National Aeronautics and
Space Administration

VIPER

VIPER Industry Day:

Technical Briefing, Questions and Answers

Feb 13, 2025

VIPER Industry Day: Welcome and Logistics

Daniel Andrews (VIPER PM)

Welcome!

NASA welcomes you to a discussion on the VIPER mission.

The goal is to start a conversation about the capabilities of the VIPER system, team and operational readiness.

The next few hours will describe the breadth of the VIPER project developments at NASA, as well as the status and maturity of its systems and team expertise.

Agenda

- [10 min] Industry Day Welcome & Logistics
  - Agenda + Team introductions
- [15 min] VIPER Status
- [37 min] VIPER Mission Overview & Capabilities
  - Science, Exploration, and Technology opportunities
- [26 min] VIPER Measurements and Instruments
- [20 min] VIPER Roving Platform
- [24 min] VIPER System Testing (ground & rover)
- [15 min] (break)
- [66 min] VIPER Mission & Science Ops / Ground Systems
- [13 min] VIPER-Lander Integration and Launch Site Planning
- [7 min] Summary/Close/Q&A

Your VIPER presenters today

(Alphabetical order)

- Daniel Andrews: VIPER Project Manager
- Bill Bluethmann / Terry Fong: VIPER Rover Leads
- Tony Colaprete: VIPER Project Scientist
- Steve Jara: VIPER S&MA & Range Safety Lead
- Tom Luzod: VIPER Lander/LV Interface Lead
- David Petri: VIPER SI&T Lead
- Jay Trimble: Mission Systems (Ops and Ground)
- Ryan Vaughan: VIPER Mission Systems Engineer

VIPER Framing

(Daniel Andrews)

VIPER System Status

- The Rover:
  - 100% built
  - Completed vibration testing and post-test checkout
  - Completed acoustic testing and post-test checkout
  - Completed TVAC testing
  - Completed post-environmental test checkout
  - Operations verifications in progress

- The Mission System:
  - High value engineering/qual units/testbeds available for integration work
  - Mission Operations Center (MOC) outfitted with *feature-complete* software
  - 1000+ hrs of integrated Ops team test and training
    - Integrated Simulations & Engineering Readiness Testing
    - Testing with MOC in the loop – hardware test stand and flight vehicle
    - Mobility Testbed rover testing and training
  - 7167 people hours of training

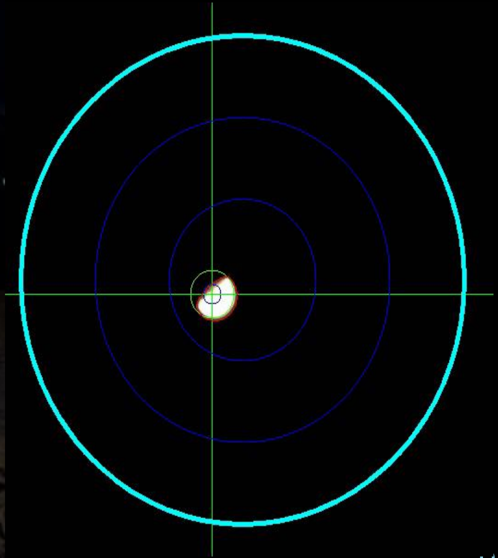
- Lander Integration:
  - Team well-experienced with lander integration planning/coordinating/testing

- Range Safety:
  - Range Safety products developed, reviewed, and Safety Review II ready
  - MGSE & EGSE have passed Range Safety initial review

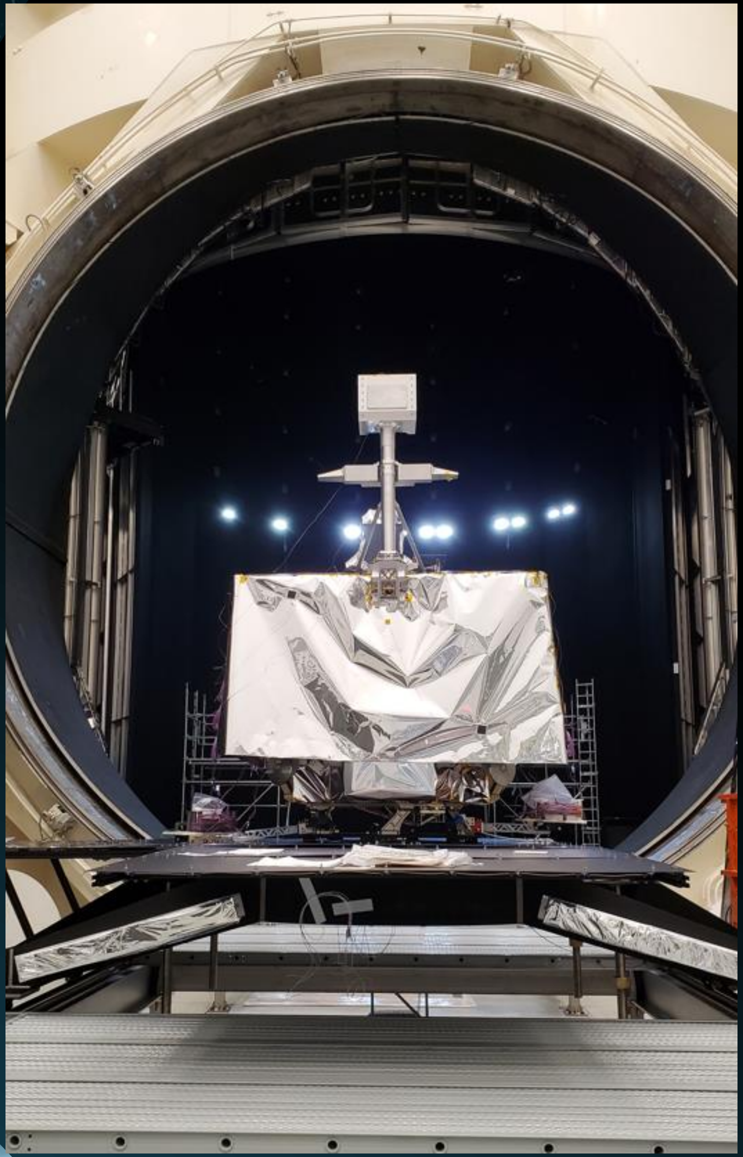
VIPER Development

- VIPER built for Lunar science objectives, but has broad capabilities for other use-cases
- VIPER was cast as an R&T mission, different than typical NASA missions
  - Enables tailoring-away traditional NASA requirements (and cost)
  - VIPER’s IRB focused on forward feasibility, not just checking Agency boxes
- VIPER team highly-practiced in commercial engagement
  - Instruments developed closely with commercial industry
  - VIPER experience shaping the next round of CLPS contracts
- VIPER team organized from the beginning to work with a lander partner
  - A dedicated VIPER focal point exclusively works partner interfacing
  - VIPER is ready with an IDD (Interface Definition Document)
- VIPER rover design unlike any other NASA mission
  - Hybrid flight avionics, split on-board/off-board software stack, interactive real-time science ops, and extensive Agile development for all software and mission operations
- VIPER managed as a low-cost, risk-tolerant pathfinder mission
  - Pandemic supply chain issues drove VIPER integration schedule and development costs higher

VIPER Maturation: Mission Systems



VIPER Maturation: Rover Development



VIPER Rover Development

VIPER Build Status:

Rover build completed 6/4/24 @ 4:30p CT

VIPER Test Status:

Rover Vibe: Complete

Rover Acoustic: Complete

Rover TVAC: Complete

Post-environmental Testing: Complete

Rover-MMOC Operational Verifications: In progress

VIPER Ground Development

VIPER Operations Status:

GDS Build-9 released – SW *Features Complete*

Simulations completed:

- Surface Housekeeping
- Rails Driving
- Science Station Ops
- Transit Housekeeping
- Transit Payload Checkouts & Calibrations
- Launch, Activation & Rover Checkouts
- Safe Haven and Hibernation
- Post landing checkouts & egress
- Mission Planning

Ops procedures baselined in simulations

A total of 1000 team-hours have occurred so far in SIMs, ERTs, Mobility Testbed and vehicle test stand/flight vehicle testing

VIPER Mission Overview & Capabilities

(Dr. Anthony Colaprete)

VIPER Designed to Support a Broad Community

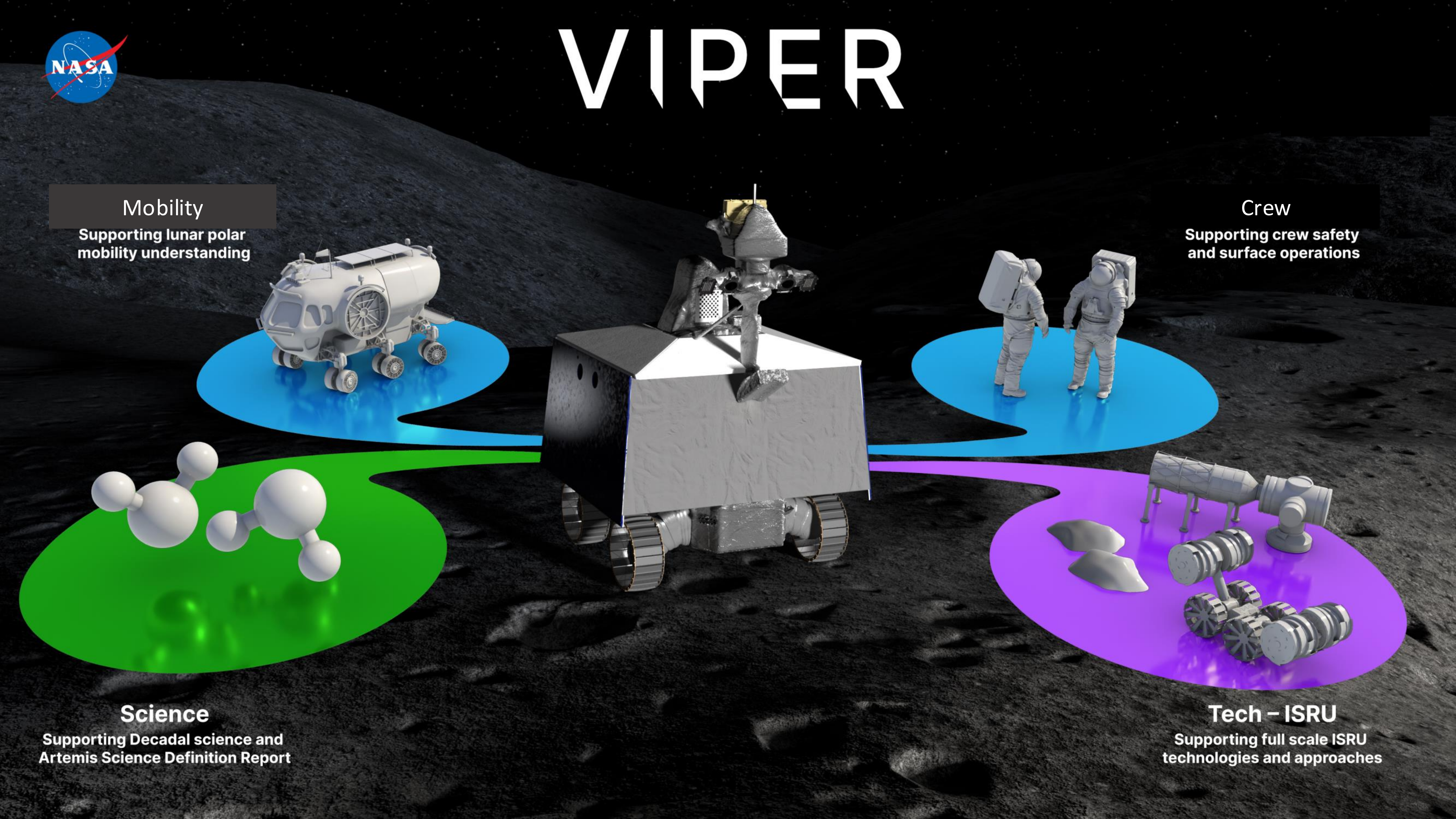
Decadal Survey-Level Science

- Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith.

Exploration / Technology

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

Given these broad goals the resulting “toolbox” (rover, instruments, GDS and expertise) can be broadly applied and adapted to meet a variety of goals.


VIPER
Mobility
Supporting lunar polar mobility understanding
Crew
Supporting crew safety and surface operations
Science
Supporting Decadal science and Artemis Science Definition Report
Tech – ISRU
Supporting full scale ISRU technologies and approaches

VIPER is at the Epicenter of Science, Exploration and Commerce

Data sets that address volatiles, their distribution, origin and accessibility constitute some of the highest return on investment to Science, Exploration and Commercial communities

Thus, VIPER's design uniquely sits at the epicenter between Science, Exploration and Commerce and its application adjusted to emphasize any one of these groups

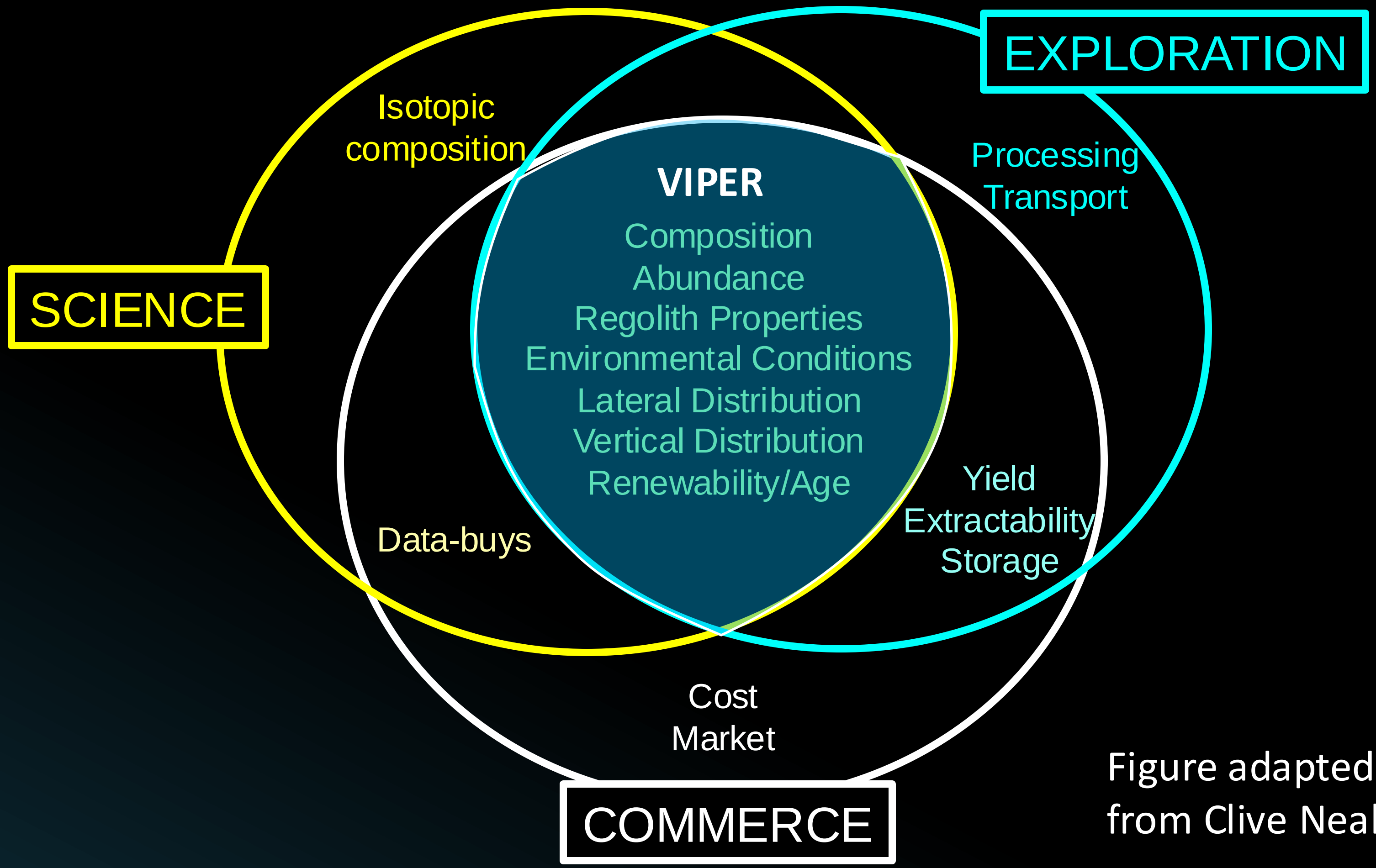


Figure adapted from Clive Neal

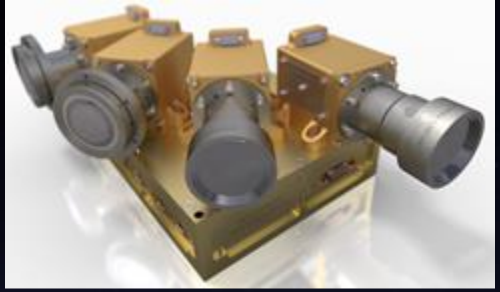
VIPER Rover

- **Rolling Mass:** ~450kg
- **Power:** ~450W (corner-facing) or 320W per array
- **Communications:** X-band
- **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:** 15cm / 15deg
- **Expected Cold Environment:** ~40K

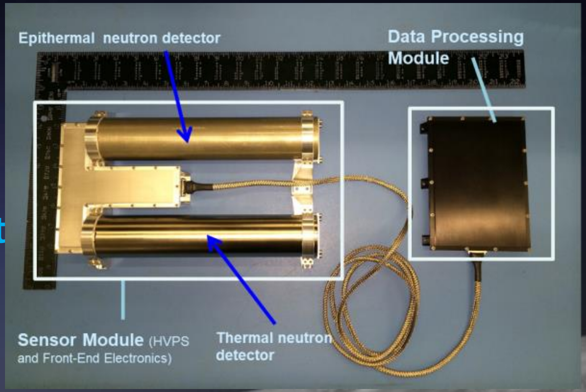
Instruments

Subsurface excavation
TRIDENT Drill

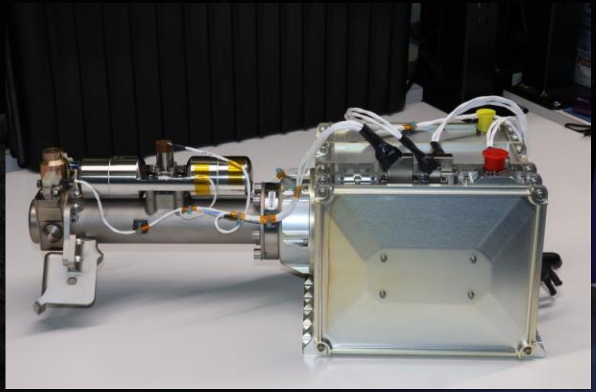
Imaging Science
VIS



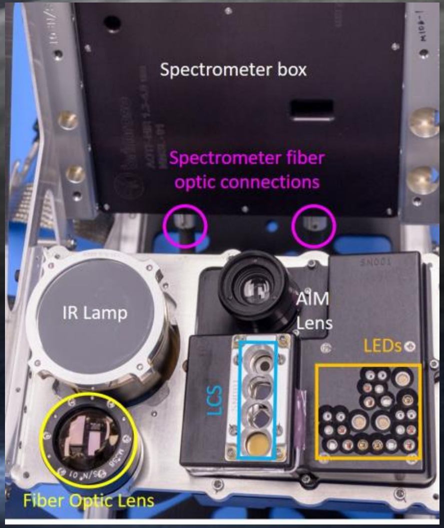
Prospecting
Neutron Spectrometer System (NSS) Instrument



Subsurface Sounding
Rover IMU

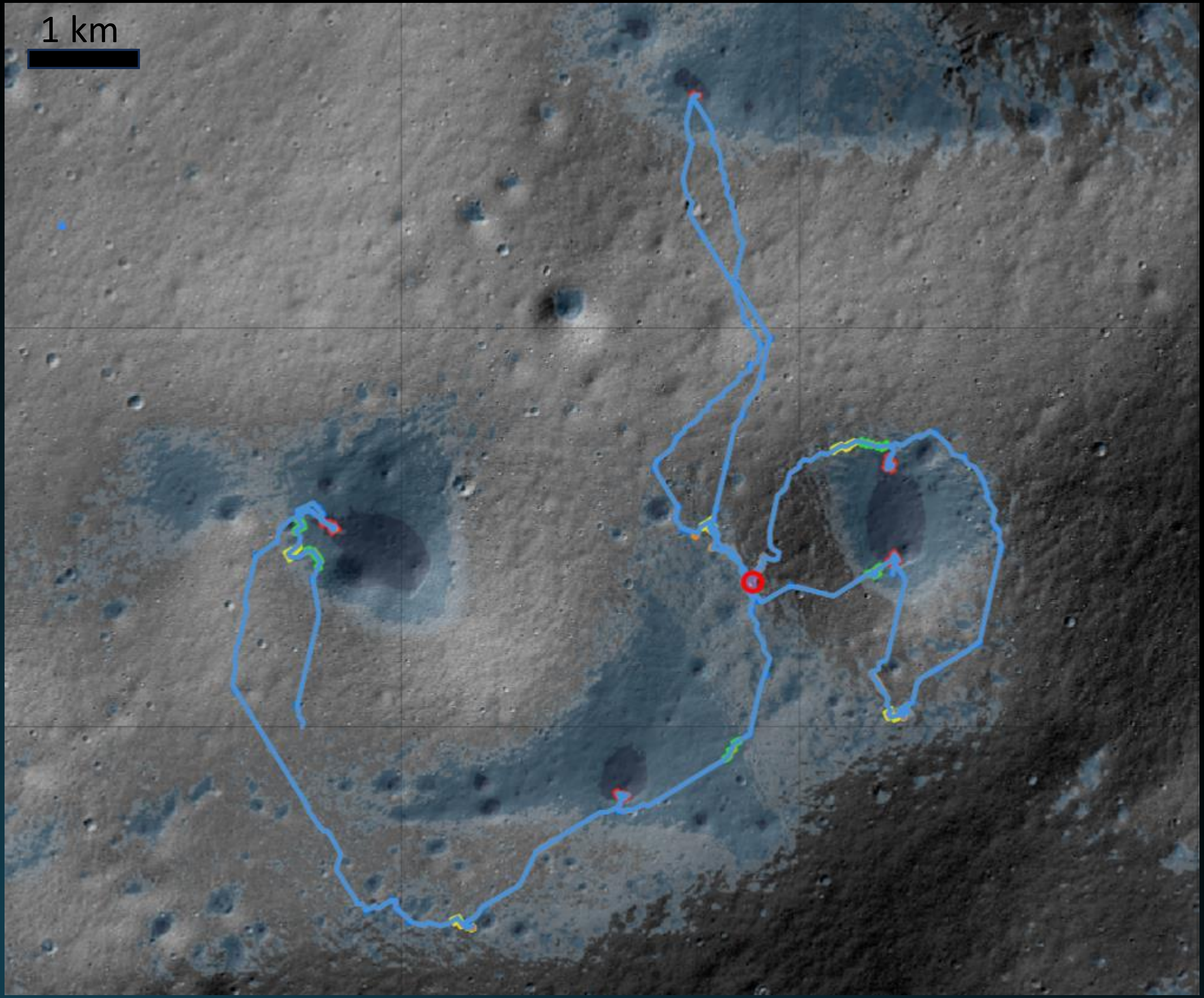


Prospecting & Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS) Instrument

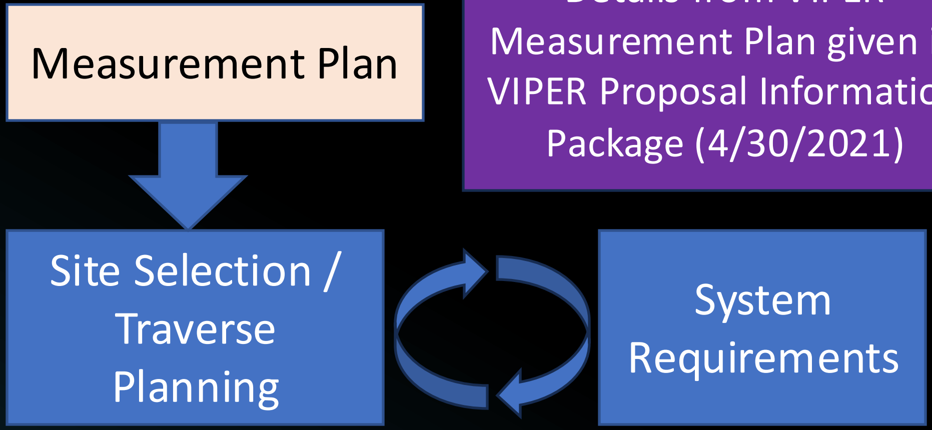


Prospecting & Evaluation
Mass Spectrometer Observing Lunar Operations (MSolo) Instrument

VIPER Mission Capabilities – Mission Summary



- VIPER's capabilities were motivated through an iterative process of integrating science objectives, exploration planning & system development
- Measurement requirements were developed using geostatistical evaluation of necessary coverage, areal density, and number of sample points
- Traverses were built that met these requirements and these traverse solutions identified necessary system capabilities
- System trades were made against traverse trades



Details from VIPER Measurement Plan given in VIPER Proposal Information Package (4/30/2021)

An Integrated Science, Rover and Mission Design

The effort to integrate Science throughout the VIPER system began with mission area selection and continued through rover design, traverse planning and Mission Systems

The Moon offers a unique opportunity to work in near real-time to maximize science return reacting to:

- New realities (e.g., unidentified hazards from pre-mission data)
- Discoveries
- Use real-time analysis to optimize sampling

Integration of these systems developed through testing, engineering tests and simulations

- Included entire mission team (engineering and science)
- Tests refined rover and instrument design, operations and necessary real-time analysis
- Systems validated in Operations Readiness Testing with the vehicle, operation centers and team

Luck

Applied Science

Examples of Cohesive Systems Integration

Instrument data evaluated in real-time and derived products integrated as new map layers

- This includes “Driving Reports” on trafficability and annotated layers marking hazards or high value targets

Planners evaluating with a range of relevant time horizons

- Total accrual of an ISR type, Speed Made Good
- Evaluating traverse changes with Science and Flight

Integrated Science in the Drive team

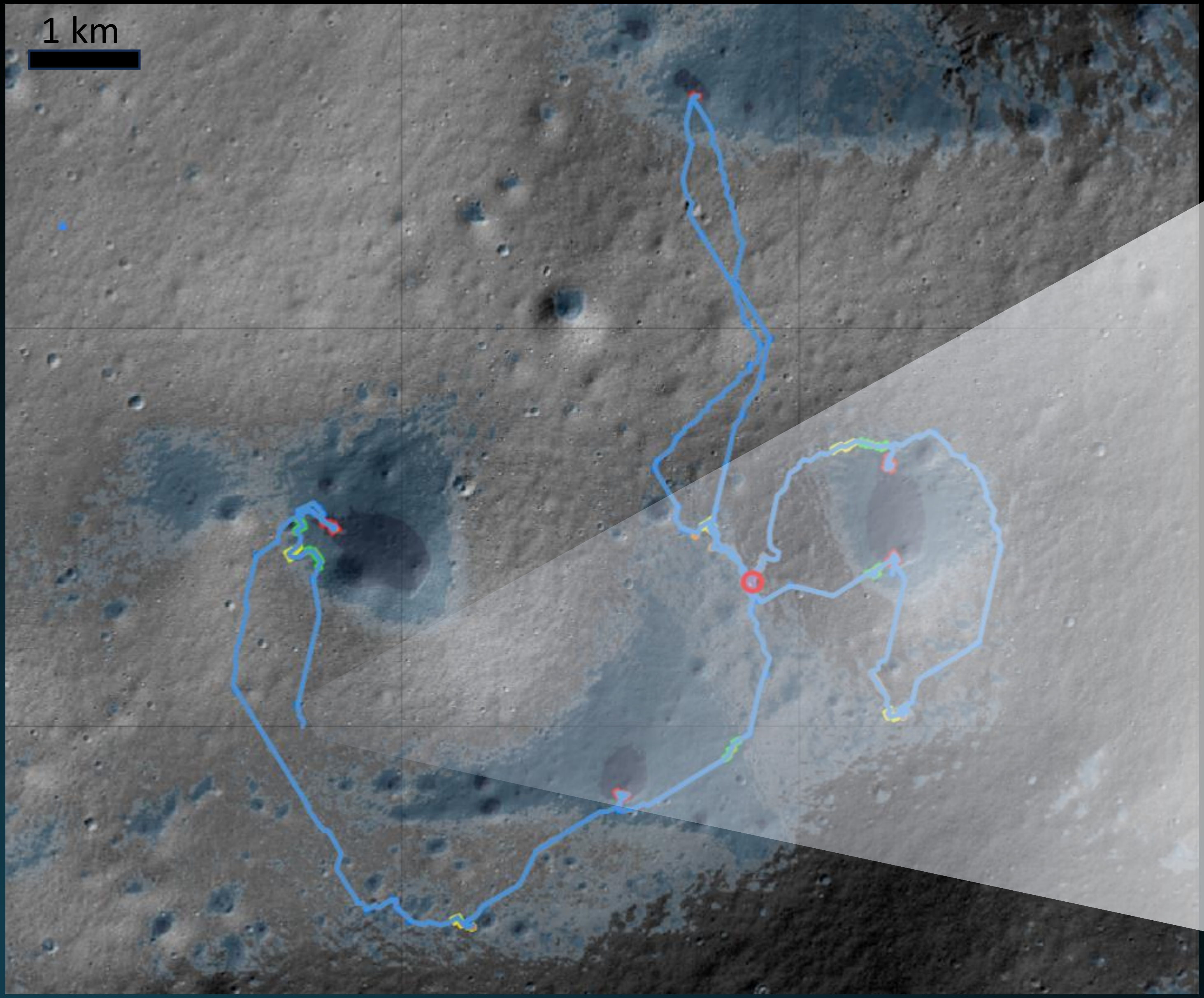
- Working directly with the Rover driver to provide input on trafficability and tactical science decisioning
- Keeps the driving decision cycle to ~5 min, critical to maintain Speed Made Good
- Informed by Mission Science Lead and Mission Science Center

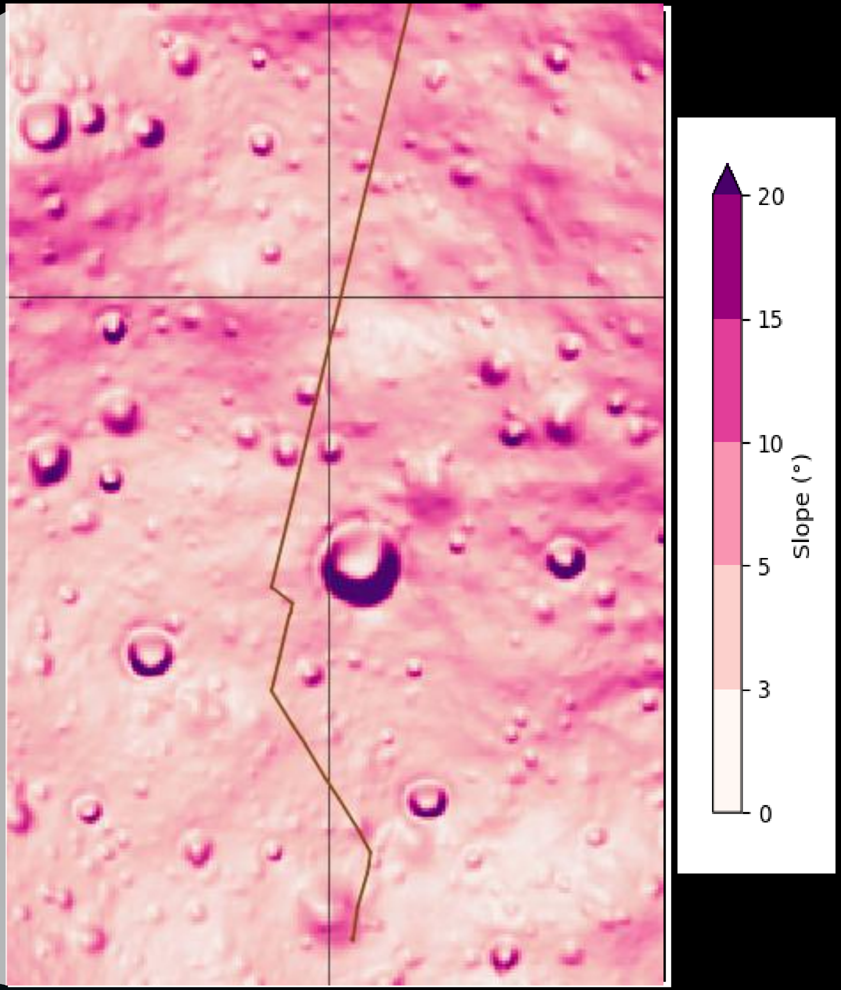
Ground Data Systems allow the exchange and use of data across all elements

- Mission Science Center, Mission Operations Center and Payload Operation Center
- The system allows near real-time shared derived products
- Includes, for example, map layers, target ranges and hazard maps
- Assists the team in driving and maximize science, to be accessible across all console positions

Rapid Surface Transit

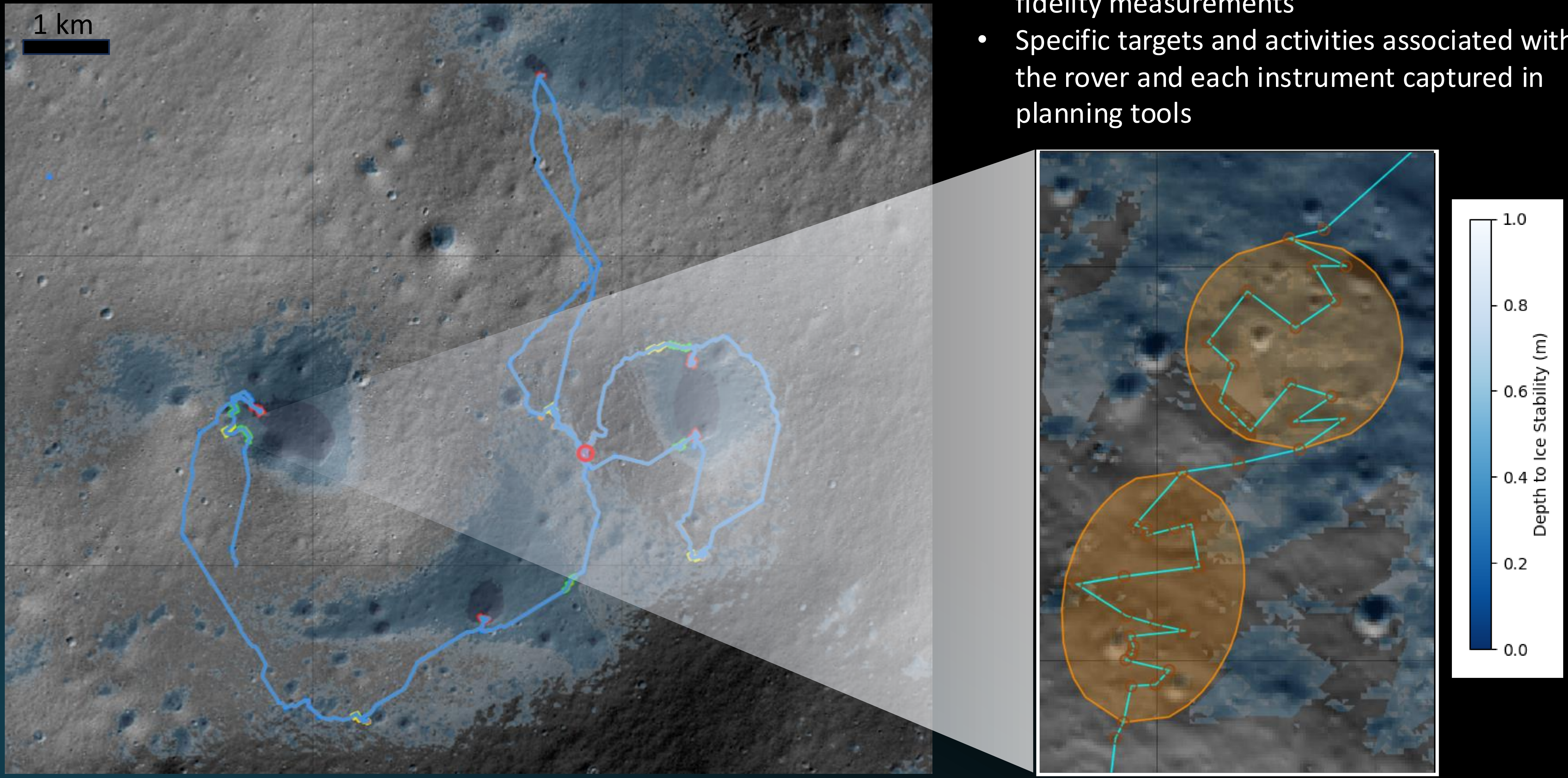
- From landing site, traverse in “Rails” driving mode – quickly and safely get from A to B while still incurring scientific and exploration learning about the environment
- Traverse optimized with AI Tools within hazards, sun and comm constraints





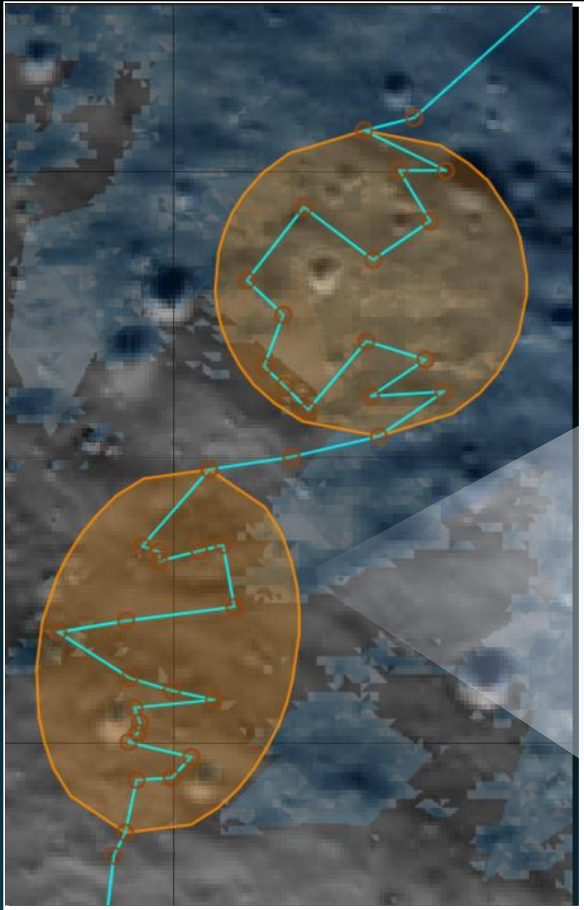
High Fidelity Planning

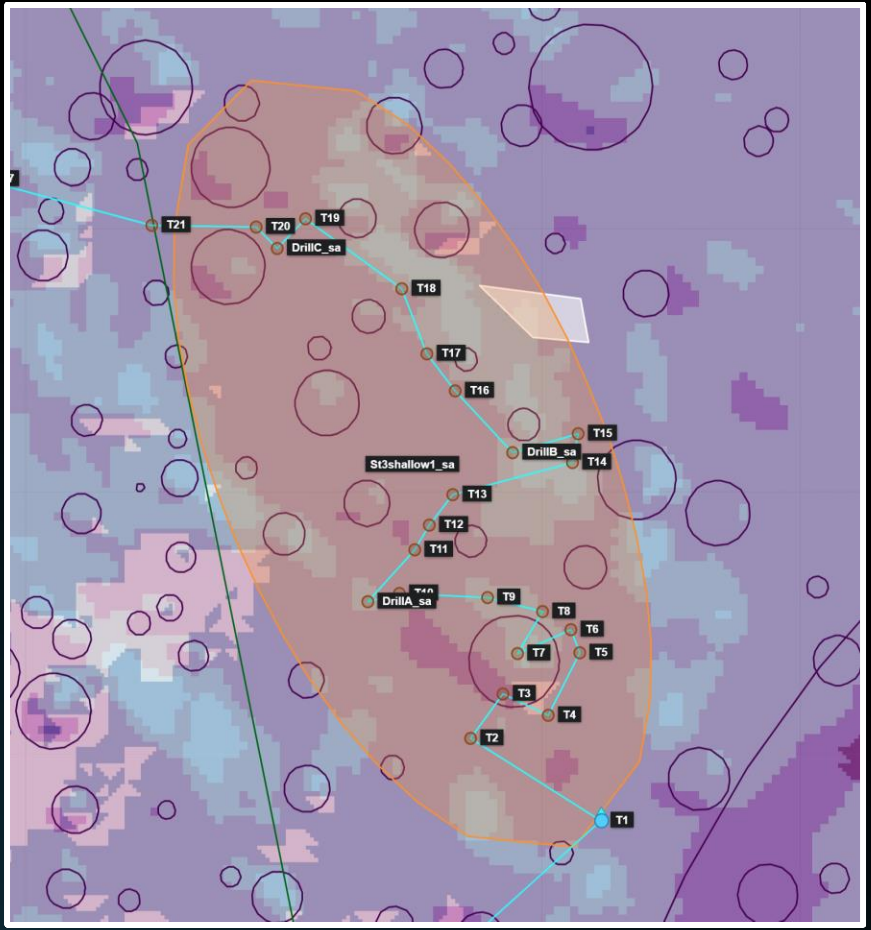
- In locations of interest, drive mode changed to “Prospecting” which allows for higher fidelity measurements
- Specific targets and activities associated with the rover and each instrument captured in planning tools



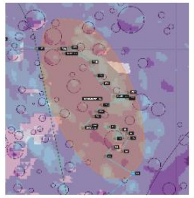
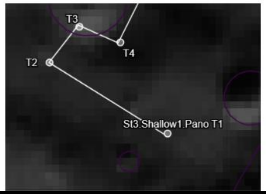
Science Traverse Planning: Strategic and Tactical

- The Science Traverse planning products are focused on optimizing science return from within these science stations and tracking returns from the areas between science stations
- The Science Traverse planning activities occur in advance of landing (pre-mission) and following SOP and Standard Analytical Methods (SAMs) the science traverse is updated based on real-time science and exploration while at the Lunar South Pole



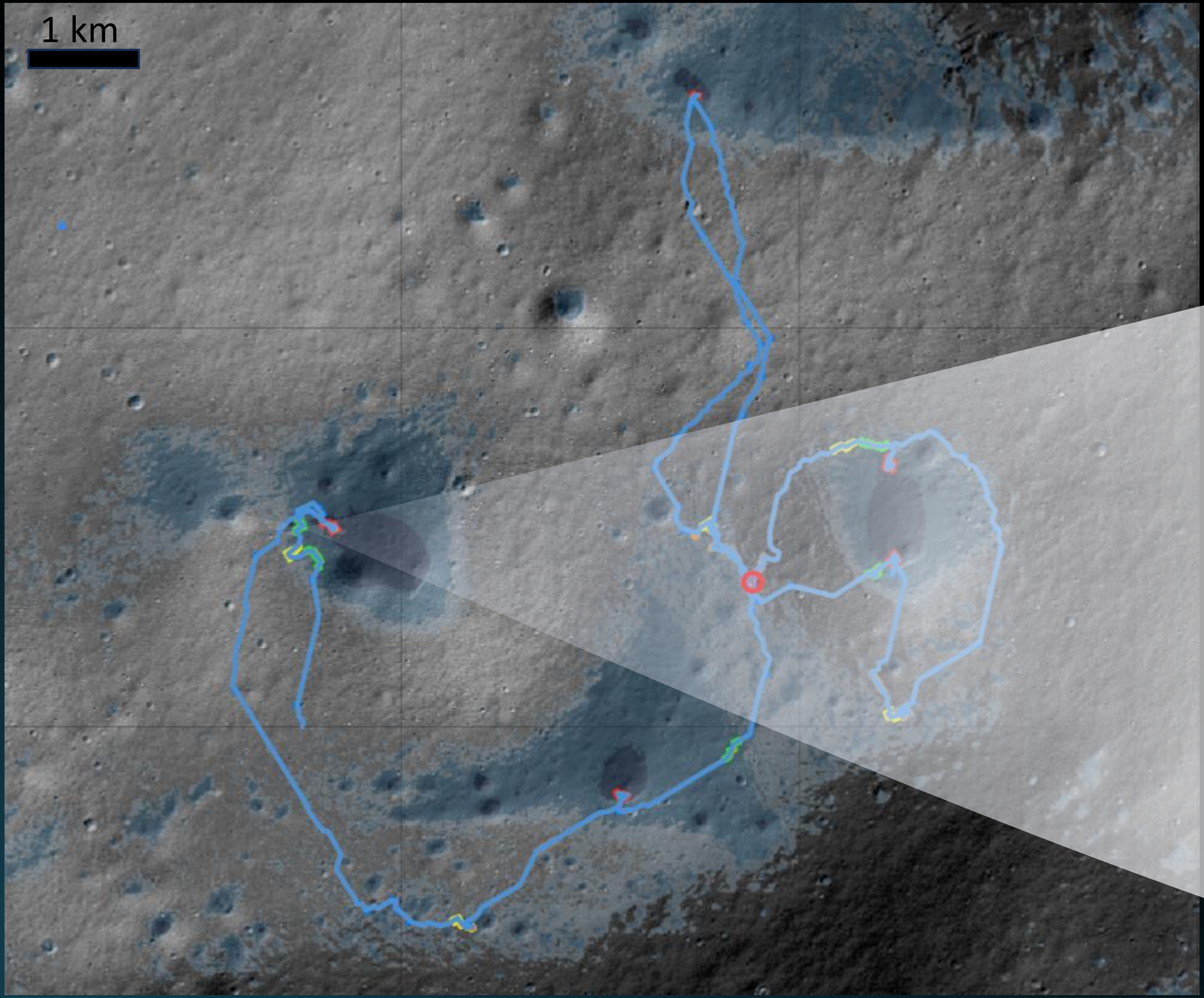


TRAVERSE DESCRIPTION:

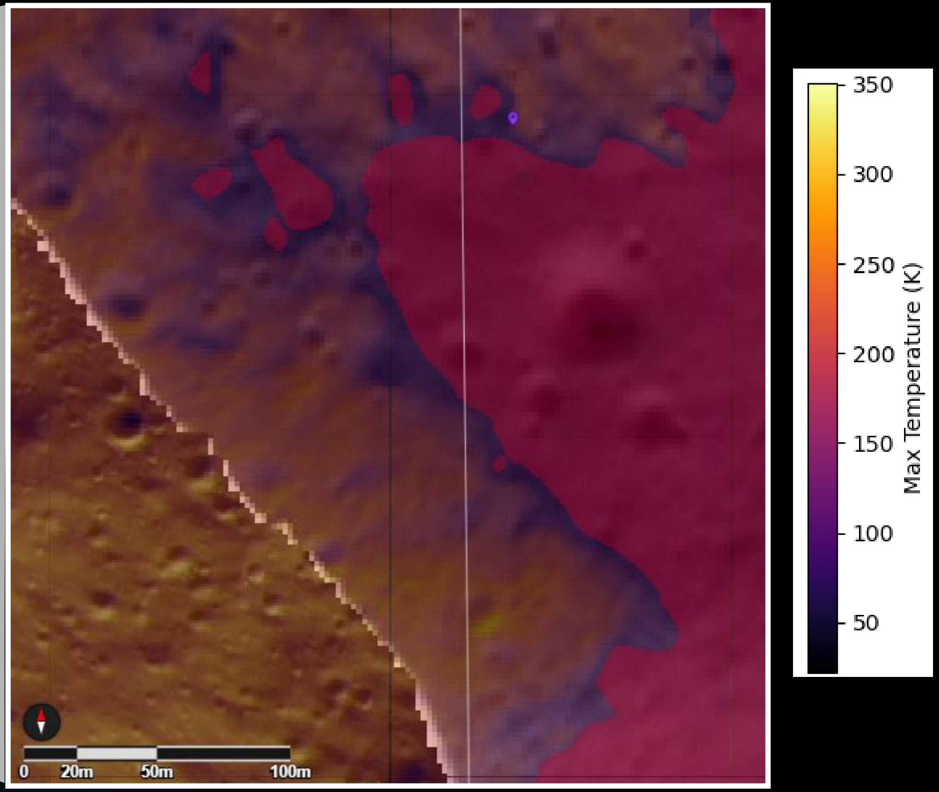
Science Station	Science Traverse Segment of Interest	Science Rationale	Traverse Tolerance	Screen grab of segment	LDST Obj #
L1.St3.Shallow1					
T1	Pano.T1	**Image Request:** 360 pano to coincide with Entry Nav Pano, but orient rover towards T2. Goal: Characterize geologic context and textures running	3 m		2.c.1 **2.c.7** 2.e.3 4.c.1

VIPER Science Traverse Objectives Table

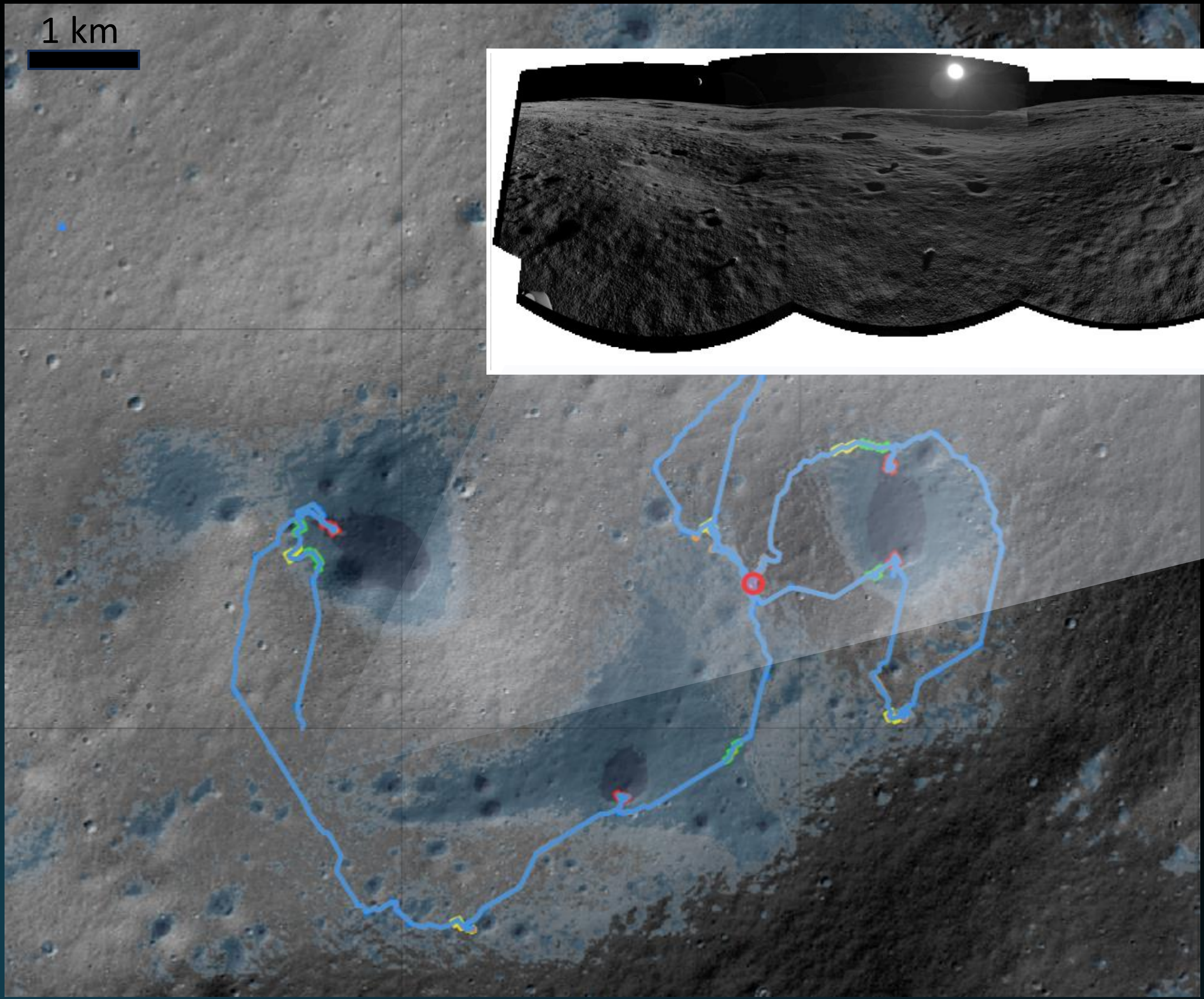
Shadow Operations Endurance

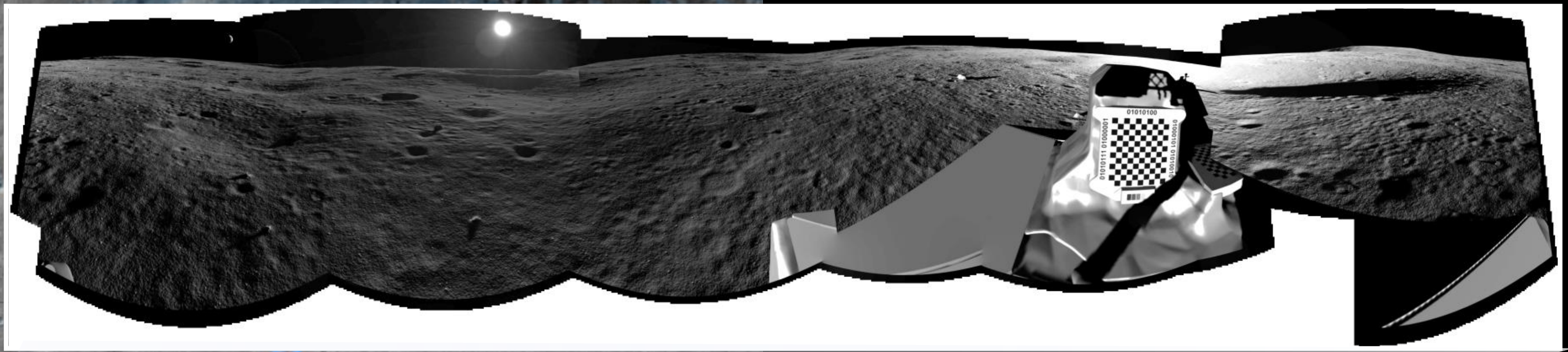


- Batteries sized to allow for 9 hours of shadowed operations, including PSR operation, with all prospecting instruments operating and drilling to 1-meter depth
- Active illumination on rover and instruments allow in-shadow operation.



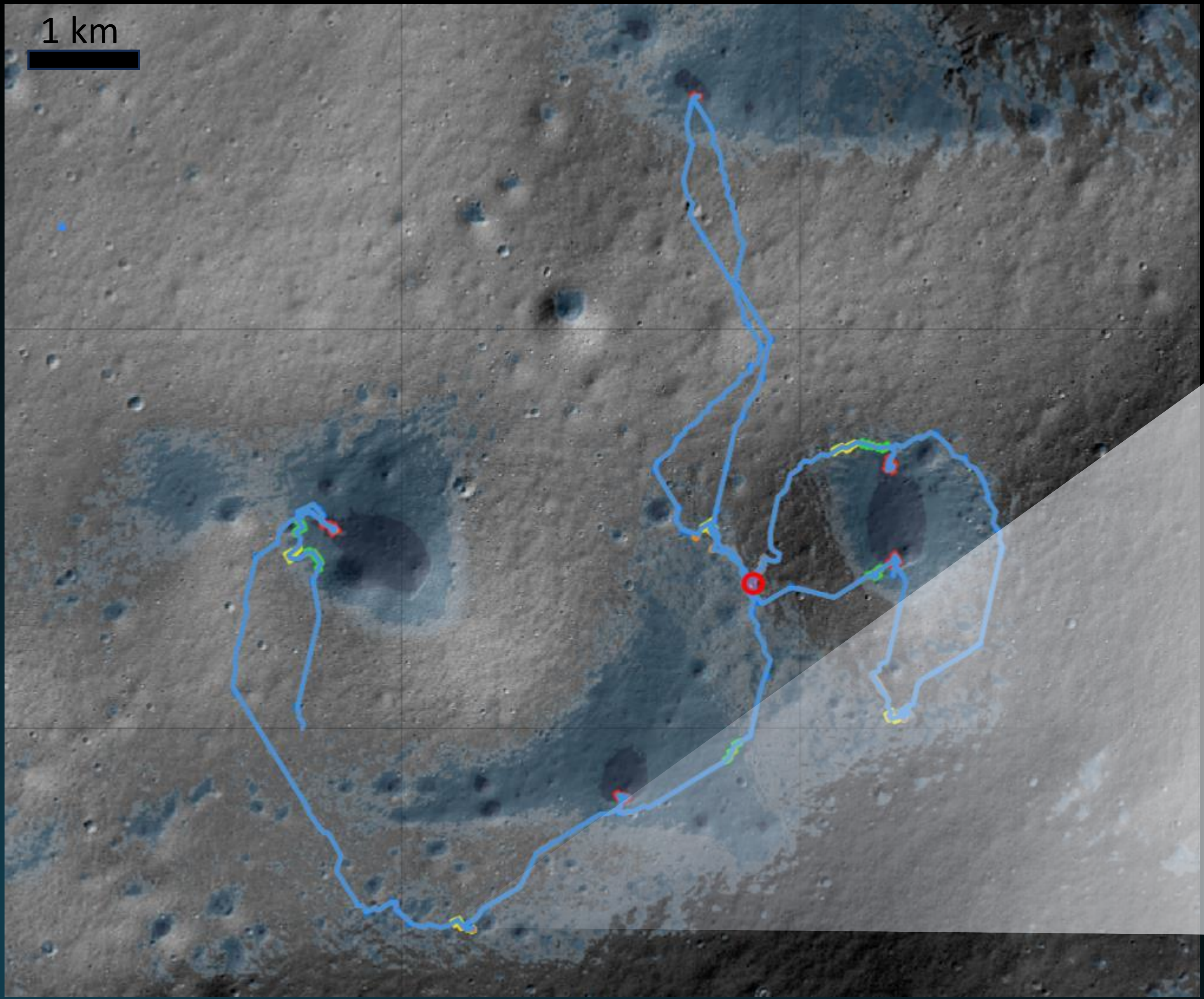
Absolute and Relative Localization



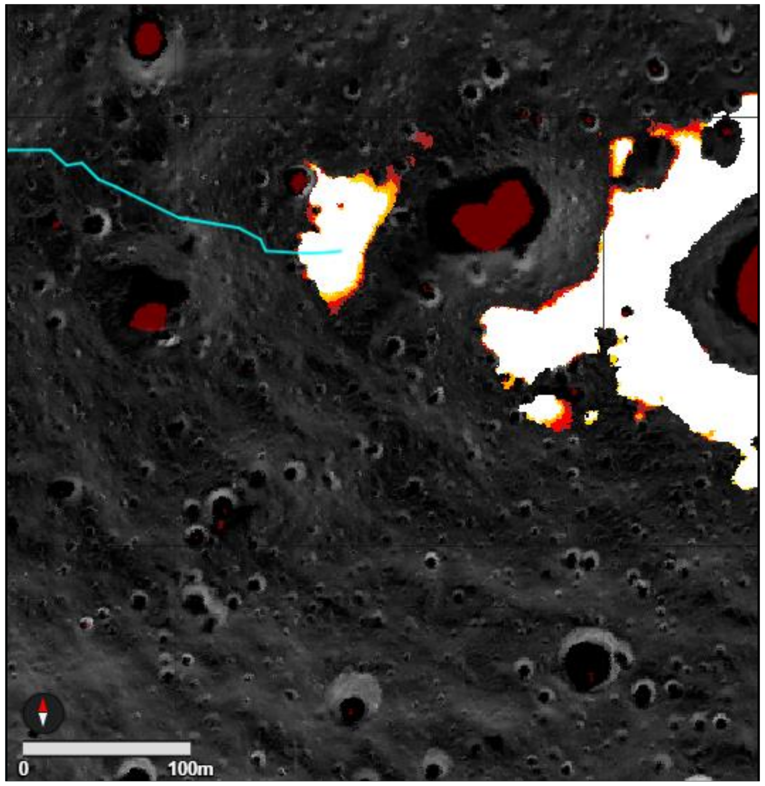


- Localization of the Rover in absolute and relative frames is accomplished using several methods including Terrain Registration, Visual Odometry, and a Manual Feature Alignment Tool
- Panoramas are used as part of the automated Terrain Recognition tools

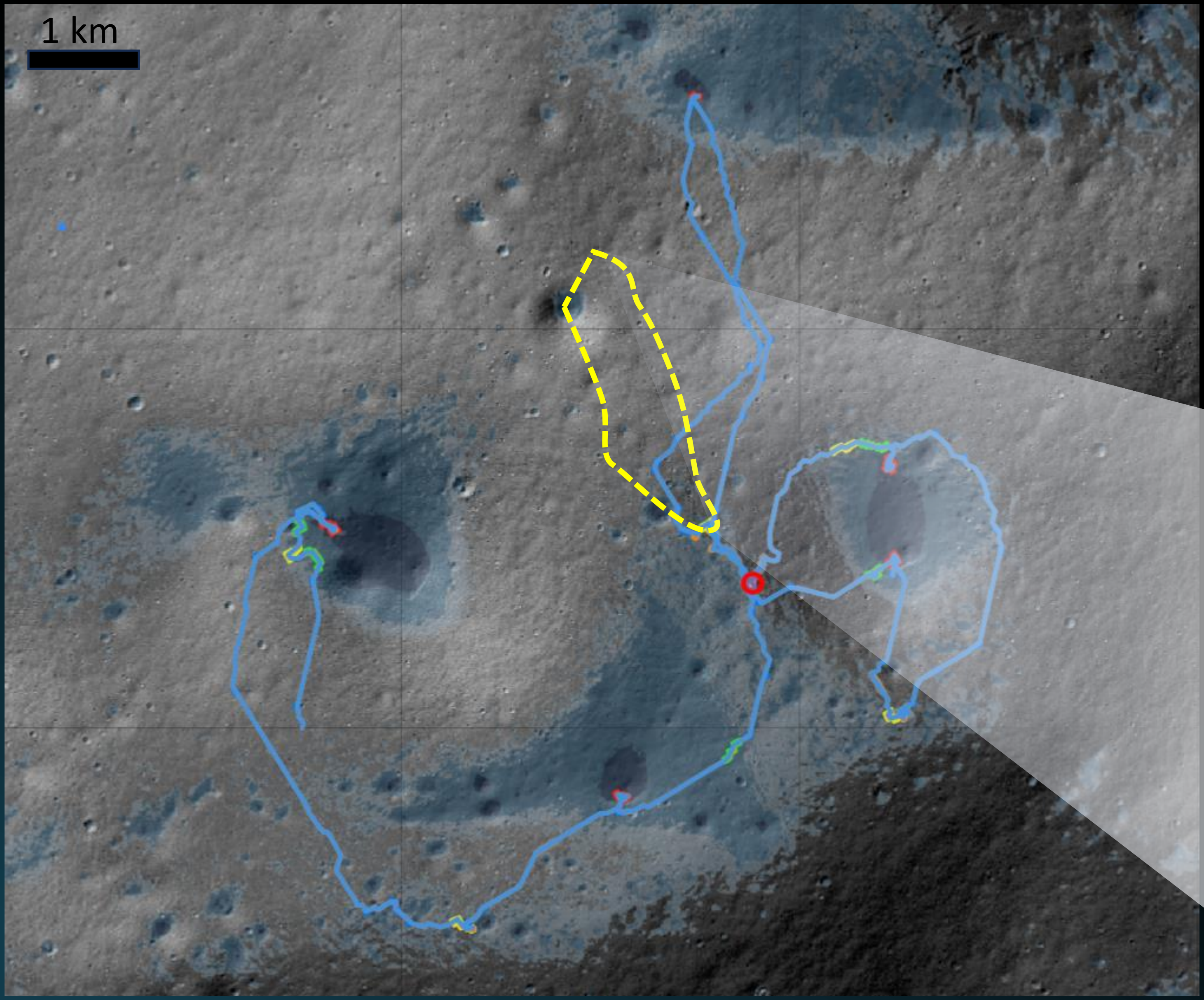
Shadow Period Survival



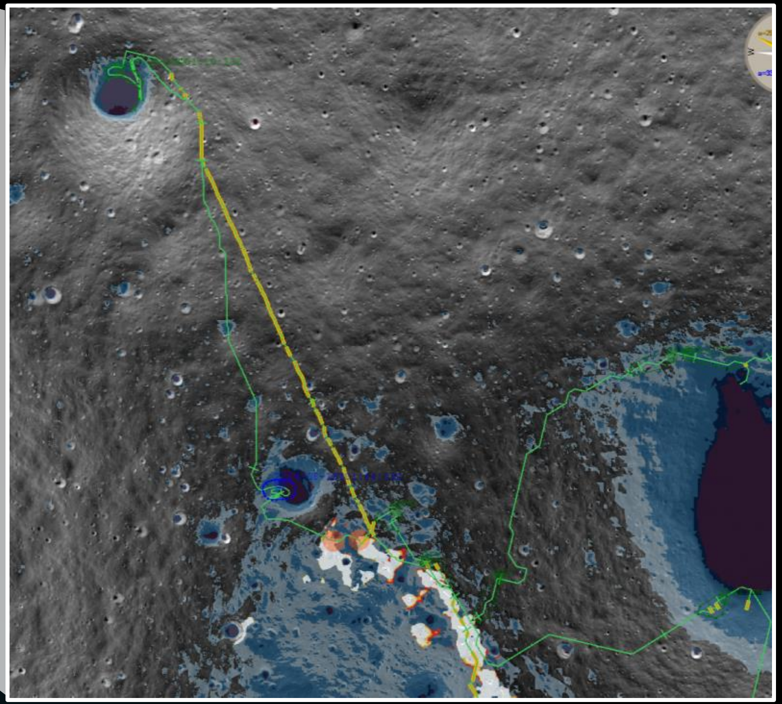
- “Safe Havens”, locations with shadow periods <50 hours long identified with 1-m DEM and illumination modeling
- The Rover is parked to ”hibernate” at these Safe Havens while Earth is not in view



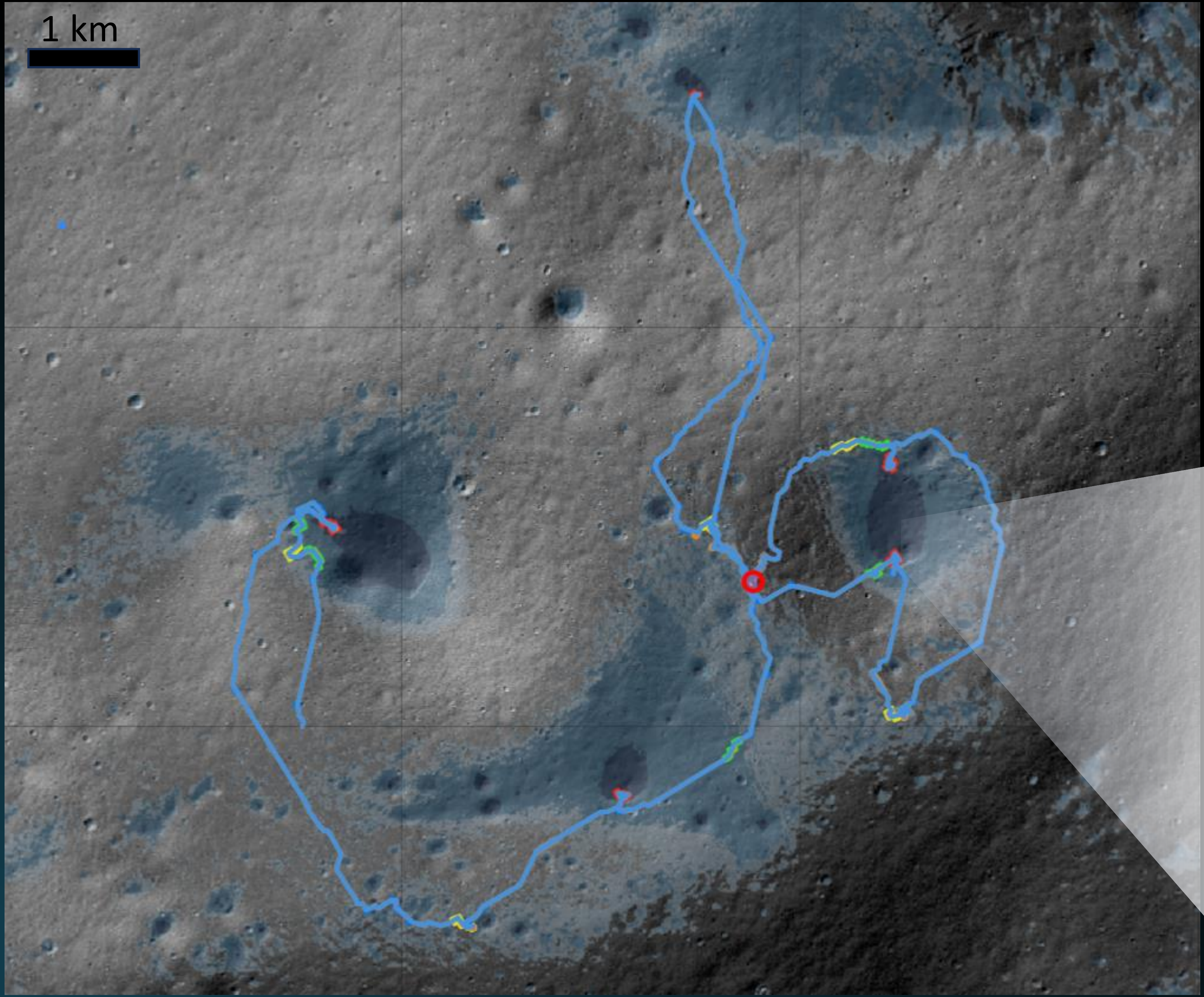
Rapid Replanning



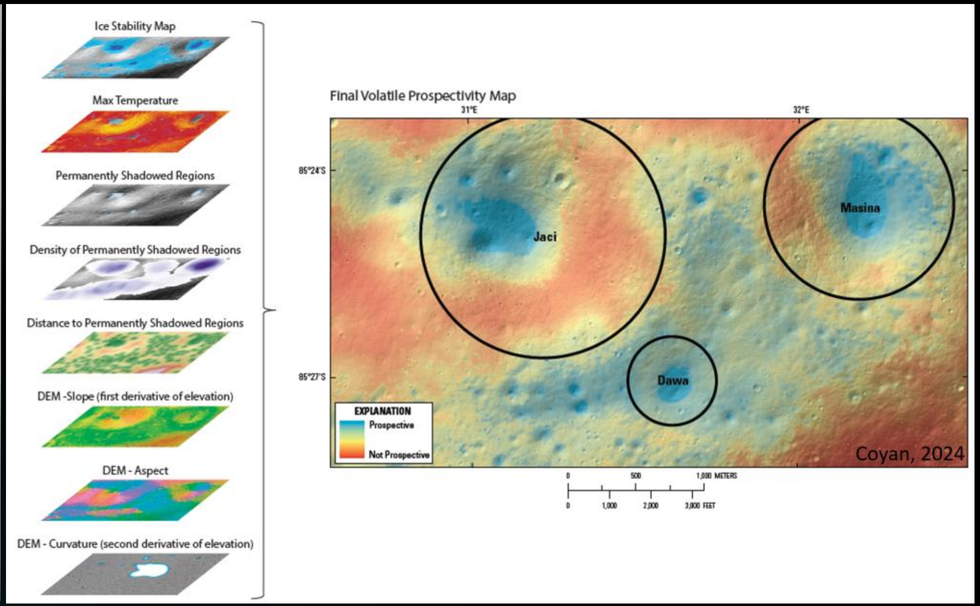
- Replanning is expected and designed for. Tactical planning can occur on time scales of hours, for example moving a drilling location
- During Hibernation Periods between lunar days, the Science Team will update priorities based on what they have learned and work with Mission Systems to update the plan based on these new priorities and actual rover performance.
- In this example, a shorter ‘sunward drive’ was selected which visited different ice stability regions



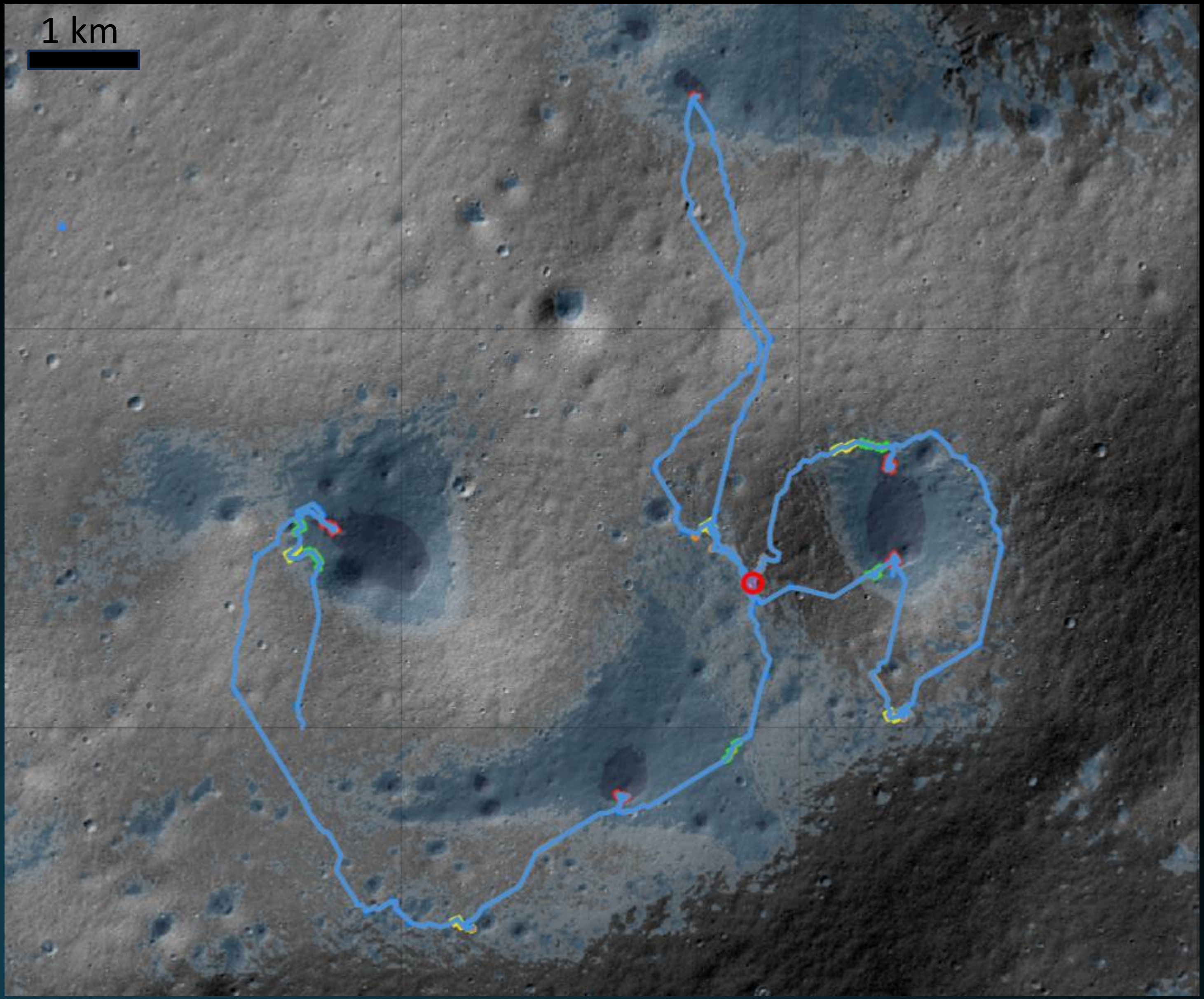
Real-Time Data Processing



- Near real-time data processing and derived data products, including:
  - Resource Maps (e.g., Water Favorability Maps & Trafficability Maps)
  - Trend analysis
  - Correlation analysis
- Real-time displays of derived instrument parameters (e.g., Water Equivalent Hydrogen, H2O spectral absorption strength and ion ratios)
- Products inform drill site positioning and traverse planning



VIPER Mission Capabilities - Summary



- 5-6 lunar days of operations
- 20 km of traverse distance, with potential for 30+ km
- 1700 m of driving in PSRs + 5 1-m PSR drilling activities (>80 hours of shadow operations)
- ~50 1-meter drilling activities
- Multiple different PSR entries
- Exploring temperature regimes ranging from 40 K to 300 K

Developed Mission Products

Real-time derivation of resource models, including:

- Trend analysis
- Correlation analysis
- Lunar resource map
- Mineral potential map
- Water equivalent and burial depth maps
- Surface hydration, other volatiles and mineralogy and toxicity maps

Derived geotechnical products, including:

- Wheel Slip
- Wheel sinkage
- Wheel degradation
- Rover tilt and surface slope
- Wheel load profile
- Modulus of subgrade reaction
- Regolith porosity
- Angle of repose

Derived environments, in addition to geotechnical environments (listed above):

- Surface and subsurface temperatures
- Lighting conditions (validating DEMs and DEM uncertainties)
- Earth visibility (validating DEMs and DEM uncertainties)
- Small scale hazard populations (rocks, craters and slopes) in sunlit areas and PSRs

Measurements and Instruments

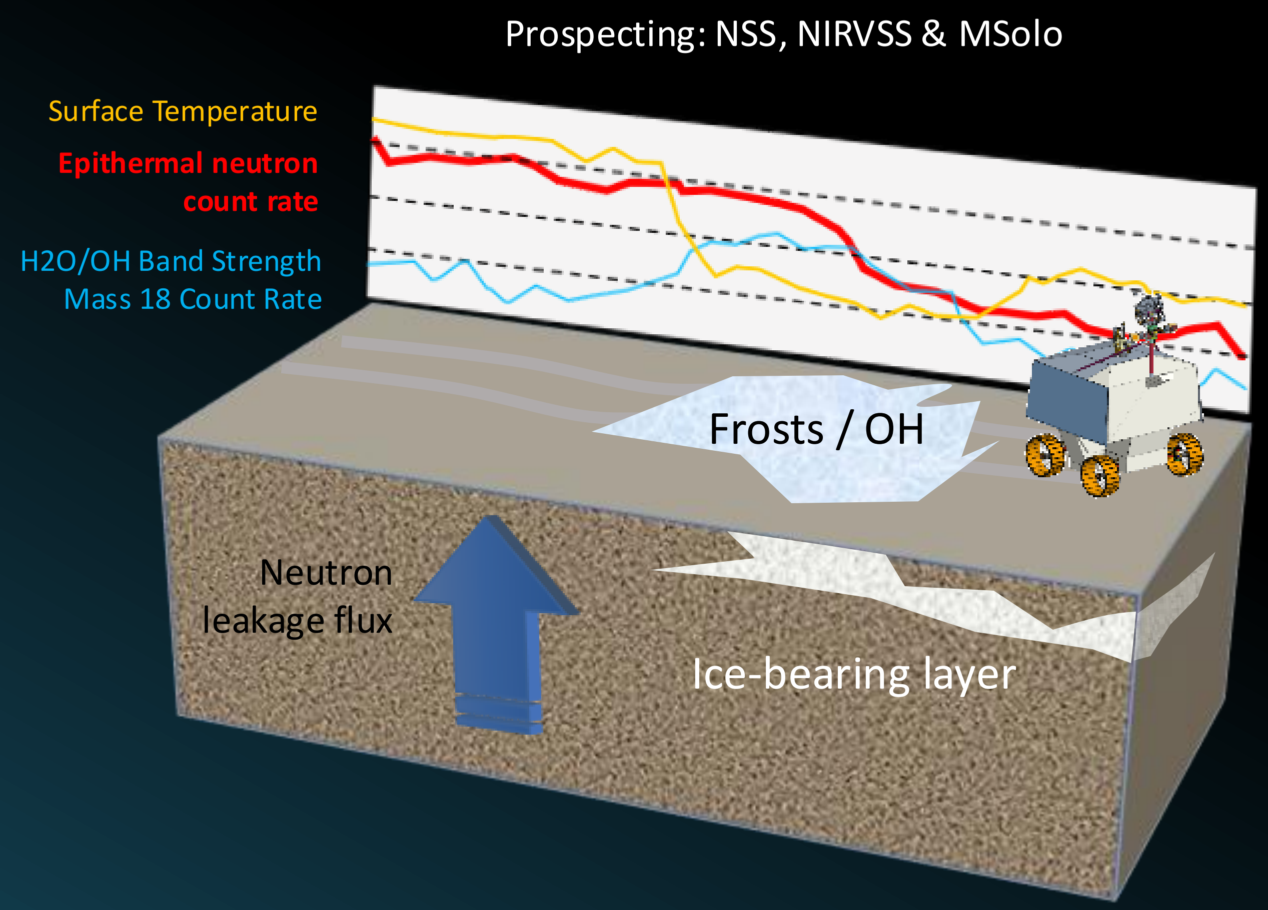
(Dr. Anthony Colaprete)

NSS (Neutron Spectrometer System)

Capable of determining bulk composition and hydration of the upper ~1 meter of regolith. Low mass, power and footprint based on Lunar Prospector Neutron Spectrometer approach.

- ***Sensor Module:***
  - Two large area, rugged helium-3 gas proportional counter neutron detectors.
  - Low-noise charge-sensitive preamplifiers.
  - High-voltage power supply.
- ***Data Processing Module:***
  - Digital pulse integration and multi-channel analysis.
  - HVPS control, thresholding, telemetry packaging.
  - Simple electrical (RS422) and mechanical interface to host.
- ***Low power, low mass, low telemetry bandwidth*.**

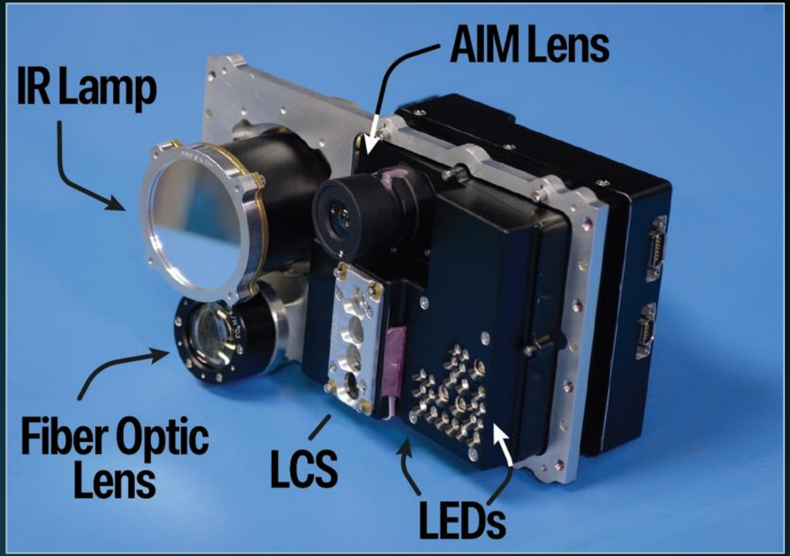
NSS Observation Possibilities



- Constant 1 Hz measurements enables continuous mapping while roving.
- NSS data provides estimated *burial depth* and *H abundance* along traverse path.
- Complements NIRVSS and MSolo measurements of surface volatiles.
- Supports drilling activities (ground truthing).
- NSS thermal neutron measurements constrain bulk composition (eg. Fe and Ti) in the upper meter.
- NSS also provides a first alert warning of solar proton events.

NIRVSS (Near Infrared Volatiles Spectrometer System)

Capable of determining the surface composition (e.g., mineralogy, hydration, frosts) along traverses and from drill cuttings piles



Spectrometer

- Spectral range: 1300 - 4000 nm, 1 nm spectral sampling, 7-50 nm spectral resolution
- IR tungsten filament lamp available to illuminate spectrometer FOV with sapphire window blocking $\lambda < 1000$ nm
- On-instrument spectral binning and averaging

Ames Imaging Module (AIM)

- 4-megapixel CMOS camera
- Custom f/8, fixed 16 mm focal length, UV optimized lens
- FOV that encompasses the FOV of both spectrometer and LCS
- LEDs: 340, 410, 540, 640, 740, 905, 940 nm
- Provides hyperspectral images of the (illuminated) scene
- Supporting electronics for image capture, storage and on-board processing

Longwave Calibration Sensor (LCS)

- Provides direct correction for longwave thermal emission contributions to near-infrared observations of the surface.
- Four single-channel thermopile sensors and filters with 36ºC FOV: 6.1-20+ (broadband), 10.5 µm, 13.8 µm, and 14.5-17.5 µm
- Eight gain settings; cycles through one gain setting takes ~ 1.8 s

NIRVSS Observation Possibilities

Spectrometer

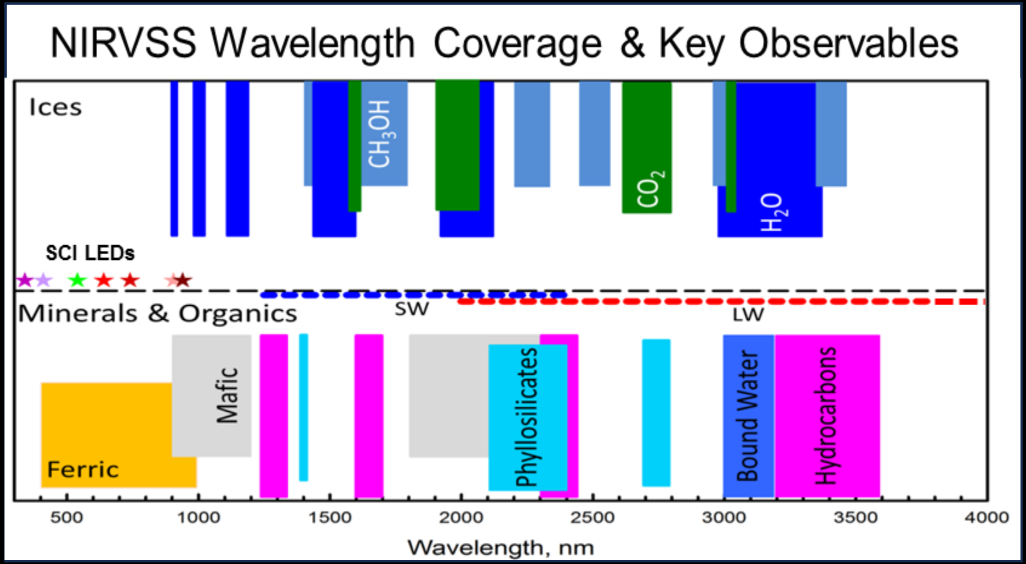
- Volatile identification / quantification (e.g., H2O, H2S, SO2, CO2, NH3, CH4, hydrocarbons)
- Minerology (mafic, Phyllosilicates)

AIM

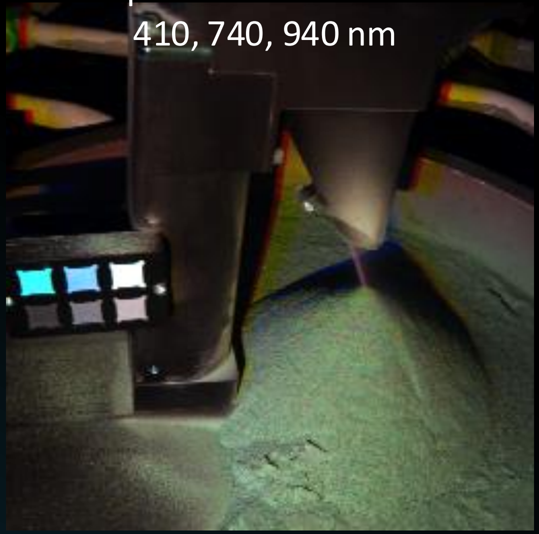
- Water Ice at high spatial resolution
- Mineralogy (e.g.,Ferric, Ilmenite… correlation with He3)
- Regolith maturity (space weathering)
- Geotechnical properties (textures, grain sizes, 3D structure based on stereo, NeRF and Multi-Focus Reconstruction)

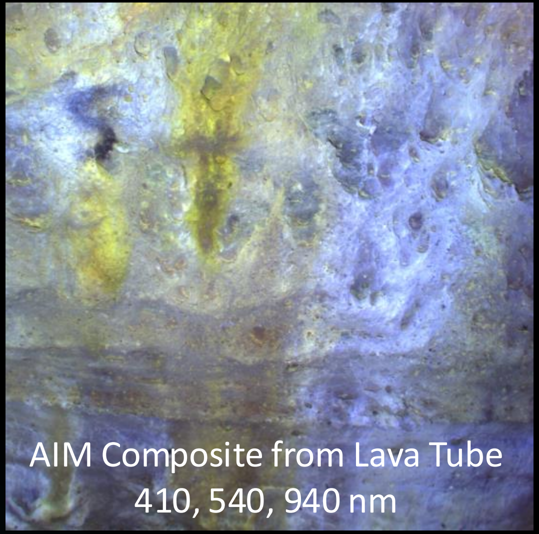
LSC

- Surface temperatures
- Regolith properties (e.g., porosity from thermal inertia)



AIM Composite from TVAC With Drill
410, 740, 940 nm





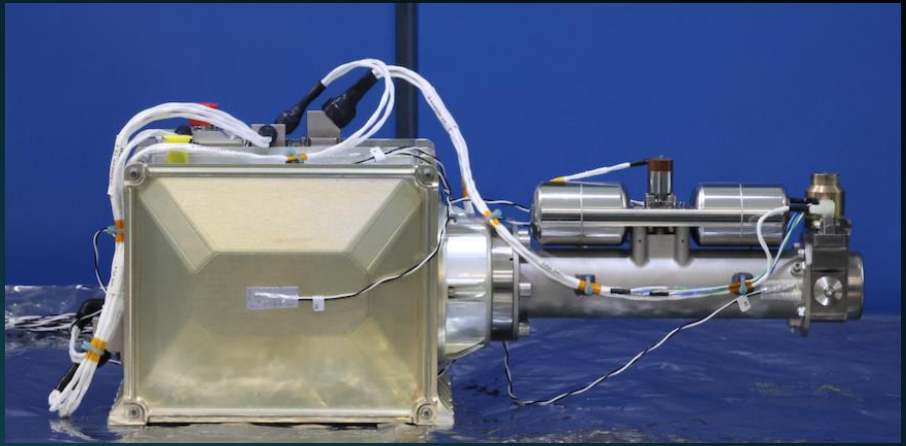
AIM Composite from Lava Tube
410, 540, 940 nm

MSolo (Mass Spectrometer Observing Lunar Operations)

Capable of measuring low-molecular weight volatiles between 1-100 amu along traverses and from drill cuttings piles

Avionics

Sensor & Cal Gas



Modified COTS instrument based on ***INFICON's Transpector® MPH*** high performance quadrupole mass spectrometer designed for residual gas analysis

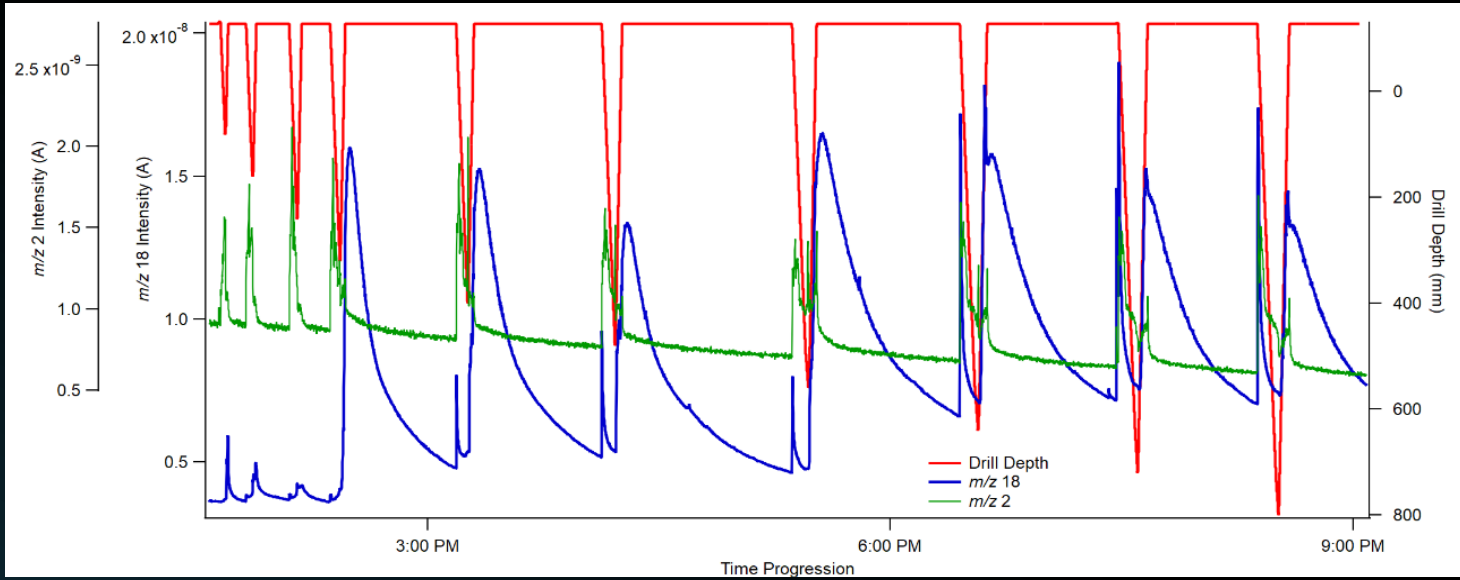
Key Measurements:

- Identify low-molecular weight volatiles between 1-70 amu with unit mass resolution (H_2, HD, He, H_2O, CH_4, N_2, CO, O_2, H_2S, Ar, CO_2, HCN, SO_2 , etc)
- Methods completely customizable to focus on masses between 1-100amu, methods can be changed during mission and uploaded to respond to data as it's collected
- Can switch between a full scan for analysis of total inventory of volatiles and then go to a focused analysis on species of interest or bulk isotope measurements
- Electron multiplier detector allows for low signal detection while faraday cup can measure higher gas loads
- Cross beam ion source has enhanced directional sensitivity to optimize for measurement of species from a specific source vs background
- Adjustable ion source settings allow for variable ionization energy - nominally run at 70eV for comparison to NIST spectra, can be varied to distinguish between isotopologues and avoid isotope interferences
- Dual filaments for redundancy and longer operational lifetime
- Contamination cover (non-hermetic) to prevent contamination prior to lunar landing
- Gas calibration system that can be used to measure instrument sensitivity in addition to mass tuning, capable of supporting over 50 individual calibration activities

MSolo Observation Possibilities

- A variety of species are anticipated with amu between 1-100 am, including H_2, HD, He, H_2O, CH_4, N_2, CO, O_2, H_2S, Ar, CO_2, HCN, SO_2 , etc.
- Monitoring these gasses while driving can constrain regolith entrainment and release, including the binding energy for various species
- This will help constrain models of volatile transport including lander exhaust plume contamination
- Measuring outgassing of various species from drill cuttings pile will constrain the absolute concentration of these volatiles at depth
- Identification and mapping of potentially hazardous / toxic compounds, e.g. H_2S

MSolo data from TVAC testing with TRIDENT-analog at GRC showing H_2 & H_2O ion trace while drilling



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

TRIDENT Objectives:

- Deliver subsurface regolith to surface for analysis by MSolo and NIRVSS in 10 cm bites from a depth of up to 100 cm
- Measure subsurface temperature

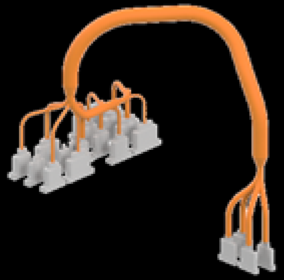
TRIDENT consists of:

- Drill Mechanism & Launch Locks
- Avionics
- Cable Harness

Parameter	Value
Bit Diam. (mm)	25.4
Nominal Auger Spin (RPM)	90
Auger Average Power Consumption (W)	50 – 150
Percussion Impact Energy (Joules/Blow)	2
Feed Stage Stroke (mm)	1240
Maximum Drill Depth (mm)	1020
Deployment Stage Stroke (mm)	380
Z Stage Force Cont. (N)	500
Drill and Launch Locks Mass (kg)	20
Avionics + Harness Mass (kg)	8

Avionics
(Not to Scale)

Cable Harness
(Not to Scale)



TRIDENT Observation Possibilities

TRIDENT can obtain the following science data:

- Geotechnical properties of regolith
- Volatile concentration and physical state of ice
- Thermal properties of regolith

TRIDENT data can constrain and/or supplement data from MSolo, NIRVSS, NSS

Some data products can be used as is (*) and some need modeling/analysis (#)

Cuttings cone (*):

- Angle of Repose
- Density at Dr of ~0%

Footpad sinkage provides (#):

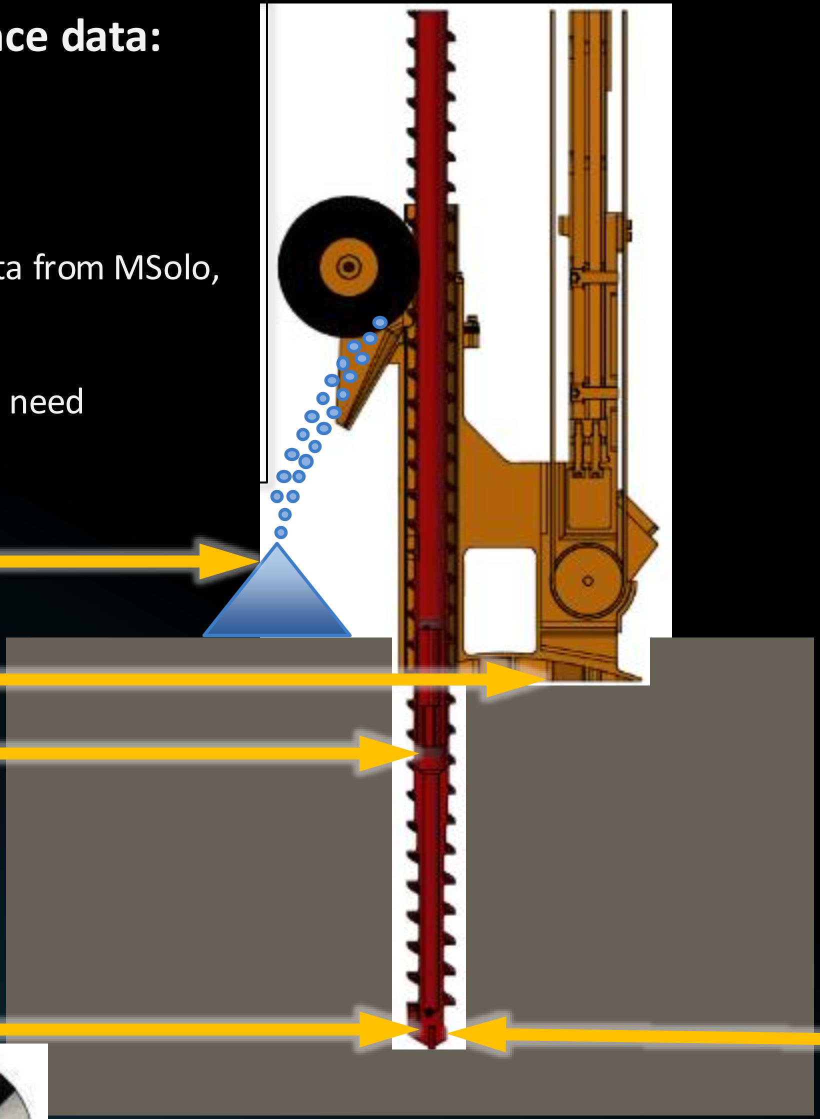
- Bearing capacity

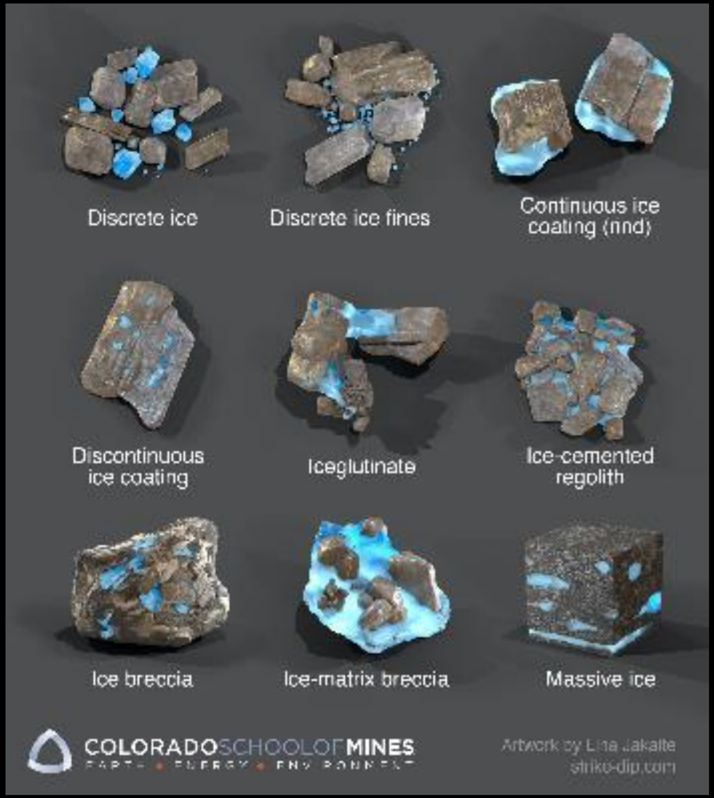
Heater (#):

- Thermal Conductivity (with Temp. Sensor)

Bit Temperature Sensor (#):

- Subsurface Temp vs Depth



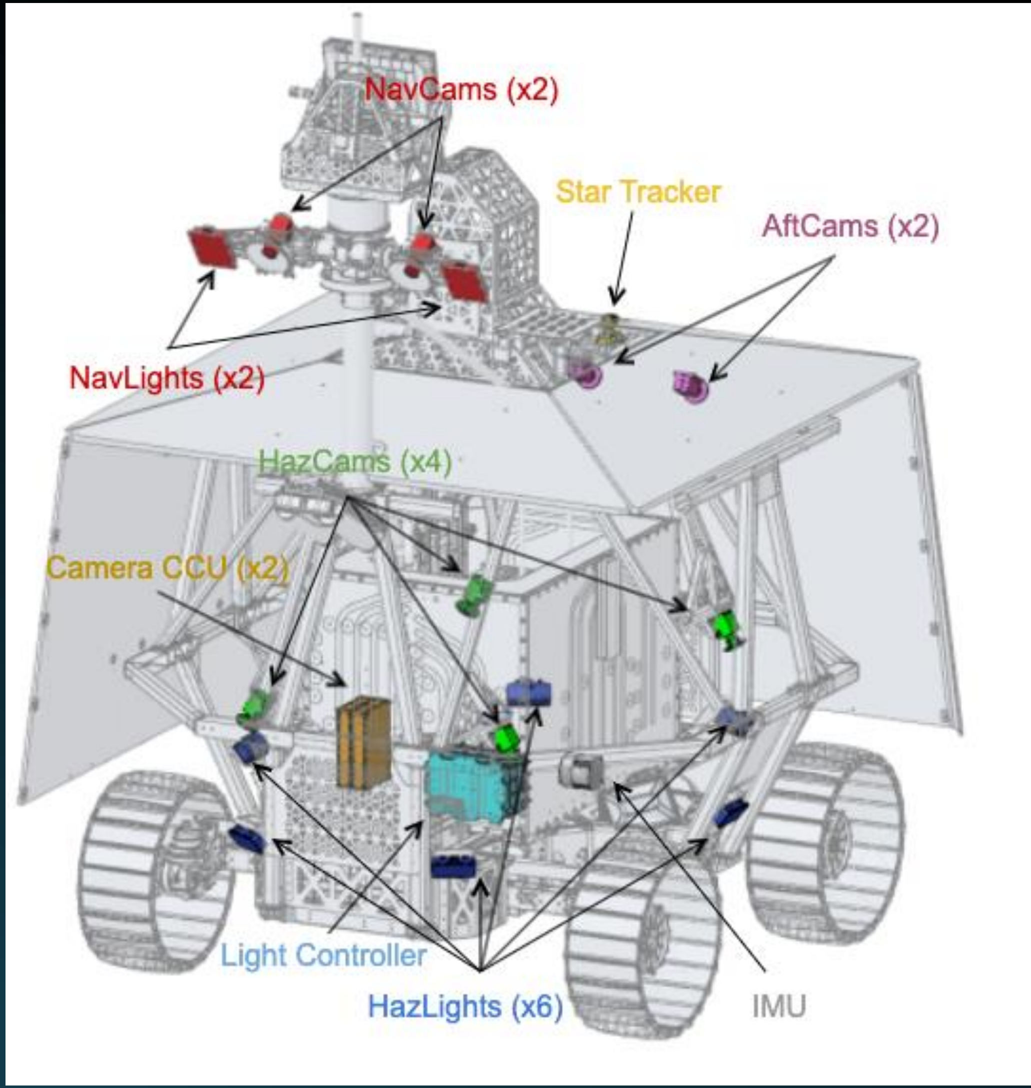


Courtesy Kevin Cannon

Drilling Power (#):

- Material Strength vs. Depth
- Water-ice concentration
- Loose ice grains vs ice cemented regolith

VIPER Visible Imaging System (VIS)



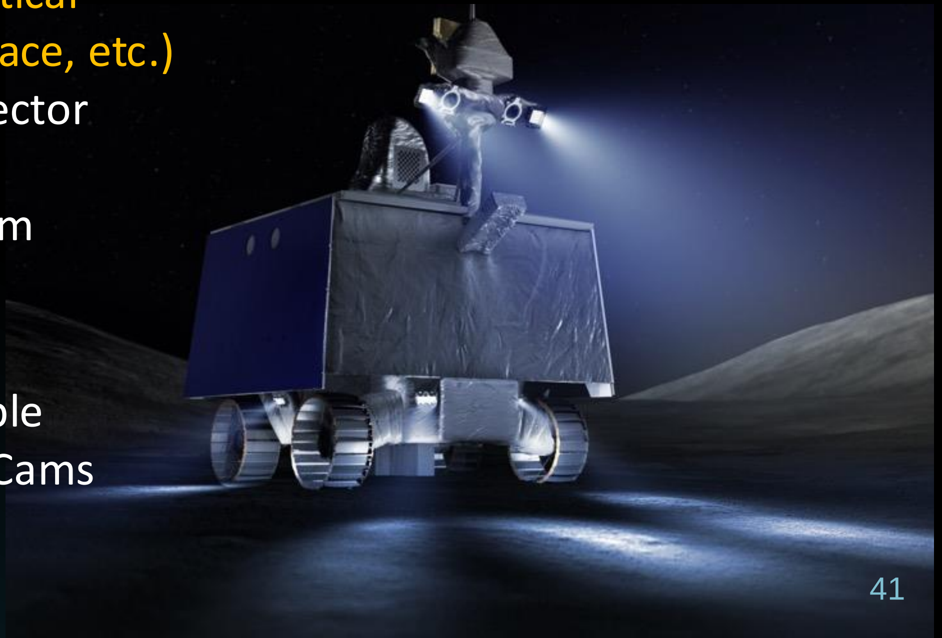
NavCams
- Stereo, PTU-mounted
- 65° FoV
- Can resolve (>= 5 pixels)
  - 10 mm features at 2 m
  - 55 cm features at 20 m

AftCams
- Stereo, body-mounted aft
- 110° FoV

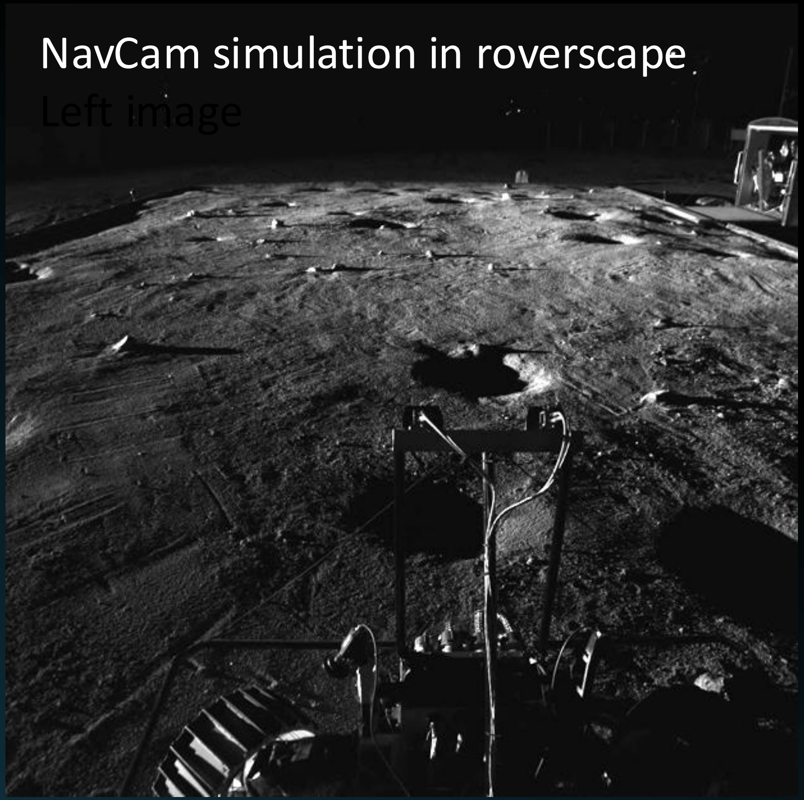
HazCams
- Mono, looking at each wheel
- 110° FoV

All camera bodies are identical (detector, hardware, interface, etc.)
- 2048 x 2048 CMOS detector
- 12-bit grayscale range
- bandpass: 425 to 495 nm

Luminaires (LED lights):
- Independently operatable
- 2 PTU-mounted by NavCams
- 6 around base of rover

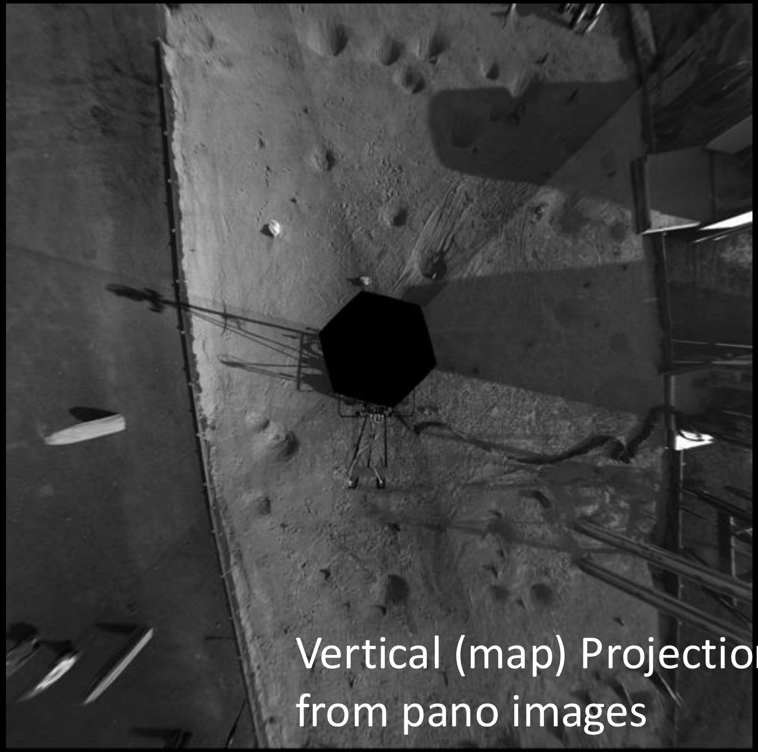


VIS Observations and derived products



NavCam simulation in roverscape
Left image

HazCam simulation in Regolith Lab

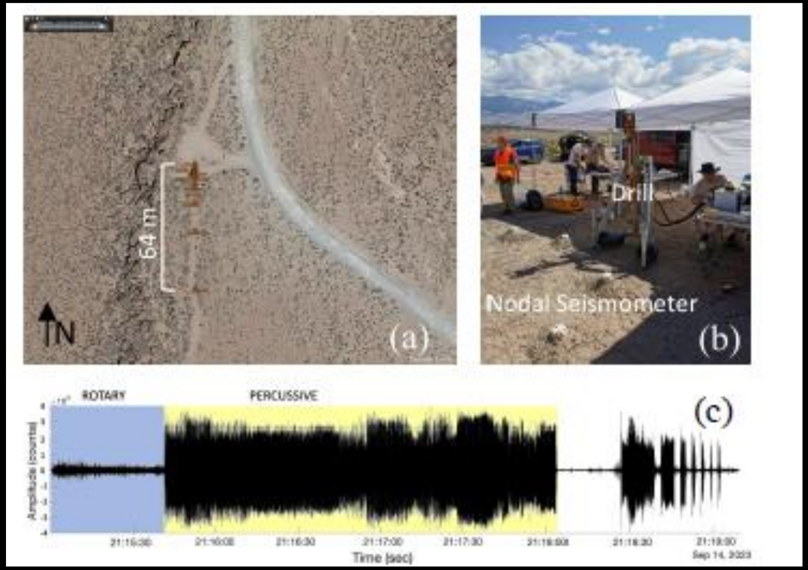


Vertical (map) Projection
from pano images

Panoramic Projected images

Rover Data

Example of seismic waveforms from the rotary and percussive mode of a TRIDENT-analog instrument, Gansler et al., 2024



IMU (Inertial Measurement Unit)

Gravity Measurements

- IMU is used during traverse to measure lunar gravity, looking for anomalies that correspond to changes in bulk mass/structure bellow the rover
- Has been demonstrated on Mars Curiosity
- Relative Time Sequences (RTS) developed to capture IMU data at 10 Hz at waypoints

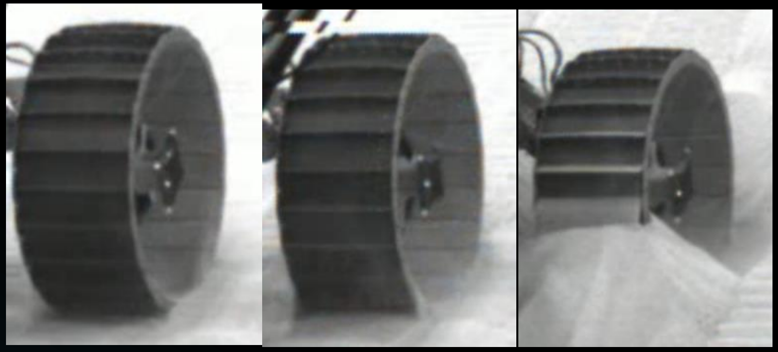
Seismic Measurements

- IMU can be used during drilling to measure returned signal from TRIDENT percussions
- Sensitive to subsurface structure and ice down to ~3 meters
- RTS developed to capture IMU data at 100 Hz for fixed duration while TRIDENT commands individual percussions

Other rover data

Other rover data can be used to ascertain rover slip, wheel load profile and wheel degradation to inform rover performance and regolith properties, especially as they relate to mobility and durability

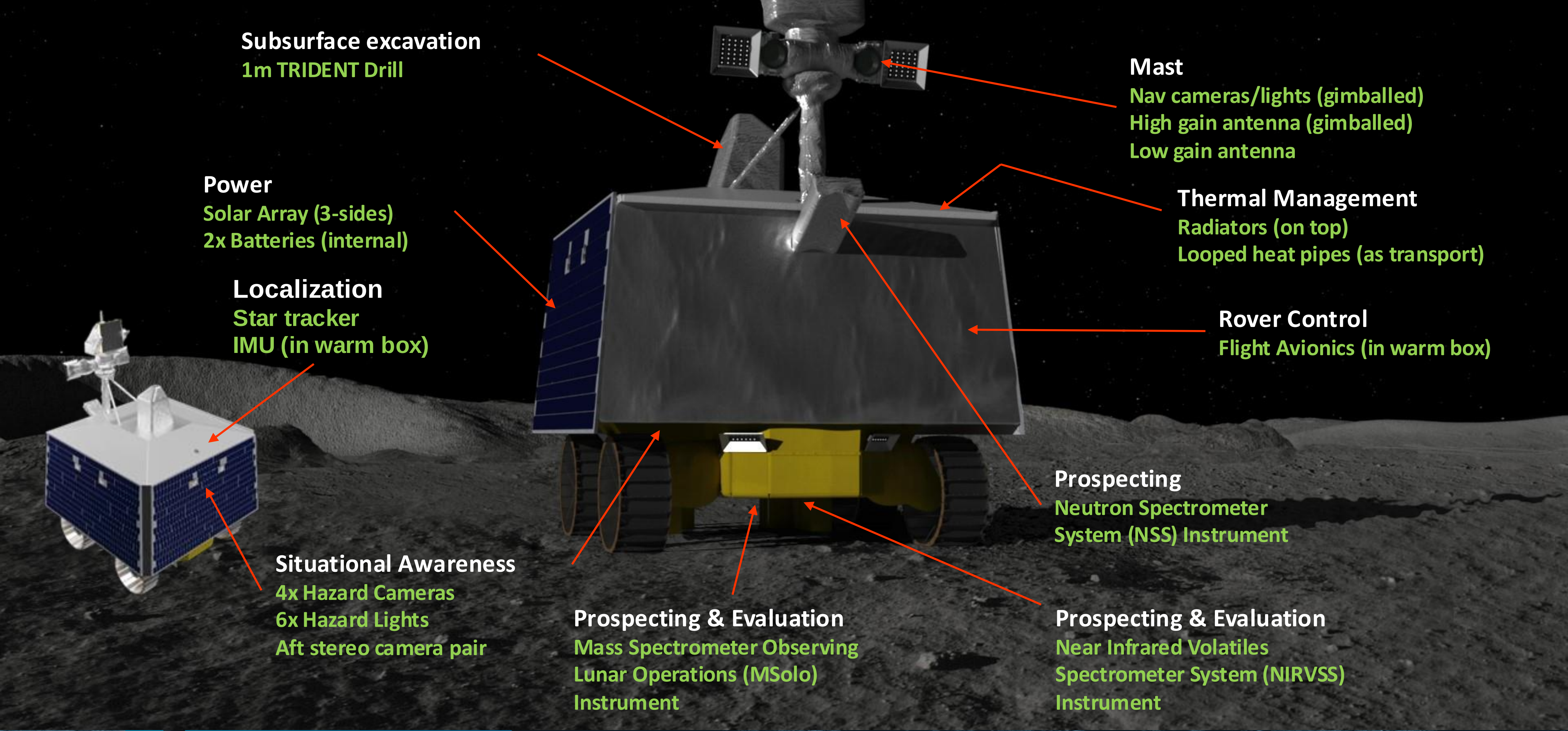
Wheel sinkage vs slope testing at GRC



Roving Platform

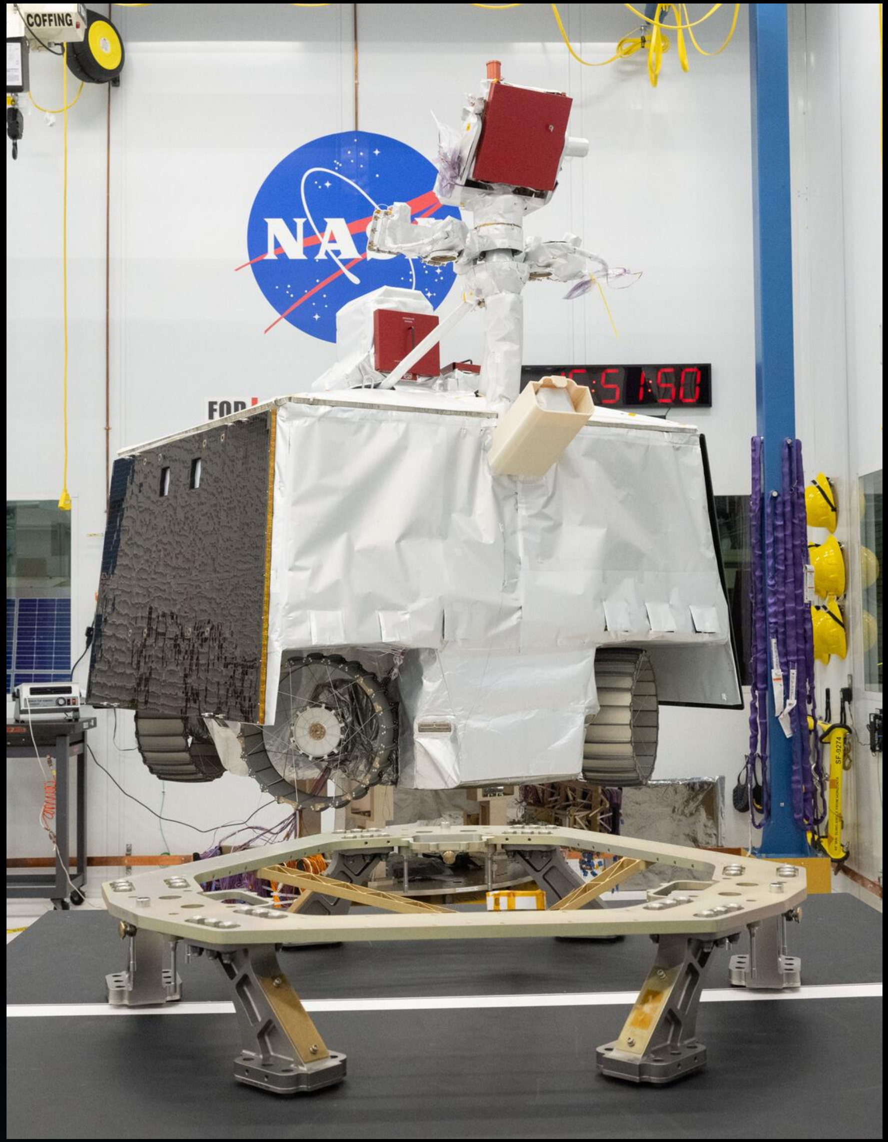
(Bill Bluethmann/Terry Fong)

VIPER Rover


Subsurface excavation
1m TRIDENT Drill
Power
Solar Array (3-sides)
2x Batteries (internal)
Localization
Star tracker
IMU (in warm box)
Situational Awareness
4x Hazard Cameras
6x Hazard Lights
Aft stereo camera pair
Prospecting & Evaluation
Mass Spectrometer Observing
Lunar Operations (MSolo)
Instrument
Mast
Nav cameras/lights (gimballed)
High gain antenna (gimballed)
Low gain antenna
Thermal Management
Radiators (on top)
Looped heat pipes (as transport)
Rover Control
Flight Avionics (in warm box)
Prospecting
Neutron Spectrometer
System (NSS) Instrument
Prospecting & Evaluation
Near Infrared Volatiles
Spectrometer System (NIRVSS)
Instrument

Rover Specifications

- **Mass:** launch = 490kg, roving = 447kg
- **Dimensions:** 1.7m x 1.7m x 2.5m
- **Power:** solar array generation with battery storage
  - **Solar generation:** 450W (corner-facing) or 320W per array
  - **Battery capacity (beginning of life @ 0C):** 5420 W-hr
- **Communications:** X-band DTE/DFE [1]
  - **Transmit**: 250sps/8Msps (min/max)
  - **Receive**: 250sps/75ksps (min/max)
  - Gimballed high gain antenna, fixed low gain antenna
- **Thermal system**
  - **Architecture**
    - MLI wrapped warm box containing avionics
    - Passive looped heat pipes, radiators, & warm box
    - Thermal control value on each heat spreader to start/shutdown radiators
  - **Shadow capabilities**
    - 50+ hours survival (hibernation) in low power mode
    - 9 hours ops in Permanently Shadowed Region (PSR)



VIPER Rover and Rover Release Mechanism

[1] DTE = Direct-To-Earth / DFE = Direct-From-Earth

Mobility System

- **Locomotion Design**
  - 12-DOF: independent drive + steering + suspension
  - Drive: top speed 20cm/s, nominal speed 10 cm/s
  - Steering: explicit with +/-50 deg range
  - Suspension: adjustable with downforce control
  - Wheels: 50 cm diameter with 2.5 cm grousers
- **Terrain Performance**
  - Slopes up to 15 deg and obstacles to 15 cm
  - Adjustable ground clearance from 7- 43cm
- **Drive modes**
  - Primary: Waypoint driving with nominal 4-5m steps
  - Other: point turn, precision movement, individual actuator, hybrid "gaits" (combined drive-steer-suspension) for embedding/entrapment recovery
- **Testing**
  - Mobility system qualified to 20 km
  - Hundreds of test hours (driving, egress, slip and embedding) with multiple engineering units

Mobility testing at GRC SLOPE (video)

Wheel endurance test (video)

Hybrid gait testing (video)

Navigation System

- **Sensors**
  - **Navigation Cameras (65 deg FOV, 2048x2048 pixel, 12-bit)**
    - Gimballed stereo pair on mast
  - **Hazard cameras (110 deg FOV, 2048x2048 pixel, 12-bit)**
    - 4x wide angle mono hazard cameras in wheel wells
  - **Aft cameras (110 deg FOV, 2048x2048 pixel, 12-bit)**
    - Fixed stereo pair on aft chassis
  - **Lights: 2x mast (gimbaled) + 6x body fixed / custom LEDs**
  - **Inertial Measurement Unit (IMU) + Star Tracker**
- **Functions**
  - **Absolute localization**: 20m (95% confidence)
    - Terrain relative navigation using visual odometry, 3D point matching to high-res (1 m/pixel) DEMs
  - **Relative localization:** 3m over 224m (95% confidence)
    - Star tracker, wheel odometry, and IMU
  - **Terrain hazard detection**
    - Up to 8m range for obstacles greater than 10 cm
    - Hazard maps provide decision support to rover driver
  - Maintain HGA **antenna pointing** at Earth while roving

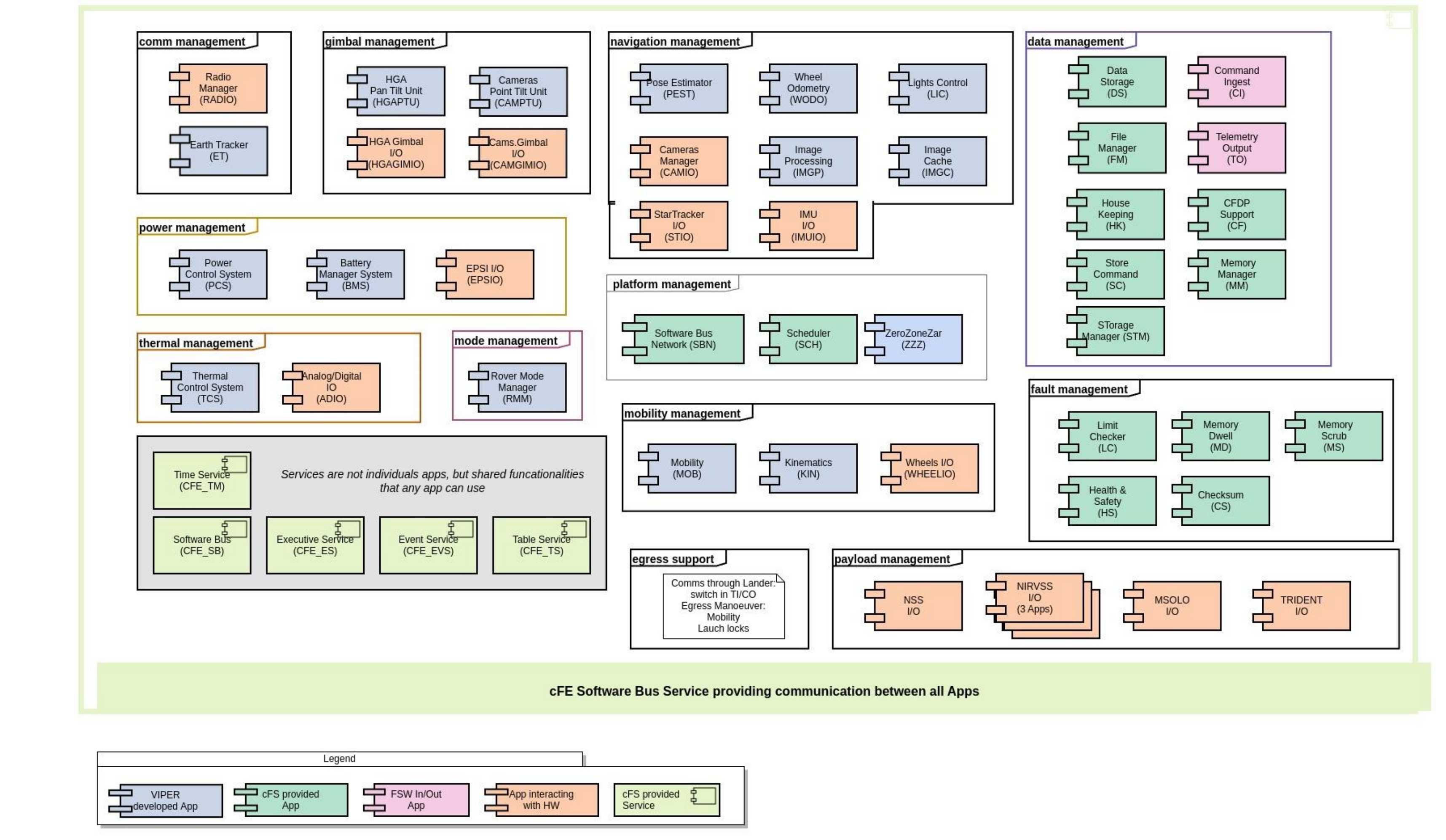
View from Haz Cam

Nav Light burn-in test (video)

Pointing while roving test (video)

Rover Flight Software (RFSW)

- Runs on-board the rover on rad-hard (RAD 750) and rad-tolerant (AiTech SP0-S) CPUs
- Provides low-level hardware interfaces, mobility control, waypoint driving, odometry, error checking, and device/payload services. Built on Core Flight System (cFS).



RAD 750 and SP0-S custom drivers and boot management

14 cFS apps

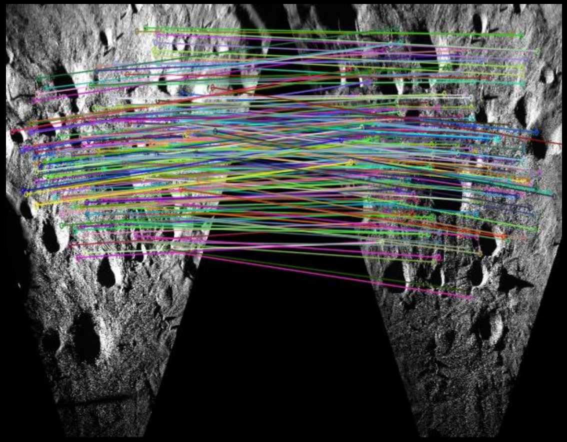
36 custom apps

8,361 automated tests (end-to-end, interface, & unit)

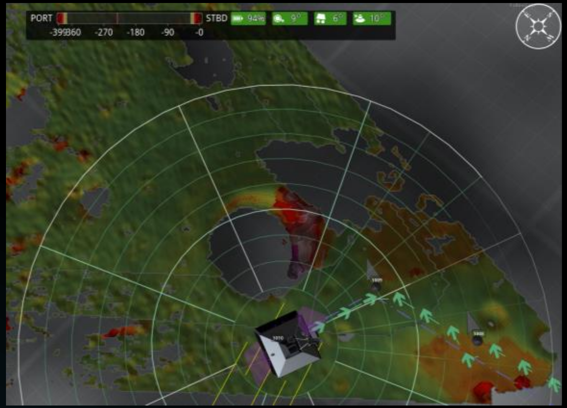
Multi-platform (x86 Linux and PowerPC VxWorks)

Rover Ground Software (RGSW)

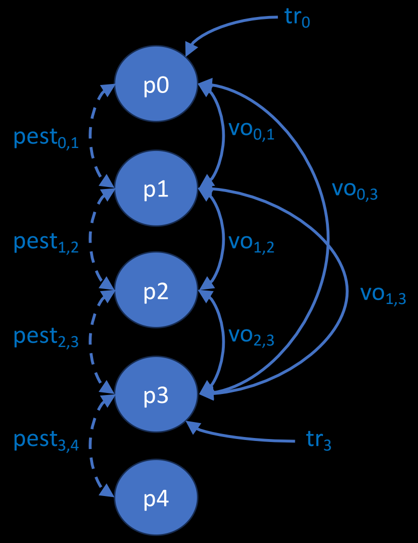
- Some “flight software” functions have been implemented in the Ground Data System and run “off-board” at mission control on desktop computing.
- Performs navigation, mapping, and generation of rover driver decision support data (e.g., hazard maps).
- Innovations
  - Implemented as an ensemble of Robot Operating System 2 (ROS2) nodes
  - Relative pose estimation using stereo-vision visual odometry (VO)
  - Absolute pose estimation using stereo-vision terrain registration (TR) for 3D point matching to high-res orbital DEM
  - Pose Corrector (PC) combines on-board pose estimate with VO and TR to achieve best estimate of current pose **and** past trajectory (continuous refinement)
  - Automated geometric terrain hazard assessment for “hazard map” generation



Visual odometry



Hazard map

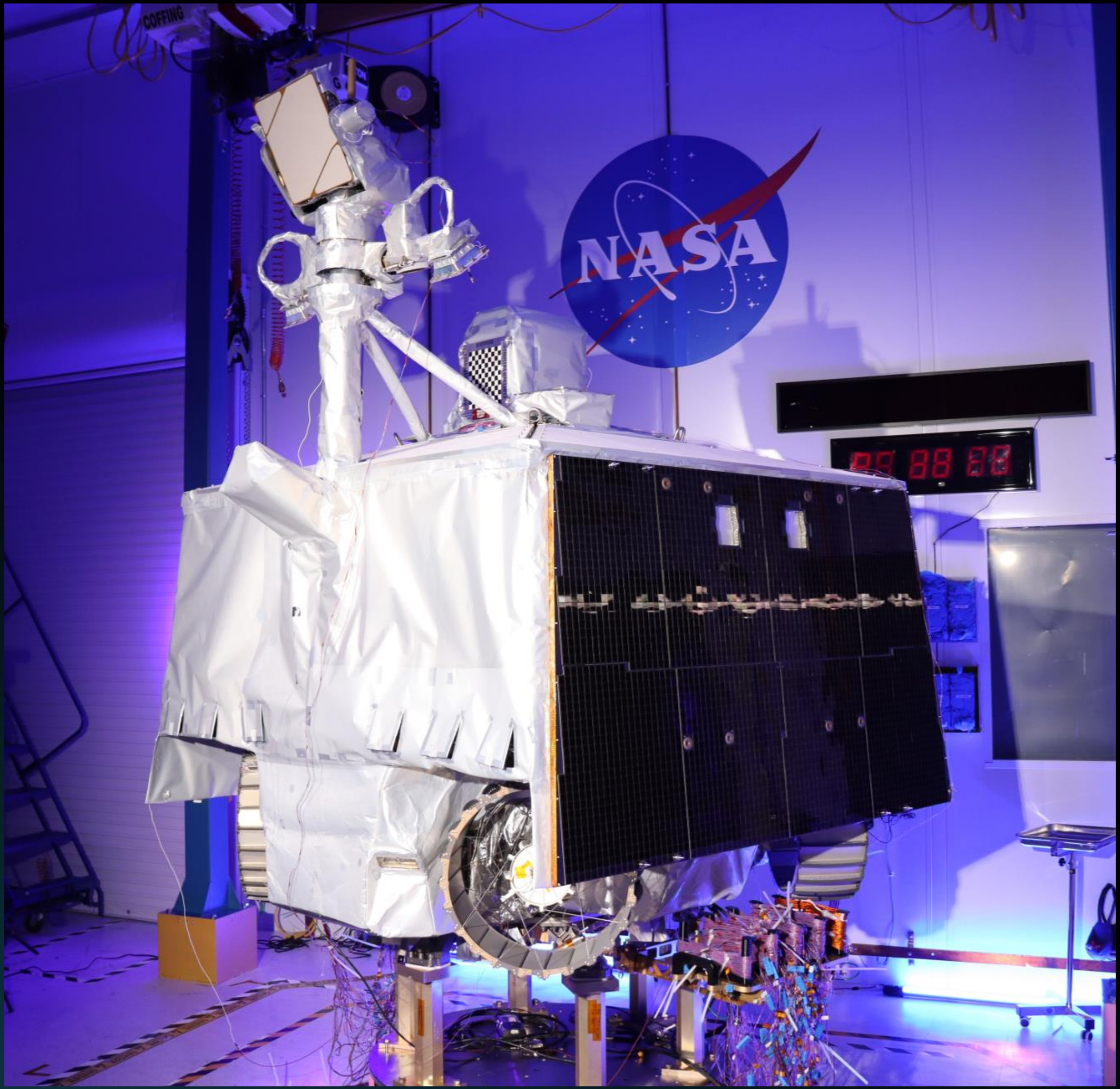


PC uses a factor graph to continuously refine pose estimates

Rover Simulation Software (RSIM)

- High-fidelity real-time lunar rover simulator for development, V&V, and ops training. Customized Gazebo with lunar lighting, precision camera models, slip models, and more.
- Incorporates high-resolution (1 m/pixel) photoclinometry-based DEMs and high-quality synthetic terrains (4 cm/pixel), both produced using NASA Ames mapping software

VIPER Rover

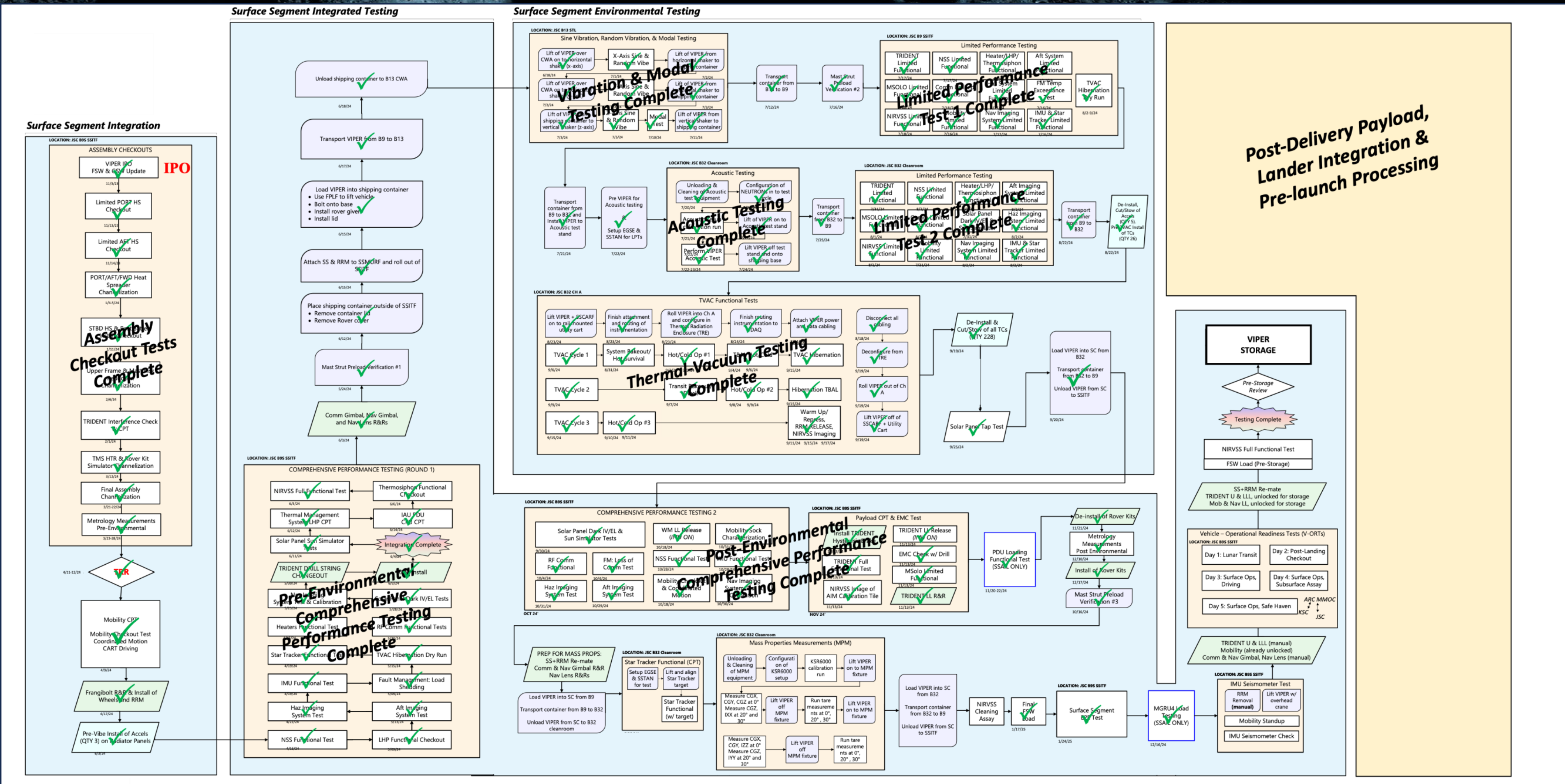


ISO 8 Controlled Work Area
Building 9 South
Johnson Space Center

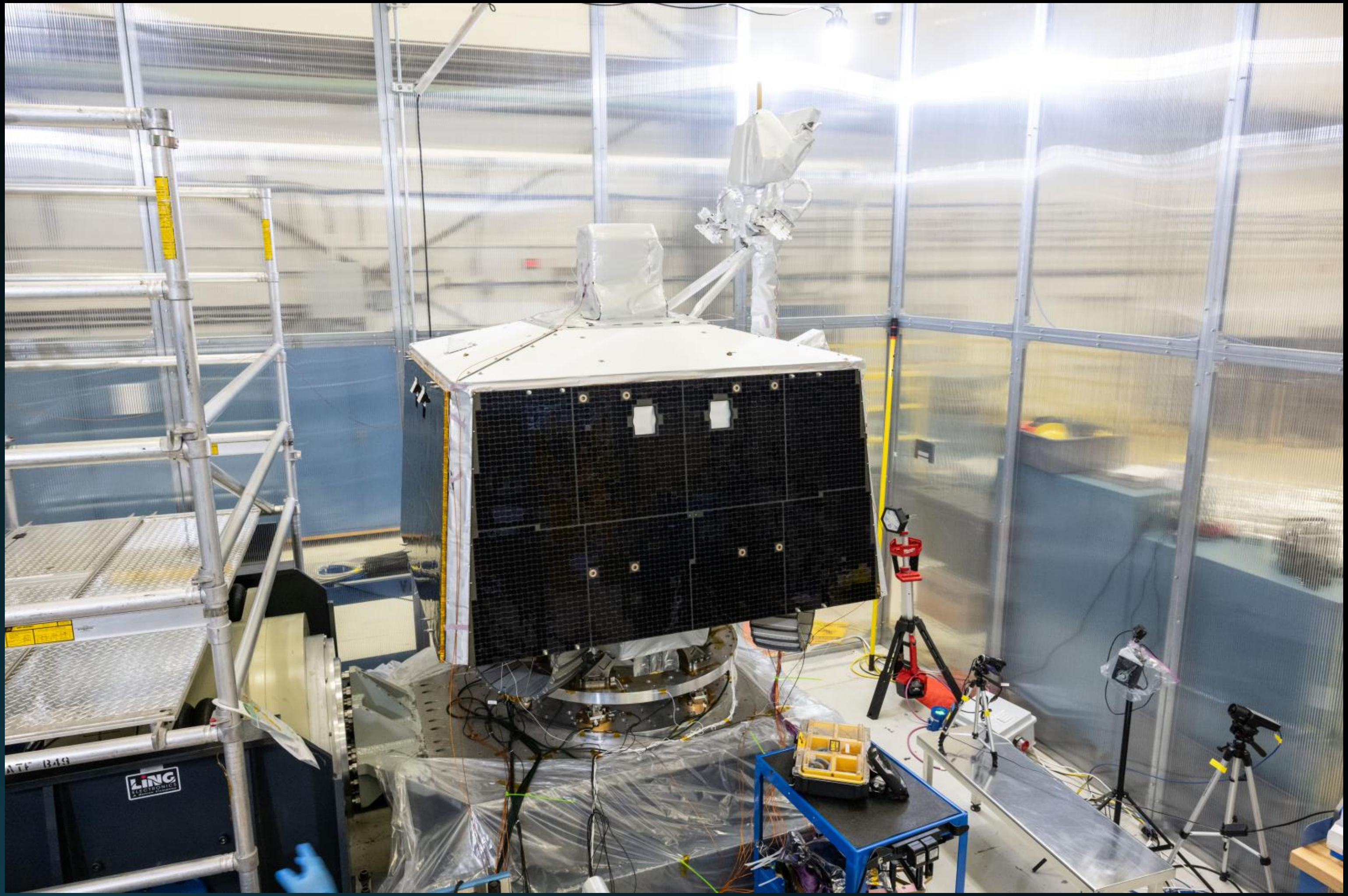
VIPER System Level Testing

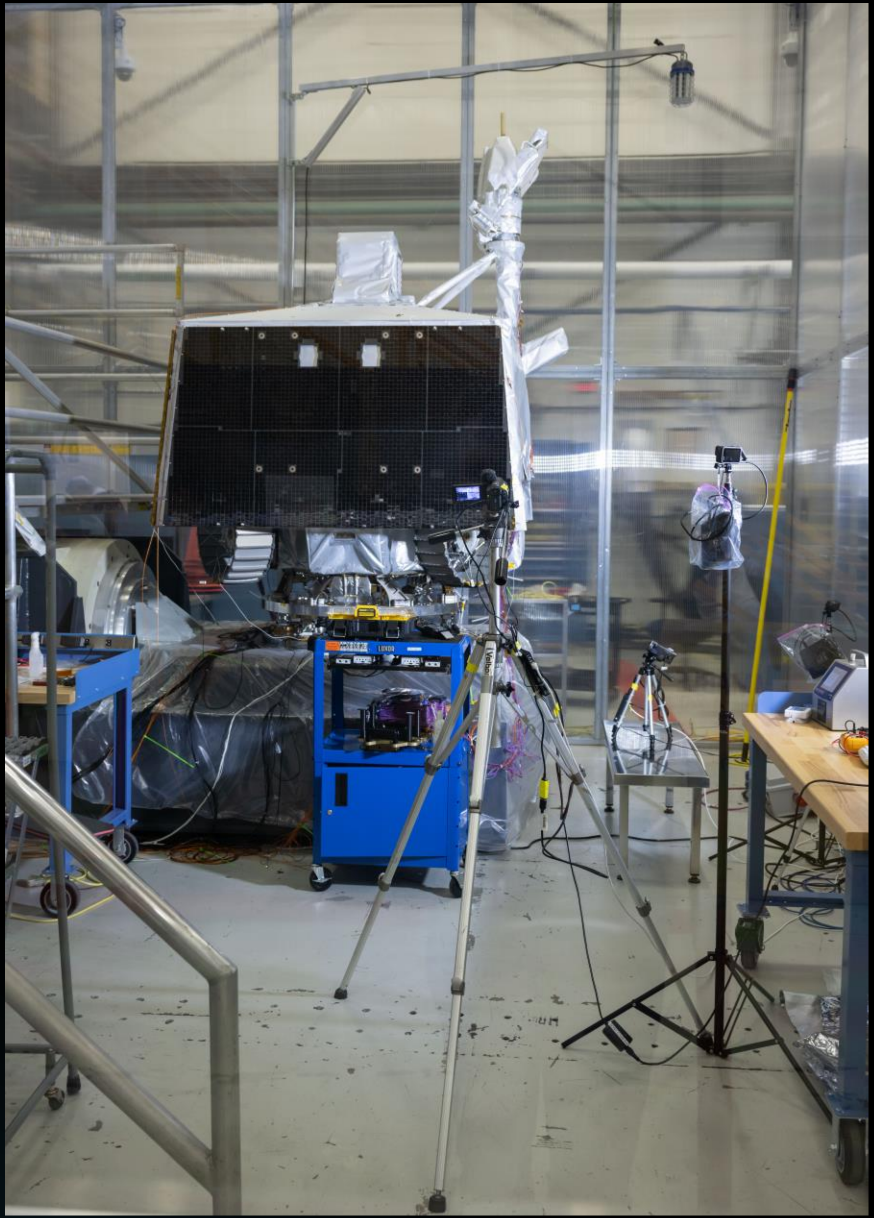
(David Petri)

VIPER Flight Vehicle Test Campaign



VIPER Rover Vibration Testing





ISO 8 Controlled Work Area
Building 13 Structural Test Lab
Johnson Space Center

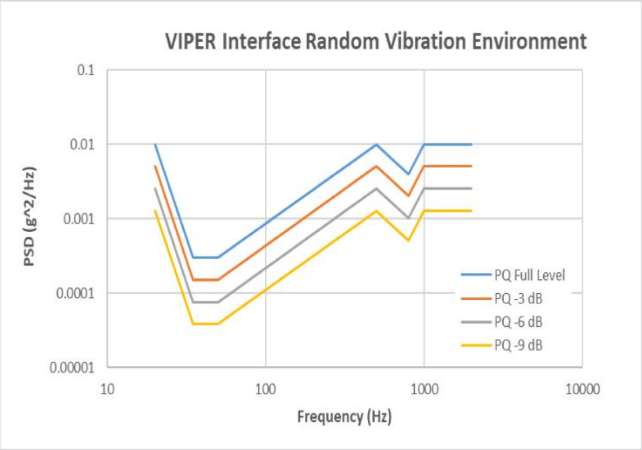
June 6 – July 5, 2024

Vibration Test Environments

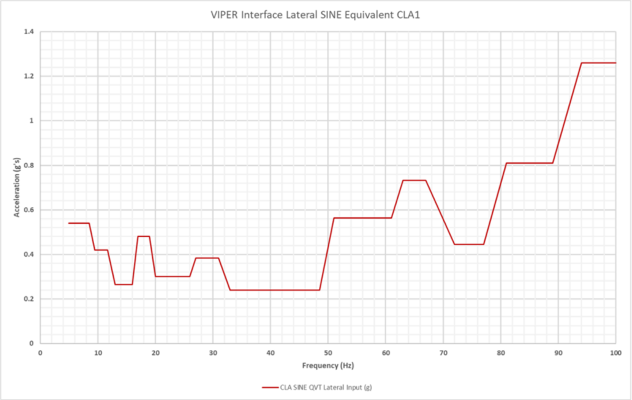
Note:
- VIPER rover tested based on previous lunar delivery vendor (CLPS)
- VIPER has further margin beyond what was tested for other partner arrangements

Same profiles for X, Y , and z test configurations.

PQ Random Spectra				
Freq (Hz)	PQ -9 dB	PQ -6 dB	PQ -3 dB	PQ (g^2/Hz)
20	0.001259	0.002512	0.005012	0.01
35	0.000038	0.000075	0.000150	0.0003
50	0.000038	0.000075	0.000150	0.0003
500	0.001259	0.002512	0.005012	0.01
800	0.000504	0.001005	0.002005	0.004
1000	0.001259	0.002512	0.005012	0.01
2000	0.001259	0.002512	0.005012	0.01
Grms	1.385	1.957	2.764	3.904
Duration (seconds)	30.	30.	30.	60.



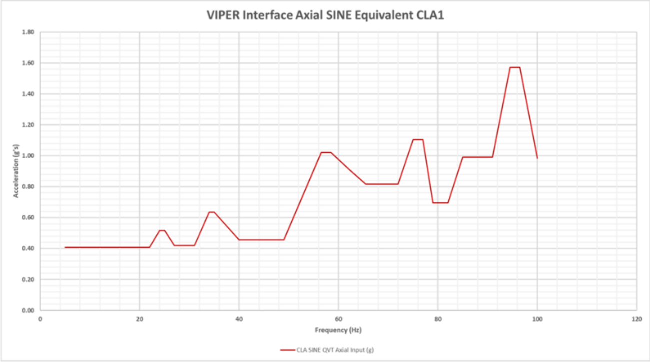
Sine CLA Input – Lateral Axes (X, Y)
Includes 1.2 Factor



CLA SINE XY-Axes QVT	
Freq (Hz)	Lateral Input (g)
5	0.54
8.5	0.54
9.5	0.42
11.7	0.42
13	0.26
16	0.26
17	0.48
19	0.48
20	0.30
26	0.30
27	0.38
31	0.38
33	0.24
48.5	0.24
51	0.56
61	0.56
63	0.73
67	0.73
72	0.44
77	0.44
81	0.81
89	0.81
94	1.26
100	1.26

2 oct/min, 2 min 10 secs duration

Sine CLA Input – Vertical Axis (Z)
Includes 1.2 Factor



CLA SINE Z–Axis QVT	
Freq (Hz)	Axial Input (g)
5	0.41
15.5	0.41
22	0.41
24	0.52
25	0.52
27	0.42
31	0.42
34	0.64
35	0.64
40	0.46
49	0.46
56.5	1.02
58.5	1.02
62.5	0.90
65.5	0.82
69	0.82
72	0.82
75	1.10
77	1.10
79	0.70
82	0.70
85	0.99
91	0.99
94.5	1.57
96.5	1.57
100	0.98

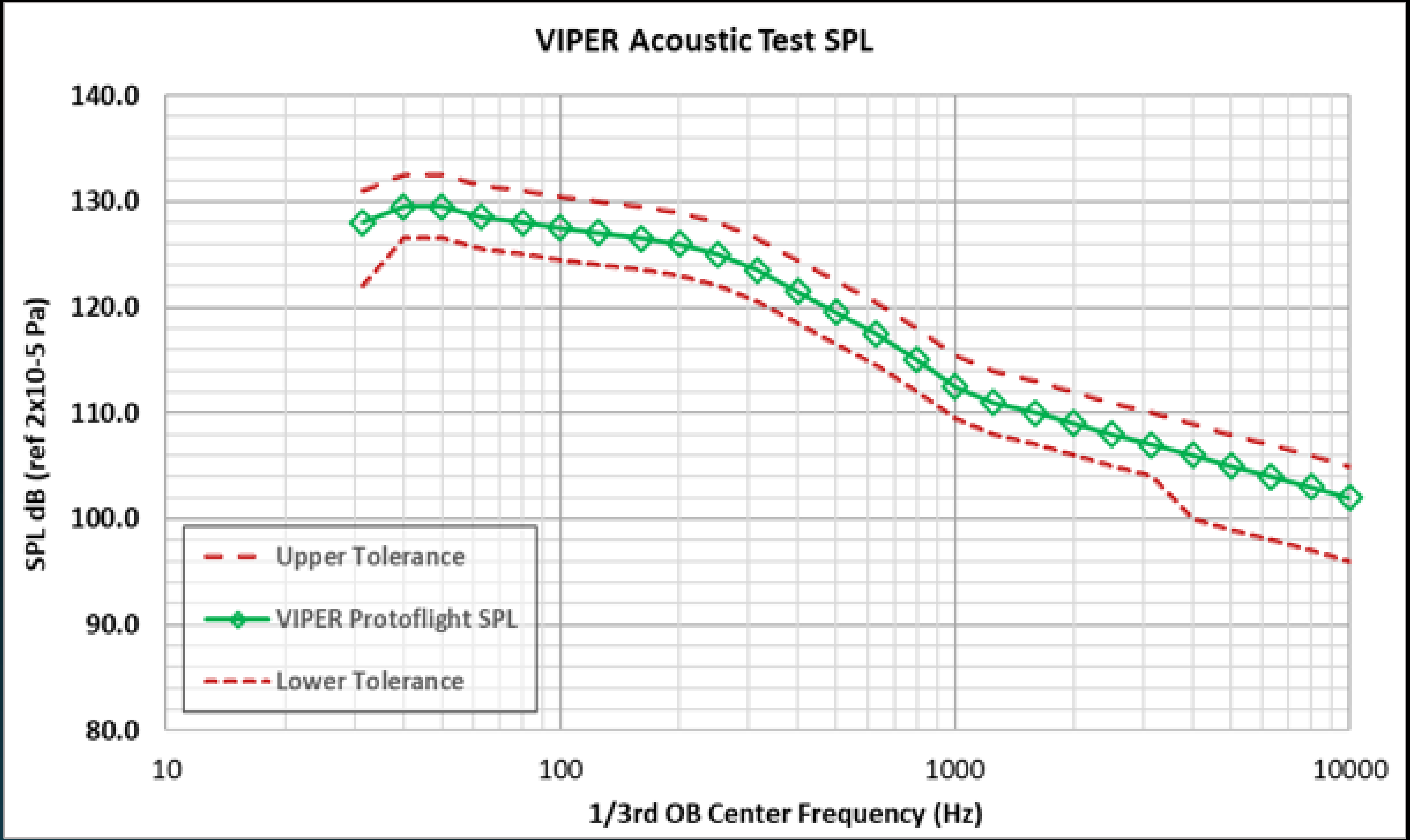
2 oct/min, 2 min 10 secs duration

VIPER Rover Acoustic Testing

July 22-23, 2024

Chamber A Cleanroom
Building 32
Johnson Space Center

Acoustic Test Environment



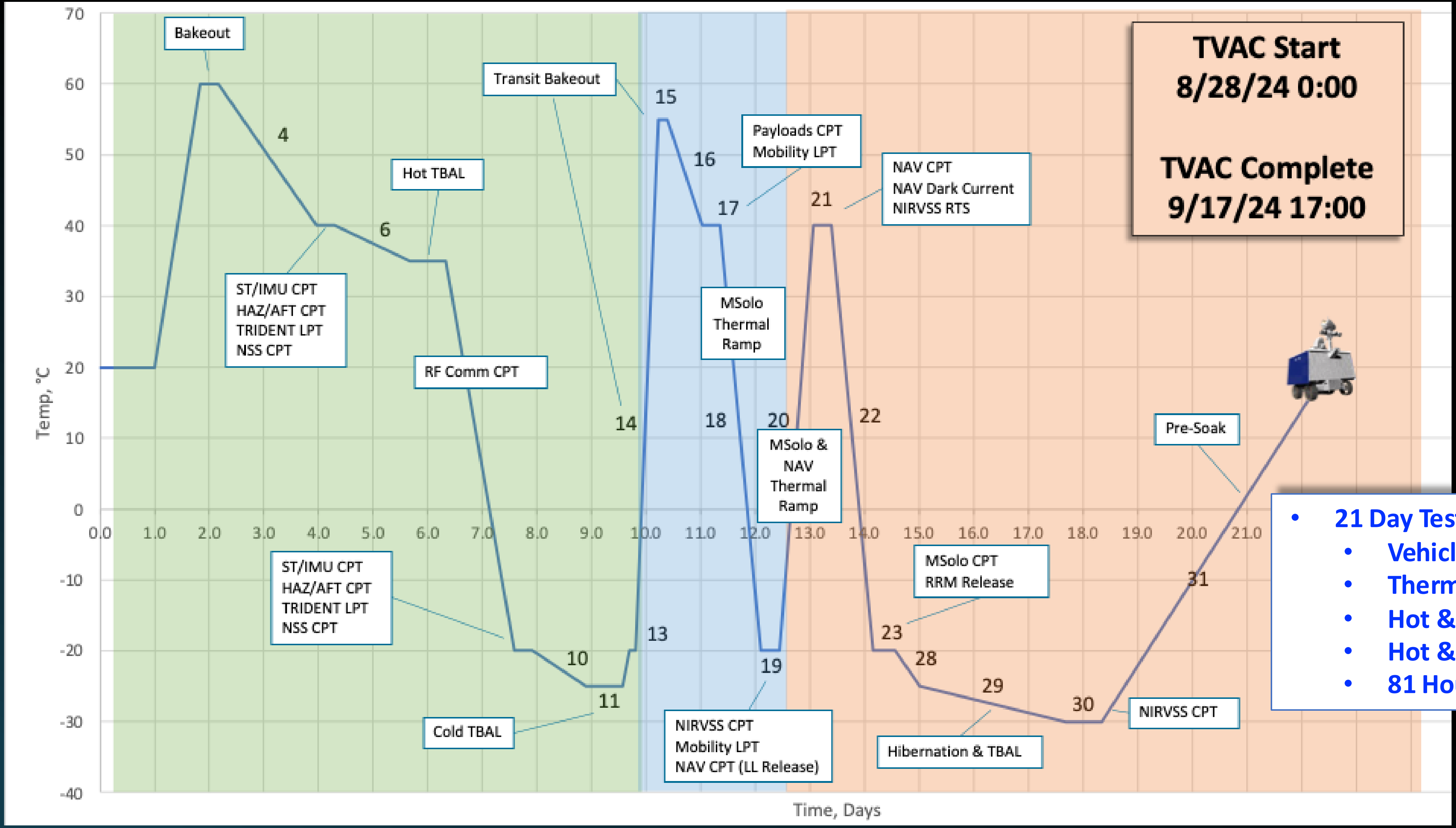
As Tested Acoustic Profile

VIPER Thermal-Vacuum Test

Space Environment Simulation Lab
Thermal-Vacuum Chamber A
Building 32
Johnson Space Center

Aug 28 – Sept 17, 2024

VIPER Rover Thermal-Vacuum Test



- **21 Day Test with 3 Thermal Cycles, including:**
  - **Vehicle Bake-outs**
  - **Thermal Balance Hot & Cold Ops**
  - **Hot & Cold Ramp Powered-on Tests**
  - **Hot & Cold Ops Powered-on Tests**
  - **81 Hour Hibernation Test**

Mobility Testbed

- Mobility platform equivalent to VIPER’s lunar surface weight
  - Engineering evaluation
    - Lander egress, lighting evaluation
    - Test anomaly investigations
  - Verification and Validation
    - Mobility, Software, Navigation
  - Operations training
  - Flight anomaly investigation
- Platform is re-configurable depending on test objectives, such as:
  - Adding camera systems, mast, lights
  - More representative of CG or MOI

Mobility Testbed with Haz/Nav lights on

Egress Testing w/Mobility Testbed

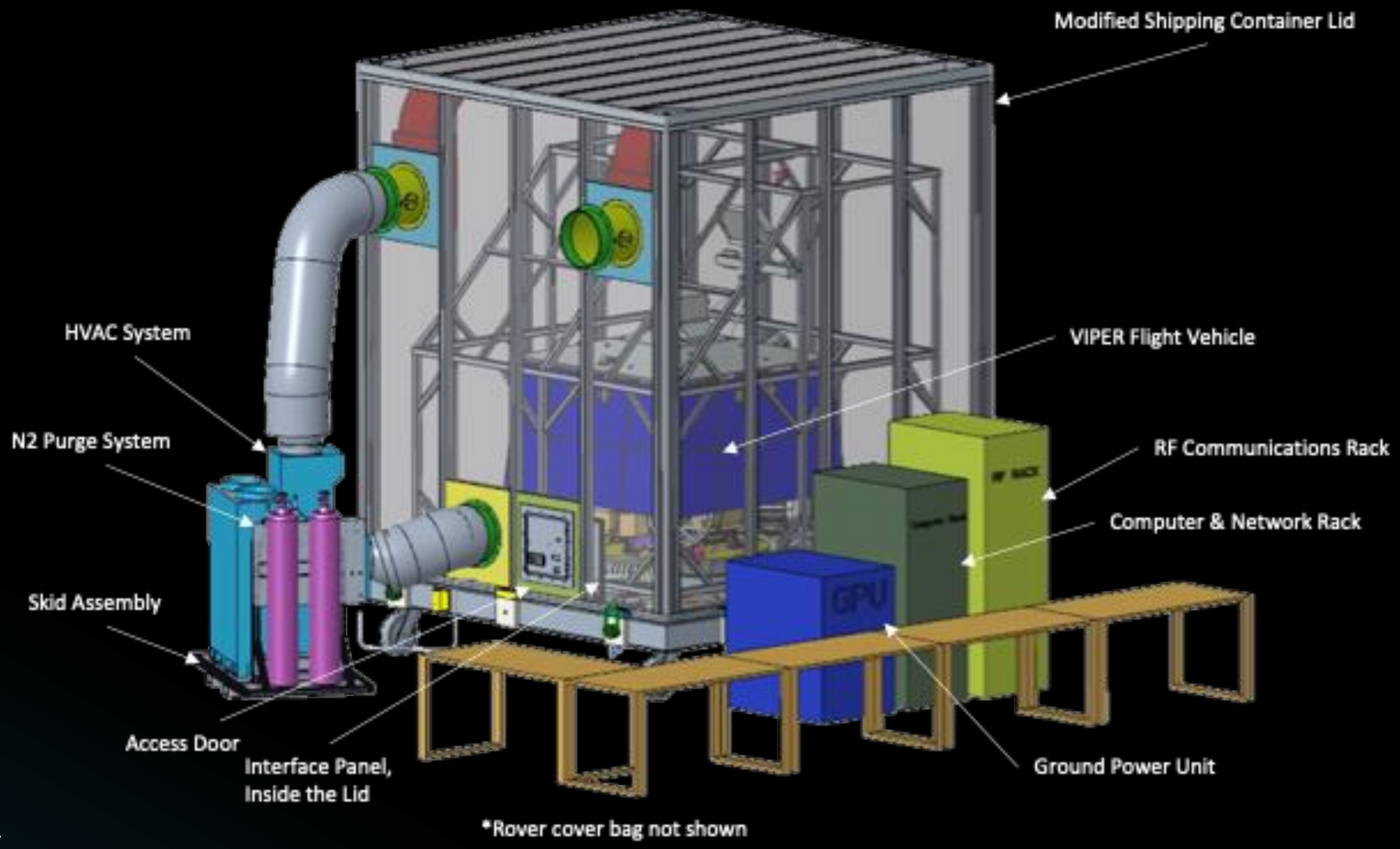
HGA comm gimbal pointing

Surface Segment Avionics Integration Lab (SSAIL)

- VIPER's high-fidelity avionics, power and software testbed (FlatSat)
  - Engineering development
  - Test procedure development and dry runs
  - Software regression testing
  - Anomaly investigations
- Full VIPER system functionality, including
  - Mobility Testbed mobility
  - Flight and ground software
  - GSE including ground power unit, load racks, RF comm rack
  - NSS, NIRVSS, MSolo, TRIDENT instruments
- All flight vehicle test procedures are validated in SSAIL before testing on vehicle

VIPER Long Term Storage

- The VIPER Shipping Container is being modified to accommodate long term storage and checkout of the Flight Vehicle
  - Environmental Control
    - Temperature
    - Humidity
    - Contamination
    - EMI/EMC
    - Electrostatic Discharge
  - Power, RF, Data & Instrumentation Pass-throughs
  - Cameras & Lighting
- Periodic Monitoring & Vehicle Checkout
  - 72-hour container operational inspection
  - 6-month Flight Vehicle Power-up
    - Verify vehicle functionality
    - Charge batteries to maintain 30-50% state-of-charge
    - Exercise motors to distribute lubricant



VIPER placed into Long Term Storage July 2025

Mission Systems: Operations, Science and Ground Systems

(Jay Trimble, Anthony Colaprete)

VIPER is Operationally Unique

The Lunar South Polar Environment and Vehicle Design

- Operational decisions
  - Vehicle is designed to take advantage of short Earth-Moon distance
  - Operational decisions and many software functions are ground-based
  - Command cycle is minutes
- Vehicle is solar powered and requires sun to operate, with batteries for shadow ops
  - Dynamic lunar polar lighting environment, shadow speed variable, can exceed rover speed
  - Requires the capability to plan for sun shadow movement
  - Provides little margin for any loss of mobility/anomaly situation
- Vehicle requires direct line of sight communication with Earth to operate
  - Dynamic comm environment, comm shadow speed variable
  - Requires comm shadow/traverse planning capability

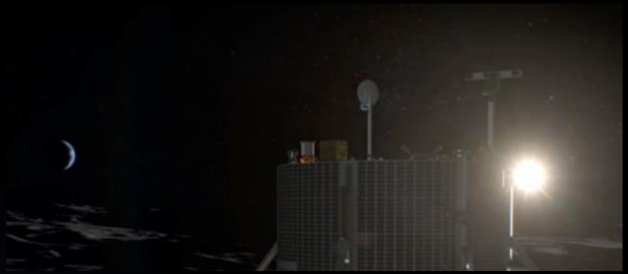
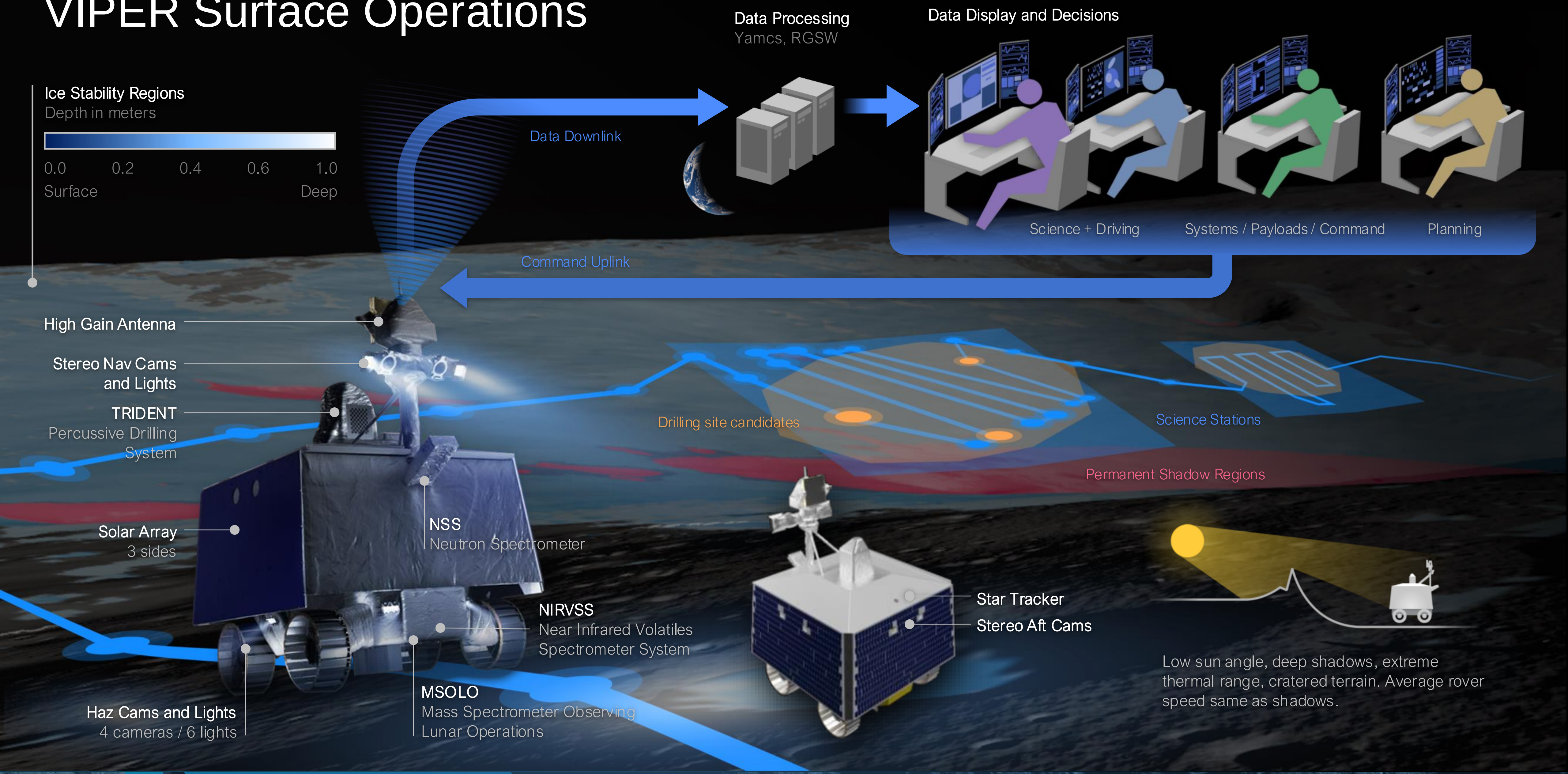


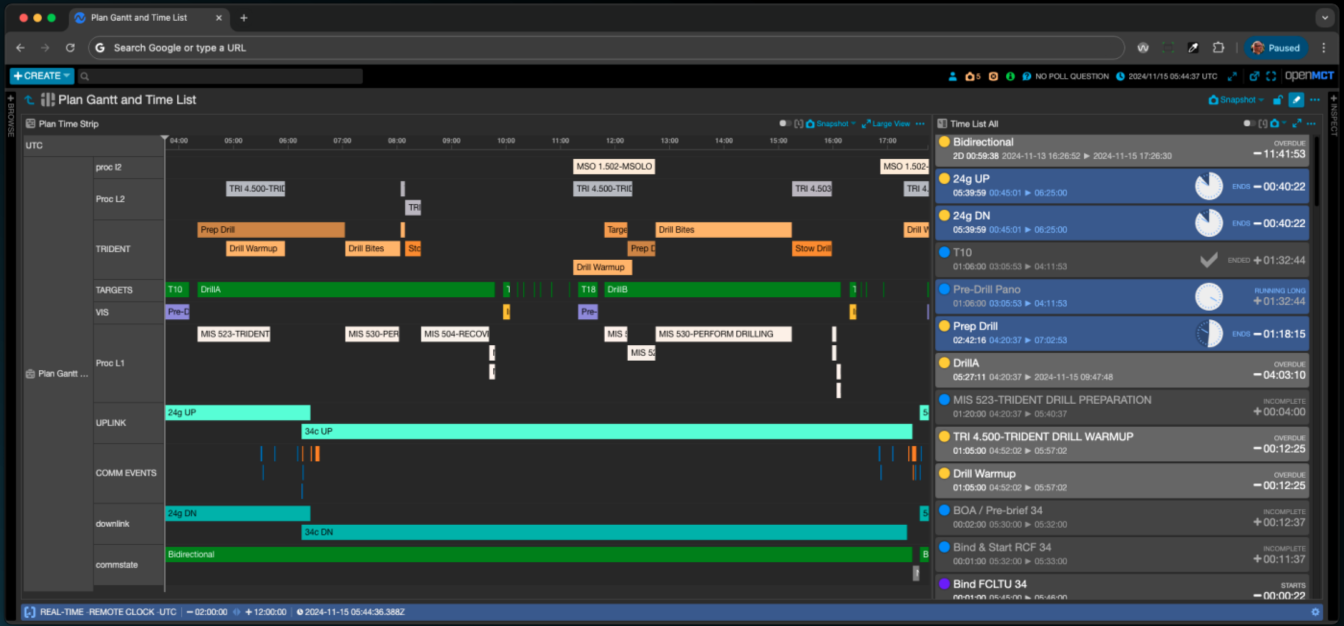
Image courtesy ESA

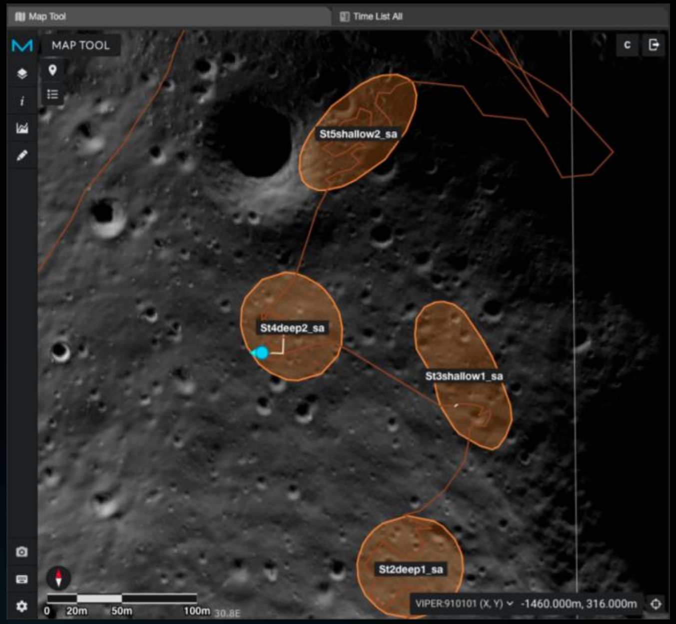
VIPER Surface Operations



VIPER is Operationally Unique (Cont.)

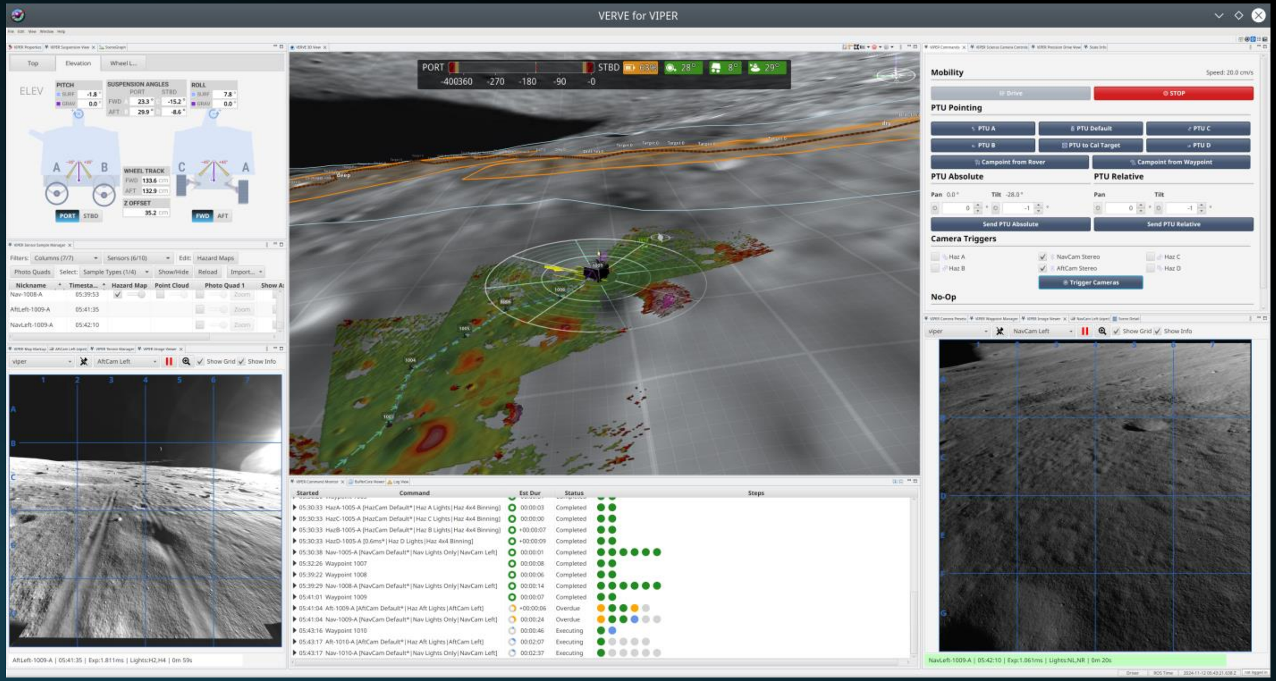
- Real-time surface mission variables and non-determinism make standard mission timelines inadequate
  - Cannot monitor progress v. plan by a traditional mission timeline as you could on a trajectory-driven mission
    - Requires real-time situational awareness capabilities
    - Where we are → Map
    - When we are → Real-time actuals v. active activities progress

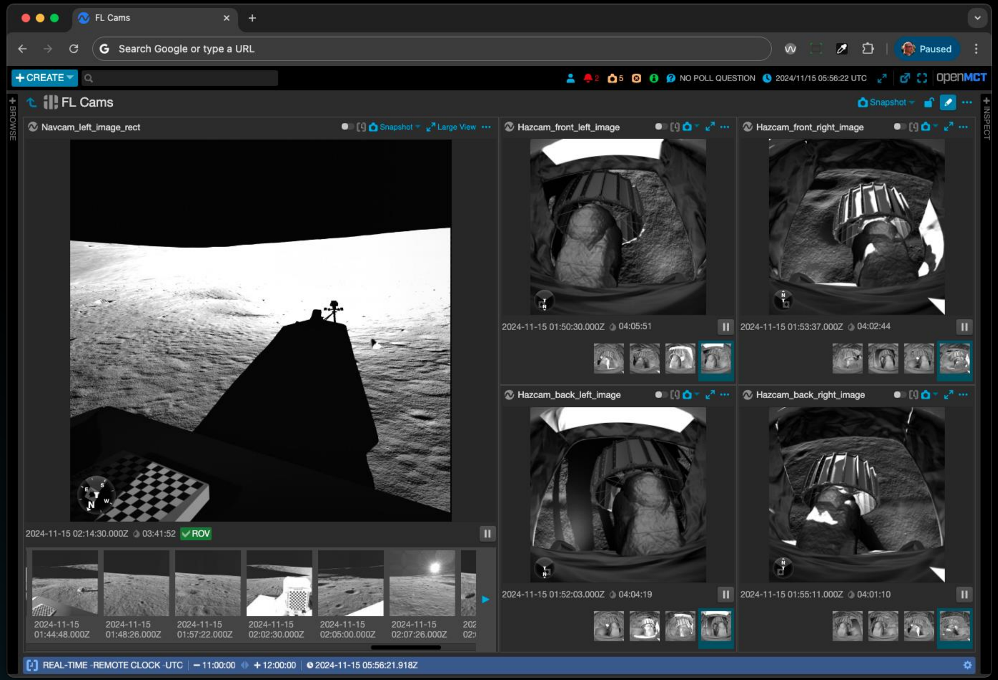




VIPER is Operationally Unique (Cont.)

- Supporting a command cycle measured in minutes requires driver decision information to support the mission tempo to maintain speed made good (SMG) which is driven by the lighting and comm shadows combined with vehicle design characteristics and mission objectives
  - Stereo pipeline, terrain reconstruction, Hazard maps
  - Navigation and hazard camera imagery
  - Real-Time Science





VIPER Operational Characteristics

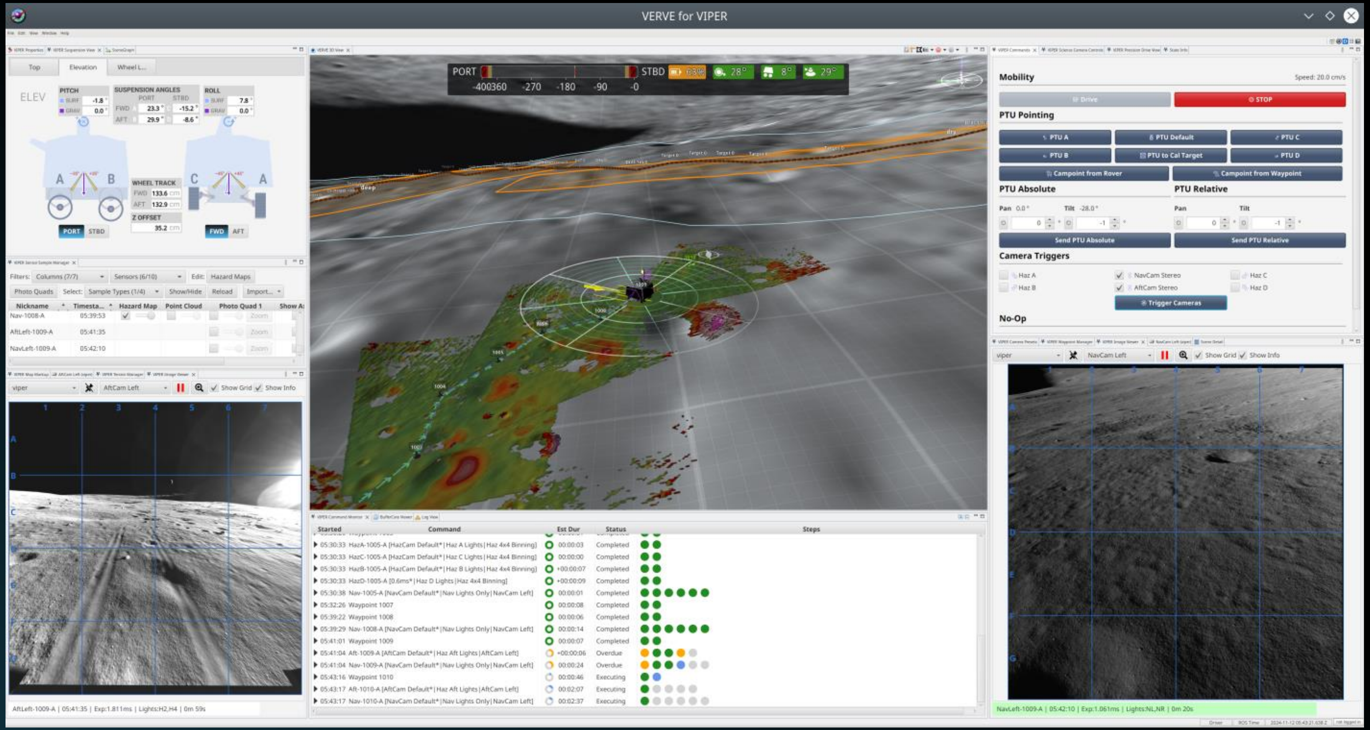
- Surface traversability
  - Slope <= 15 deg for VIPER
  - Obstacle size is 15cm positive
  - Traverse power positive or trade against charging time v average speed
  - Shadows, Sun angle, rover orientation for solar power, surface characteristics
  - Permanently shadowed region surface characteristics unknowns
- Thermal
  - Temperature range is 40 deg k (PSR) to ~323 deg k
- Localization challenges
  - Limitations in resolution and accuracy of a priori maps (mosaics, DEMs)
  - Wheel slip driving on slopes in granular material
  - Time delay, wheel slip, accuracy of hazard detection, interaction of wheels with slopes, vehicle software and hardware capability optimization for the environment

Operations System Design

VIPER Mission System – Plan, Train, Drive

- Mission Operations System (MOS)
    - Processes
        - Procedures, Flight Rules, Displays, Scripts, Limits
    - Operations Team
        - Driving/Science
        - Engineering
        - Payloads
        - Planning
        - Science Analysis and Decisions (real-time, tactical, strategic)
- Ground Data System (GDS)
    - Tools, Control center, Infrastructure
- Mission Planning
    - Traverse Plan, Activity Dictionary
- Training

VIPER Driving



- Near real time but too much delay for direct rate control
- Image and elevation data at lunar poles is limited. Rover data will show exact surface topography and composition
- VIPER relies extensively on robotics capabilities in the ground system
- Driving combines:
  - Following the Traverse Plan, including the Science Measurement Plan
  - Knowledge of the lunar surface environment including Sun, Earth, terrain hazards, mobility system capabilities on slopes, craters, and rocks...
  - Following Flight Rules and Procedures
  - Understanding Flight SW behaviors and commanding to achieve desired outcomes

VIPER Science Payload Operations

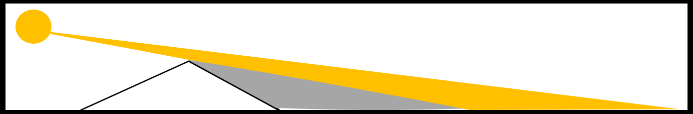
VIPER traverse is driven by science mission objectives

- Instruments for surface and subsurface volatile characterization
  - NIR/VIS, Mass, and Neutron spectrometers
  - Drill (1m depth)
  - Cameras
  - IMU and other Rover systems
- Instrument operators in the POC with Instrument Scientist in the MSC
  - Instrument Operator commands the instrument and monitors health and status
  - Instrument Scientist monitors quality of data and instrument mode/settings as it pertains to the science plan
  - Instrument Scientist and Theme Scientists in MSC perform SOPs and SAMs (Standard Analytical Methods) to provide real-time analysis products to rest of the team

Mission Planning

THE PROBLEM

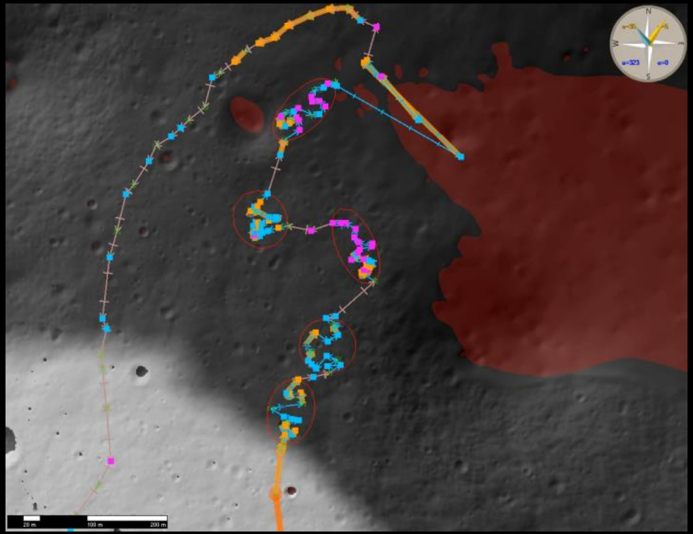
- At the poles, the sun casts long shadows
- Terrain also blocks the direct radio links from ground stations causing radio shadows
- Teleoperation from Earth yields an average speed around 1 cm/sec
- Shadows move from .1 – 1.5 cm/s
- A solar-powered rover must move almost continuously



Sun angle (yellow) at the poles casts long shadows (grey area)

VIPER'S SOLUTION

- Generate
  - High-resolution terrain (1m/pixel) via machine vision processing of orbital images
  - Maps summarizing thermal history (where might ice be, i.e., where do we want to explore?)
  - Time-series maps integrate rover position constraints: slope, sun/comm shadows, lander views … (where can the rover actually go?)
- Model rover performance (avg speed, slope & slip, battery capacity, power generation, electrical loads, simple faults, e.g., slow progress)
- Automated search for traverse plans that meet constraints while balancing science productivity vs. risk



Part of a traverse. Red arrow is rover's position. Ovals are science focus areas, each involving 3 drill sites and 24 hours of measurements

The Operations Team

- Mission Ops Team Design Principles
  - Based on established design patterns
  - Streamlined for efficiency
  - Combined disciplines
  - Subject Matter Experts require minimal training
- Drive Team
  - Driving
  - Navigation
  - Integrated real-time science
- Engineering team
  - Systems
  - Command & Data Flow
- Science Team
- Mission Planning Team
- Instrument Teams
- Anomaly Response Team

VIPER Mission Operations Center

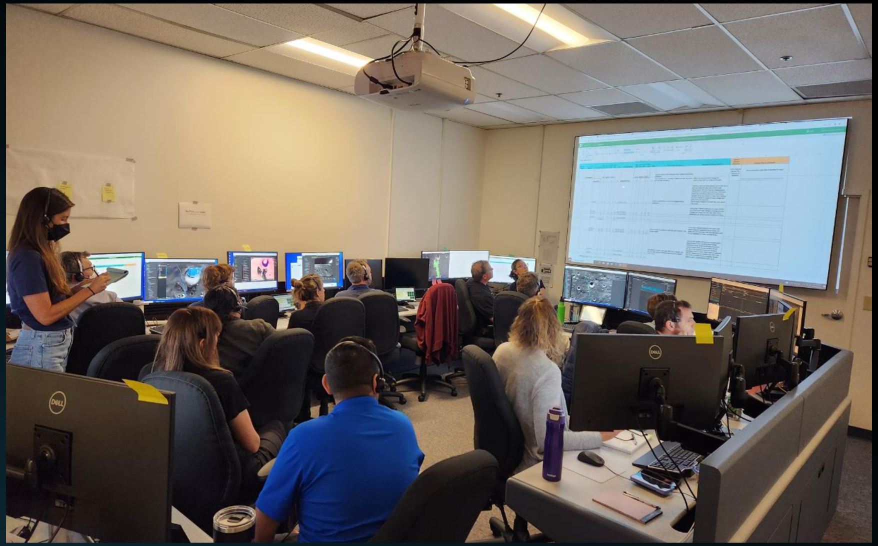
Real-time science collaborative decisioning systems

Science in the Mission Ops Center (MOC):

- 24/7 ops center presence
- Integrated within drive team real-time decisioning:
  - Real-Time Science (RTSci)
  - Science Lead (SciLead)
- Connected to Mission Science Center Lead and MSC collaborative real-time decisioning and operational protocols

Collaborative science in the Mission Science Center (MSC):

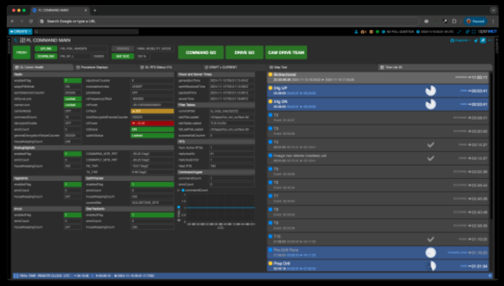
- 24/7 connection to Science in the MOC and Payload Operations Center (POC)
  - MSC Lead
  - MSC Instrument Scientists
  - MSC Theme Scientists
  - Real-Time Science (RTSci)
  - Science Lead (SciLead)
- Standard Analytical Methods (SAMs) and Standard Ops Protocols (SOPs) for real-time collaborative science decisioning



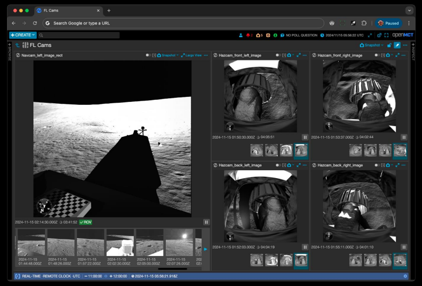
VIPER Ground Teams User Software Overview

Planning Timeline and Map

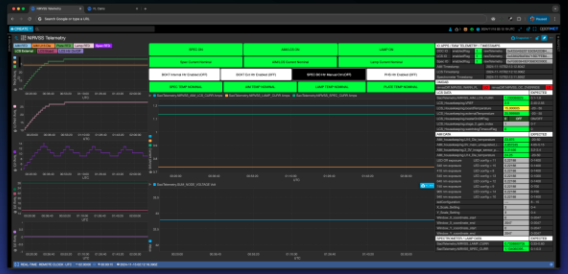
Mission Manager Integrated Overview



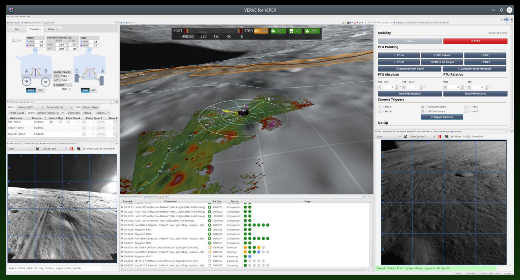
Situational Awareness and Activities



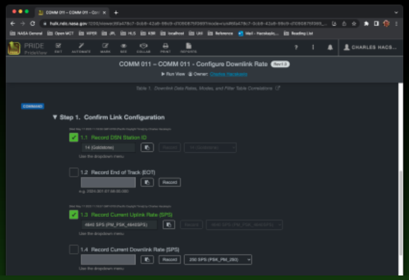
Nav and Haz Cameras



Instrument Health and Status



VERVE Driving Software

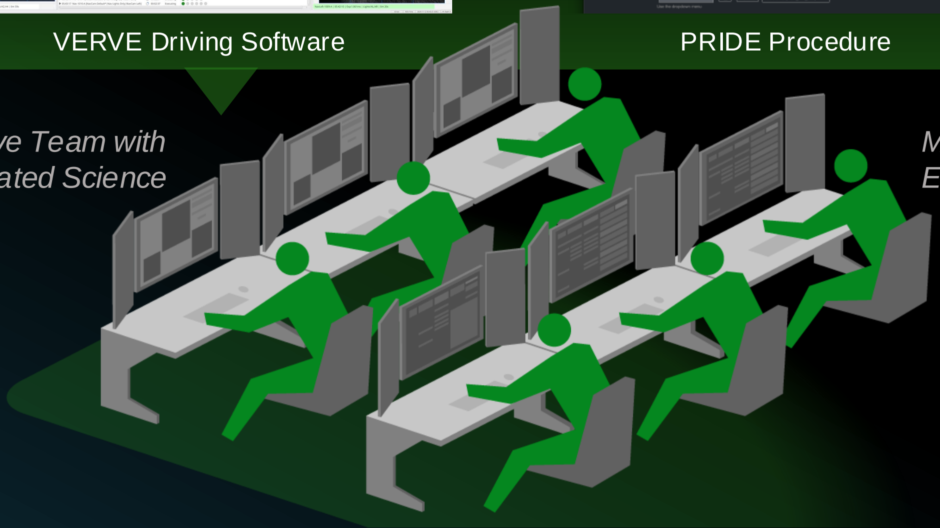


PRIDE Procedure

Instrument and Planning Teams

POC

Drive Team with Integrated Science



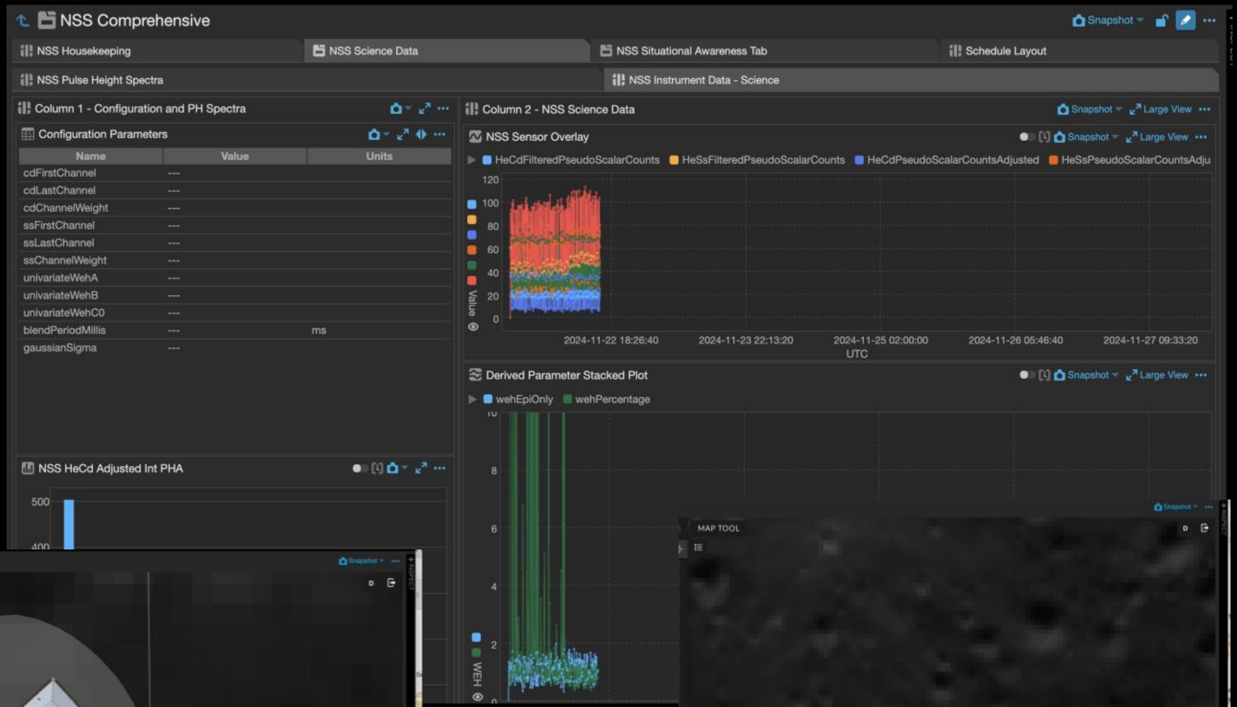
Mission and Engineering Team

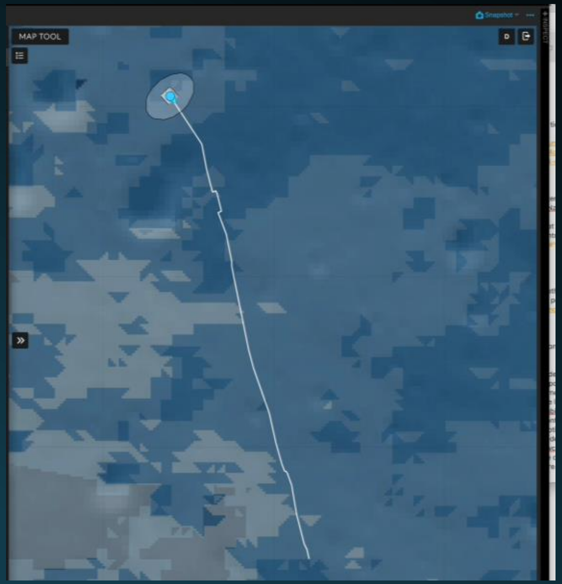
MOC

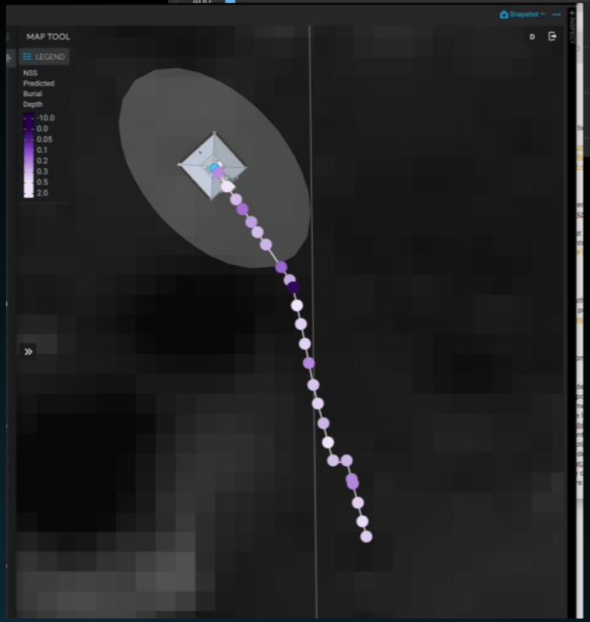
Integrated Collaborative Decision Support

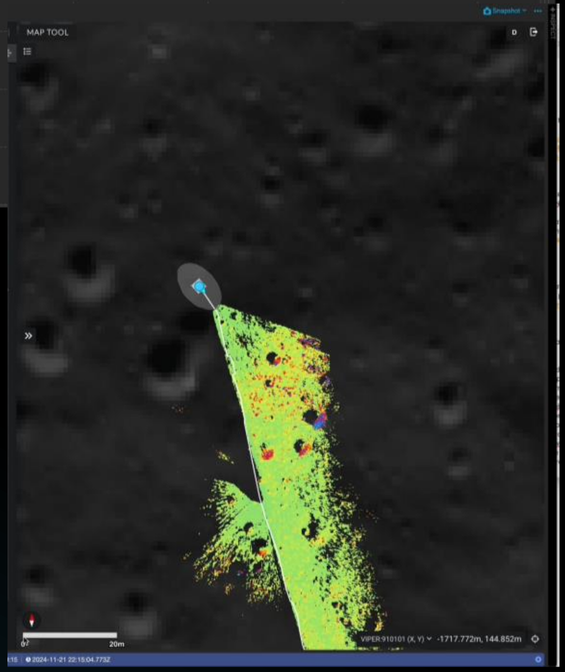
We anticipated the need for a variety of decisional data products during mission planning. We worked with Mission Systems to integrate these capabilities into our mission operations tools. E.g.:

- Shared, live view of all data and telemetry.
- Instrument data heat maps.
- Rover ground level imagery
- Image panoramas

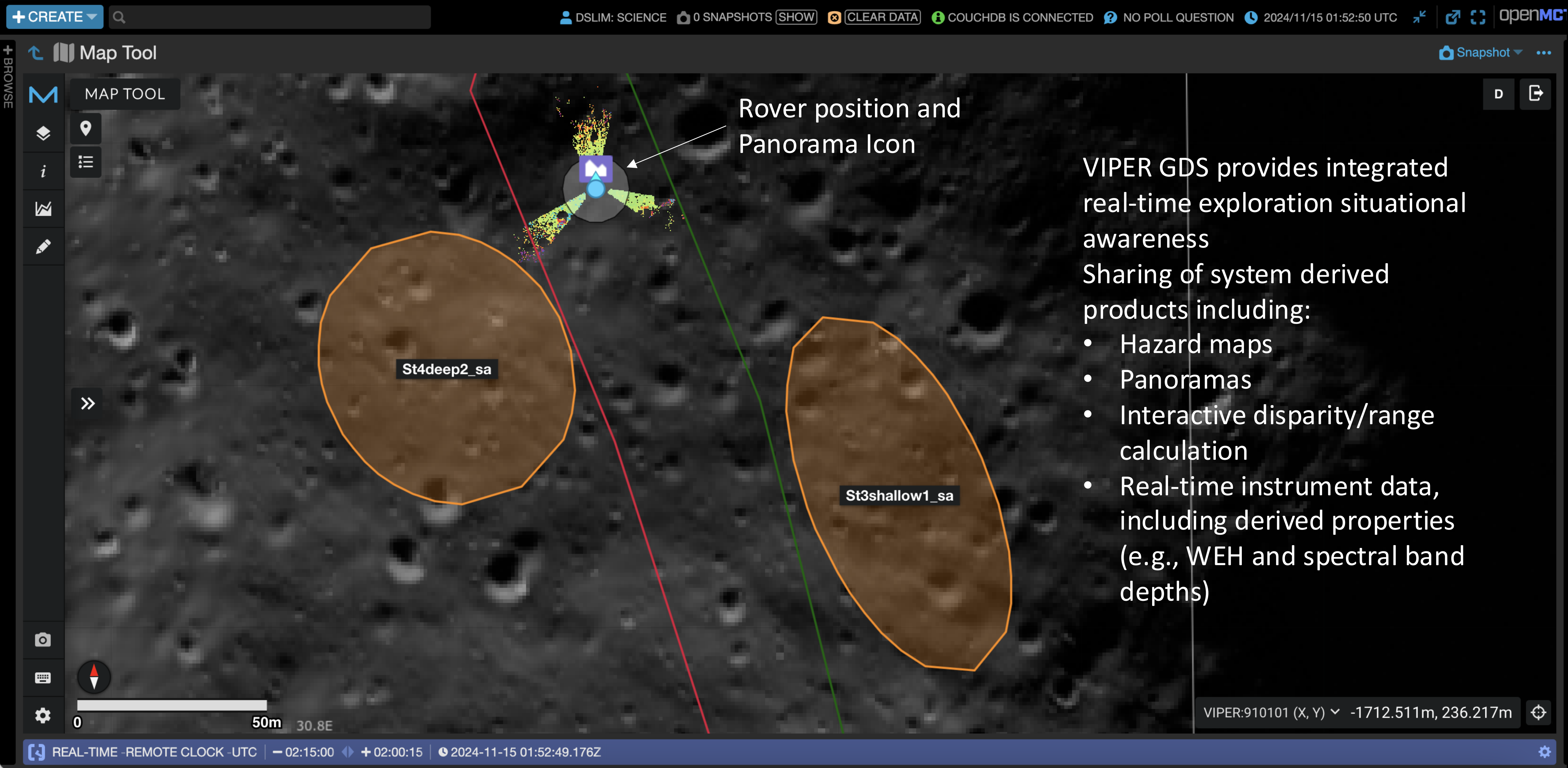








Real-time Shared Operational Context of Explored Area



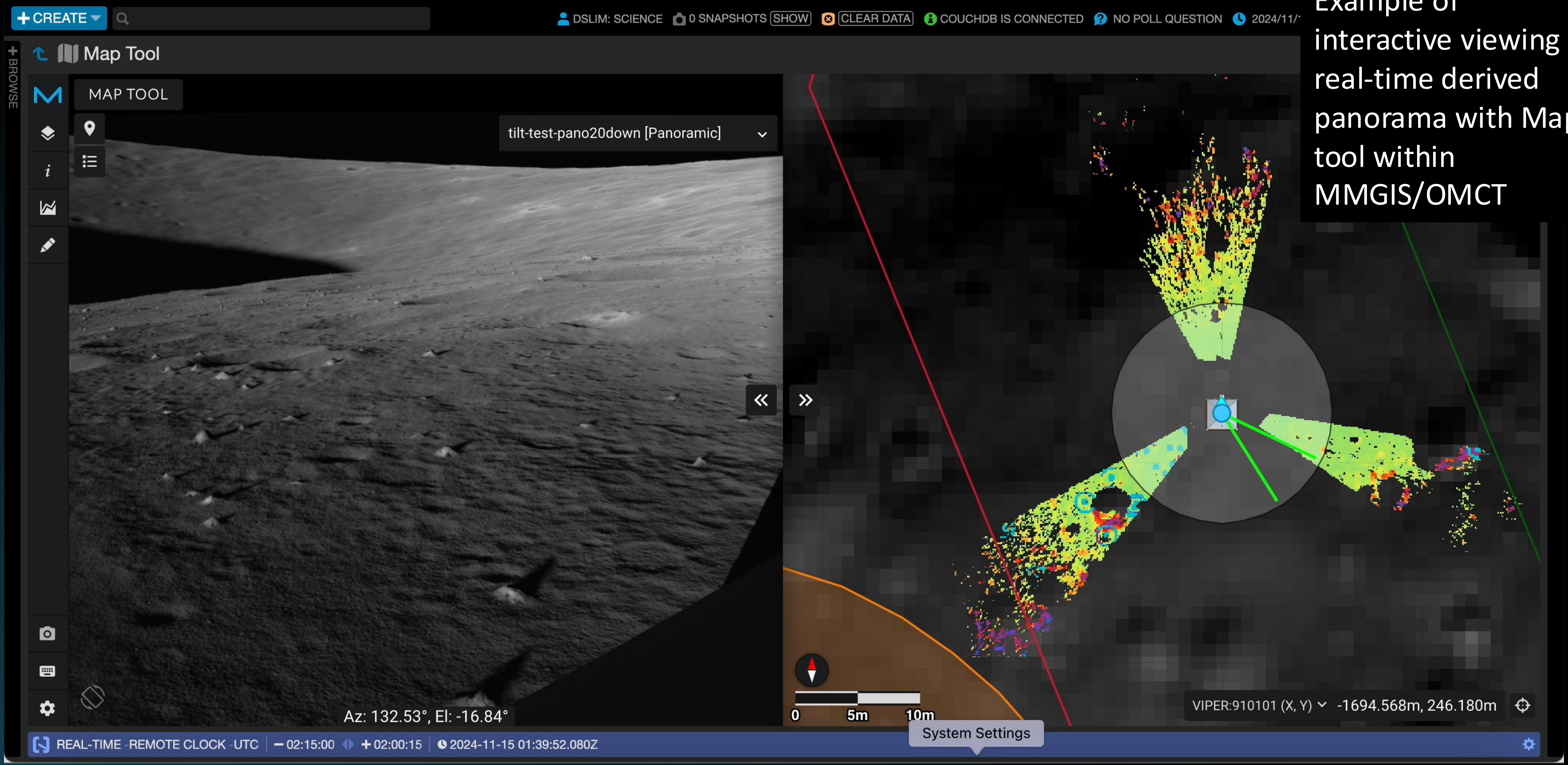
Rover position and Panorama Icon

VIPER GDS provides integrated real-time exploration situational awareness

Sharing of system derived products including:

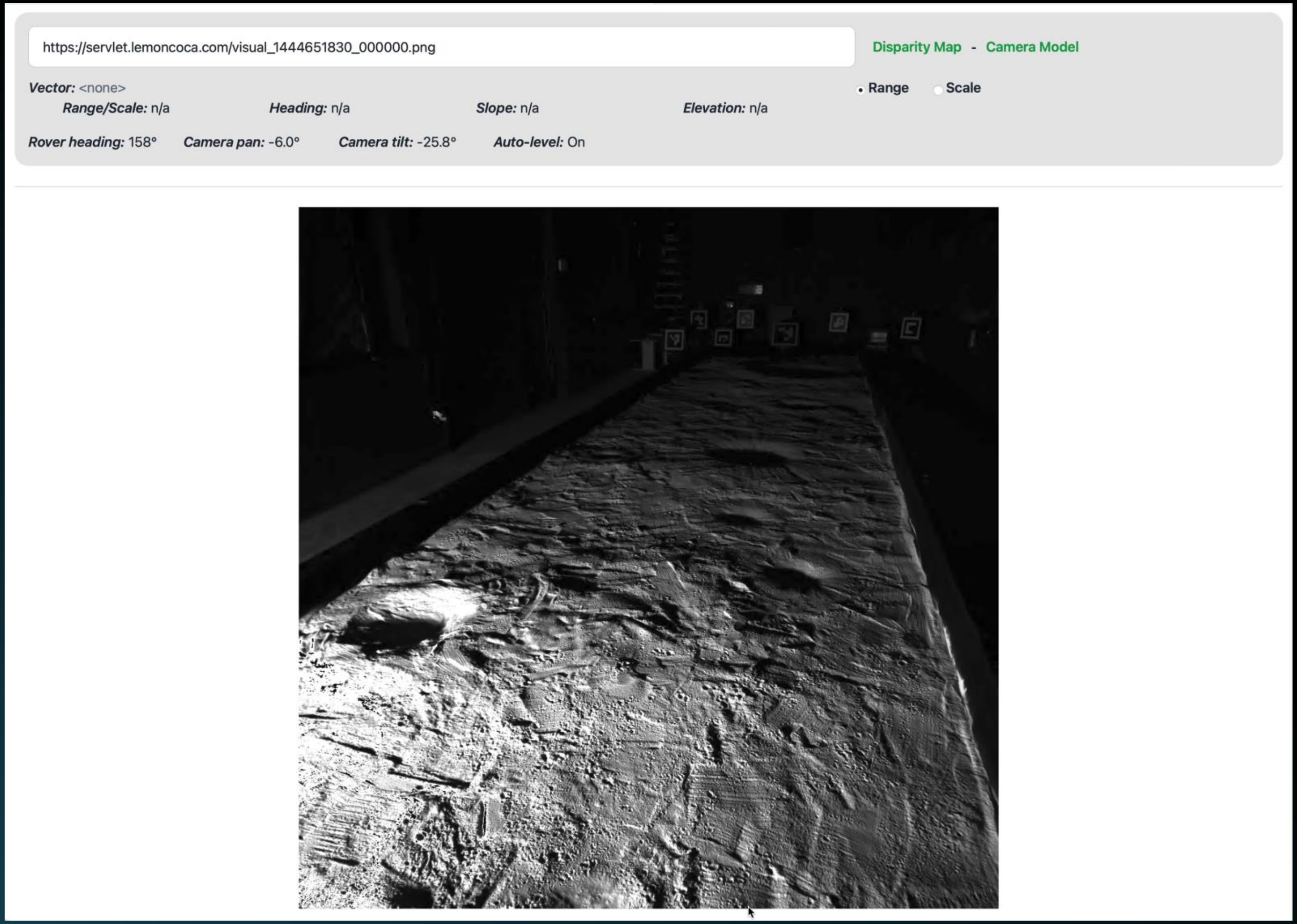
- Hazard maps
- Panoramas
- Interactive disparity/range calculation
- Real-time instrument data, including derived properties (e.g., WEH and spectral band depths)

Real-time Shared Operational Context of Explored Area



Example of interactive viewing a real-time derived panorama with Map tool within MMGIS/OMCT

Real-time Shared Operational Context of Explored Area



Disparity – Range Maps

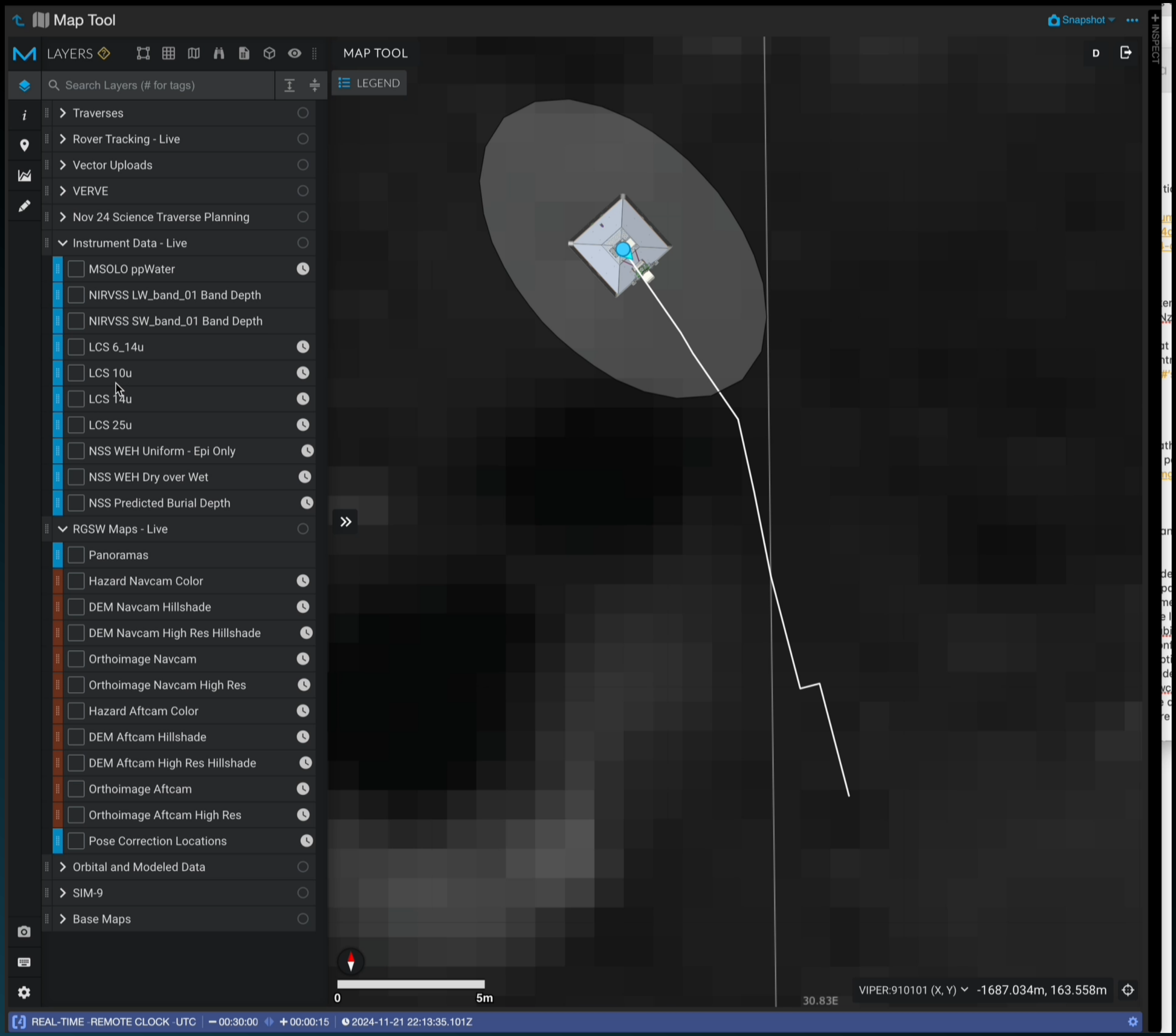
The uncertainty associated with scale in the lunar operating environment, can hamper discourse and rapid decisioning.

Disparity* maps are derived from stereo-imagery and result in interactive range-to-target and scale calculations that can be accessed across all positions to produce a shared frame of reference.

Real-time disparity maps create a shared operational perspective of the Moon

**The horizontal shift of the same point between the left and right images is the "disparity."*

Real-time Shared Operational Context of Explored Area



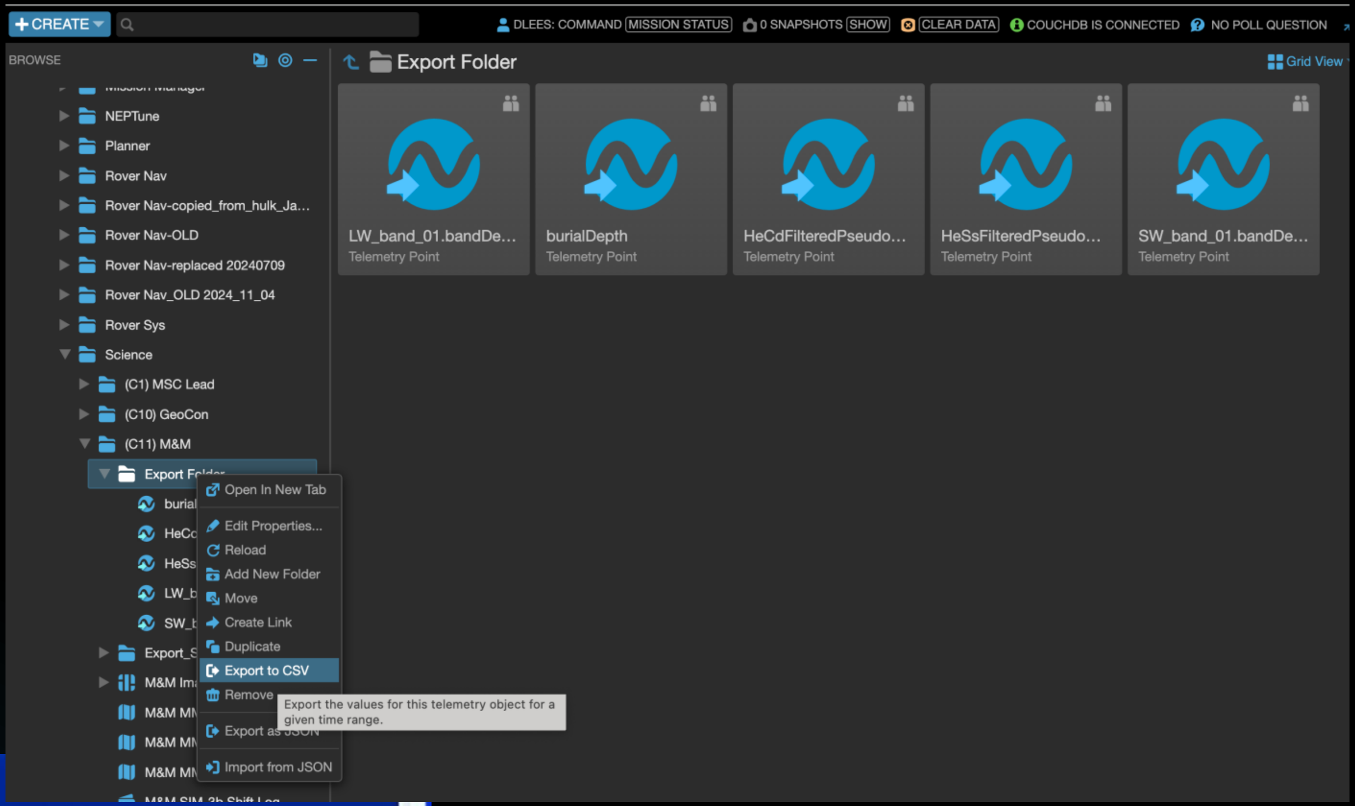
Example of integrated, real-time shared mission data, including:

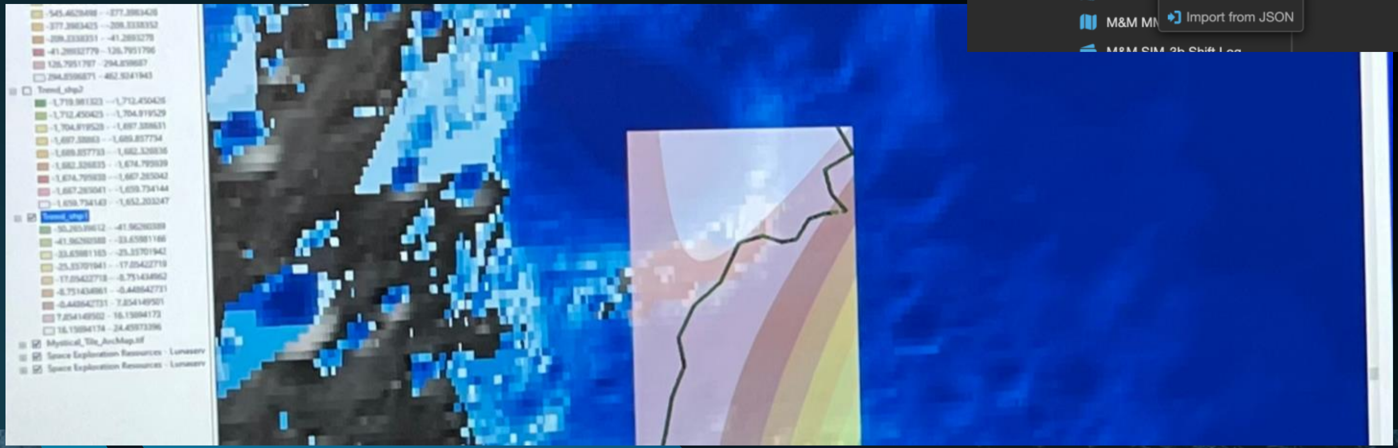
- "live" instrument derived data, e.g., Water Equivalent Hydrogen, Water absorption strength, Mass 18 partial pressure
- Hazard maps
- All integrated into Map Tool/OMCT allowing for multiple static/dynamic overlays (e.g., orbital data sets)

Rapid On-site Analysis to Guide Operations

We cannot anticipate and support every possible need pre-mission – both because of technical complexity and the nature of exploration.

- Exploration means we can't anticipate everything. We are discovering.
- Need the ability to rapidly export selected data and analyze it in popular tools (e.g. ArcGIS)
- Results must be made available in ops tools to support collaborative decisions.
- Export and analysis cycle must be rapid enough to inform science and mission operations.

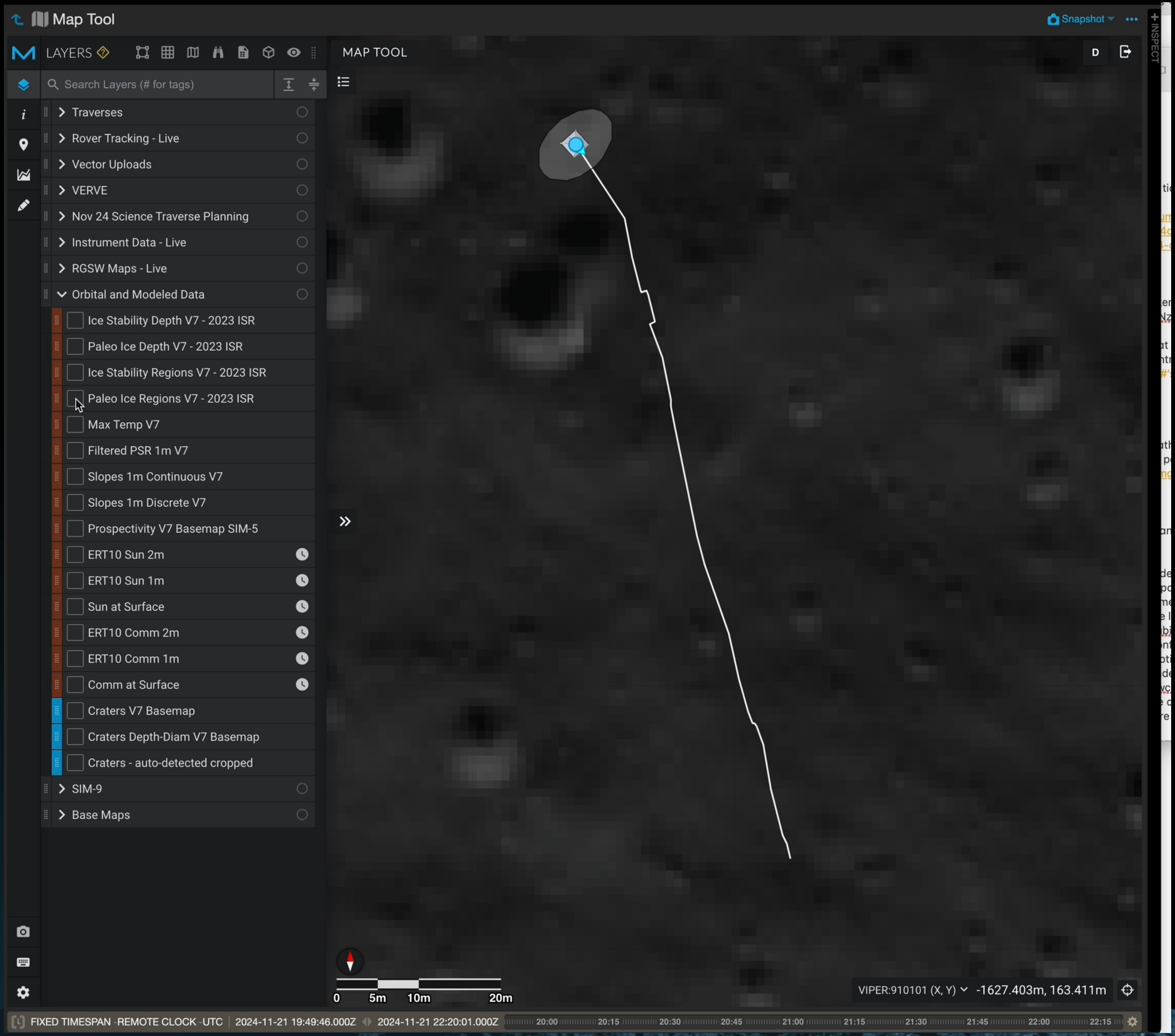




Data Products – Pre-Flight

Example Data Products used in Planning:

- 1-meter DEM
- Slopes
- Illumination and comm maps vs time
- Ice Stability Regions
- Crater locations and d/D
- Predicted surface temperatures vs time
- Shadow depth map
- Geologic Map
- ShadowCam
- Time since sun
- Time since shadow
- Distance to sun shadow
- Distance to comm shadow



Real-time Science Analysis and Decisioning

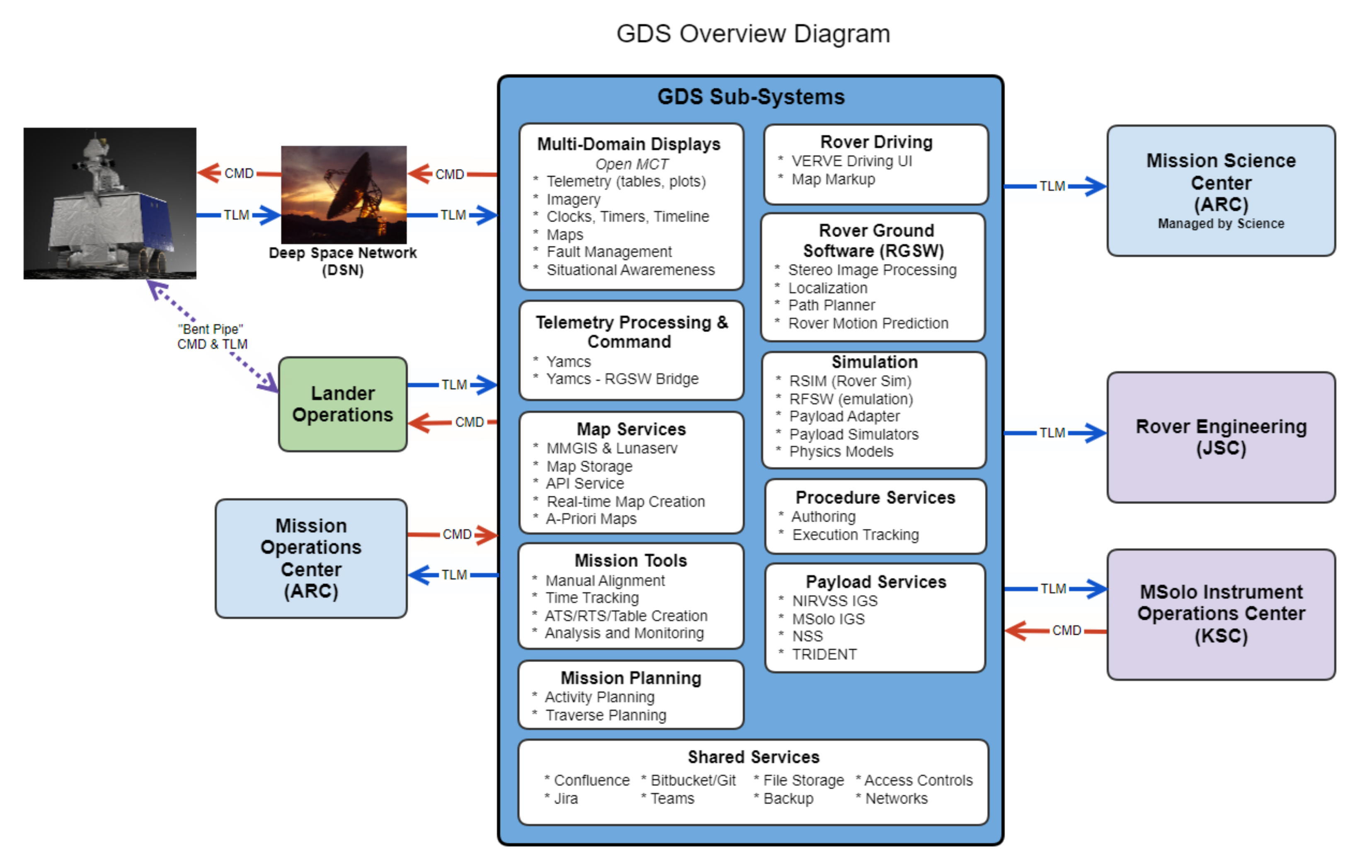
Takes advantage of the integrated GDS and science team to generate products to support operations

- Extends analysis from the MSC to the Drive and Planning teams
- Maximizes science and exploration by providing very fast, tactical decisioning
- Team has developed and trained to operationalize toward this real-time support

Examples of Real-time Analysis Products

- Trend analysis
- Correlation analysis
- Mineral potential map (Prospectivity Map)
- Water equivalent and burial depth maps
- Surface hydration, other volatiles and mineralogy and toxicity maps
- Trafficability (“Driving Report”)

Ground Data System Subsystems



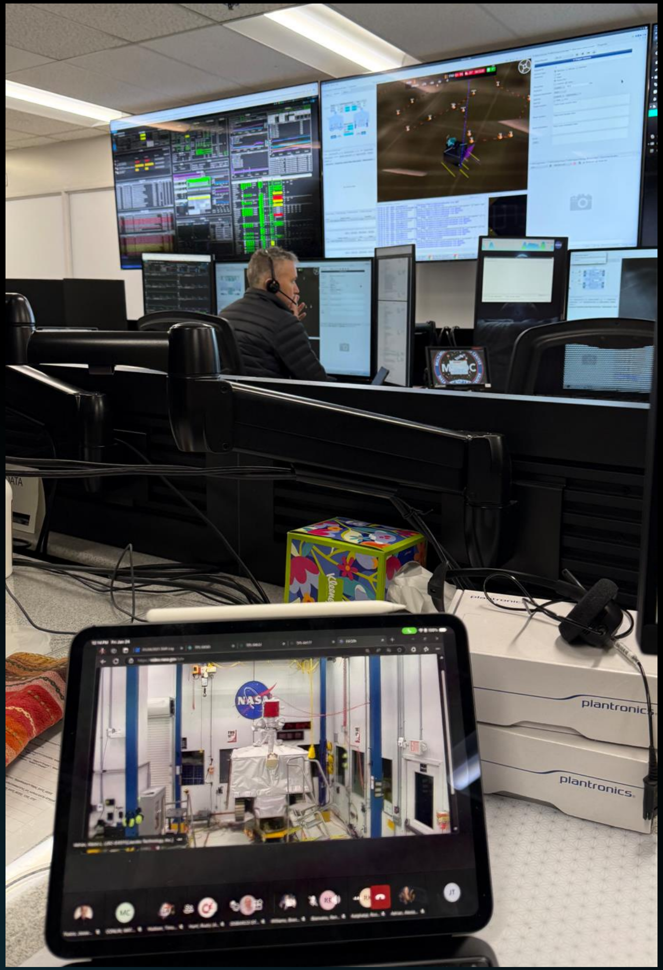
- Build 9 – feature complete
- Integrated into operational environment across operational positions
- Tested in Activity-Based Operational Thread Tests
- Tested in Integrated Simulations
- Integrated testing underway with flight hardware
- Full Verification Testing planned for November 2024

Test and Training

Mission Simulation

Training, Testing Ops Products, Processes and GDS

End to End Command & Data Flow

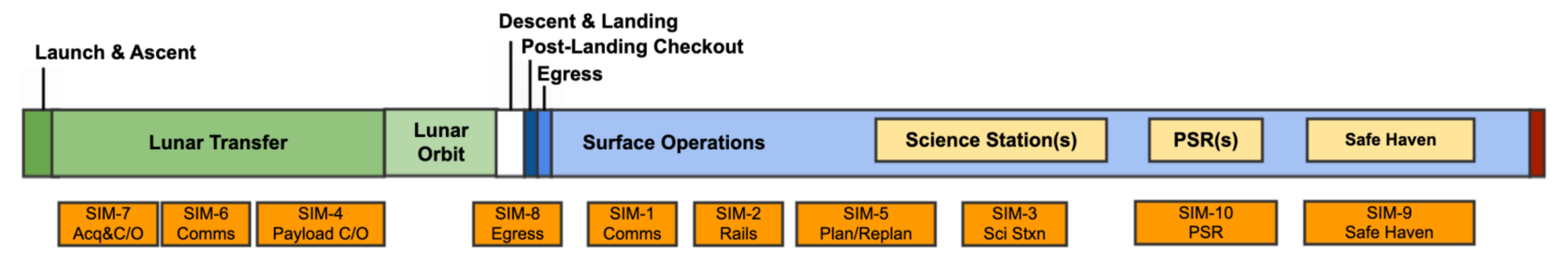


Mobility Testbed Driver Training

Integrated Operations Test and Training

- Operator training for 24/7 fast tempo near real-time teleoperations
- Simulations
  - Developed the system through use and iterative improvement
  - Test and training for the integrated MOS + GDS
- Testbeds and Flight Vehicle
  - EDU Rover and Flatsat: ✅
  - End-to-End Test: ✅
  - Flight+Ground Operational Readiness Tests: April '25

Test & Training Stats	
Team/Processes/Software System Hours	388
Engineering Readiness Test Hours	263
Testbed and Flight Vehicle Test Hours	356
Total Team Training Hours	979
Individual Training Hours	7167



Mission Phase	Activities	Dev Sims	Mini Sims	Integrated SIMs
Launch, Activation, and Checkout	Launch, power-up, initial acquisition, establish transit power configuration, thermal assessment.		✅	✅
Transit: Rover+Comm Checkouts	Rover checkouts via Lander. Transit Comm handover, comm checkouts w/DSN.		✅	✅
Transit: Payload C/O's and Cals	Payload aliveness, checkouts, bakeouts, and calibrations.		✅	✅
Transit Housekeeping	Daily status checks, data store downloads, file uploads.	✅		✅
Landing and Egress	Descent, landing, power and comm handover, rover and payload checkouts and calibrations, localization, egress to surface.	✅ + 3 Egress Tests w/EDU's	✅	✅
Surface Housekeeping	AOS, LOS, DSN interactions, File Downloads and Uploads, AOS, LOS.	✅		✅ x2
Rails Driving	Waypoint driving, obstacle avoidance, team interaction, instrument ops.	✅ x5		✅
Science Stations Engineering Ops	Prospecting, drilling, mode/configuration transitions, timelining.	✅		✅ x3
Surface Operations, Planning/Re-Planning	Science operations, ISR accruals, tactical re-planning, traverse adaptations, drill site selections.	✅	✅	✅ + May '25
Permanently Shadowed Regions	FM configuration, PSR entry, prospecting, drilling, exit, recharge, recovery.	✅	✅	✅
Safe Haven/Hibernation	Localization, assessment, configuration, entry, hibernation, exit, recovery.		✅	✅ + Jun '25

Additional Operational Capabilities Information

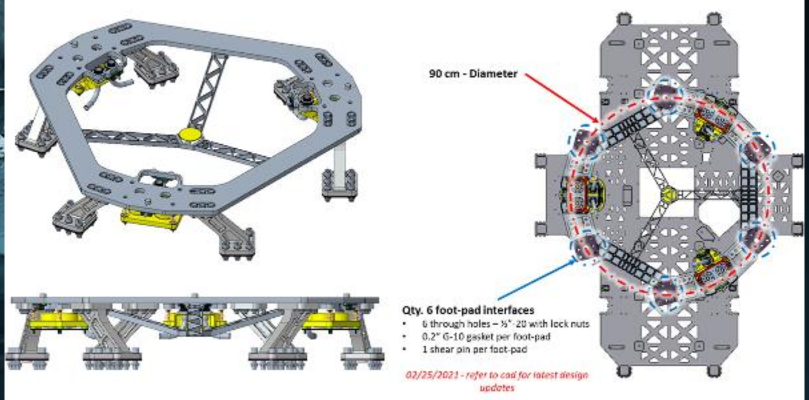
- The VIPER team is developing several closeout products to facilitate knowledge exchange to help proposer/partner understand VIPER systems and capabilities
- These plans are in development as part of VIPER closeout
- A VIPER Surface and Science Operations Overview Document is in works to help illustrate the complexities of VIPER rover & science operations

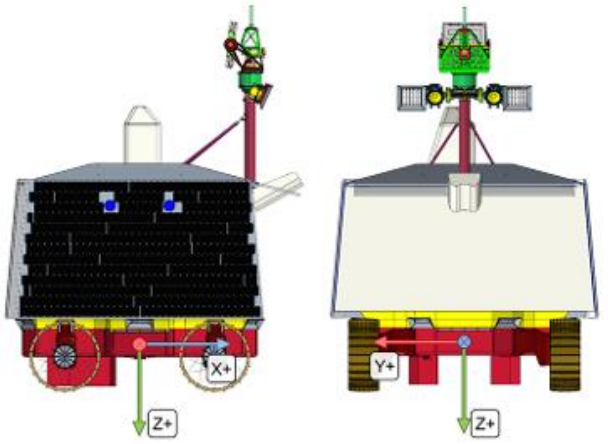
Lander Integration, Launch Site, & Range

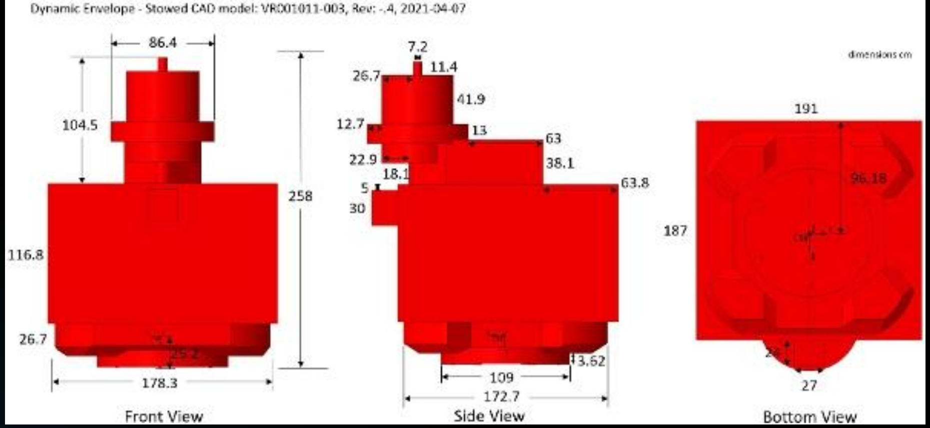
(Tom Luzod & Steve Jara)

VIPER Ready to Interface

- VIPER’s Rover Release Mechanism (RRM) Interface is modular and can adapt to many platforms
  - VIPER’s Data and Power Interface is self-contained within the RRM design
  - VIPER's interface maturity can advance development of lander's interface
    - VIPER side of interface can streamline the ICD development
- VIPER has produced a wide range of products to exchange to advance Mission Analysis
    - Models (OML, Craig-Bampton, FEM, Thermal)
    - Analysis (Power, Thermal, Dynamics)
    - VIPER Activities (Power and Data allocations)
    - Interface Drawings (cable harness, routing, RRM, wheel characteristics)





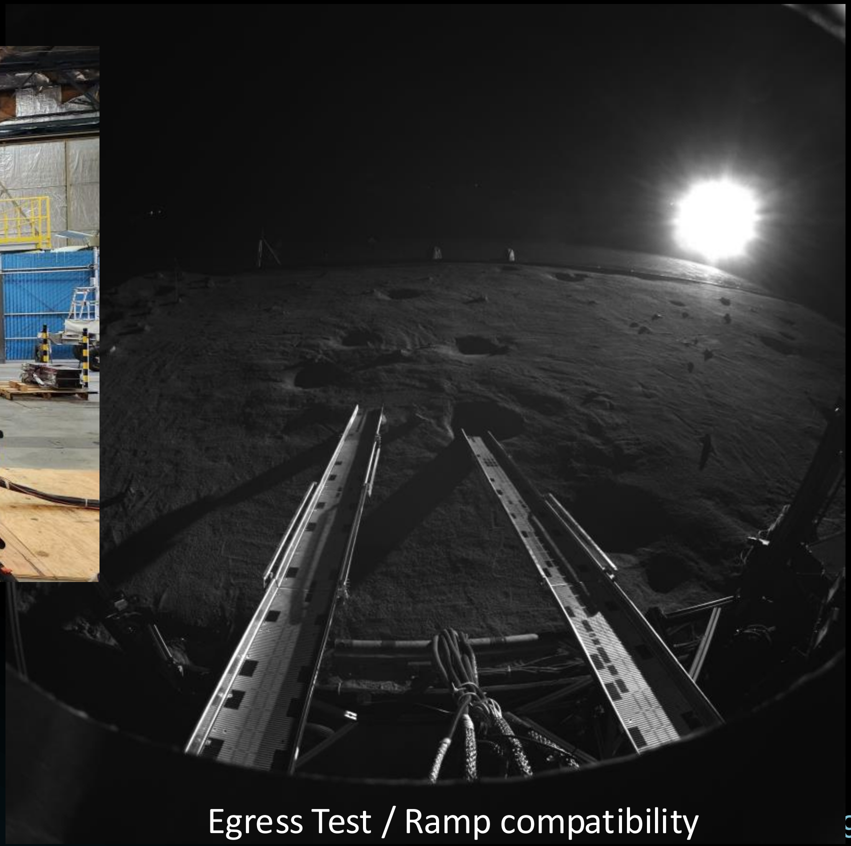


VIPER Team Ready to Collaborate

- VIPER's defined set of plans/processes can advance testing flow and system development
  - Coordinated set of tests that build confidence in Data/Power/Comm Interface Tests
  - Proven fit checks for mechanical integration process and accessibility evaluation
  - Successfully completed various Egress tests for lander compatibility
  - Compressed set of Launch Site End-to-End Tests

FlatSat Data Communication Test

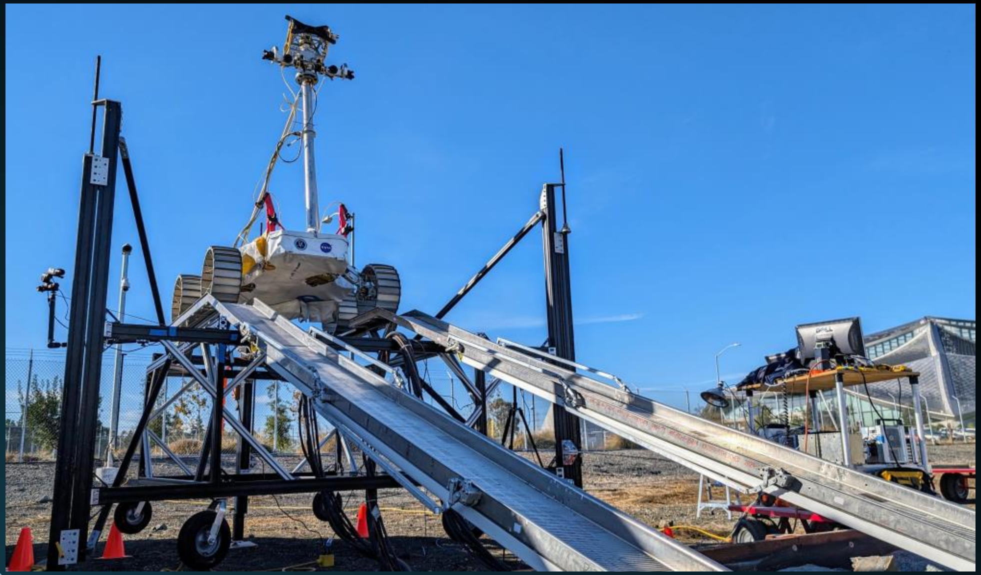
Integration Checks / Lifts

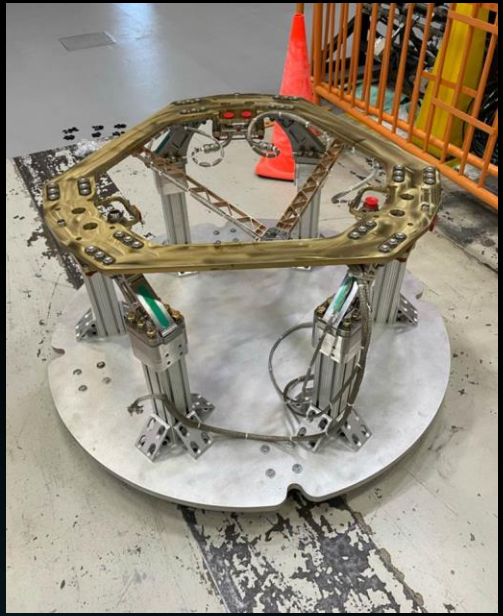


Egress Test / Ramp compatibility

VIPER Collaborative Hardware Capabilities

- VIPER hardware can be used to aid in lander partner interfacing and planning
  - Mobility Testbed – mobility system to support egress testing
  - SSAIL (VIPER FlatSat; resides at NASA JSC)
  - Subsystem EDUs (Power and Avionics)
  - VIPER Volumetric Simulator
  - RRM Models / Templates
  - 1/6g Loop Heat Pipe TVAC Thermal Management Testing Platform
  - VIPER Egress Test Structure (VETS)



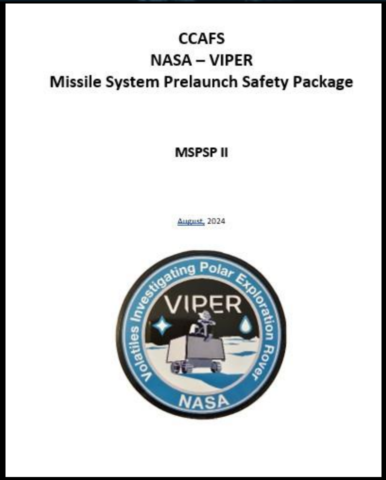


VIPER ready for Lander Partner Launch Site Plan

- VIPER’s Launch Site Plan is ready to inform your launch site processes and can adapt to your lander integration process
  - Leverage VIPER SI&T executed procedures for Payload Processing Facility (PPF) Plan
    - Including PPF VIPER layouts, vehicle movements, RBFs, ground equipment, lifts, integrated tests, team roles, and PPF facility equipment
  - 4.5 Weeks of VIPER-only and integrated VIPER-Lander Activities
    - 10-days = Setup and Post-Ship functionals
    - 10-days (CBE) = Lander integration
    - 3-days = Support Equipment Setup and Testing (Pre-E2E)
    - 5-days = Integrated Tests (End-to-End at PPF)
    - 5-days = Closeout, charging of batteries, configure for launch
      - Note: Above allocations are CBE and do not include Lander-only & LV activities on range

VIPER is interface ready
VIPER is ready to support your timeline
VIPER team stands ready to support your Launch Site process if requested

Safety Deliverables


CCAFS
NASA – VIPER
Missile System Prelaunch Safety Package

MSPSP II

August, 2024

- Missile System Prelaunch Safety Package (MSPSP)
  - Completed Safety Review 1 with Range Safety (Cape Canaveral Launch Site)
  - Incorporated minor comments from the Review
  - Includes VIPER developed EGSE and MGSE for launch processing at the Eastern Range
- Range Safety Compliance Matrix
  - AFSPCMAN 91-710, rev 2004
    - Range approved SpaceX tailored version
  - Safety Compliance Checklist is complete
    - Reviewed with no comments from the Range Safety Officer
- VIPER Hazard Reports
  - Of the Forty-Five Project Hazard Reports, 2 remain open:
    - Instruments, Rover, SI&T activities, Launch Site Processing, and launch through separation Subsystem vendor HRs have been reviewed and approved (Comm System, IAU/PDU, SEPIA, Thermal System, and Solar Arrays)


BY ORDER OF THE COMMANDER
AIR FORCE SPACE COMMAND

AIR FORCE SPACE COMMAND
MANUAL 91-710 VOLUME 3

1 JULY 2004

Safety

RANGE SAFETY USER REQUIREMENTS
MANUAL VOLUME 3 - LAUNCH VEHICLES, PAYLOADS, AND GROUND SUPPORT SYSTEMS REQUIREMENTS

COMPLIANCE WITH THIS PUBLICATION IS MANDATORY

NOTICE: This publication is available digitally on the AFDPO WWW site at: http://www.e-publishing.af.mil.

OPR: AFSPC/SEC (Lt Col John Humphries)
Certified by: AFSPC/SE (Col Billy Colwell)
Pages: 239
Distribution: F

Range Safety Deliverables (Rover, MGSE, EGSE) are ready for final Range Safety Review and Approval.

VIPER Safety Deliverables are independent of any Lander and are ready to work in partnership with for the final Safety Package.

VIPER Summary Assessment

(Daniel Andrews)

VIPER Take-Aways

- *Groundbreaking lunar volatiles science is achievable with a highly-integrated humans/hardware/software approach*

- Rover 100% built & verifications testing complete:
  - Vibration, Acoustic and TVAC testing complete

- Mission System
  - Ground data system (GDS) software is *features-complete*
  - GDS software has 1000+ hrs. of active use in testing and simulation
  - VIPER operations team has 7167 person-hours of test and training, if support is requested

- VIPER team built to be partner-ready:
  - Team well-experienced with lander integration planning/coordinating/testing, if support requested

- Range-ready:
  - Safety products reviewed and Safety Review II ready
  - MGSE & EGSE have passed Range Safety initial review

Ad lunam!