National Aeronautics and Space Administration

VIPER

Volatiles Investigating Polar Exploration Rover

Terry Fong

Chief Roboticist

VIPER Deputy Rover Manager

NASA Ames Research Center

2 November 2022

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)**

Toward Understanding Lunar Water

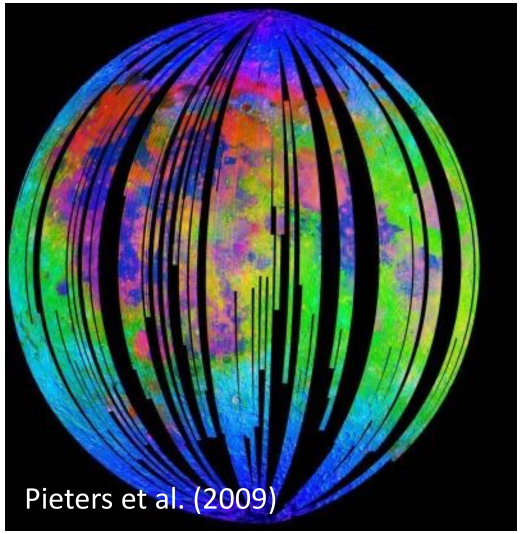
Moon now known to host all three forms of Solar System water: endogenic, sequestered external and in-situ*

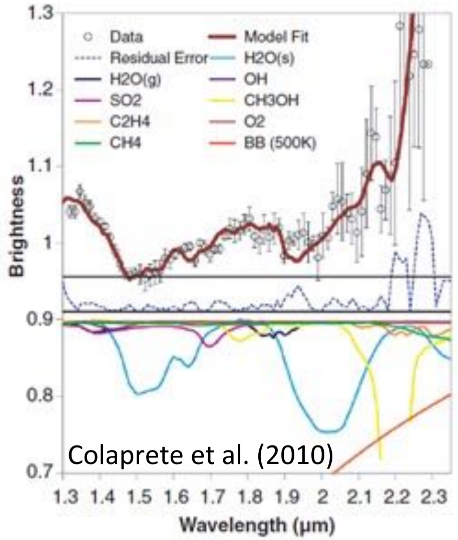
- Do not yet understand the concentration, evolution and interrelated dynamics of these varied sources of water

Understanding the distribution, both laterally and with depth, addresses key exploration and science questions

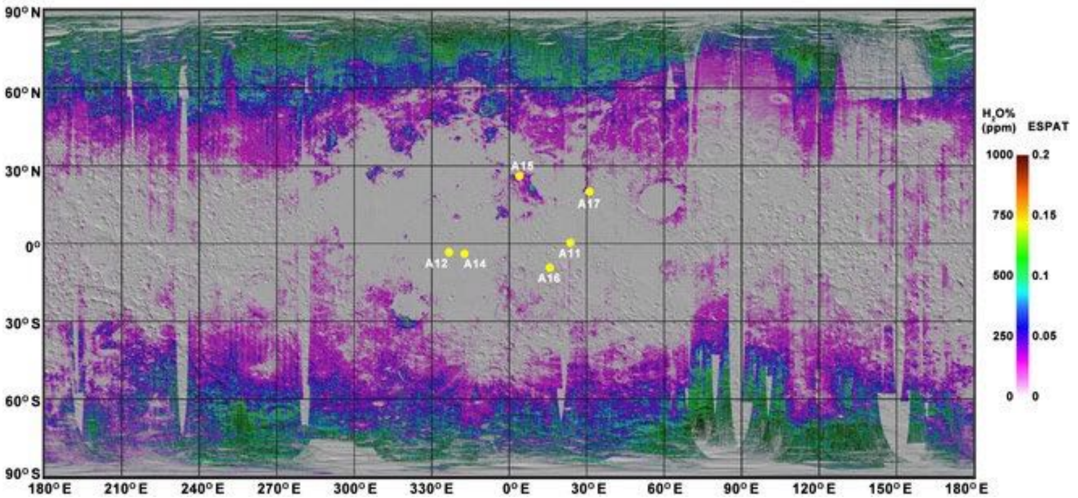
- Surface measurements across critical scales are necessary to characterize the spatial distribution and state of the water

"Prospecting" for lunar water at poles is the next step in understanding the resource potential and addressing key theories about water emplacement and retention


Pieters et al. (2009)



Colaprete et al. (2010)



Li and Milliken (2017)

*From Peters et al. Transformative Lunar Science (2018)

VIPER Mission

Lunar south pole

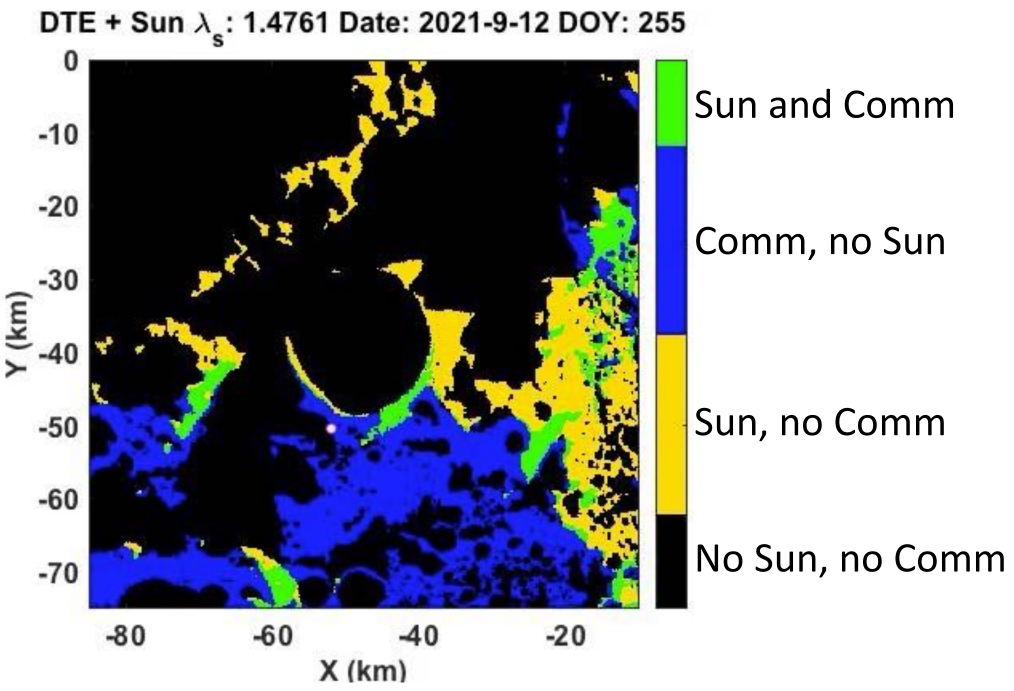
- Planned for Nov 2024 launch
- 100+ day mission (including extended survival periods)
- Up to 20 km total drive

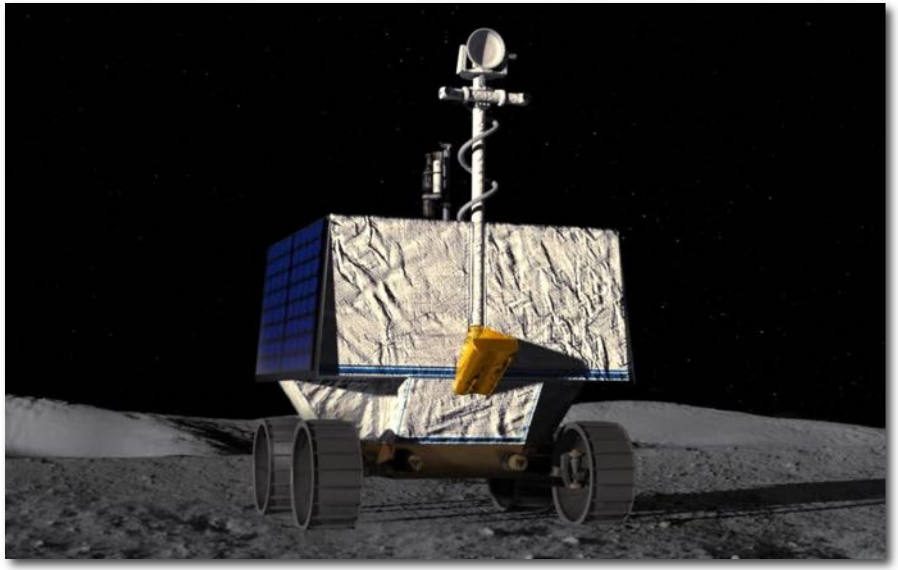
Science objectives

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

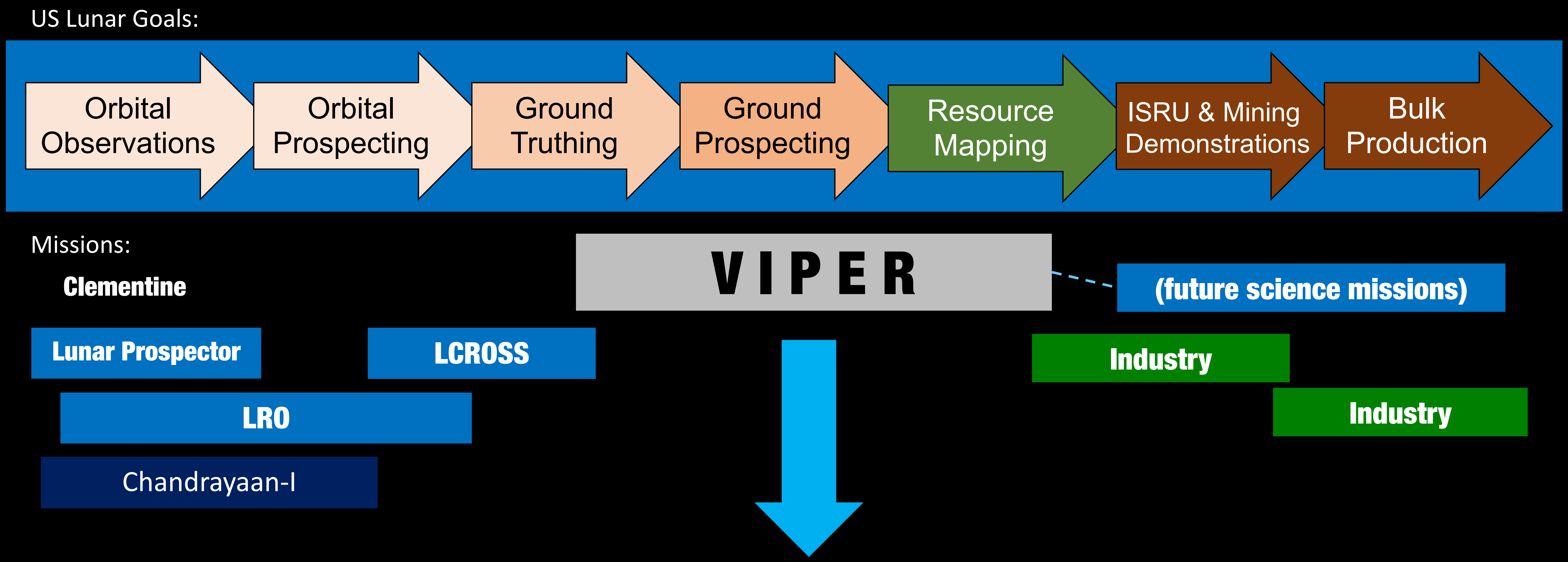
A few unique challenges (among many…)

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





The Big Picture of Lunar Resources



VIPER bridges Government and Industry missions – informing and reducing risk for future utilization of in-situ volatiles

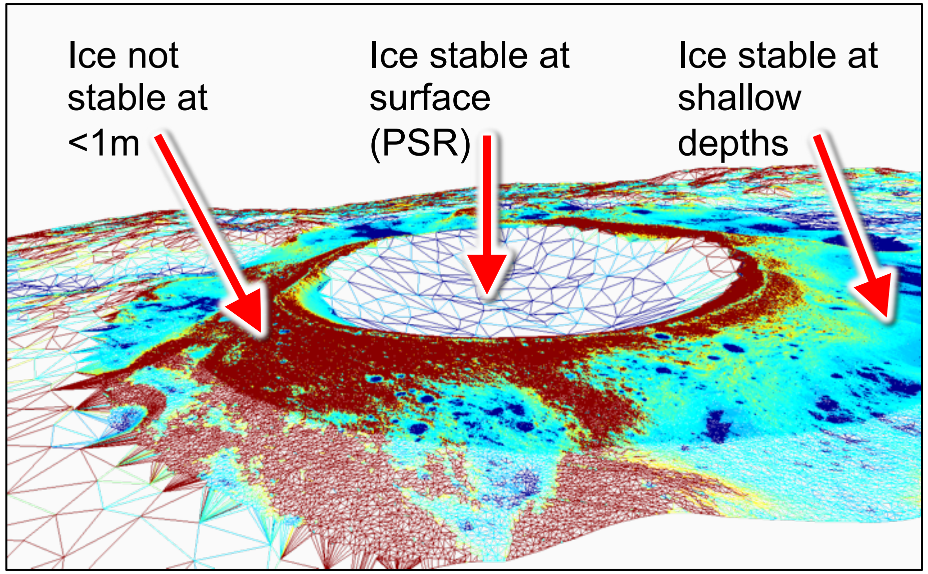
Where is water (ice) at the lunar poles?

Environmental factors

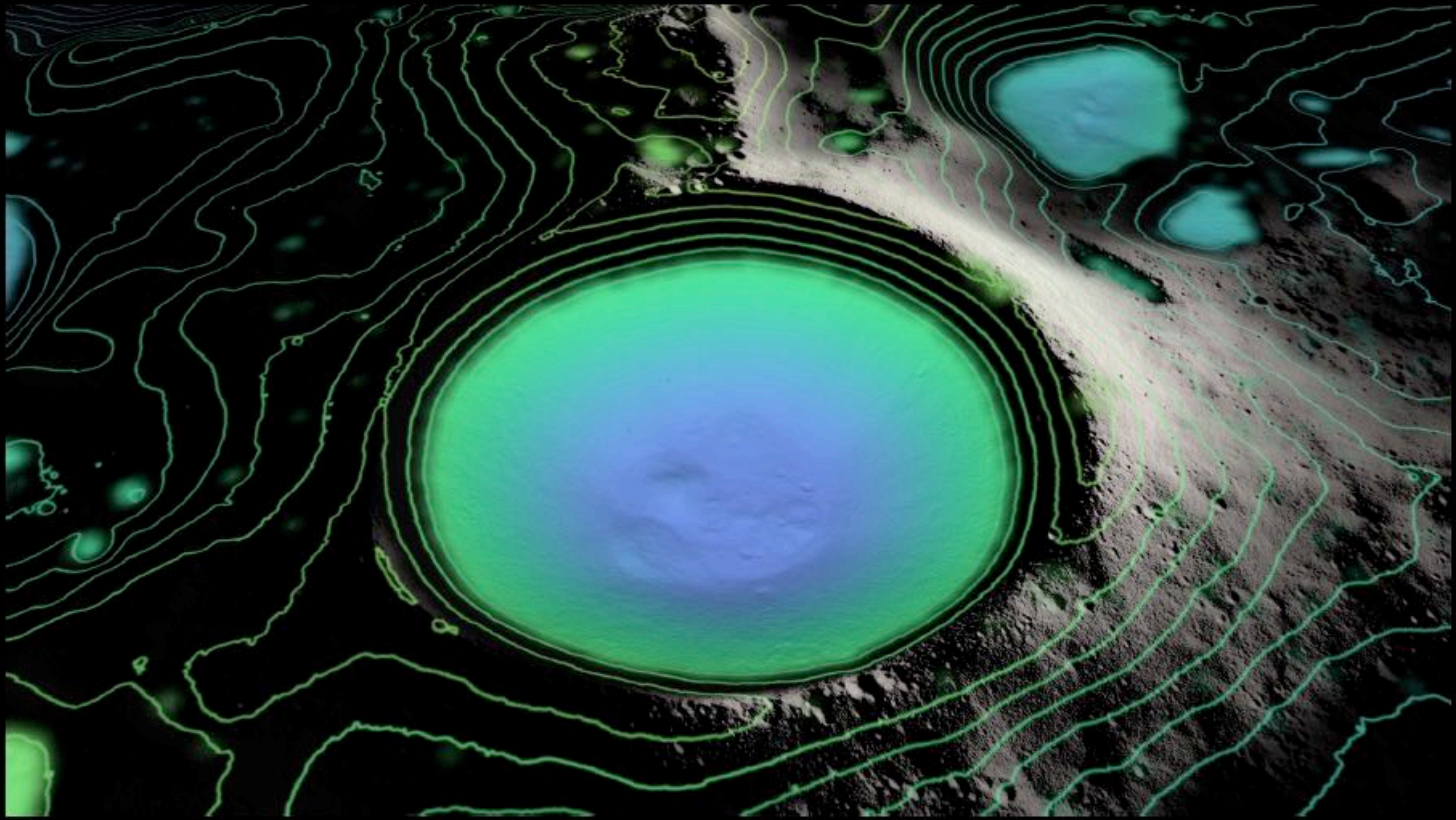
- Temperatures (surface or subsurface) must be low enough to retain water ice
- Geophysical properties (topography, materials, depth, etc.)

Ice Stability Regions

- **Dry**: Temperatures in the top meter expected to be too warm for ice stability
- **Deep**: Ice expected to be stable between 50-100 cm of the surface
- **Shallow**: Ice expected to be stable within 50cm of surface
- **Surface**: Ice expected to be stable at the surface (e.g., within a Permanently Shadowed Region or “PSR”)



Permanently Shadowed Regions on the Moon

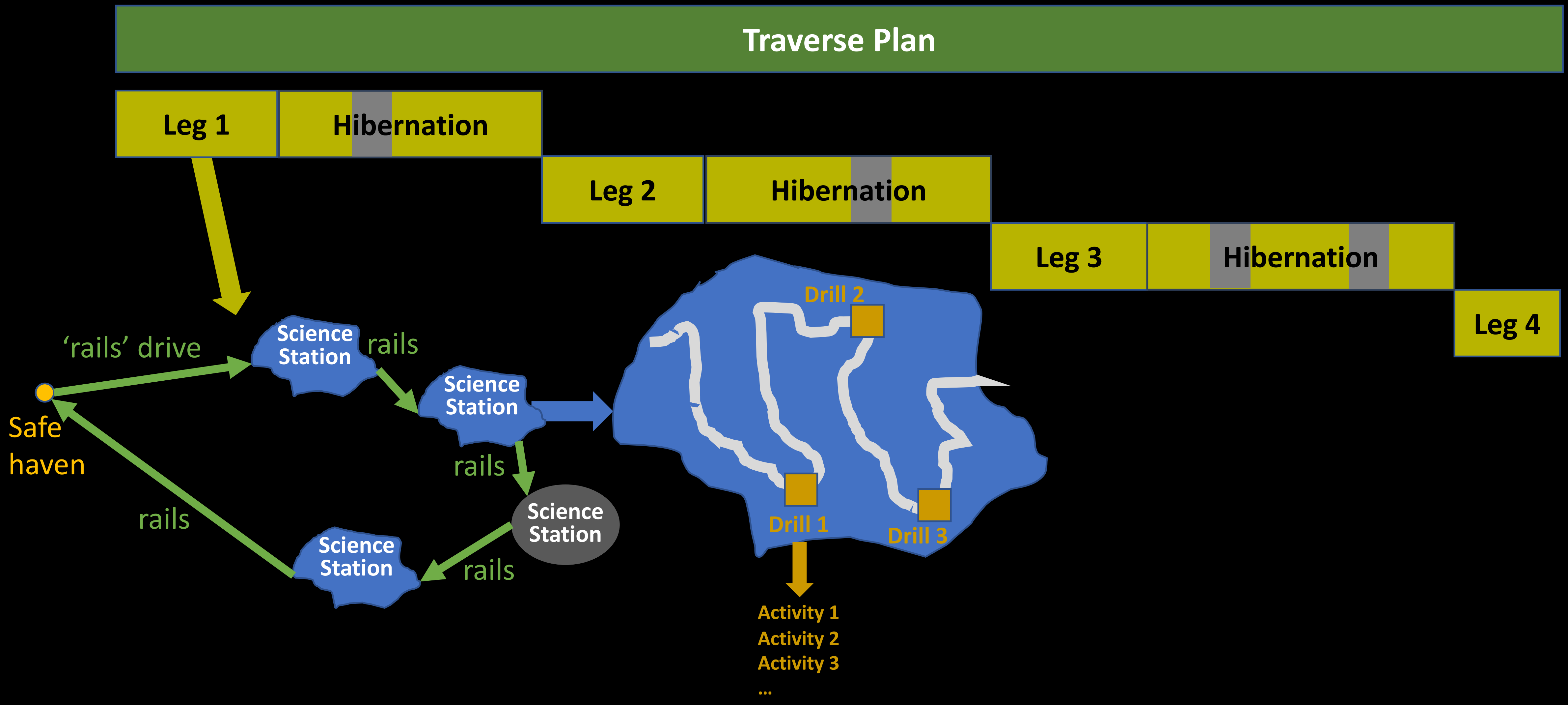


NASA SVS

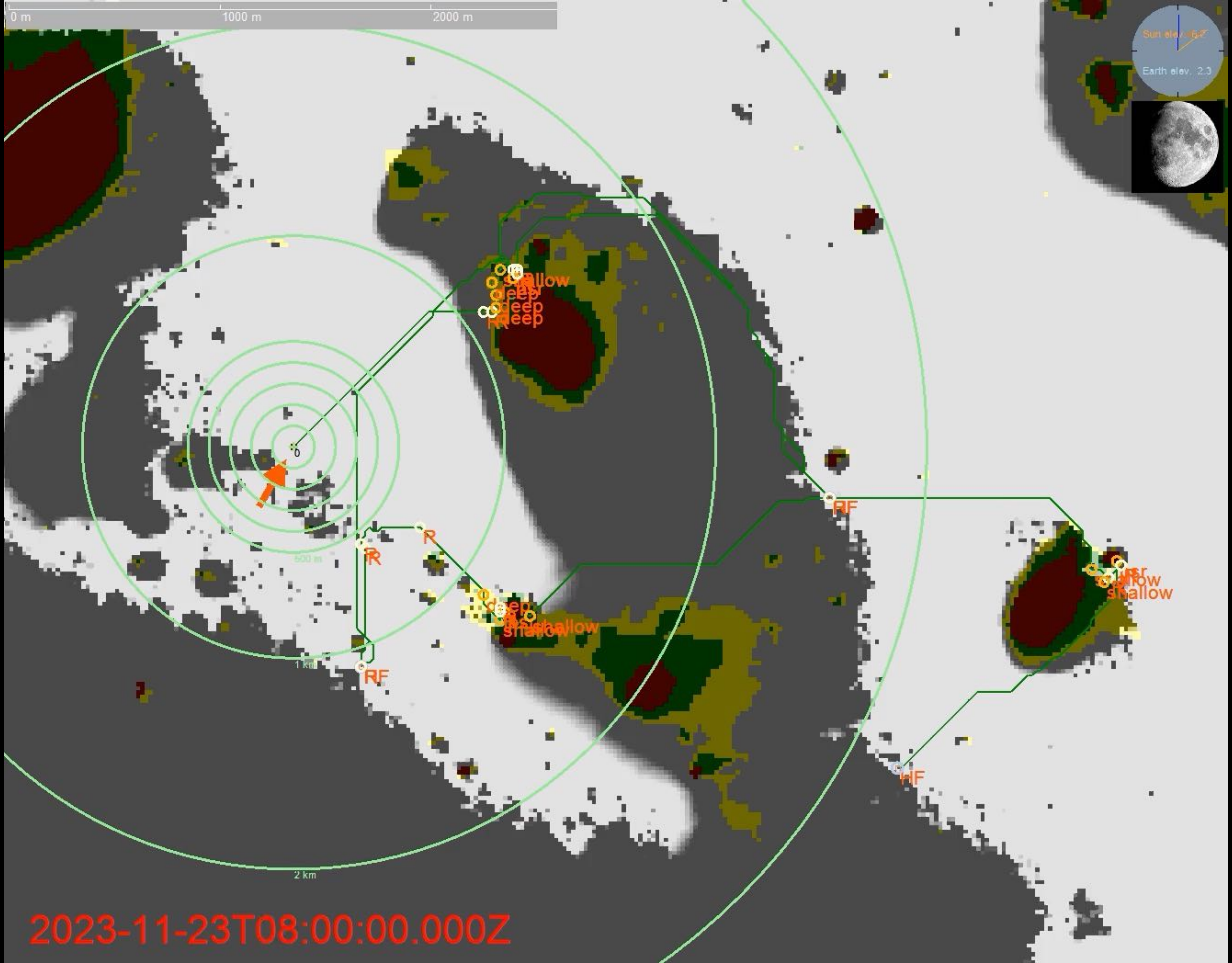
- Low obliquity.
- At high latitudes, topography creates permanently shadowed regions.
- $>10^4$ km^2 area of PSR.
- These exist on size scales ranging from sub-mm to 10 km.

https://svs.gsfc.nasa.gov/4043

VIPER Surface Mission

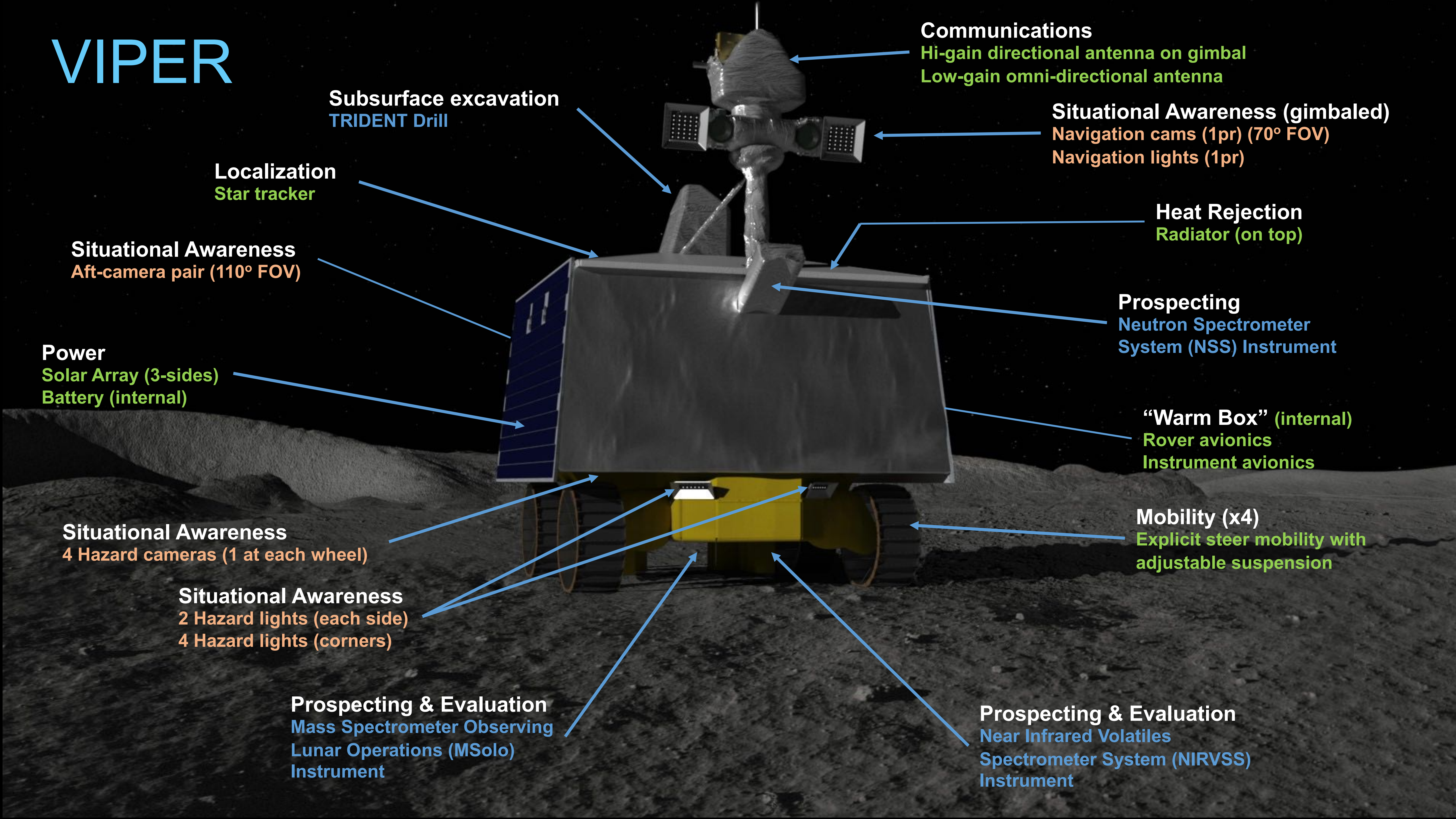


Nobile A Traverse Plan *(notional)*



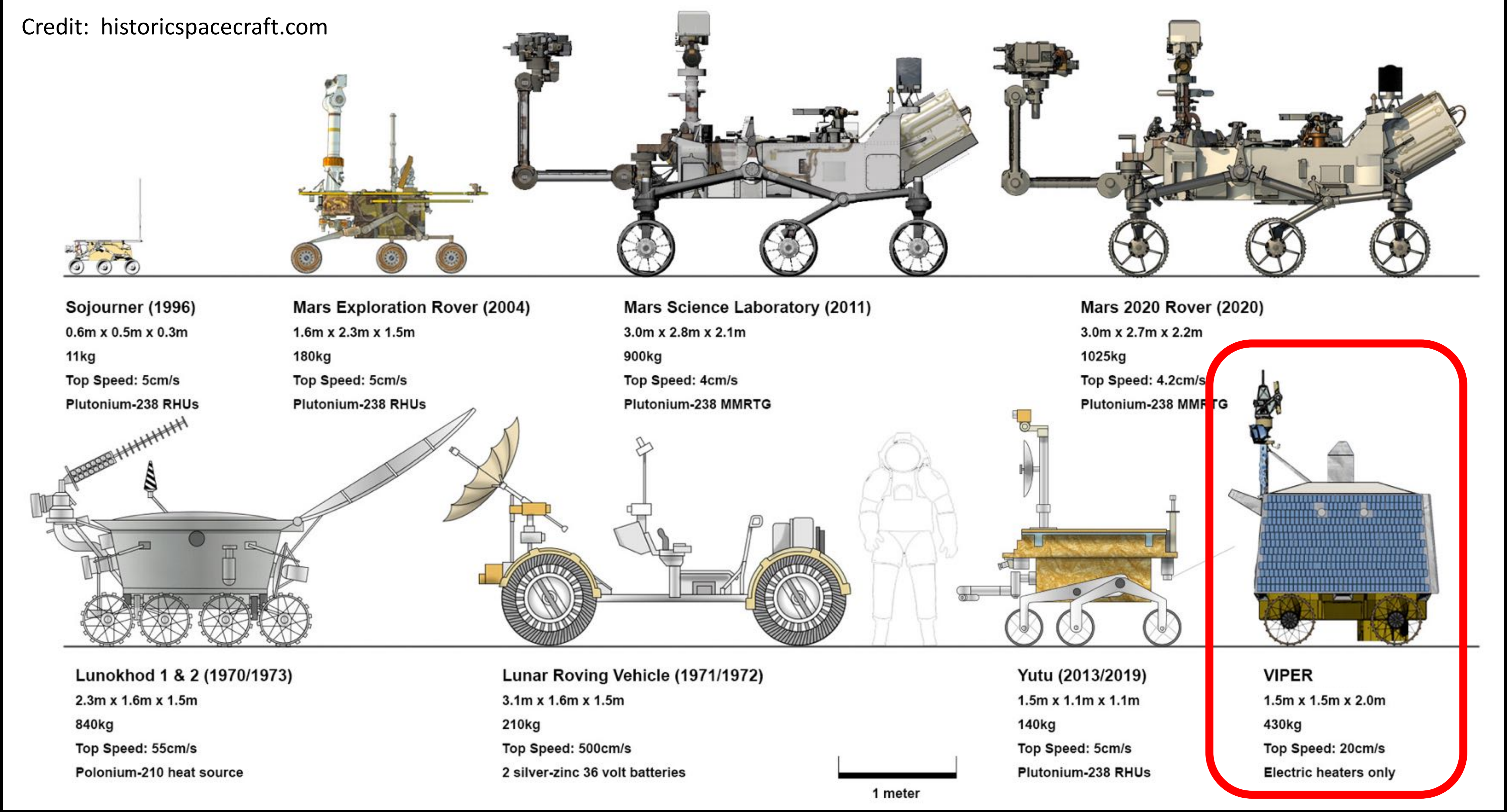
2023-11-23
to
2024-03-07

106 days



VIPER
Communications
Hi-gain directional antenna on gimbal
Low-gain omni-directional antenna
Subsurface excavation
TRIDENT Drill
Situational Awareness (gimbaled)
Navigation cams (1pr) (70º FOV)
Navigation lights (1pr)
Localization
Star tracker
Heat Rejection
Radiator (on top)
Situational Awareness
Aft-camera pair (110º FOV)
Prospecting
Neutron Spectrometer
System (NSS) Instrument
Power
Solar Array (3-sides)
Battery (internal)
"Warm Box" (internal)
Rover avionics
Instrument avionics
Mobility (x4)
Explicit steer mobility with
adjustable suspension
Situational Awareness
4 Hazard cameras (1 at each wheel)
Situational Awareness
2 Hazard lights (each side)
4 Hazard lights (corners)
Prospecting & Evaluation
Mass Spectrometer Observing
Lunar Operations (MSolo)
Instrument
Prospecting & Evaluation
Near Infrared Volatiles
Spectrometer System (NIRVSS)
Instrument

Rover Comparison



VIPER Rover

Mass: approx. 490 kg

- Rover, instruments, and lander release

Dimensions

- Approx. 1.8m x 1.8m x 2.6m (L x W x H)
- 0.5 m wheel diameter

Mobility: 4 wheels with adj. suspension

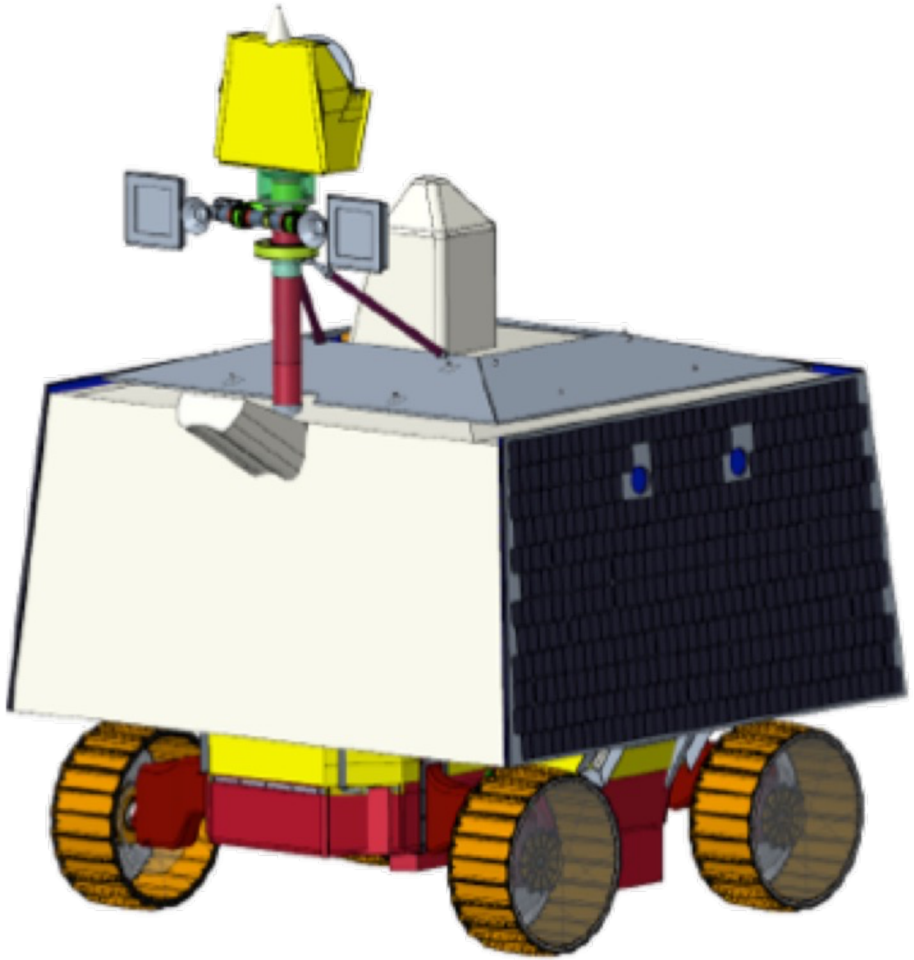
- 10-20 cm/s with 20 km range
- 20 cm obstacles, 15 deg slopes

Power: approx. 450W (peak)

- Solar arrays (sides + aft) & batteries

Comm: X-band “Direct to Earth” (DTE)

- 256 kbps downlink, 2 kbps uplink
- 6-10 sec round-trip delay



A new type of planetary rover

First NASA lunar rover

- Designed for the “dynamic” lunar environment
- Emphasis on high operational cadence and traverse speed
- Significantly lower cost than Mars rovers (but higher risk)

Interactive operations

- “Real-time” mission control: rover operations + science team
- Single waypoint driving (approx. 4 m / command cycle)
- Hybrid of human exploration (Shuttle, Space Station) and Mars rover mission operations

Hybrid avionics and software

- RAD 750 (rad-hard) + SP0 (rad-tolerant) computing
- Flight software is split between on-board and ground
- Ground software uses Robot Operating System 2 (ROS2)

Mobility Architecture

Independent Wheel Modules (4x)

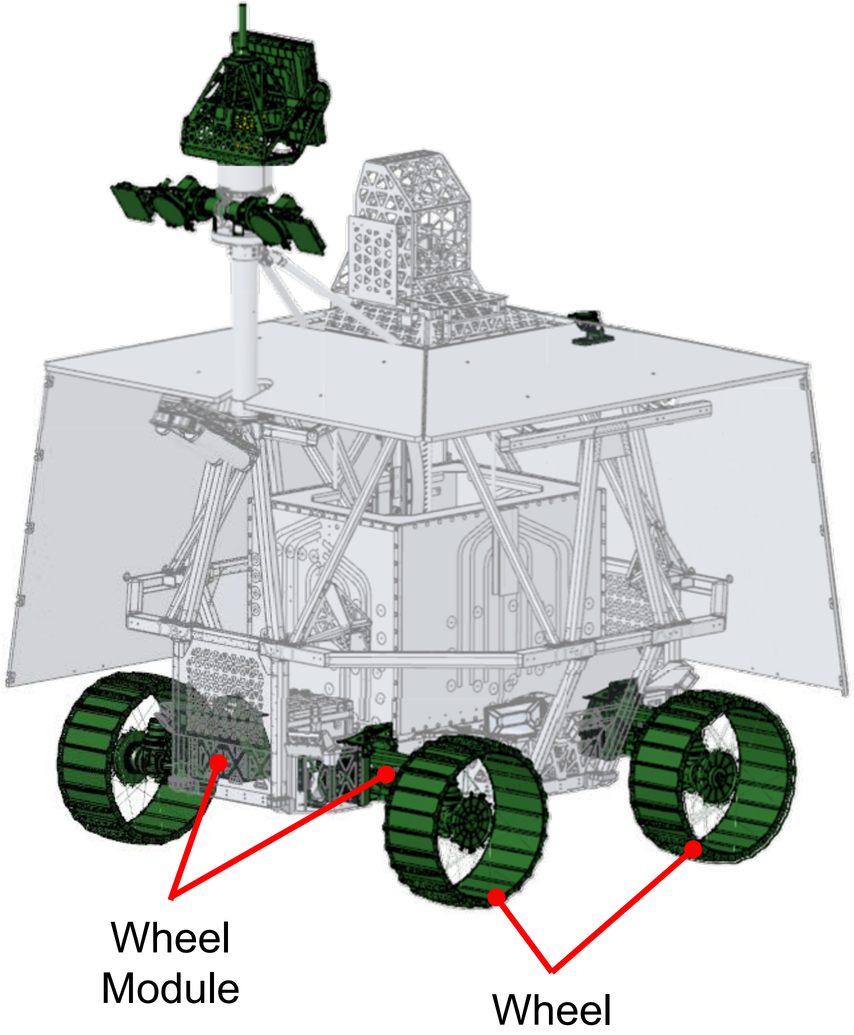
- Suspension
- Steering
- Propulsion

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 (with sufficient torque to perform skid steering)
- Alternate mobility (e.g., “inchworming”)



Independent Steering

Offset steering axis

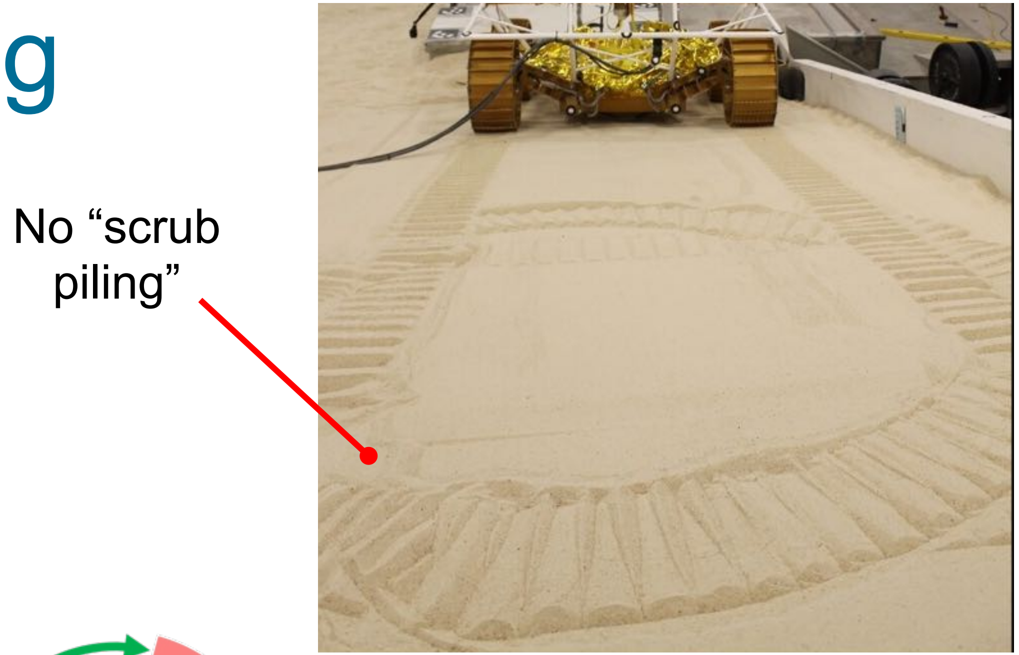
- Reduces wheel scrub
- Reduces risk of embedding
- Allows for point turns

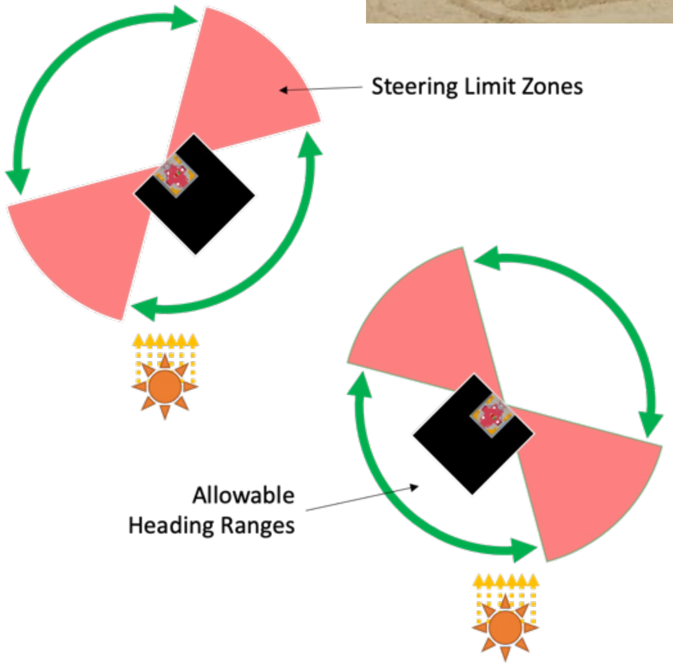
Wide steering range (> ±45 deg)

- Enables near-holonomic motion
- Allows the rover to translate in almost any direction while also maintaining optimal exposure of the solar arrays

Limitations

- More complex than skid steering
- High actuator & part count





Actuated Suspension

Adjustable (not active)

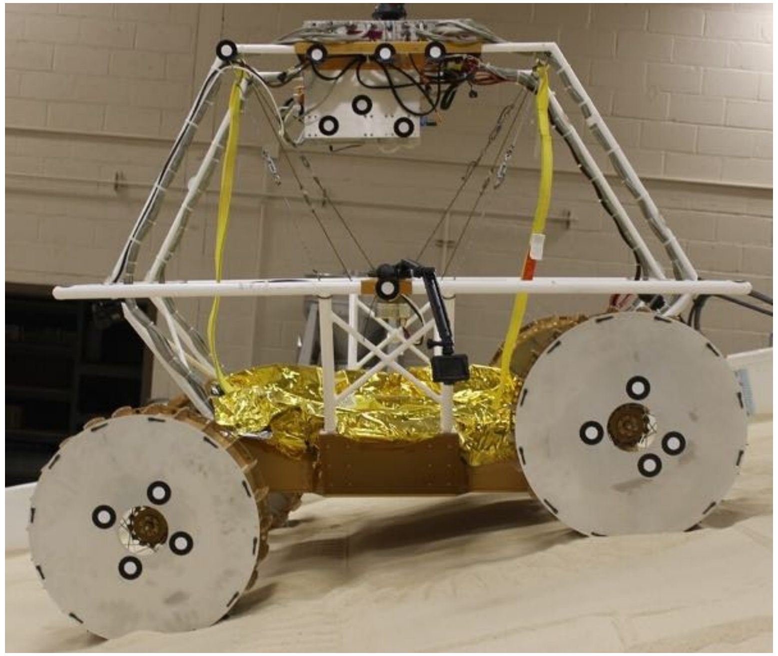
- Low control cycle (10 Hz)
- Suitable for low-speed, primarily kinematic (non-dynamic) motion

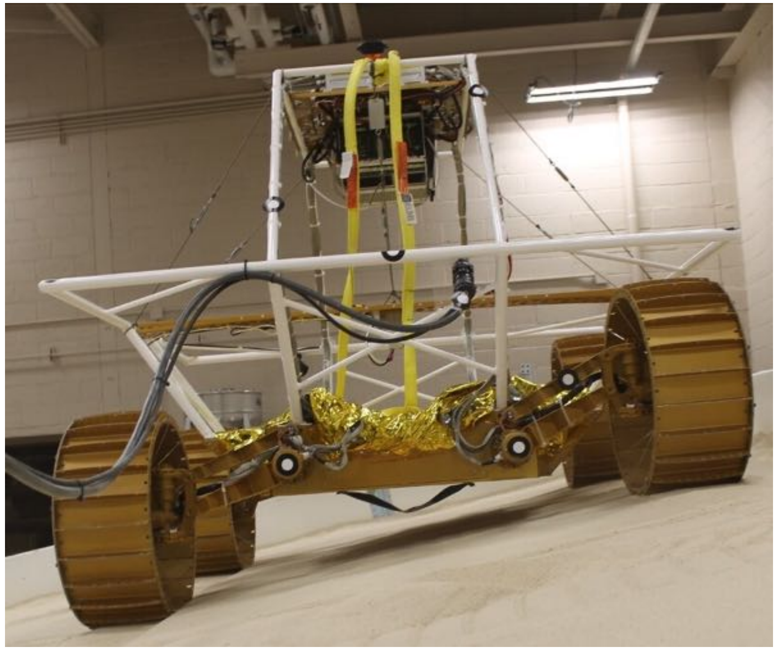
Obstacle & slope climbing

- Articulation increases stability margin
- Articulation and body attitude control improves cross-slope trafficability

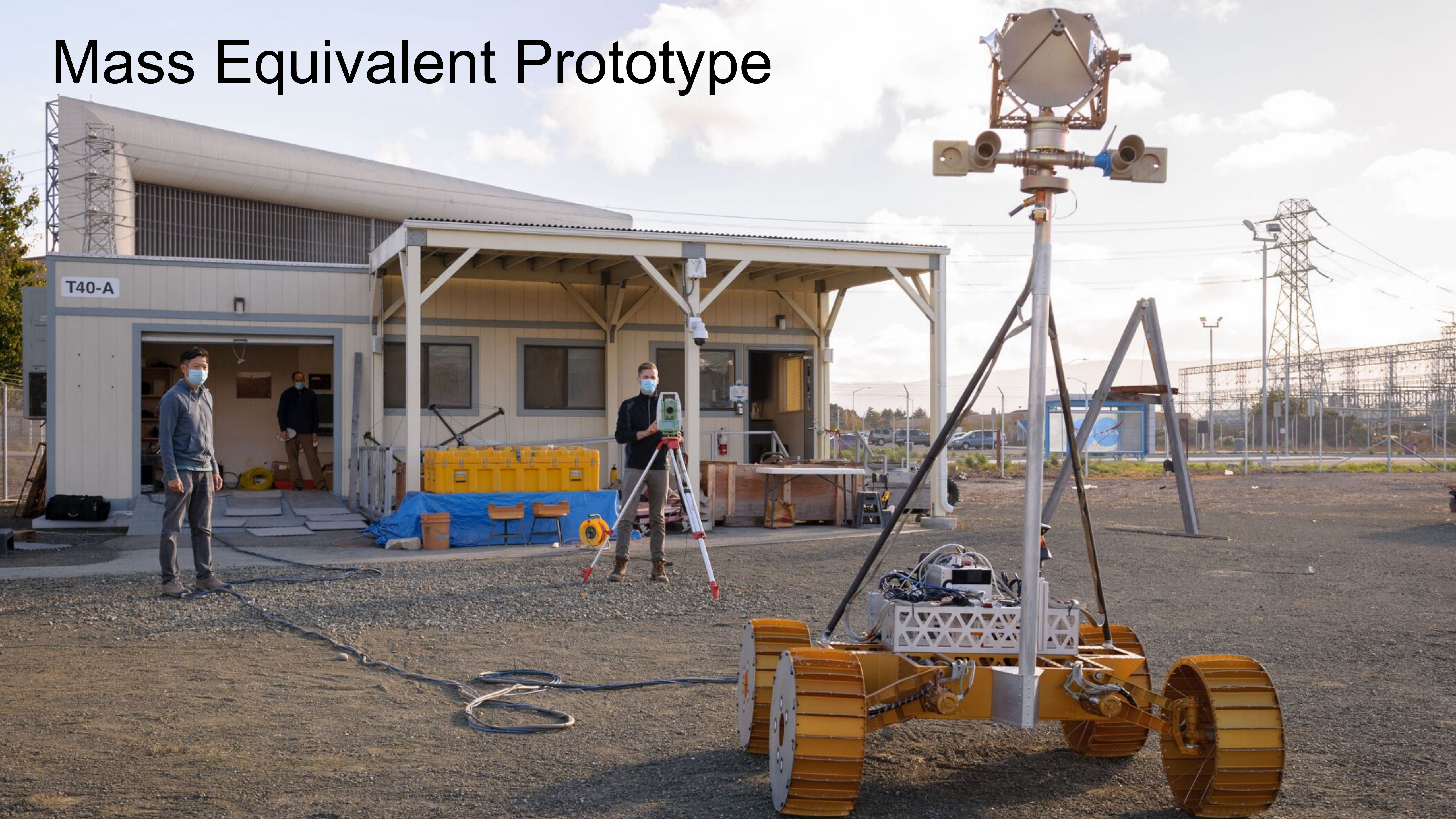
Ground clearance

- Adjustable ride height reduces collision and high-centering risk
- Increases egress flexibility
- Facilitates drill positioning and alignment control

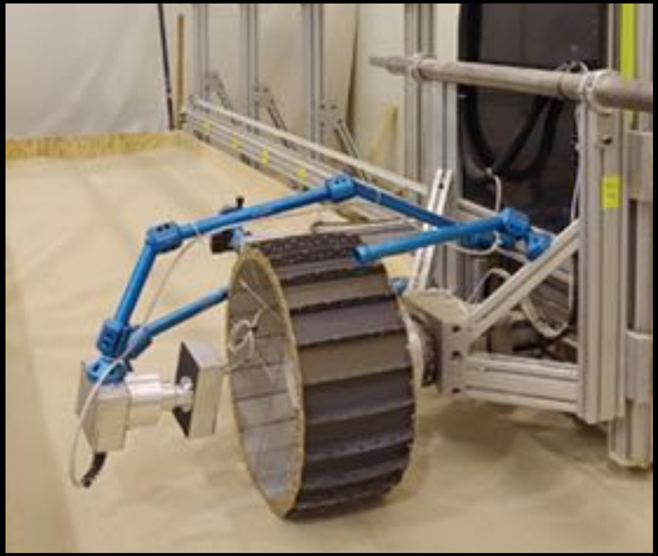


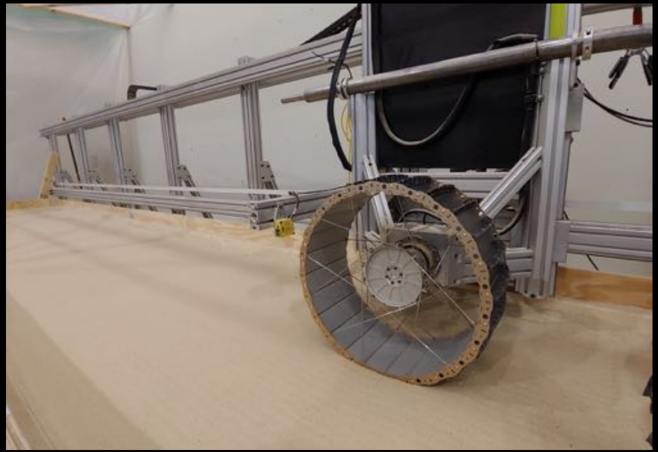


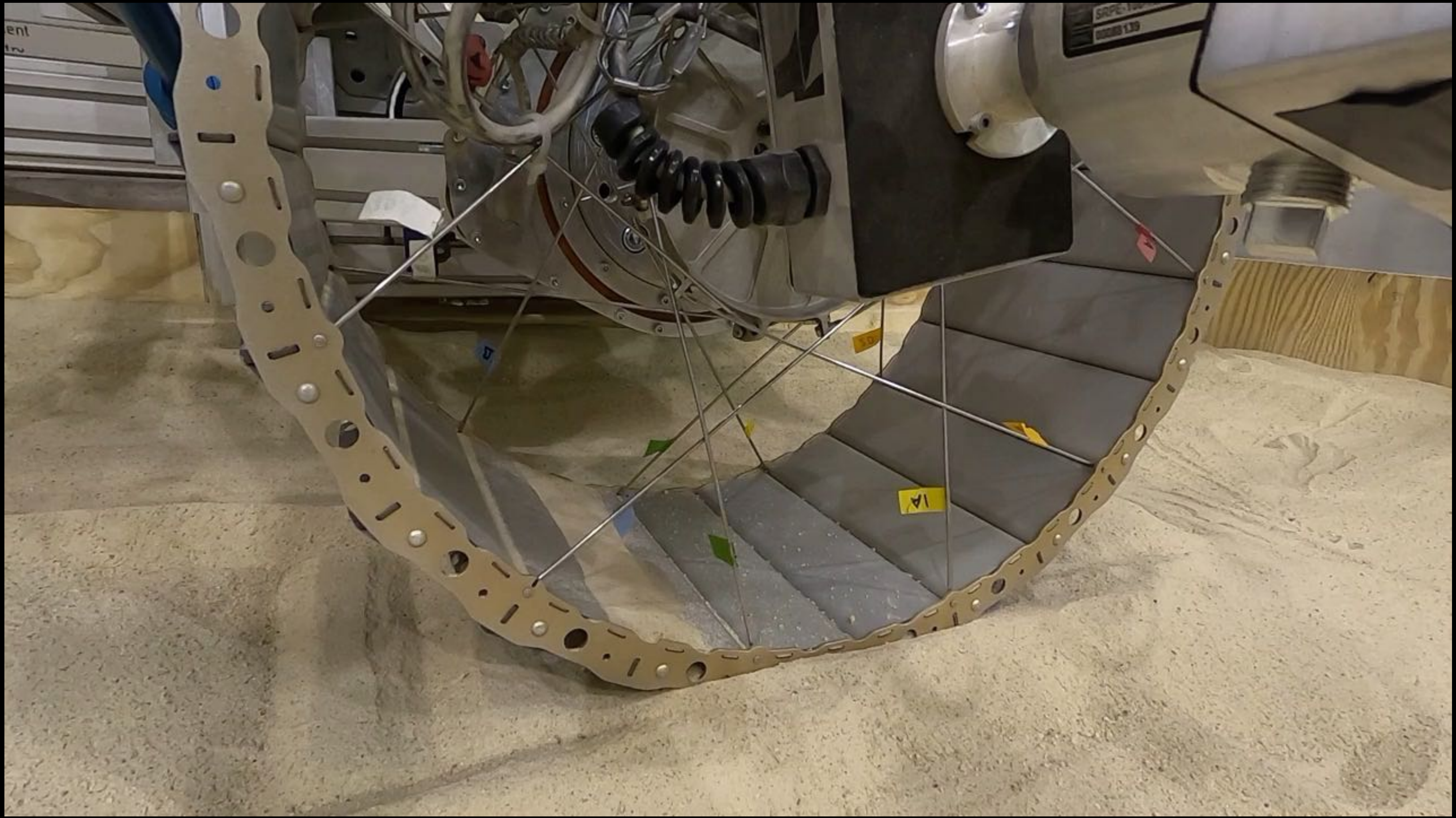
Mass Equivalent Prototype



Wheel Prototype Testing

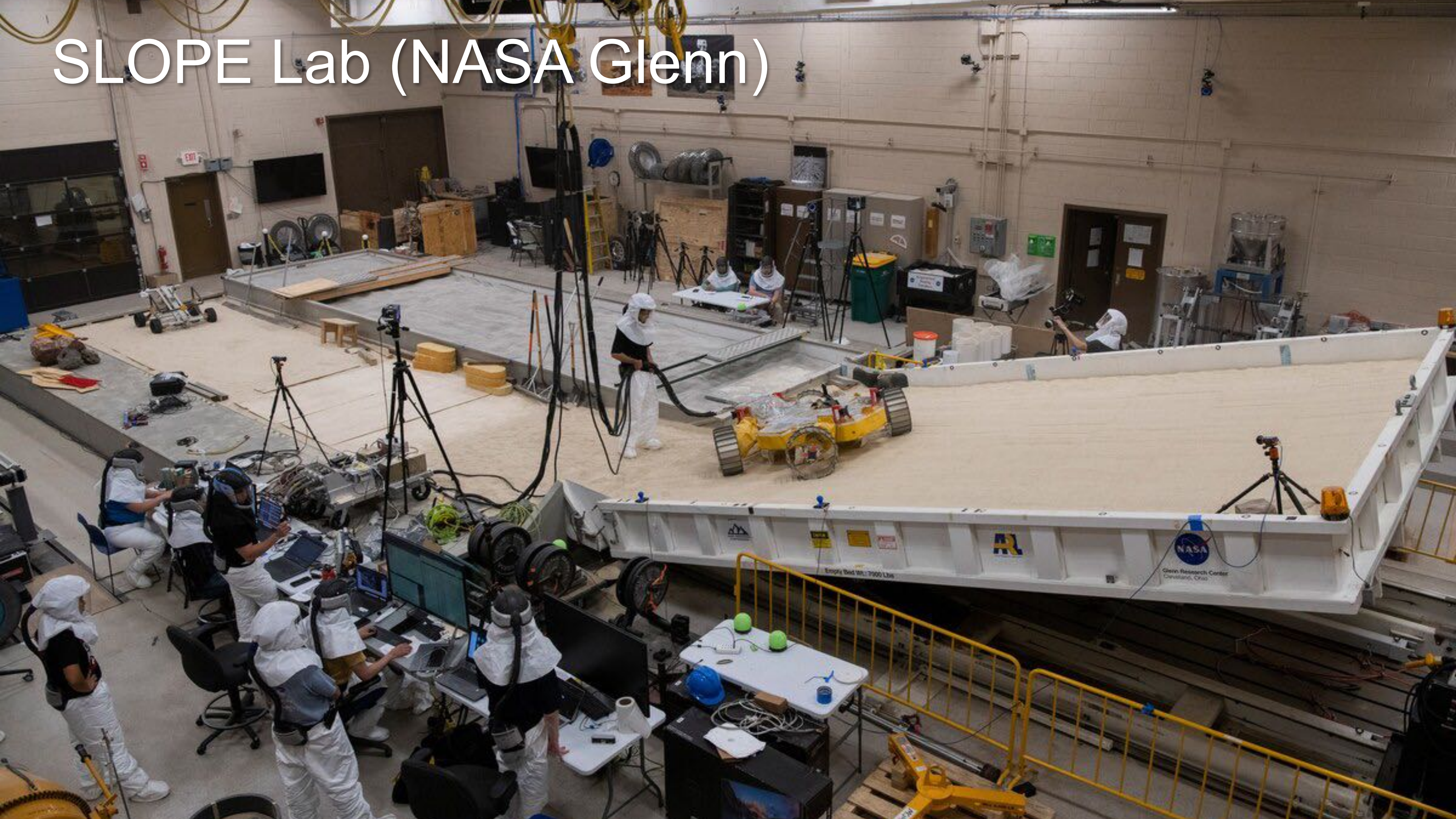






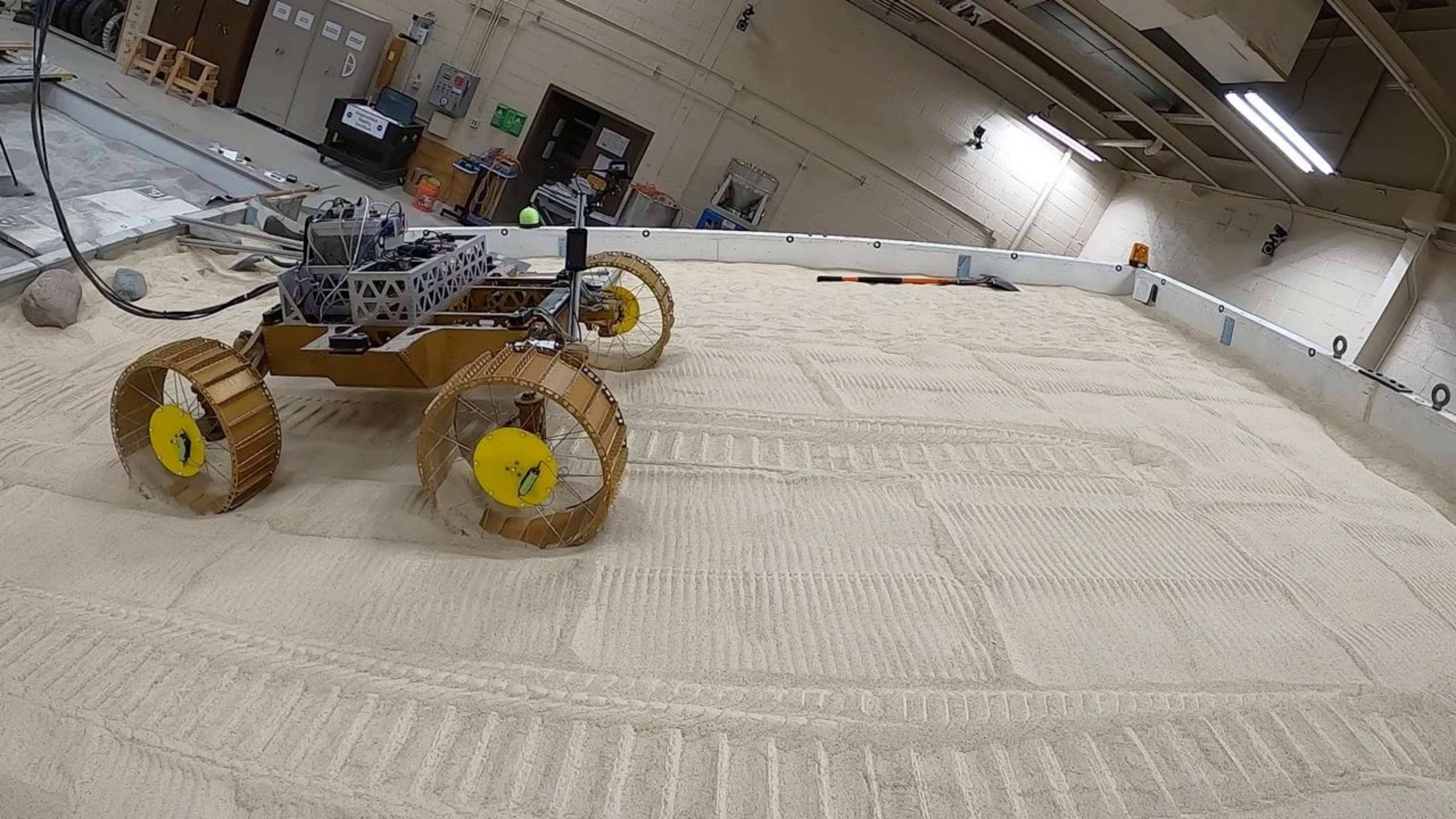
Characterization and endurance testing performed by ProtoInnovations, LLC (Pittsburgh)

SLOPE Lab (NASA Glenn)



Entrapment Testing

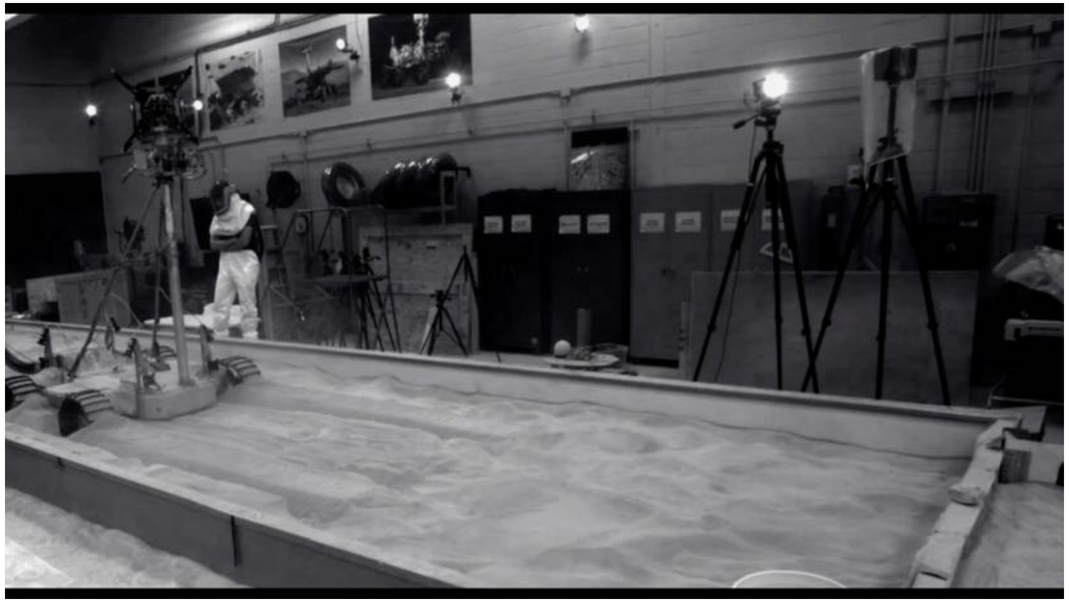
Slip Testing

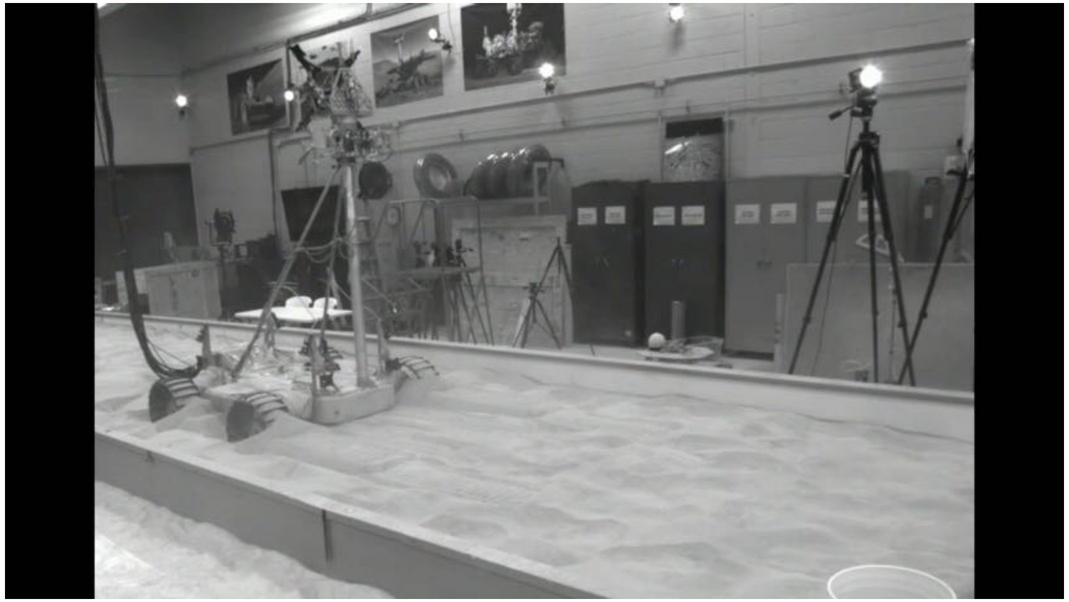


Crater Traversal Testing

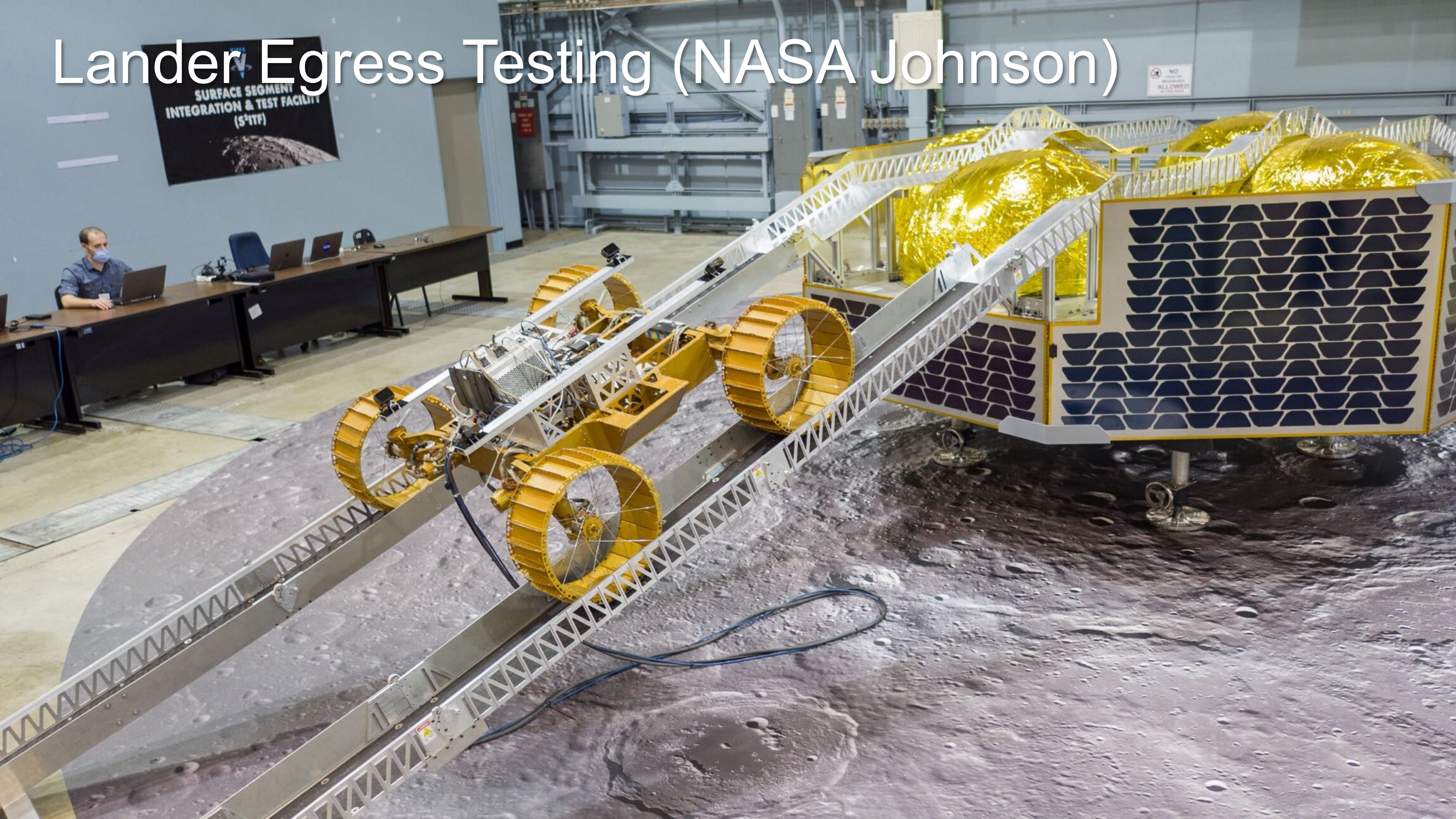
Alternate Mobility Modes

8x speed

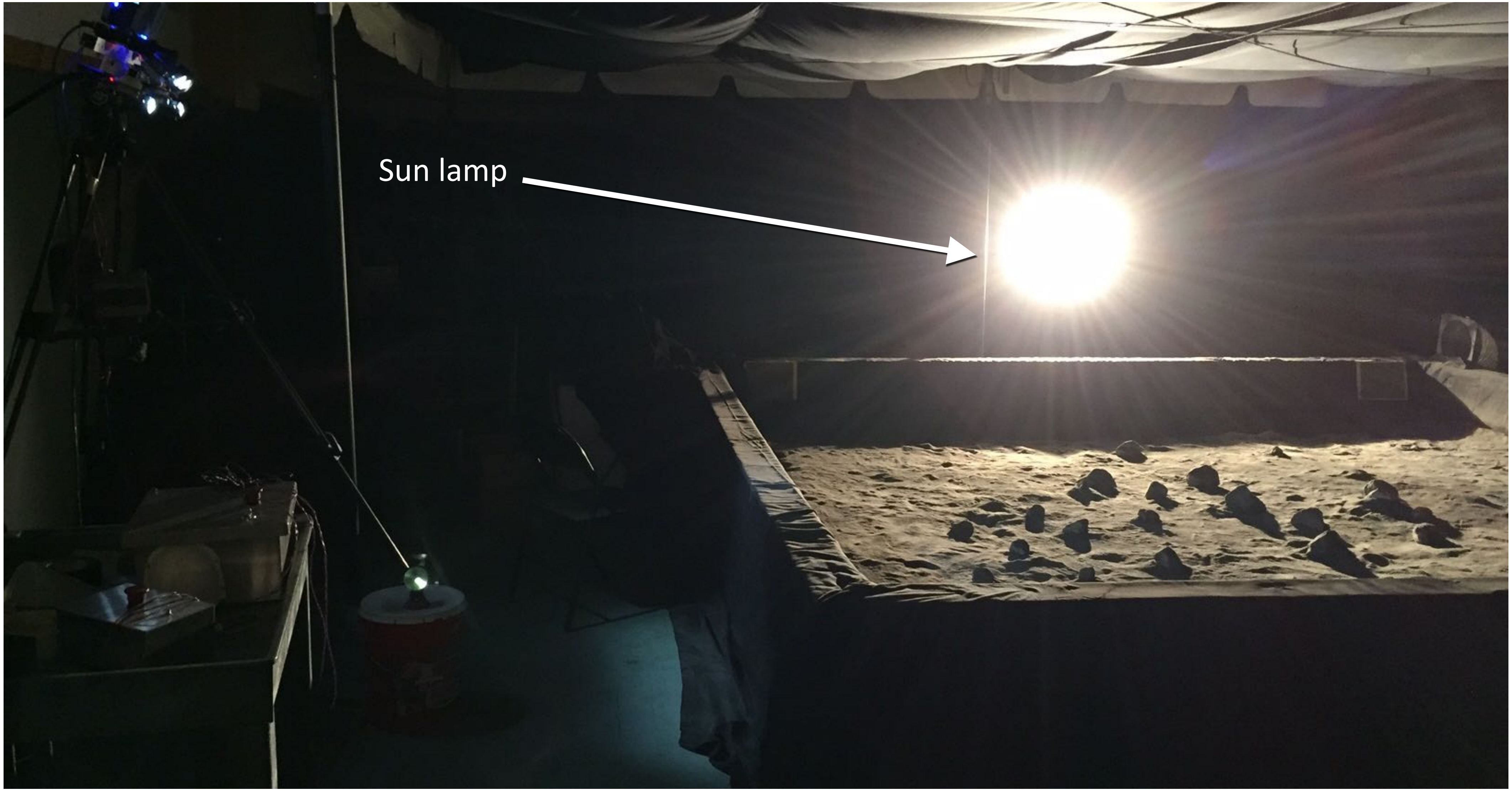




Lander Egress Testing (NASA Johnson)

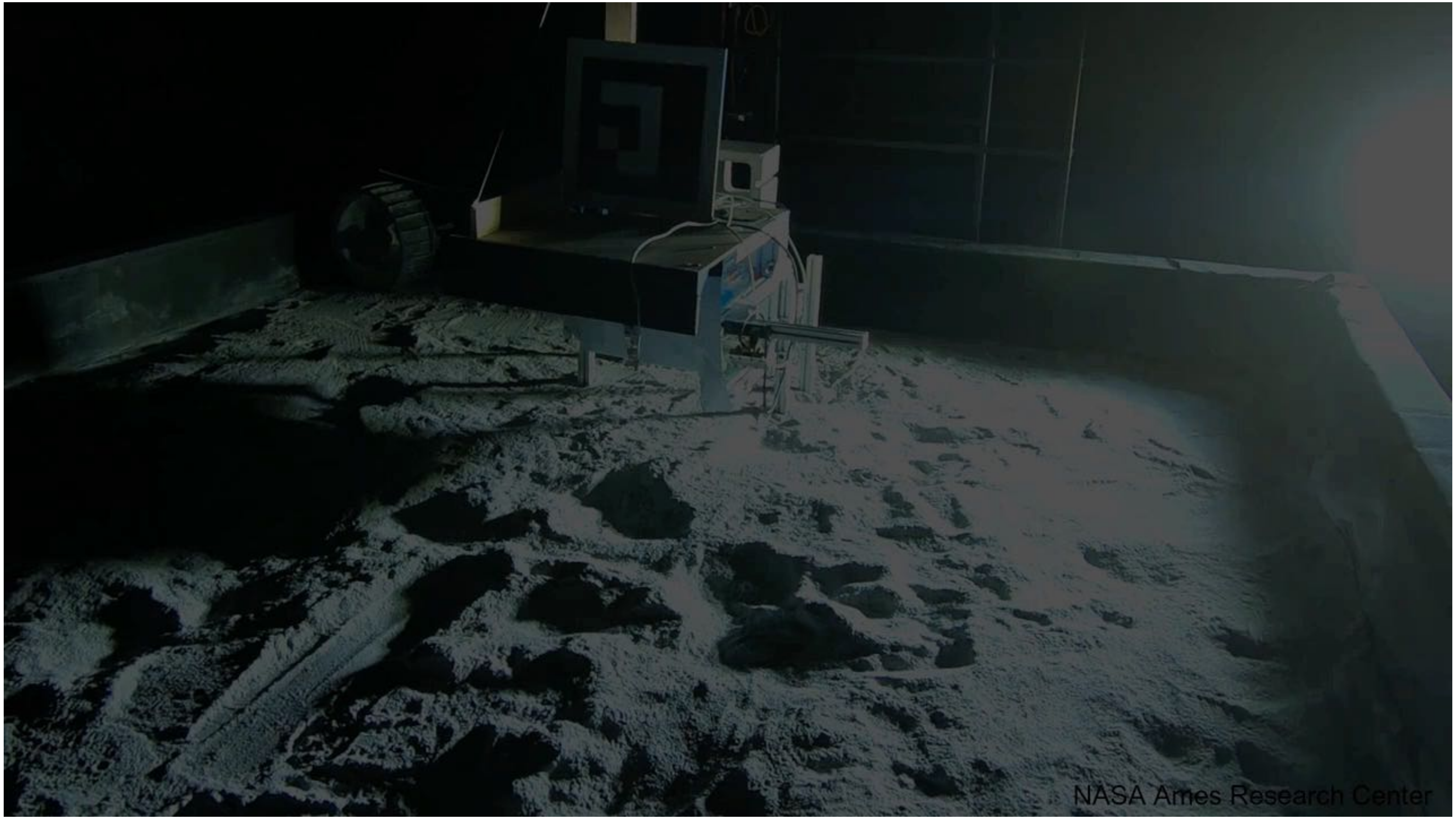


Lunar Lab (NASA Ames)



4m x 4m sandbox with 8 tons of JSC-1A lunar regolith simulant

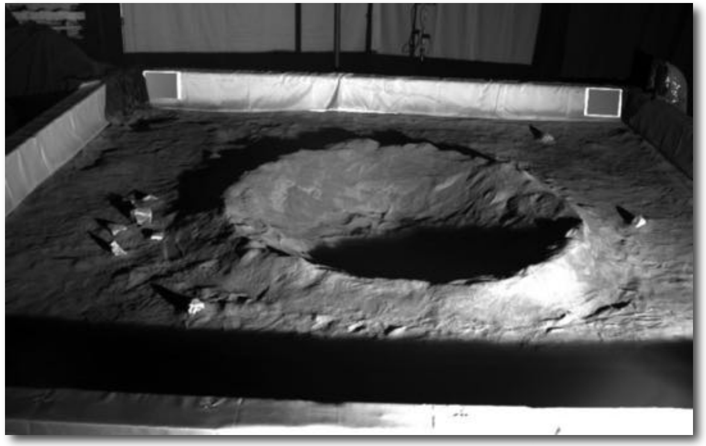
Simulating Lunar Surface Conditions



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

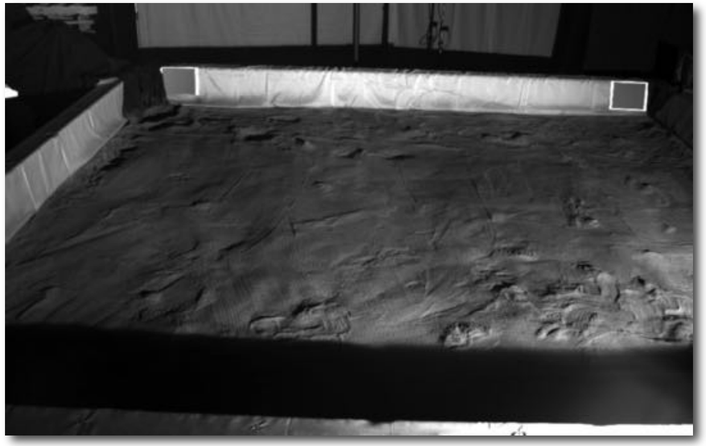
Camera & Lighting Test Cases

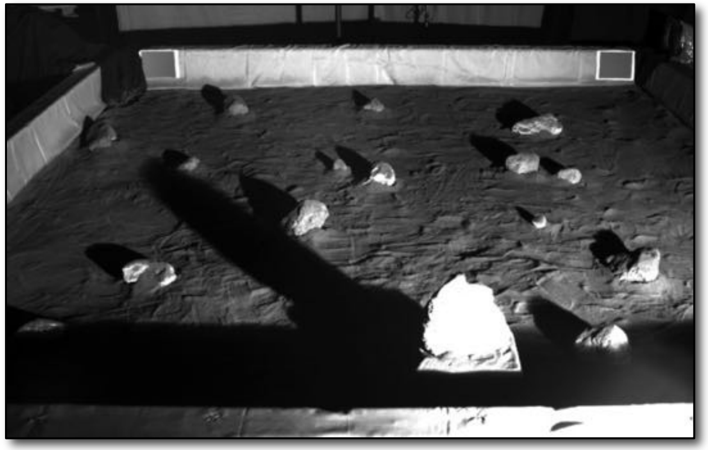
Negative Obstacle



Defined Rim → **Eroded**

Positive Obstacle



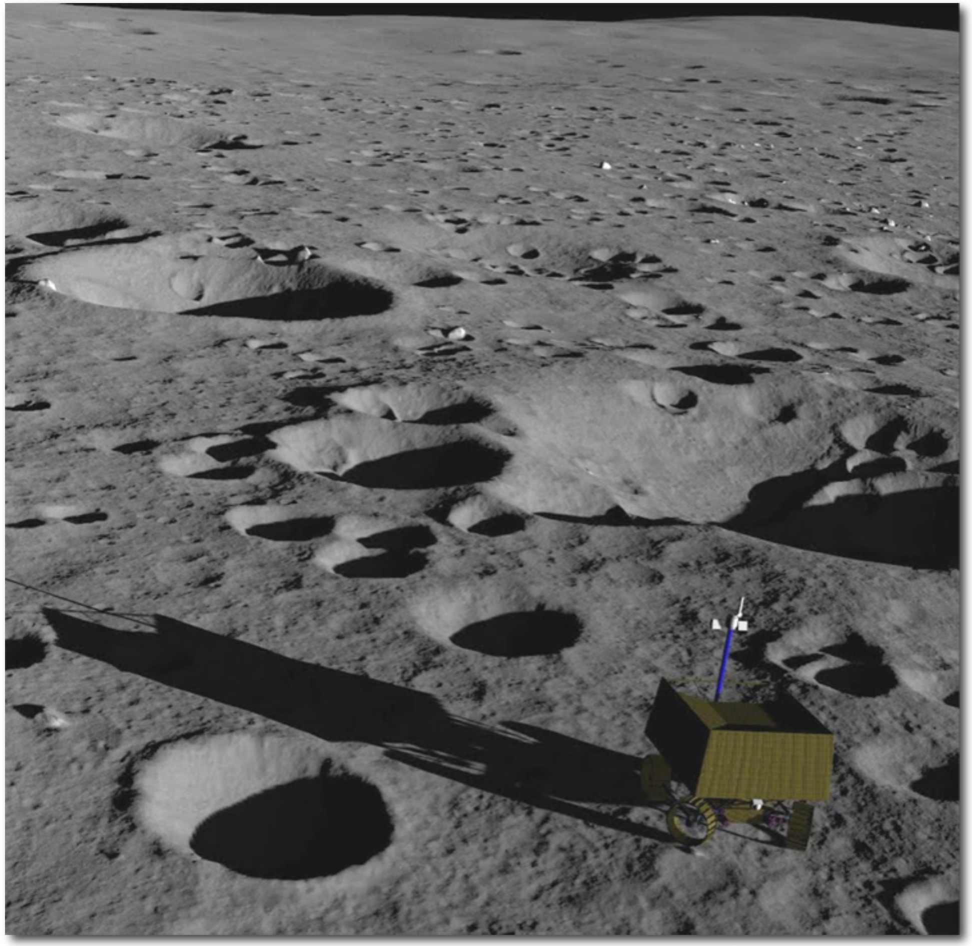


Smooth → **Rough/Rocky**

Lunar Surface Simulation

Key Features

- High dynamic range rendering
- Real-time shadows
- Support for high resolution terrains
- Support for custom terrain appearance
- Rover wheel tracks and slip modeling
- Rover lights with custom pattern
- Simulated lens flare and noise
- Lunar regolith reflectance model
- Accurate Sun & Earth emphemeris



Lunar surface simulator based on Gazebo

Synthetic Lunar Terrain Modeling

Need

- High-resolution DEMs (10 cm/post) are needed for conops studies, development of rover navigation systems, mission simulations, etc.
- Best-available lunar DEMs are 1-10 m/post and typically noisy

Typical model

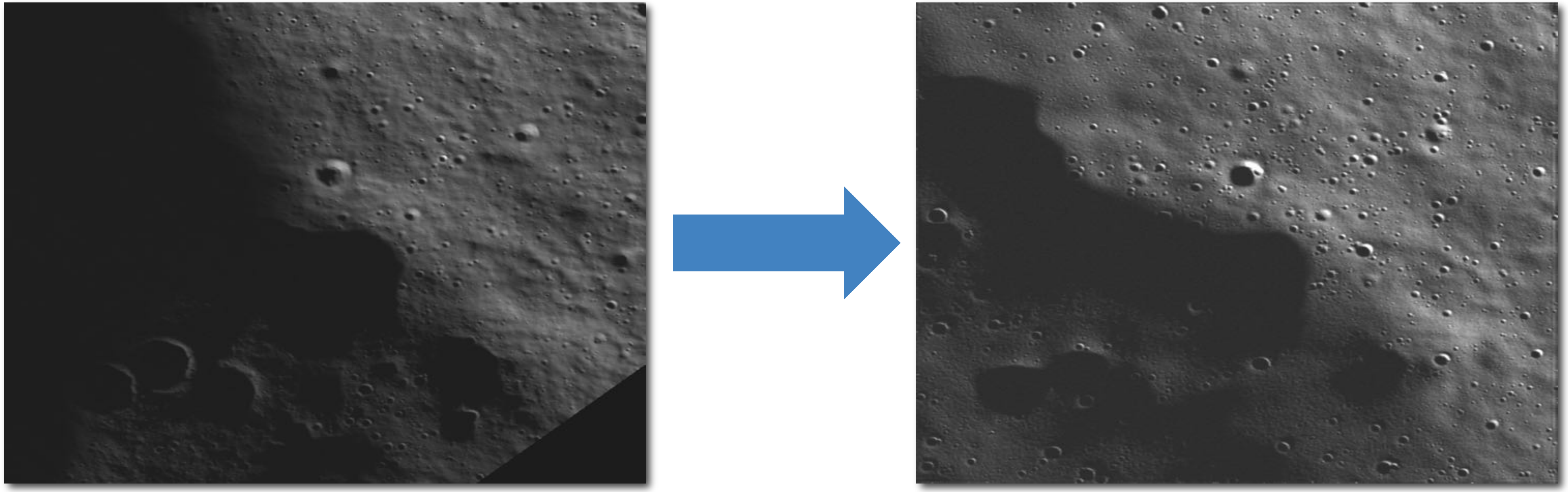
- 1 km x 1 km area, high-latitude site
- 4 cm / post

Disclaimer

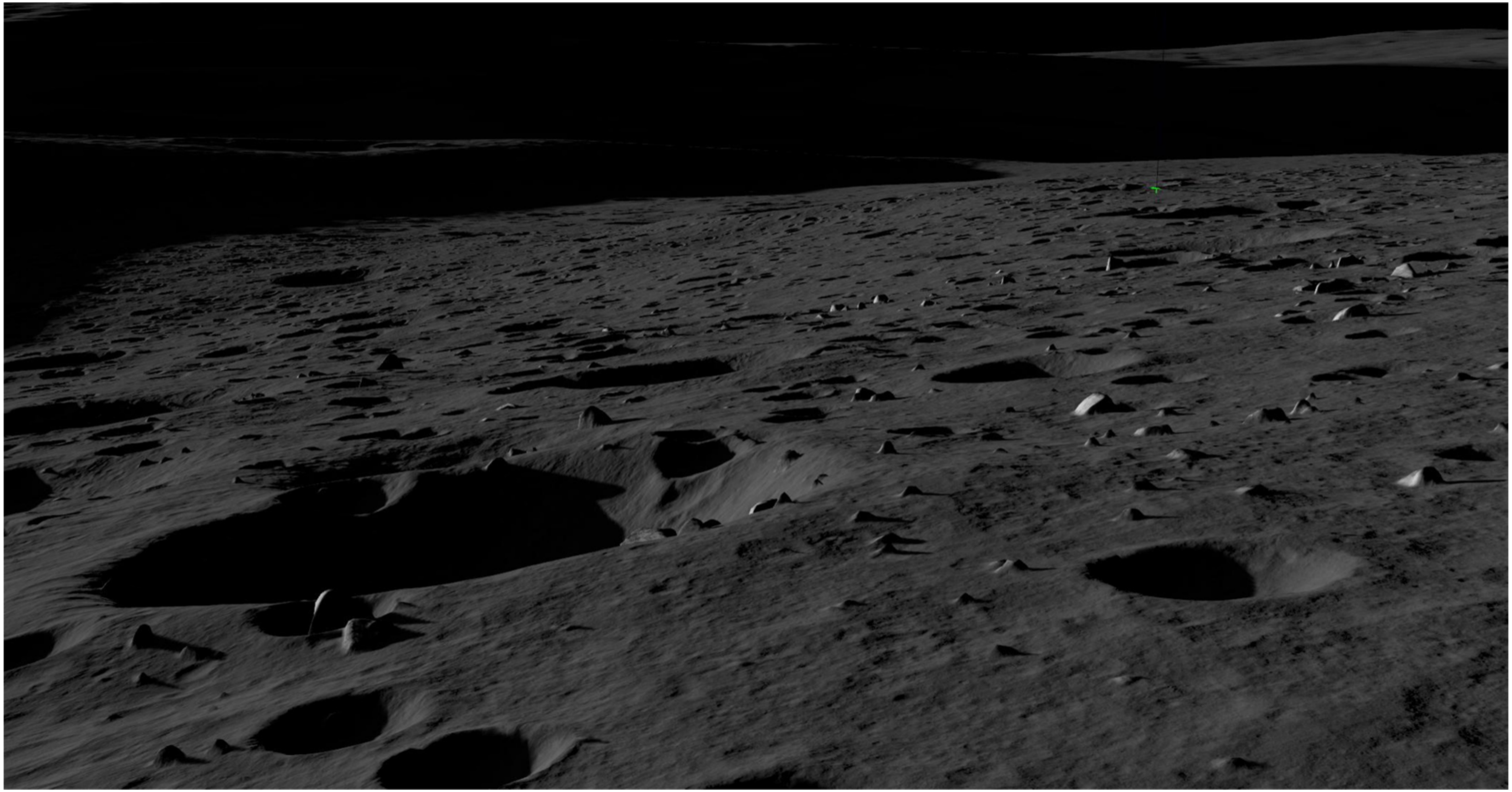
- NOT an accurate measurement of the actual lunar terrain
- NOT appropriate for lunar mission planning or operations
- Suitable for education use, outreach activities, research, or simulation

Synthetic DEM Generation Process

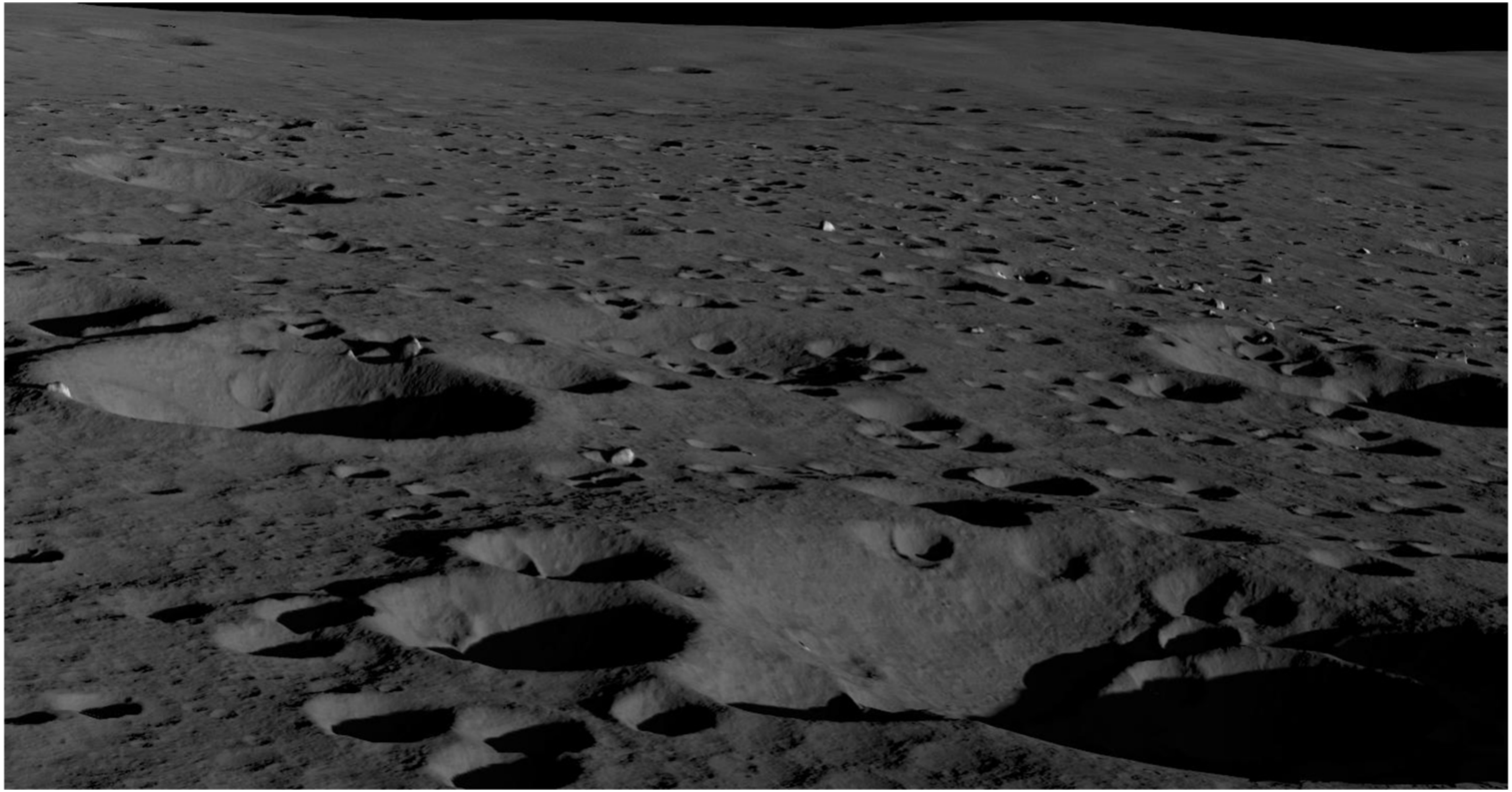
- LROC-NA Images and LOLA laser altimetry
- Create initial DEM with 1 m/post using photoclinometry
- Synthetically enhance DEM via fractal synthesis to create high-resolution surface detail that is consistent with lunar morphology
- Add synthetic craters and rocks using a parametric shape model with size-frequency distributions to control density



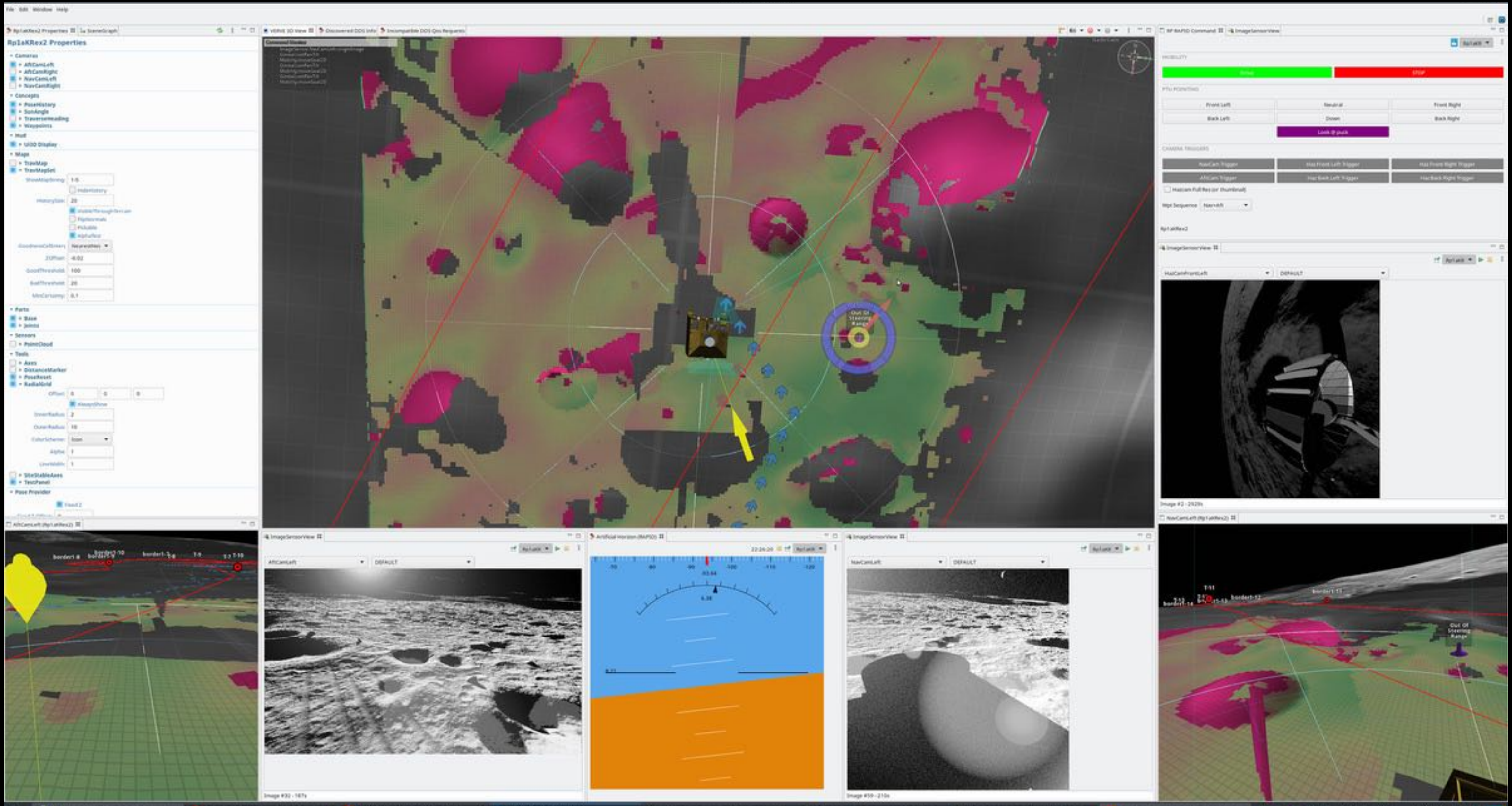
Synthetic Terrain Results



Synthetic Terrain Results



VERVE: Rover Driving Interface



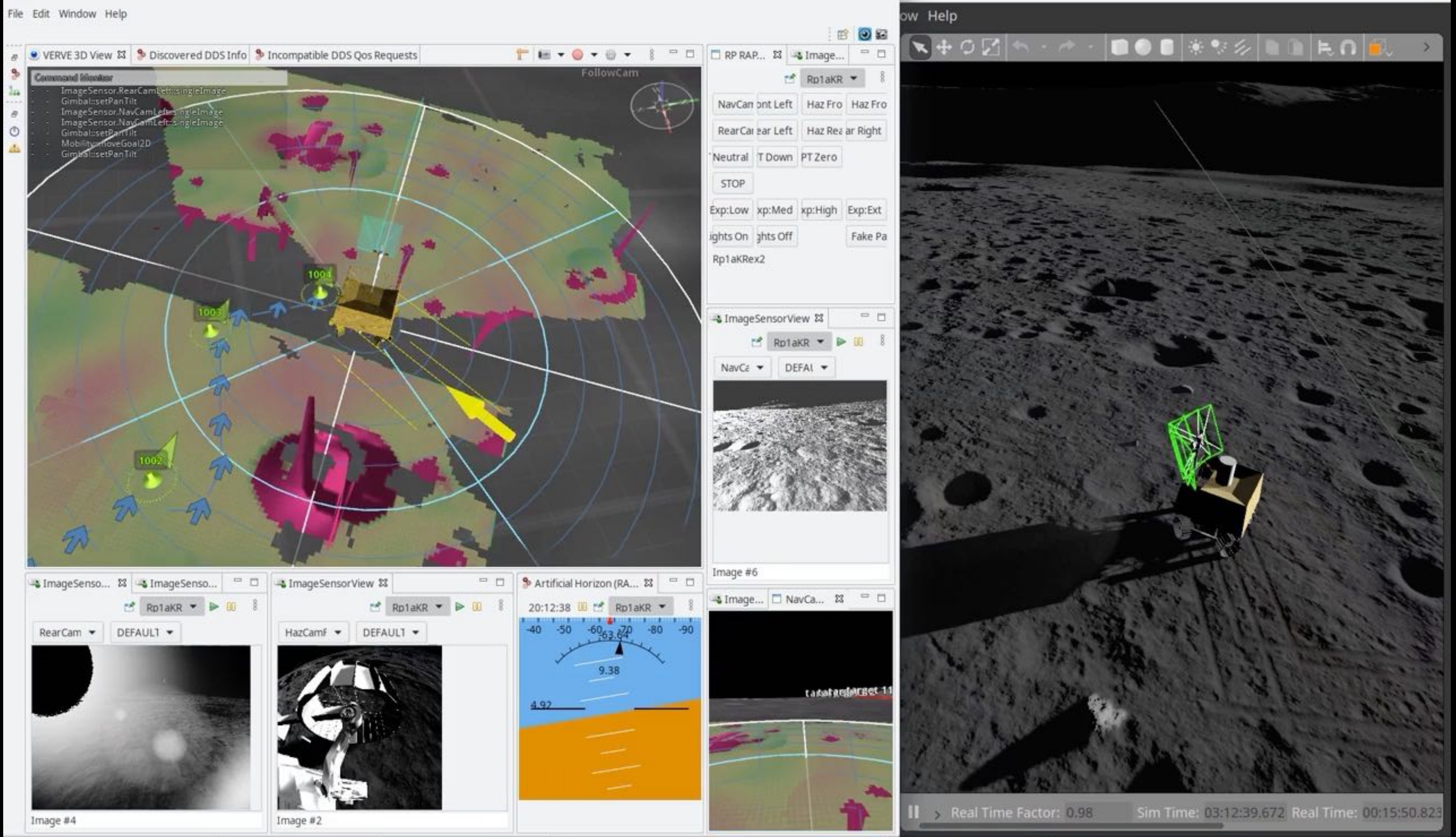

File Edit Window Help
VERVE 3D View
Discovered DDS Info
Incompatible DDS Qos Requests
Command Monitor
ImageSensor.RearCamLeft::singleImage
Gimbal::setPanTilt
ImageSensor.NavCamLeft::singleImage
ImageSensor.NavCamLeft::singleImage
Gimbal::setPanTilt
Mobility::moveGoal2D
Gimbal::setPanTilt
FollowCam
1004
1003
1002
RP RAP...
Image...
Rp1aKR
NavCam
Haz Fro
Haz Fro
STOP
Exp:Low
xp:Med
xp:High
Exp:Ext
Fake Pa
Rp1aKRex2
ImageSensorView
Image #6
ImageSenso...
RearCam
DEFAULT
Image #4
HazCamf
Image #2
Artificial Horizon (RA...
20:12:38
9.38
4.92
NavCa...
Help
Real Time Factor: 0.98
Sim Time: 03:12:39.672
Real Time: 00:15:50.823

Image courtesy of Astrobotic