VIPER

A lunar water reconnaissance mission

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August 19, 2021

VIPER

The past decade of observations have built a fascinating and complicated story about lunar water

- From "frosts" to buried ice blocks, there appears to be water everywhere, but its nature and distribution is very uncertain

The next steps in exploration require surface assets, including surface mobility

VIPER will conduct exploration science, modeled after terrestrial resource exploration processes and techniques

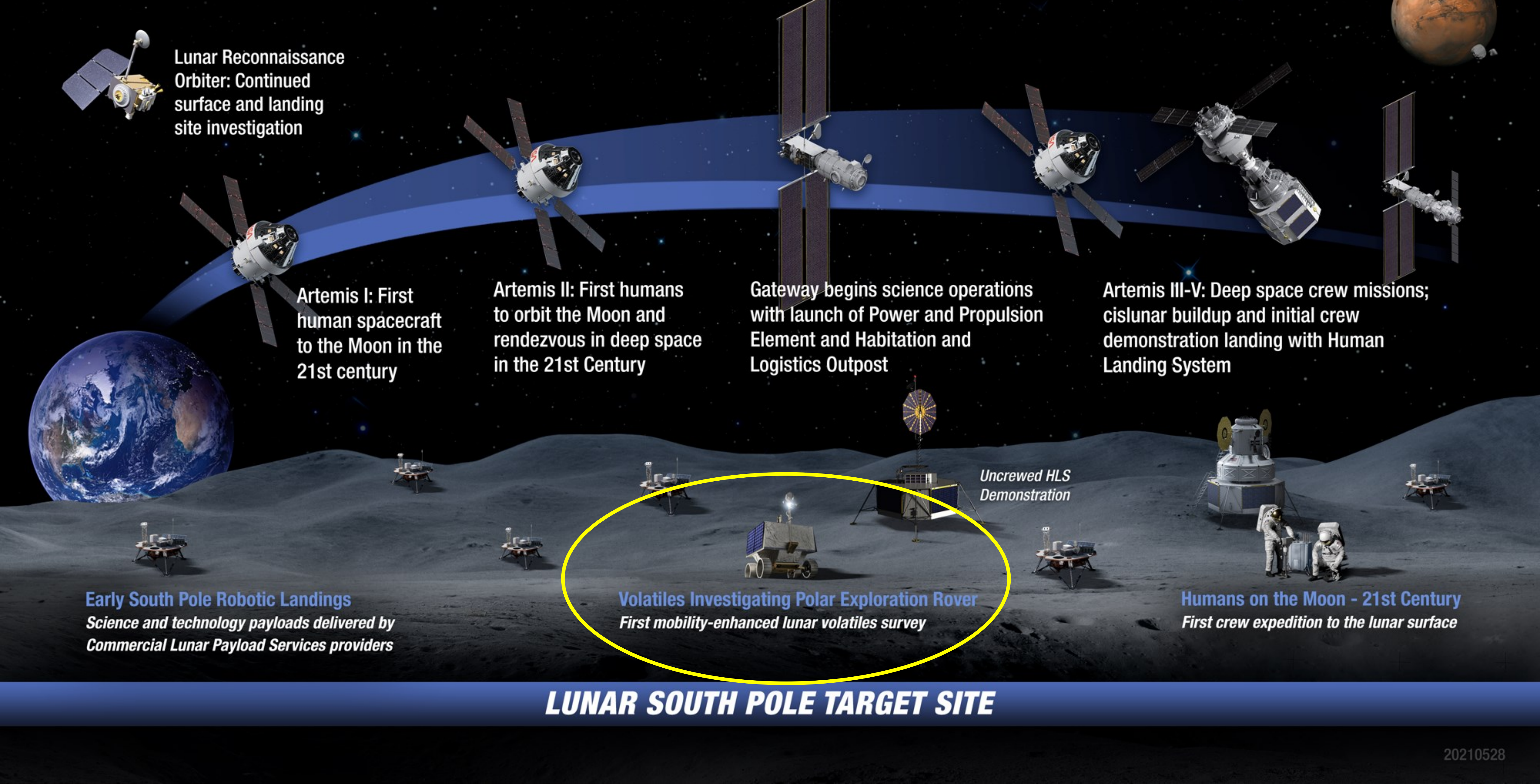
Passed Mission Critical Design Review (October 19-20, 2021)

VIPER new Science Co-I proposals in review (50 proposals received)

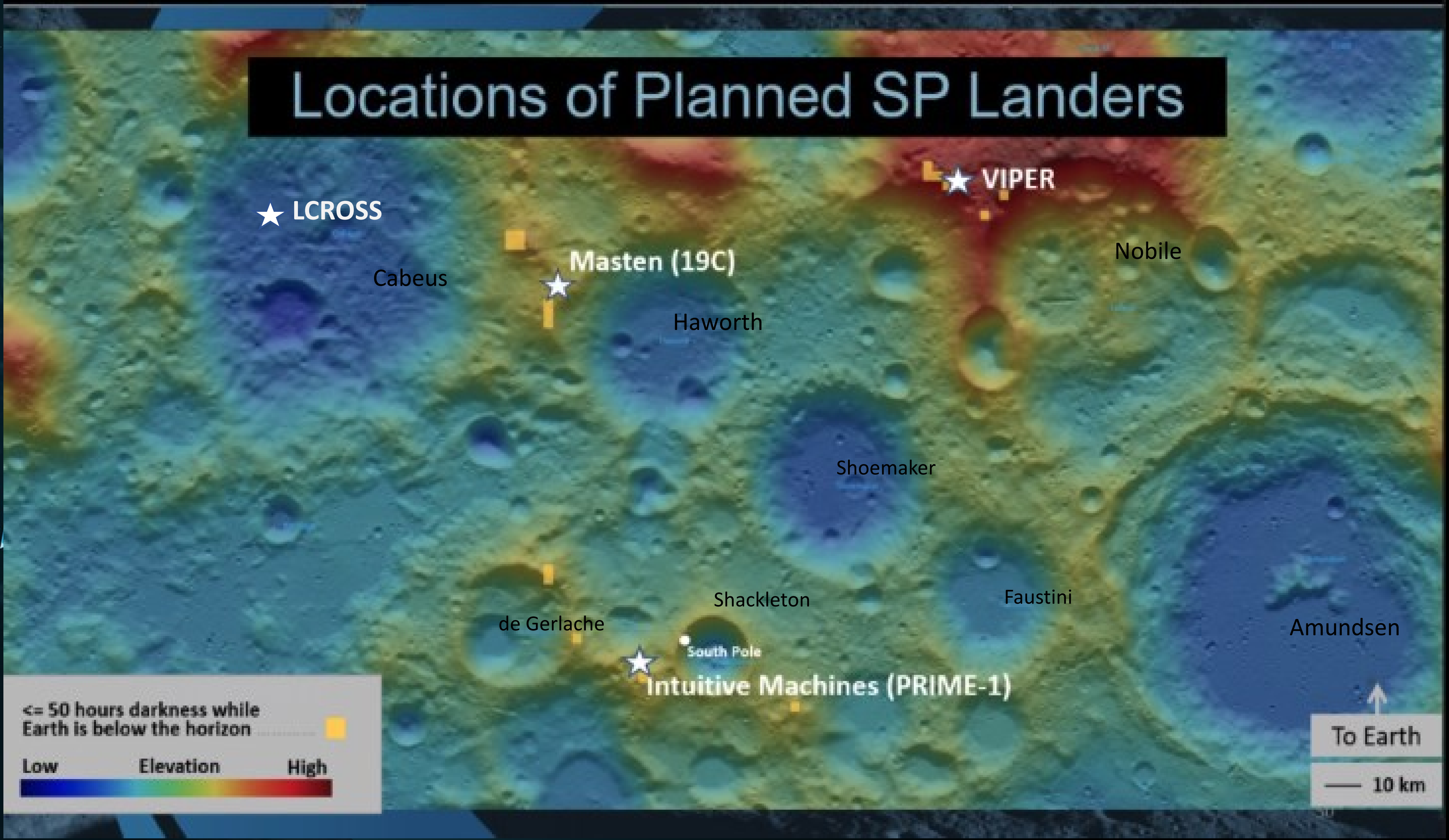
Launch November 2023

https://www.nasa.gov/viper

Artemis: Landing Humans On the Moon



Lunar South Pole Missions (plan)



Understanding Lunar Water

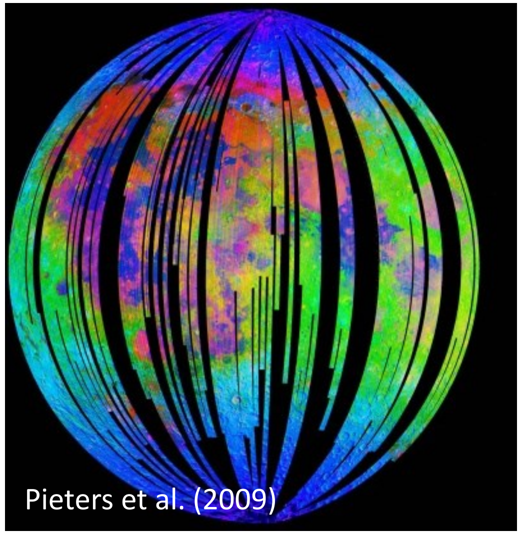
Moon now known to host all three forms of Solar System water: endogenic, sequestered external and in-situ*

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

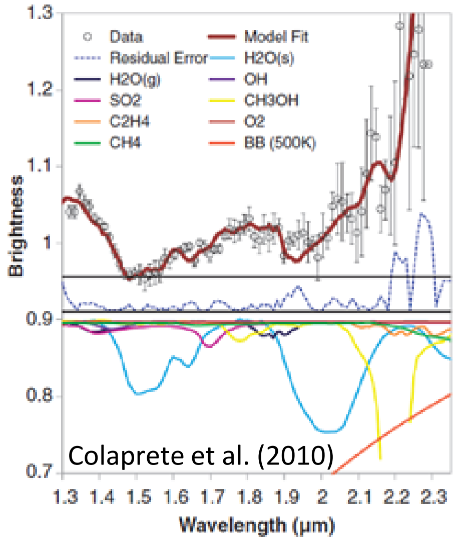
Understanding the distribution, both laterally and with depth, addresses key exploration and science questions

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

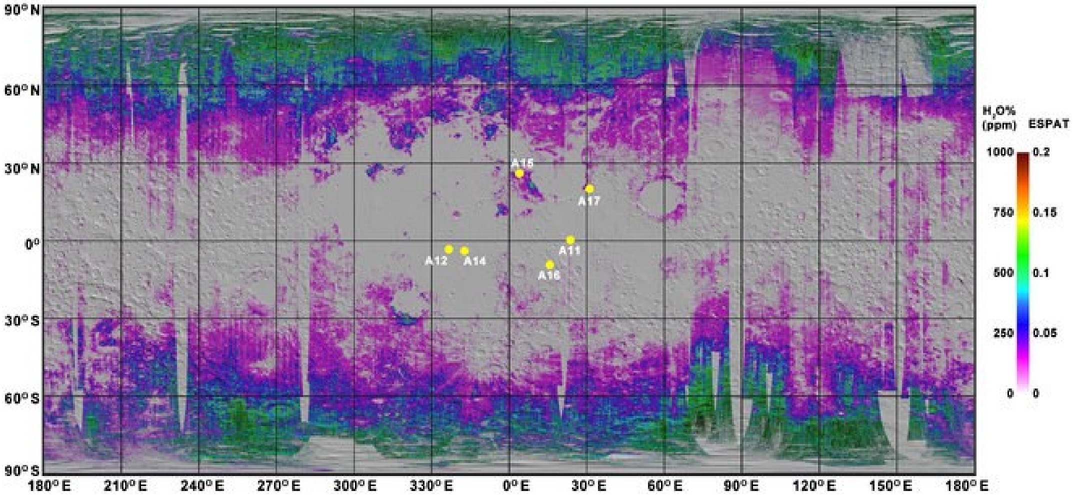
"Prospecting" for lunar water at poles is the next step in understanding the resource potential and addressing key theories about water emplacement and retention



Pieters et al. (2009)



Colaprete et al. (2010)



Li and Milliken (2017)

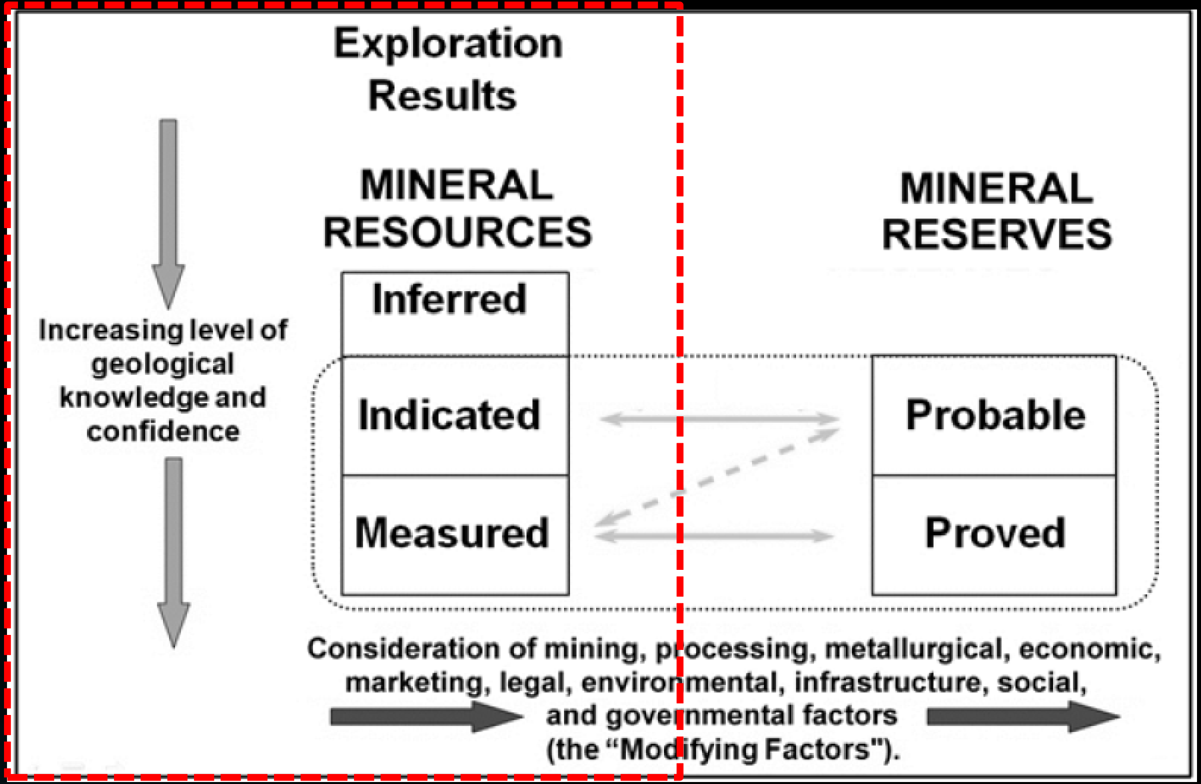
*From Peters et al. Transformative Lunar Science (2018)

Lunar Polar Volatile Exploration: Science and Exploration

Critical Observations Needed

- Volatile Distribution (concentration, including lateral and vertical extent and variability)
- Volatile Physical State (H_2, OH, H_2O, CO_2, Ice vs bound, etc).
- The Context and Correlation, including:
  - Accessibility/Overburden: How much and type of material needing to be removed to get to ore?
  - Environment: Sun/Shadow fraction, soil mechanics, trafficability, temperatures
  - Distribution and Form vs Environment
  - Extrapolates small scale distributions to global data sets, critical for developing “mineral/resource models”

Lunar Polar Exploration



From “Committee for Mineral Reserves and International Reporting Standards, 2013

Distribution. Physical State. Context. Correlation.

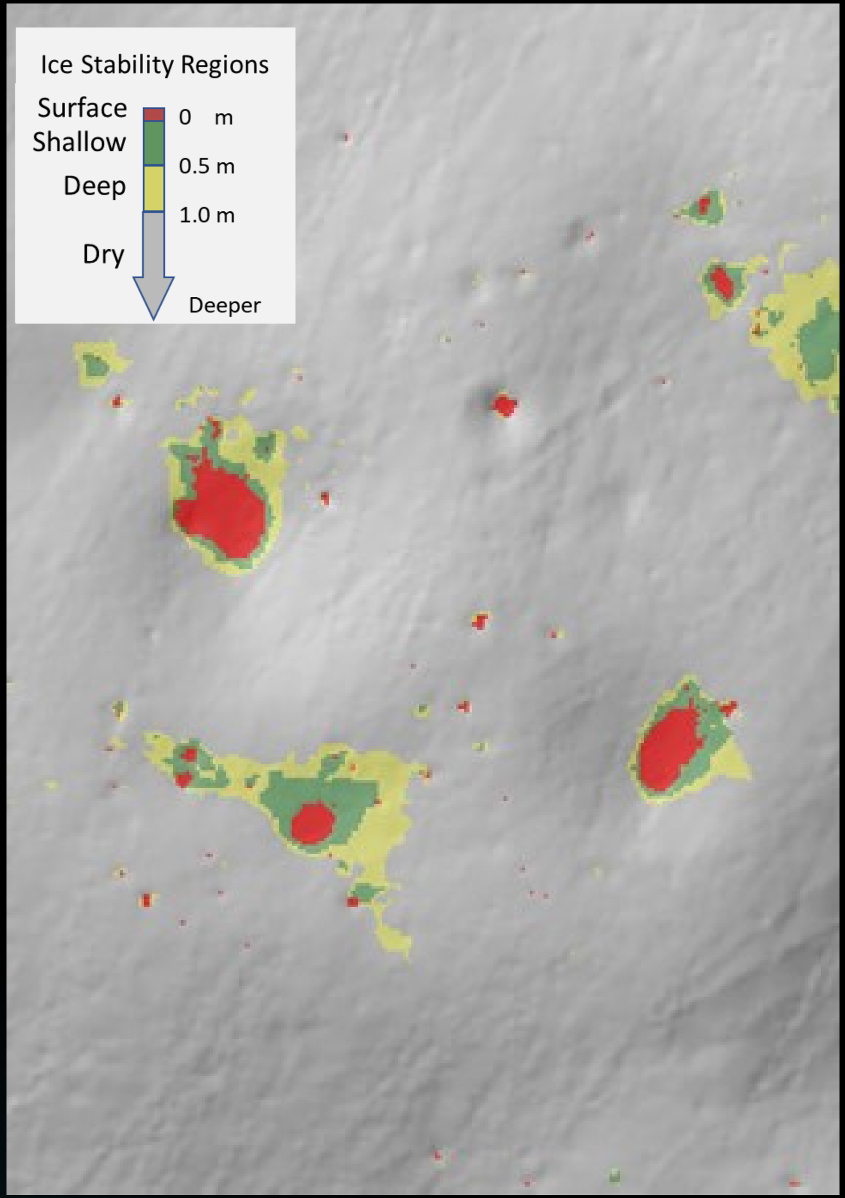
VIPER Measurements

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

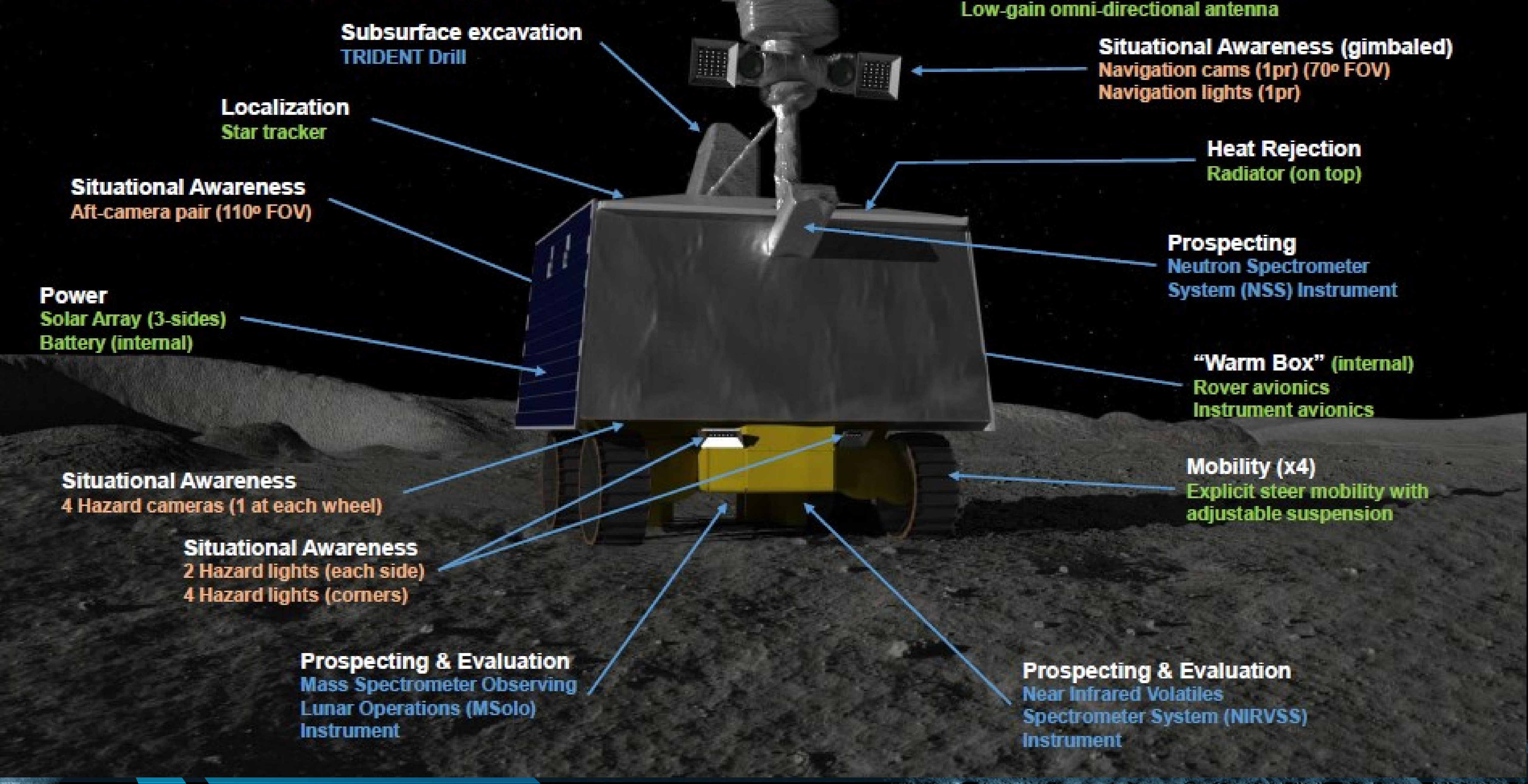
VIPER will explore four polar **"Ice Stability Regions"** (ISRs)*:

- "**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)

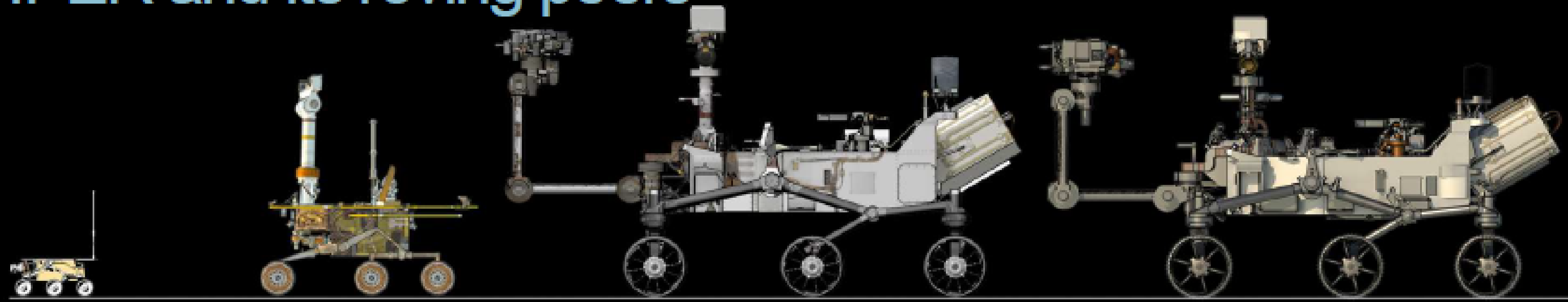
* *ISR's are based on the predicted thermal stability of ice with depth*



VIPER Surface Segment



VIPER and its roving peers



Sojourner (1996)
0.6m x 0.5m x 0.3m
11kg
Top Speed: 5cm/s
Plutonium-238 RHUs

Mars Exploration Rover (2004)
1.6m x 2.3m x 1.5m
180kg
Top Speed: 5cm/s
Plutonium-238 RHUs

Mars Science Laboratory (2011)
3.0m x 2.8m x 2.1m
900kg
Top Speed: 4cm/s
Plutonium-238 MMRTG

Mars 2020 Rover (2020)
3.0m x 2.7m x 2.2m
1025kg
Top Speed: 4.2cm/s
Plutonium-238 MMRTG

Lunokhod 1 & 2 (1970/1973)
2.3m x 1.6m x 1.5m
840kg
Top Speed: 55cm/s
Polonium-210 heat source

Lunar Roving Vehicle (1971/1972)
3.1m x 1.6m x 1.5m
210kg
Top Speed: 500cm/s
2 silver-zinc 36 volt batteries

1 meter

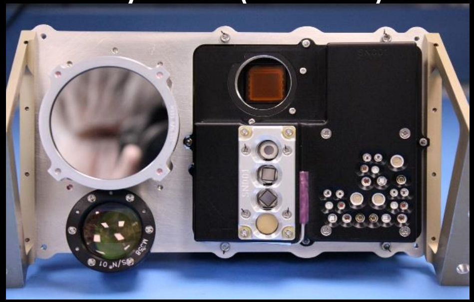
Yutu (2013/2019)
1.5m x 1.1m x 1.1m
140kg
Top Speed: 5cm/s
Plutonium-238 RHUs

VIPER (2023)
1.5m x 1.5m x 2.0m
430kg
Top Speed: 20cm/s
Electric heaters only

VIPER Instrument overview

Neutron Spectrometer System (NSS)

Near InfraRed Volatiles Spec. System (NIRVSS)



Mass Spec. Observing Lunar Operations (MSolo)

The Regolith and Ice Drill for Exploring New Terrains (TRIDENT)

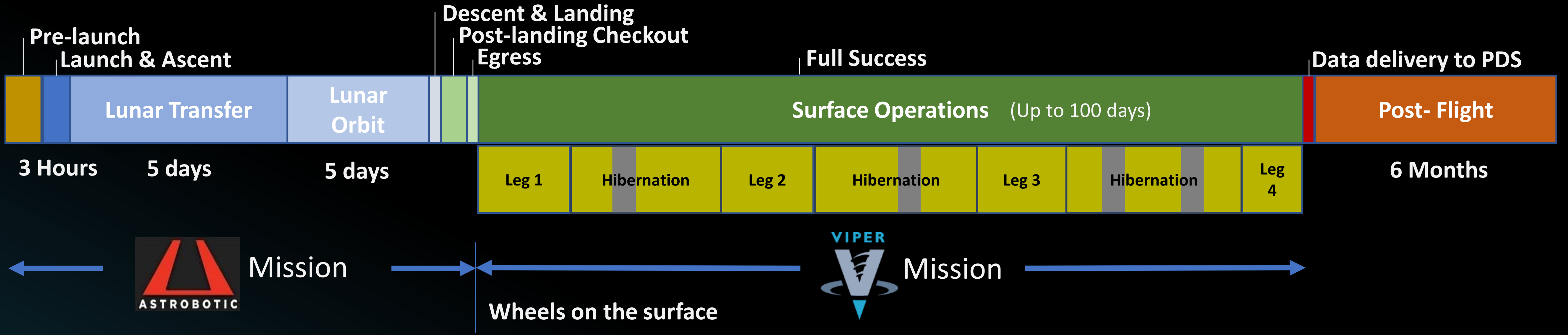
Instrument	Measurements	Observations
NSS	Thermal and Epithermal Neutrons	Water Equivalent Hydrogen and burial depth along traverse
NIRVSS	NIR reflectance spectra from 1300-4000 nm Imaging (2048 x 2048 pxl max resolution) with 7 color LEDs from 348 to 940 nm Thermal Radiometry at 10, 14, 18 and 6-25 um	Surface composition (mineralogy, hydration, frosts) along traverse and from drill cuttings pile Context imaging below the rover along the traverse; High resolution imaging (<100 um/pxl) at drill sites Surface temperatures under the rover and during drilling down to <100 K
MSolo	Mass spectra between 1-100 amu	Subliming surface volatiles along traverse and from drill cuttings pile Key isotope ratios
TRIDENT	Excavation of subsurface material in 10 cm increments down to 100 cm Subsurface temperatures at 2 locations (separated by 20 cm)	Regolith geomechanically properties, including discerning ice-rich from dry regolith Subsurface temperatures and thermal conduction

VIPER Instrument Earlier Flights

VIPER's instruments expected to fly (at least once) on other CLPS Mission opportunities ***prior to*** the VIPER mission

Instrument:	**Mission:**	**Landing site:**	**CLPS Task:**	**Flight:**
NSS NIRVSS MSolo	Astrobotic Peregrine Mission 1	*Lacus Mortis, northern latitude*	CLPS-02	2022
MSolo TRIDENT	PRIME-1	*Shackleton Connecting Ridge, South Pole*	CLPS PRIME-1	Nov/Dec 2022
NSS NIRVSS MSolo	Masten Mission One	*Haworth crater, South Pole*	CLPS-19C	~~2022~~ Nov/Dec 2023

VIPER Mission Phases



- Surface Ops consist of periods of activity ("traverse legs") and periods of inactivity ("hibernations")
  - <u>Traverse legs</u> are in view of Earth and sun (except for planned shadow (PSR) ops (<8 hours))
  - <u>Hibernations</u> are NOT in view of Earth, but in view of sun, with periods of sun shadow (<72hrs)
  - Lunar Day = one Traverse Leg + one Hibernation
- Mission Success:
  - Minimum Mission Success planned by end of Lunar Day 1
  - Full Mission Success planned by end of Lunar Day 2
  - Lunar Days 3 (and 4 if possible) offer either contingency time, or improved science data

NASA CLPS program has selected Astrobotic Technology to deliver VIPER to the lunar South Pole in late-2023 aboard their Griffin Lander

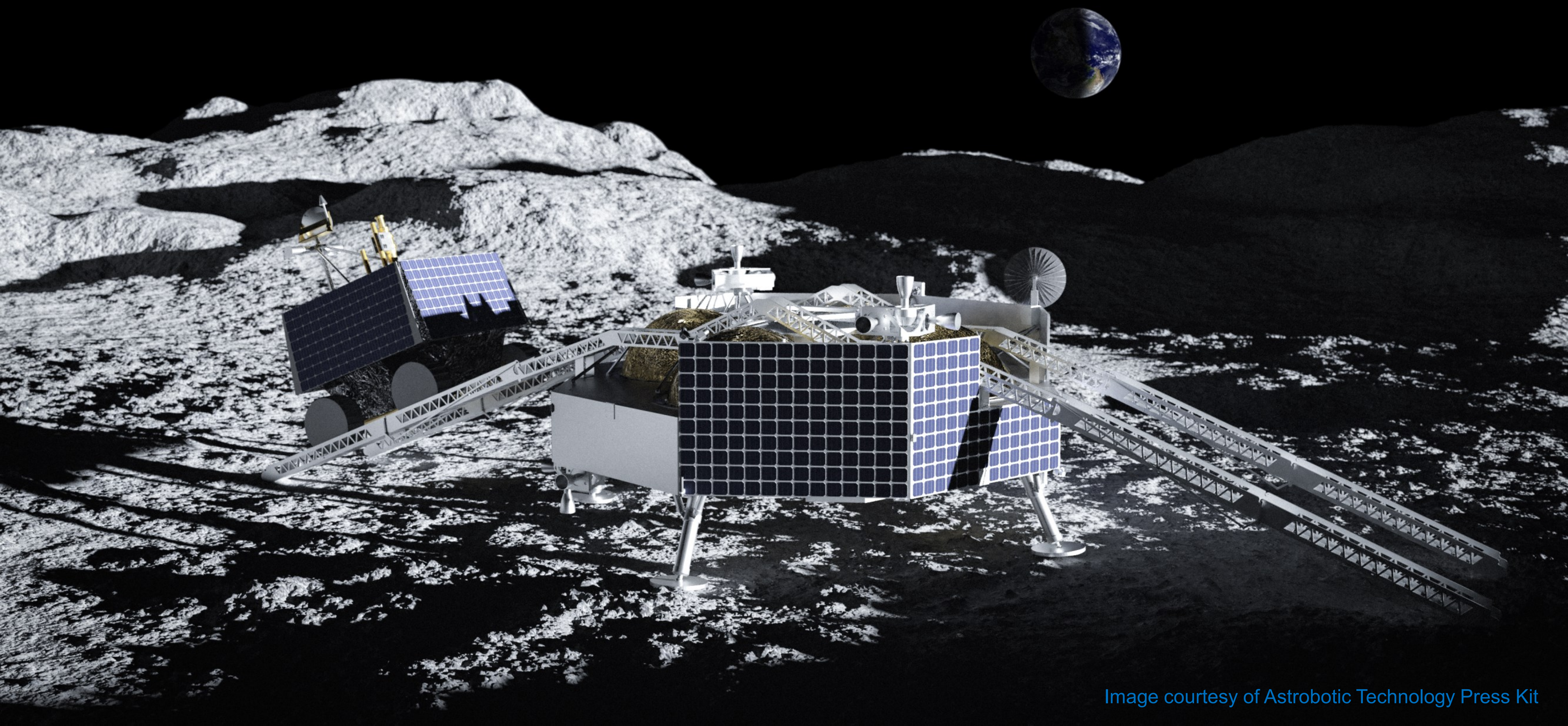
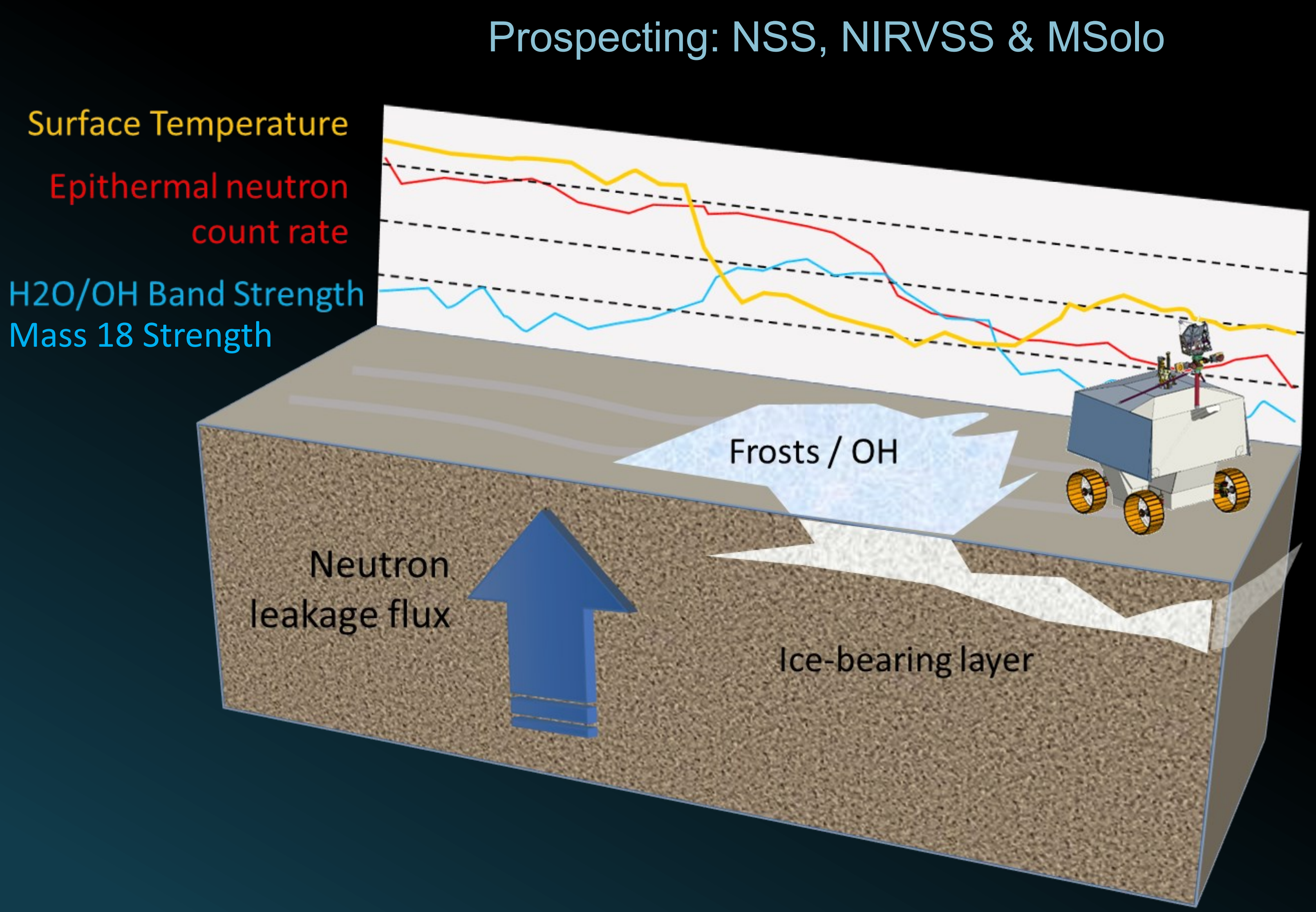


Image courtesy of Astrobotic Technology Press Kit

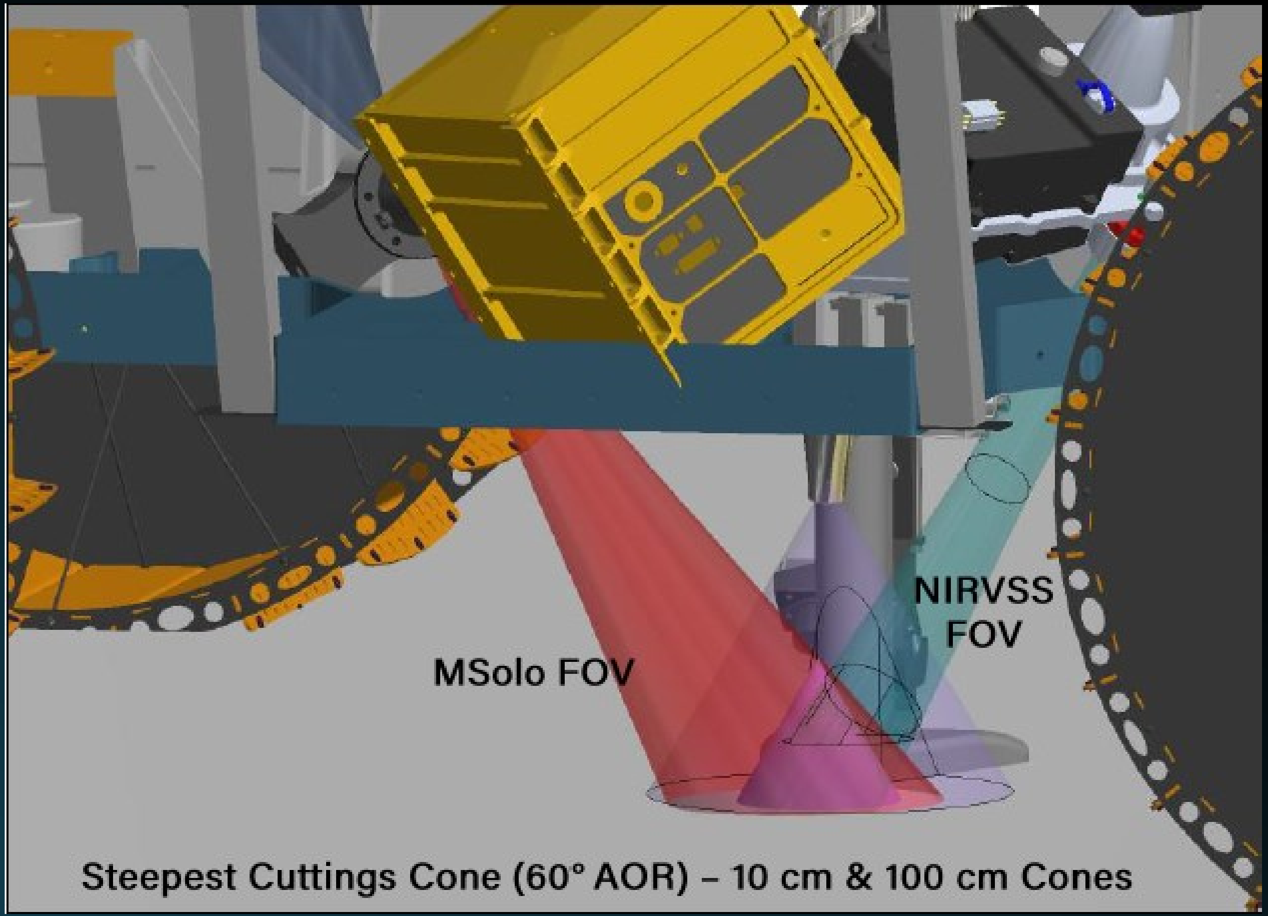
Prospecting characterizes regions & identifies points to drill



- 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 Mission Area

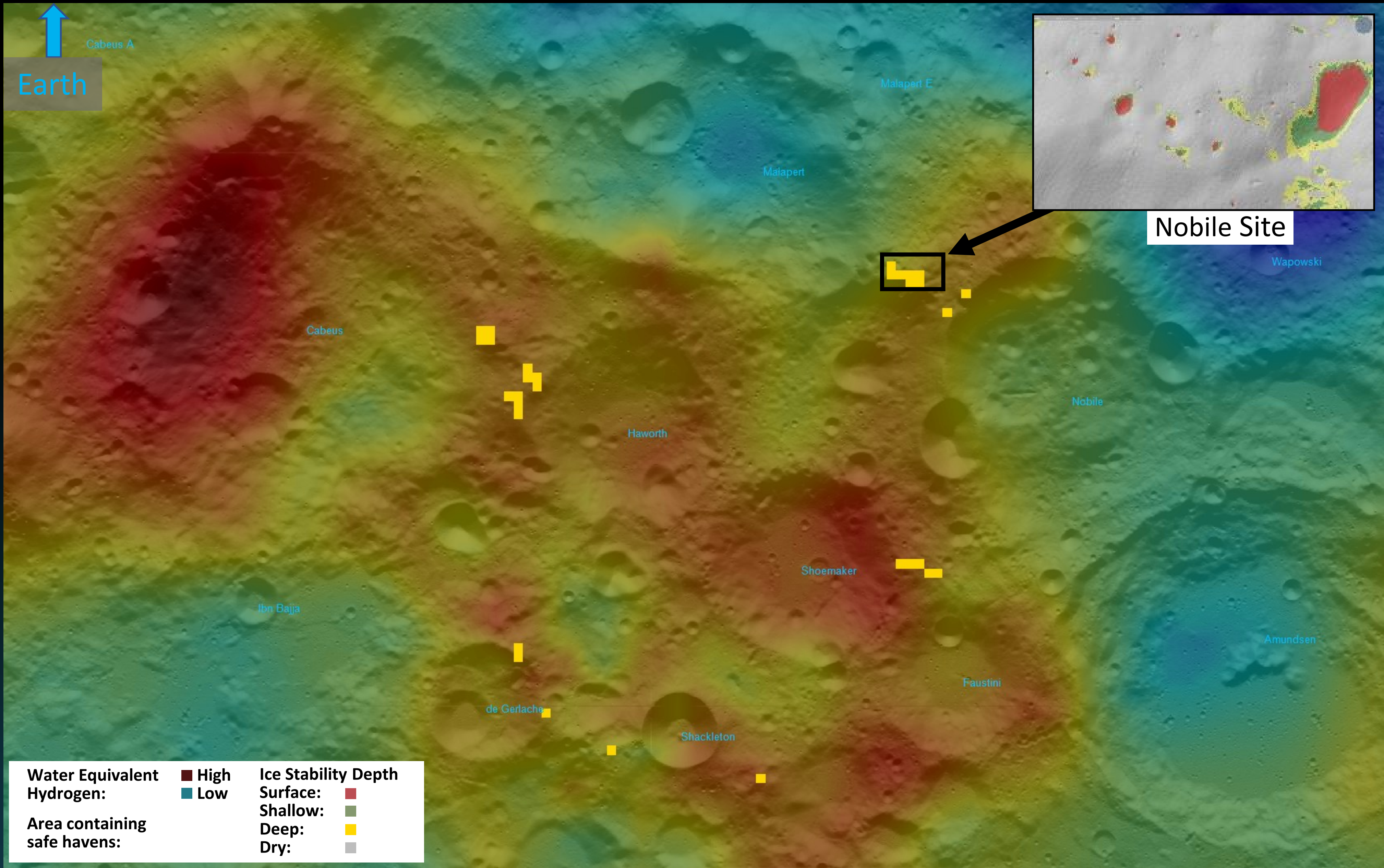
Needed: location with …

High water-equivalent hydrogen (background map)

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

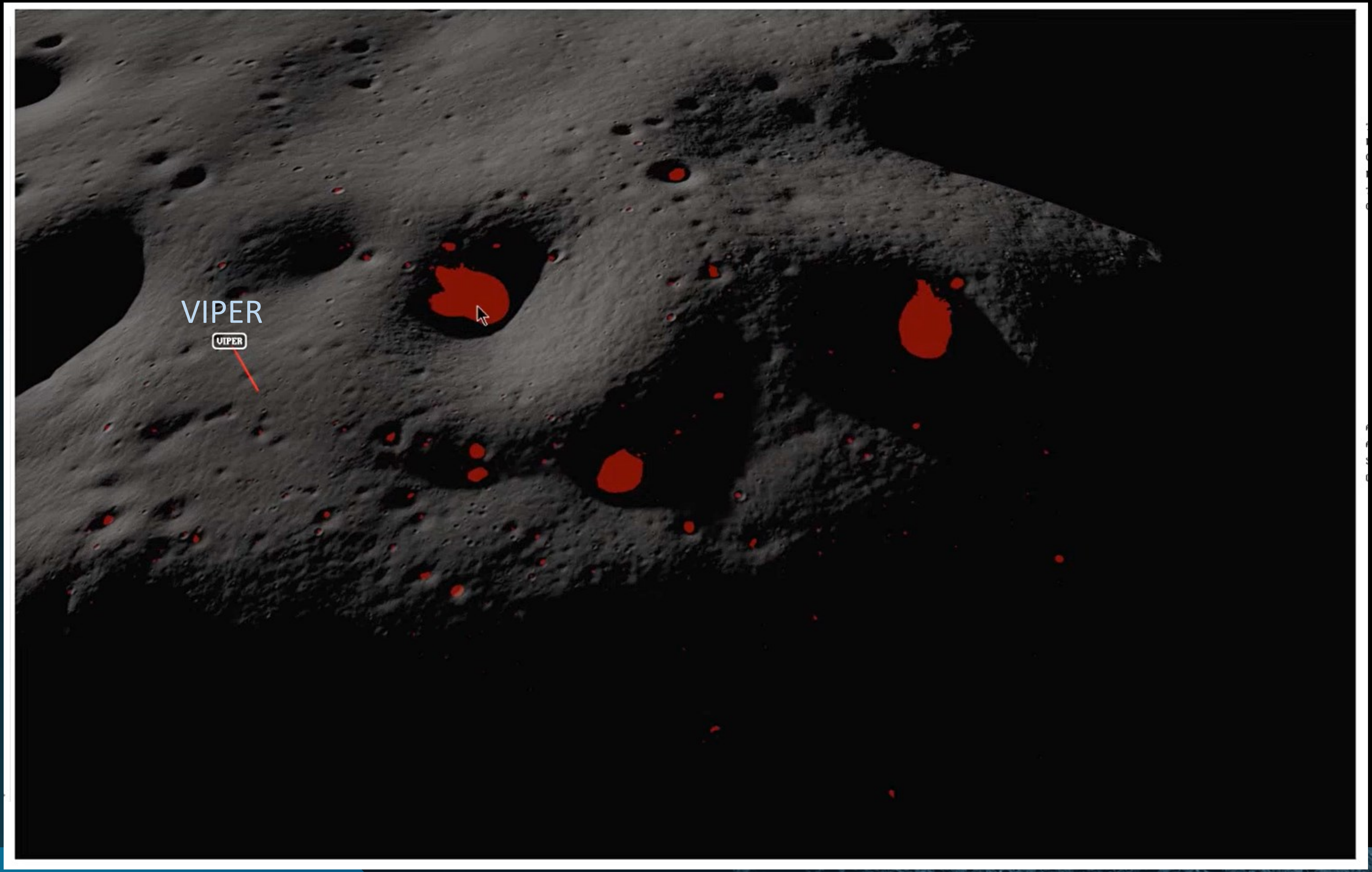
Periods of shadow short enough for the rover to survive (yellow blocks)

Unobscured line-of-site to Earth for communications



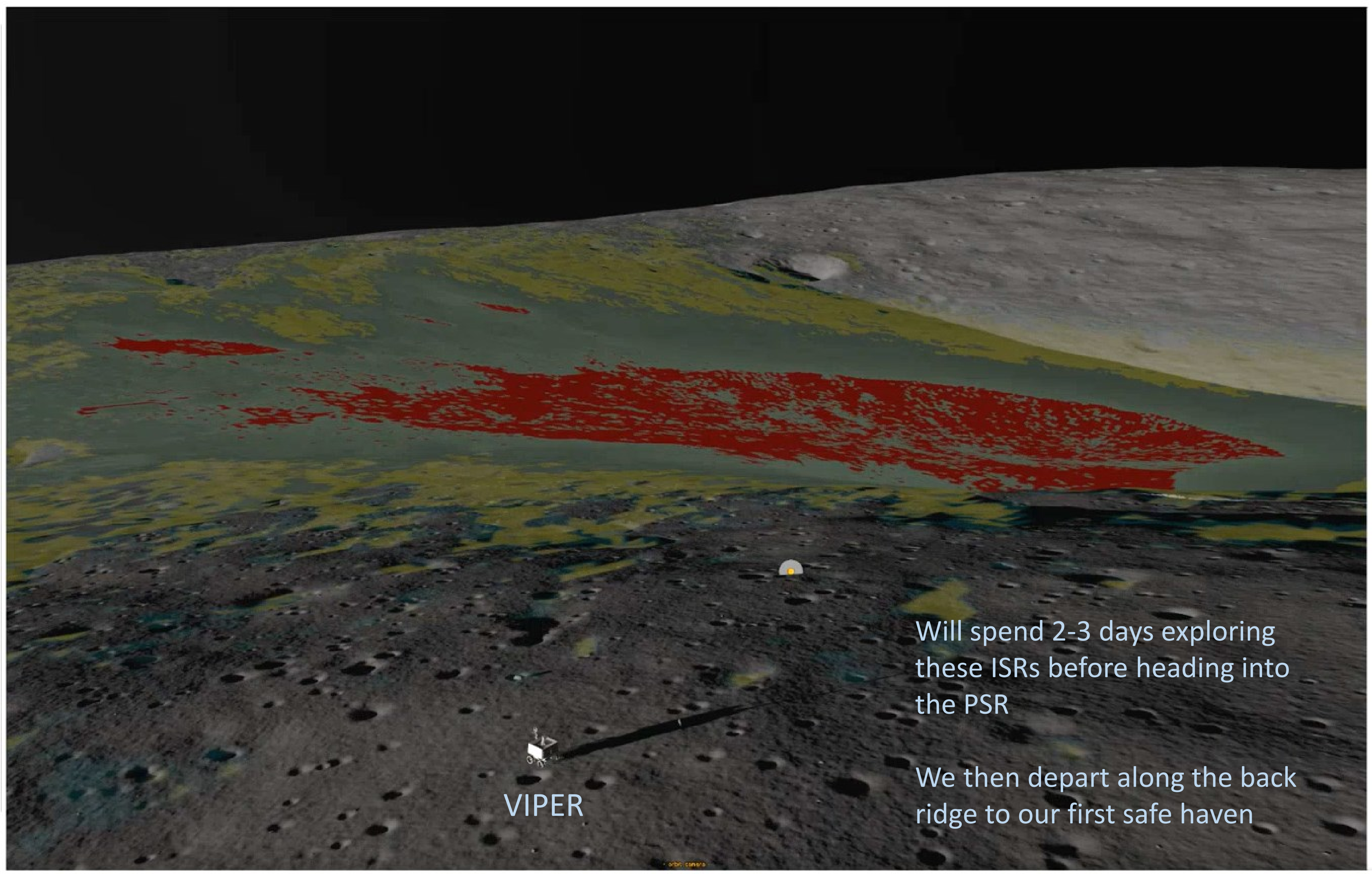
VIPER Nobile mission region on the Lunar South Pole

~10 km



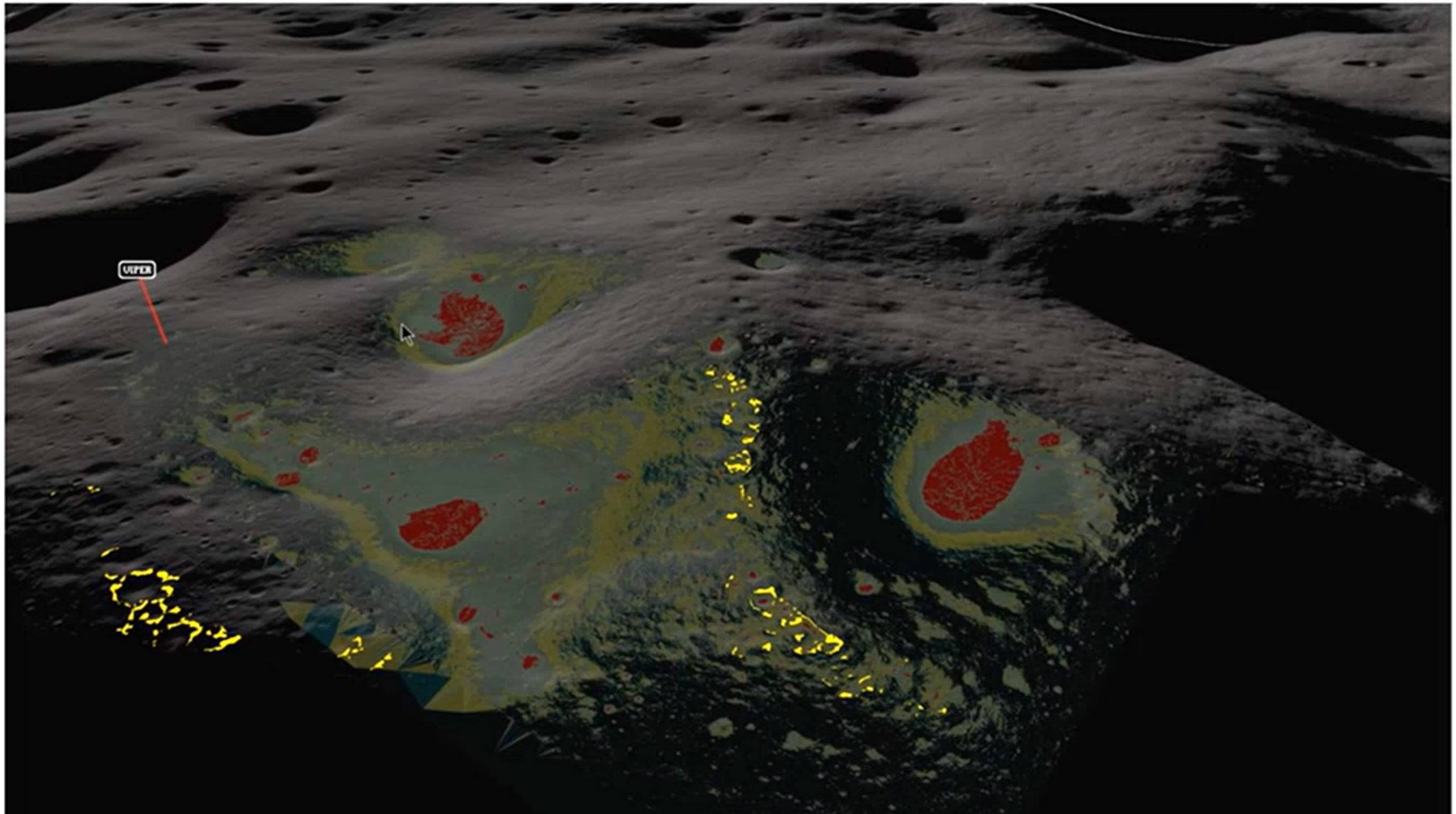
Screenshot from the VIPER Traverse Planning tool /M. Shirley

VIPER and the four Ice Stability Regions (ISRs)



Screenshot from the VIPER Traverse Planning tool /M. Shirley

Nobile region with Safe Havens

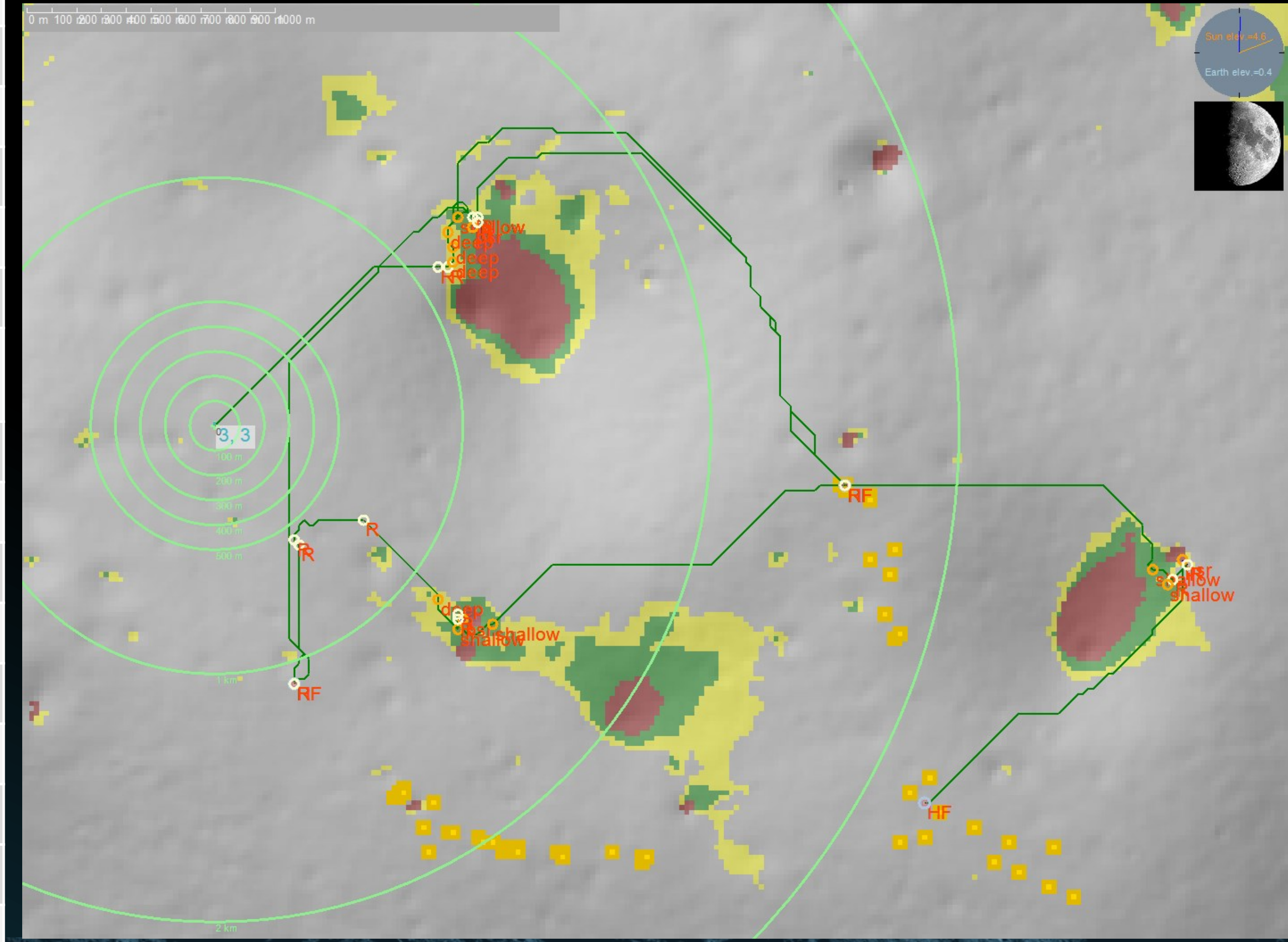


Yellow Safe Havens experience less than 50hrs of contiguous shadow during the 2 weeks VIPER is out of view of Earth

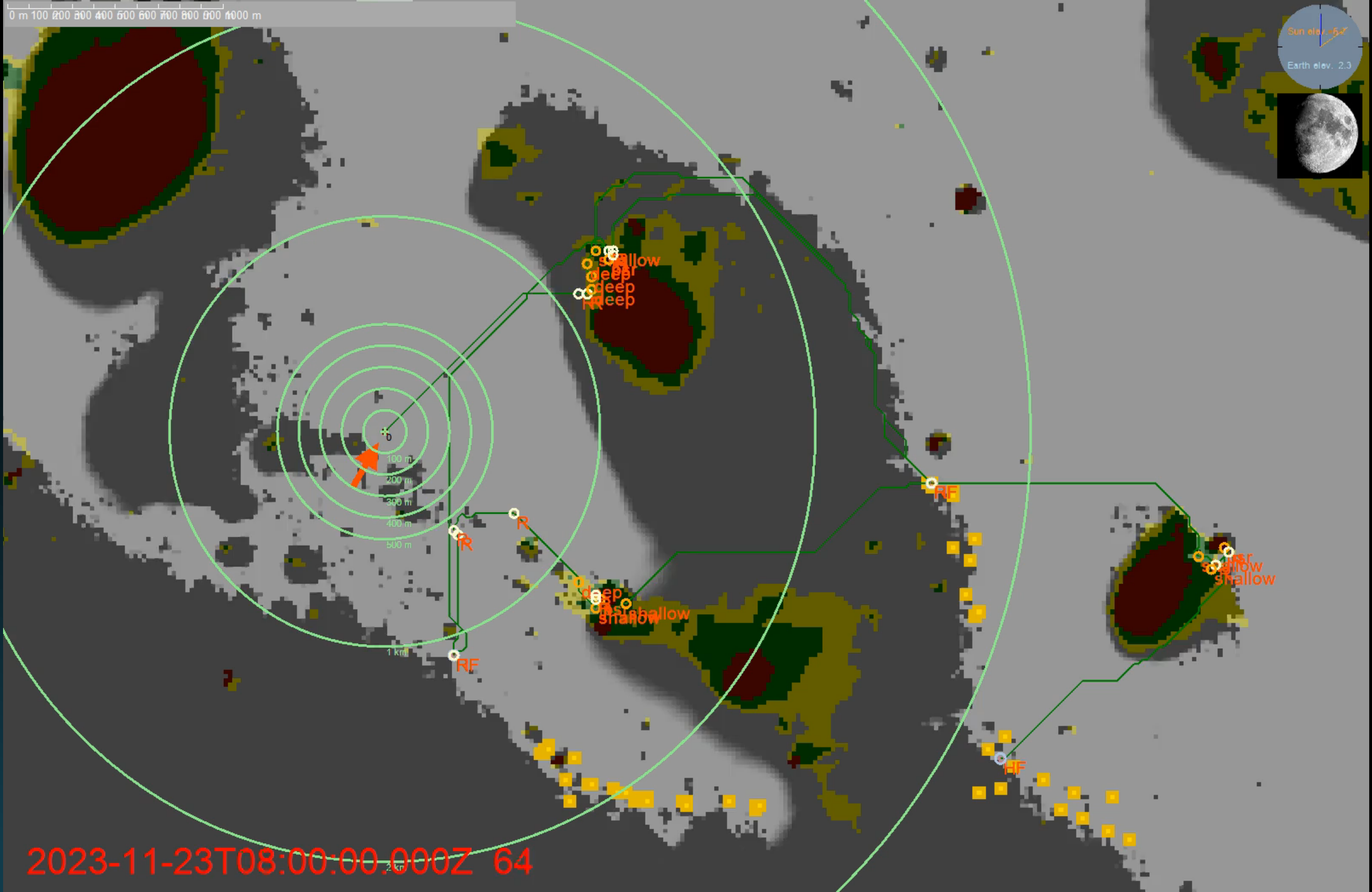
Screenshot from the VIPER Traverse Planning tool /M. Shirley

Top Ranked Nobile Area Traverse

<table>
<tr><th>Key Parameter</th><th colspan="3">Value</th></tr>
<tr><td>Launch Date (est)</td><td colspan="3">3 pm 11/10/2023 (all times UTC)</td></tr>
<tr><td>Lunar transfer duration</td><td colspan="3">5 days</td></tr>
<tr><td>Lunar Orbit Insertion (est)</td><td colspan="3">10:45pm 11/15/2023</td></tr>
<tr><td>Lunar orbit duration</td><td colspan="3">7 days</td></tr>
<tr><td>Landing time</td><td colspan="3">8 am 11/23/2023</td></tr>
<tr><td>Total mission duration</td><td colspan="3">106 days + option for 28 more</td></tr>
<tr><td>Surface mission duration</td><td colspan="3">94 days + option for 28 more</td></tr>
<tr><td>Active days on the surface</td><td colspan="3">45 days + option for 10 more
(but limited science)</td></tr>
<tr><td>Landing location</td><td colspan="3">85.449452S, 31.064135E</td></tr>
<tr><td>Average slope at landing site</td><td colspan="3">5^o</td></tr>
<tr><td>Light and comm at landing site</td><td colspan="3">12 days</td></tr>
<tr><td>Total driving distance</td><td colspan="3">4.4 km prospecting, 27.4 total</td></tr>
<tr><td>Max distance from landing site</td><td colspan="3">3 km</td></tr>
<tr><td rowspan="2">Science Stations</td><td rowspan="2">12</td><td>2 psr</td><td>4 shallow</td></tr>
<tr><td>4 deep</td><td>2 dry</td></tr>
<tr><td>Full mission success reached</td><td colspan="3">Day 37, near end of 2^{nd} lunar day</td></tr>
<tr><td>Driving Speed</td><td colspan="3">0.813 cm/s normal
0.613 cm/s sunward</td></tr>
</table>



In the Nobile Area



0 m 100 200 300 400 500 600 700 800 900 1000 m
Earth elev. 2.3
100 m
200 m
300 m
400 m
500 m
1 km
shallow
deep
deep
deep
R
R
RF
RF
HF
shallow
shallow
2023-11-23T08:00:00.000Z 64

VIPER

Rover lander egress testing with full-scale lander mockup and test rover at JSC

VIPER

Rover build pathfinder at JSC

Rover thermal test unit in TVAC at MSFC

Questions?

VIPER Instrument overview

Neutron Spectrometer System (NSS)

NSS (NASA ARC, Lockheed Martin ATC)

PI: Rick Elphic (NASA ARC)

Instrument Type: Two channel neutron spec

Key Measurements: NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring down to 0.5% (wt) WEH while roving

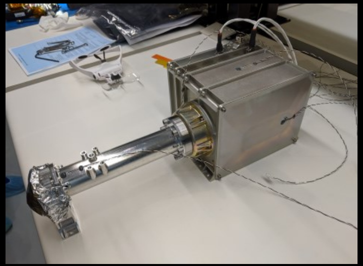
Operation: On continuously while roving

Specs: 1.9kg, 1.6w, 21x32x7cm (sensor) / 14x18x3cm (Data proc. module)

Mass Spec. Observing Lunar Operations (MSolo)

MSolo (KSC, INFICON)

PI: Janine Captain (NASA KSC)



Instrument Type: Quadrupole mass spectrometer

Key Measurements: Identify low-molecular weight volatiles between 1-100 amu, unit mass resolution to measure isotopes including D/H and $0^{18}/0^{16}$

Operation: Views drill cuttings, volatile analysis while roving and during drill activities

Specs: 6.0kg, 35w, 16x20x46cm

Near InfraRed Volatiles Spec. System (NIRVSS)

NIRVSS (ARC, Brimrose Corporation)

PI: Anthony Colaprete (NASA ARC)

Instrument Type: NIR Point Spectrometer, 4Mpxl Panchromatic Imager w/7 LEDs, 4-ch thermal radiometer

Key Measurements: Volatiles including H_2O, OH, and CO_2 & mineralogy, surface morphology/temps

Operation: On continuously while roving and during drill operations

Specs: 3.6kg, 29.5w, 18x18x9cm (spec) / 20x13x15cm (Obs bracket)

The Regolith and Ice Drill for Exploring New Terrains (TRIDENT) Drill

TRIDENT (Honeybee Robotics)

PI: Kris Zacny (Honeybee)

Instrument Type: 1-meter hammer drill

Key Measurements: Excavation of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth

Operation: Subsurface assays to 100 cm in <1 hr, depositing cuttings at surface

Specs: 18kg, 20w/175w (nom/max), 27x22x177cm