National Aeronautics and Space Administration

VIPER

Rover Design and Mission Operations

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NASA Ames Research Center

24 April 2025

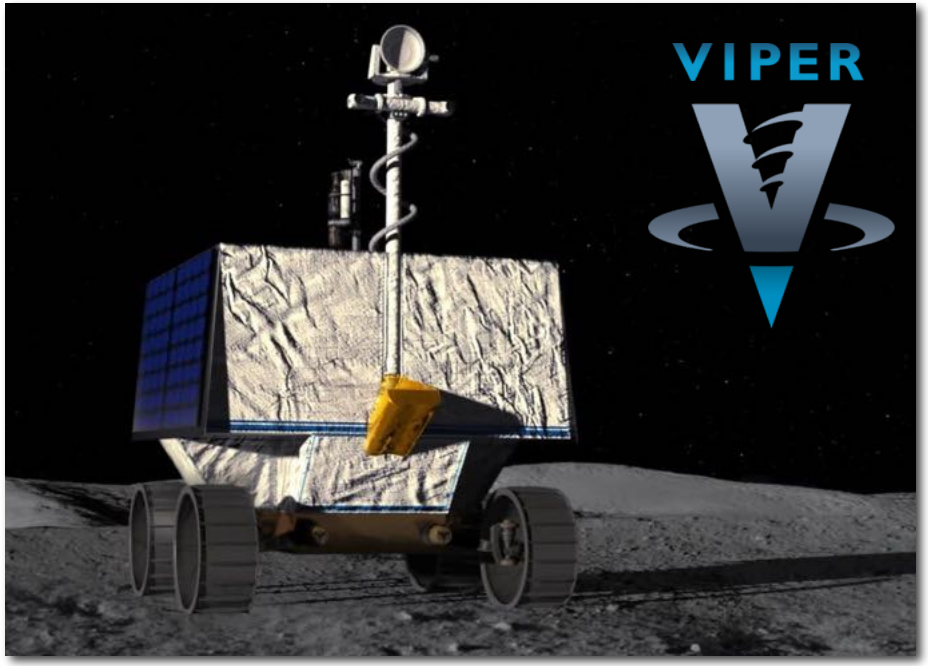
VIPER Mission

Science objectives

- Characterize distribution and physical state of volatiles (water ice, etc)
- Evaluate the potential for lunar ISRU

Unique challenges (among many…)

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



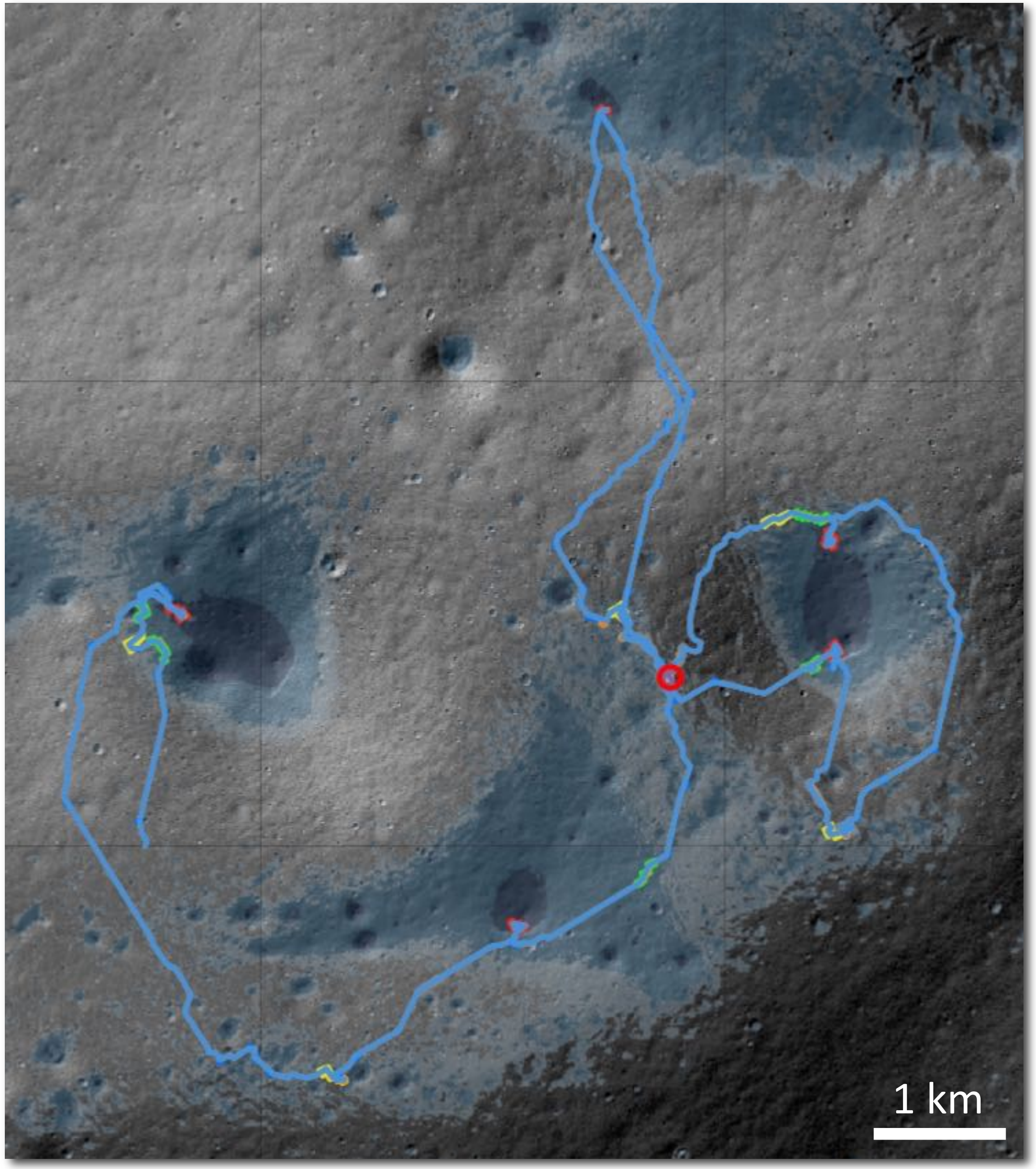
Current status

- Original NASA Science (SMD) mission canceled on July 17, 2024
- Flight hardware, software (flight & ground), and mission ops (products & process) are all complete and ready for flight
- NASA Exploration Science Strategy Integration Office (ESSIO) is now developing a partnership mission (“VIPER: some delivery required”)

VIPER Capabilities

Lunar south pole

- 5-6 lunar days of operations
- 20 km of traverse distance (with potential for 30+ km)
- Exploring temperature regimes ranging from 40 K to 300 K
- 50x 1m drilling activities
- 1,700 m of driving in PSRs (multiple entries)
- 5x 1m drilling activities in PSR
- 20 cm/s max driving speed (approx. 5x Perseverance)
- 0.8 cm/s “Speed Made Good” (approx. 25x Perseverance)



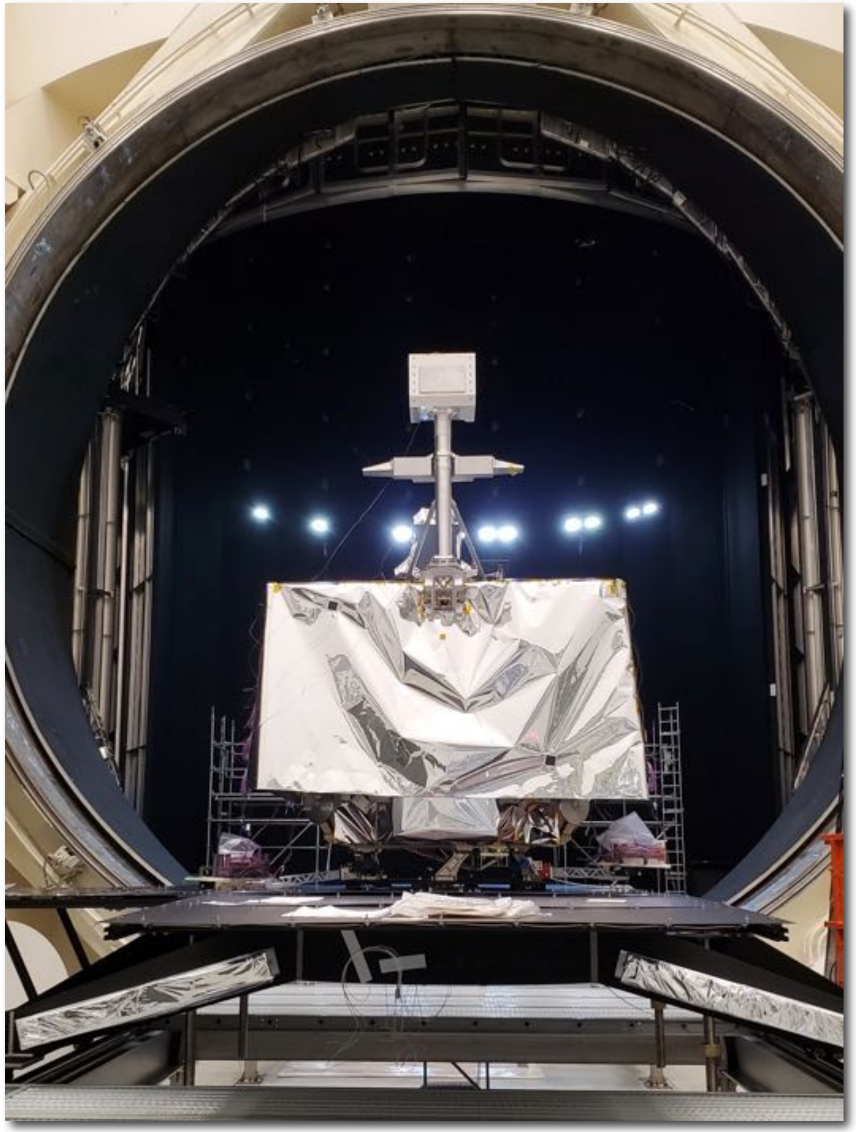
Not your usual NASA mission

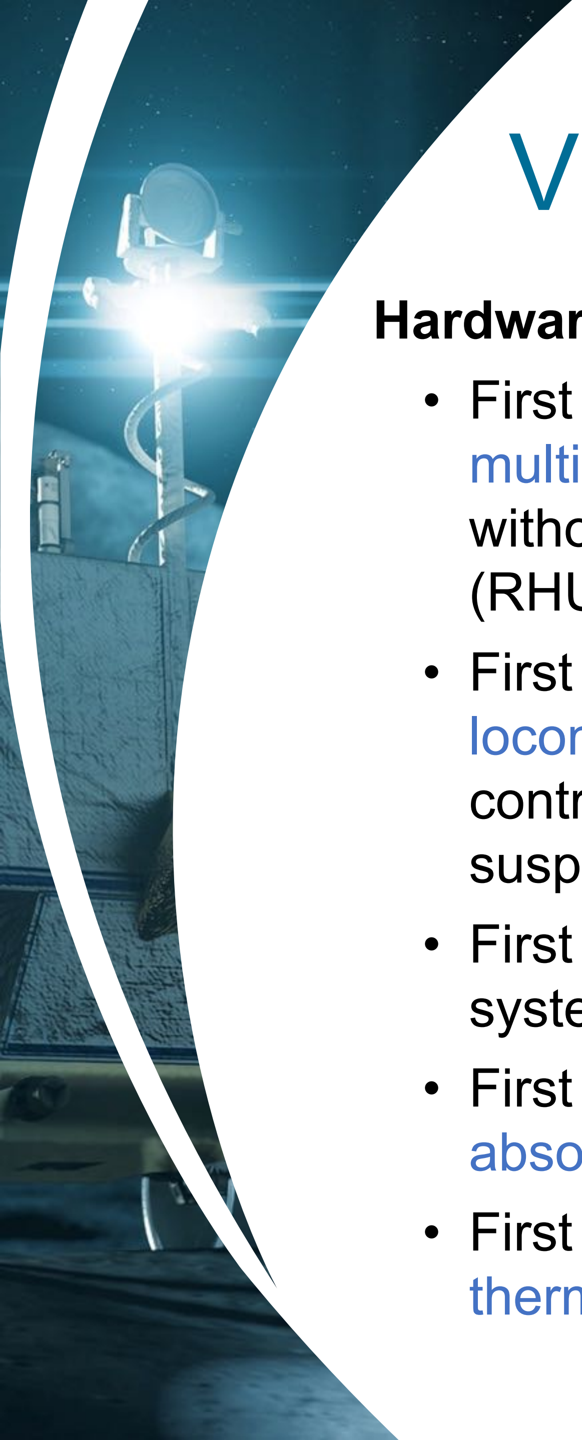
Research & Tech (R&T) mission

- Significant tailoring of traditional NASA flight requirements for cost & schedule savings
- VIPER managed as a low-cost, risk-tolerant pathfinder mission

Significant commercial engagement

- Instruments developed with industry (SBIR/STTR program)
- First major ($500M) NASA mission to rely on CLPS program for launch and landing service





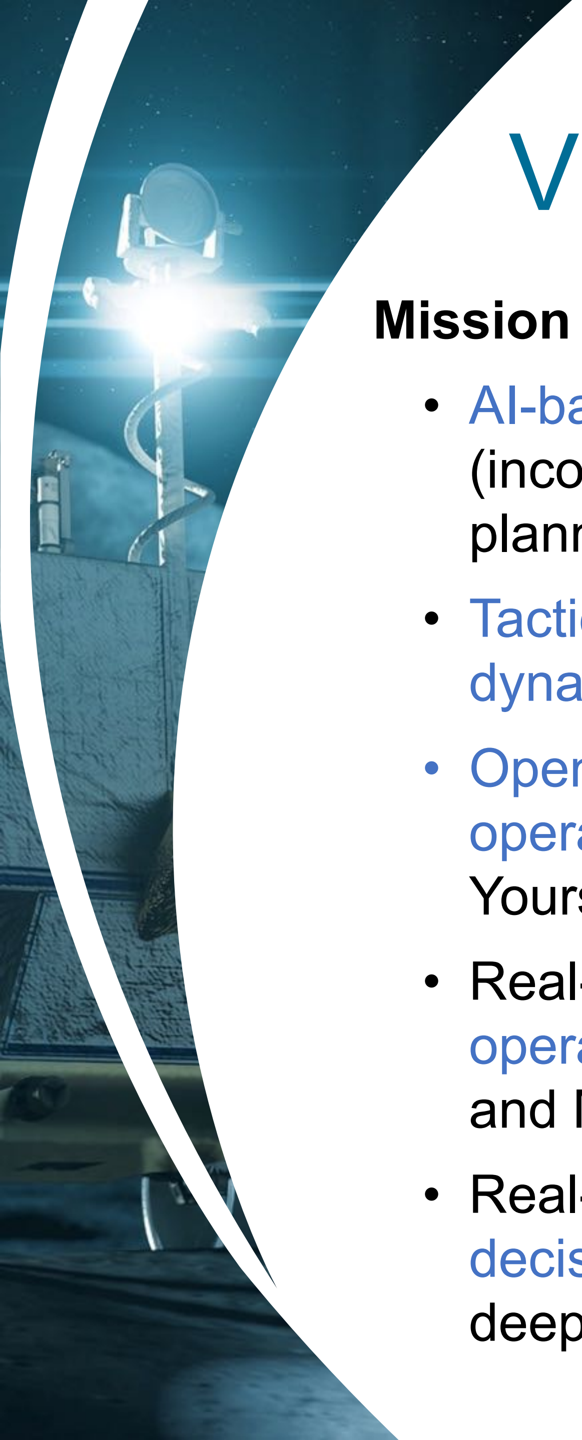
VIPER Innovations

Hardware

- First rover designed to operate for multiple lunar day/night cycles without use of any radioisotopes (RHU or RTG)
- First NASA rover with hybrid locomotion gaits (combined active control of propulsion, steering, and suspension)
- First rover with artificial lighting system for ops & perception
- First rover with star tracker for absolute orientation measurements
- First lunar rover with loop heat pipe thermal management system

Software

- First hybrid flight software for lunar rovers using cFS (on-board) and ROS2 (off-board)
- High-fidelity lunar rover simulator for dev, V&V, and ops training
- High-resolution (1 m/pixel) "shape from shading" DEM production
- High-quality (4 cm/pixel) synthetic terrain modeling
- Terrain-relative localization: relative (3m) and absolute (20m)
- Real-time directional comm antenna Earth pointing while driving
- Autonomous comm link recovery



VIPER Innovations

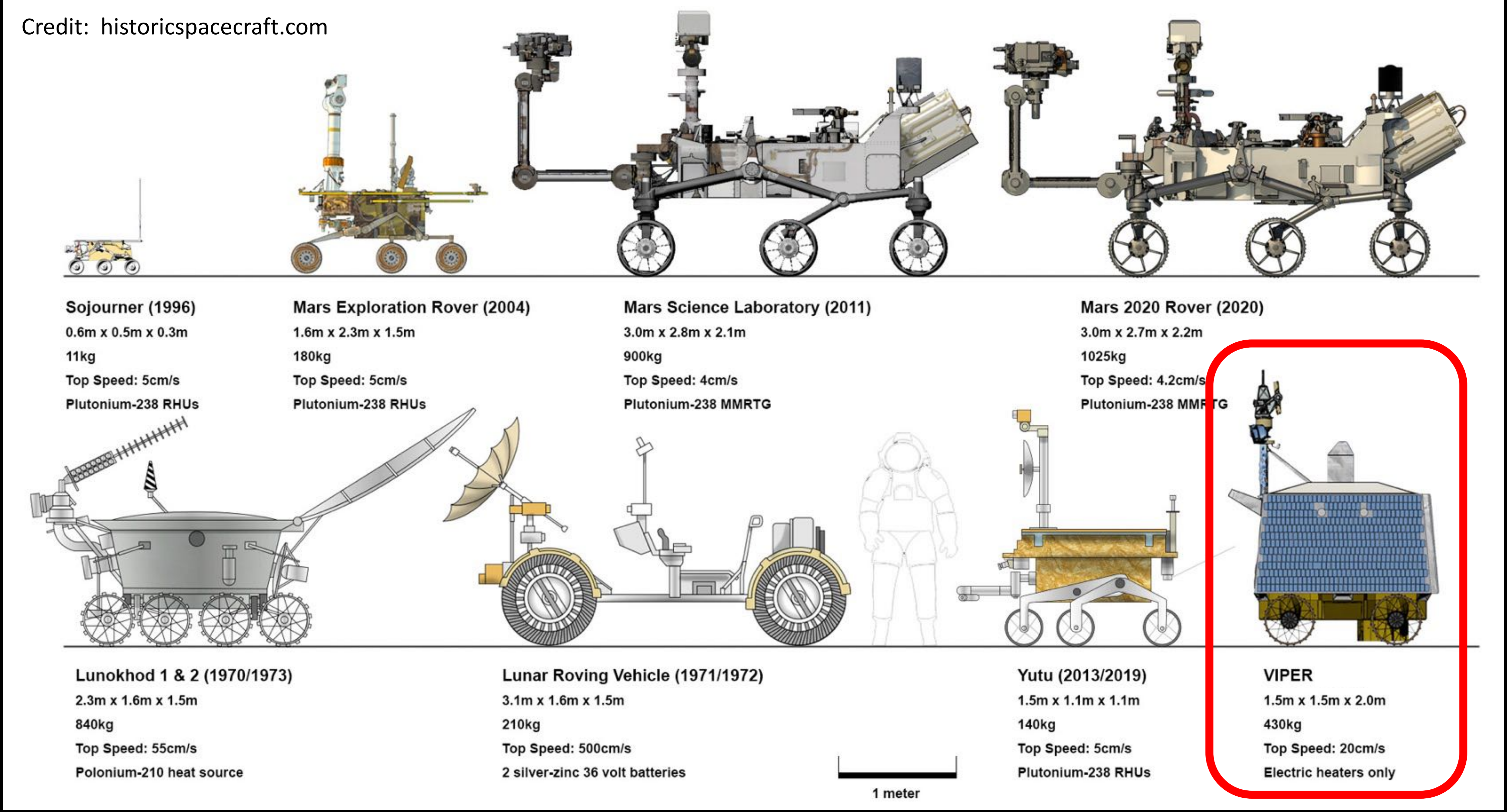
Mission Ops

- AI-based strategic traverse planning (incorporates multiple solvers and planning under uncertainty)
- Tactical planning technology for dynamic operational environment
- OpenMCT open-source mission operator interfaces (including "Do It Yourself" public mission control)
- Real-time interactive rover operations (hybrid of ISS real-time and Mars rover command-cycle)
- Real-time science operations and decision making (similar to ROV deep-sea exploration)

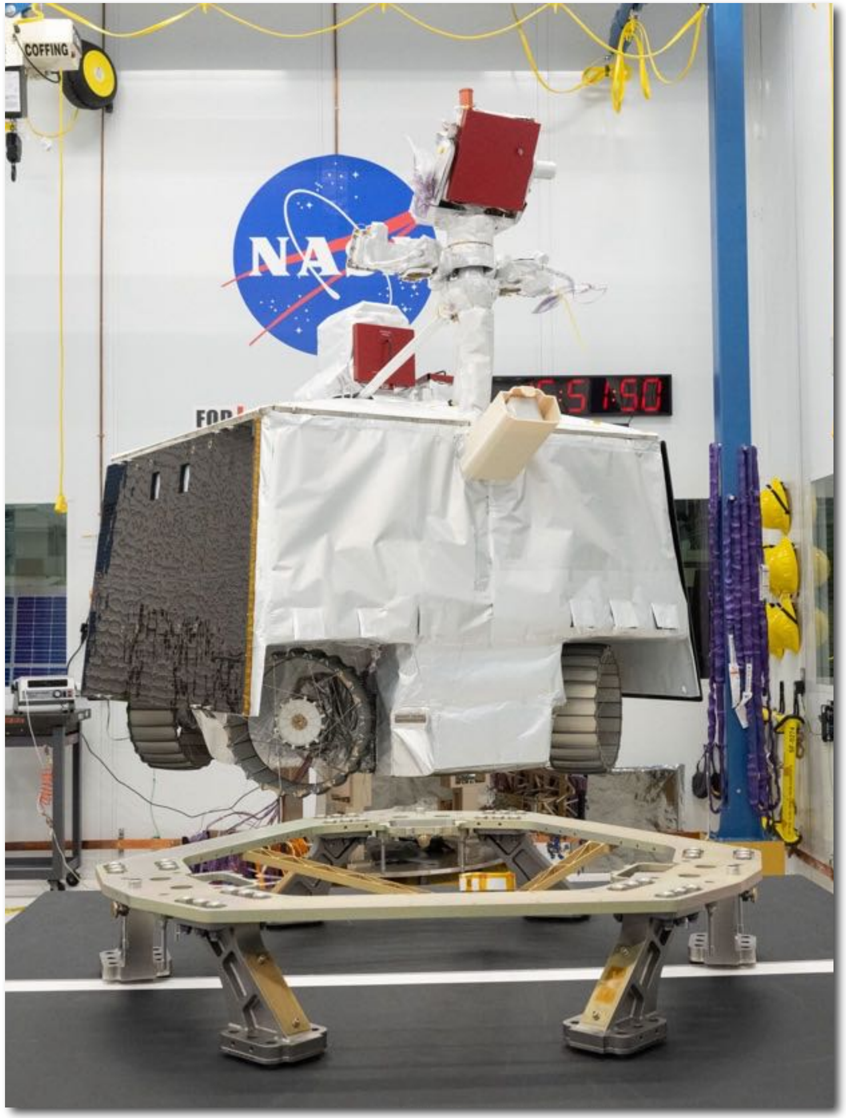
Commercial Partnerships

- Real-time slip estimation software (ProtoInnovations, SBIR/STTR)
- Hybrid mobility gait control software (ProtoInnovations, SBIR/STTR)
- TRIDENT rotary-percussive drill (Honeybee, SBIR)
- Modified spectrometer for NIRVSS (Brimrose, SBIR)
- Modified COTS mass spectrometer for MSOLO (Infinicon, SBIR)
- PRIDE ops procedure system (TRACLabs, SBIR)

Rover Comparison



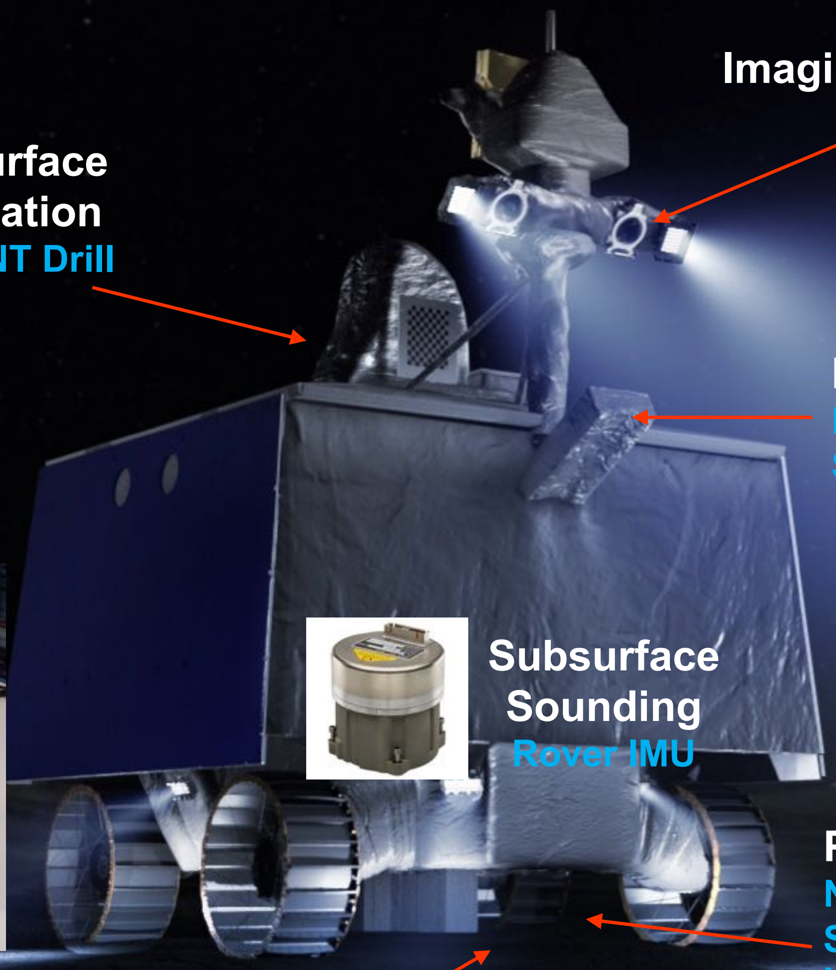
Flight Rover



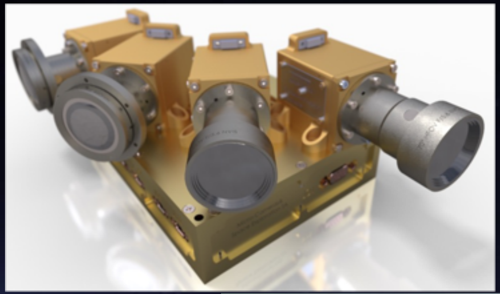
Assembly
complete
4 June 2024

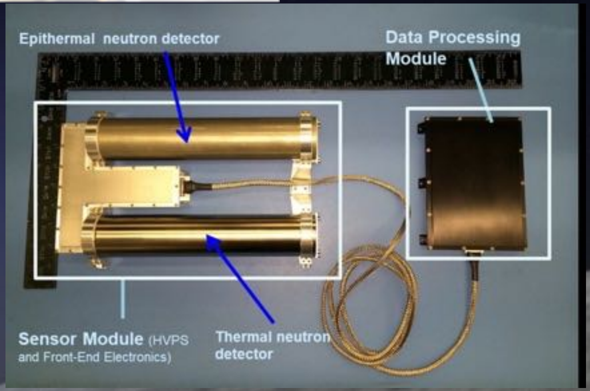
Instruments

Subsurface excavation
TRIDENT Drill



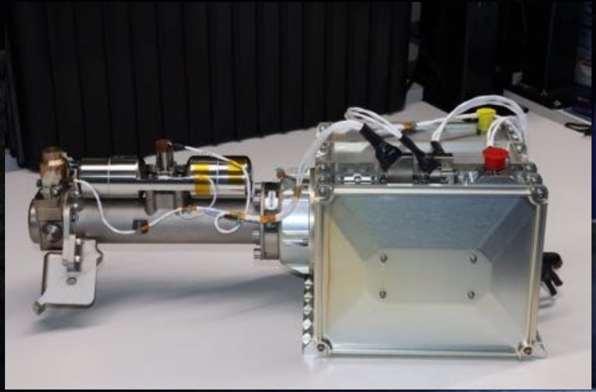
Imaging Science
VIS



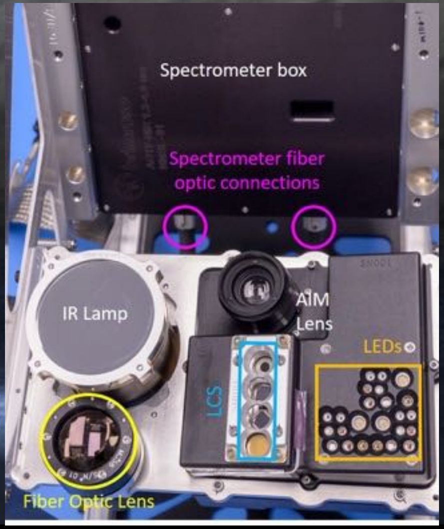


Prospecting
Neutron Spectrometer System (NSS) Instrument

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)

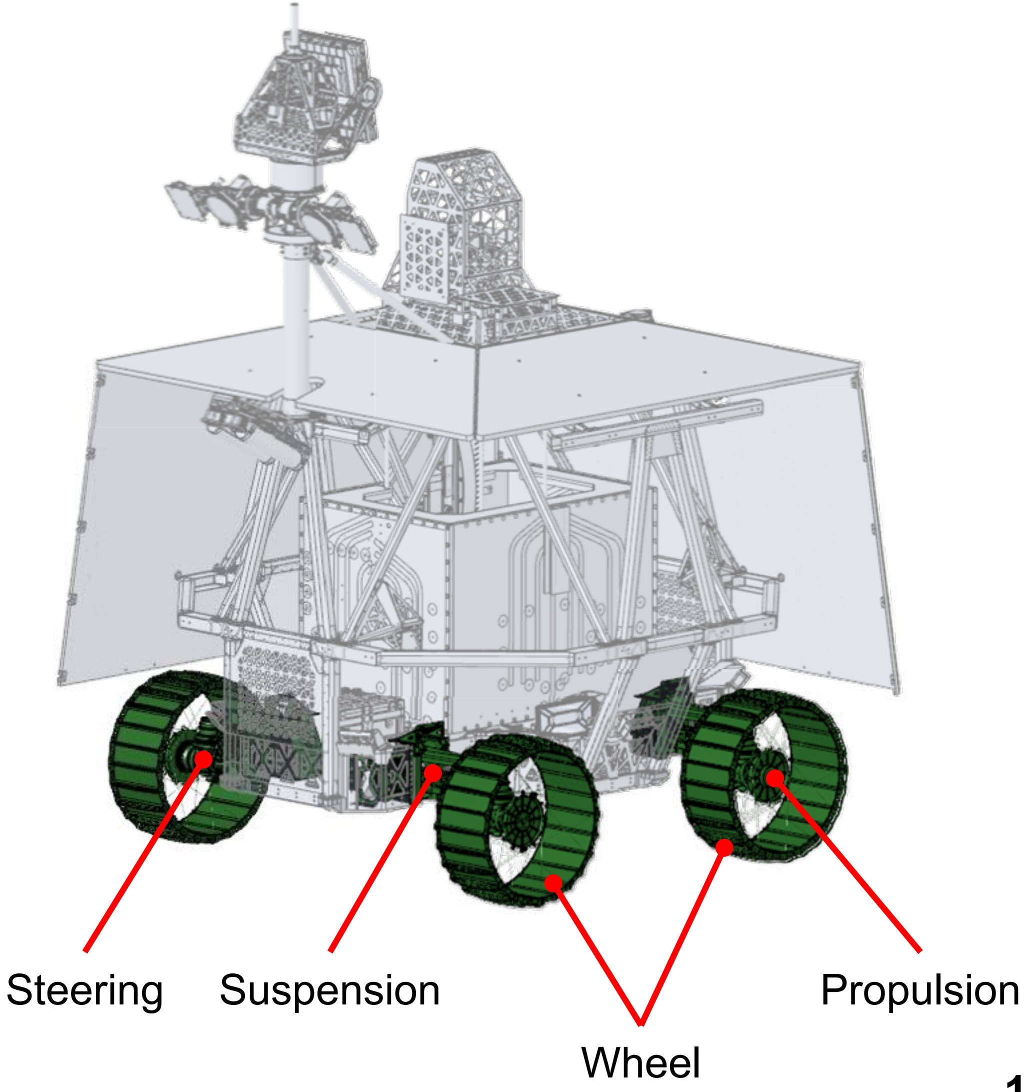
- Suspension: ± 40º, 200 N·m torque
- Steering: ± 50º, 130 N·m torque
- Propulsion: 20 cm/s, 200 N·m torque

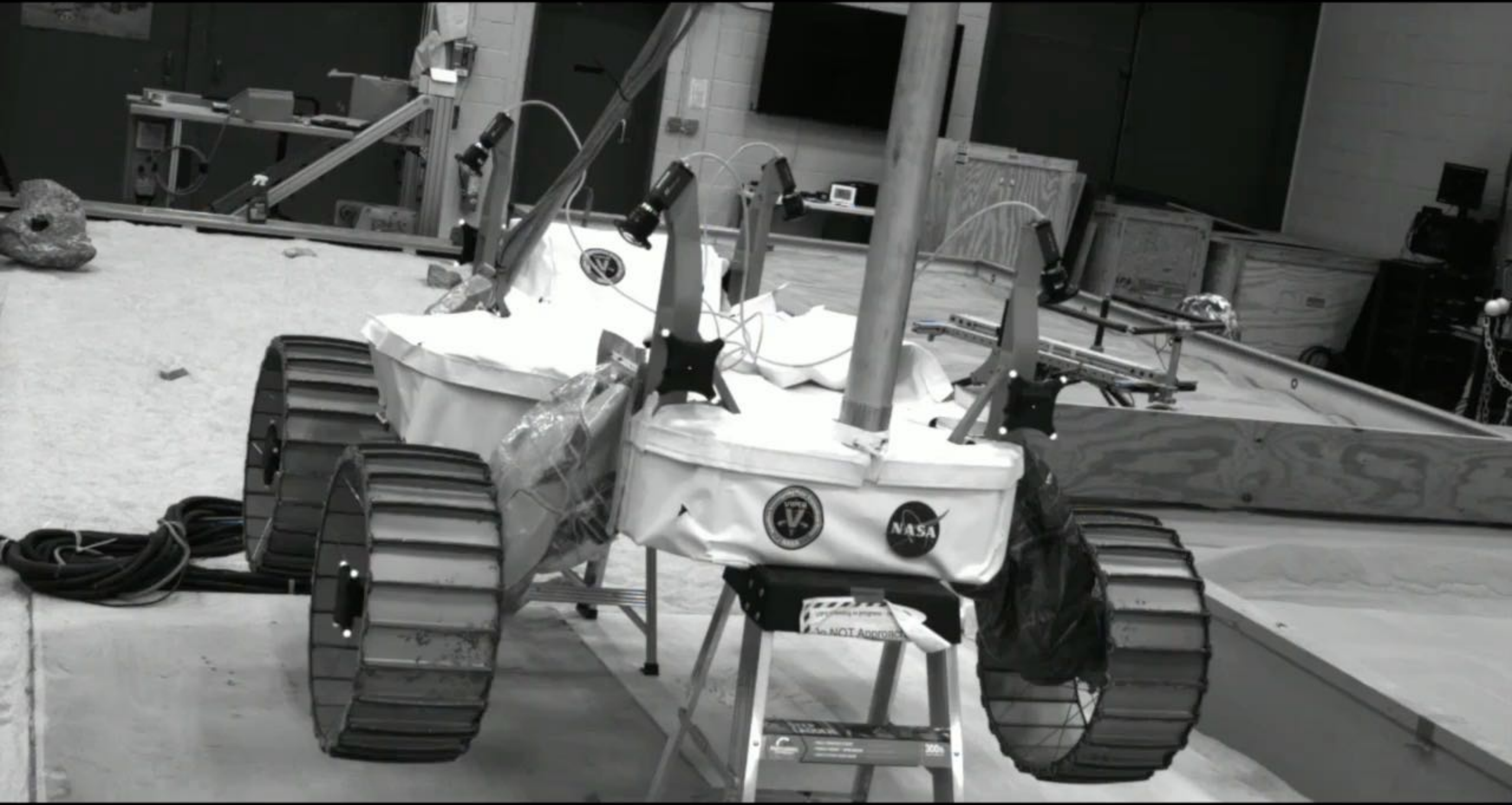
Wheels (4x)

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

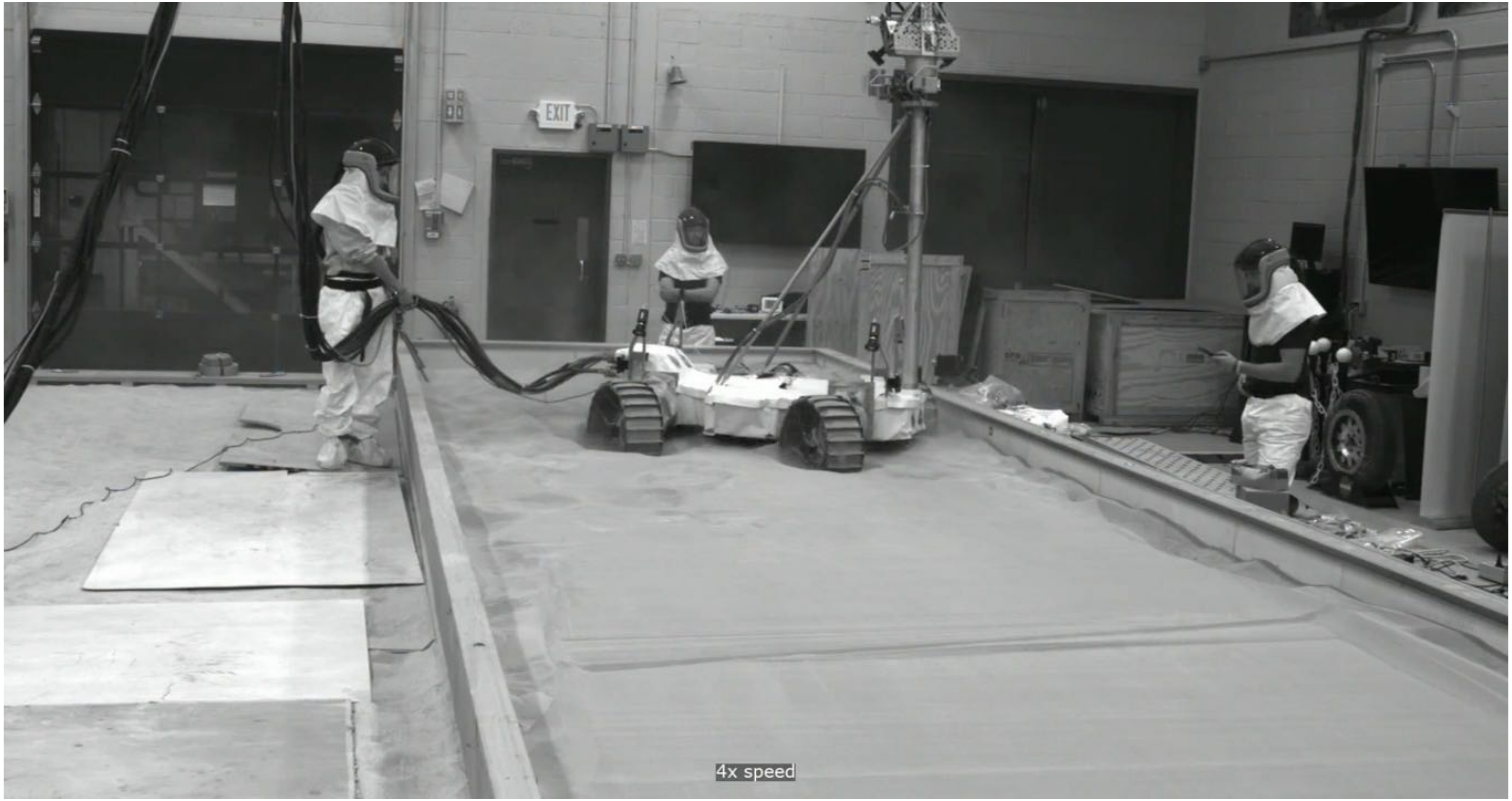
Capabilities

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



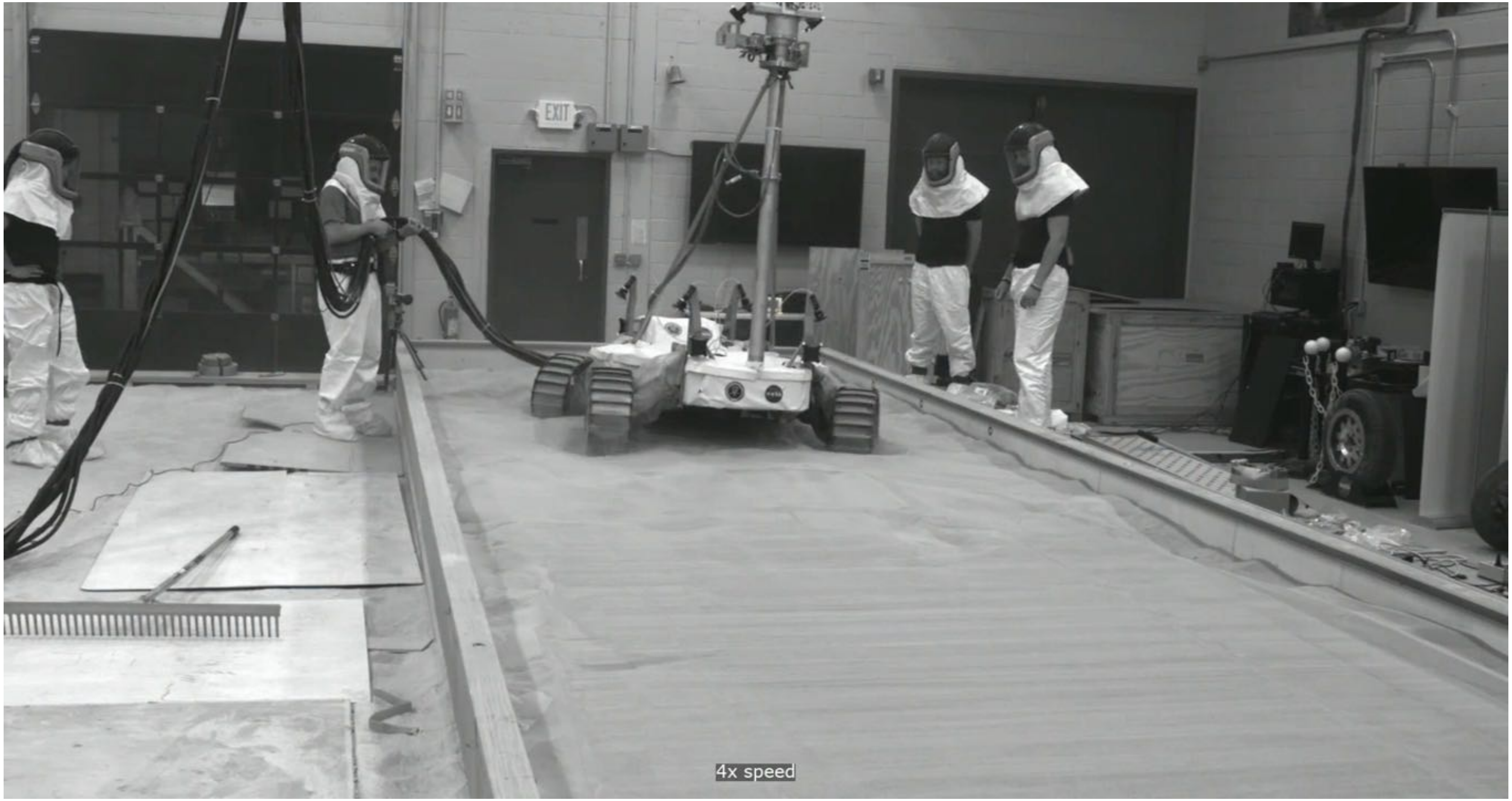

NASA

Alternate Mobility Modes



"Inchworm"

Alternate Mobility Modes



“Wheel Walking”

VIPER Simulator

High-quality lunar lighting

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

High-fidelity camera models

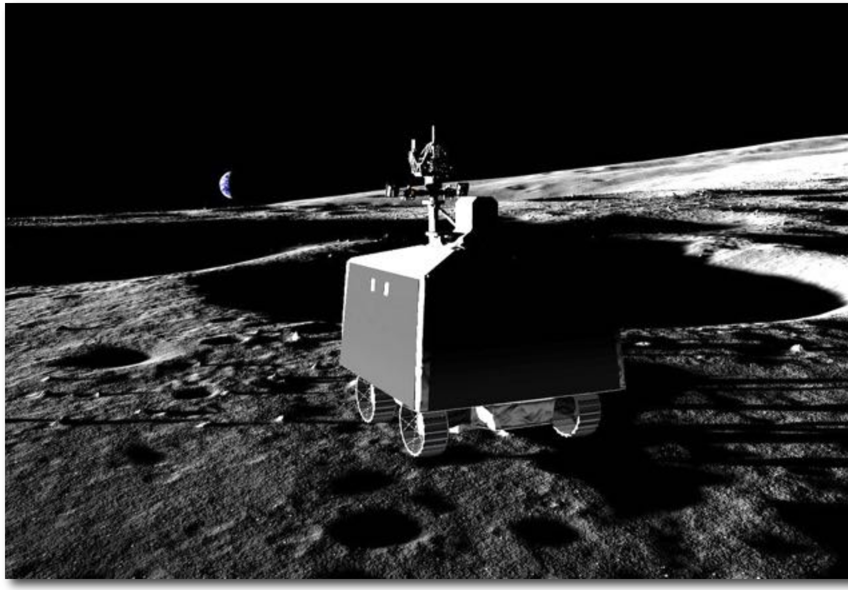
- Exposure, distortion, flare, fixed pattern noise, pixel defects, bit depth, read noise, etc.
- Tuned using NASA Ames “Lunar Lab” tests with camera/light EDUs

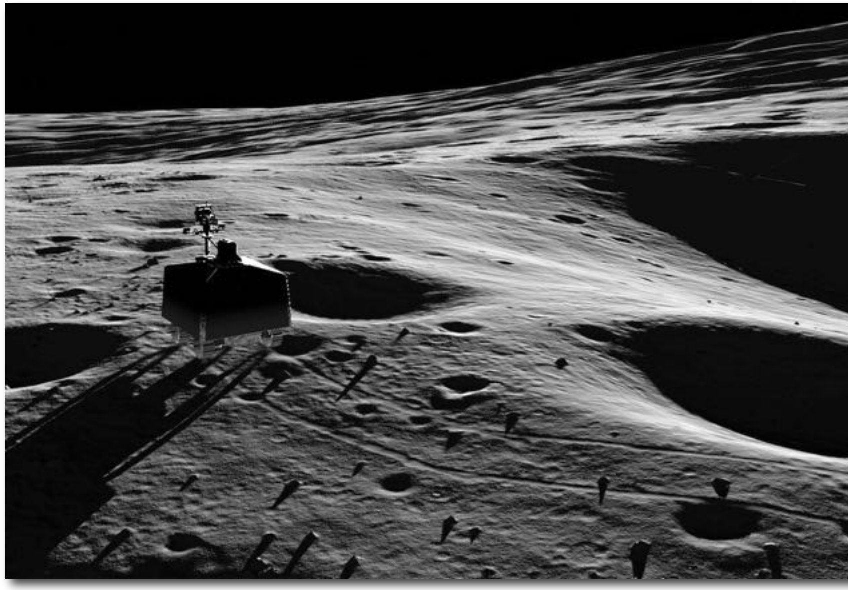
Real-time slip modeling

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

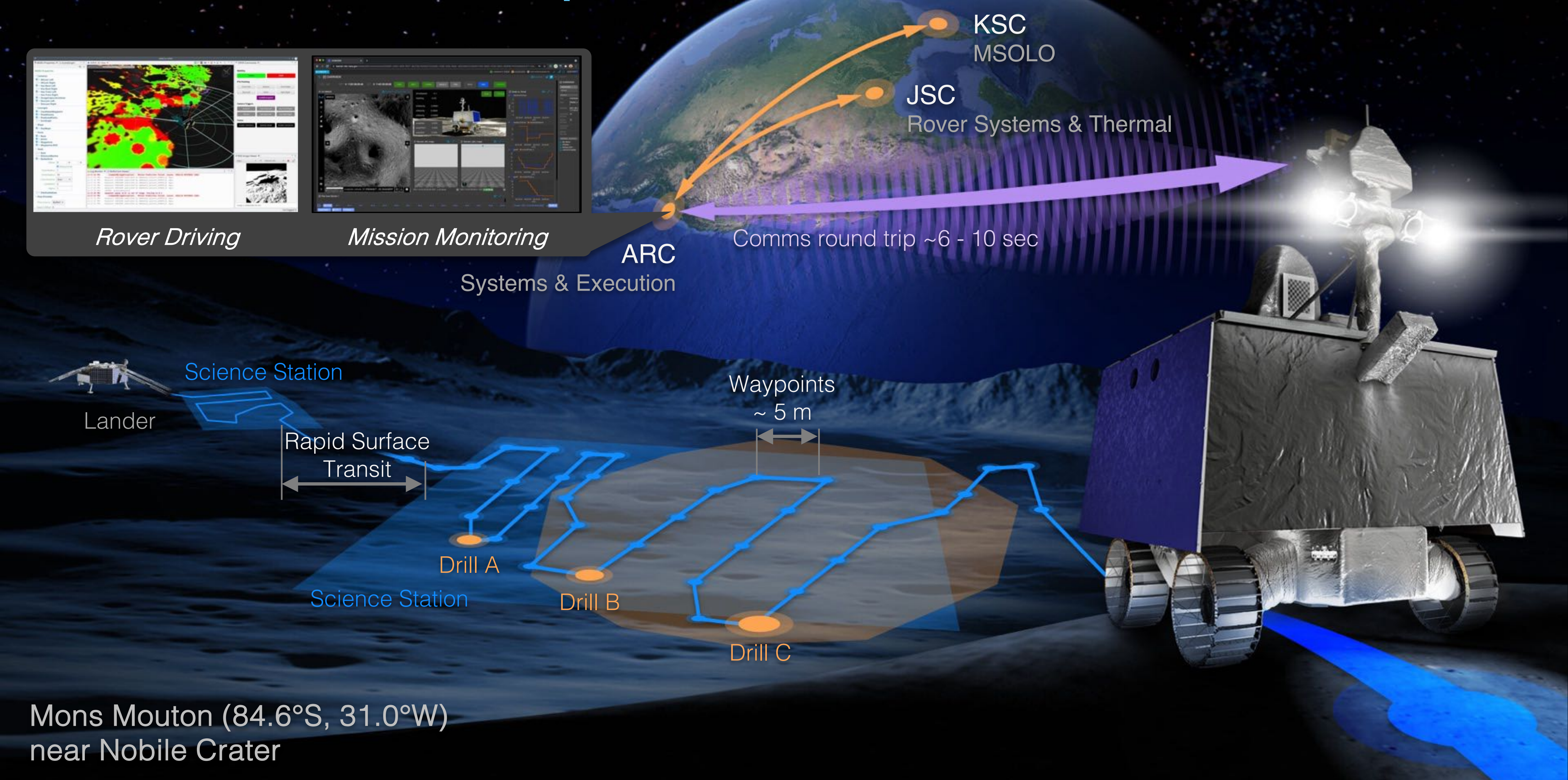
High-resolution lunar terrain models

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



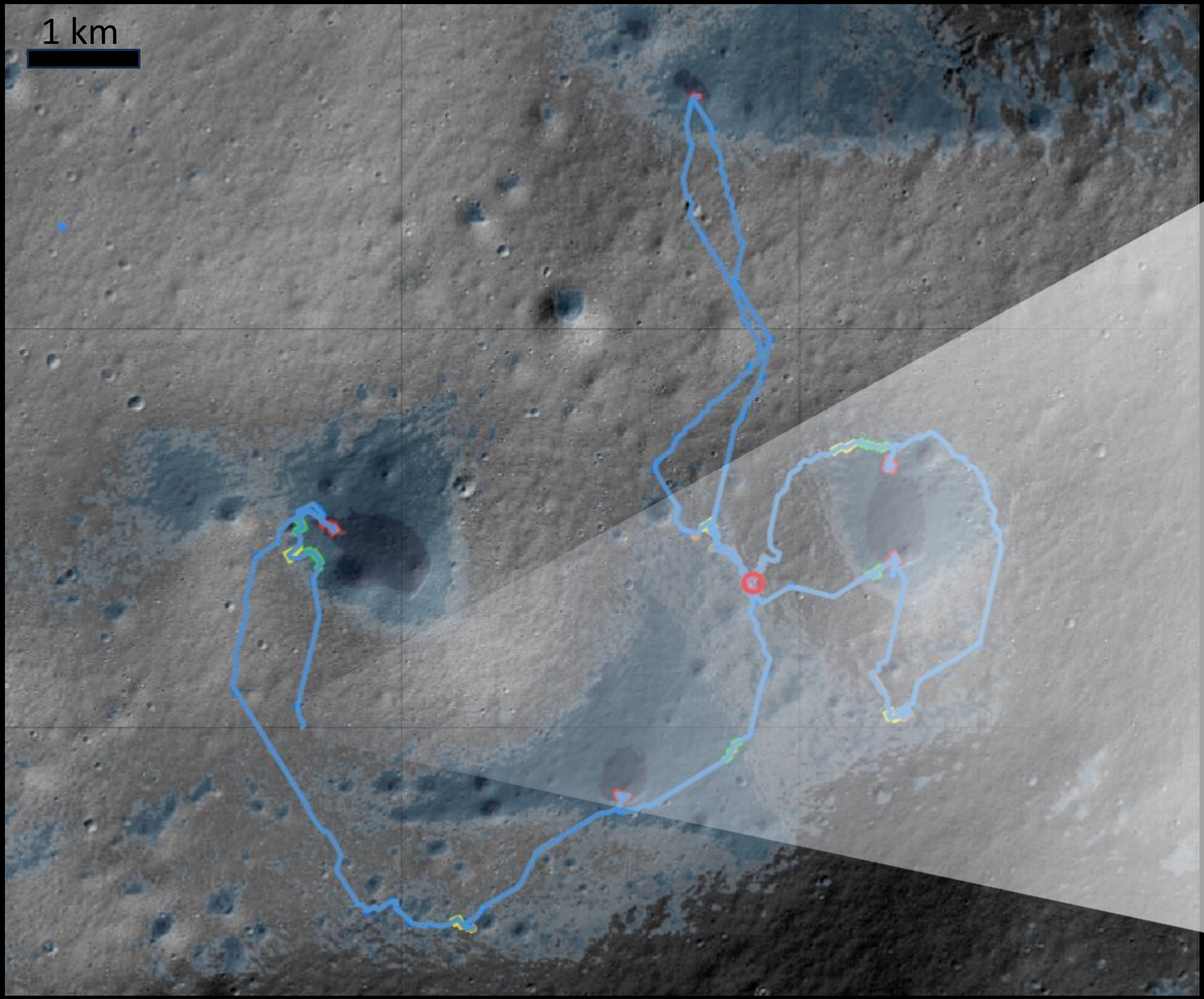


VIPER Mission Ops

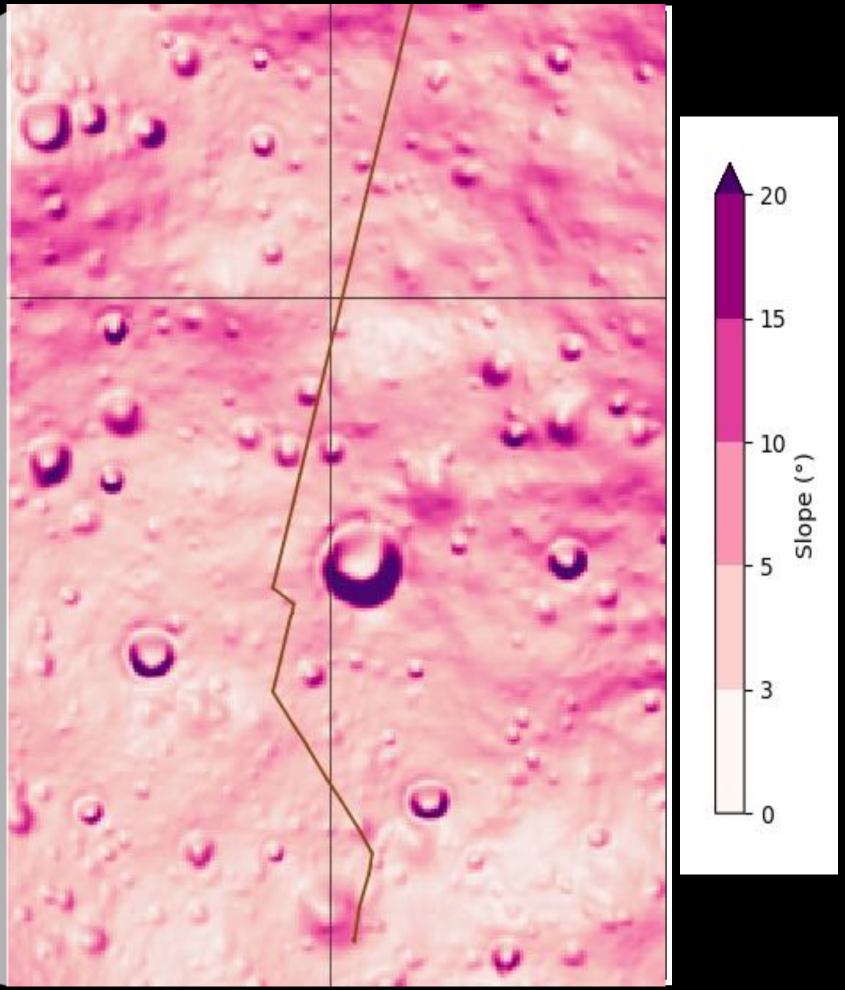


Mons Mouton (84.6°S, 31.0°W)
near Nobile Crater

Rapid Surface Transit

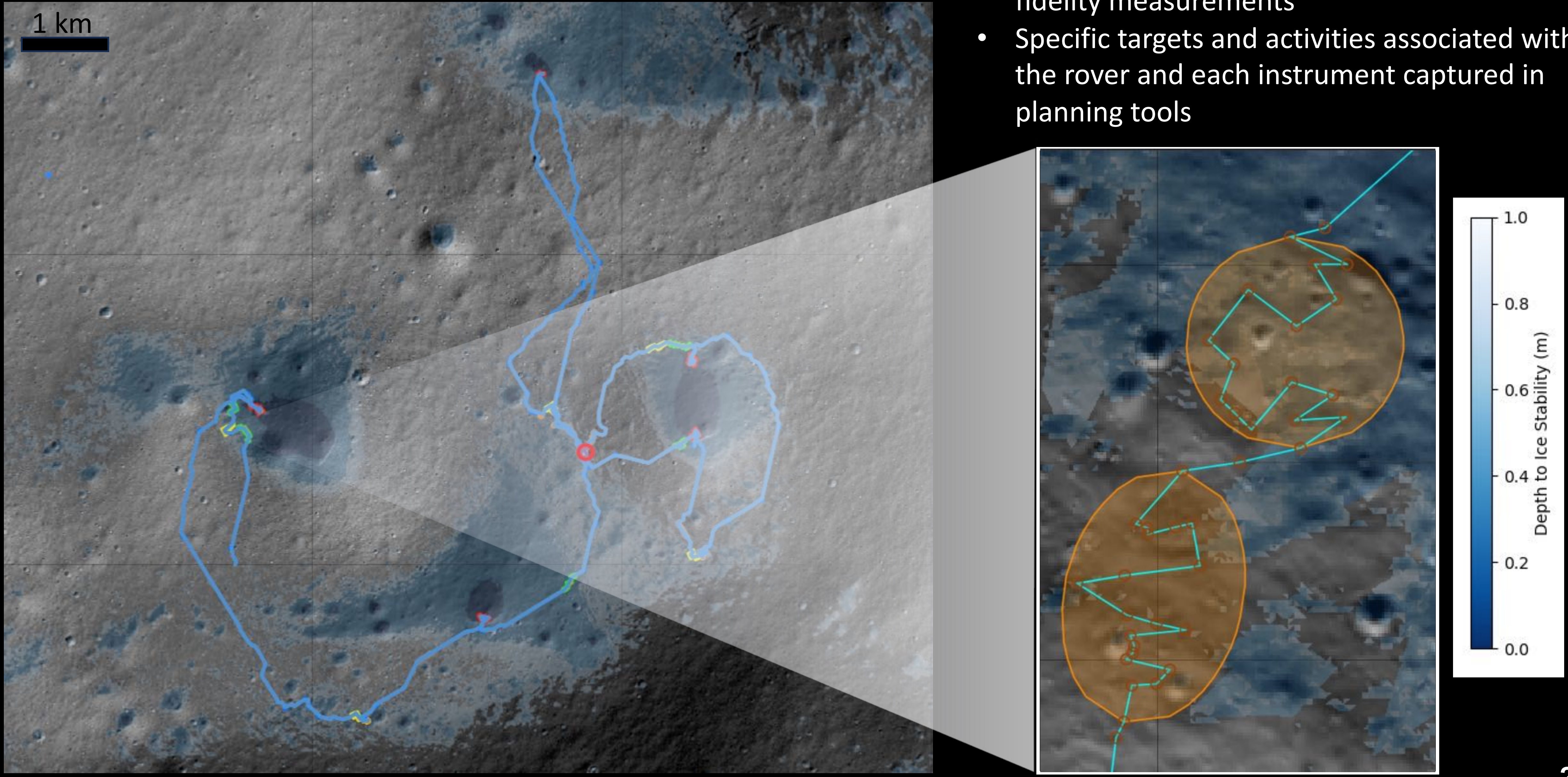


- From landing site, traverse in "Rails" driving mode – quickly and safely driving between Science Stations while rapidly collecting surface images and neutron measurements (NSS)
- Traverse optimized with AI Tools within hazards, sun and comm constraints



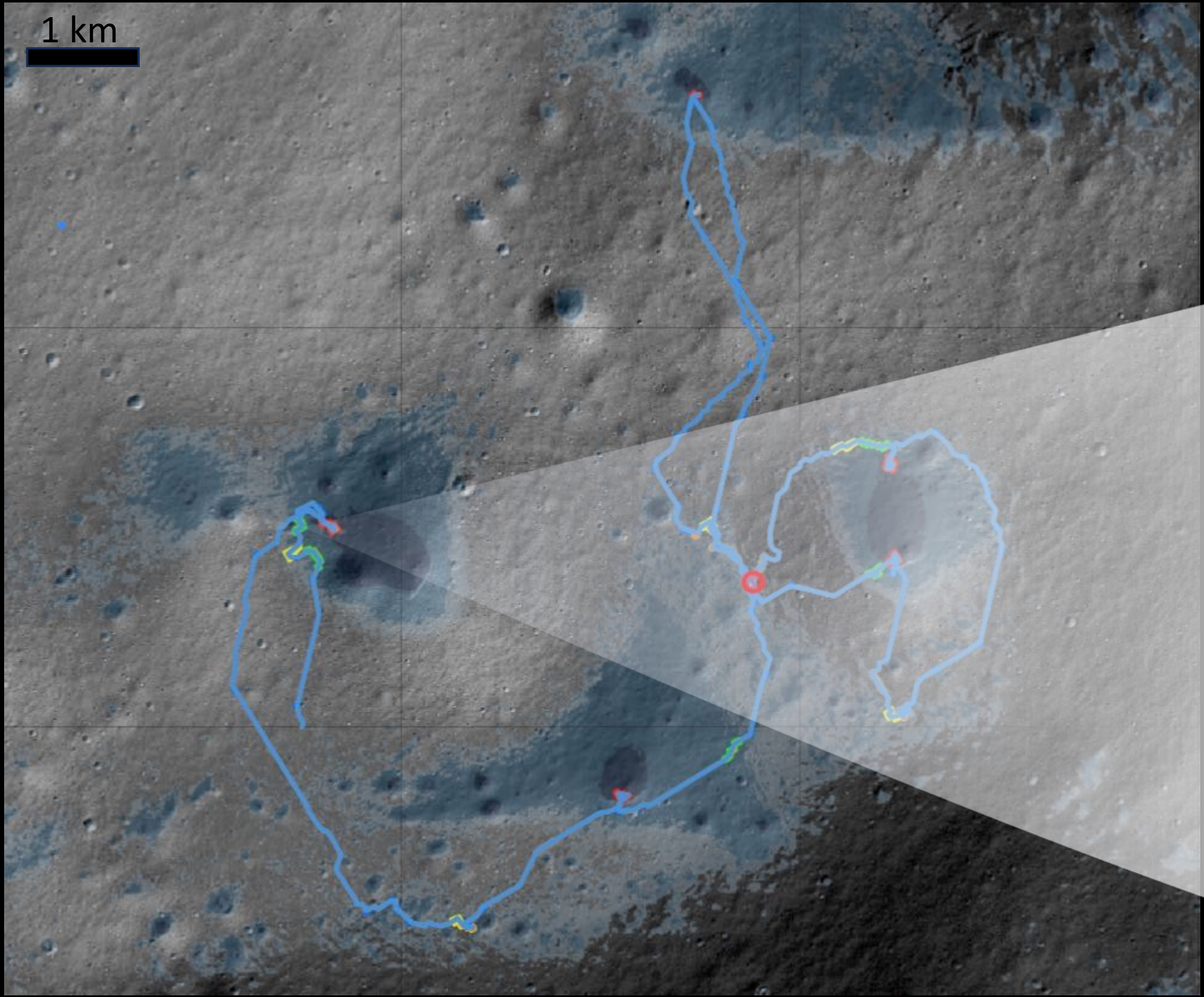
Science Stations

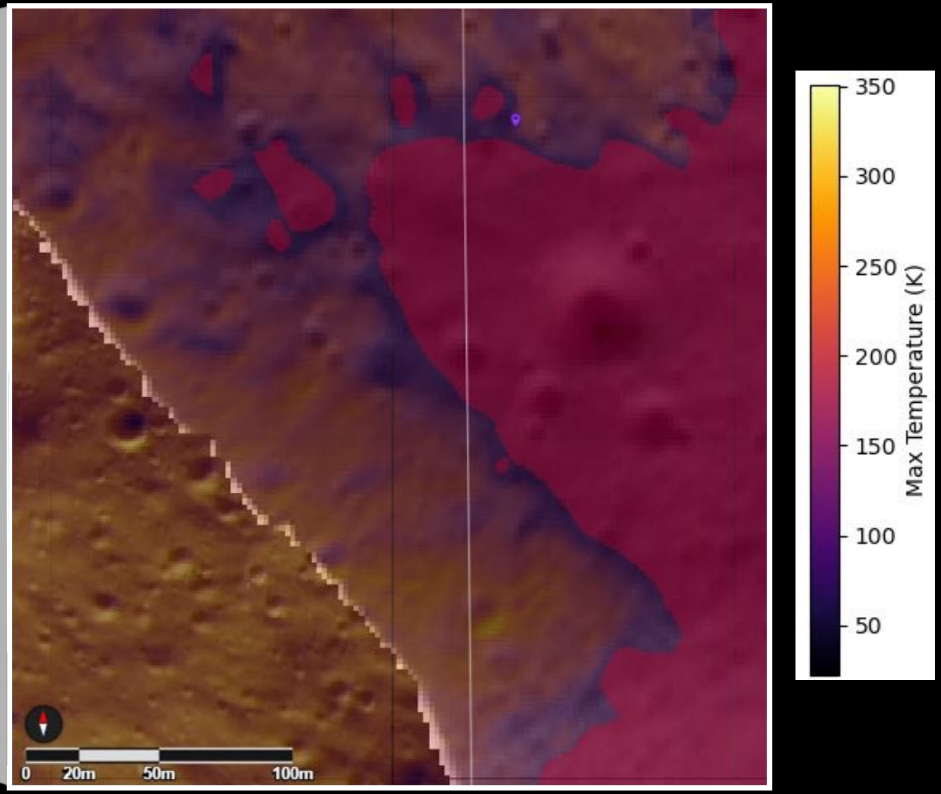
- In locations of interest, drive mode changed to “Prospecting” which allows for higher fidelity measurements
- Specific targets and activities associated with the rover and each instrument captured in planning tools

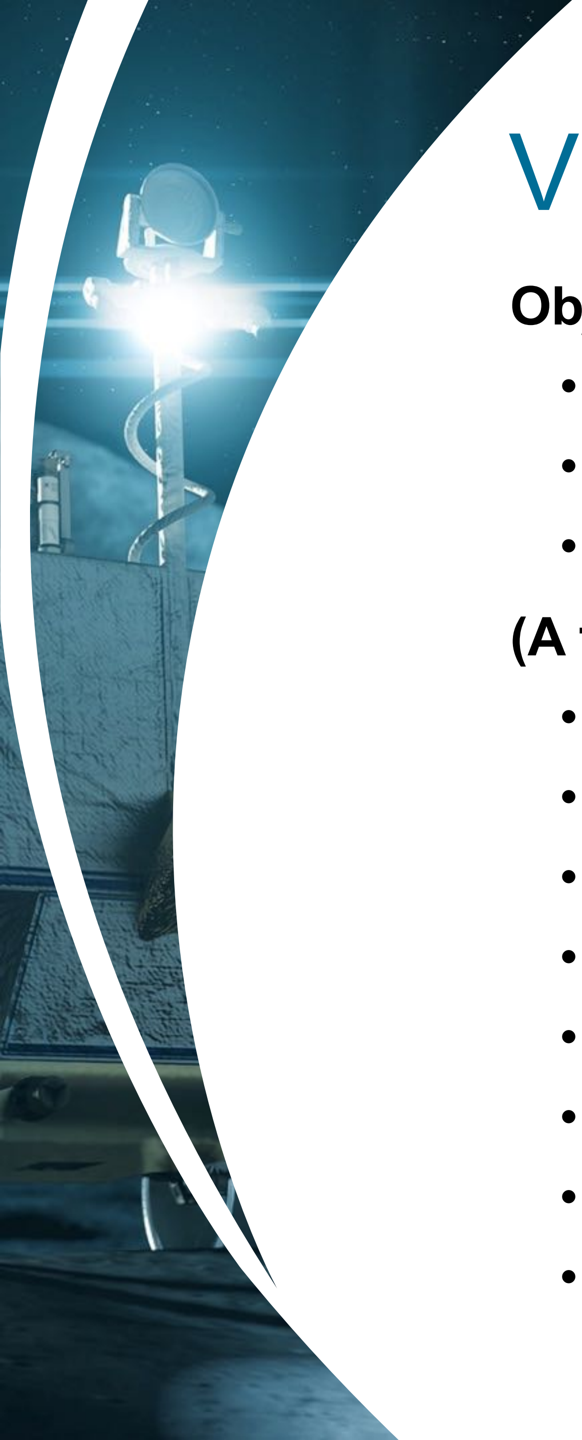


Shadowed Operations

- Batteries sized to allow for 9 hours of shadowed operations, including PSR operation, with all prospecting instruments operating and drilling to 1-meter depth
- Active illumination on rover and instruments allow in-shadow operation.







VIPER Mission Planning

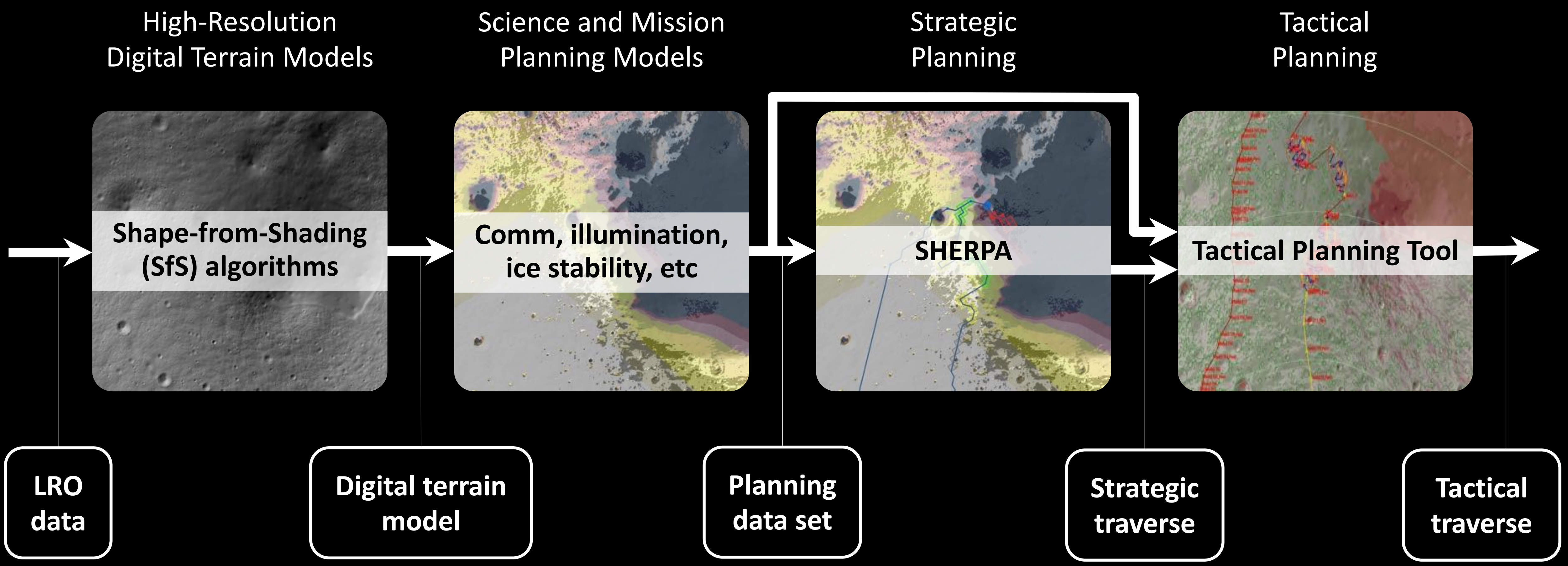
Objectives

- 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)

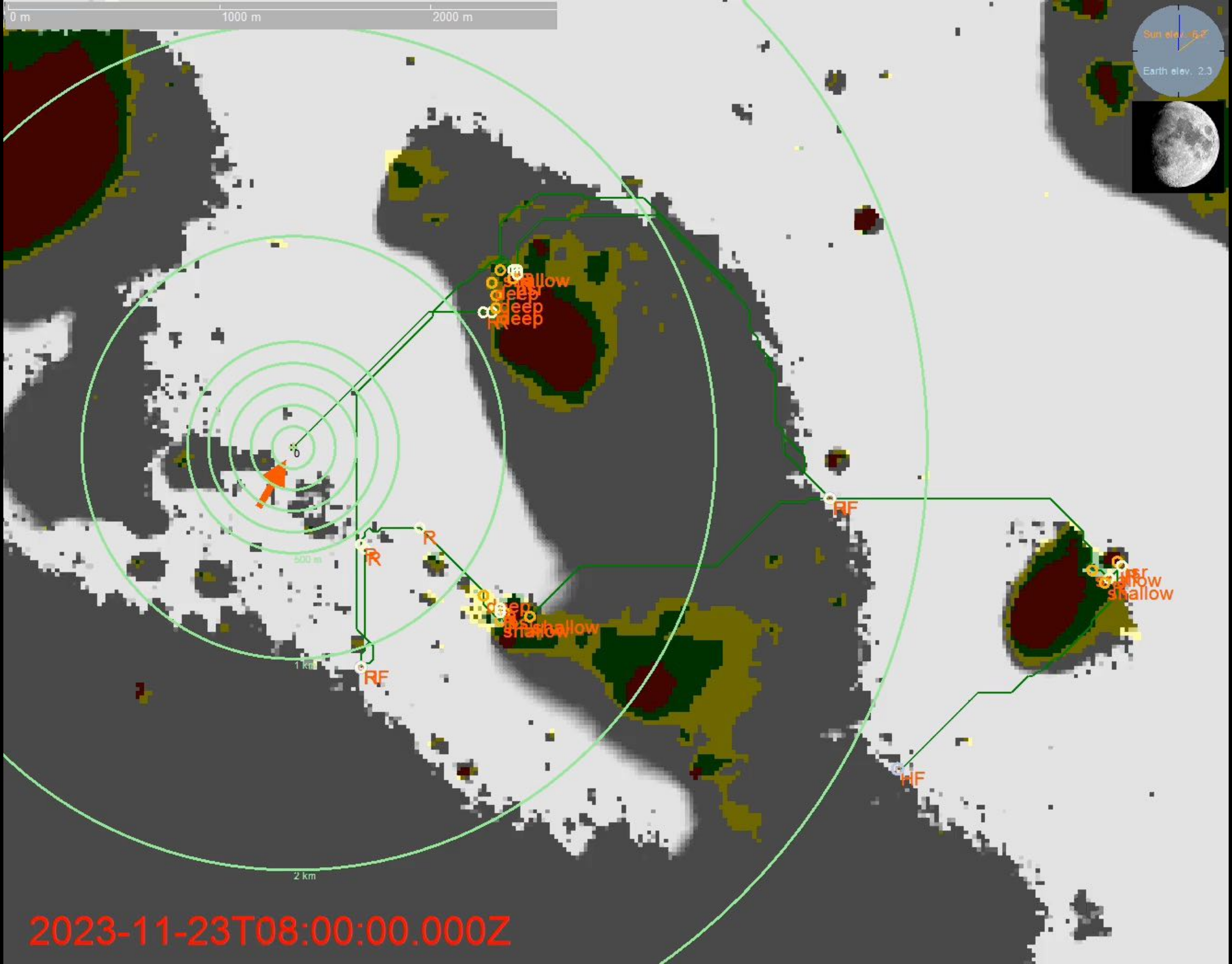
Planning Process



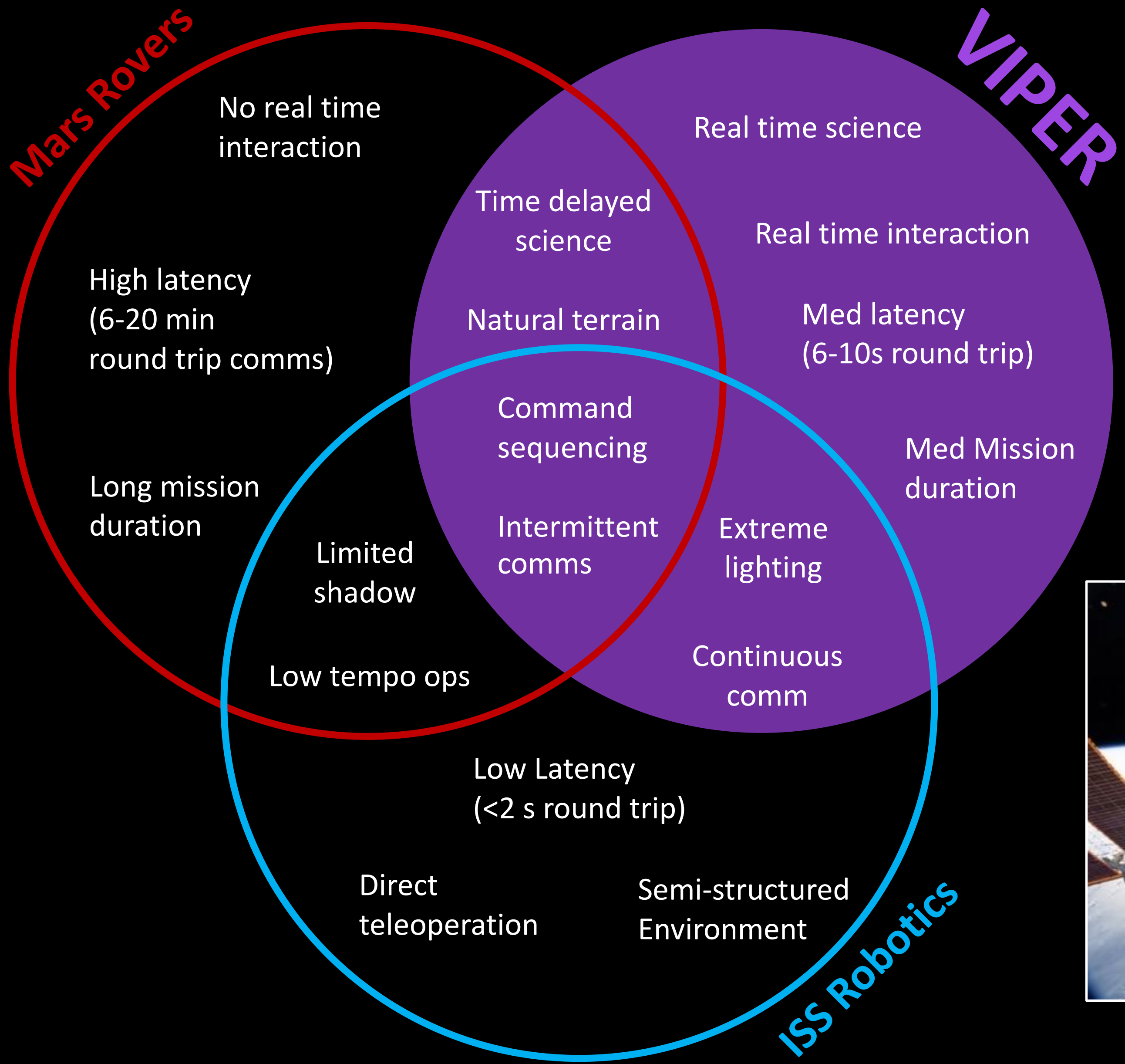
Example Traverse Plan

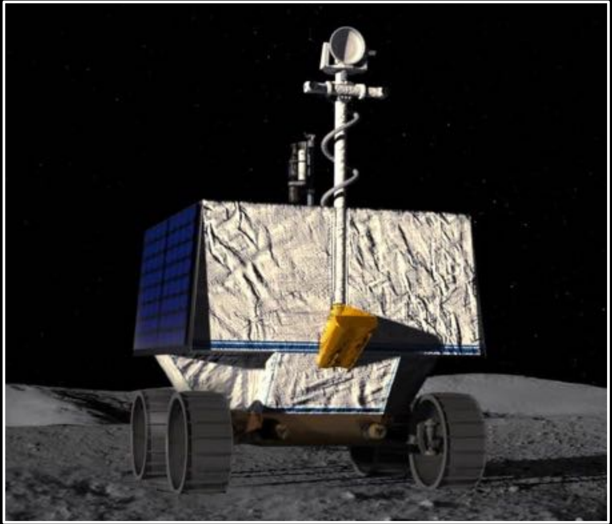
2023-11-23
to
2024-03-07

106 days



VIPER vs ISS vs Mars Rovers

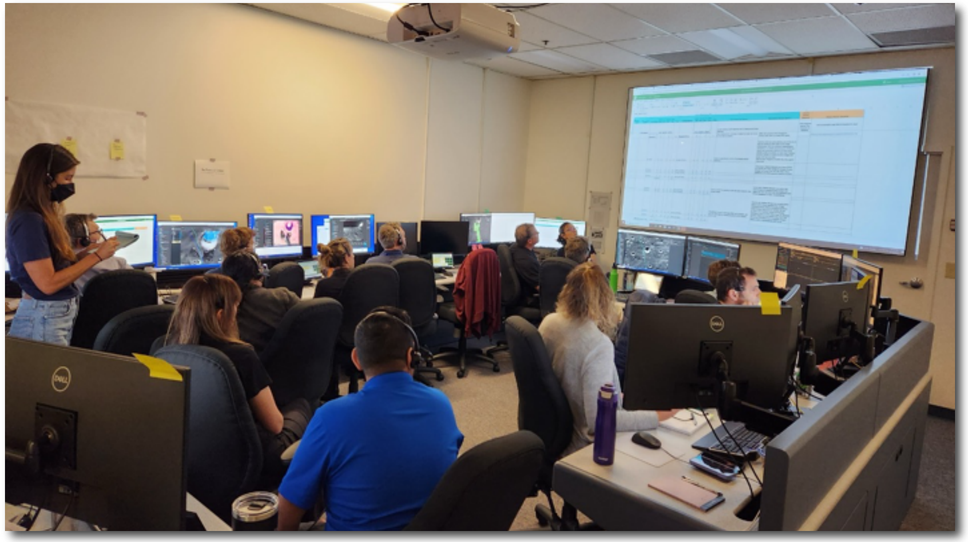




Real-Time Science Operations

Interactive decision making

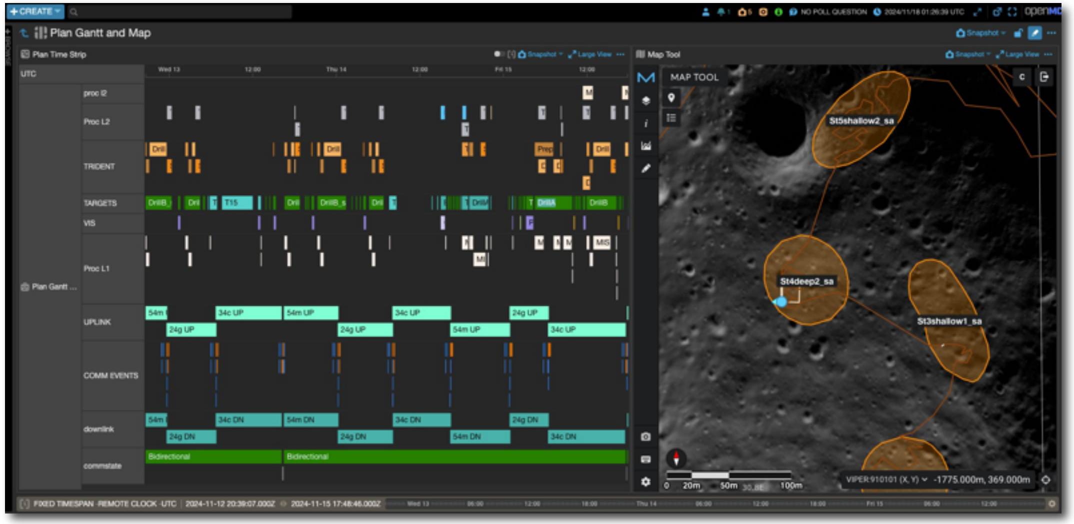
- Tight integration between science and spacecraft ops
- Fluid, interactive presentation, exploration of data **as it is collected**
- Rapid, on-site data analysis using pre-defined packages with multiple tools ARCGIS, Excel, MATLAB, etc.
- Planning and replanning of rover traverse and activities **based on real-time science measurements**



OpenMCT

Ground data system framework

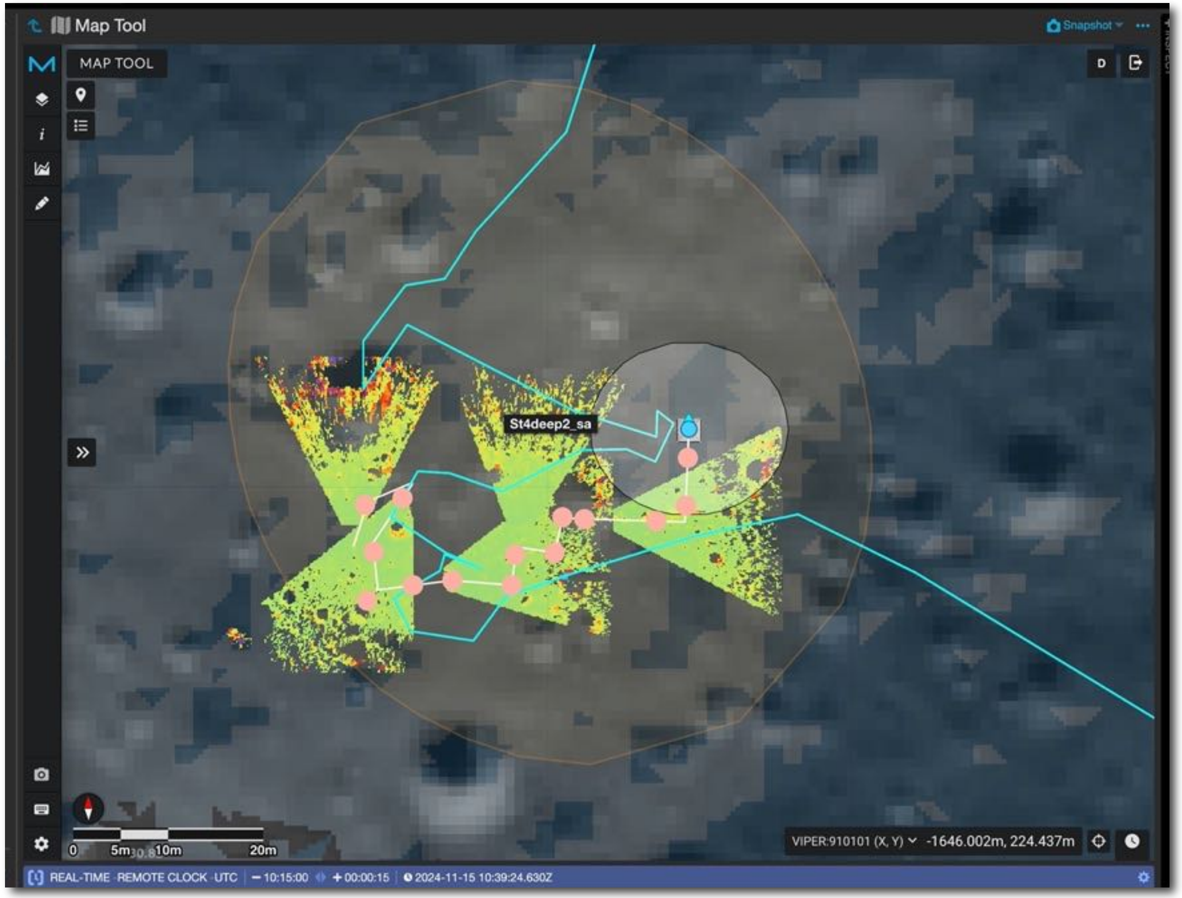
- Web-based front-end
- Data management (annotate, export, filter, search, etc).
- Real-time status displays
- Time series data displays (raw and computed)
- Integrated tools (e.g., MMGIS)
- NASA open-source https://nasa.github.io/openmct

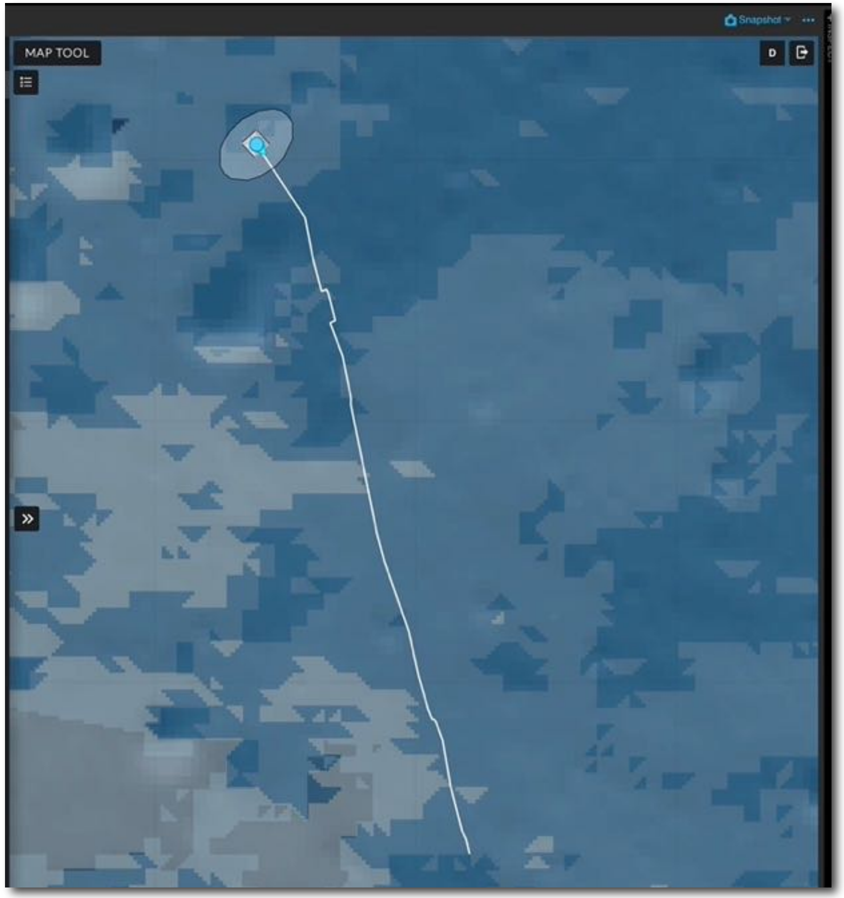


MMGIS

Map-based Geographic Information System tool

- Real-time geospatial data from rover and instrument measurements
- Multiple map layers (including sets, overlays, annotation, search)





Rover Operations

NASA Ames Multi-Mission Ops Center (MMOC)

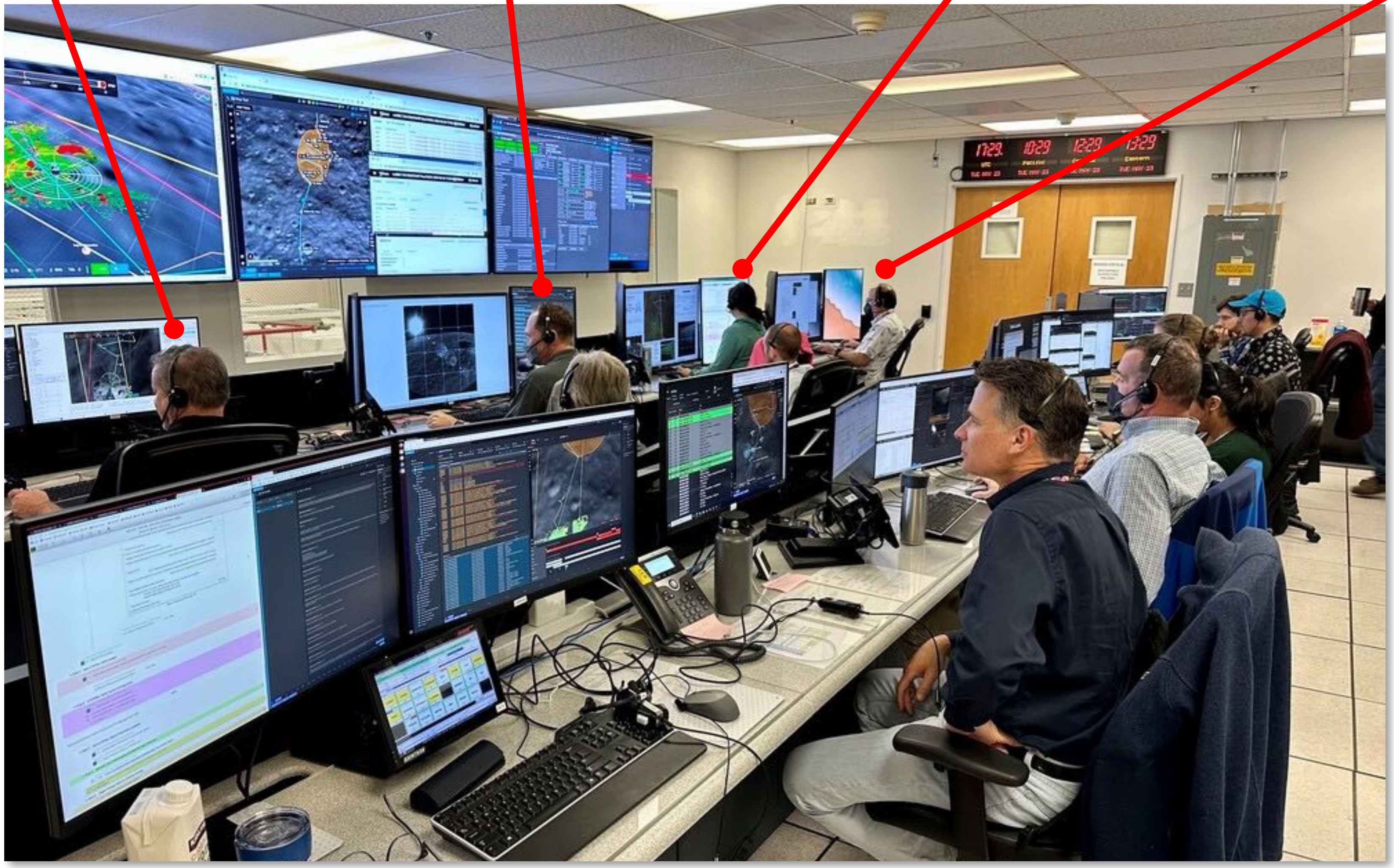
"Drive Team"

Real-Time Science

Driver

Co-Driver

Navigator



VIPER Interactive Rover Driving

"Drive Team" Ops Structure

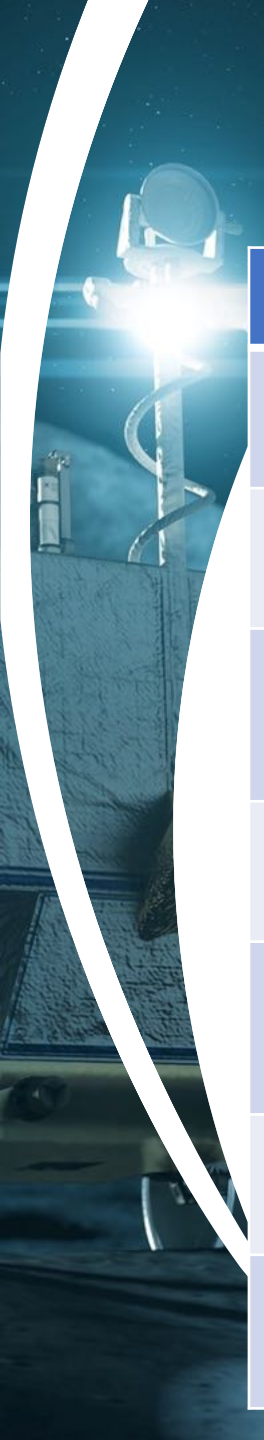
- **Driver** – command rover mobility and imaging
- **Co-Driver** – supports decision making, mobility monitoring, voice loops
- **Navigator** – monitors pose (absolute/relative) and nav sensor health
- **Real-time Science** – supports real-time science ops, liaison to science team

Command Cycle (5 min duration)

- Terrain hazard assessment, tactical motion planning, image capture planning, interactive science, and waypoint driving
- Highly interdependent teamwork using decision support tools

Primary Motion Control = Waypoint Driving

- Interactively command rover to drive to a waypoint 4-8m away
- Rover on-board control achieves the waypoint
- Employ a variety of tactical driving techniques to handle different surface conditions and environments (slopes, craters, shadows, etc)

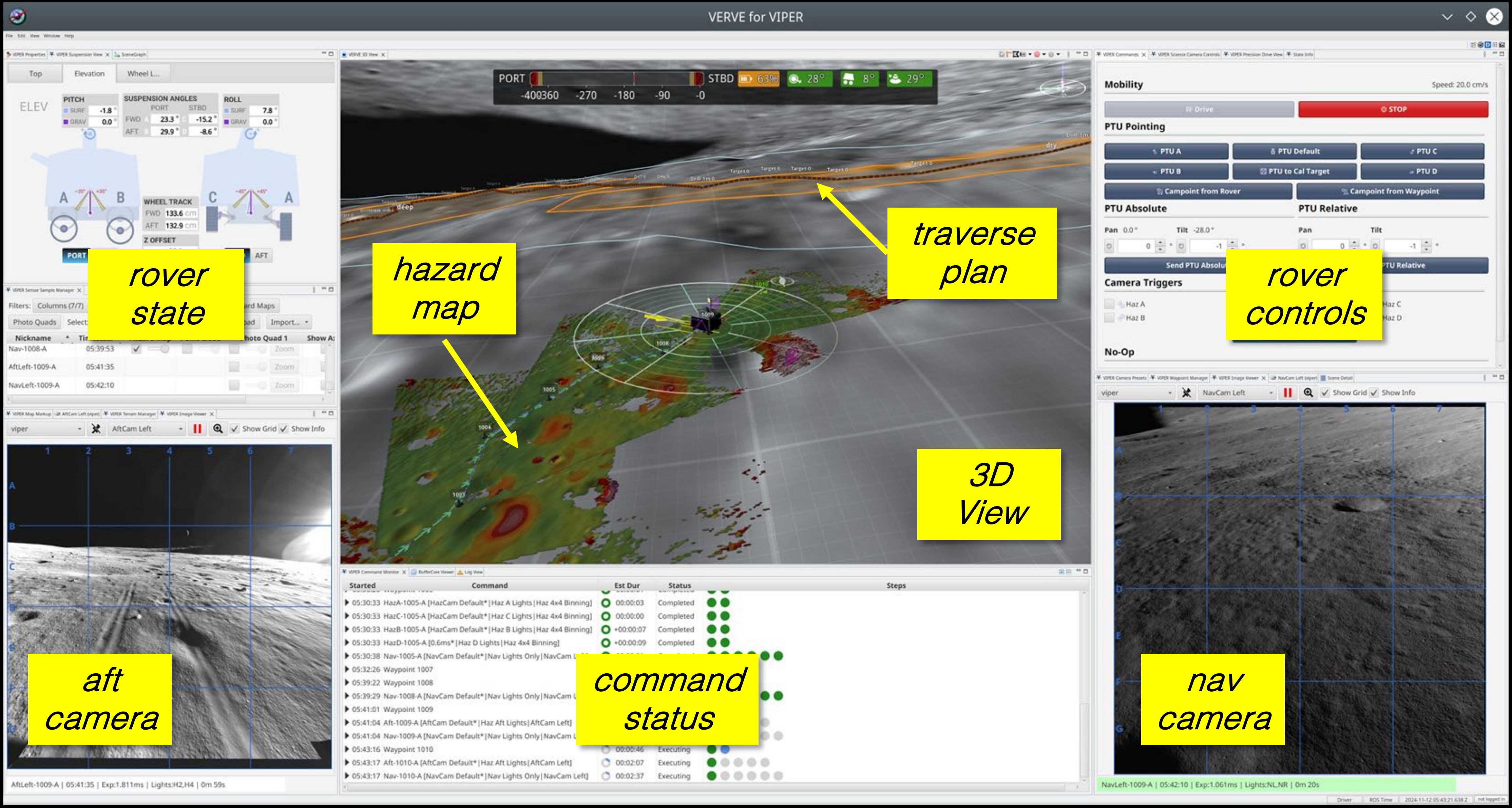


Drive Team Command Cycle Tasks

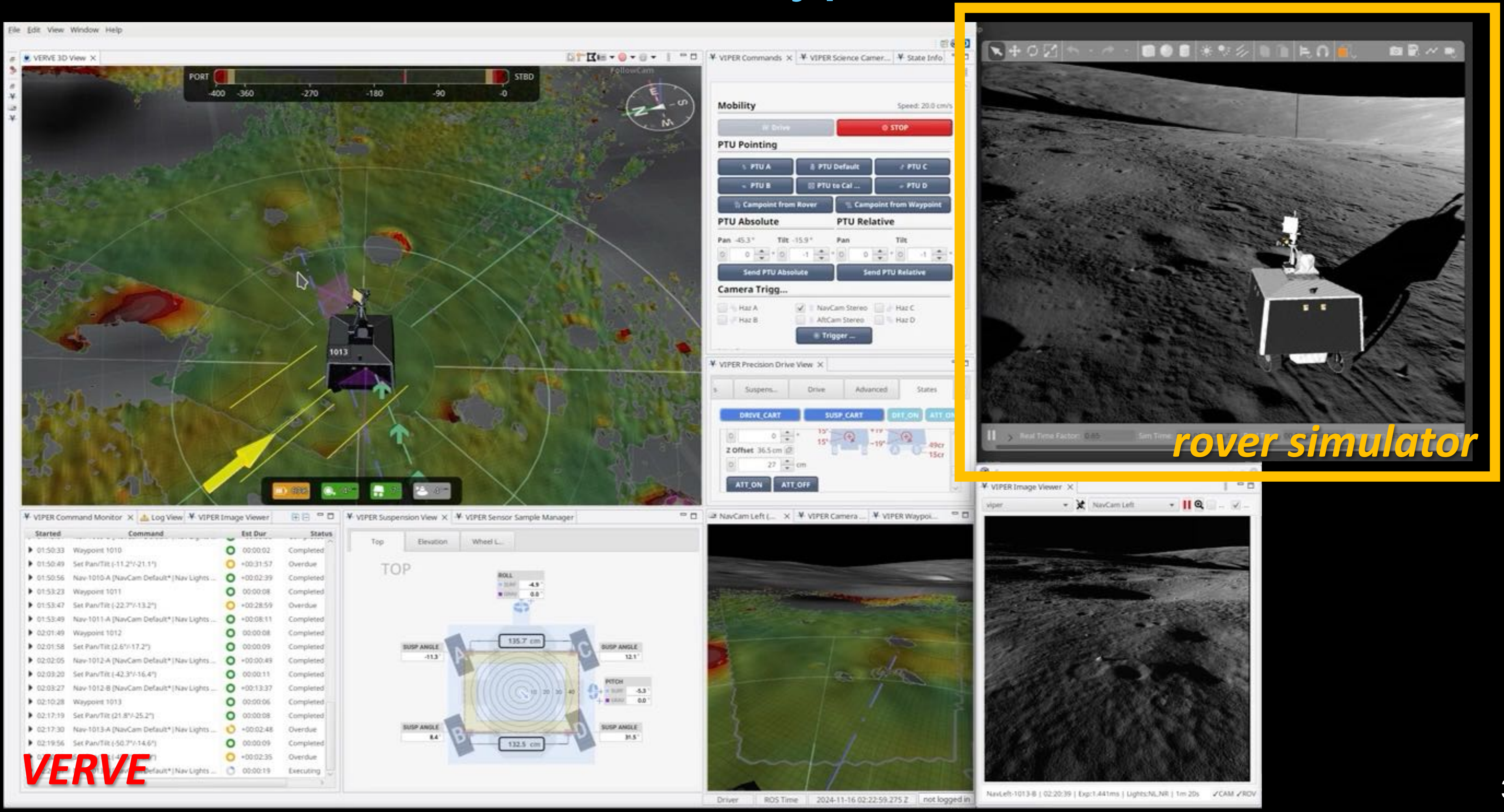
Task	Driver	Co-Driver	Navigator	Real-Time Sci
Assess rover state	Review mobility state Review mobility health Review current pose	*Shadow driver (when possible)*	Review nav sensor state Review nav sensor health Review localization quality	
Assess terrain hazards	Assess geometric hazards Assess non-geometric hazards (near/mid-field)	*Shadow driver (when possible)*	Assess data 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 movement (posture or pose change, drive mode, etc)	Sanity check (concur)		
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	*Call halt if needed*	*Call halt if needed*	*Call halt if needed*
Command navigation imaging	Confirm imaging is authorized Countdown to command Execute command	*Call halt if needed*	*Call halt if needed*	*Call halt if needed*

5 min duration

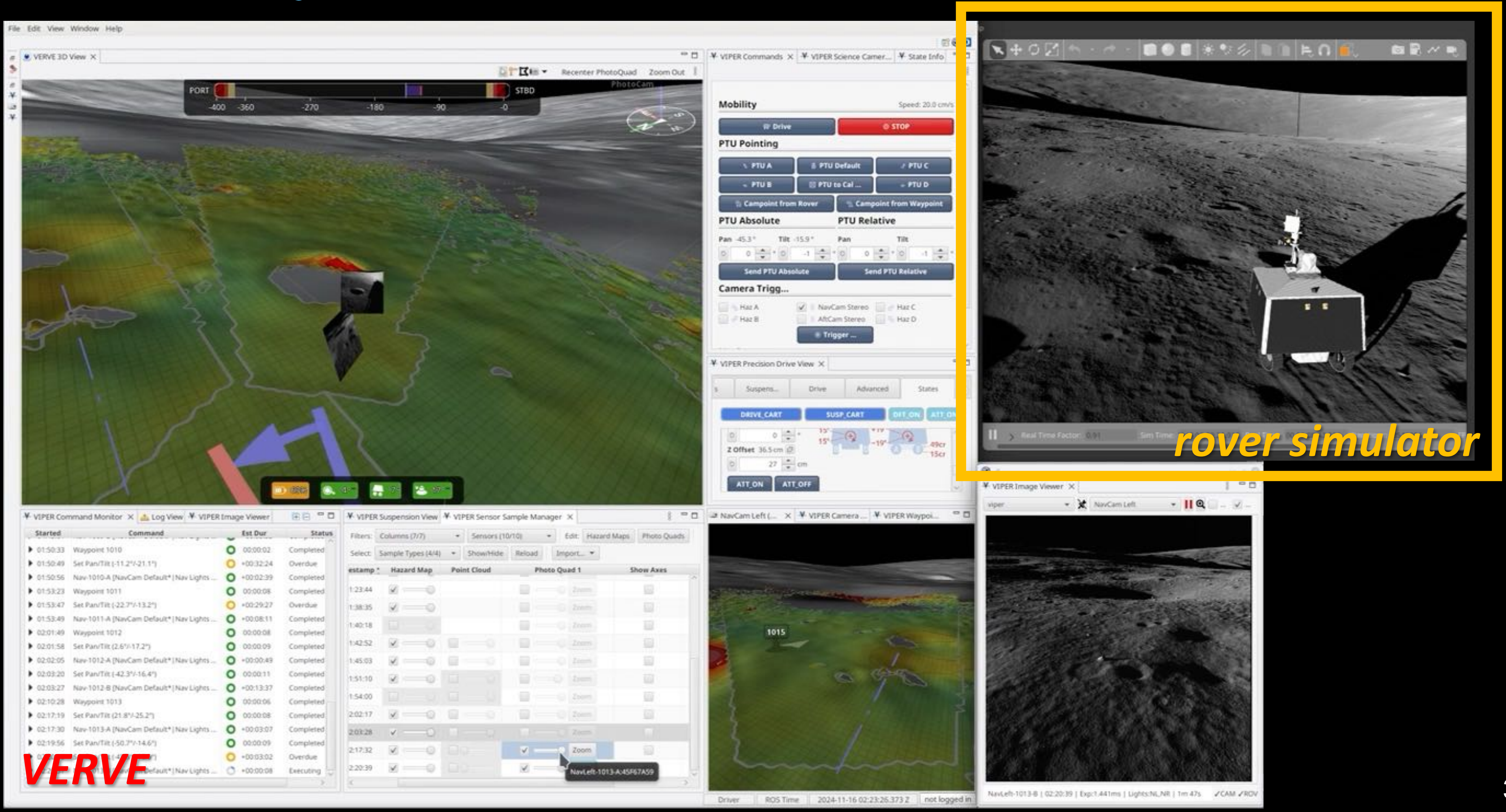
Rover Driving Interface (VERVE)



Assess Terrain + Place Waypoint



Refine Waypoint + Command Motion



Mission Ops Key Points

Human factors

- High-cadence decision making: 5 min command cycle
- Continuous ops: 8 hr shifts, 24 hr / 7 days when possible
- Short duration mission: high-pressure to achieve goals, limited time to achieve high-performance, limited time for anomaly response

Mission design emphasizes interactive, supervisory ops

- First lunar surface volatiles prospecting – do not know what will find find
- Significant uncertainty regarding surface environment – terrain hazards
- Real-time science = real-time discovery – anything can happen at any time

Human-robot teaming

- Mission ops team tightly couples science ops and spacecraft ops
- Operators make use of real-time rover data + decision support tools
- Humans compensate for limitations of automated perception (hazard mapping), state estimation (localization), decision making (tactical motion planning), and risk assessment (multiple areas of consequence)

VIPER

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

Questions?