National Aeronautics and
Space Administration

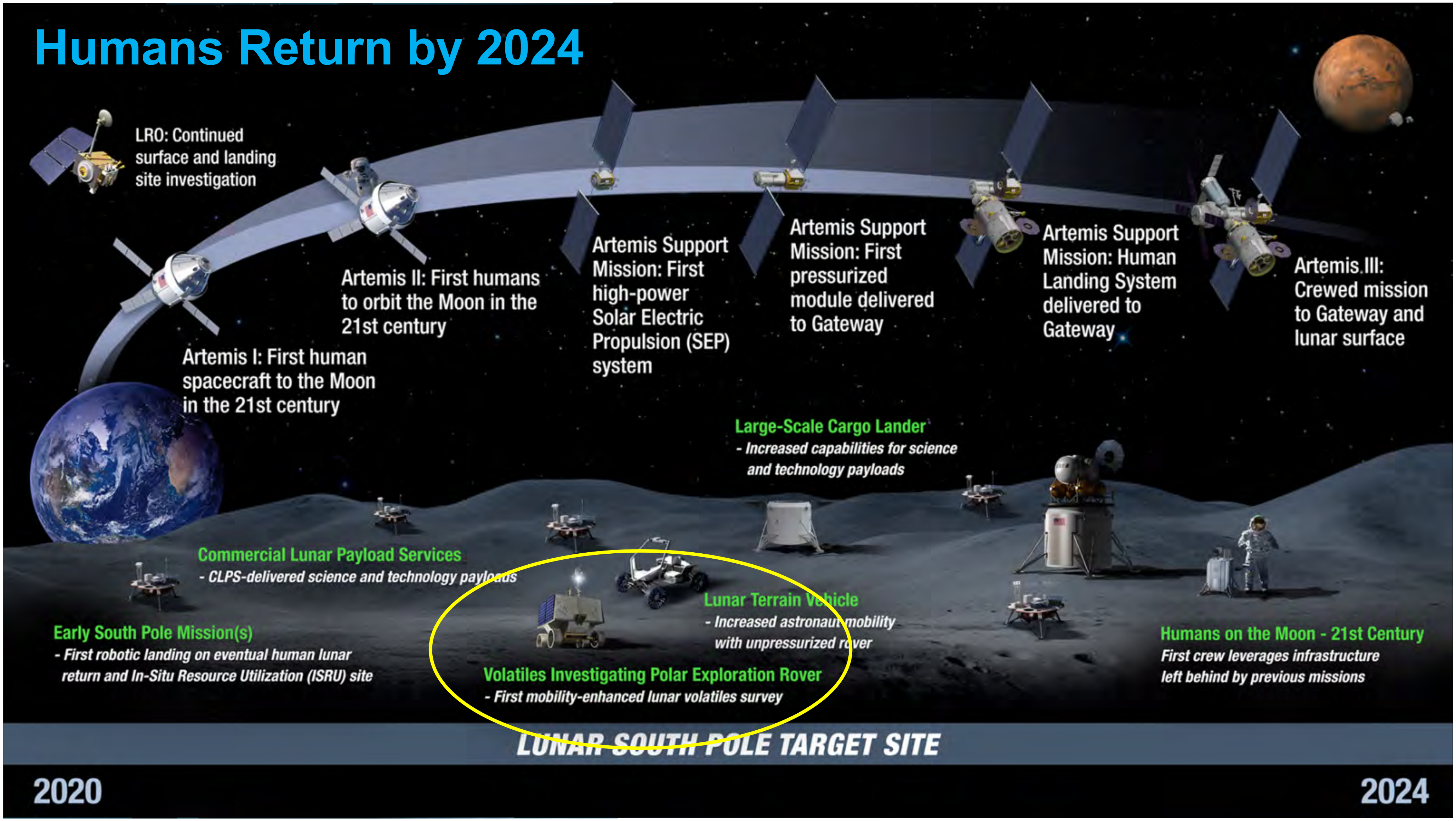
VIPER

Mission Overview

Interplanetary Small Satellite Conference

Ryan Vaughan, VIPER Mission Systems Engineer

May 11, 2020



Humans Return by 2024
LRO: Continued surface and landing site investigation
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon in the 21st century
Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system
Artemis Support Mission: First pressurized module delivered to Gateway
Artemis Support Mission: Human Landing System delivered to Gateway
Artemis III: Crewed mission to Gateway and lunar surface
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Commercial Lunar Payload Services
- CLPS-delivered science and technology payloads
Lunar Terrain Vehicle
- Increased astronaut mobility with unpressurized rover
Early South Pole Mission(s)
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
Volatiles Investigating Polar Exploration Rover
- First mobility-enhanced lunar volatiles survey
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2020
2024

NASA-ARC Low-cost Lunar Missions Portfolio

Lunar Prospector (Launched 1998, $63M*)

- First global surface composition
- Polar volatiles & global magnetic maps

LCROSS (Launched 2009, $79M*)

- Impacted lunar south pole
- Evidence for water ice in cold, shadowed regions

LADEE (Launched 2013, $250M*)

- Lunar atmosphere and dust
- First deep space laser communication

VIPER[1] (Launching FY23, ~$TBDM*)

- Robotic rover at lunar pole
- Resource mapping mission
- Commercial Lunar Payload Services

* Not including launch or lander

[1] Volatiles Investigating Polar Exploration Rover

VIPER Science Objectives

The science objectives of the VIPER mission are to:

- Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith to understand their origin

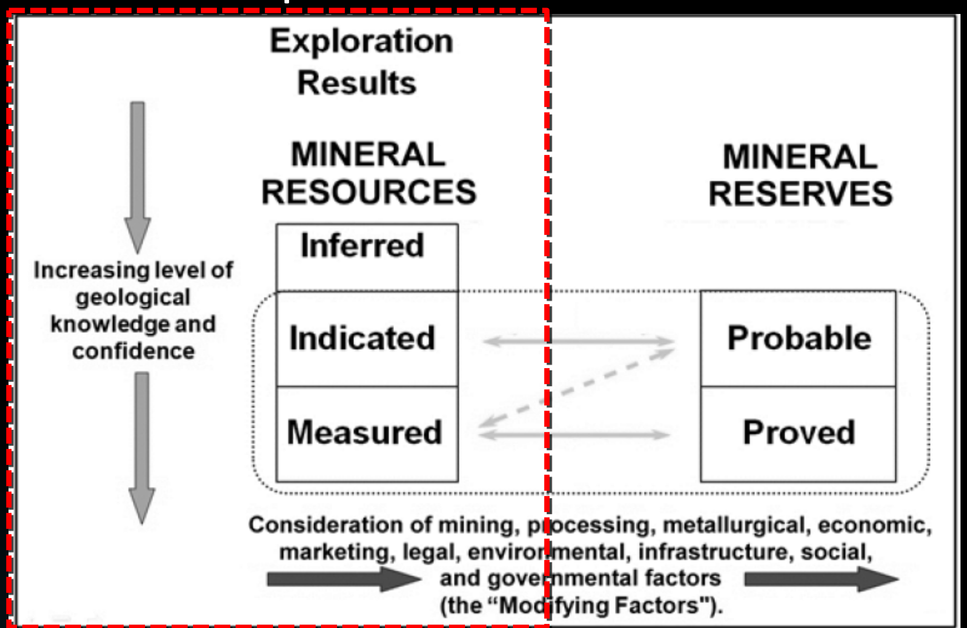
- Provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions

Lunar Polar Volatile Exploration: Science and Exploration

Critical Observations Needed

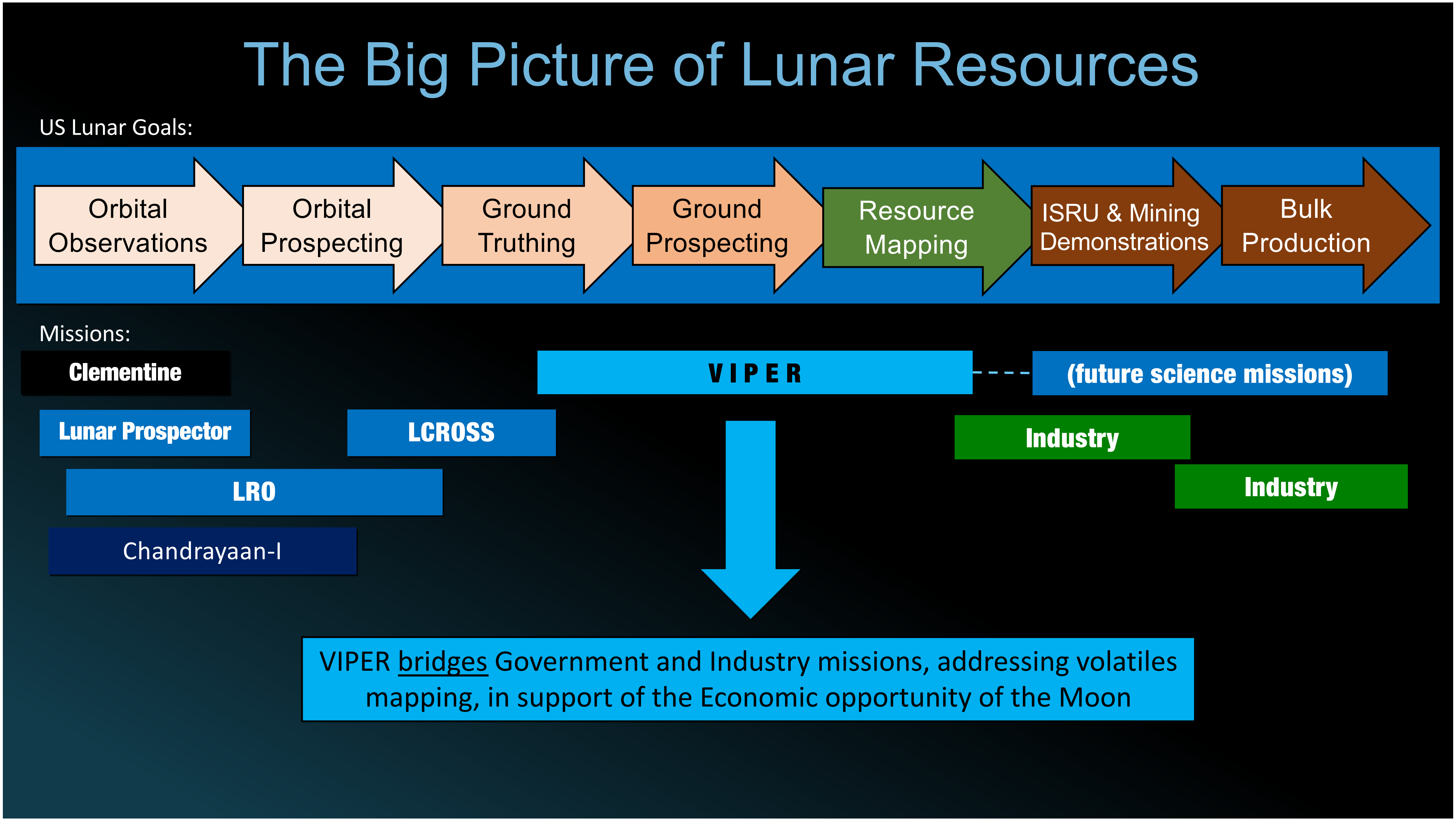
- Volatile Distribution (concentration, including lateral and vertical extent and variability)
- Volatile Physical State (H_2, OH, H_2O, CO_2, Ice vs bound, etc).
- The Context and Correlation, including:
  - Accessibility/Overburden: How much and type of material needing to be removed to get to ore?
  - 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

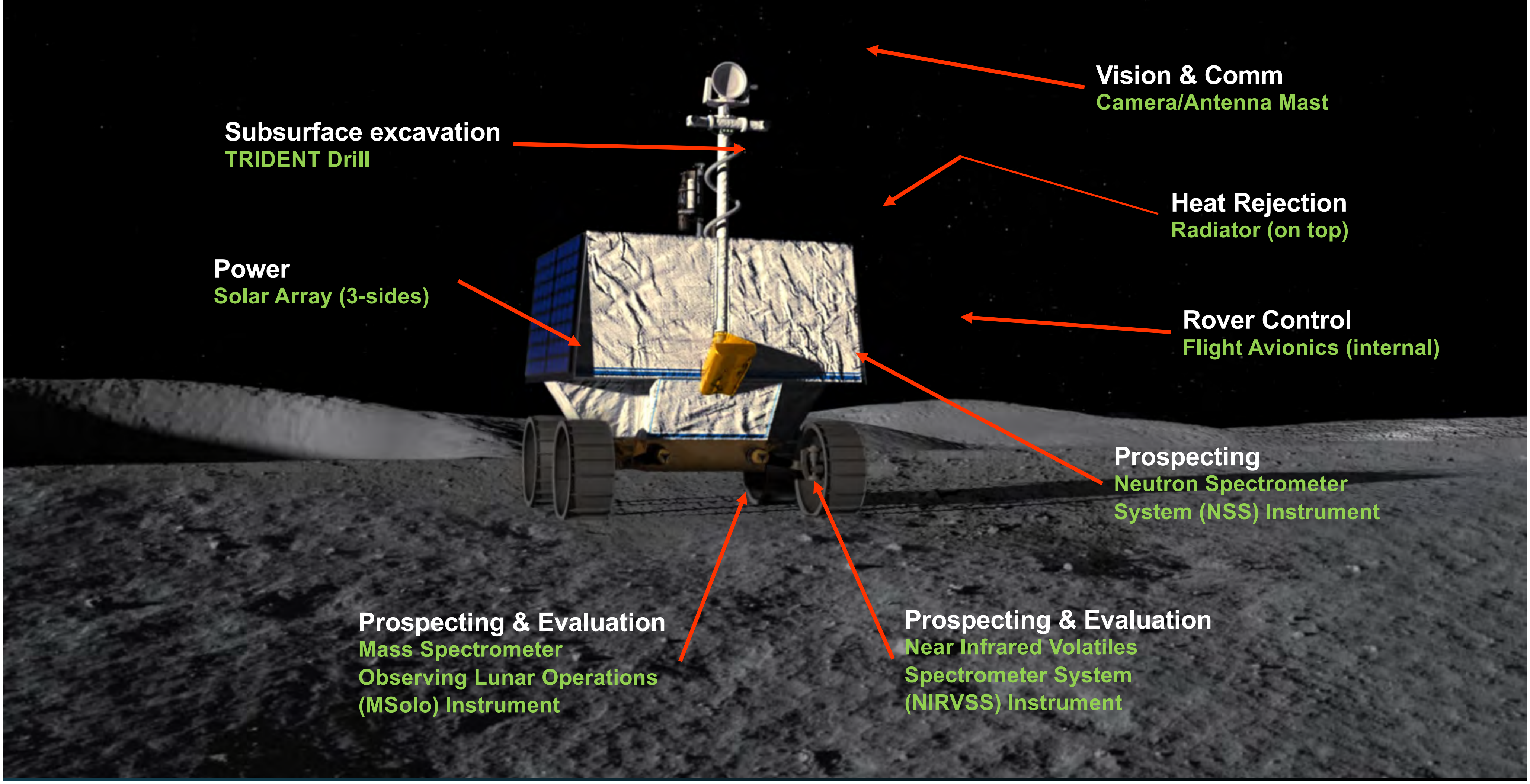


From “Committee for Mineral Reserves and International Reporting Standards, 2013

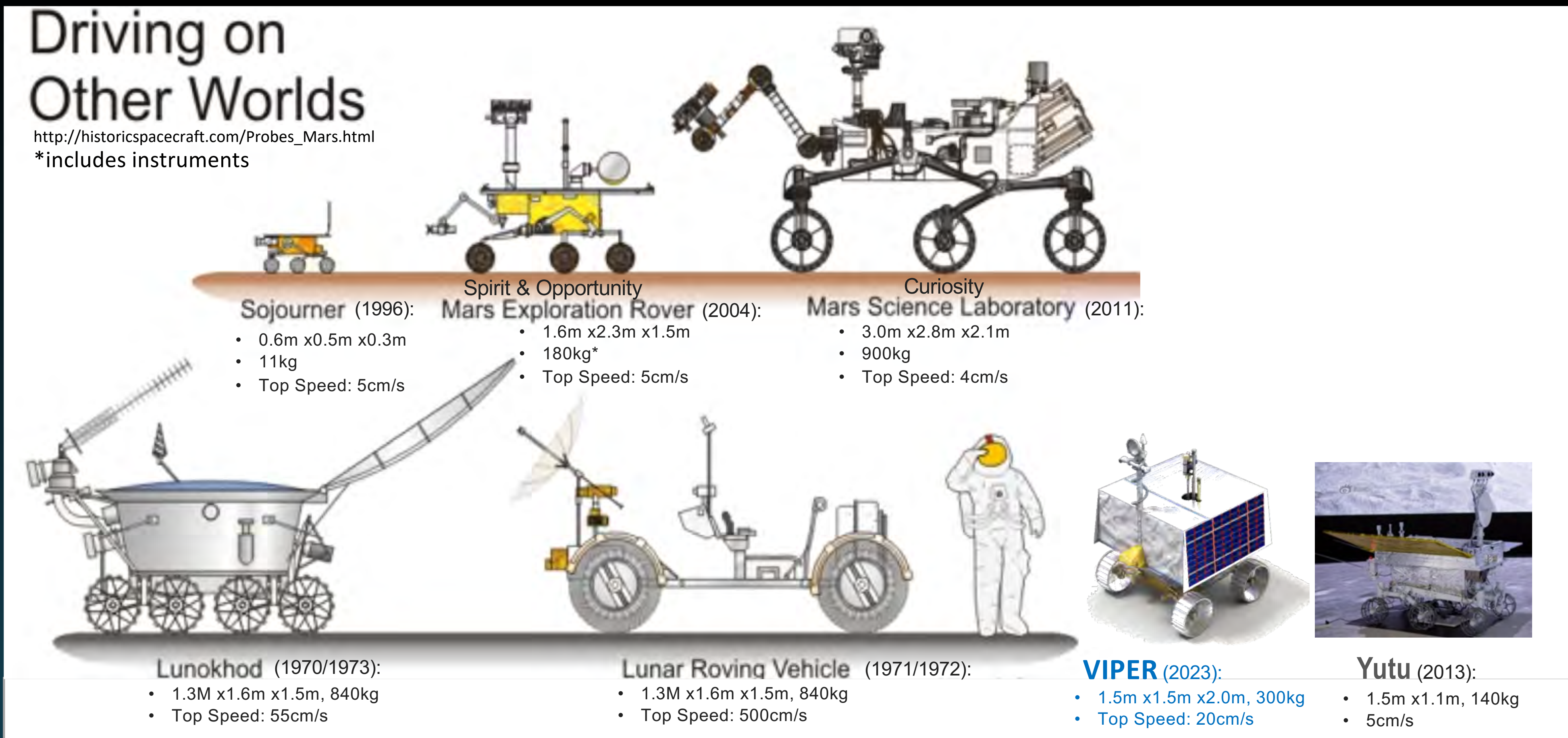
Distribution. Physical State. Context. Correlation.


The Big Picture of Lunar Resources
US Lunar Goals:
Orbital Observations
Orbital Prospecting
Ground Truthing
Ground Prospecting
Resource Mapping
ISRU & Mining Demonstrations
Bulk Production
Missions:
Clementine
Lunar Prospector
LCROSS
LRO
Chandrayaan-I
VIPER
(future science missions)
Industry
Industry
VIPER bridges Government and Industry missions, addressing volatiles mapping, in support of the Economic opportunity of the Moon

VIPER Surface Segment (Rover + Instruments)



Historical Planetary Rovers & VIPER



VIPER Instruments

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)

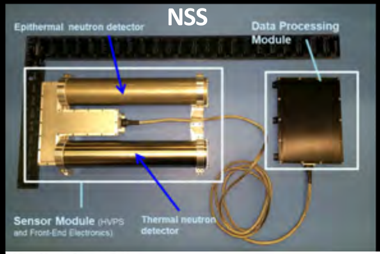
- **Instrument Type:** NIR Spectrometer, 4Mpxl Imager with 7 banks of color LEDs, four channel thermal radiometer
- **Key Measurements**: Volatiles including H_2O, OH, and CO_2 and, minerology, surface morphology and temperatures

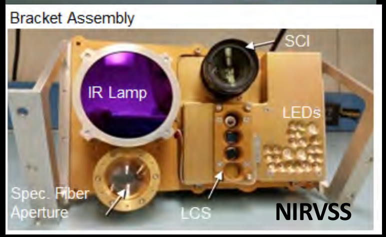
MSolo (KSC, INFICON, NSF– SHREC Space Processor, & Blue Sun – Virtual Machine Language)
PI: Janine Captain (NASA KSC)

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

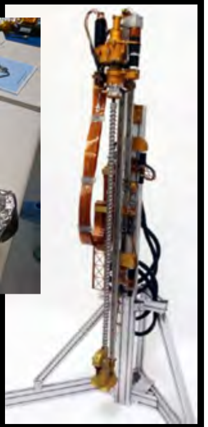
TRIDENT (Honeybee Robotics)
PI: Kris Zacny (Honeybee Robotics)

- **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)



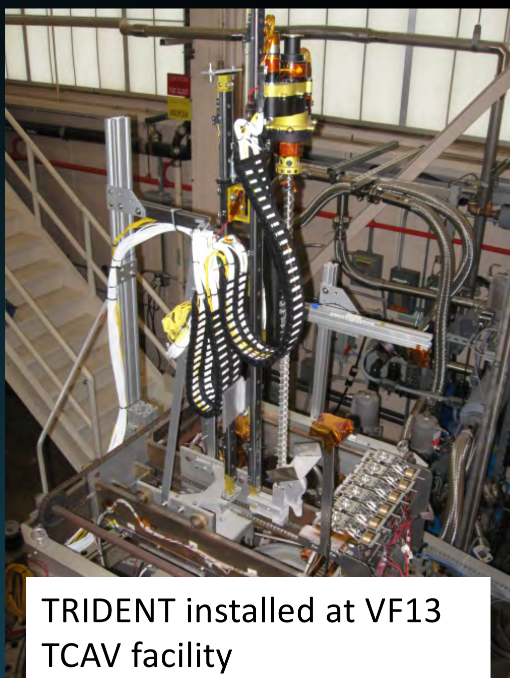


TRIDENT

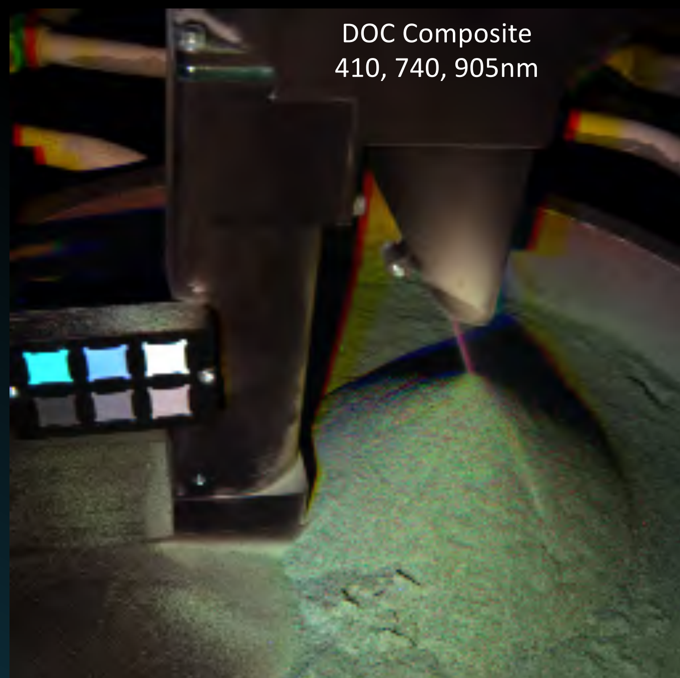


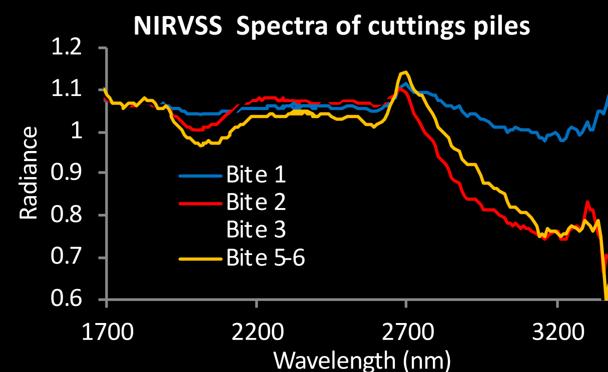
Sampling: Demonstration

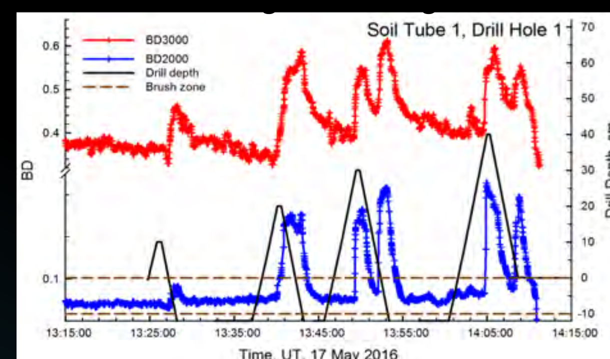
Multiple tests at GRC demonstrated the TRIDENT, MSolo and NIRVSS systems ability to capture samples at depth and identify water (at concentrations <0.25%) in real-time



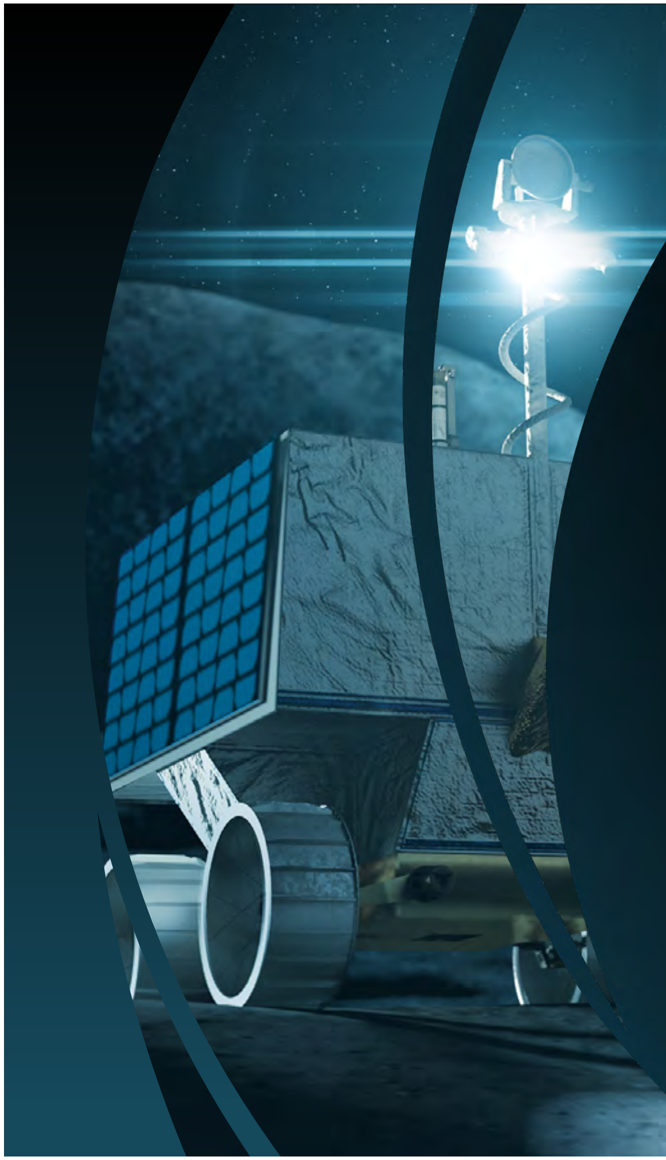
TRIDENT installed at VF13 TCAV facility





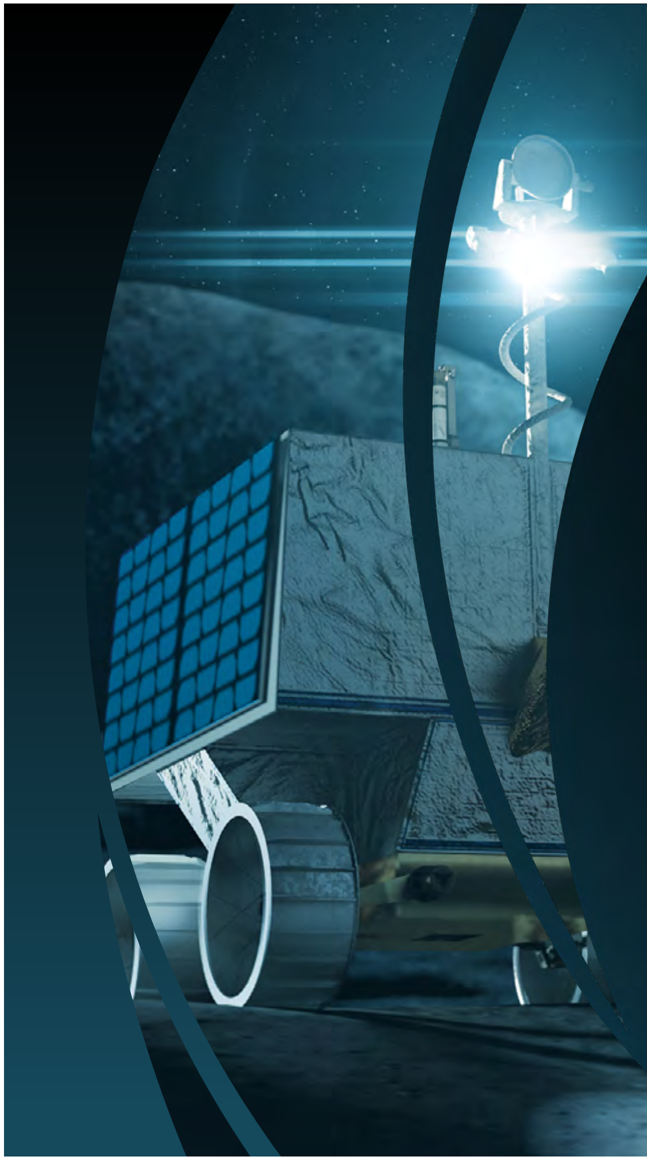


VIPER Performance Specs



- **Mass:** ~430kg (950lbs) **Power (peak):** ~450W
- **Comms (DTE[1]):** X-band (230kbps hi-gain / 2kbps omni)
- **Comms network:** DSN 34m dishes
  Canberra, Goldstone, Madrid
- **Dimensions:** 1.5m x 1.5m x 2.5m (5ft x 5ft x 8ft)
- **Top Speed:** 20cm/s (0.5 MPH)
- **Prospecting Speed:** 10cm/s (4in/s)
- **Distance Travelled (goal):** 20km (~12mi)
- **Lunar delivery:** CLPS[2] commercial contract

[1] DTE = Direct-To-Earth
[2] CLPS = Commercial Lunar Payload Services



VIPER Science Specs

- **Mission Duration:** 100+ earth days
- **Instruments:** Neutron, Near-IR, and Mass Specs; 1m Drill
- **Detectable H2O Concentration:** 0.5% (by weight)
- **Drill Depth:** 1m (~3ft)
- **# of Surface Assays (drill sites):** 30-40 sites (18 minimum)
- **Dark Survivability:** 96hrs
- **PSR Working Duration:** 6hrs
- **Surface Traverse Plan baselined:** @CDR

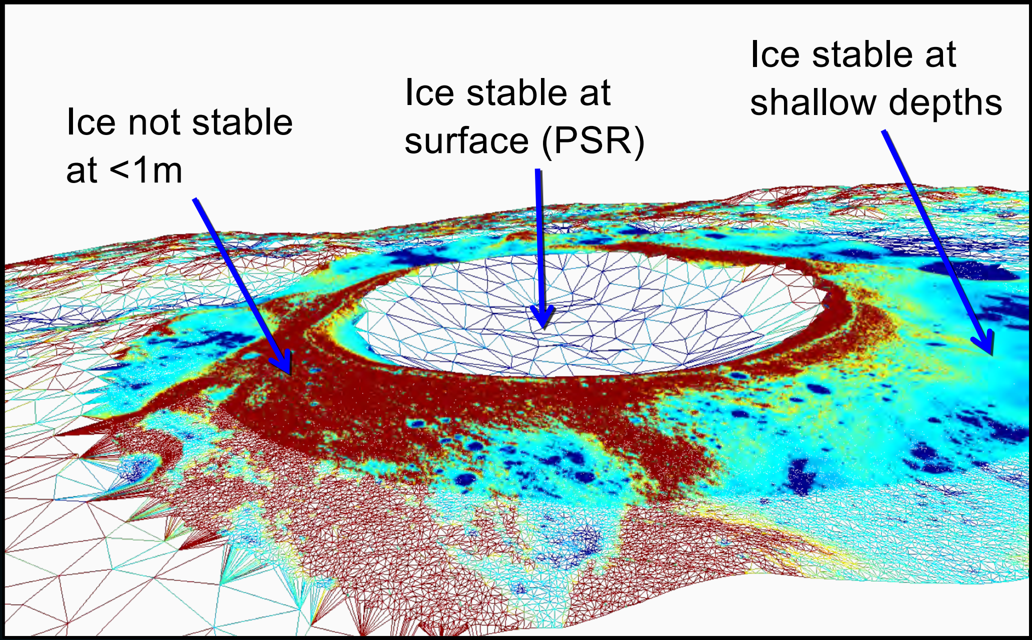
Spatial Proxies for Resource Maps and Models

Primary environmental factor is temperature

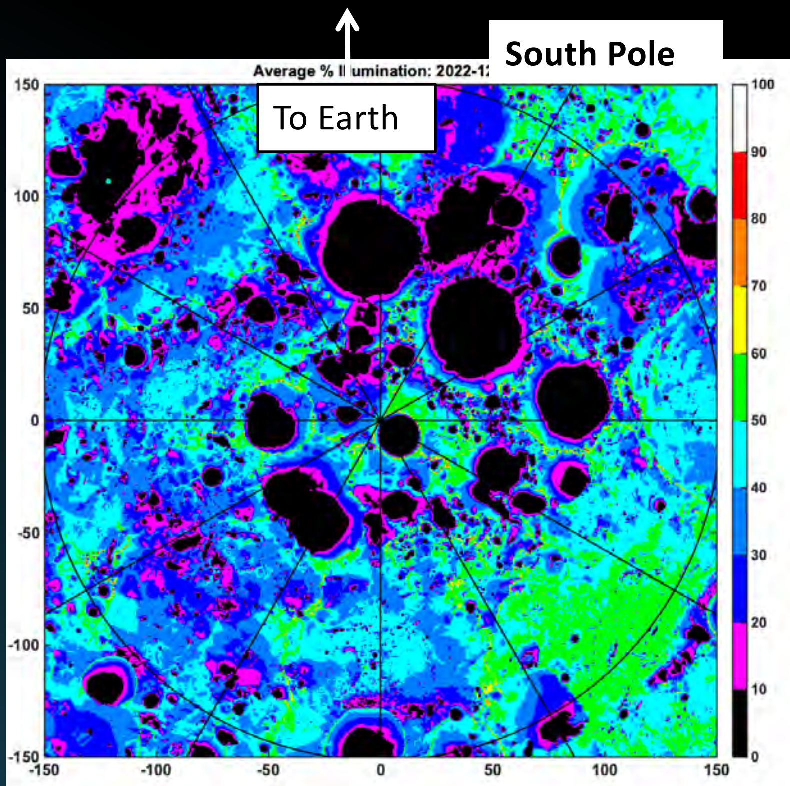
- At a minimum temperatures (surface or subsurface) must be low enough to retain water ice
- Secondary environmental factors may include geophysical properties (e.g., association with craters of a certain size and age)
- Also secondary is the ore extent, given regional data sets only extend to ~1 meter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

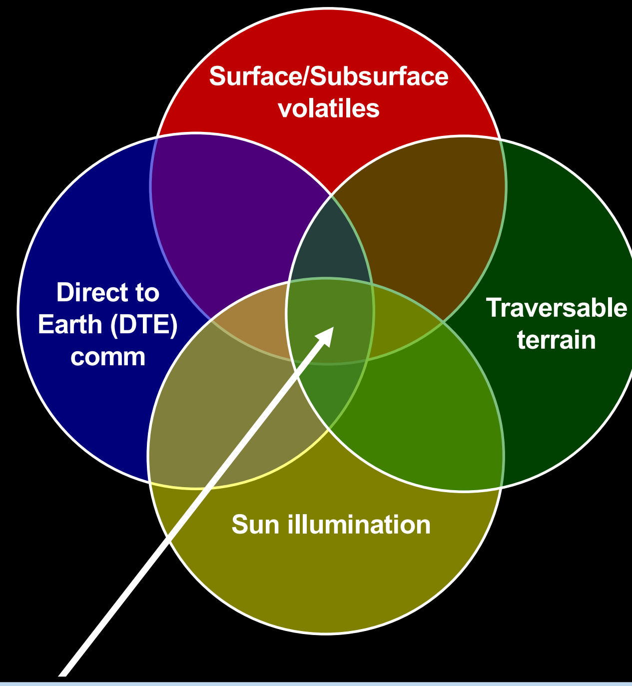
Using temperatures from the surface to 1 meter deep as primary surface proxy

- 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)



Where to Land?





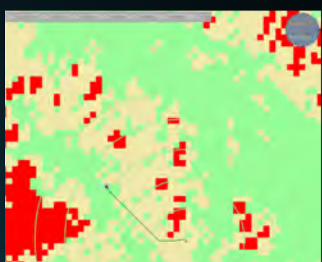
Candidate polar landing sites meet these four criteria:

1. Plausible surface/subsurface volatiles
2. Reasonable terrain for landing and traverse
3. Direct view to Earth for communication
4. Maximize sunlight for power *(including safe havens)*

Merging maps and operational constraints

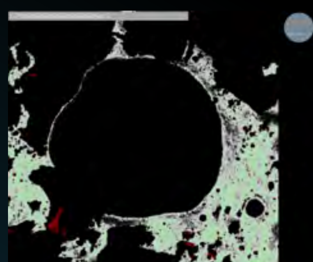
Traverse planning efficiency is enabled by generating maps that have operational constraints integrated into them

Some examples



Slope & Navigability (Static)

Color map pixels within the slope limits of the lander (green) and of the rover (green and yellow).
LOLA roughness and Diviner blockiness products are also available



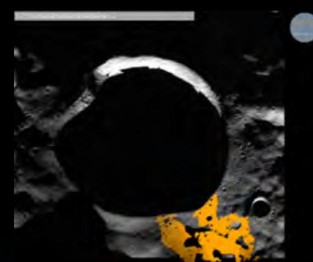
Landing Sites (Time-dependent)

Green pixels lie at center of a 100 x 100 m landing error ellipse completely within slope limits of the lander that have sun and DSN access for at least 48 hours.

Red pixels are in permanent shadow and have DSN station access

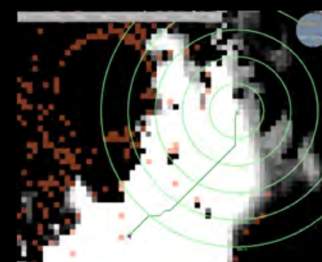
Sun Safety Margin (Time-dependent)

Color pixels that will have less than 80% sun within 48 hours yellow and within 24 hours, red



Lander line-of-site (Varies with lander)

Given a landing site, color map pixels with line-of-site between given lander and rover antenna heights



Earth Comm Blockage (Time-dependent)

Topographic maps generated from orbit have height errors, e.g., LOLA DEMs have a reported error of 1 m 1σ. These errors could result in planning to move the rover to a location where DSN stations are blocked by terrain. This map shows locations where the probability of the 2 deg horizon safety margin being exceeded is above a given risk threshold

ISRU Areas (Static)

Identify 60 x 60 meter areas that are predominantly one thermal environment and < 5 deg slope. Each is large enough to generate 1000 kg of O_2 if 0.5% water and 10% extraction efficiency. These are candidate locations for doing the required measurements

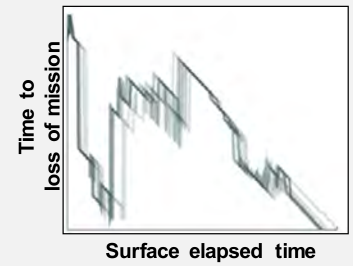
Rover Performance Model

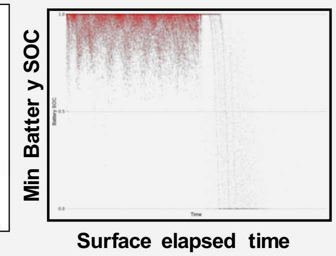
Traverse planning tools contain rover performance models covering alternatives as the rover's design has matured. Factors included are (not all in all models):

- Model inputs
  Solar cell efficiency | battery charge/discharge curve | component and heater loads
  potential energy | wheel slip | driver decision delays
  orientation policy | camera sun keepout zones | rover pose on slope

- **Activity Dictionary**
  Major modes the rover and payload can be in; each typically lasting 5-120 minutes
  Gives power used and data generated
  Determines the traverse planning level-of-detail

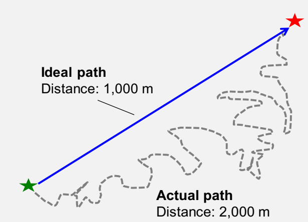
- Model outputs
  (typical) battery state-of-charge, time-to-shadow, slope, sun-fraction, surface temperature





Activity	Duration (min)	Power (Watts)
Idle (Safe Mode)		233
Idle (Stationary Mode)	N/A	242
Recharge	N/A	242
Initial Checkout		494
NSS Calibration		242
NIRVSS Calibration		272
LAVA Calibration		239
OVEN Calibration		239
Roving / Direct Drive	N/A	397
Prospecting	N/A	433
Prospecting - DOC Image at Waypoint		336
AIM - 4x8m	40	433
AIM Prospecting		433
AIM Prospecting - DOC Image at Waypoint		336
AIM Prospecting - DOC Priority Image at Waypoint		336
Panorama	4.3	424
Drill Location Targeting	38	433
Drilling Preparation	20.5	416
Subsurface Assay per 10 cm Bite	13	416
Quick Subsurface Assay (50 cm)	65	416
Deep Subsurface Assay (90 cm)	117	416
Deep Subsurface Assay (100 cm)	130	416
Stow Drill	10	416
Preheat LAVA	60	575
Deep Subsurface Assay (90 cm)/Preheat LAVA	117	511
Sample Collection and Transfer	20	535
Volatile Analysis - Sample Heat Up (Ambient to 150C)	60	670
Volatile Analysis - Sample Heat Up (150C to 350C)	30	670
Volatile Analysis - Sample Heat Up (350C to 450C)	30	670
Volatile Analysis - GC Analysis	20	442
Water Droplet Demo	40	570
Sample Dump	5	333

Activity Dictionary



Early human-in-loop sims point toward 40-50% obstacle avoidance overhead

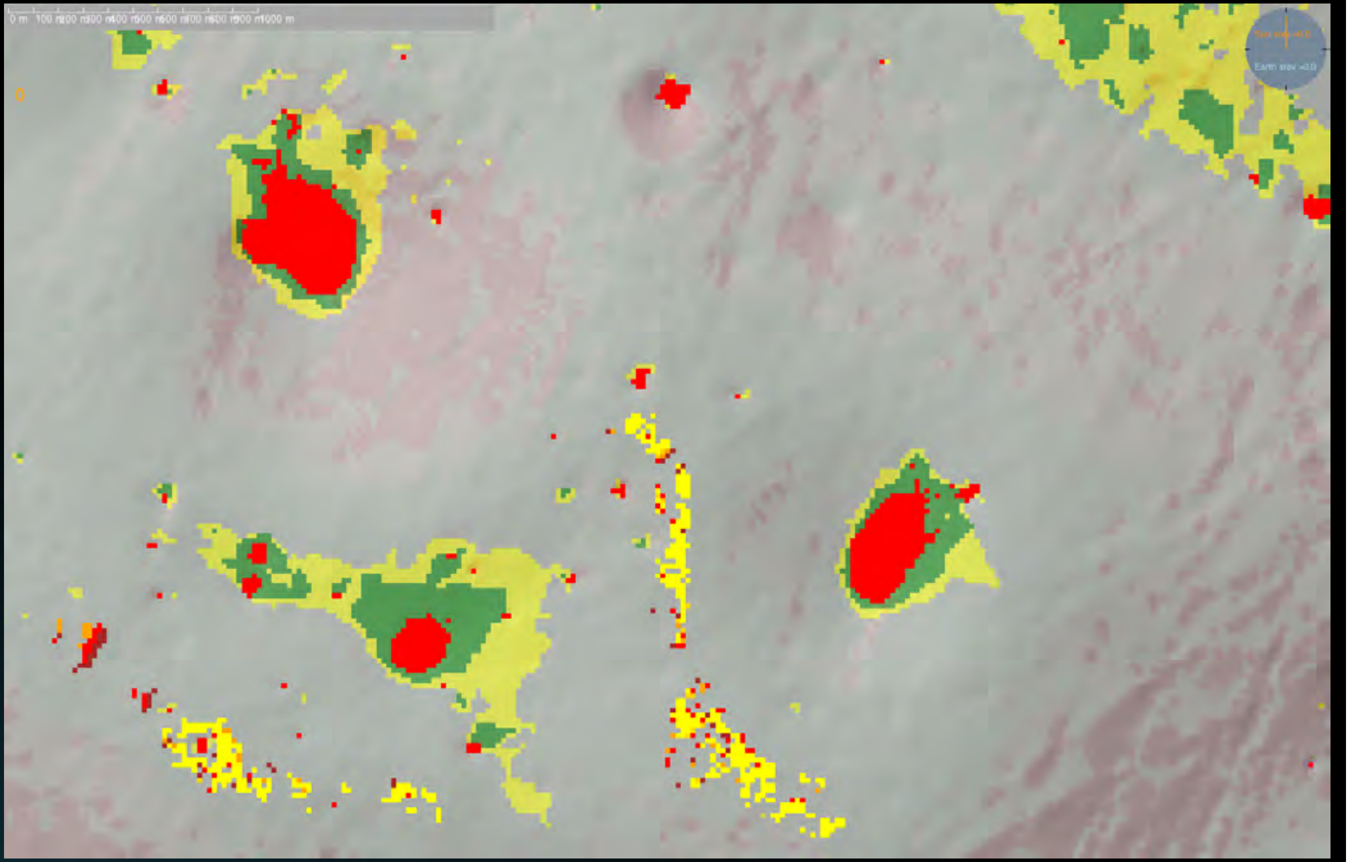
Planning Traverses

Thermal Environments

Type	Color
PSR, ice depth = 0	red
Shallow, ice depth (0, 0.5] m	green
Deep, ice depth (0.5, 1] m	yellow
Dry, ice depth (1, ∞] m, drivable	grey
Dry, ice depth (1, ∞] m, too steep	pinkish grey

Lighting Environments

Type	Color
[0, 24] hours of shadow	yellow
(24, 96] hours of shadow	orange, red, dark red



Dynamic Planning

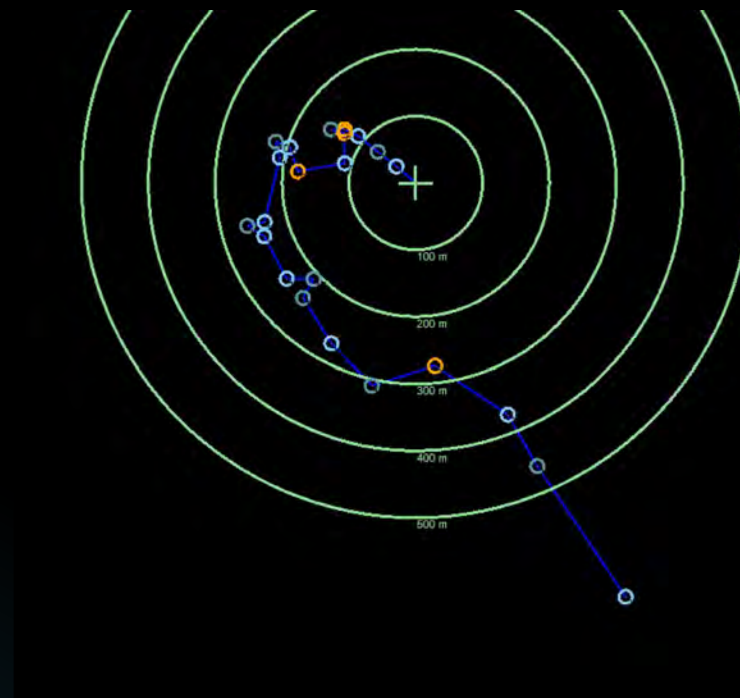
Near the pole, sun against topography casts long shadows

Similar radio shadows are cast when using a line-of-site radio link to ground stations

Sun and radio shadows move on a timescale similar to the time needed to take the required measurements

- Shadows cast by a peak 3.9 km away move at 1 cm/s

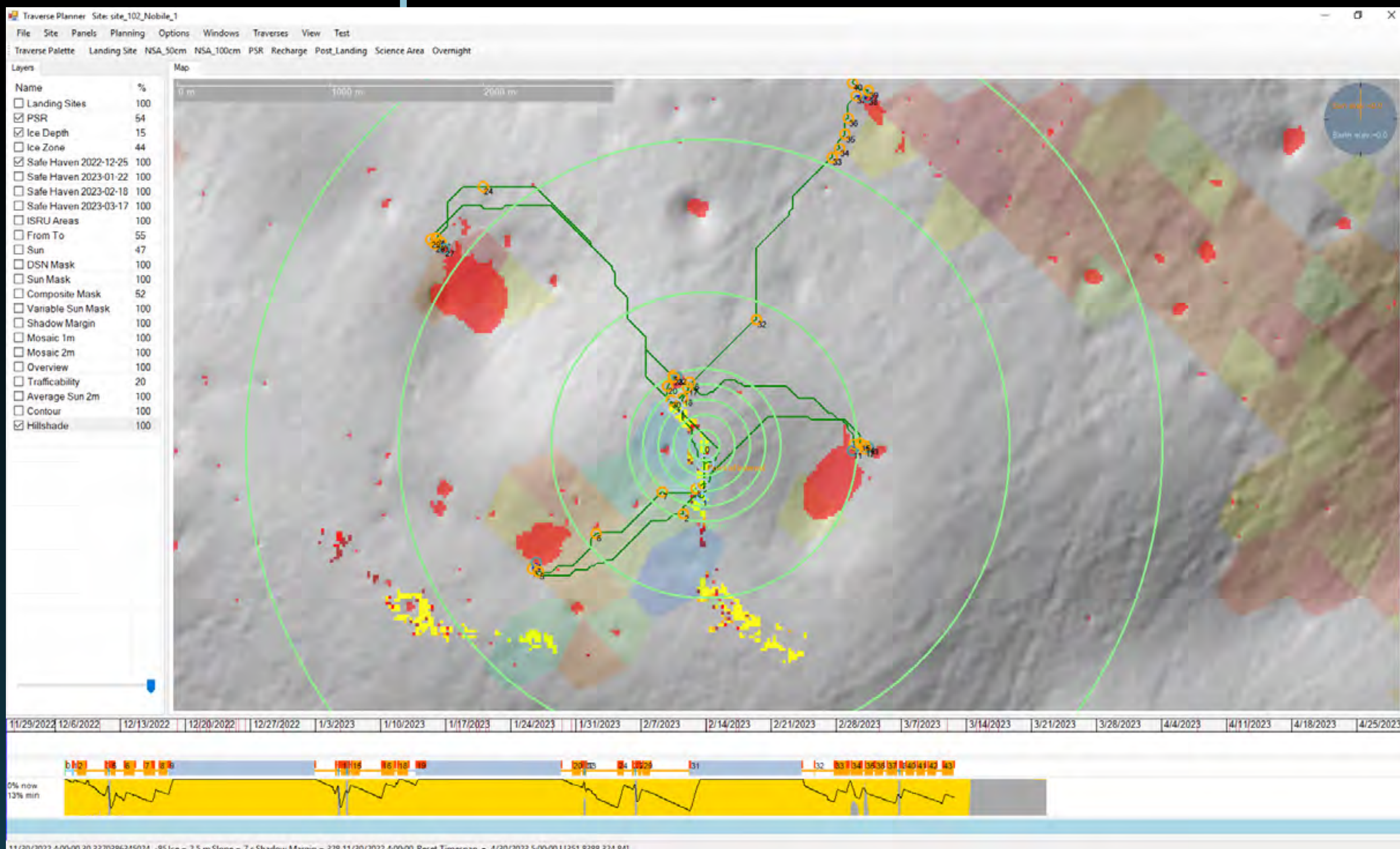
Traverse plans must plan to avoid moving shadows

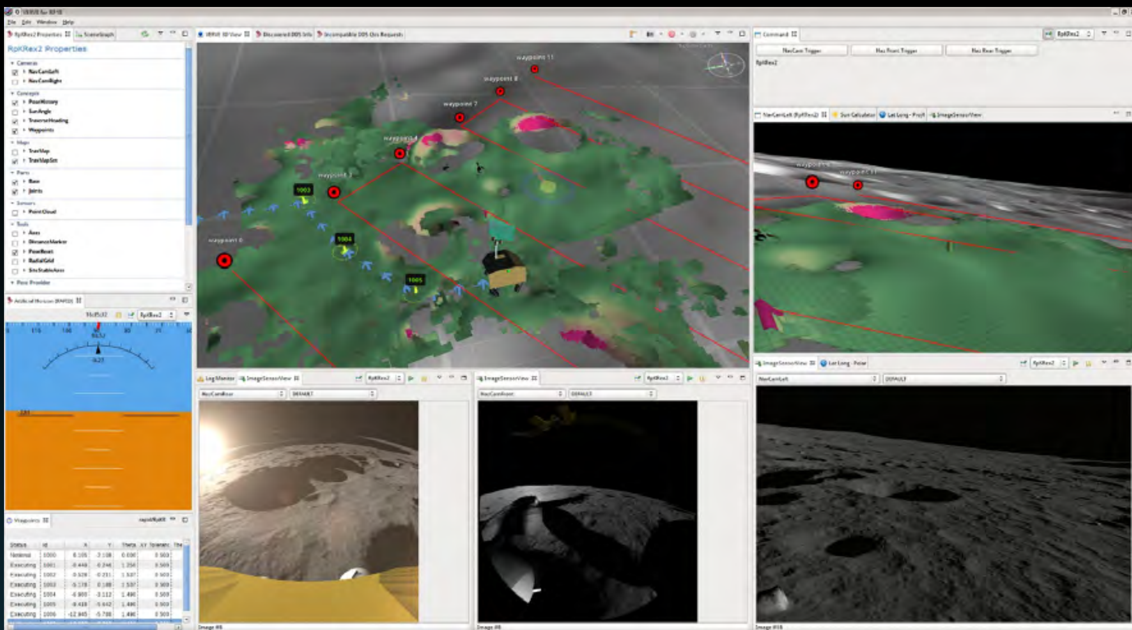


The movie shows a red square representing the rover moving as the shadows move. The rover starts at the center of the green circles. This example illustrates difficult sun and comm shadow constraints and meets all mission requirements, not a complete traverse.

grayscale=amount of sunlight, 20 meter pixels, circles=drill sites; green=candidate landing site; red square=the rover, Timespan = ~8 days

Example Traverse Near Nobile

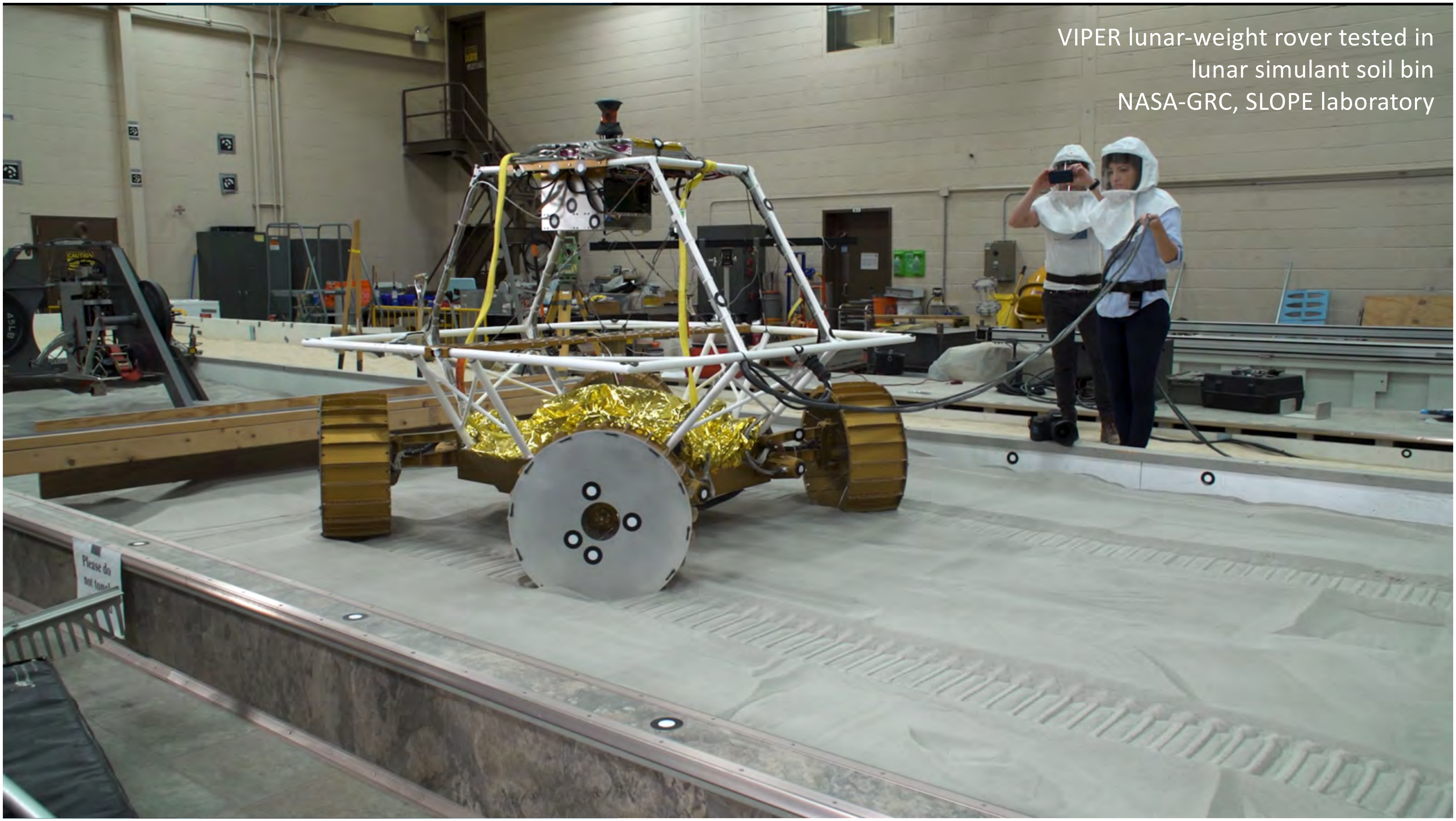




Powerful, fully-synthetic, lunar terrain sim based on Digital Elevation Maps (DEM)

- Establishing driver decision-making times

Rover Driving Simulator Capability
NASA-ARC Lunar Operations Lab


VIPER lunar-weight rover tested in
lunar simulant soil bin
NASA-GRC, SLOPE laboratory


Questions?