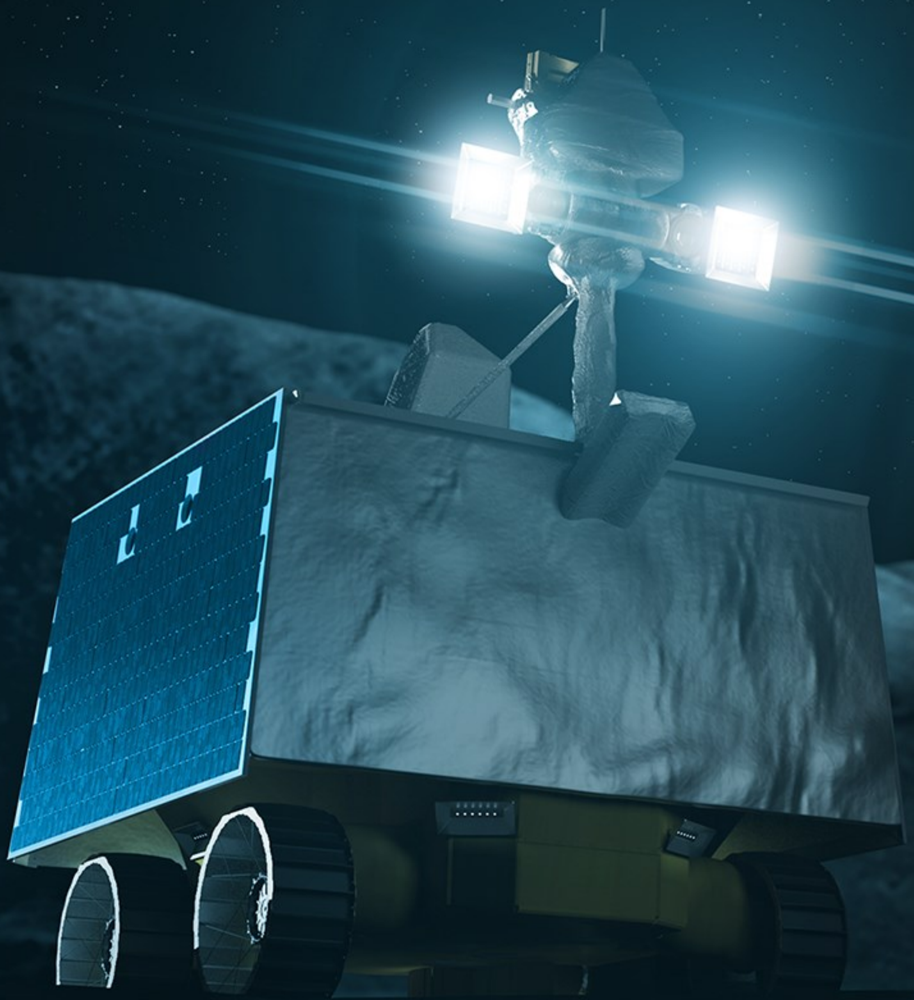


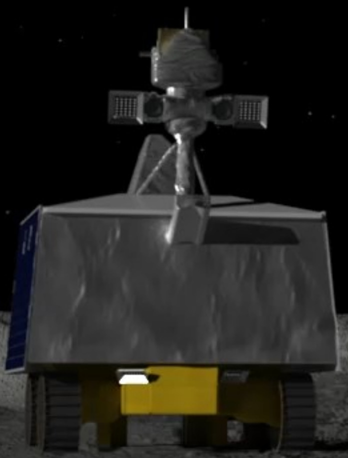
VIPER

Progress on the Volatiles Investigating Polar Exploration Rover

Anthony Colaprete, Project Scientist

October 25, 2023

VIPER



- Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith.
- Provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions.

The next great leap in understanding lunar water is mapping these volatiles at the human scale.

Resource Exploration: An Applied Science

The mission must sufficiently characterize an area to evaluate the resource need or physical processes

- Terrestrial mining companies have worked this problem for many years, developing "Mineral Models" for production evaluation
- Unfortunately the "Mineral Model" for lunar water is very uncertain, however many of the same techniques can be applied

Testing theoretical models of water emplacement and retention

- In conjunction with empirical/statistical models theories of water emplacement and retention should be built and tested
- These model provide additional predictive capability; if we have an understanding of the "how it got there" and "why it is still there" we can much better predict where the highest grade ores may occur

An ultimate outcome of resource exploration is the development of a Mineral Model, or for the Moon, a water Resource Model

- These models combine theory, statistics and observations to build a tool that helps to predict the quality of an ore in regions with diffuse or indirect data sets
- In most instances the desired resource can not be observed directly at adequate resolution or across large areas
- Critical spatially referenced parameters are used as proxies (spatial proxies) to develop a semi-quantitative estimate of resource favorability

Luck

Applied Science

Low Potential
Low Certainty
High Certainty

Medium Potential
Low Certainty
High Certainty

High Potential
Low Certainty
High Certainty

Unknown

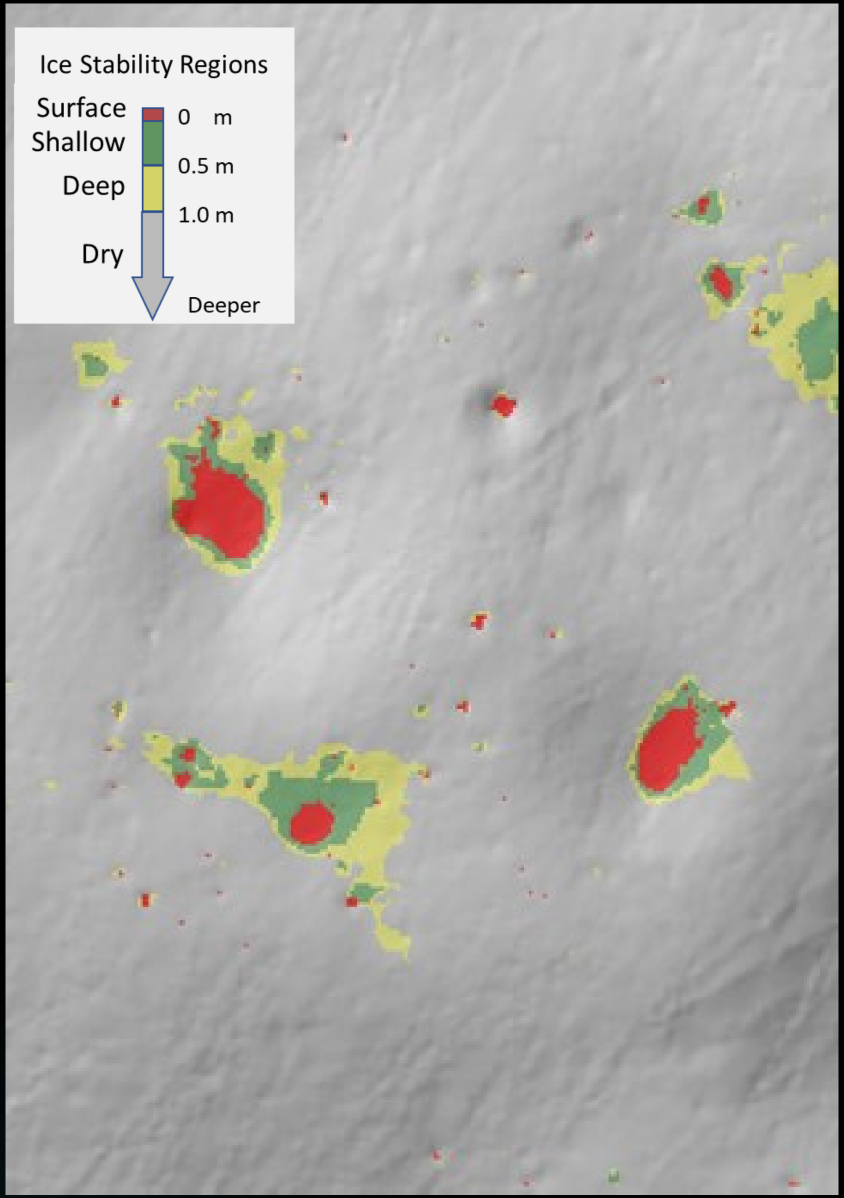
VIPER Mapping Approach: Thermal Proxy Model Concept

Rather than "find" the water VIPER methodically characterizes the range of thermal environments and geologic settings to build correlations between volatiles and environments

VIPER will explore four polar **"Ice Stability Regions"** (ISRs)*:

- "**Surface**" - Ice expected stable on the surface (PSRs – Permanently Shadowed Regions)
- "**Shallow**" - Ice expected stable between 0-50cm of the surface
- "**Deep**" - Ice expected stable between 50-100 cm of the surface
- "**Dry**" - Ice *not* expected stable (0-100cm *too warm* to be stable)

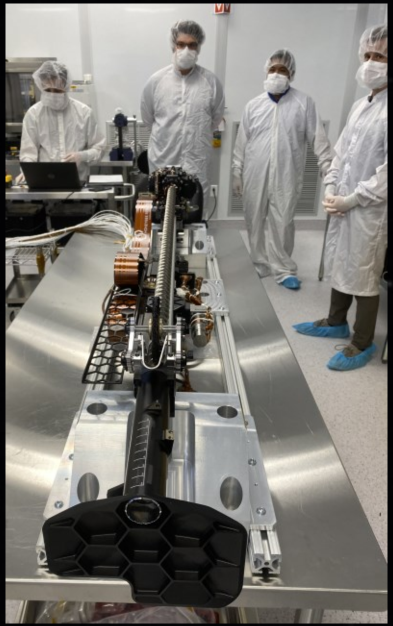
** ISR's are based on the predicted thermal stability of ice with depth*



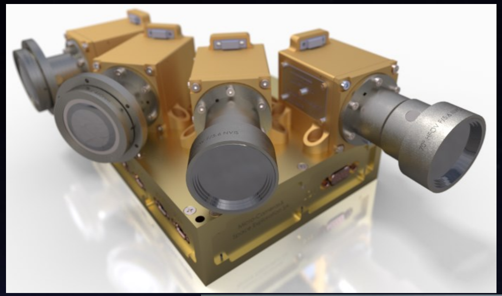
VIPER Rover

- **Rolling Mass:** ~430kg
- **Power:** ~450W (corner-facing) or 320W per array
- **Communications:** X-band
  - Downlink: 256kbps ; Uplink: 2kbps
  - 6-15 s round-trip latency
- **Dimensions:** 1.7m x 1.7m x 2.5m
- **Wheel Diameter:** 0.5m
- **Steering:** Explicit steer; adjustable suspension
- **Top Speed:** 20cm/s (0.5MPH)
- **Prospecting Speed:** 10cm/s (0.25MPH)
- **Waypoint Driving:** 4.5m command distance
- **Camera Look-ahead:** stereo to 8m
- **Obstacles / Slopes:** 20cm / 15deg
- **Expected Cold Environment:** ~40K

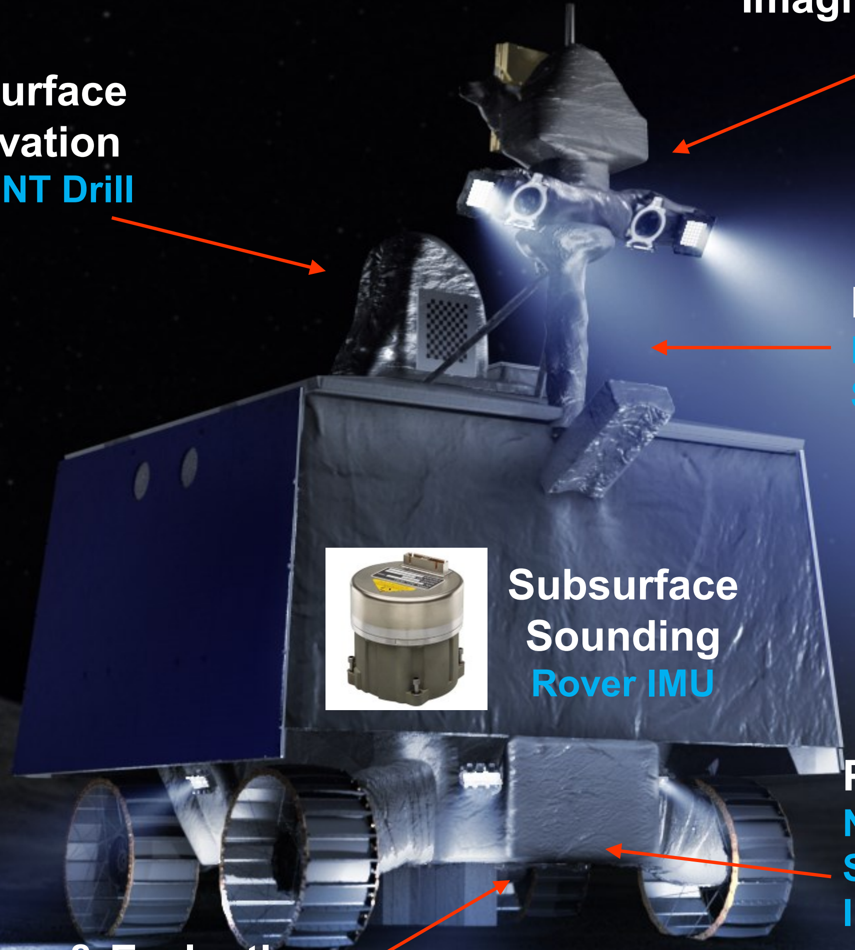
Science Instruments



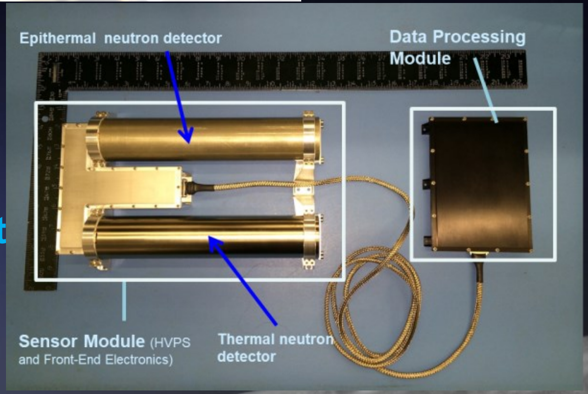
Subsurface excavation
TRIDENT Drill



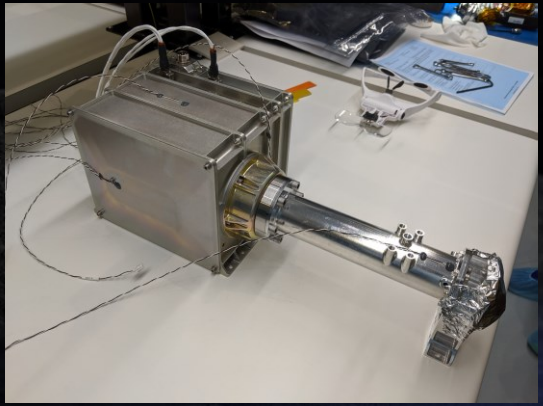
Imaging Science
VIS



Prospecting
Neutron Spectrometer System (NSS) Instrument

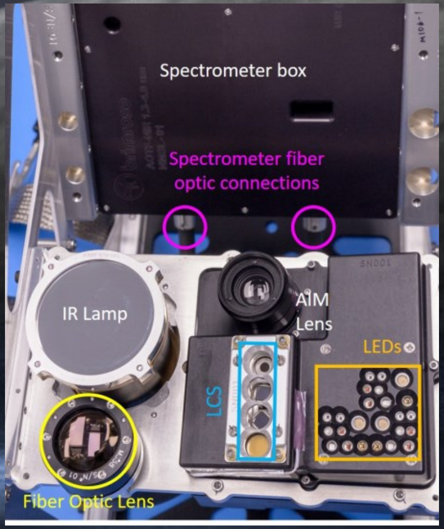


Subsurface Sounding
Rover IMU



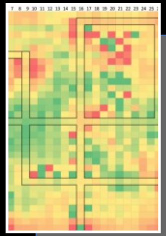
Prospecting & Evaluation
Mass Spectrometer Observing Lunar Operations (MSolo) Instrument

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

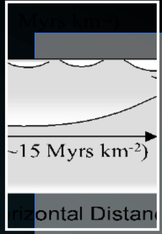


VIPER Key Science Measurements

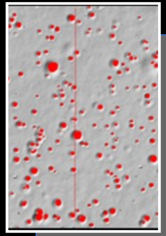
Sensitivity



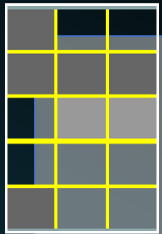
Coverage Density



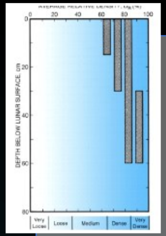
Length Scales



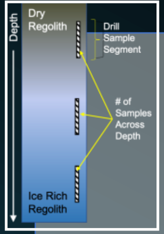
Area Coverage



Variability



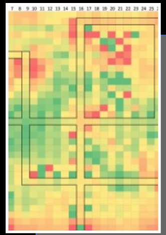
Vertical Coverage



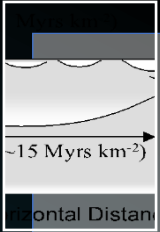
Vertical Sampling

VIPER Key Science Measurements

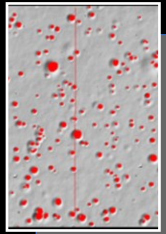
concentrations as low as 0.5% wt



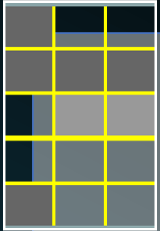
sample >10-15% per target area



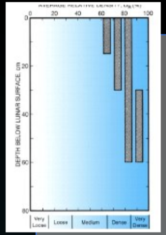
across scales from 10s to 100s of meters



>3800 m^2 per ISR type



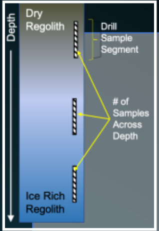
measure at scales of <5 meters and as large as 1000m, ISRs separated by 100 m



0.8 m neutrons

1 m drill depth

~5 m seismic



8-10 cm bite size, >5 samples along 0-100 cm depth

VIPER Mission Area: Mons Mouton

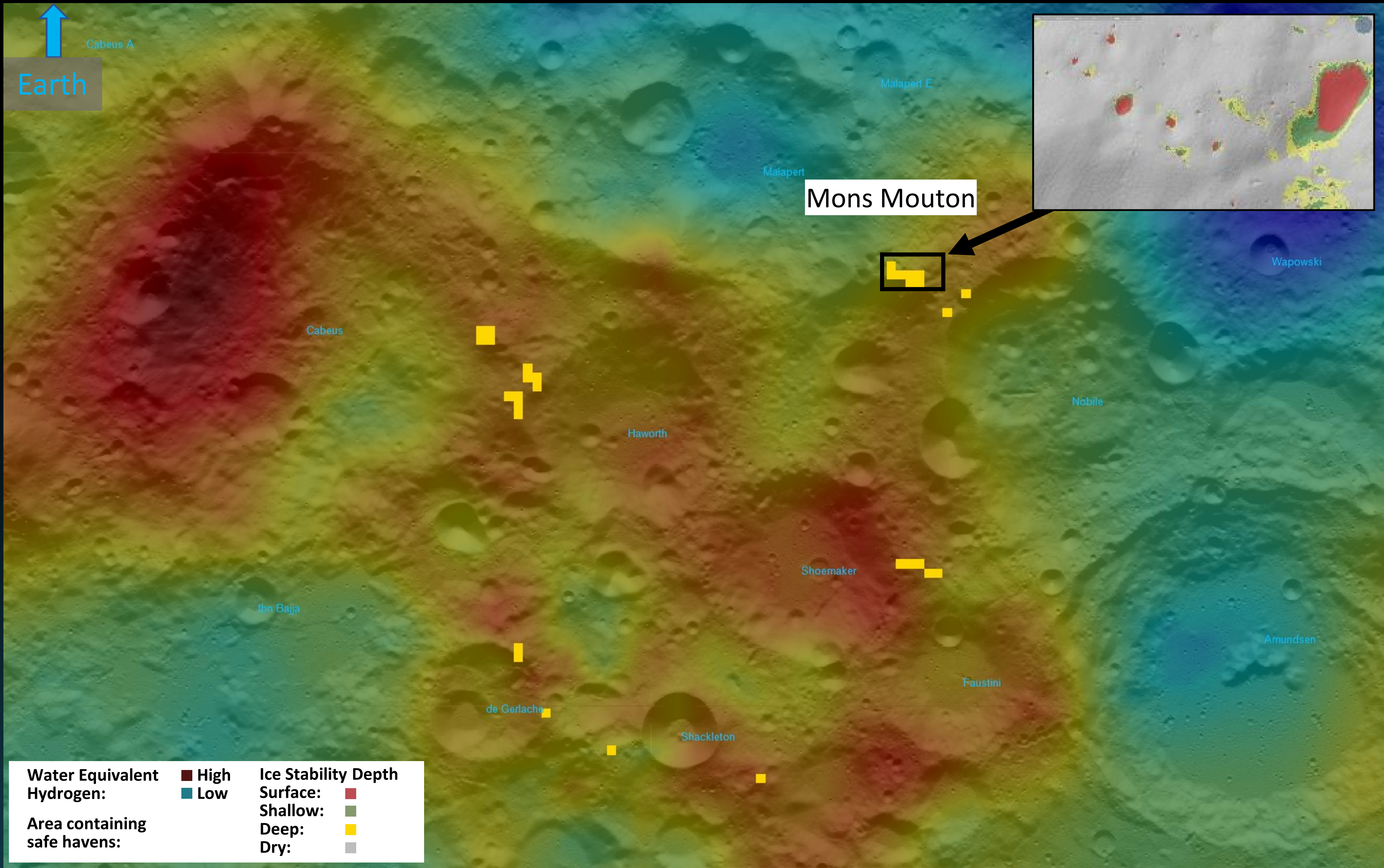
Needed: location with …

High water-equivalent hydrogen (background map)

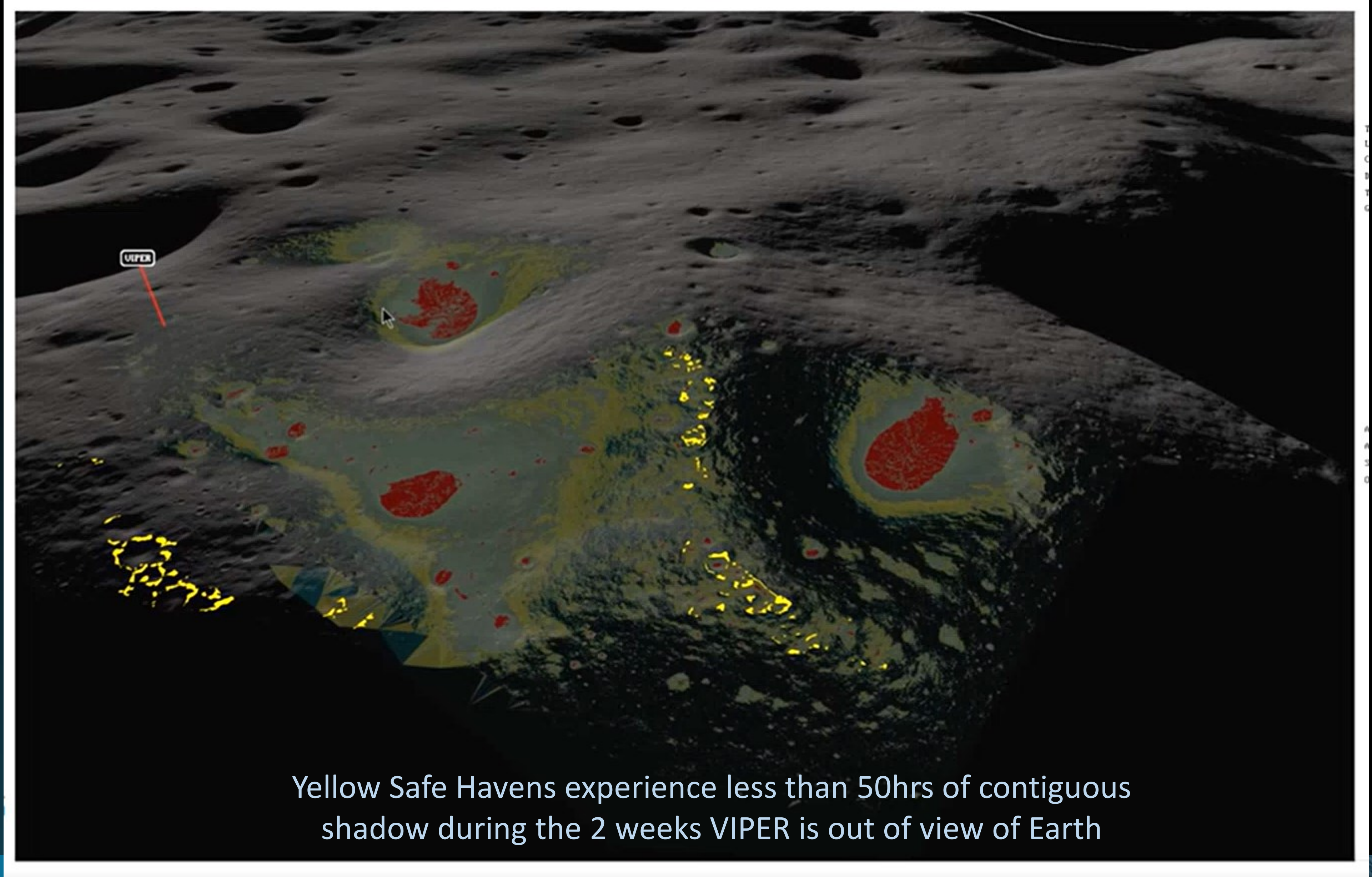
A variety of thermal environments using ice stability depth as an indicator (insets)

Periods of shadow short enough for the rover to survive (yellow blocks)

Unobscured line-of-site to Earth for communications



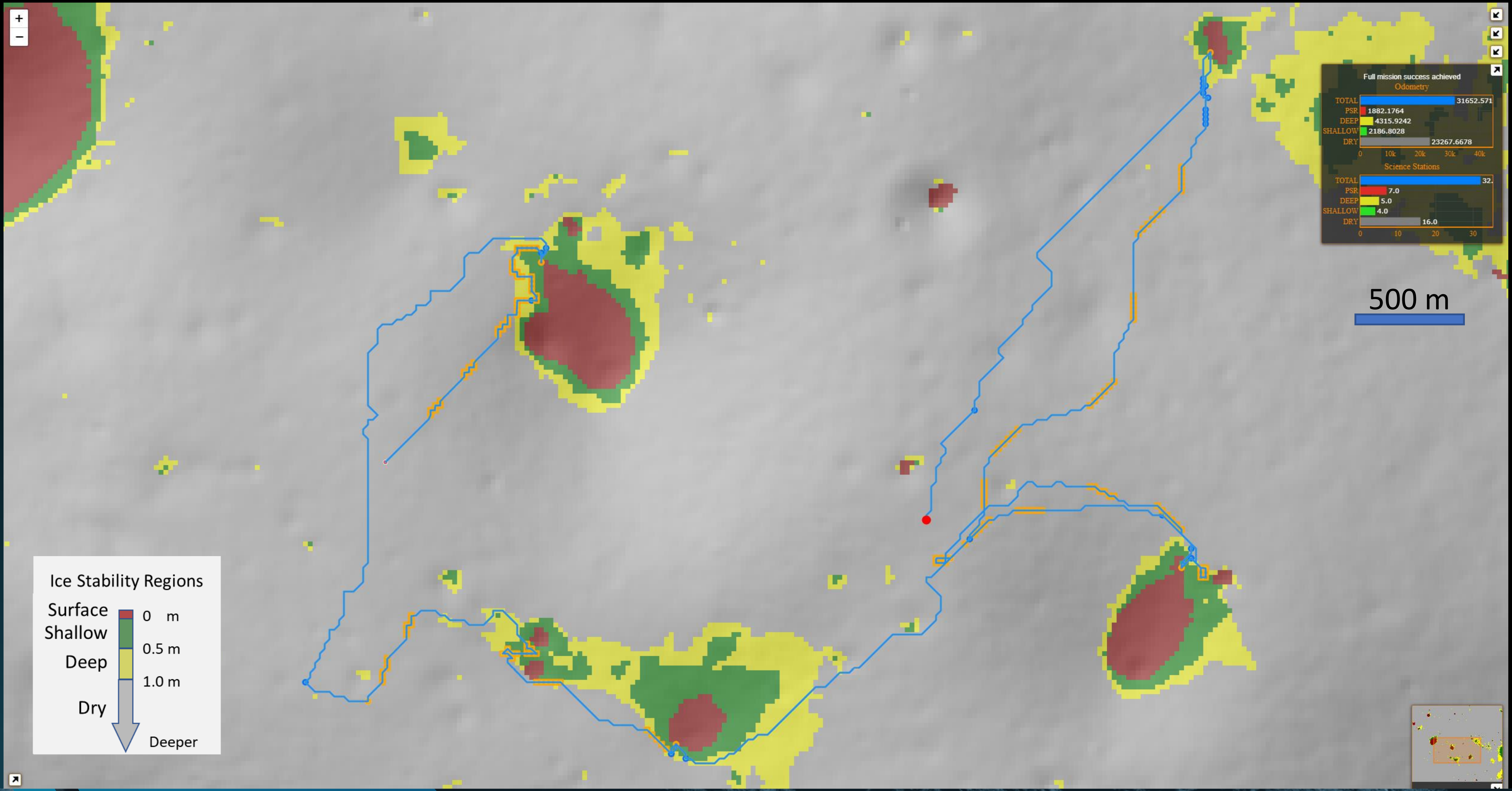
Nobile region with Safe Havens



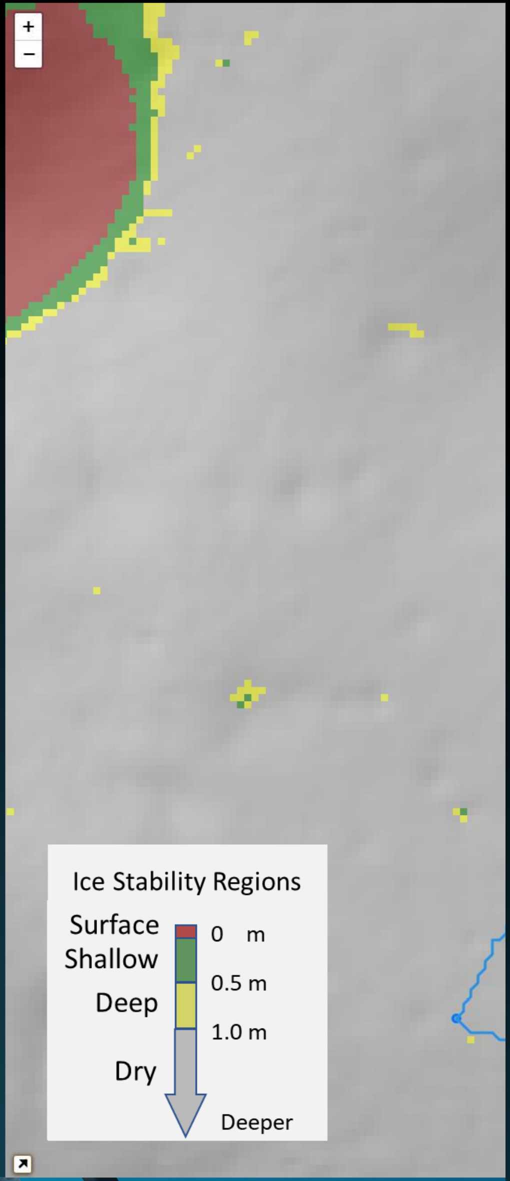
Yellow Safe Havens experience less than 50hrs of contiguous shadow during the 2 weeks VIPER is out of view of Earth

Screenshot from the VIPER Traverse Planning tool /M. Shirley

Example of a Mission Area Traverse



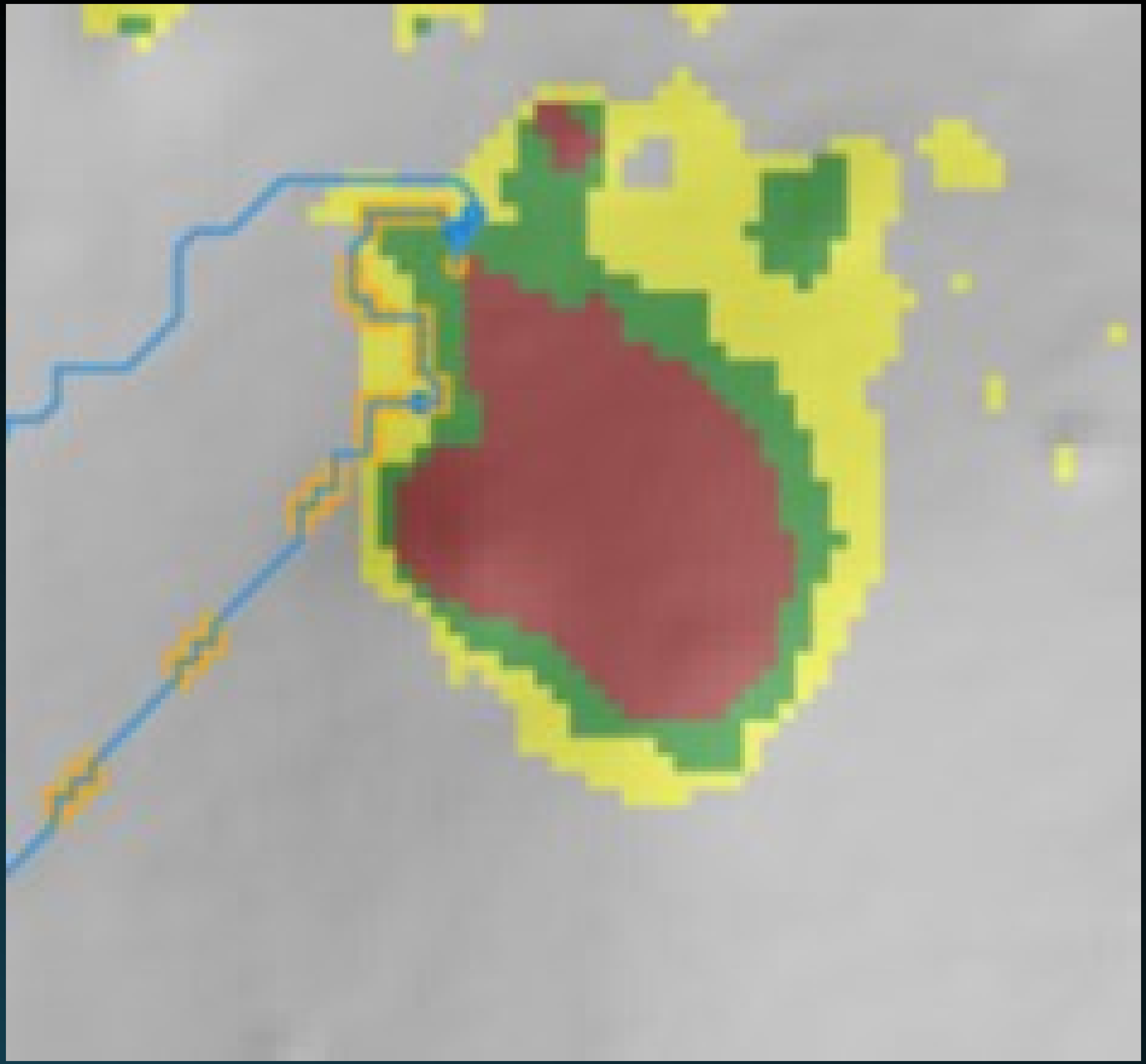
Example of a Mission Area Traverse



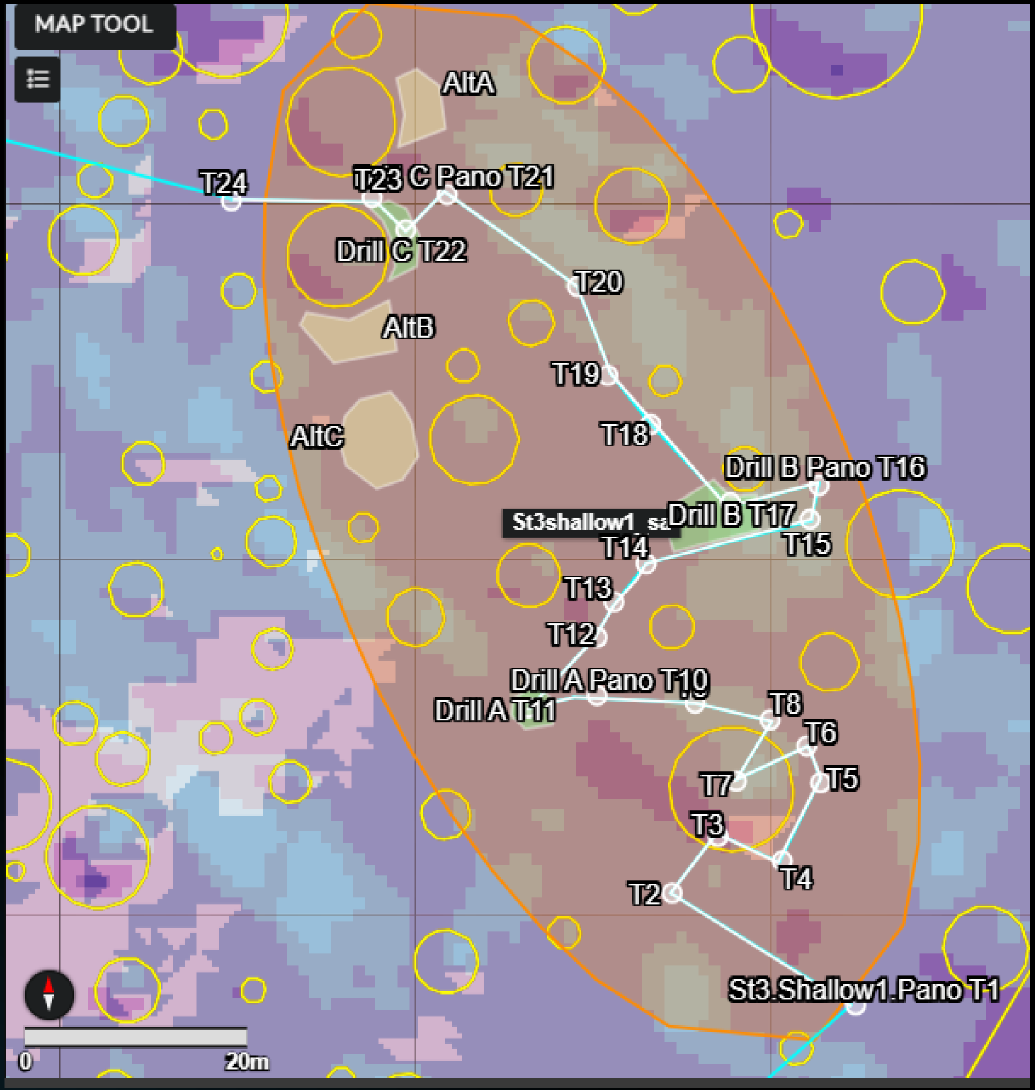
Total duration (Earth days)	111.75
Full mission success (lunar day)	1
Time to full mission success (Earth days)	9.65
Distance to full mission success (m)	4167
Odometry, total (m)	31653
Dry (m)	23268
Deep (m)	4316
Shallow (m)	2187
PSR (m)	1882
Science stations, total	32
Dry	16
Deep	5
Shallow	4
PSR	7
Drill sites	78

Strategic and Tactical Science Planning

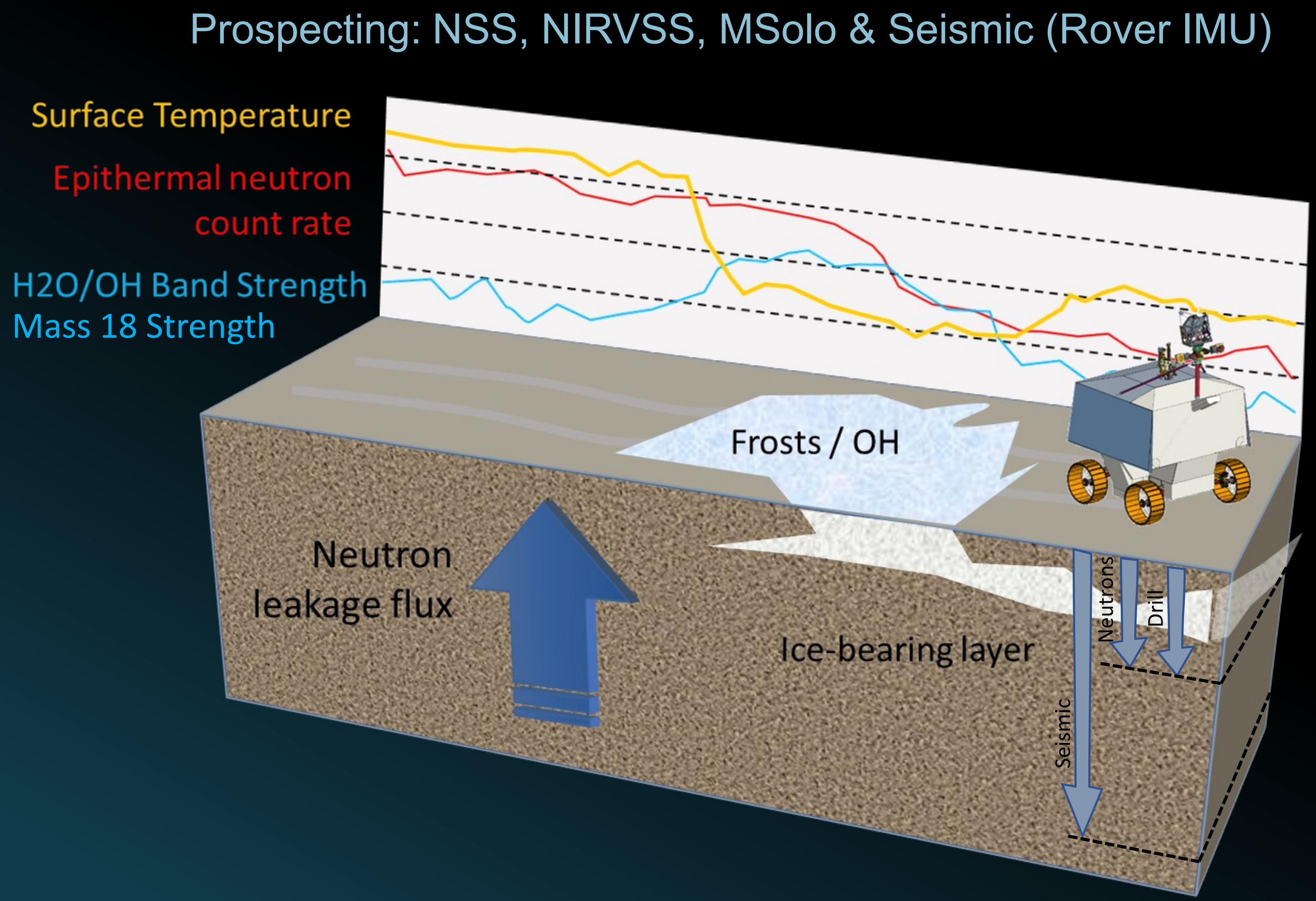
Strategic Traverse Planning



Tactical Traverse Planning



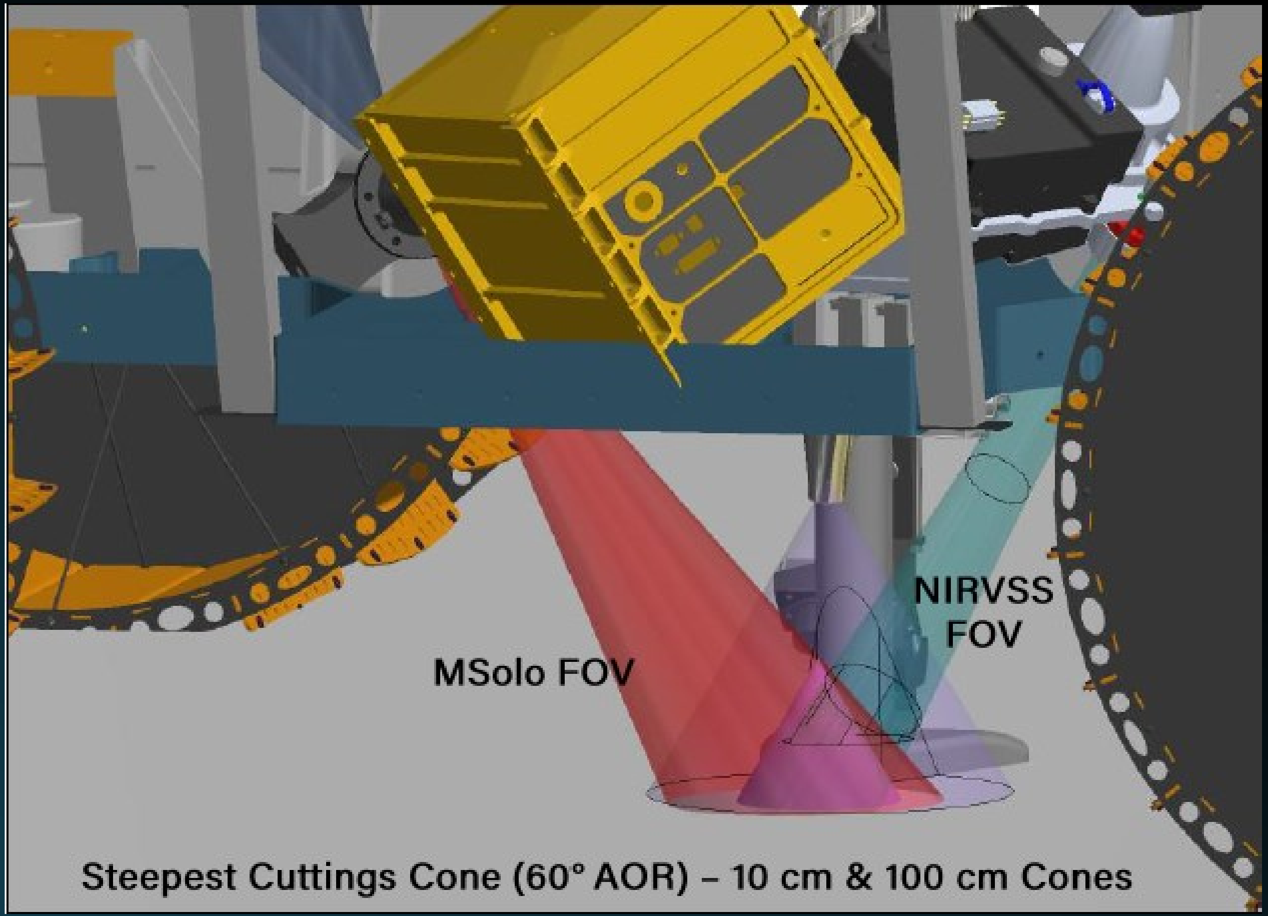
Prospecting characterizes regions & identifies points to drill



- NSS, NIRVSS & MSolo take data continuously while roving or parked
- NSS Neutron flux variations identify abundance and burial depth of hydrogenous materials
- NIRVSS NIR surface reflectance identifies surface and excavated hydration
- MSolo detects subliming gasses (H_2 or H_2O vapor) identify surface and excavated hydration

Sampling: TRIDENT, NIRVSS and MSolo

Sampling via the TRIDENT, MSolo and NIRVSS profile water (and other volatiles with depth, tying down NSS derived concentrations)



- TRIDENT samples in 10 cm “bites” down to 1 meter, using a simple auger bit
- Each 10cm sample can be brushed to the surface for inspection by NIRVSS and MSolo
- NIRVSS images the cuttings at multiple wavelengths (providing context for NIRVSS and MSolo observations) and measures the scene temperature
- This process identifies the stratification of hydrogen bearing volatiles, “tying down” NSS measurements

VIPER Actionable Science Methods

- Being a short-lived the team needs to have ready-to-g plans that address mission objectives, but also be ready to adapt and discover.
- Real-time command, control and analysis allows this.
- To facilitate pre-planning as well as re-planning (during the mission), reacting to observations and data analysis the Lunar Dynamic Science Table was created. Shannon Kobs is leading this effort.
- Combines attributes of a traditional Science Traceability Matrix with accounting of observations, analysis and findings in an “actionable” way.
- Allows the team to quickly understand what science has been addressed, and to what extent, and what more could be done with modifications to the plan.

Science Objectives in the LDST
(Each color is a Specific Topic Area)

- Characterize water (H2O) ice
- Characterize non-water H-bearing volatiles
- Characterize non-H-bearing volatiles
- Determine regolith physical strength properties as a function of volatile content and physical state

- Understand the thermal properties of the regolith
- Characterize regolith physical properties as a function of environment
- Map and characterize the cm-scale topography and rock size distribution

- Investigate if the ice in the subsurface is layered
- Investigate if the surface and subsurface ice correlated

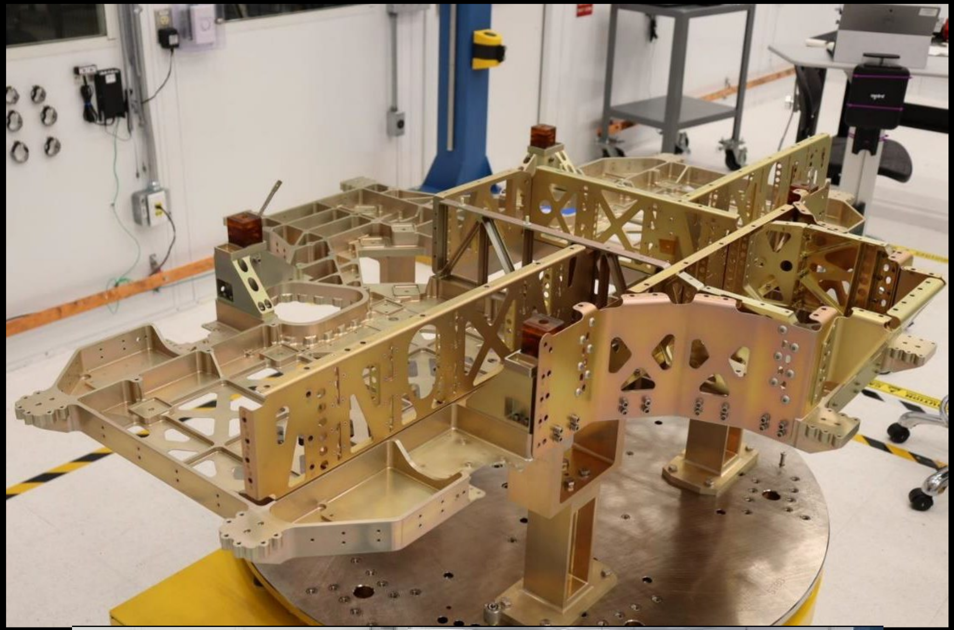
- Determine the origin of lunar volatiles
- Determine how volatiles evolve over time post-deposition
- Determine relative timescales of volatile delivery

Mission Status

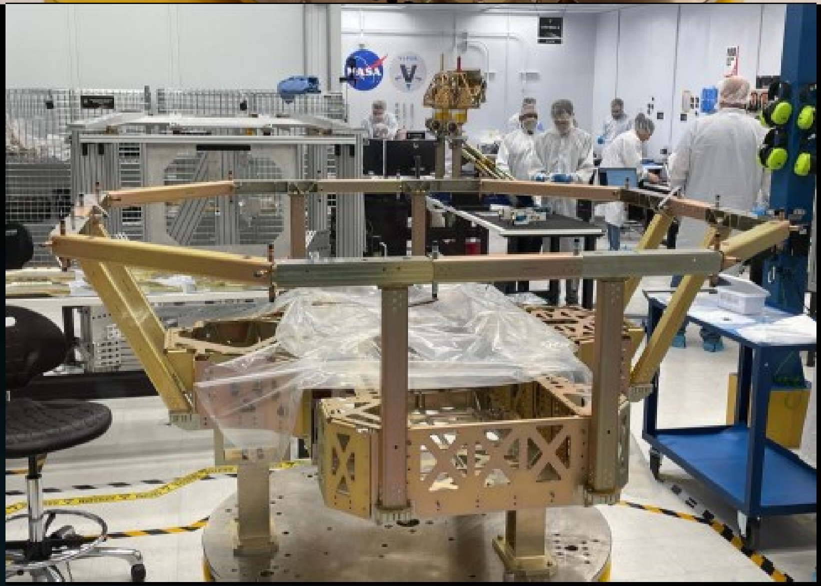
- Passed KDP-D June 15, 2023: Formally entered Flight System Integration (Phase D)
- Less than a year from rover delivery to Astrobotic for integration onto the Griffin lander
- Nominal landing date is November 10, 2024, with a 5-month mission duration
- Rover integration continues at JSC
- Integrated operations simulations continue
- Detailed Science Station planning continuing with First Lunar Leg nearly completed

Mission Update – Integration Activities

Flight Wheels and Wheel Modules



Lower Chassis

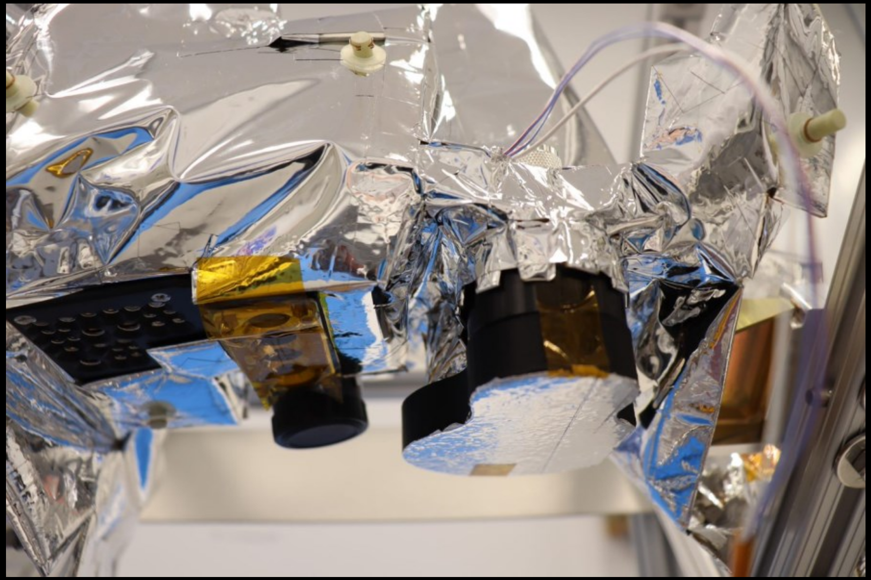


Lower Frame

Mission Update – Integration Activities

Flight Mast and Gimbal Assembly

NIRVSS Sensor Bracket MLI Closeout



Flight Nav Light Checkout

MSolo Harnessing Closeout

GRC SLOPE Entrapment Escape (@30 deg)

Thank you!