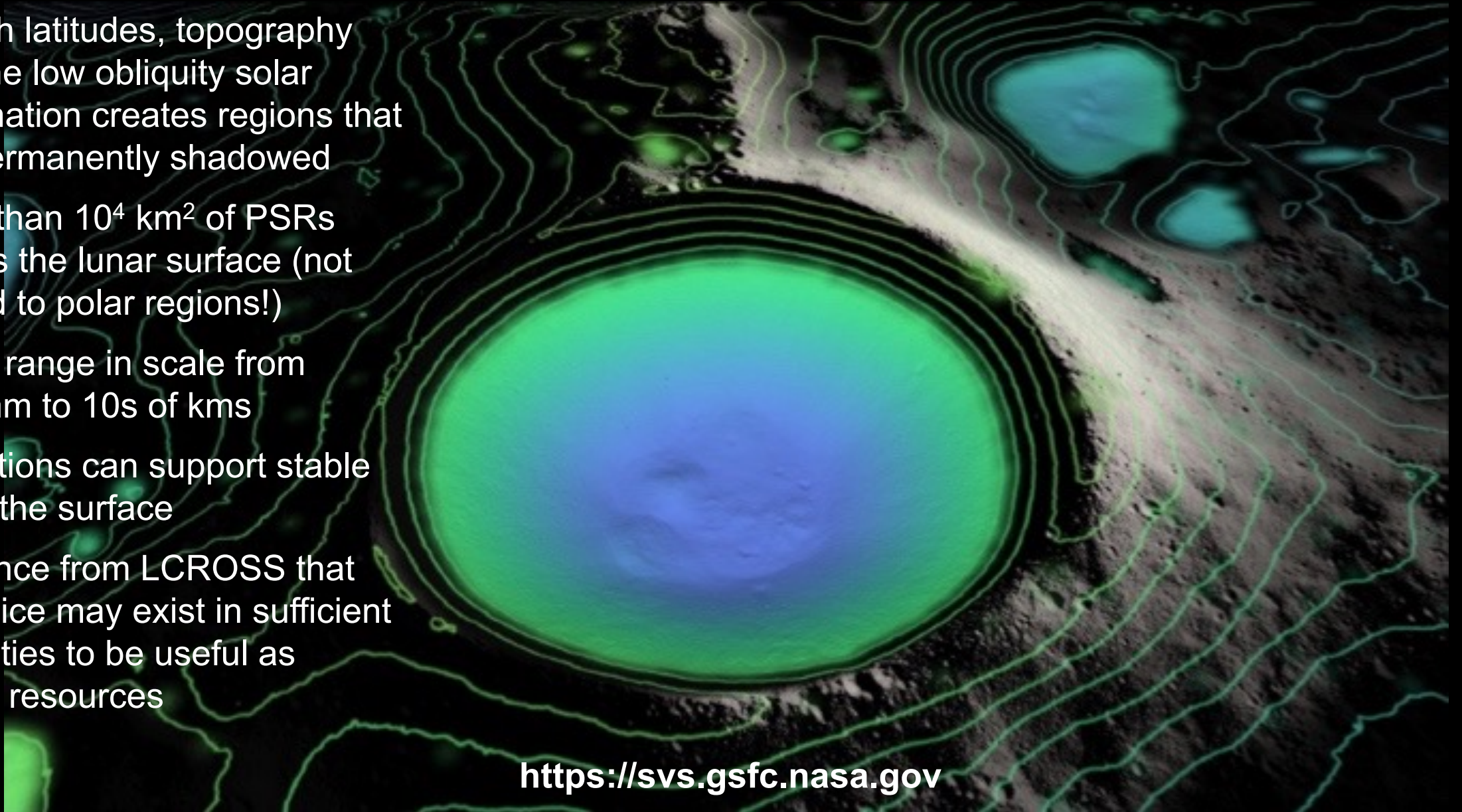
The “general” thinking was:

- The surface was relatively constant
- A thin exosphere of Argon, Sodium, Potassium
- **Bone dry (~100 ppm of water in soils)**



Permanently Shadowed Regions (PSR)

- At high latitudes, topography and the low obliquity solar illumination creates regions that are permanently shadowed
- More than 10^4 km² of PSRs across the lunar surface (not limited to polar regions!)
- PSRs range in scale from sub-mm to 10s of kms
- Conditions can support stable ice at the surface
- Evidence from LCROSS that water ice may exist in sufficient quantities to be useful as *in-situ* resources



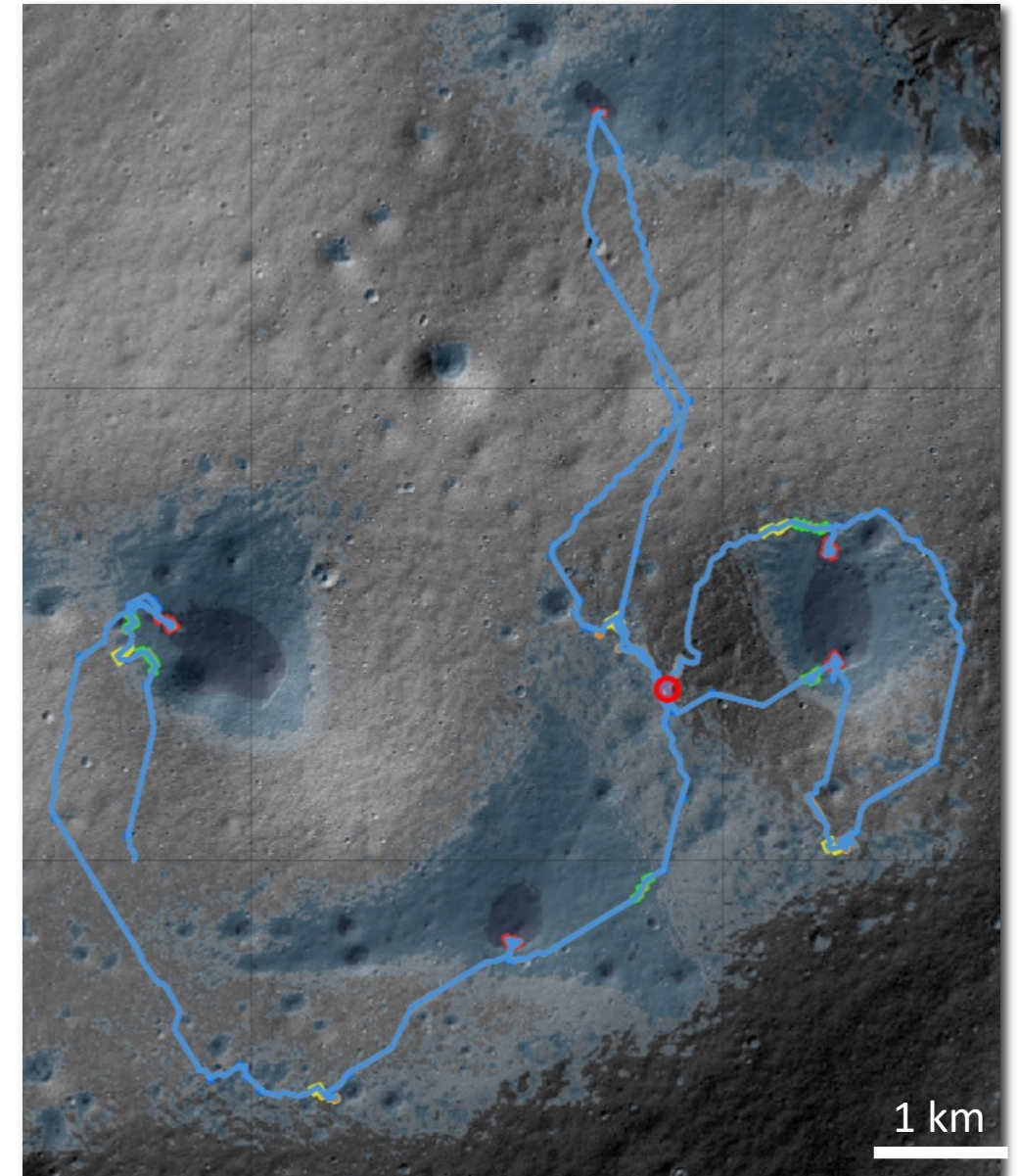
<https://svs.gsfc.nasa.gov>



Mission Specs

Lunar south pole

- 4+ lunar days near Nobile crater (approx. 84.6°S, 31.0°W)
- 20 km of traverse distance (with potential for 30+ km)
- Exploring temperature regimes ranging from 40 K to 300 K
- 50x drilling activities (to 1m depth)
- 1,700 m prospecting in PSRs (multiple entries)
- 20 cm/s max driving speed (approx. 5x Perseverance)
- 0.8 cm/s “Speed Made Good” (approx. 25x Perseverance)



Flight Rover

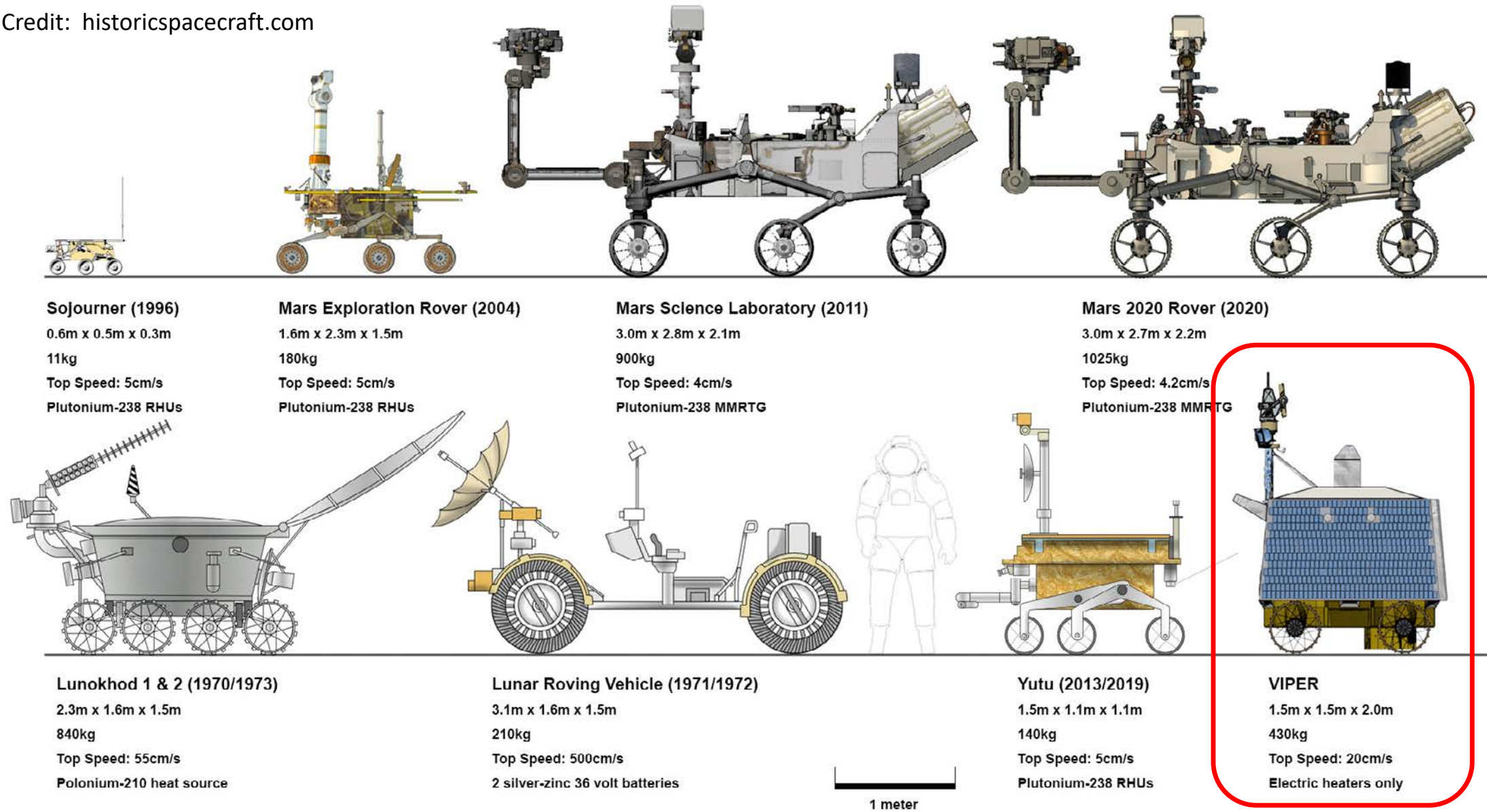


Assembly
complete
4 June 2024



Rover Comparison

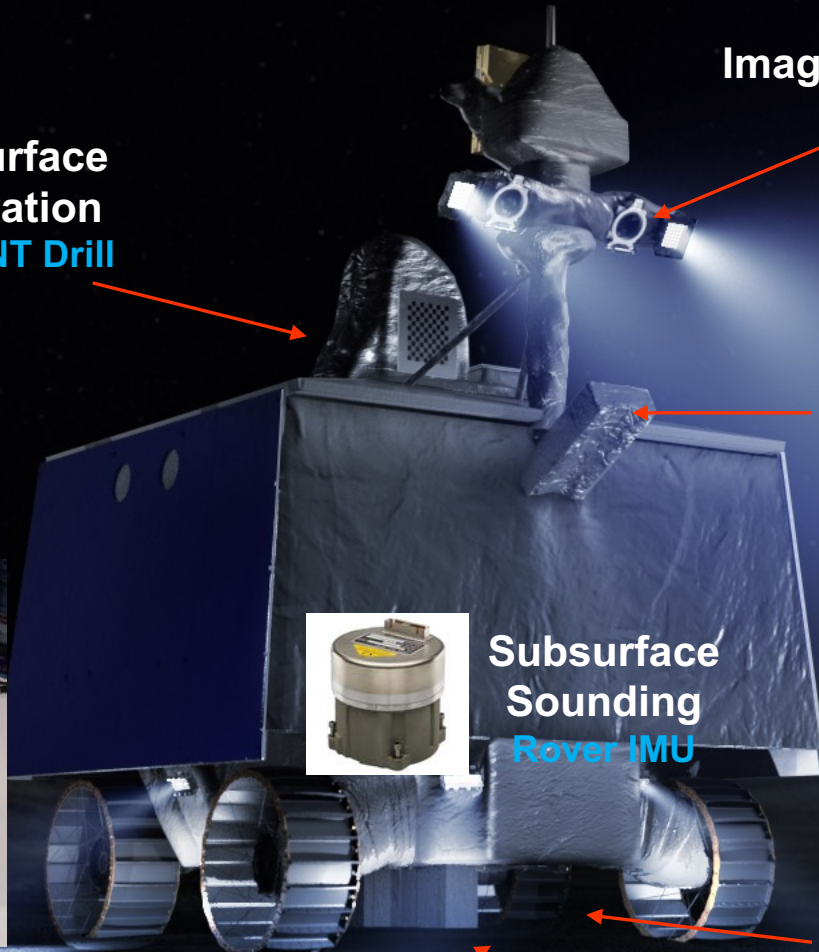
Credit: historicspacecraft.com



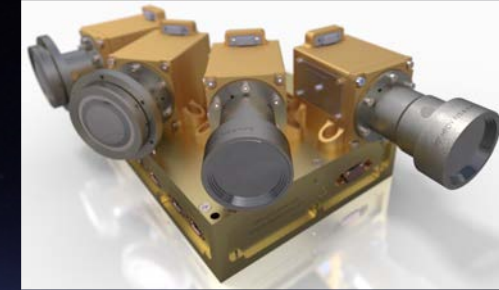
Instruments



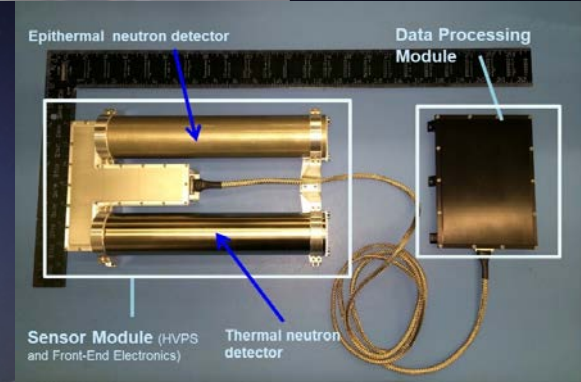
Subsurface excavation
TRIDENT Drill



Imaging Science
VIS



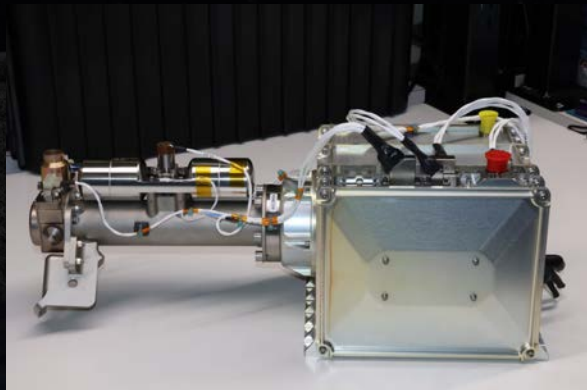
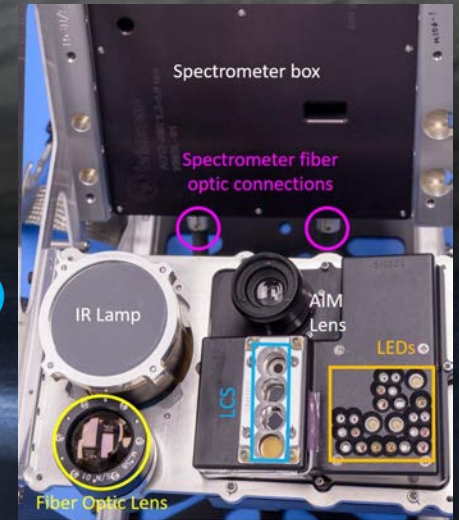
Prospecting
Neutron Spectrometer System (NSS) Instrument



Subsurface Sounding
Rover IMU



Prospecting & Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS) Instrument



Prospecting & Evaluation
Mass Spectrometer Observing Lunar Operations (MSolo) Instrument

Mobility Architecture

Independent Wheel Modules (4x)

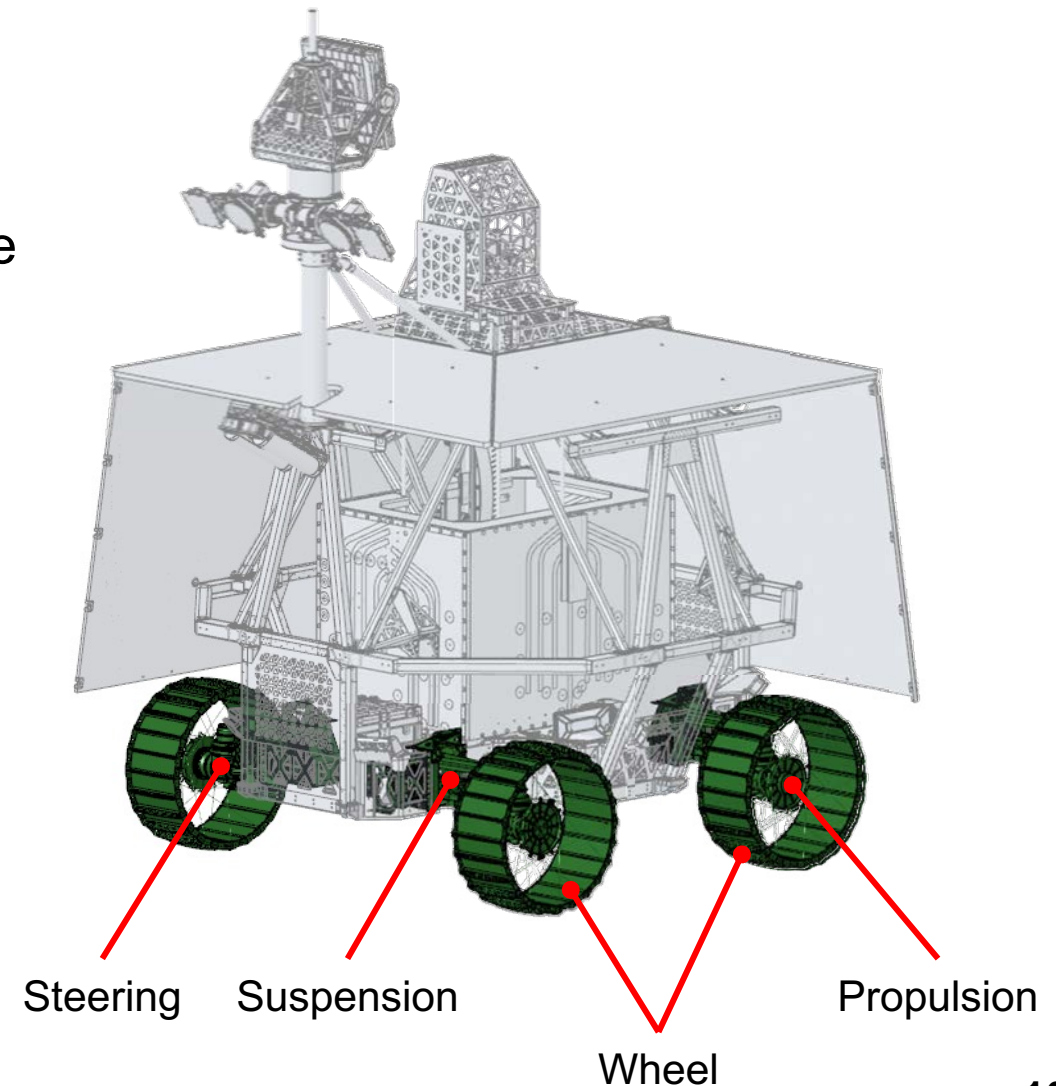
- Suspension: $\pm 40^\circ$, 200 N·m torque
- Steering: $\pm 50^\circ$, 130 N·m torque
- Propulsion: 20 cm/s, 200 N·m torque

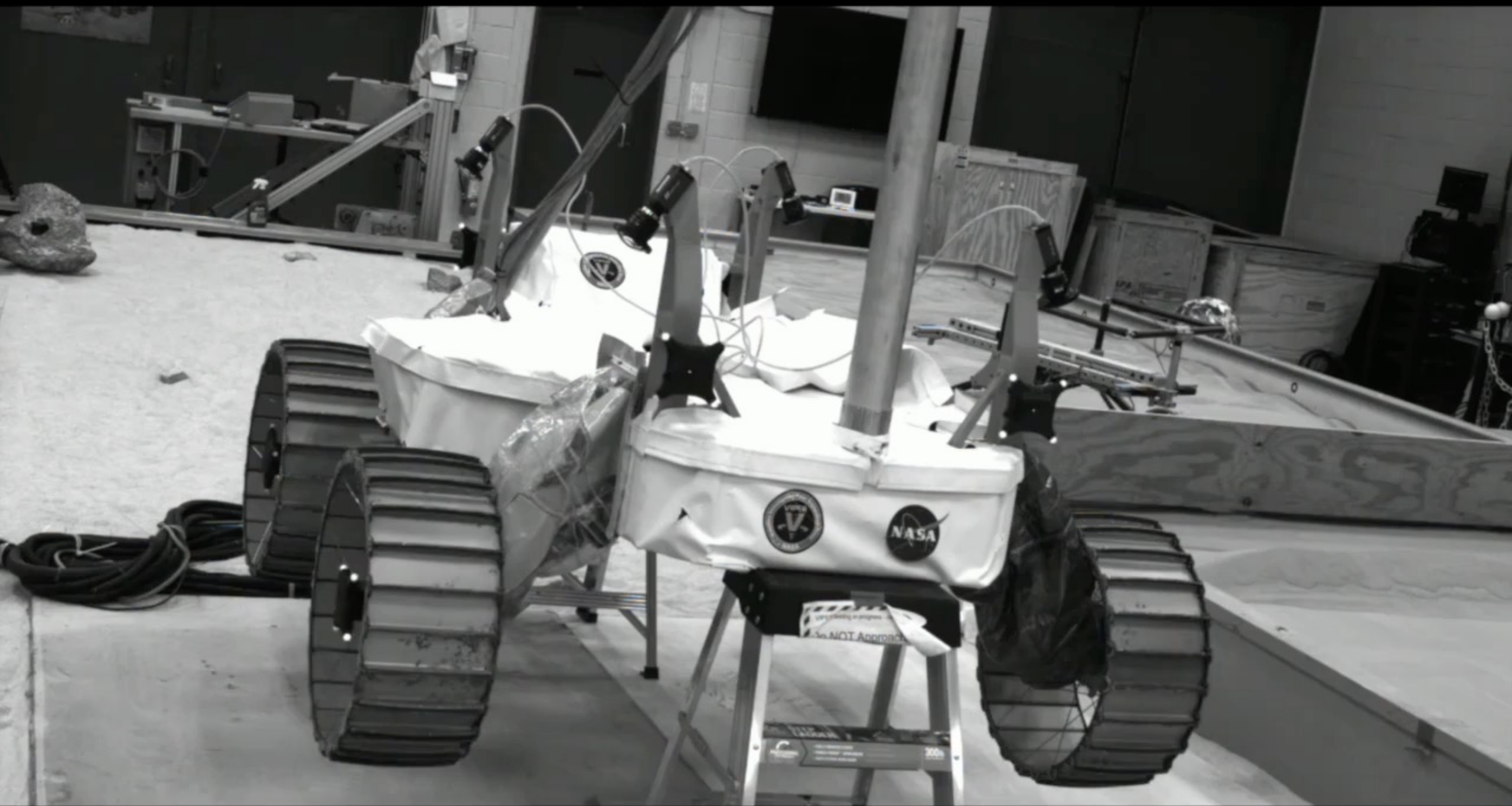
Wheels (4x)

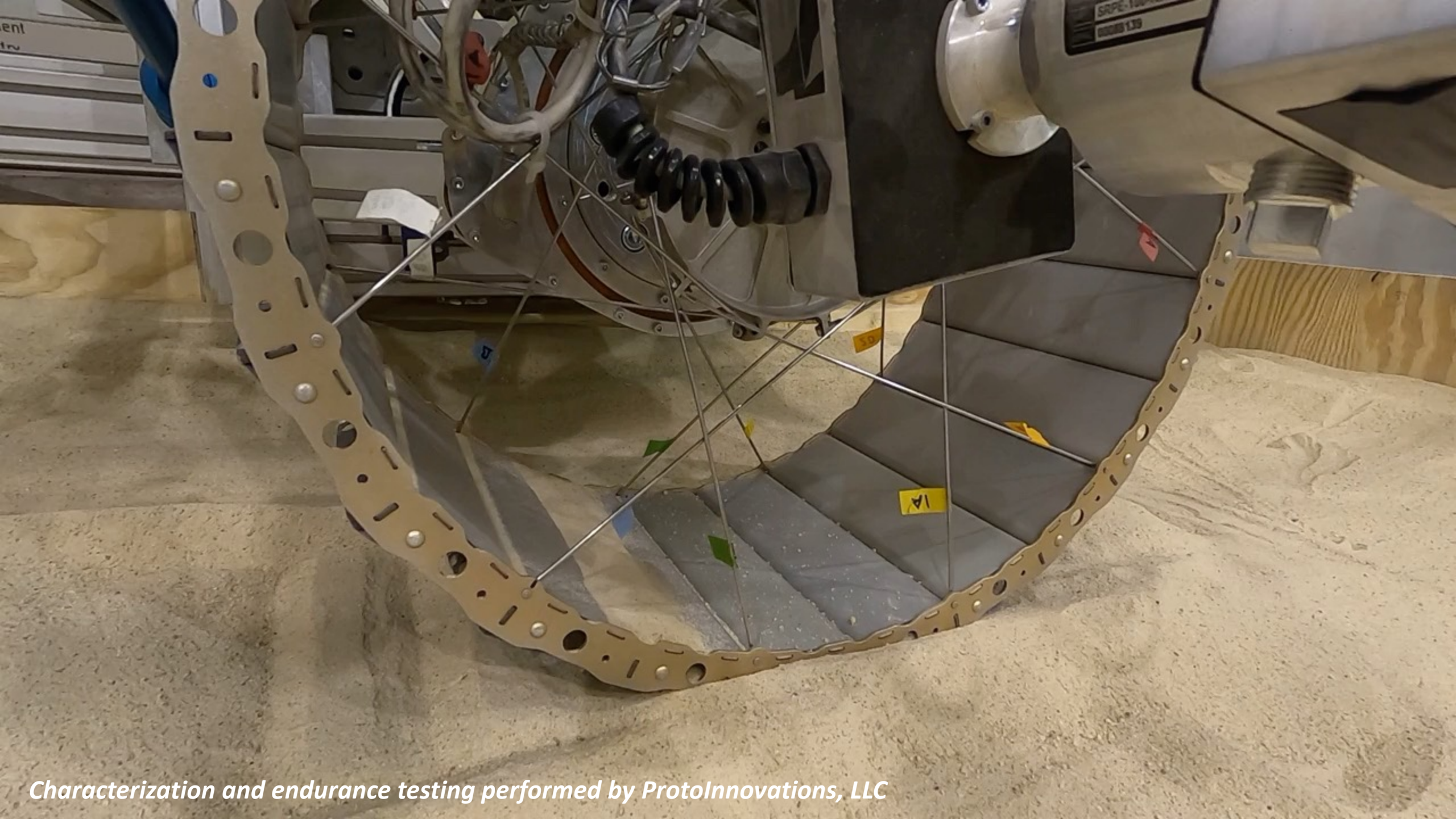
- 50 cm diameter, 20 cm wide
- Rigid sheet metal with spokes
- Rim grousers

Capabilities

- Actuated suspension enables body attitude and clearance control
- Explicit steering and skid steering
- Alternate mobility

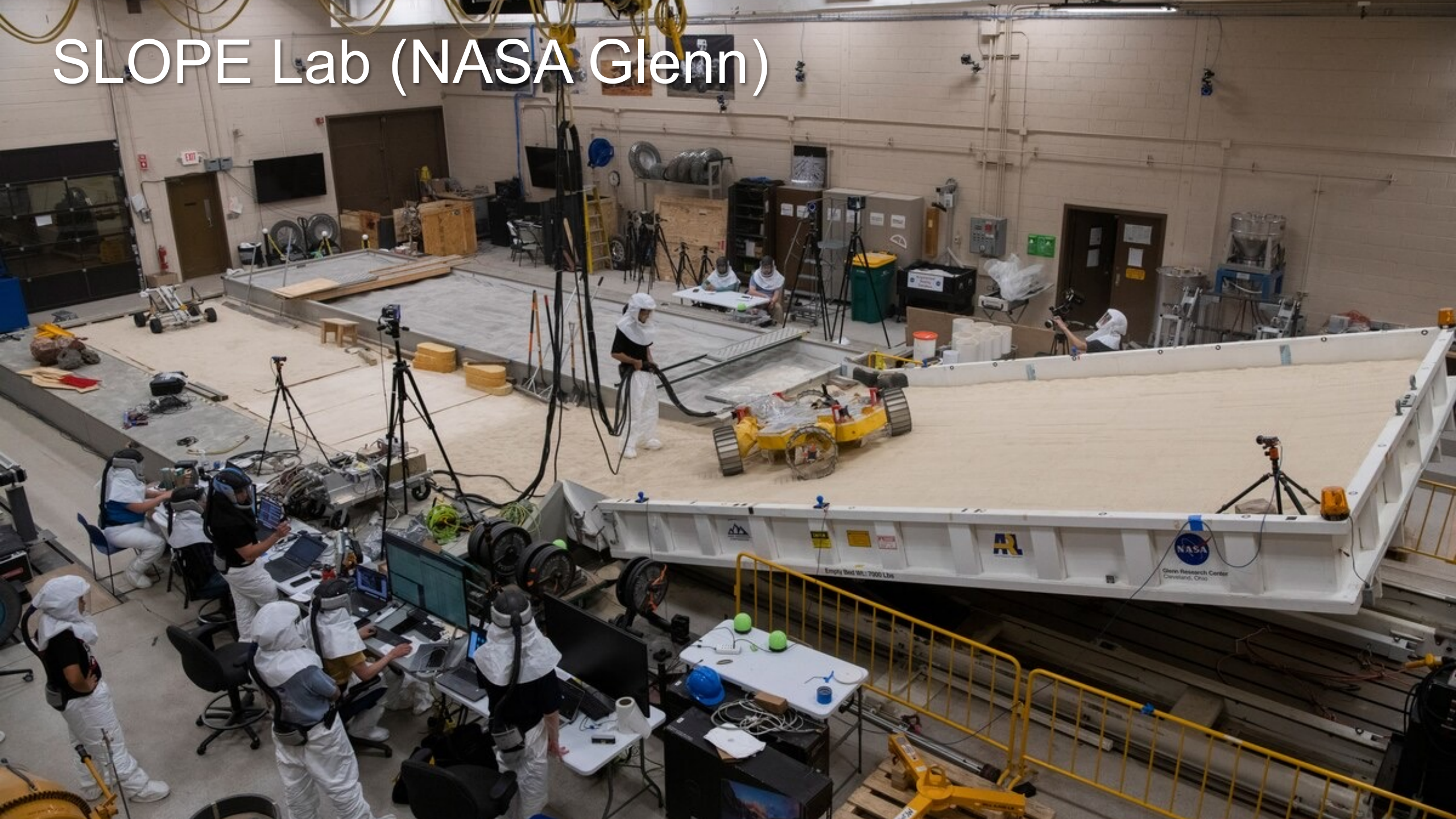






Characterization and endurance testing performed by ProtoInnovations, LLC

SLOPE Lab (NASA Glenn)



Rock Traversal Testing



Rock with attached load cell

Crater Traversal Testing



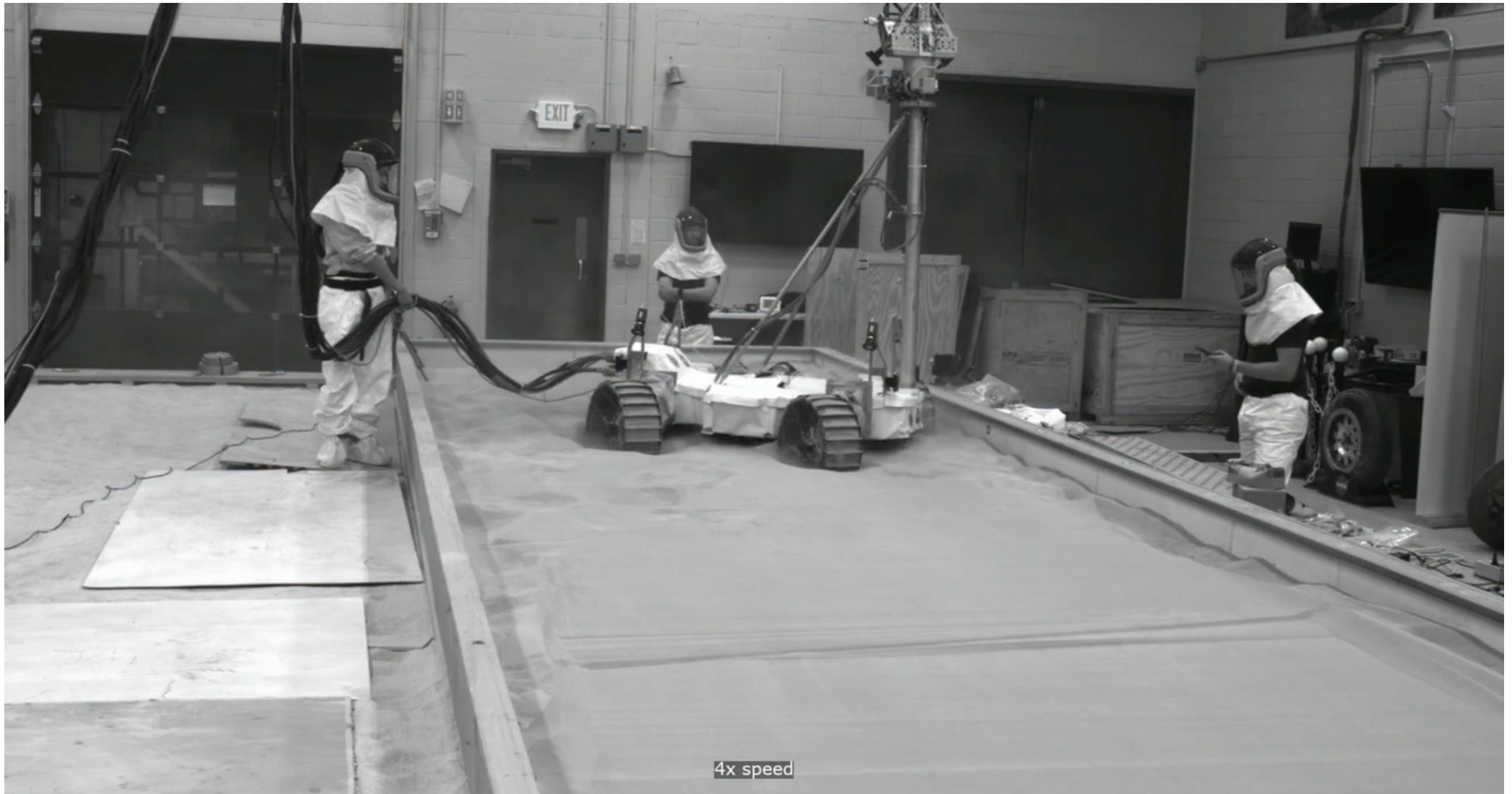
Slip Testing (30° Slope)



Entrapment Testing

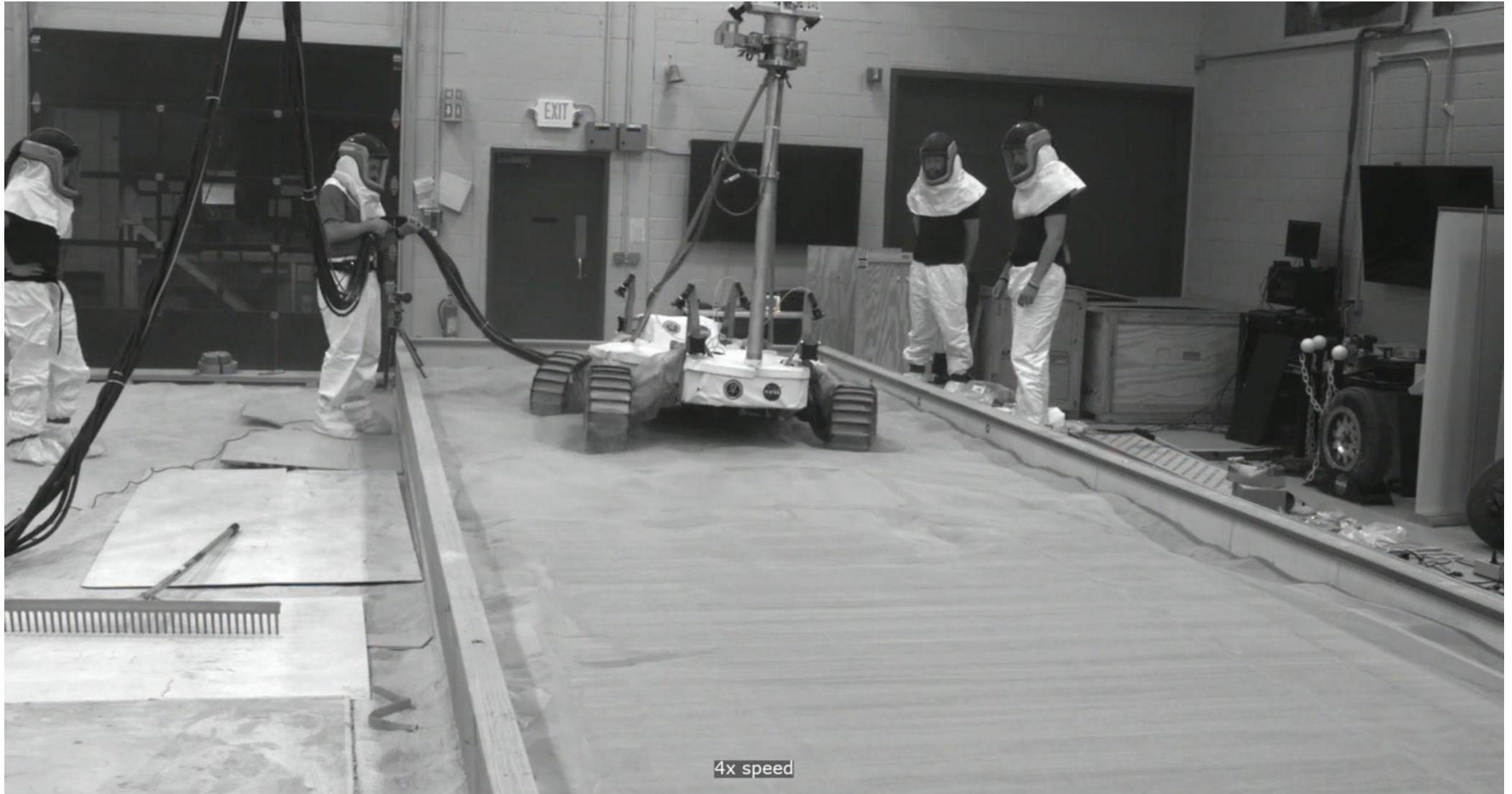


Alternate Mobility Modes



“Inchworm”

Alternate Mobility Modes



“Wheel Walking”

Camera & Light Testing

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

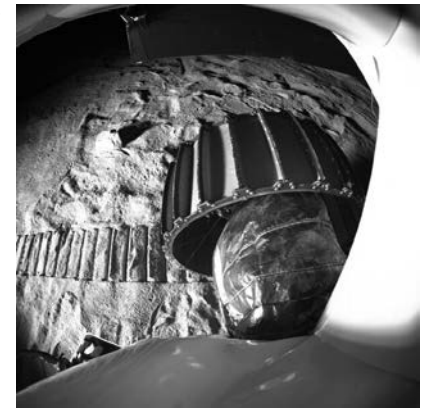
Experimental setup

- 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



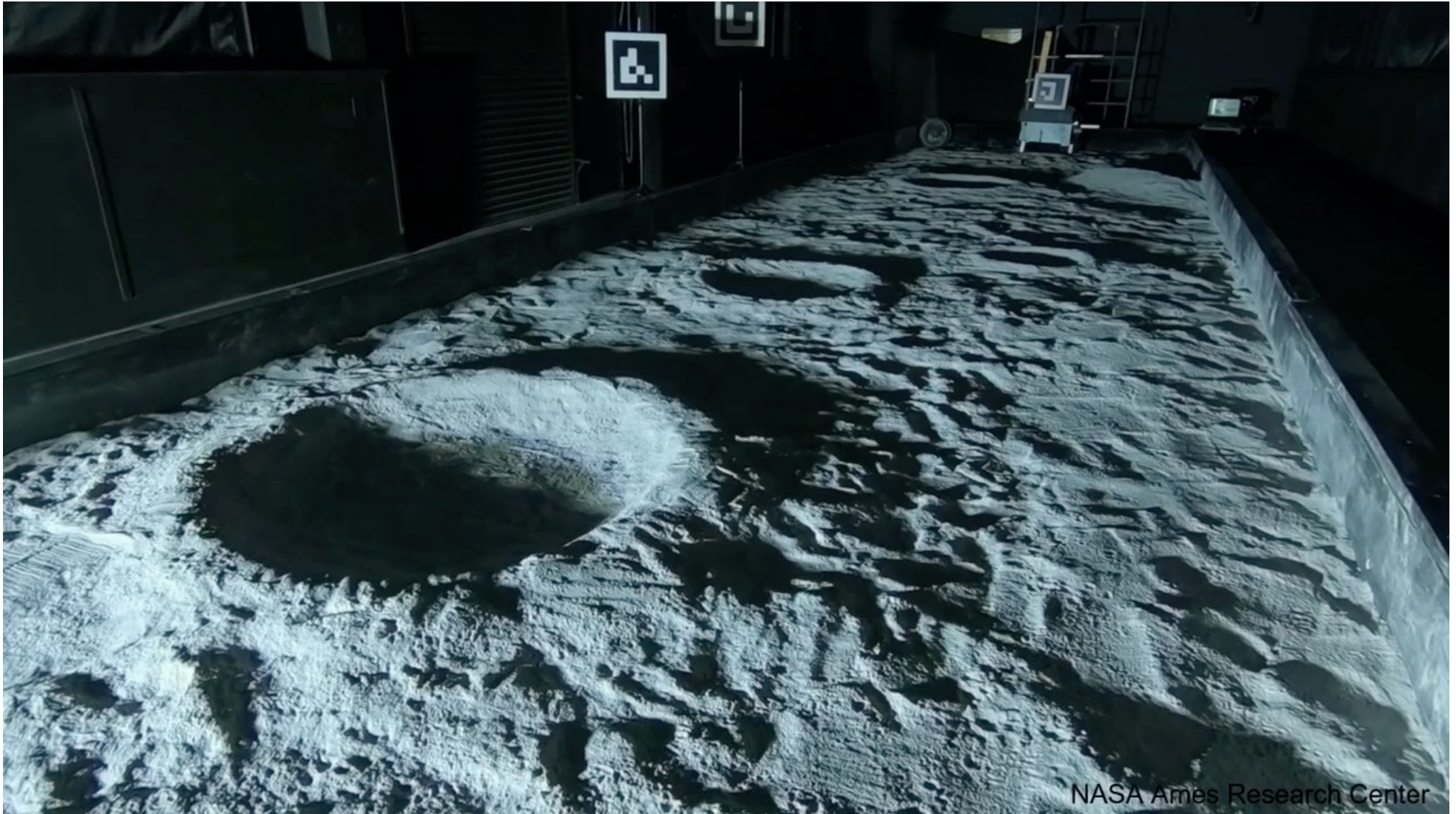
Simulated polar lighting on LHS-1 terrain

*Appearance of
VIPER rover wheel
and tracks*



*Sliding gantry over
LHS-1 terrain*

NASA Ames “Lunar Lab”



NASA Ames Research Center

4m x 19m sandbox with 12+ tons of LHS-1 lunar regolith simulant



VIPER Mission Planning

Objectives

- Develop activity, resource, and traverse plans
- Strategic and tactical plans
- Robustly achieve full science success under uncertainty

(A few) constraints

- Measure distribution and state of lunar polar volatiles
- Solar-powered rover with limited battery (shadow endurance)
- Lunar summer “season” (~100 Earth days max)
- Line-of-sight data communications to Earth
- 20 km max drive distance (design limit)
- 15 deg slopes + 20 cm step obstacles (design limit)
- 10 cm/s drive speed while prospecting (instrument limit)
- Moving shadows cast by rover and terrain (0.1 to 1.8 cm/s)

Traverse Planning

Challenge

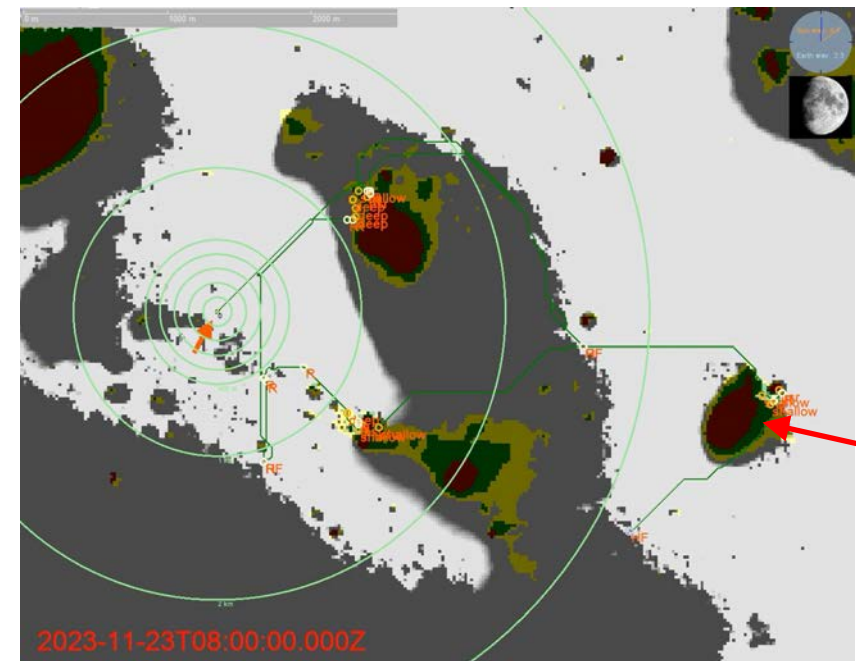
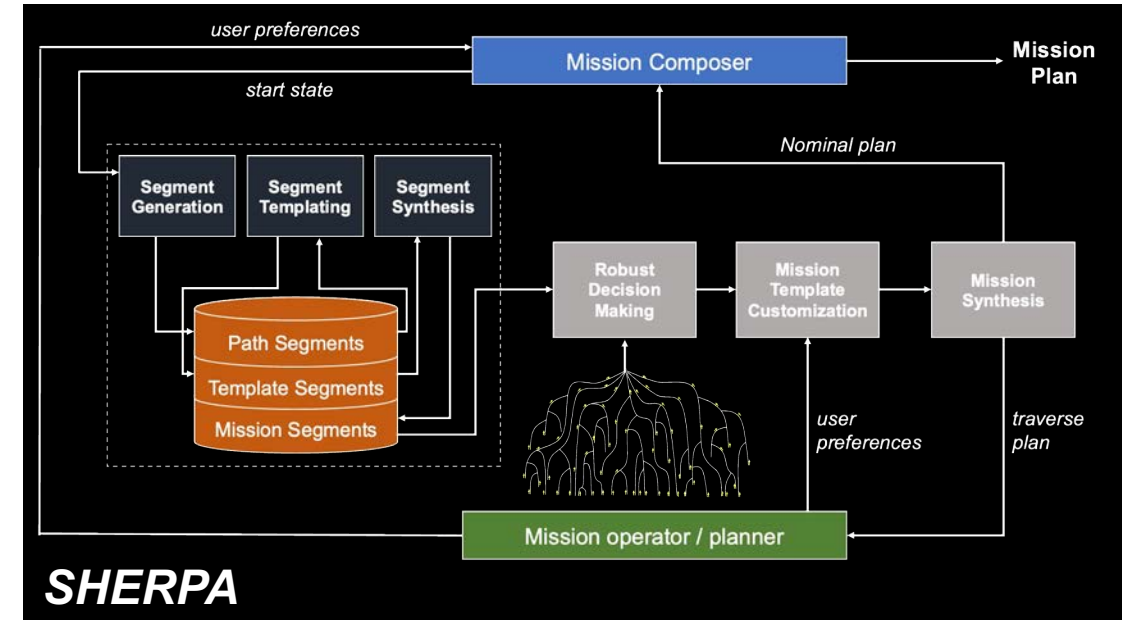
- Identify **feasible rover path** in a complex, dynamic environment
- Required to make the mission conops & mission plan possible

AI solution

- AI decision support system
- Multiple AI solvers (rule-based, Markov processes, etc)
- Monte Carlo sims to evaluate thousands of candidate plans

Impact

- Saves many work-years of manual planning
- Enables real-time replanning



100 day
traverse
with
dynamic
shadows

Permanently
Shadowed
Region (PSR)

VIPER Rover SIM

High-quality lunar lighting

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

High-fidelity camera models

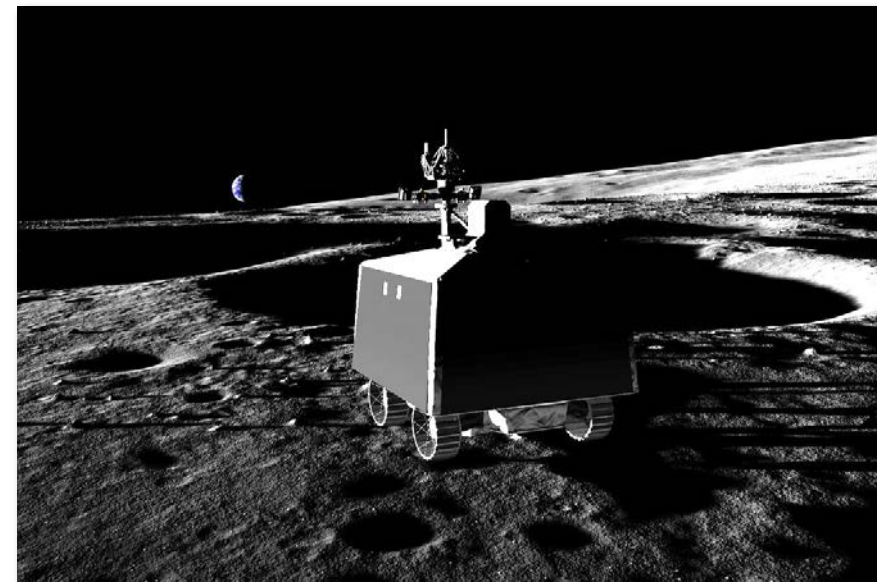
- Exposure, distortion, flare, fixed pattern noise, pixel defects, bit depth, read noise, etc.
- Tuned using NASA Ames “Lunar Lab” tests with camera/light EDUs

Real-time slip modeling

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

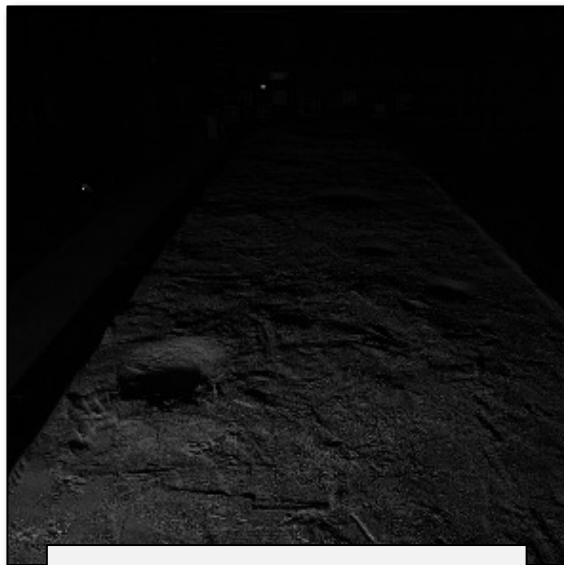
High-resolution lunar terrain models

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

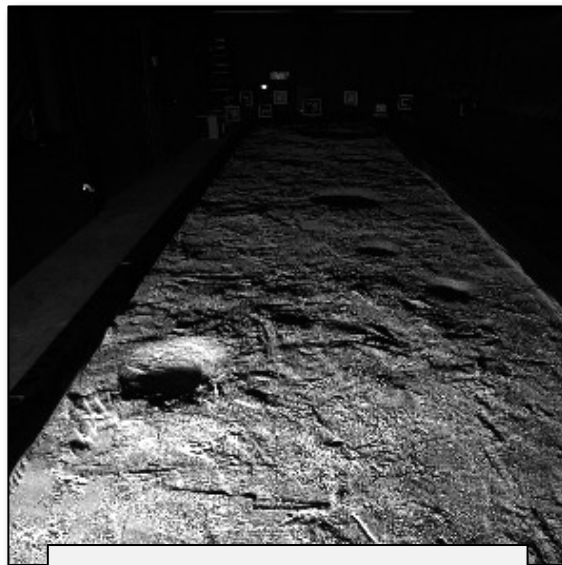


High-fidelity Camera Models

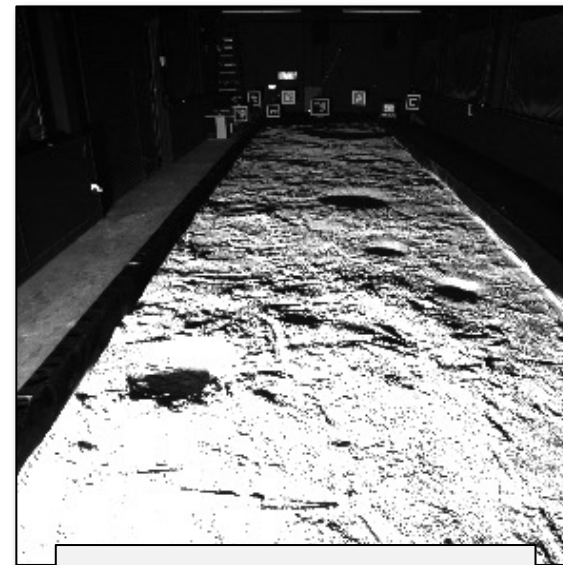
Lunar Lab



Under Exposure

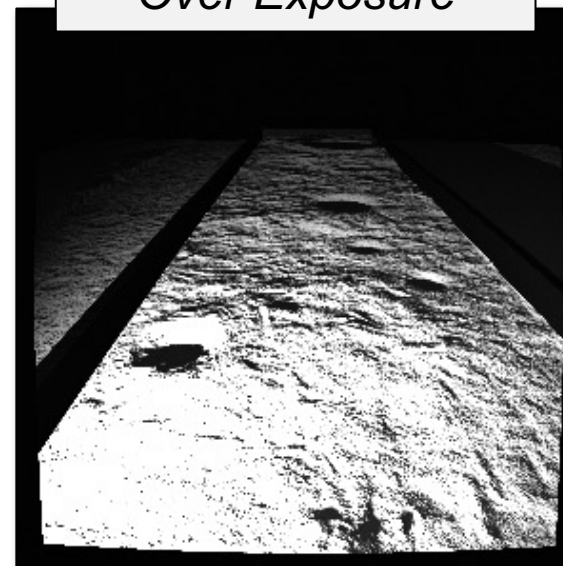


Optimal Exposure



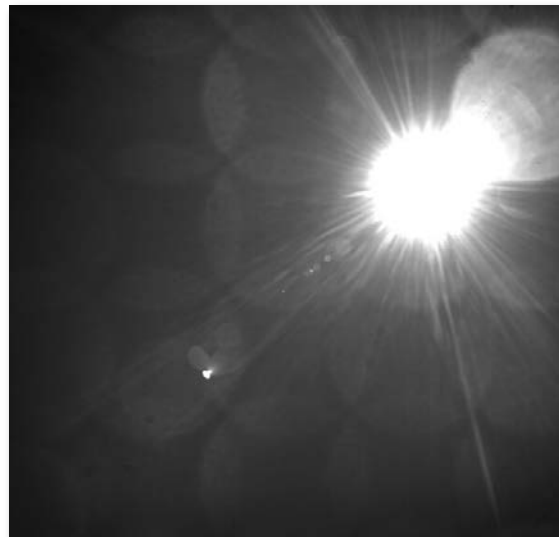
Over Exposure

RSIM



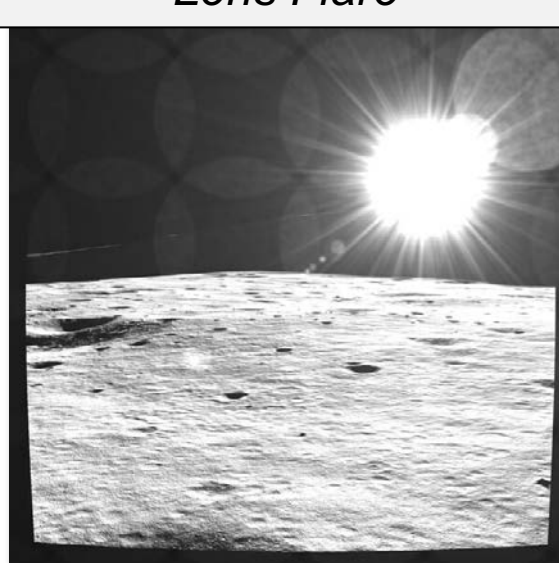
High-fidelity Camera Models

Lunar Lab



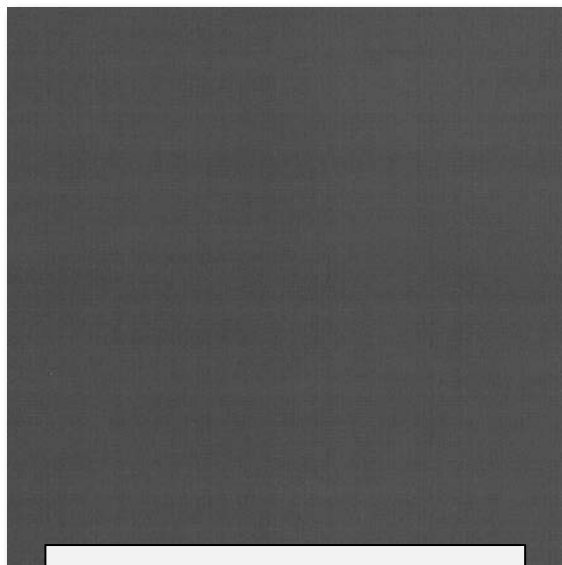
Lens Flare

RSIM

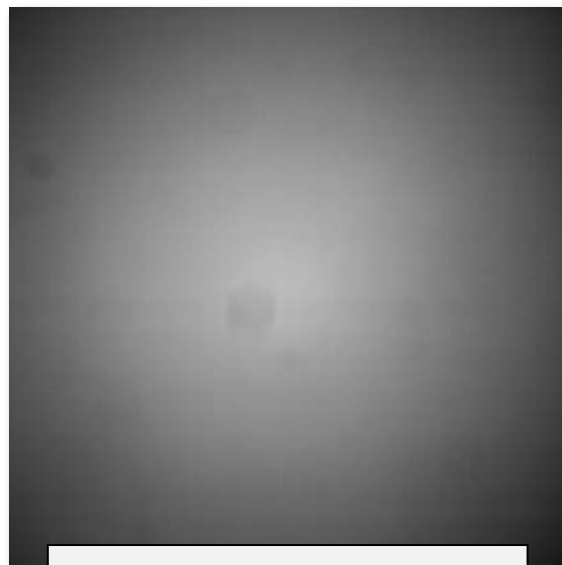


High-fidelity Camera Models

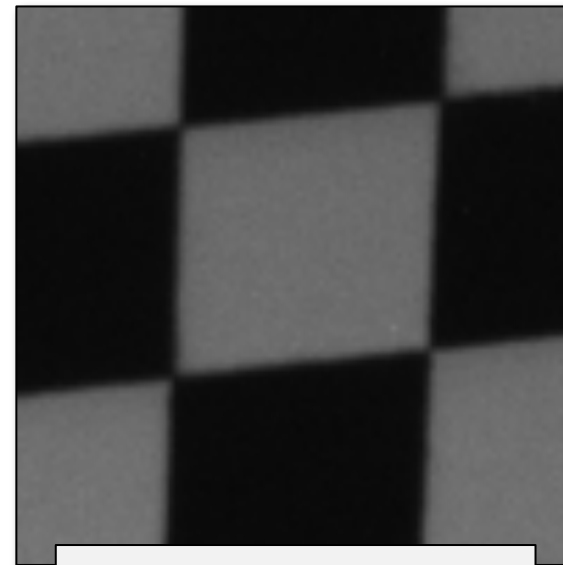
Lunar Lab



Fixed Pattern Noise

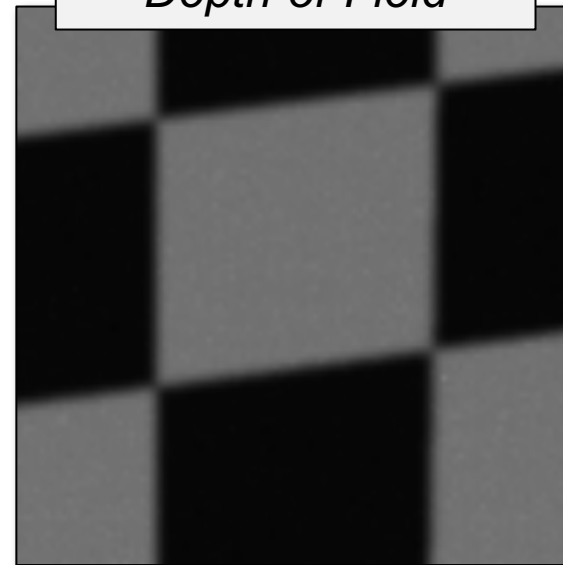
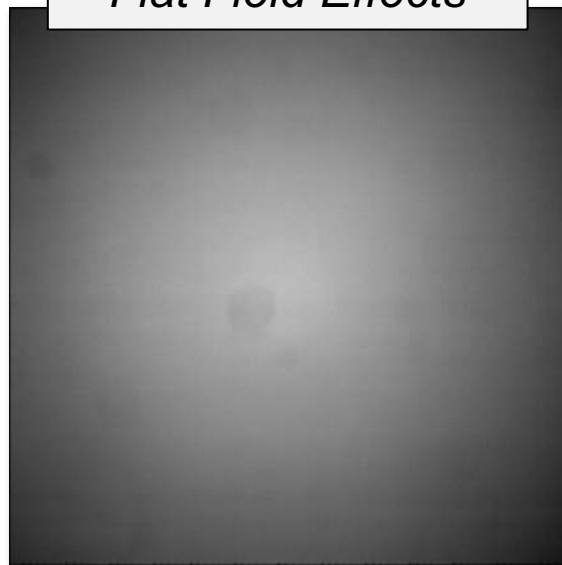
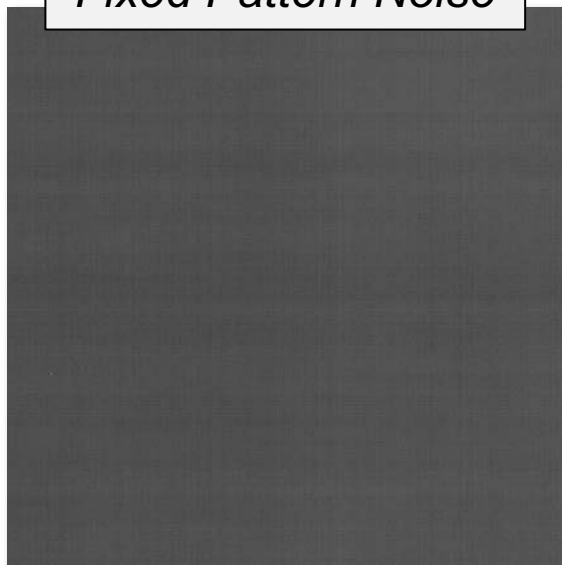


Flat Field Effects



Depth-of-Field

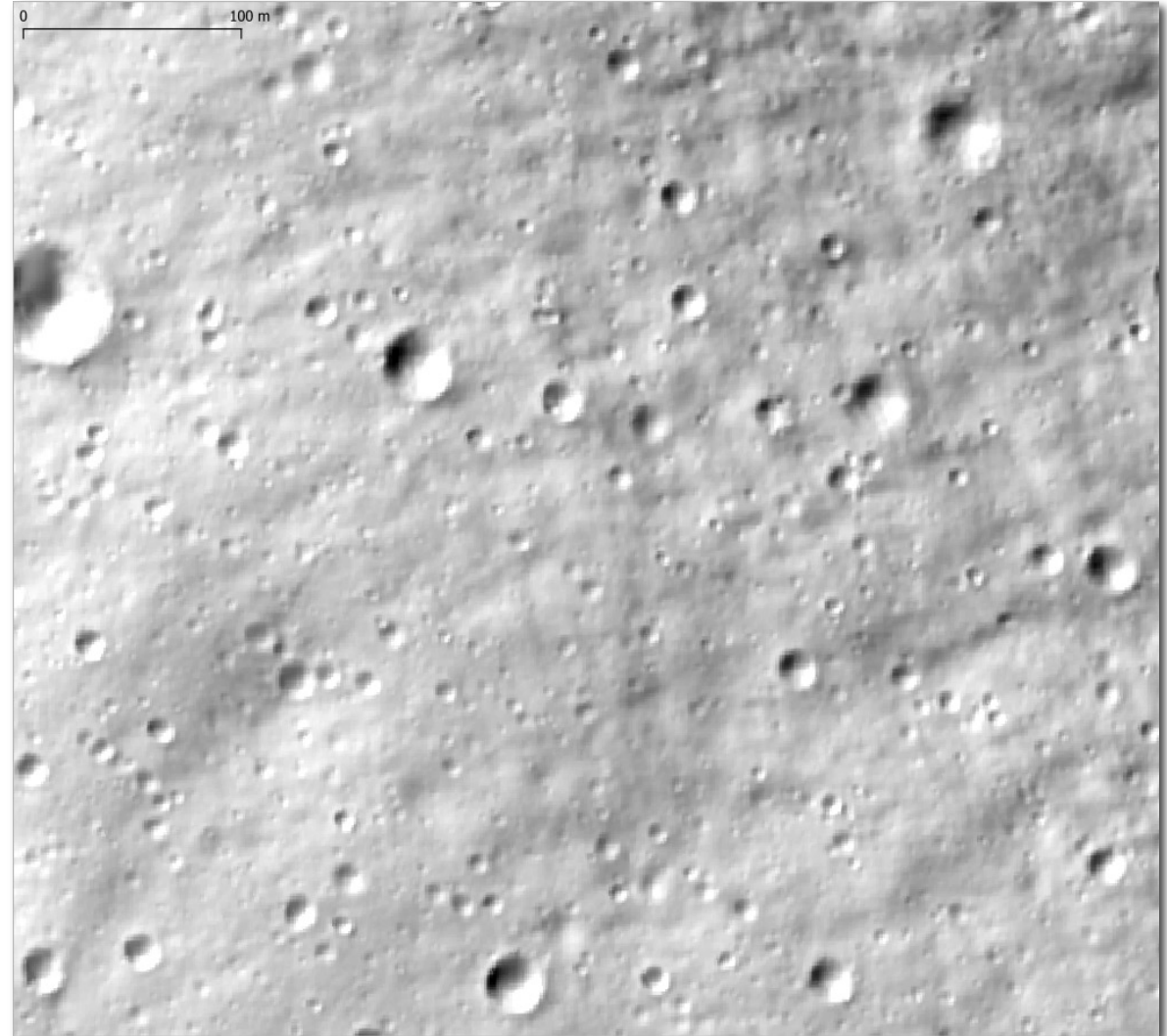
RSIM



Lunar Digital Elevation Models (DEM)

Ames Stereo Pipeline

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



"Shape from Shading" (SfS) DEM at 1 m/pixel

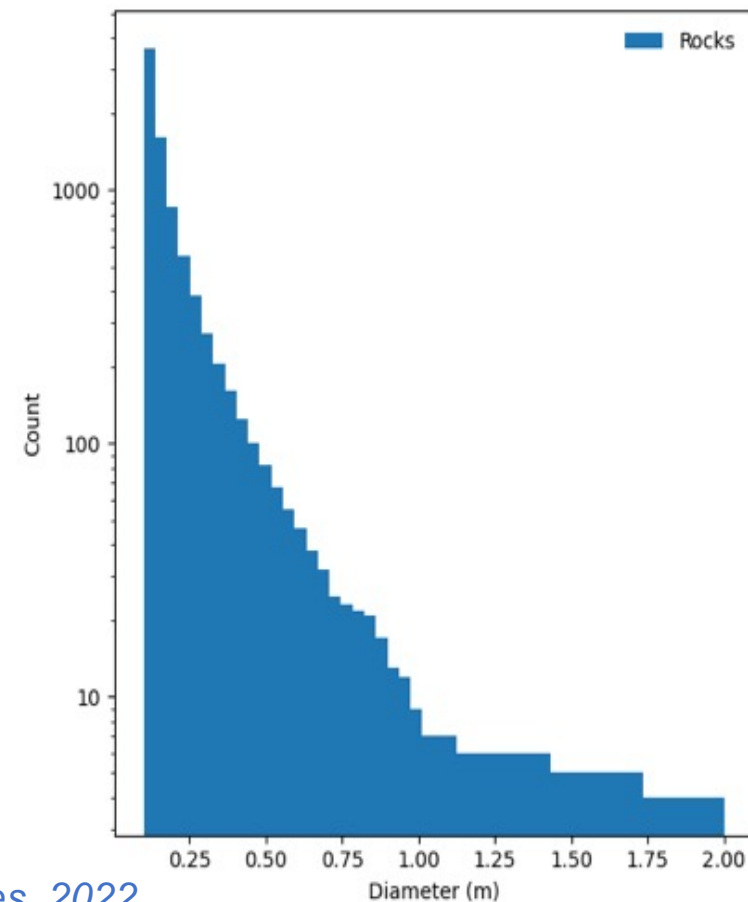
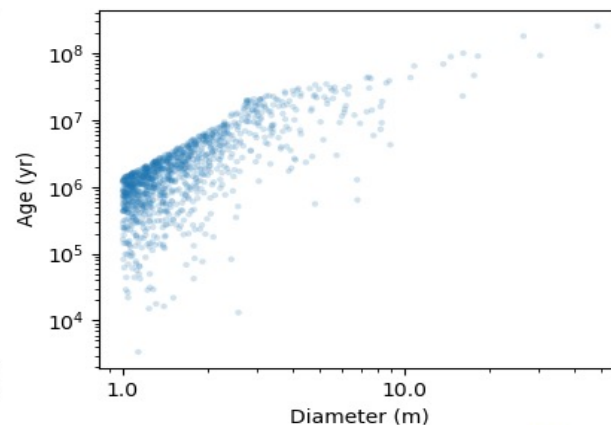
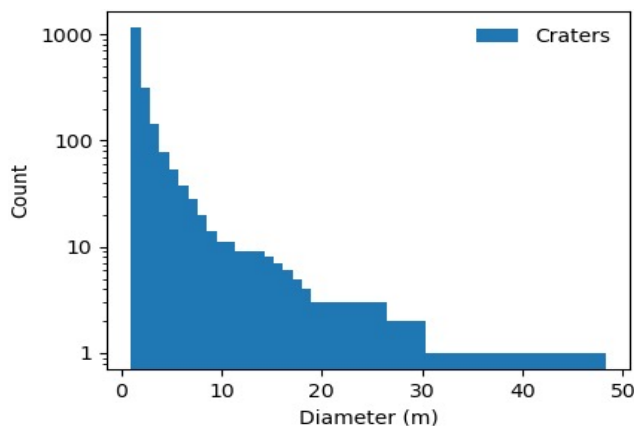
VIPER Synthetic Terrain Tools

Objective

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

Approach

- Begin with lunar SfS DEM (1 m/pixel)
- Upscale DEM via fractal synthesis (4 cm/pixel)
- Add synthetic craters and rocks based on size-frequency distribution studies*
- Apply age effects (e.g., crater shape)

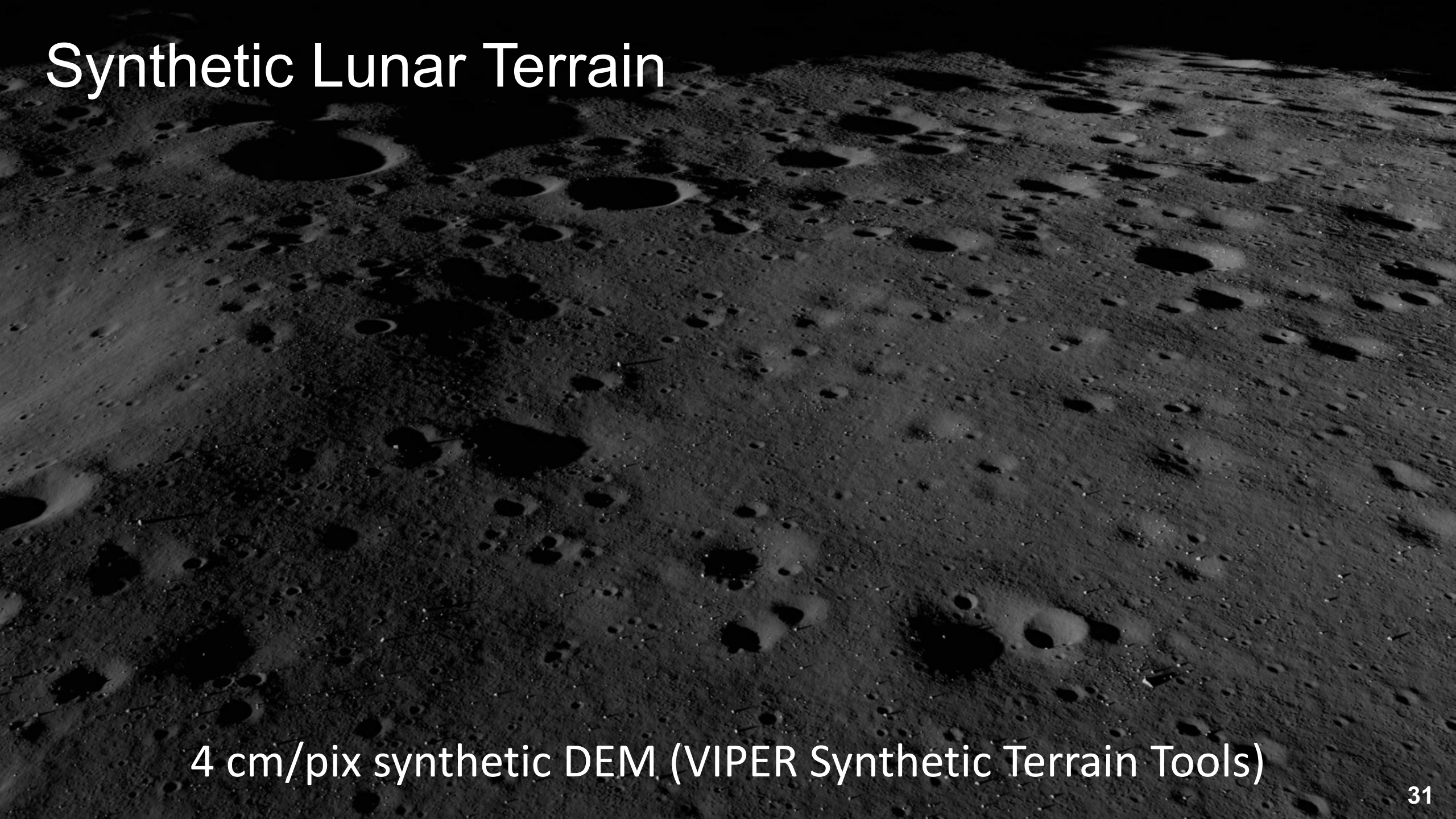


*VIPER Environmental Specification, VIPER-MSE-SPEC-001, NASA Ames, 2022.

Actual Lunar DEM

1 m/pix SfS DEM (Ames Stereo Pipeline)

Synthetic Lunar Terrain

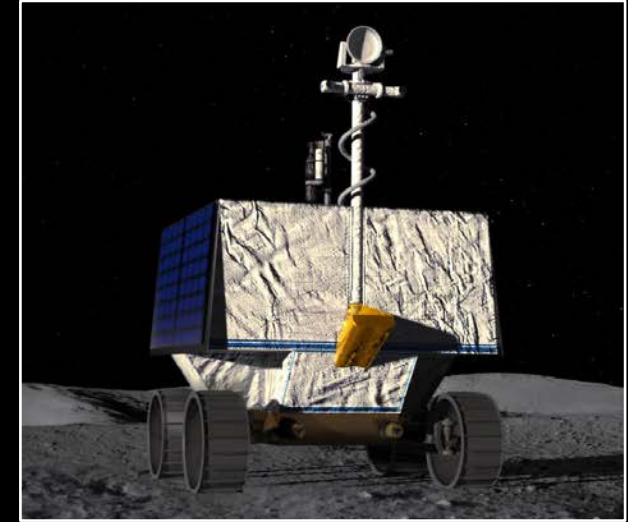
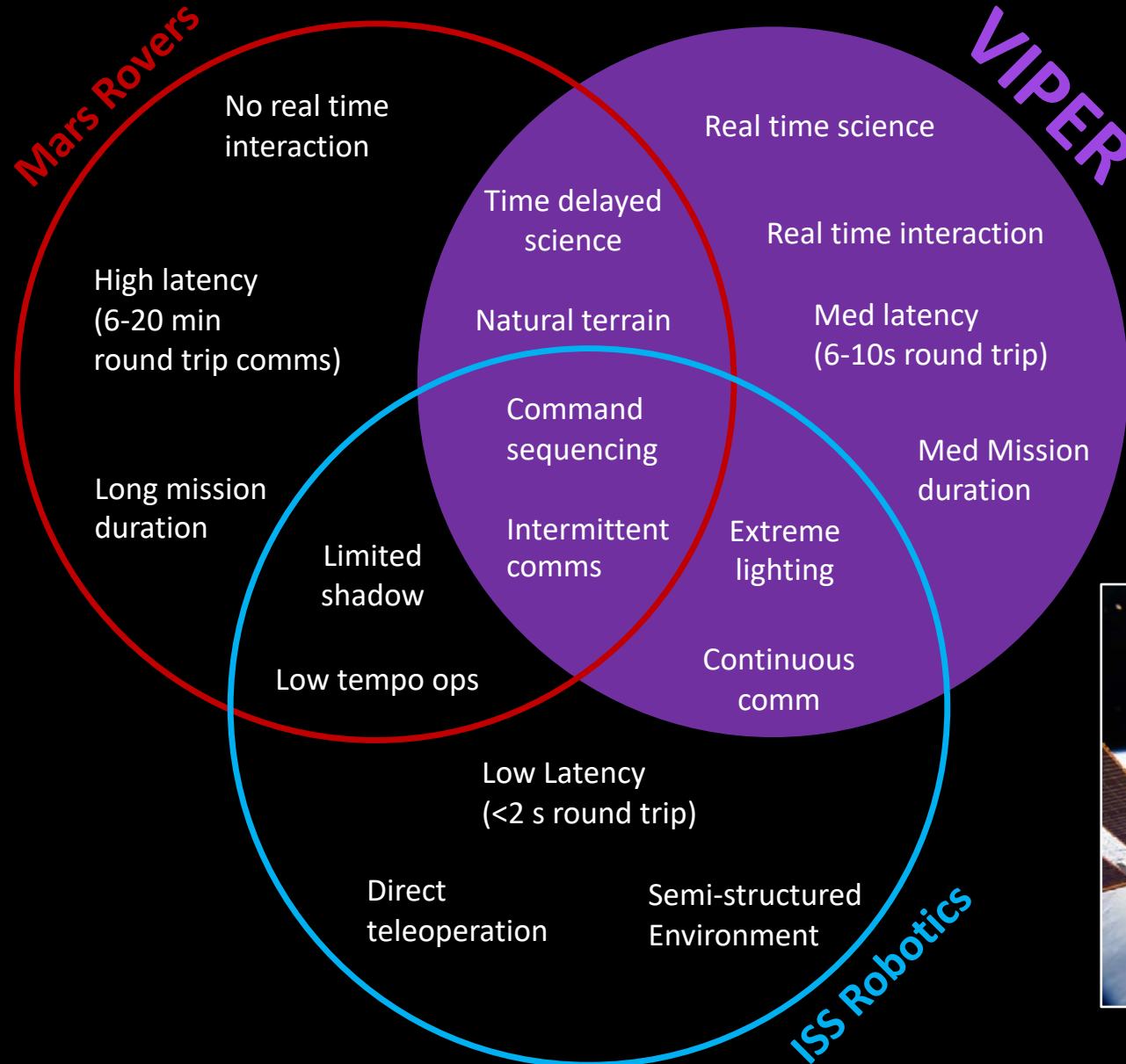
A grayscale synthetic Digital Elevation Model (DEM) of the lunar surface. The terrain is covered with numerous craters of various sizes, from small pits to large, deep basins. The lighting creates strong shadows, highlighting the rugged topography and the distribution of impact features across the landscape.

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



Real-time lunar surface simulation (VIPER RSIM)

Robotic Mission Operations



Rover Navigation

Challenge

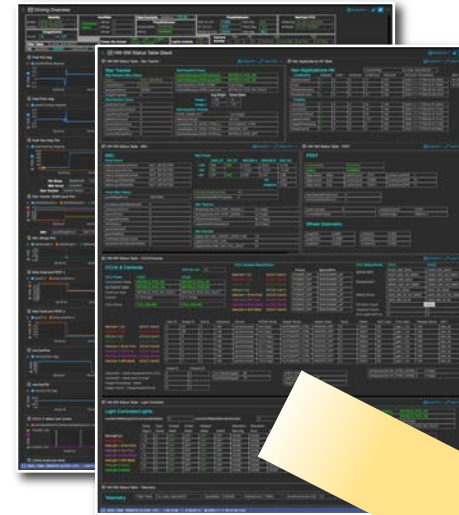
- **Navigation mission ops** is high-stress, high-workload, and mission critical for rover safety & science
- 1 operator is responsible for 21 HW components + 4 SW modules

AI solution

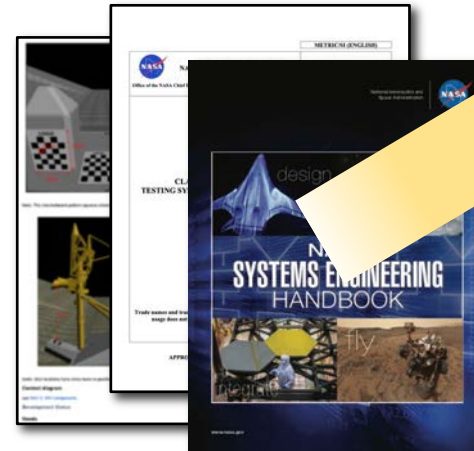
- Large Language Model (LLM) + Physics Informed Neural Net
- Provides automatic event summarization, knowledge retrieval, and anomaly response
- Collab with Microsoft Azure

Impact

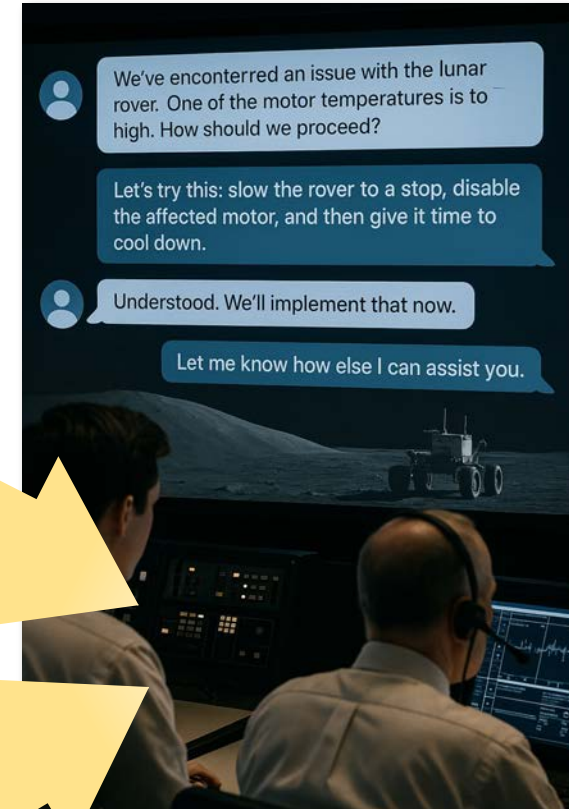
- Improves operator efficiency and increases mission robustness



telemetry



documentation



AI decision support



Rover Driving



VIPER Mission Operations Center (NASA Ames)

“Drive Team”

Real-Time Science

Driver

Co-Driver

Navigator



Drive Team Command Cycle Tasks

Task	Driver	Co-Driver	Navigator	Real-Time Sci
Assess rover state	Review mobility state Review mobility health Review current pose	<i>Shadow driver</i>	Review nav sensor state Review nav sensor health Review localization quality	
Assess terrain hazards	Assess geometric hazards Assess non-geometric hazards (near/mid-field)	<i>(when possible)</i>	Review hazard product (hazmap, point clouds) quality	Assess non-geometric hazards (mid/far field)
Plan tactical path	Define tactical path based on traverse plan, terrain hazards, ops constraints (power, science, thermal, etc.), & drive techniques	Sanity check (concur)	Provide nav constraints	Provide science constraints (spatial & temporal tolerances)
Plan rover motion	Define next rover move (posture or pose change mode, etc)			
Plan navigation imaging	Define next imaging based on consideration of traverse plan, imaging constraints (incl science), and localization needs	Sanity check (concur)	Sanity check (concur)	Sanity check (concur)
Command rover motion	Confirm driving is authorized Countdown to command Execute command	<i>Call halt if needed</i>	<i>Call halt if needed</i>	<i>Call halt if needed</i>
Command navigation imaging	Confirm imaging is authorized Countdown to command Execute command	<i>Call halt if needed</i>	<i>Call halt if needed</i>	<i>Call halt if needed</i>

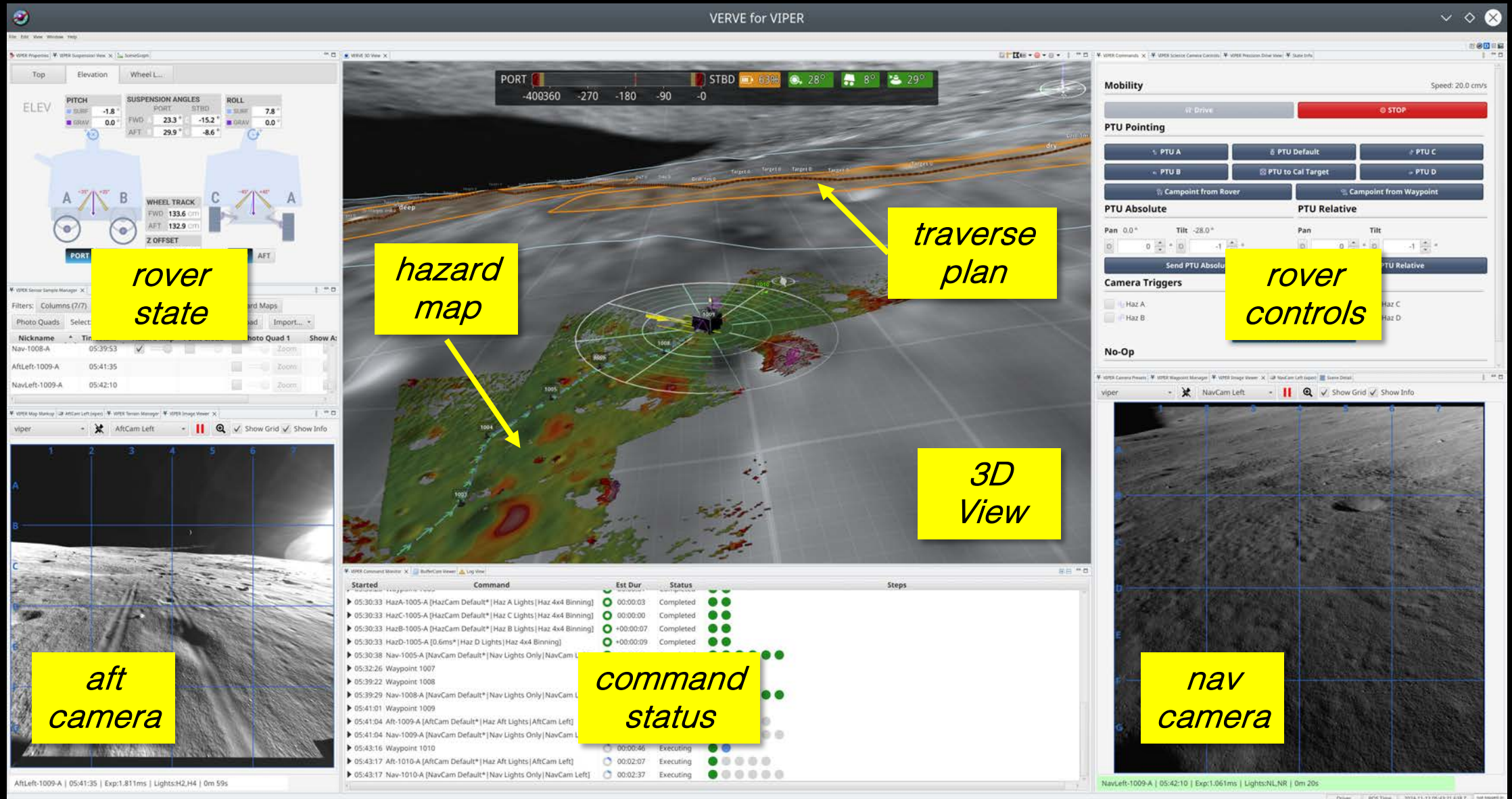
SENSE

PLAN

ACT

5 min duration

Rover Driving Interface (VERVE)



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
	Nav-1013-B [NavCam Default*] [Nav Lights ...]	+00:02:35	Overdue
		00:00:19	Executing

VERVE Suspension View

VERVE Science Camer...

State Info

Mobility

Speed: 20.0 cm/s

Drive

STOP

PTU Pointing

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

NavCam Stereo

AftCam Stereo

Haz C

Haz D

Trigger ...

VERVE Precision Drive View

Suspens...

Drive

Advanced

States

DRIVE_CART

SUSP_CART

DFT_ON

ATT_ON

Z Offset

36.5 cm

27 cm

ATT_ON

ATT_OFF

rover simulator

VERVE Image Viewer

NavCam Left

NavCam Left

VERVE Camera

VERVE Waypoi...

NavCam Left

NavCam Left

Refine Waypoint + Command Motion

The screenshot displays the Verve 3D View interface, which is used for controlling a rover in a simulated environment. The main window shows a 3D perspective view of the rover on a lunar surface, with a color-coded terrain map overlaid. The interface includes several panels and controls:

- VERVE 3D View:** The main 3D rendering area showing the rover and the terrain. A color scale at the top indicates elevation from -400 to 0.
- VERVE Commands:** A panel on the right containing controls for mobility (Drive/STOP), PTU pointing (PTU A, B, C, D, Default, Cal), and camera triggering (Haz A, B, C, D, NavCam Stereo, AftCam Stereo).
- VERVE Precision Drive View:** A panel below the commands showing drive parameters like Z Offset (36.5 cm) and various status indicators (ATT_ON, ATT_OFF).
- VERVE Command Monitor:** A table at the bottom left listing commands, their status, and completion times.
- VERVE Sensor Sample Manager:** A panel at the bottom right showing sensor data and sample types.
- VERVE Image Viewer:** A panel on the right showing a live video feed from the rover's camera.

The text "rover simulator" is overlaid in orange on the right side of the image. The word "VERVE" is written in large red letters in the bottom left corner.

Started	Command	Est Dur	Status
01:50:33	Waypoint 1010	00:00:02	Completed
01:50:49	Set Pan/Tilt (-11.2°/-21.1°)	+00:32:24	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°)	+00:29:27	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 ...	+00:03:07	Completed
02:19:56	Set Pan/Tilt (-50.7°/-14.6°)	00:00:09	Completed
02:20:00	Nav-1013-B [NavCam Default*] Nav Lights ...	+00:03:02	Overdue
02:20:08	Nav-1013-A:45F67A59	00:00:08	Executing

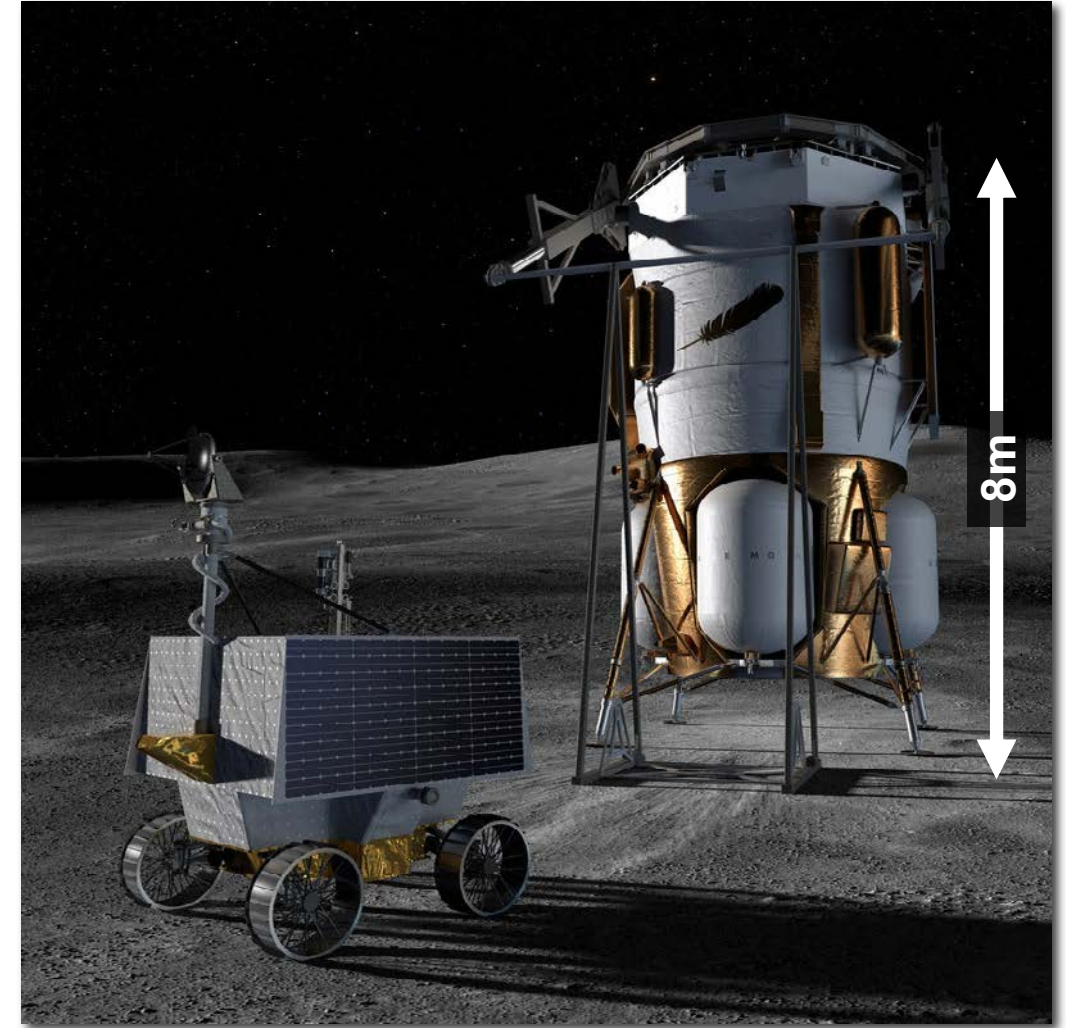
VIPER Flight Mission

To the Moon!

- Sept. 19, 2025 – Blue Origin selected to deliver VIPER to the Moon (CLPS CS-7 mission)

Blue Moon MK1 Lander

- Largest lunar lander built to date
- 8m tall, > 45,000 kg launch mass
- LOX/LH2 BE-7 engine
- Cold gas + Hot gas dual mode integrated RCS system
- Designed for the Blue Origin “New Glenn” launch vehicle (7m diameter fairing)



Credit: Blue Origin

Mission Schedule

Jan 2027	Flight rover integration to MK1 lander (SN-002)
Aug 2027	Launch (Cape Canaveral)
Sept 2027	Landing / start operations
Jan 2028	End of surface operations
Sept 2028	End of mission (data release to PDS)

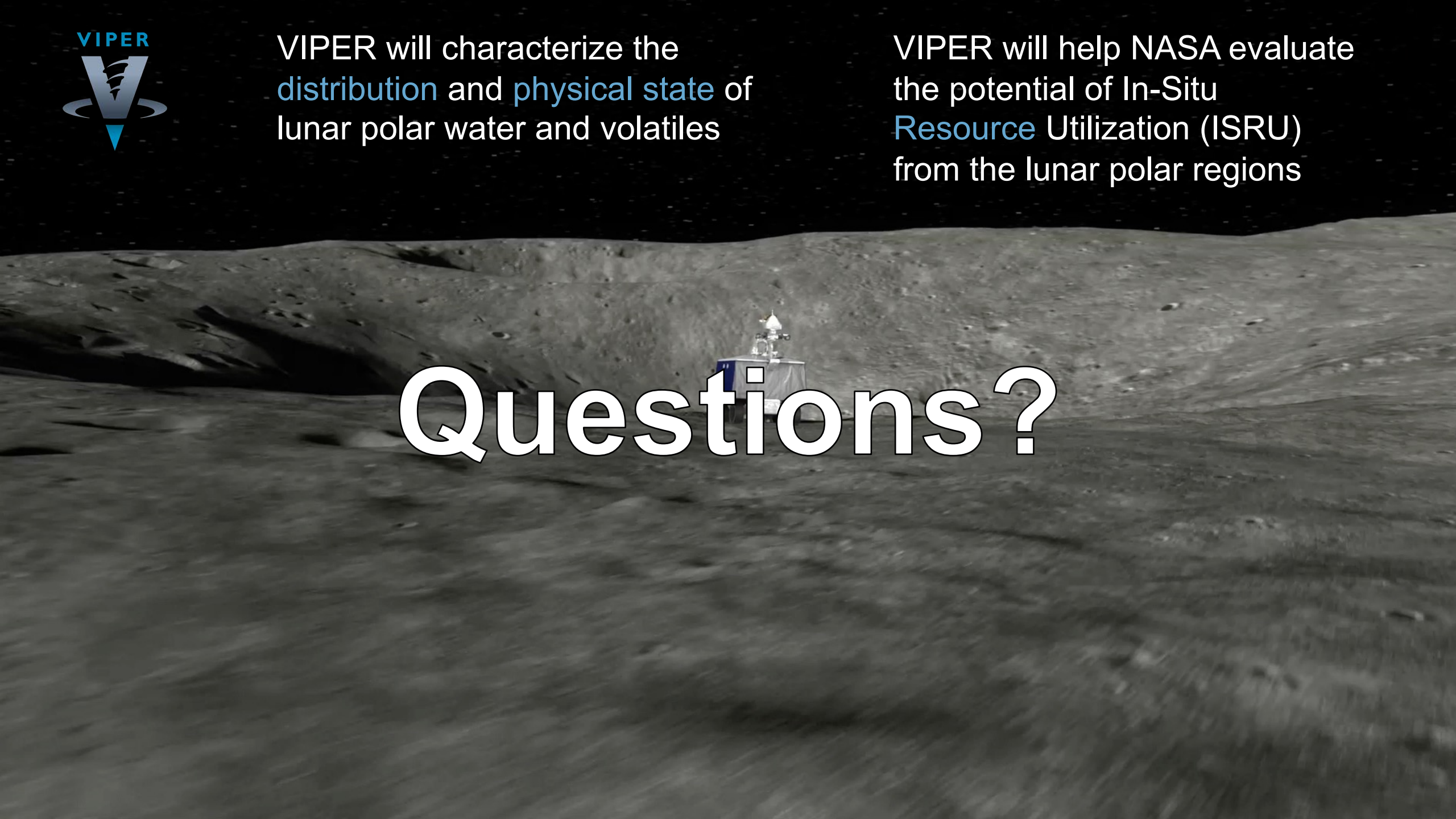


Flight rover operational readiness test
(17 April 2025)



VIPER will characterize the distribution and physical state of lunar polar water and volatiles

VIPER will help NASA evaluate the potential of In-Situ Resource Utilization (ISRU) from the lunar polar regions

A grayscale image of the lunar surface, showing a vast, cratered landscape under a dark sky. A small rover is visible in the distance, positioned on a ridge. The word "Questions?" is overlaid in large, white, sans-serif font with a thin black outline.

Questions?