VIPER

A lunar water reconnaissance mission

Anthony Colaprete, VIPER Project Science

August 17, 2020

Volatile Investigating Polar Exploration Rover (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

VIPER Mission Preliminary Design Review August 26-27, 2020

Launch November 2023

https://www.nasa.gov/viper

Understanding Lunar Water

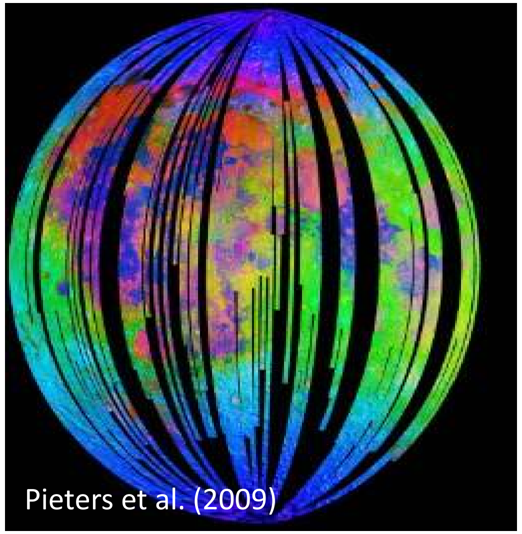
Moon now known to host all three forms of Solar System water: endogenic, sequestered external and in-situ*

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

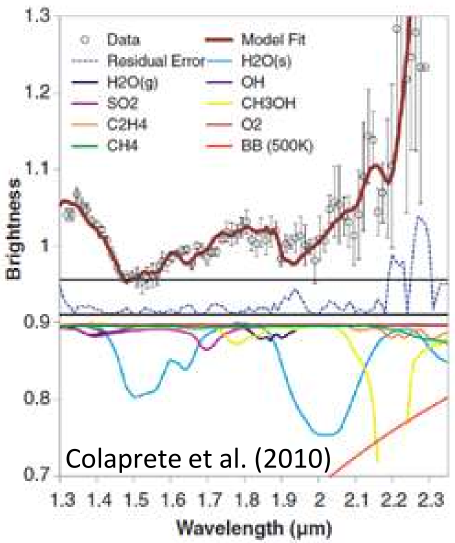
Understanding the distribution, both laterally and with depth, addresses key exploration and science questions

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

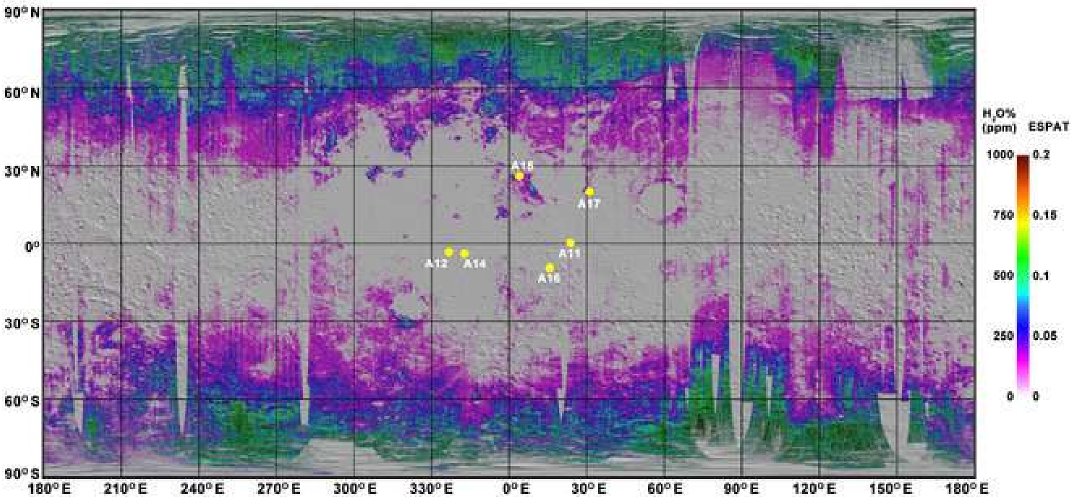
"Prospecting" for lunar water at poles is the next step in understanding the resource potential and addressing key theories about water emplacement and retention



Pieters et al. (2009)



Colaprete et al. (2010)



Li and Milliken (2017)

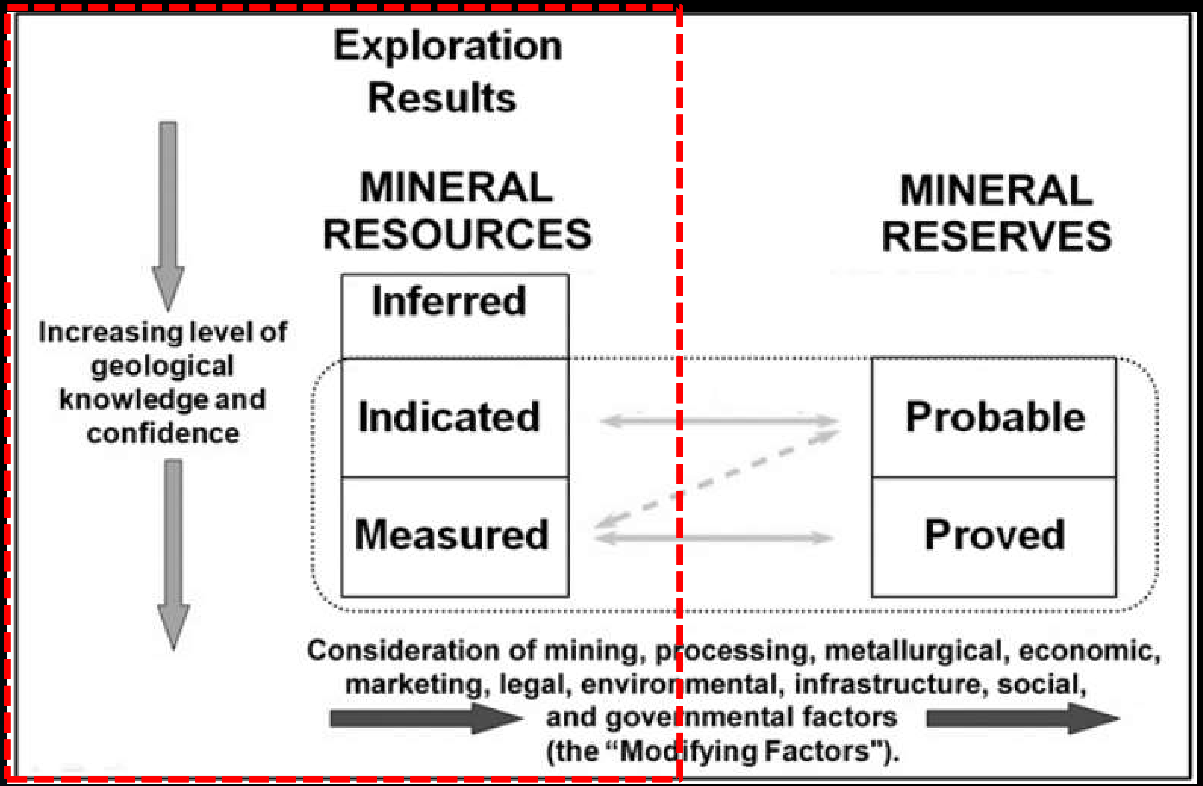
*From Peters et al. Transformative Lunar Science (2018)

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.

How to Measure Volatiles at the "Human Scale"?

How to determine the distribution across a broad area at resolutions of ~meters?

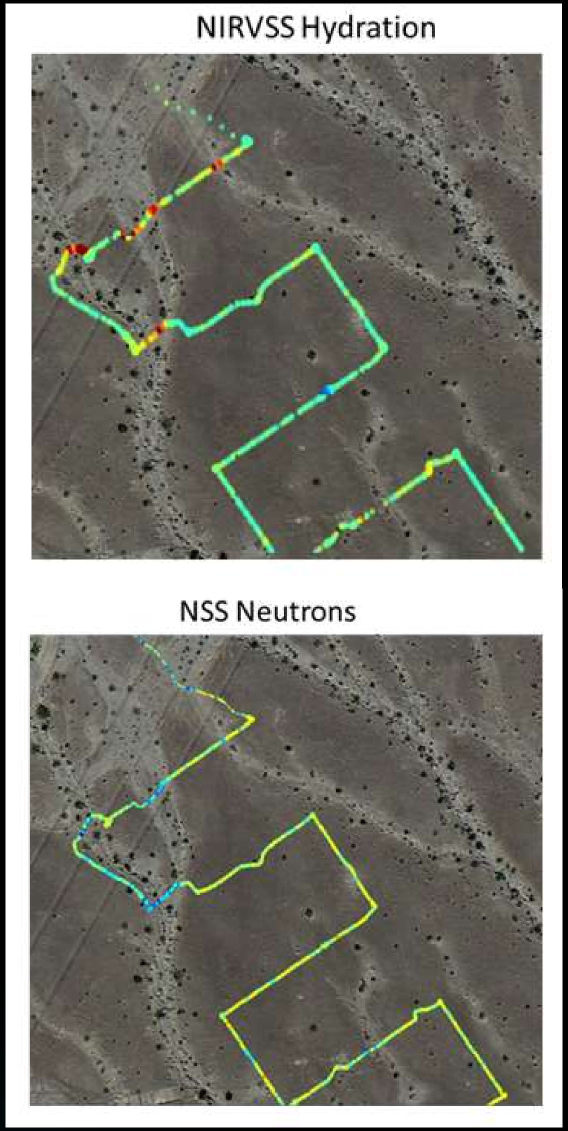
- Drilling alone would require an unreasonable number of drill sites and result in significant production uncertainty
- Measurements while moving give continuous sampling, however reflectance observations are only surficial, and neutron data can have significant uncertainty due to modeling assumptions about vertical distribution

Boreholes used to tie-down neutron observations by constraining vertical profile

- A combined Drill / Composition Analysis system can measure the vertical distribution of water constraining neutron modeling – provides the "tie point" for the prospecting data

Real-time Data Analysis allows for smart sampling

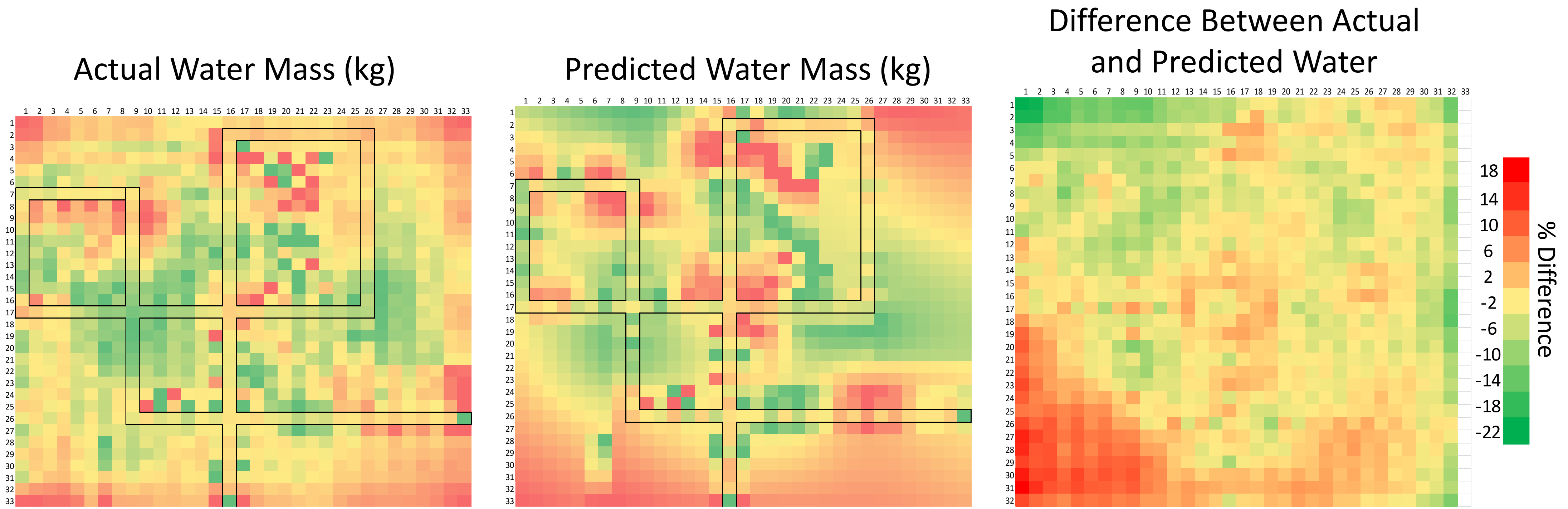
- Rather than drive randomly or drill blindly VIPER capitalizes on the Moon's proximity to inform mapping and drill site selection
- Data is processed in near real-time and used, along with a variety of modeling technics to optimize traverse planning



How much Sampling is Needed?

Interpolated total water from traverse measurements

- Used predicted water along traverse based on neutron measurements, including measurement uncertainties
- Performed a Kriging (Gaussian process regression) interpolation across entire area
- Errors within/near the traverse area are typically <20%
- The error is a strong function of the number of unique sites sampled (the traverse path)



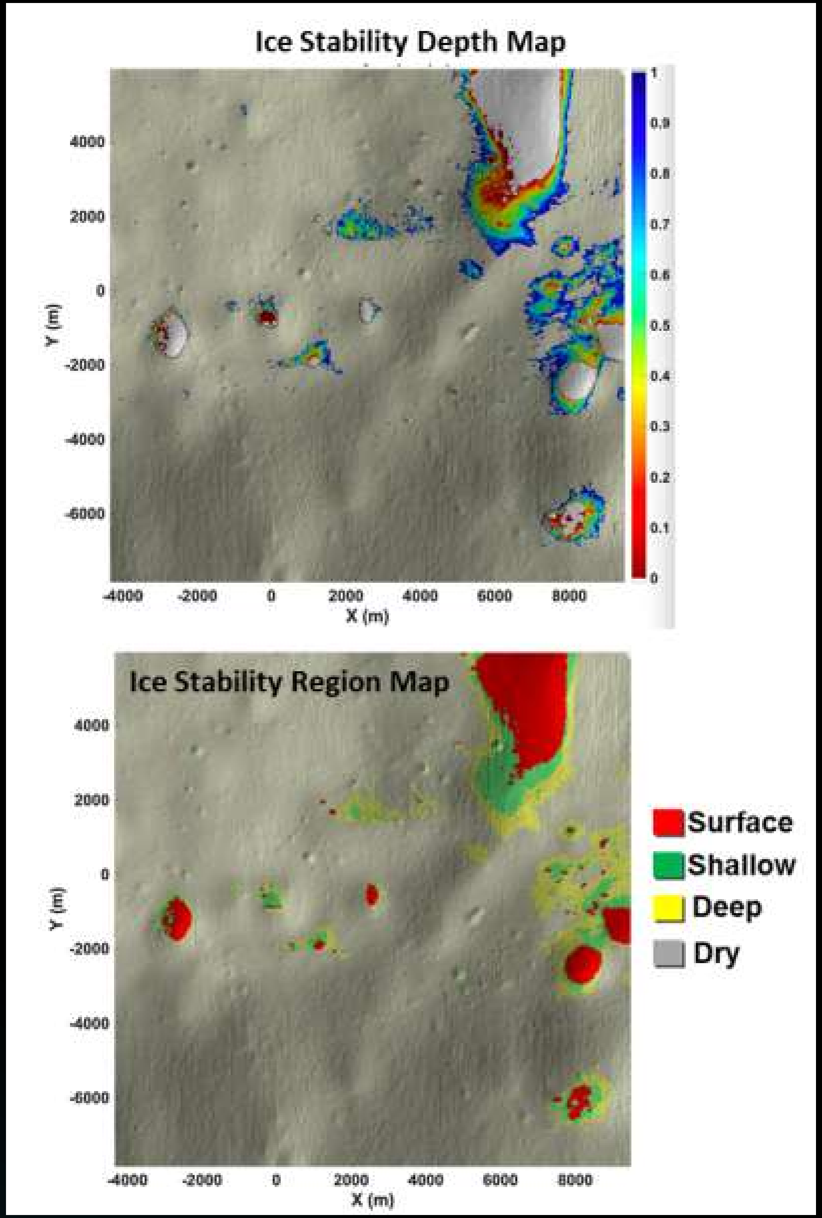
Spatial Proxies for Resource Maps and Models

Primary environmental factor is temperature

- At a minimum temperatures (surface or subsurface) must be low enough to retain water ice
- Secondary environmental factors may include geophysical properties (e.g., association with craters of a certain size and age)
- Also secondary is the ore extent, given regional data sets only extend to ~1 meter deep (i.e., neutron observations)

Using the predicted stability of water over time with depth

- Four environments defined based on the predicted thermal stability of ice with depth, the **Ice Stability Regions** (ISRs):
  1. **Dry**: Temperatures in the top meter expected to be too warm for ice to be stable
  2. **Deep**: Ice expected to be stable between 50-100 cm of the surface
  3. **Shallow**: Ice expected to be stable within 50cm of surface
  4. **Surface**: Ice expected to be stable at the surface (ie., within a Permanently Shadowed Region, PSR)



VIPER Required Measurements

- **Determine water distribution and form across defined Ice Stability Regions with an uncertainty of ≤ 50%**
  → Areal measurement density of >10% for an equivalent area of at least 3800 m^2
  → Total drive distance in ISR ≥ 225 m (assuming a 1.7 m sampling width)

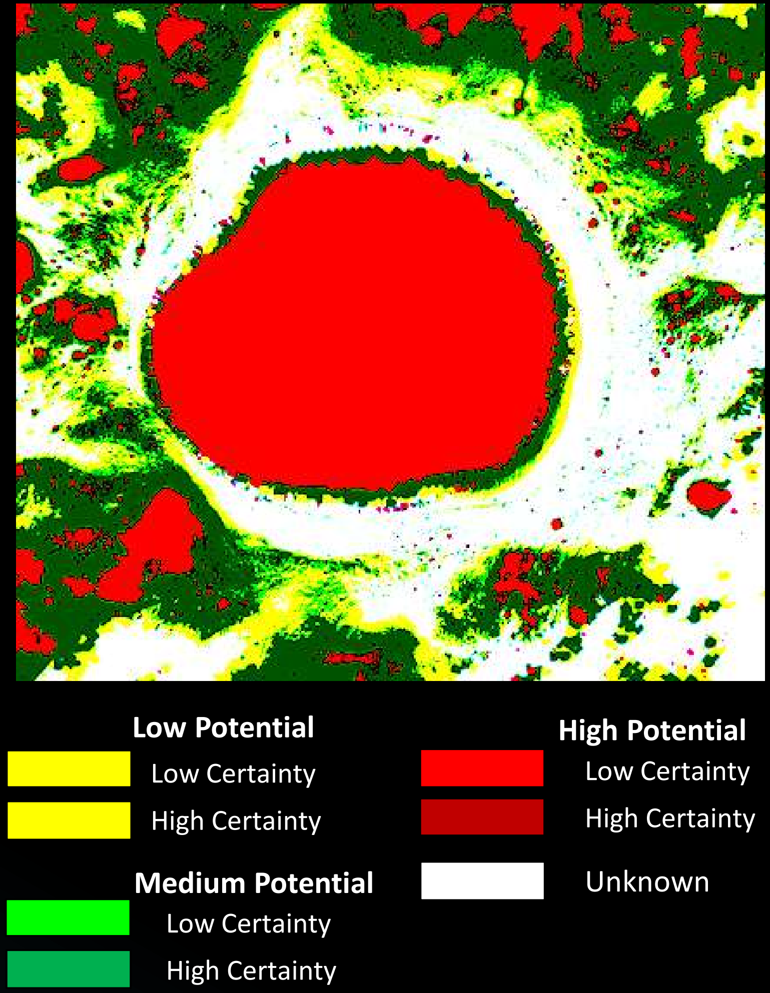
- **Must characterize water (and water equivalent hydrogen) at concentrations as low as 0.5%**
  → Must be able to measure water physical state and key isotopes

- **To account for possible scales of variability, must measure at scales of <5 meters and as large as 1000 m**
  → Minimum of two additional ISR repeat measurements separated by at least 100 meters

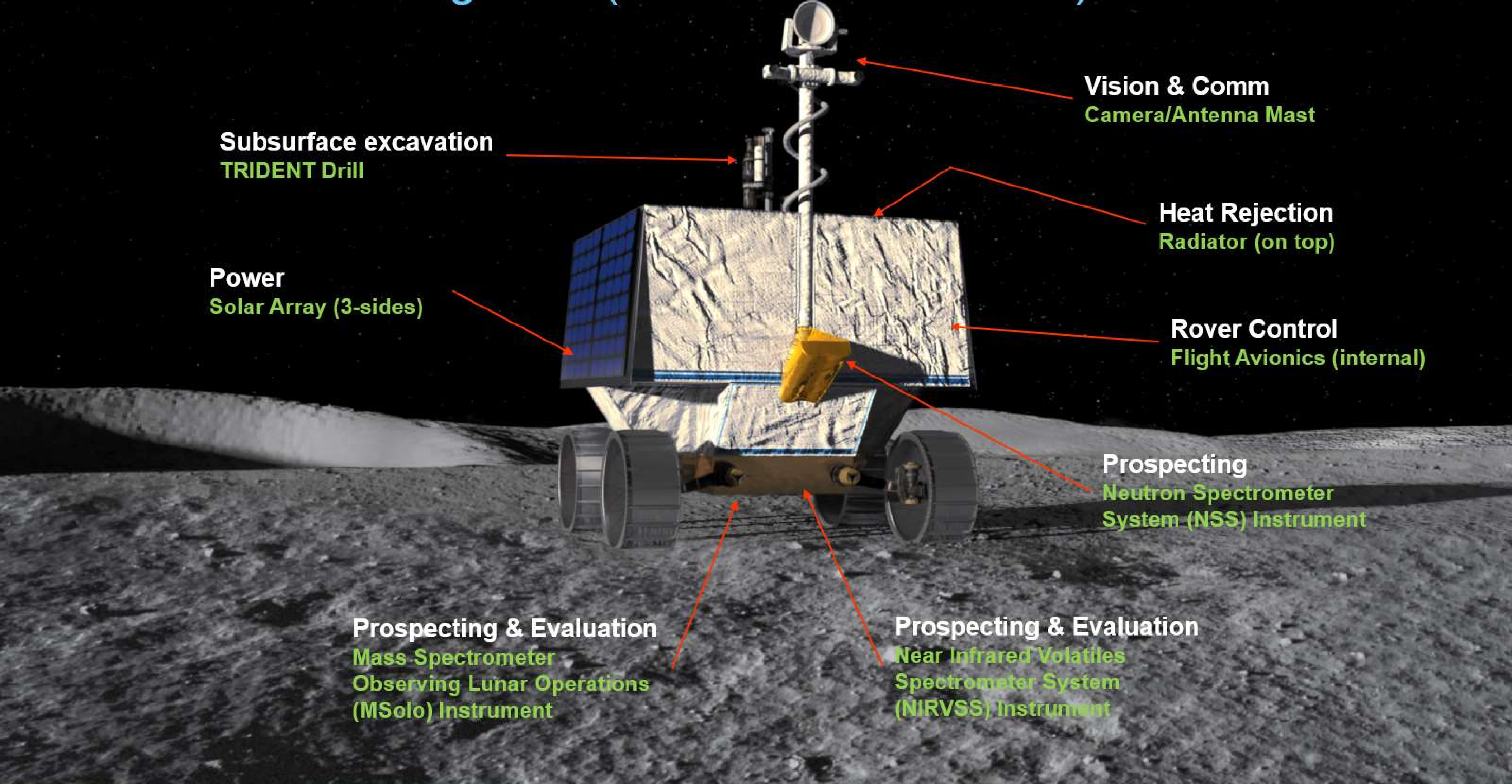
- **Minimum of three subsurface characterizations in each ISR separated by 10s of meters**
  → Subsurface measurements must sample across depths from 10 cm to 80 cm with a sampling interval of at least 8 cm

- **Characterize context, including surface and subsurface temperatures, isotopes, geology, geomorphology/geomechanics and surface composition to inform Resource Models**

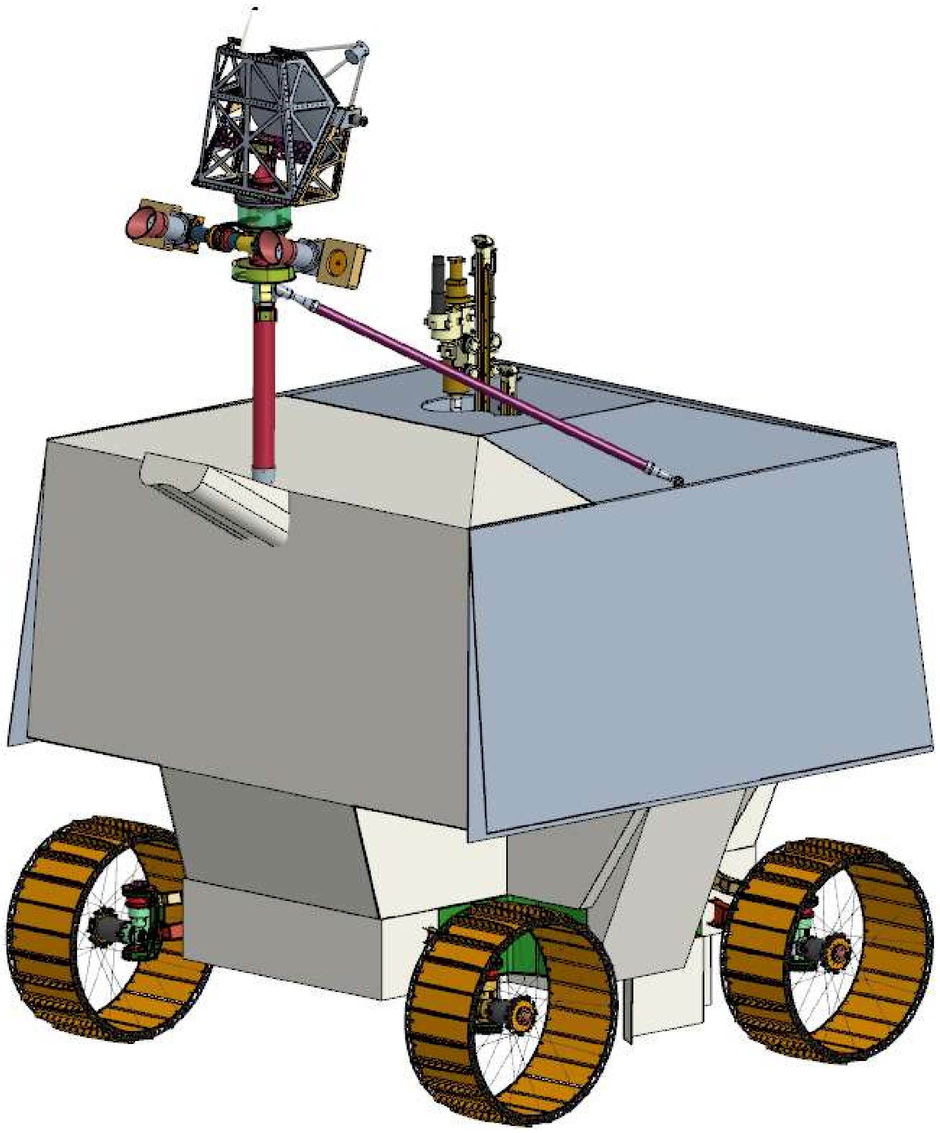
Resource Map

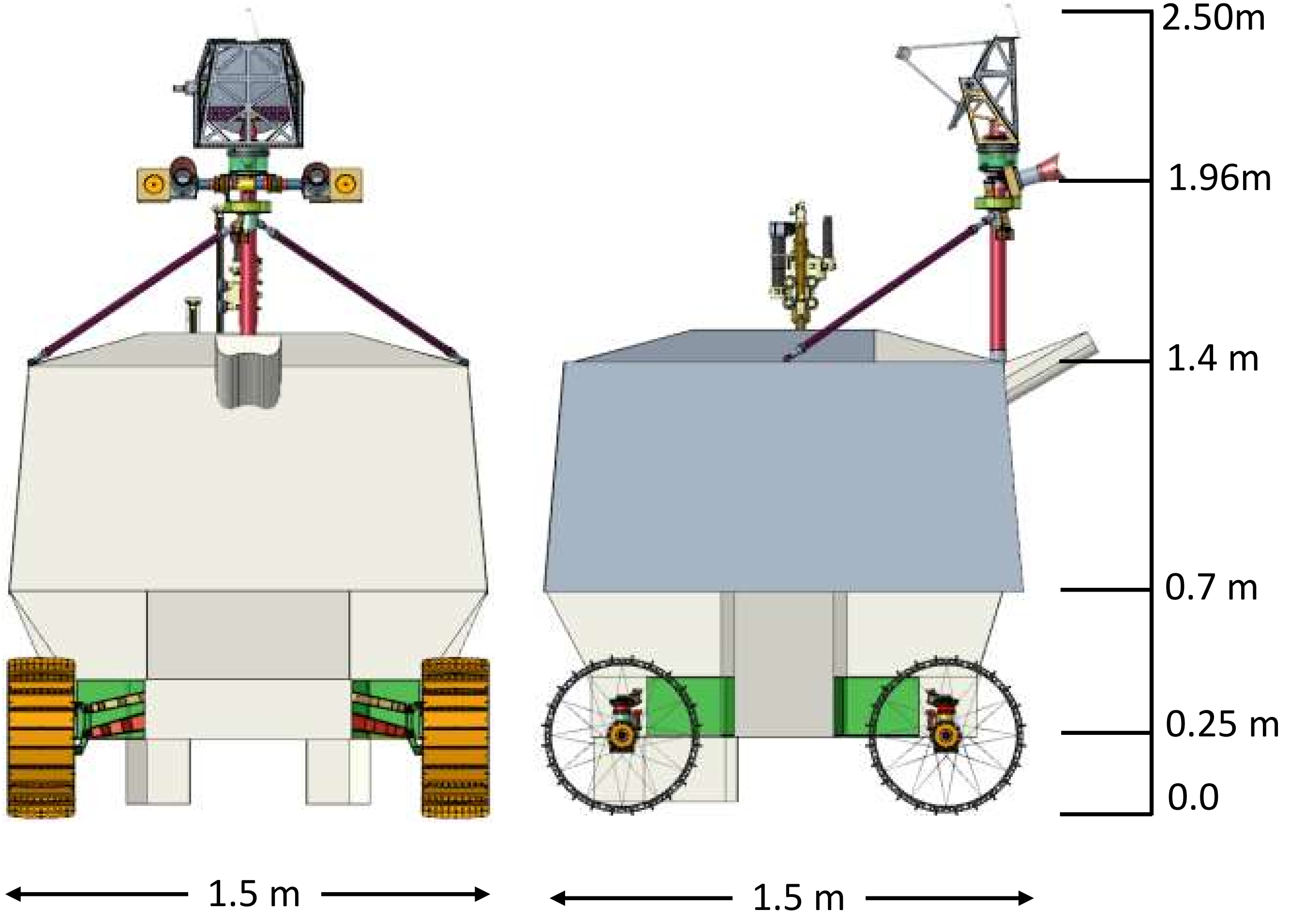


VIPER Surface Segment (Rover + Instruments)



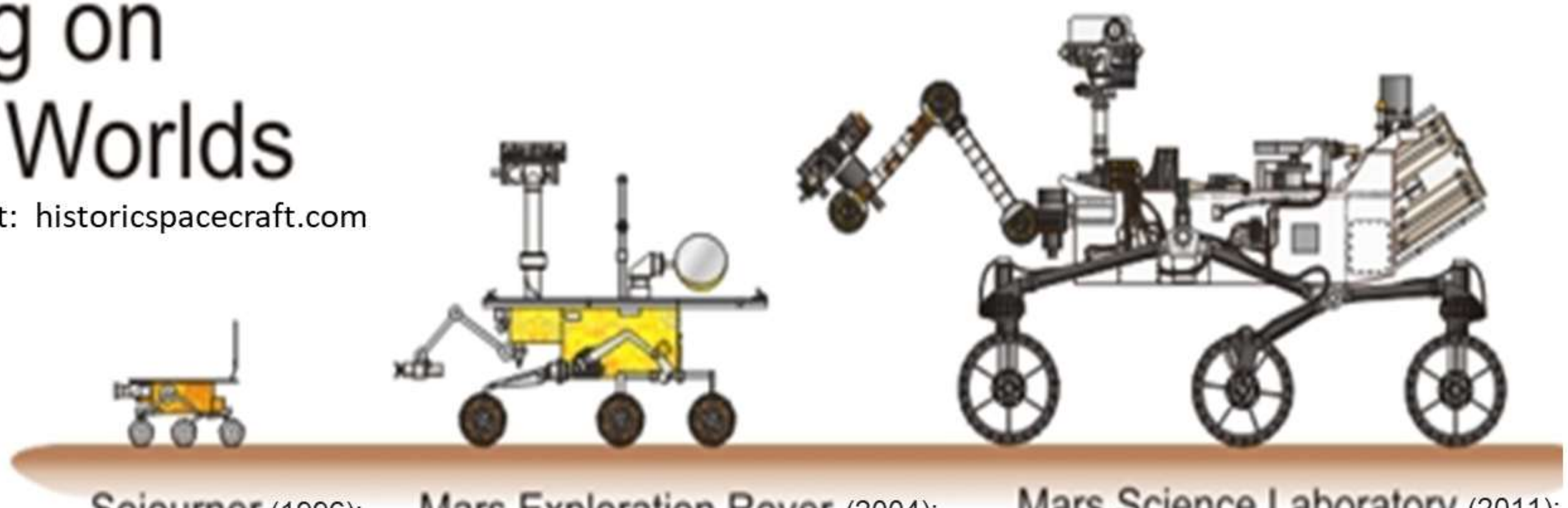
Current Integrated Rover Design





Driving on Other Worlds

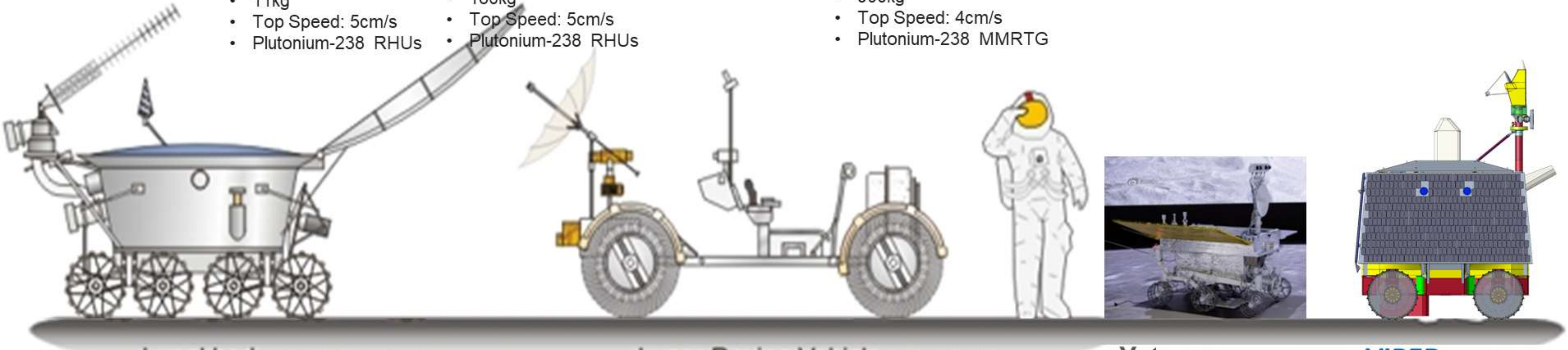
(Augmented) credit: historicspacecraft.com



Sojourner (1996):
- 0.6m x0.5m x0.3m
- 11kg
- Top Speed: 5cm/s
- Plutonium-238 RHUs

Mars Exploration Rover (2004):
- 1.6m x2.3m x1.5m
- 180kg*
- Top Speed: 5cm/s
- Plutonium-238 RHUs

Mars Science Laboratory (2011):
- 3.0m x2.8m x2.1m
- 900kg
- Top Speed: 4cm/s
- Plutonium-238 MMRTG



Lunokhod 1 & 2 (1970 / 1973):
- 1.3M x1.6m x1.5m, 840kg
- Top Speed: 55cm/s
- Polonium-210 heat source

Lunar Roving Vehicle (1971 / 1972):
- 1.3M x1.6m x1.5m, 840kg
- Top Speed: 500cm/s

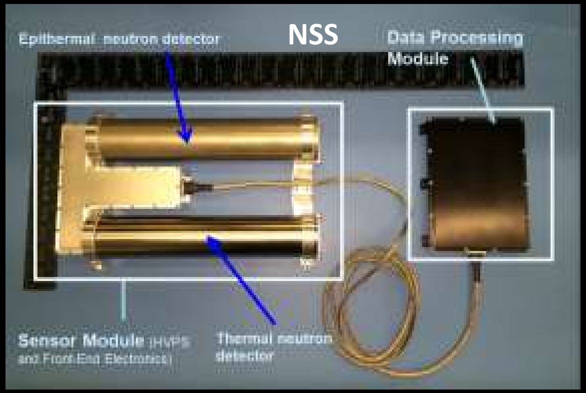
Yutu (2013 / 2019):
- 1.5m x1.1m, 140kg
- 5cm/s
- Plutonium-238 RHUs

VIPER (2023):
- **1.7m x1.7m x2.0m, 430kg**
- **Top Speed: 20cm/s**
- **Electric heaters only**

VIPER Science Payload

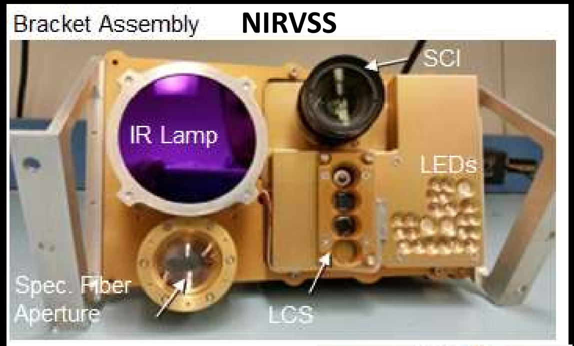
NSS (NASA ARC/Lockheed Martin ATC)
PI: Rick Elphic (NASA ARC)

- **Instrument Type:** Two channel neutron spectrometer
- **Key Measurements:** NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring down to 0.5% (wt) WEH to 3σ while roving



NIRVSS (ARC, Brimrose Corporation)
PI: Anthony Colaprete (NASA ARC)

- **Instrument Type:** NIR Spectrometer (1200-4000 nm), 4Mpxl Imager with 7 banks of color LEDs, four channel thermal radiometer
- **Key Measurements**: Volatiles including H_2O, OH, and CO_2 and, minerology, surface morphology and temperatures

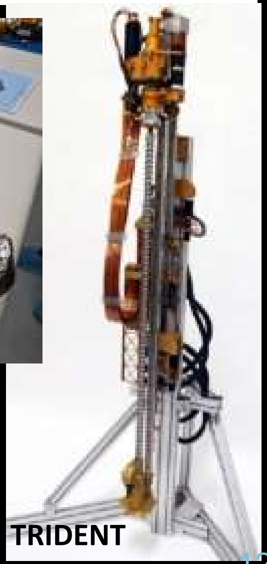


MSolo (KSC, INFICON, NSF– SHREC Space Processor, & Blue Sun – Virtual Machine Language)
PI: Janine Captain (NASA KSC)

- **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 $0^{18}/0^{16}$

TRIDENT (Honeybee Robotics)
PI: Kris Zacny (Honeybee Robotics)

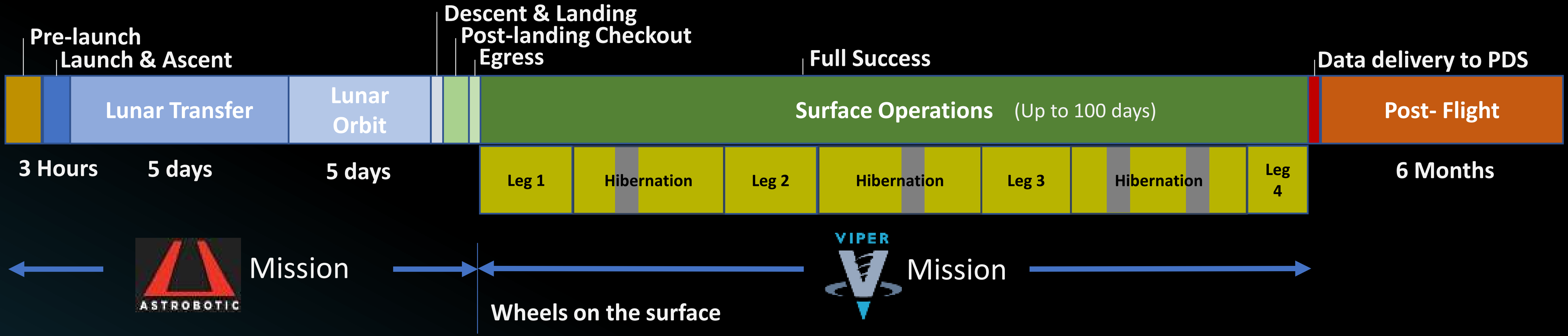
- **Instrument Type:** 1-meter percussive drill
- **Key Measurements**: Excavation of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth (info on ice-cemented ground vs. ice-soil mixture)



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

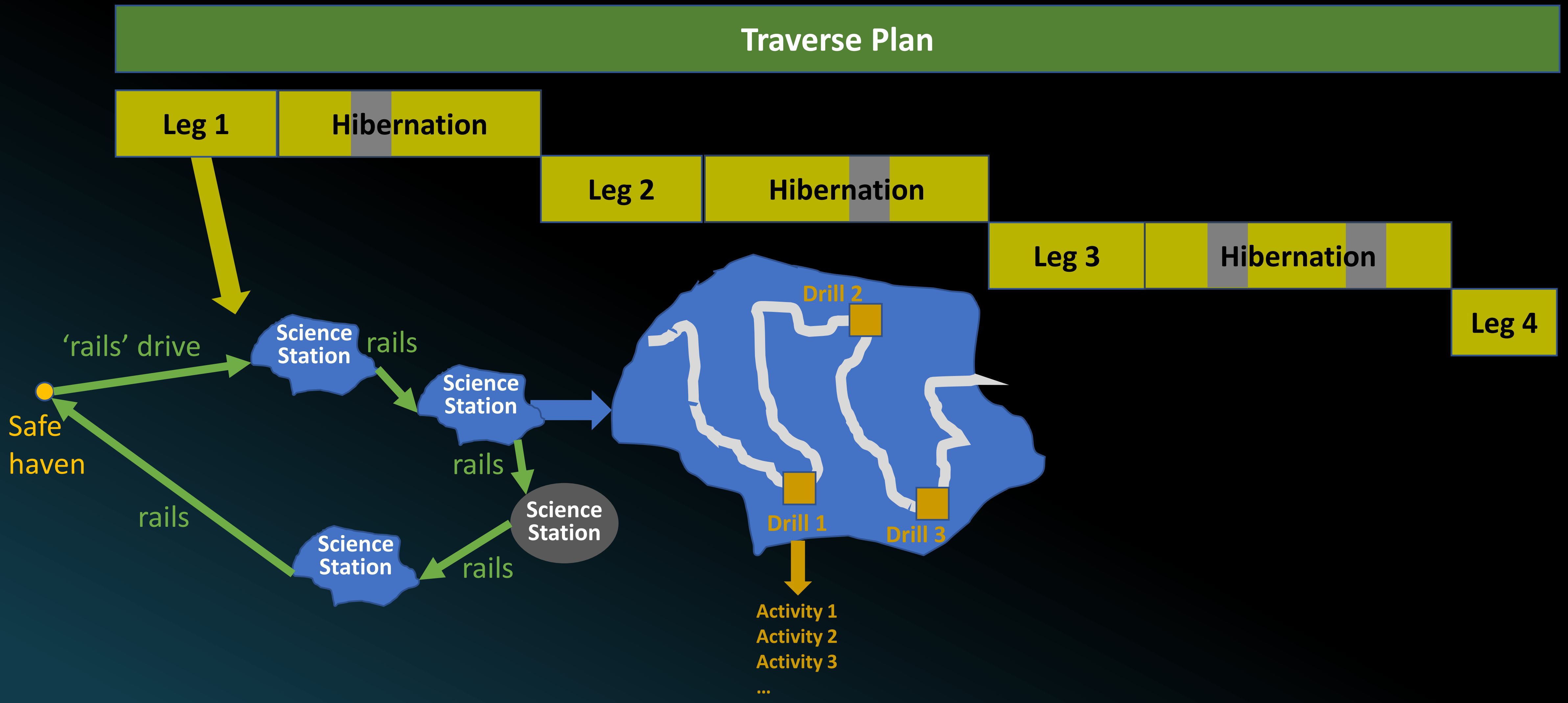
Image courtesy of Astrobotic Technology Press Kit

VIPER Mission Phases



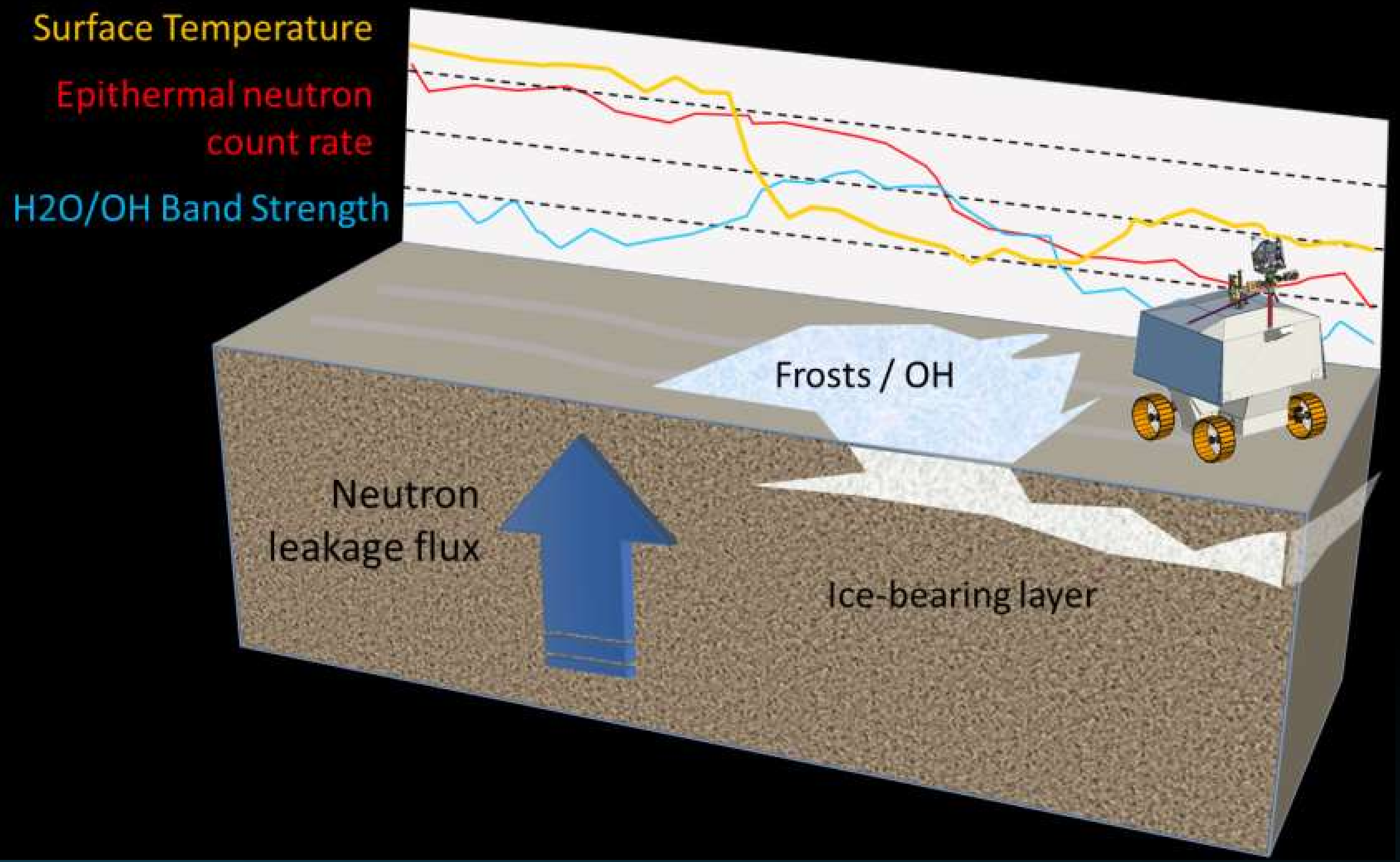
- Surface Ops consist of periods of activity (“traverse legs”) and periods of inactivity (“hibernations”)
  - Traverse legs are in view of Earth and sun (except for planned shadow (PSR) ops (<8 hours))
  - Hibernations are NOT in view of Earth, but in view of sun, with periods of sun shadow (<72hrs)
  - 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

Surface Operations



Prospecting characterizes regions & identifies points to drill

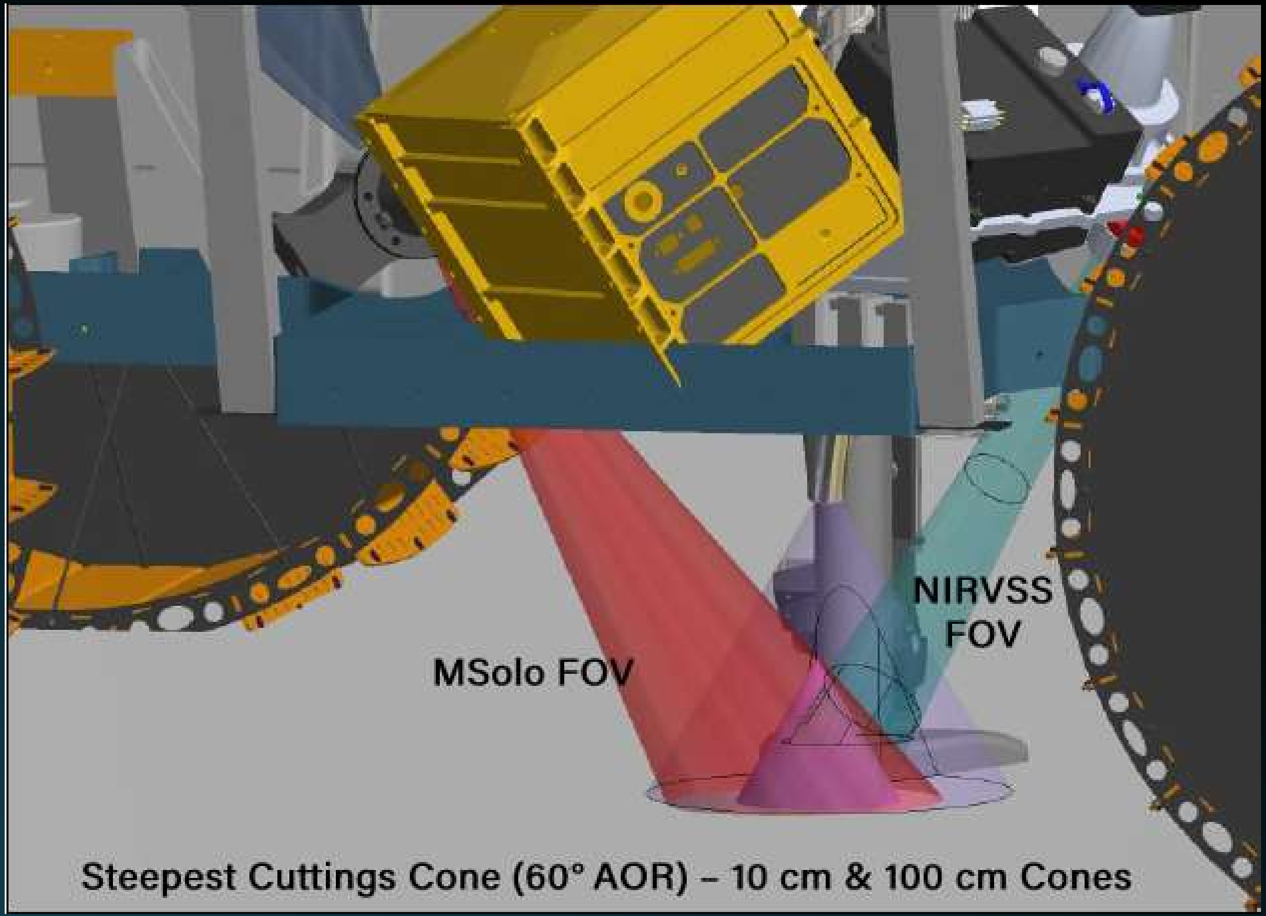
Prospecting: NSS, NIRVSS & MSolo



- 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)



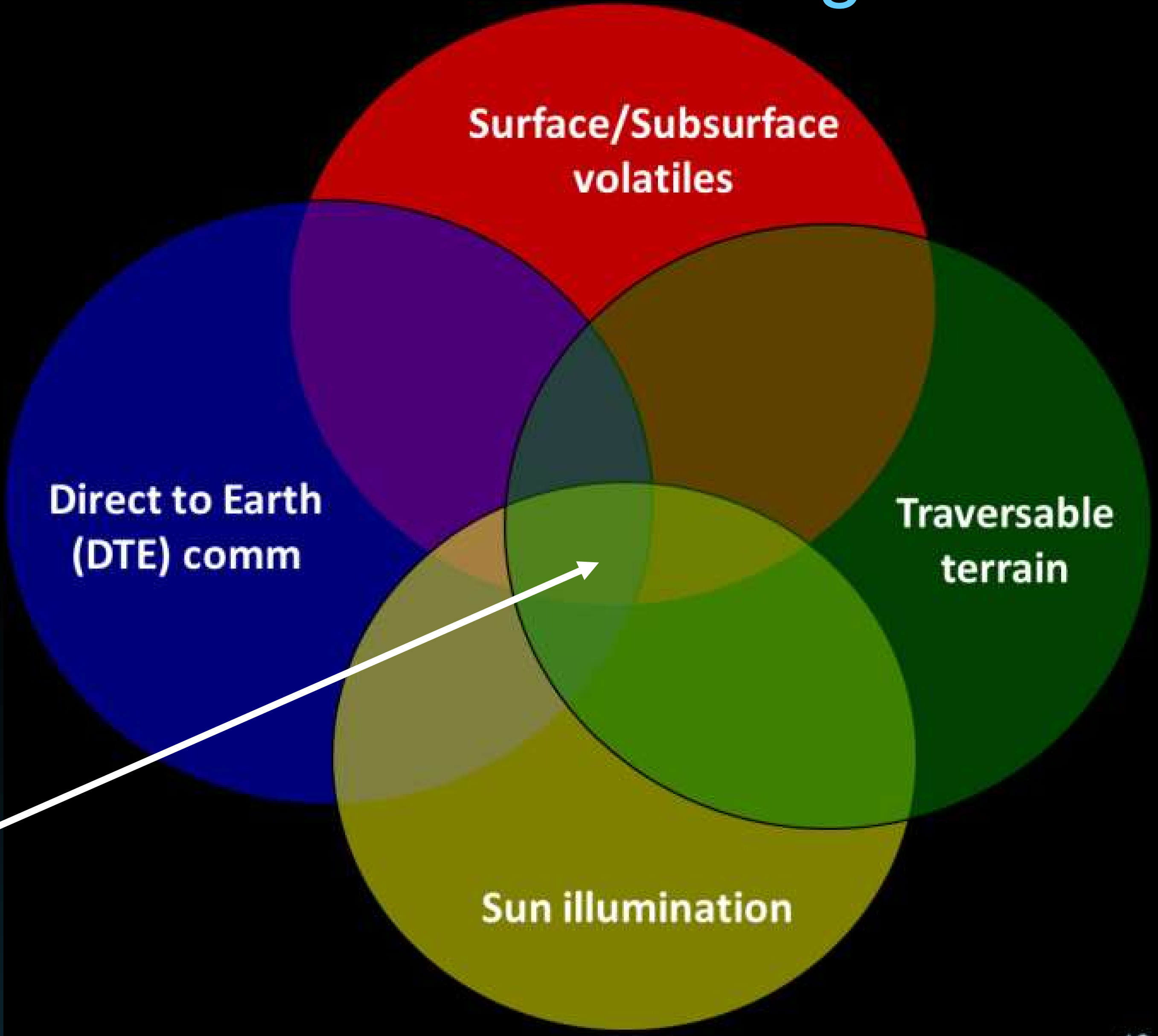
- TRIDENT samples in 10 cm "bites" down to 1 meter, using a simple auger bit
- Each 10cm sample can be brushed to the surface for inspection by NIRVSS and MSolo
- NIRVSS images the cuttings at multiple wavelengths (providing context for NIRVSS and MSolo observations) and measures the scene temperature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

Landing Site Requirements: Where are We Going?

Candidate polar landing sites meet these four criteria:

1. Plausible surface/subsurface volatiles
2. Reasonable terrain for landing and traverse
3. Direct view to Earth for communication
4. Sunlight for power

VIPER needs to find the intersection of these constraints



Three locations for traverse studies

Nobile, Haworth and Shoemaker sites

Safe haven

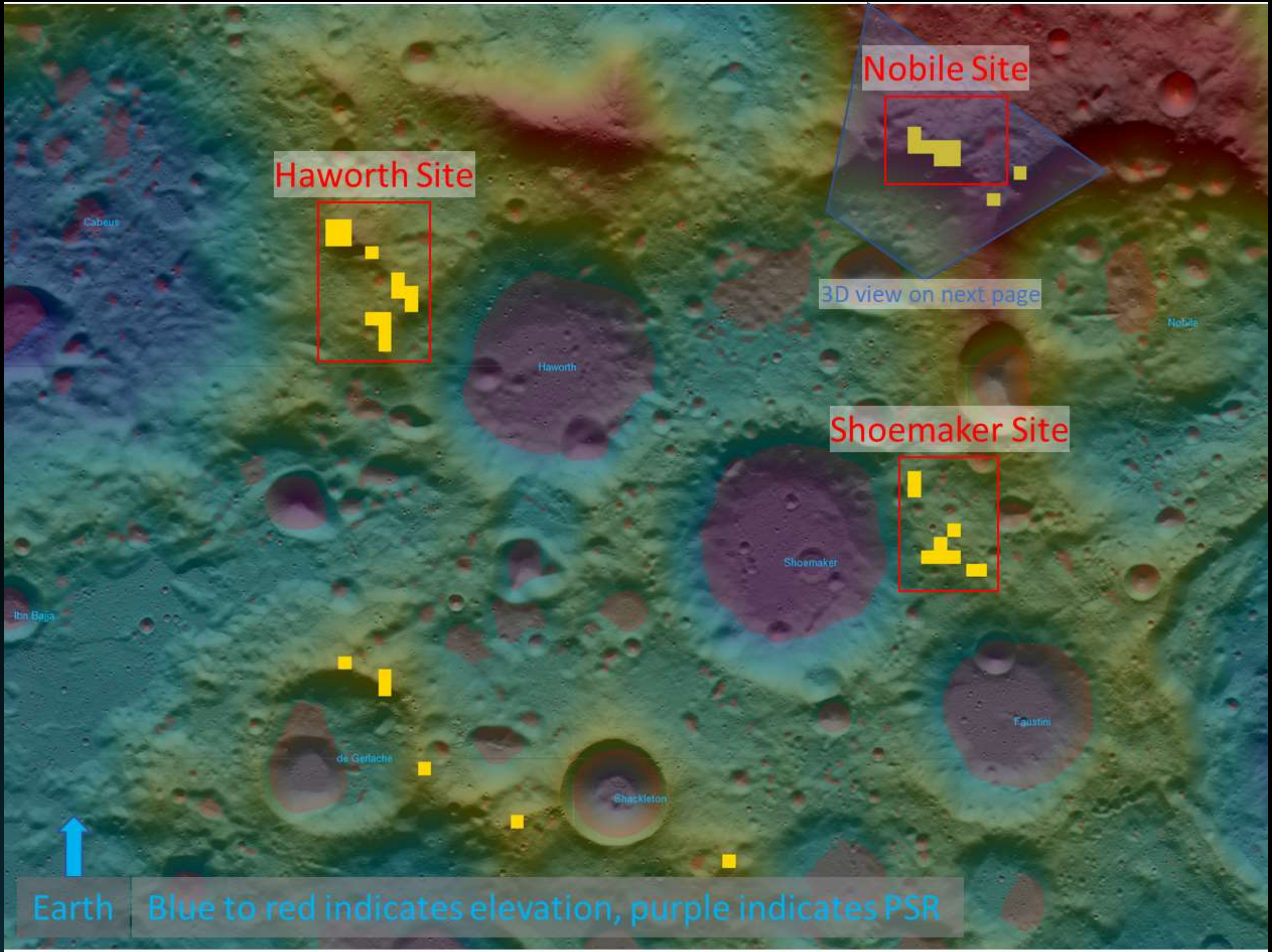
- location to park the rover while the Earth is below the horizon
- With 70 hours or less of continuous darkness

Finding working traverses requires finding safe havens close to permanent shadow

Yellow squares contain safe havens for late ‘23 and early ‘24

While all of these work for lighting, some won’t support missions due to

- Steep slopes
- Distance to PSRs
- Poor direct-to-earth comms



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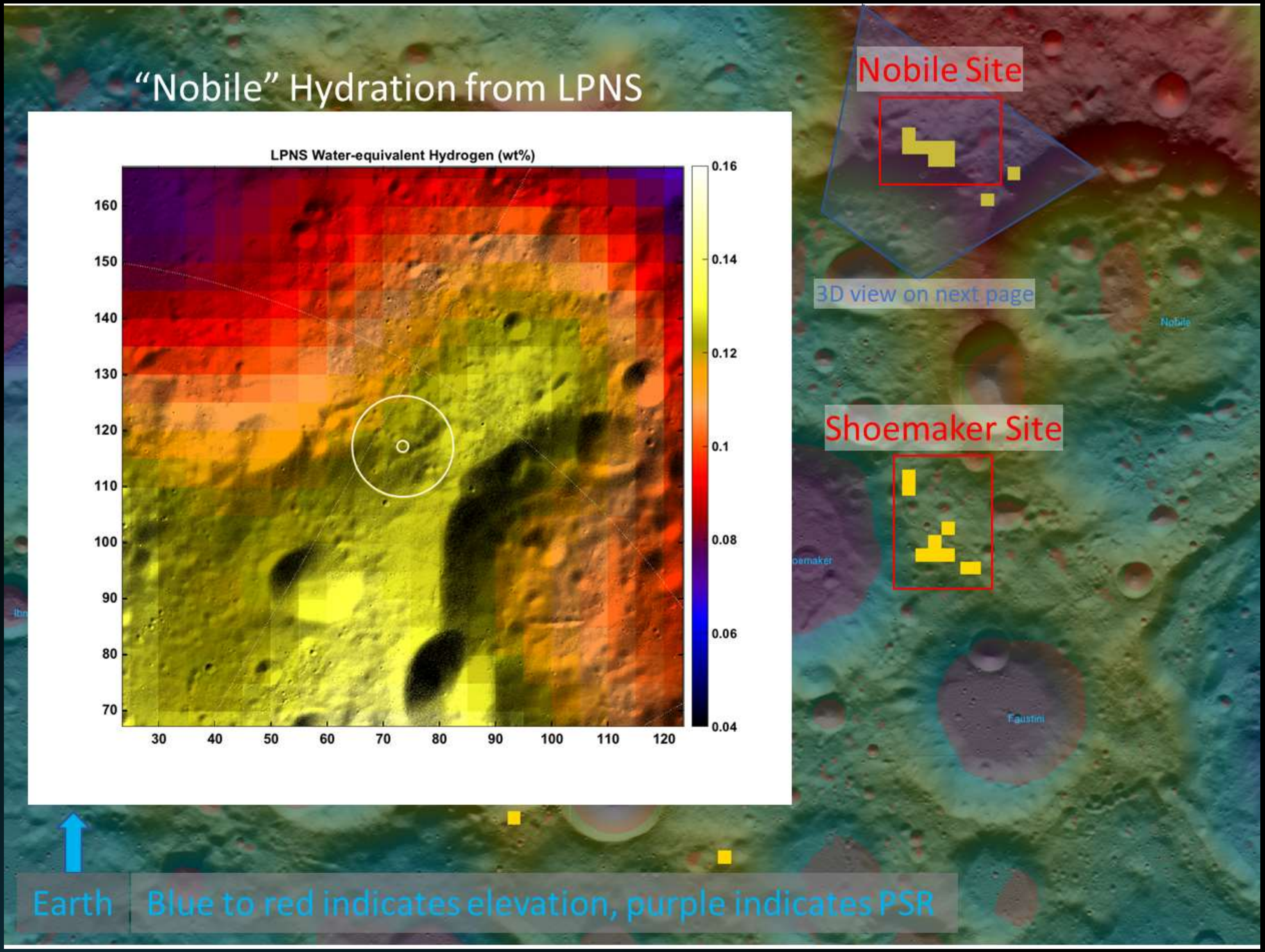
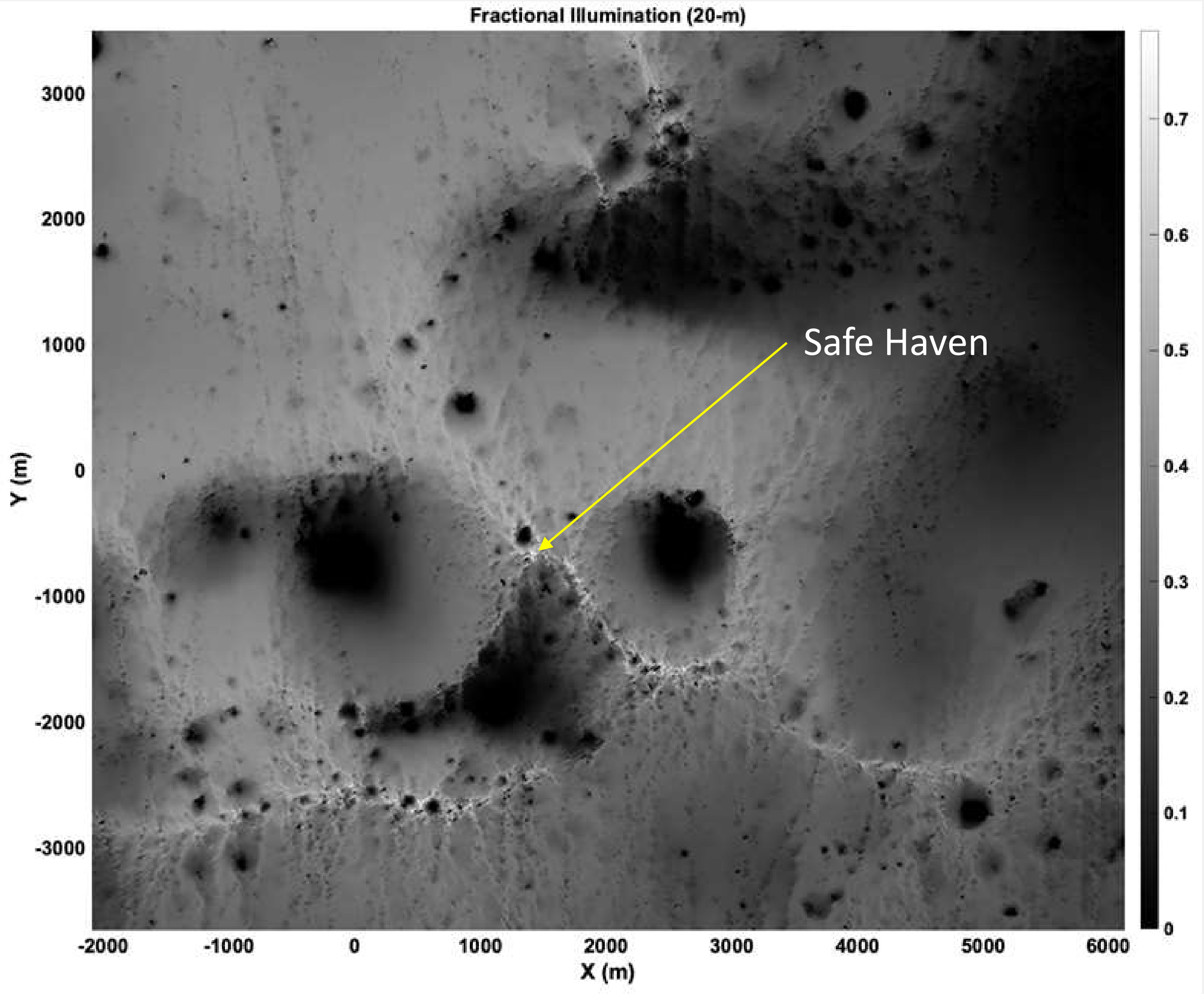


Example of a VIPER Study Traverse

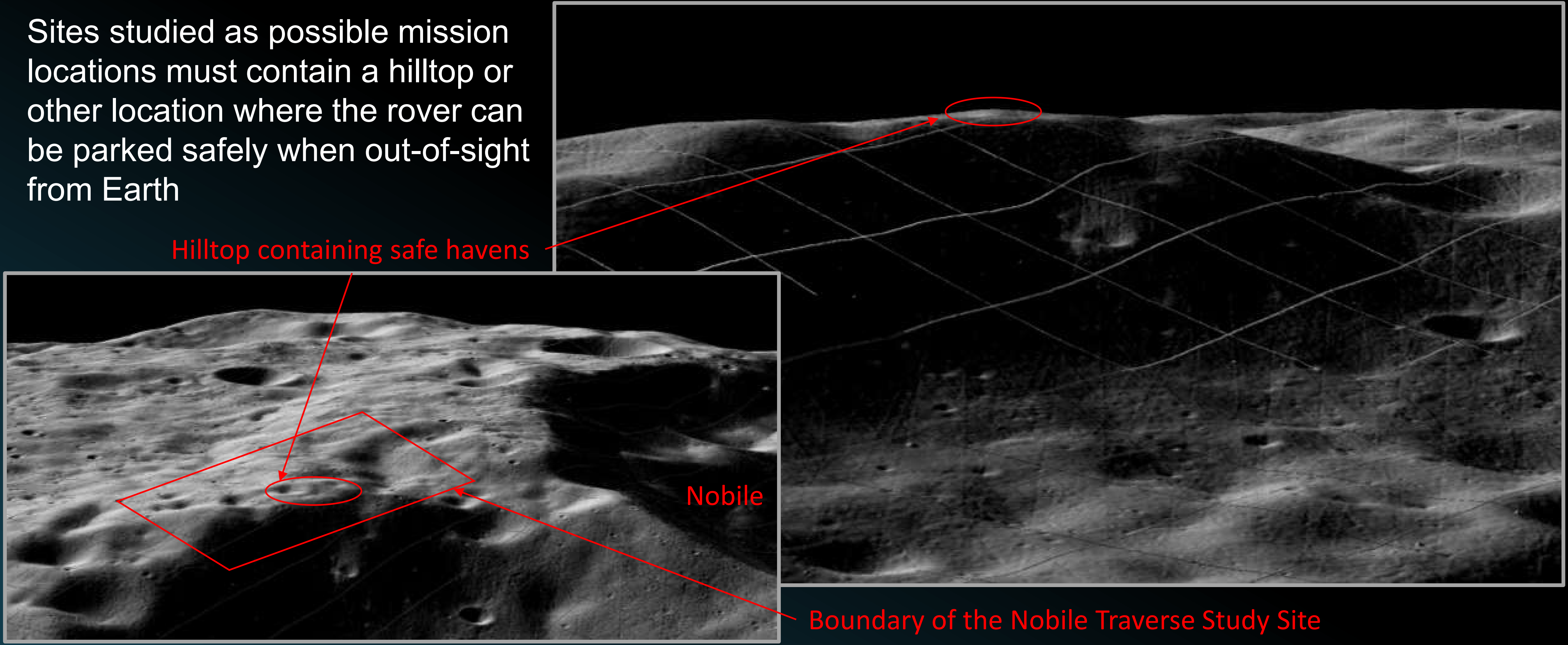
South Pole Site (North of Nobile)

- “Safe Havens” are areas that have shadow durations <96 hours over the course of summer season (about four months)
- VIPER returns to these Safe Havens each lunar day to hibernate while Earth is set (LOS)
- When Earth and Sun return rover resumes traversing
- Typical traverse from Safe Haven to Science Station 1 to 2 km



Overview of the Nobile Site

Sites studied as possible mission locations must contain a hilltop or other location where the rover can be parked safely when out-of-sight from Earth



Nobile Reference Traverse

Duration	91 days
Length	13.25 km
PSRs	2 (4 entries)
Shallow	6
Deep	3
Dry	2

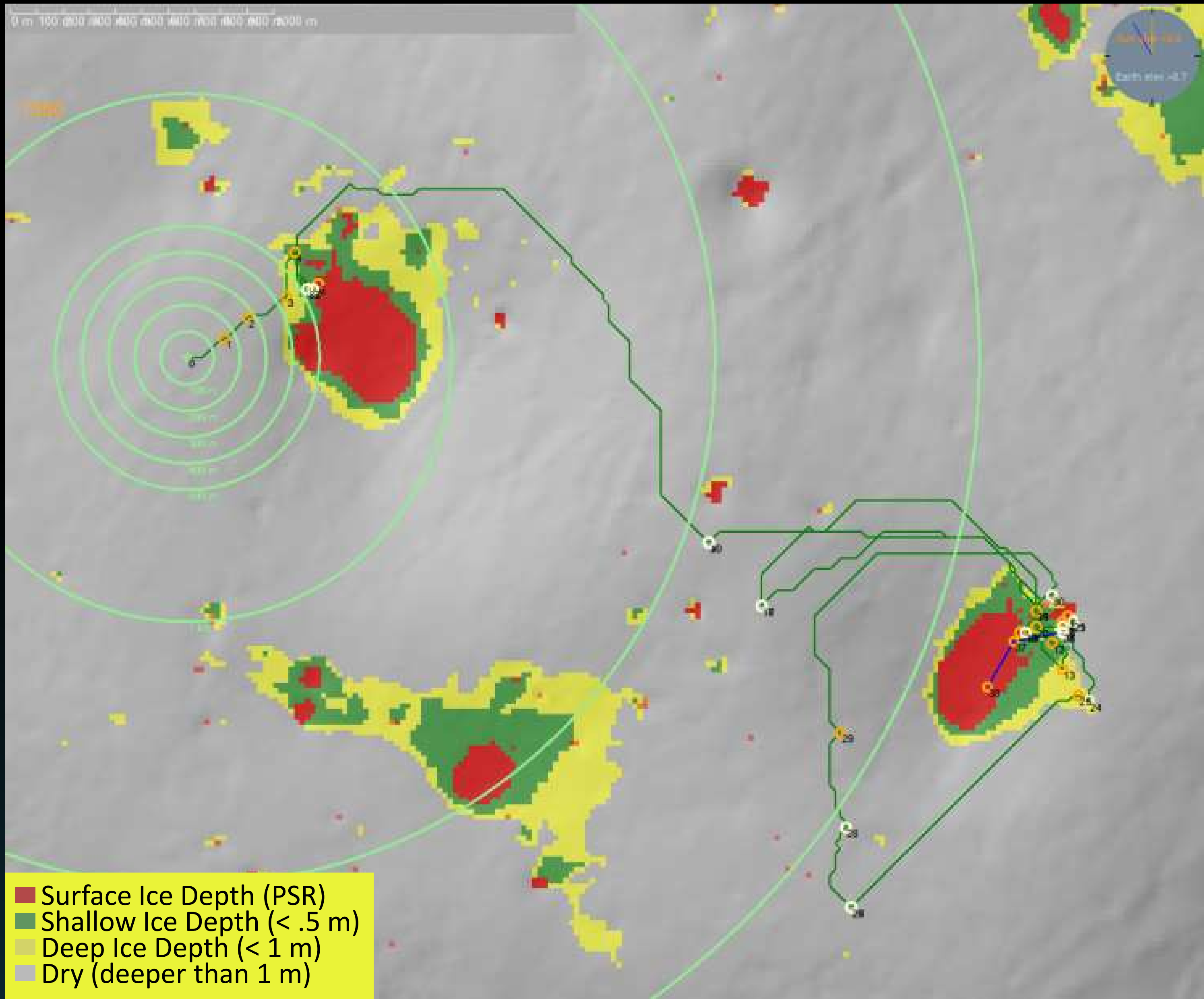
1st lunar day: 1 dry, 1 deep, 1 shallow, 1 PSR

Full mission success on mission day 36, day 7 of second lunar day

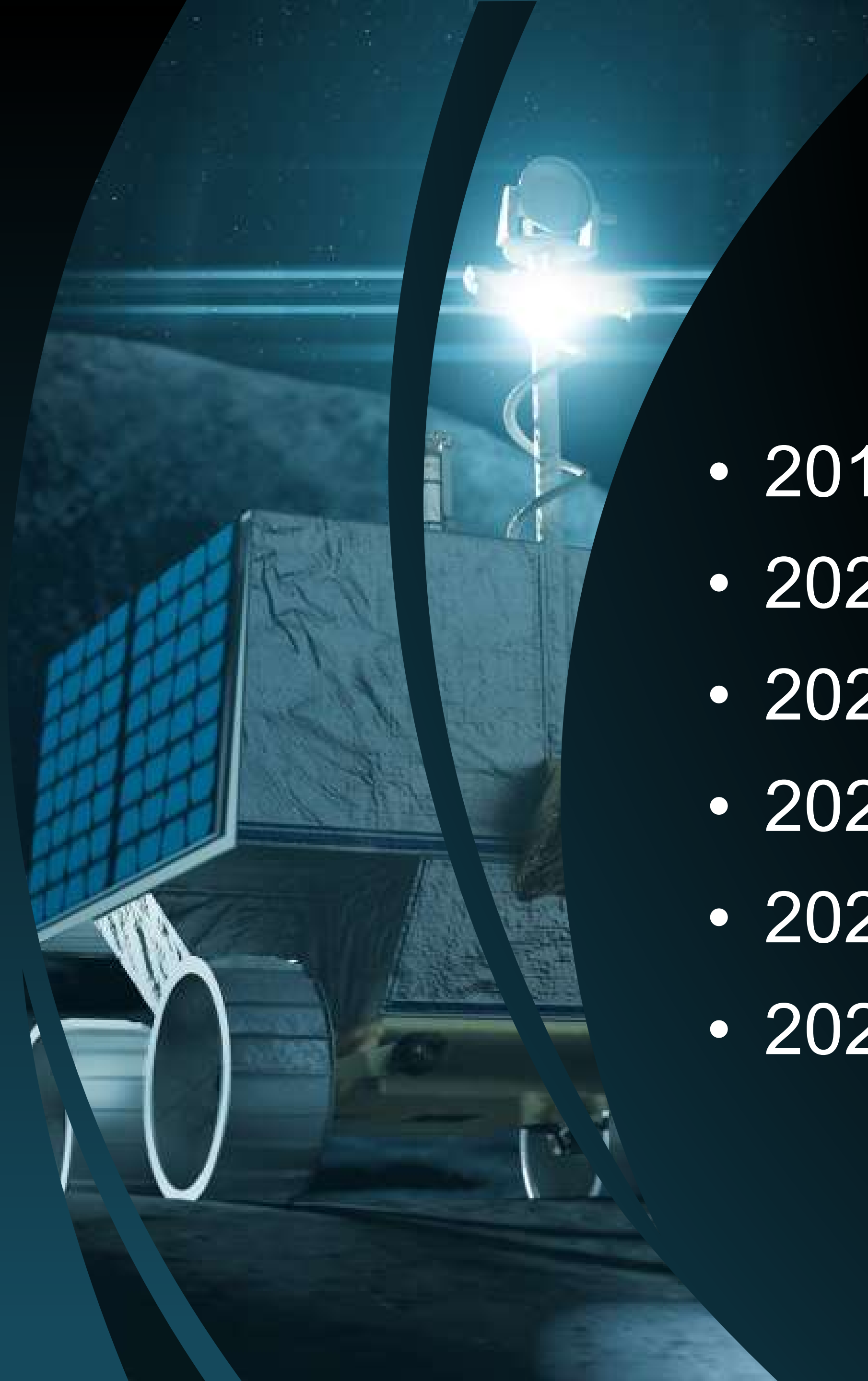
Total number of drill sites = 35

Total mapped ISR area (m^2):

- PSR = 765
- Shallow = 2295
- Deep = 1241
- Dray = 765



VIPER Timeline



- 2019: Formulation through Reqs Lockdown
- 2020: Preliminary Design ← We are here!
- 2021: Critical Design
- 2022: System Integration & Test
- 2023: Launch *(Nov 2023)*
- 2024: Mission concludes (Mar 2024)

Thank you!