National Aeronautics and
Space Administration

VIPER

VIPER Industry Day

Hosted by:

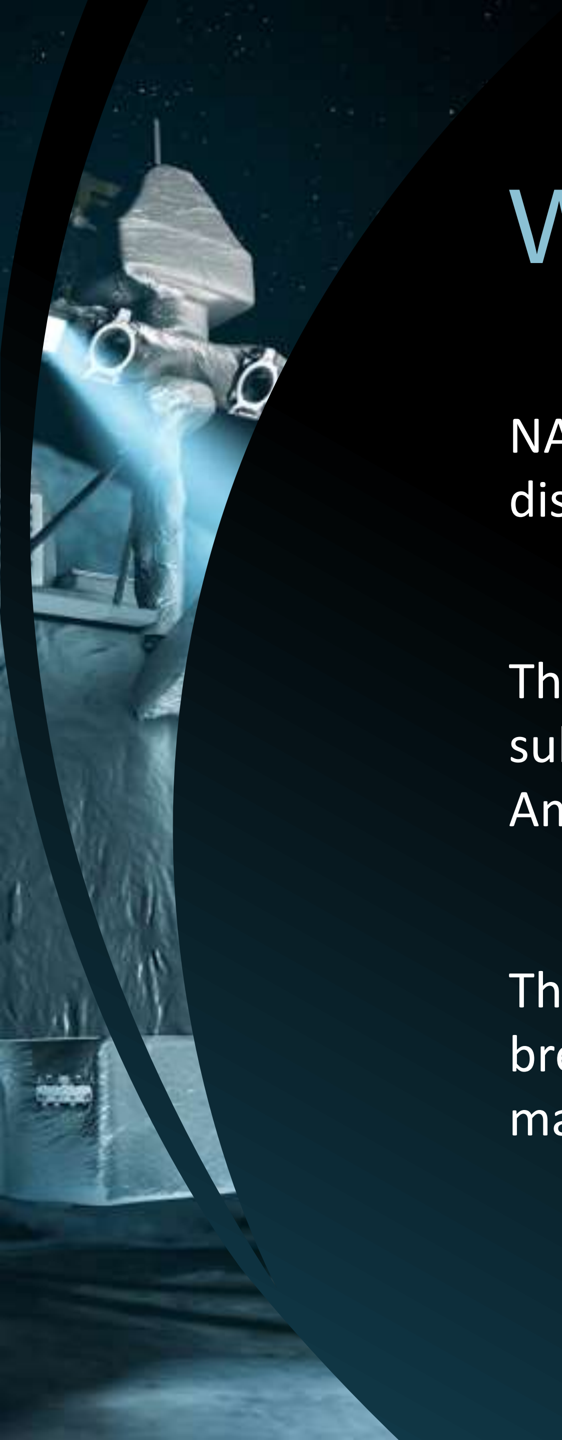
NASA Ames Research Center

VIPER team engagement with the Aerospace Sector

Aug 22, 2024

VIPER Industry Day: Welcome and Logistics

Dr. David Korsmeyer (ARC Deputy Center Director) / Daniel Andrews (VIPER PM)



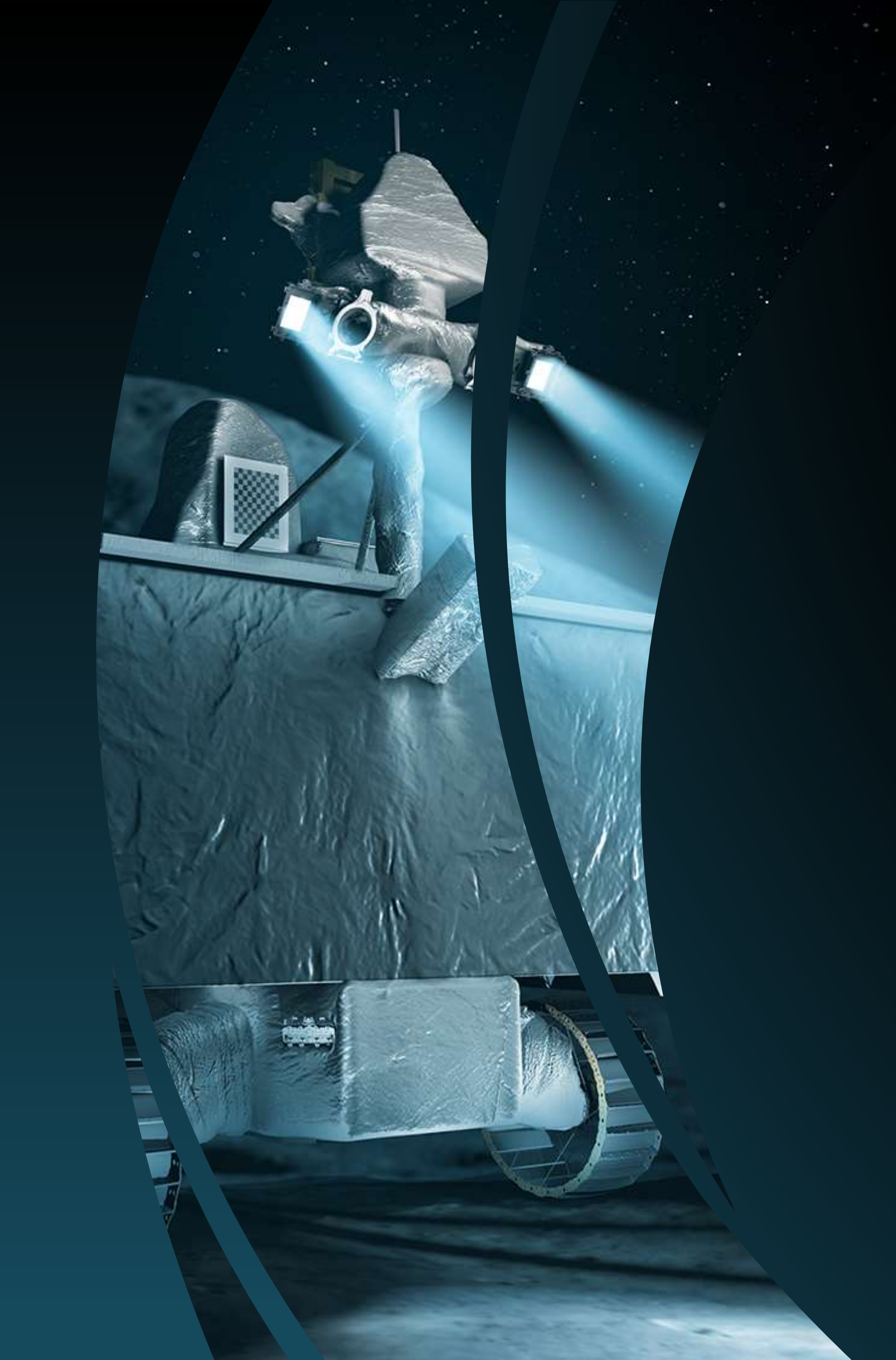
Welcome!

NASA-Ames Research Center and NASA-Johnson Space Center welcome you to a discussion on the VIPER mission.

The VIPER Mission team and Center leadership will **not** be speaking to the RFI proposal submission or the evaluation processes today. Instead, we will be sharing the available Ames/JSC capabilities to partners and the technical status of VIPER.

The Centers have asked the VIPER team to spend the next few hours describing the breadth of the VIPER project developments at Ames and JSC, as well as the status and maturity of its systems and team expertise.

Agenda



- [15 min] Industry Day Overview & Logistics
  - Agenda + Team introductions + future VIPER Experiences
- [20 min] VIPER Framing
- [40 min] Mission Overview & Possibilities
  - Science, Exploration, and Technology Advancement
- [170 min] VIPER Capabilities & Development
  - Measurements and Instruments (30 min)
  - Roving Platform (30 min)
  - Testing (ground & rover) (30 min)
  - Mission Ops / Ground Systems (50 min)
  - VIPER Lander Integration and Launch Site Plan (20 min)
  - Launch, Range Safety, and Hazards (10 min)
- [5 min] VIPER Take-aways
- [50 min] Q&A

Question-handling – Day of Event

Conference I/O session is open to collect general questions during the event

Conference I/O questions will be answered during the Q&A portion of the Agenda, starting with the top up-voted question

Submit questions using the QR code, or via this link: VIPER Questions

If you have a specific slide questions or clarifications, please raise your hand in MS Teams. Questions will be answered in order asked, while being mindful of the overall schedule

Information Logistics – Post Event

- Technical documentation can be exchanged via Box
  - Application is approved for sharing with external (non-NASA) partners
- Requests should be submitted to: Christopher.d.Youngquist@nasa.gov
- Suggested Format:
  - Name
  - Association
  - Email Address
  - Area of interest
  - Details of your request
    - Try to use “what”, “how”, and ”why” to start your questions so that the appropriate team member(s) can provide a thorough response.

VIPER Experiences (future dates):

- This Industry Day timing was selected to inform the aerospace community about VIPER, in support of the VIPER RFI
    - A virtual event made sense to be time-responsive to the 9/2/24 due date
- VIPER to offer in-person “VIPER Experiences” to encourage deeper understanding of capabilities and products. Some examples:
    - Witness an actual VIPER Operational Simulation
    - Witness Rover testing in the Roverscape
    - Visit the VIPER Flight Rover (pending ongoing testing)
    - Visit the Lunar Lighting Lab
- Stay tuned for future announcements

Your VIPER presenters today
(Alphabetical order)

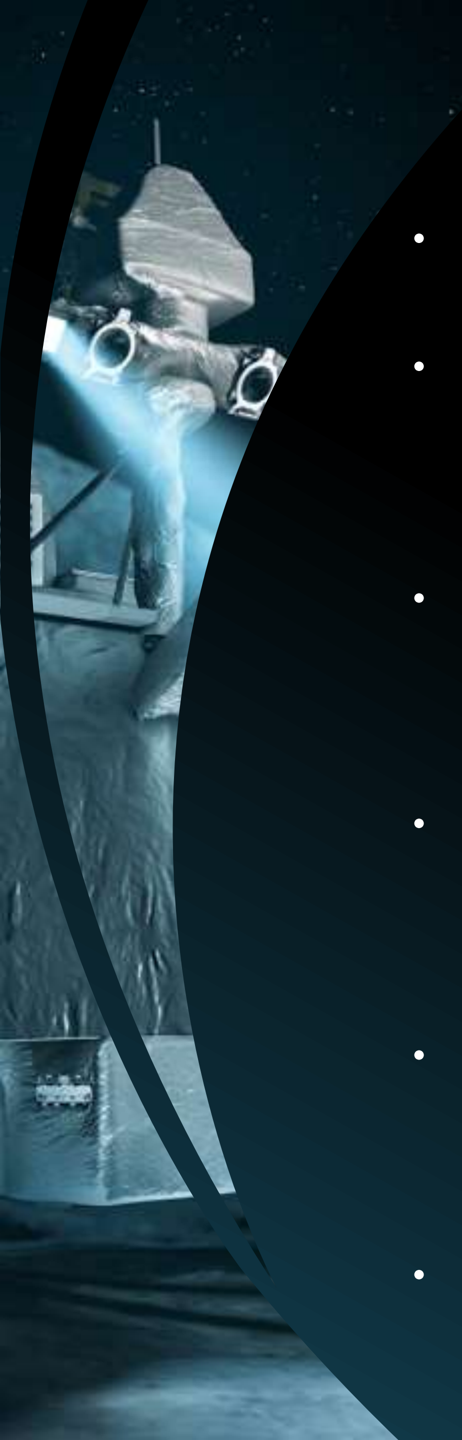
- Daniel Andrews: VIPER Project Manager
- Bill Bluethmann: VIPER Rover Lead
- Tony Colaprete: VIPER Project Scientist
- Steve Jara (Cris Andes): VIPER S&MA & Range Safety Lead
- Tom Luzod: VIPER Lander/LV Interface Lead
- David Petri: VIPER SI&T Lead
- Jay Trimble: Mission Systems (Ops and Ground)
- 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
  - Imminently entering TVAC testing, followed by post-test checkout
- The Mission System:
  - High value engineering/qual units available for integration work
  - Mission Operations Center outfitted with *feature-complete* software
  - 500+ hrs of integrated Ops team test and training
  - 200+ hrs of integrated Ops/rover training in lunar rover-scape
- 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

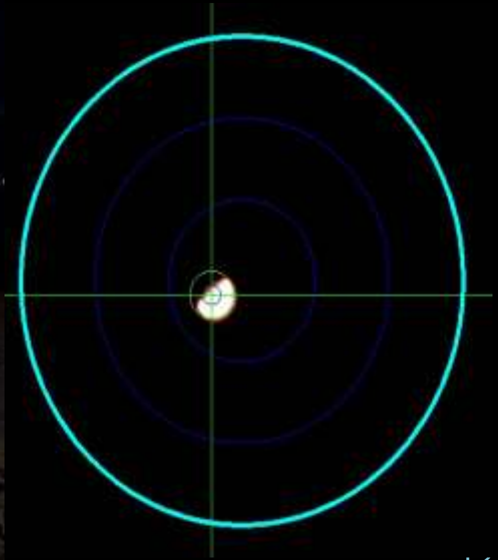
- VIPER team highly-practiced in commercial engagement
  - Instruments developed closely with commercial industry
  - VIPER experience shaping the next round of CLPS contracts

- 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)

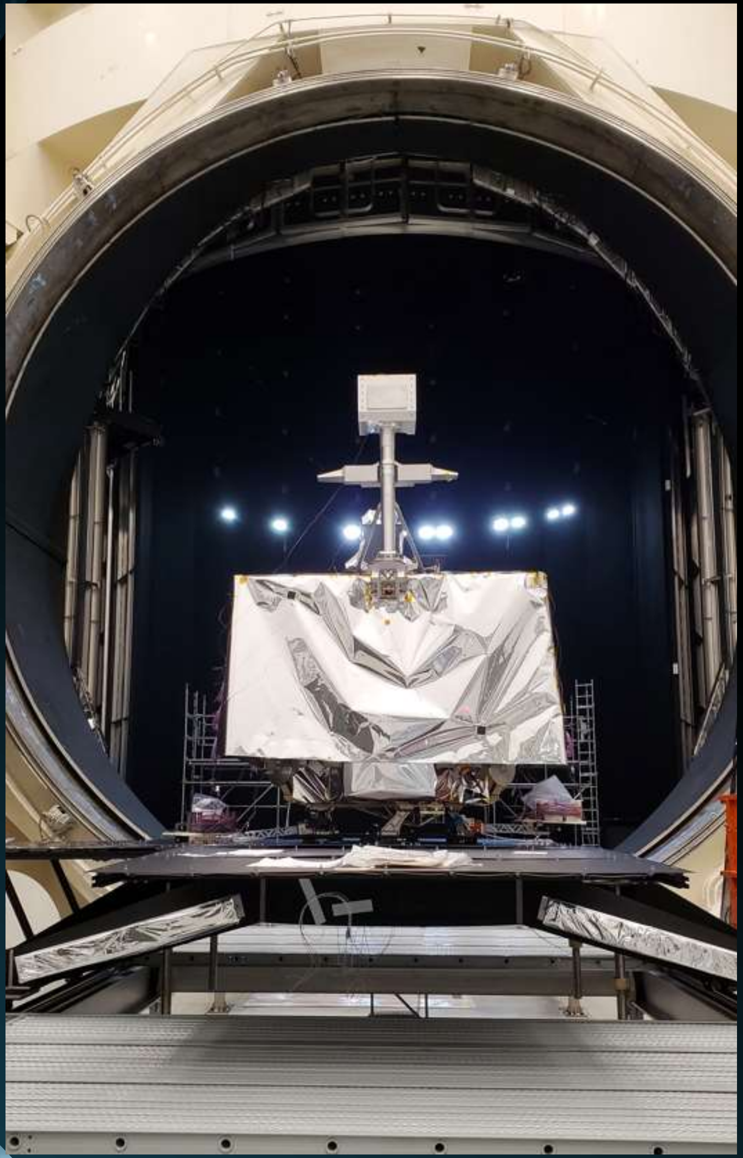
- VIPER rover design unlike any other NASA mission
  - Hybrid flight avionics, split on-board/off-board software stack, interactive real-time science ops, and extensive Agile development for all software and mission operations

- VIPER managed as a low-cost, risk-tolerant pathfinder mission - *then COVID hit*
  - VIPER's supplier community was clobbered by supply chain and quality issues
  - Drove VIPER integration schedule and development costs higher

VIPER Maturation: Mission Systems



VIPER Maturation: Rover Development



VIPER Rover Development

(Aug-2024)

Jun-2024: VIPER Build Status

464 of 464 Rover components delivered (100%)
192 of 192 Rover tasks Complete (100%)

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

Aug-2024: VIPER Test Status

Rover Vibe: Complete
Rover Acoustic: Complete
Rover TVAC: Imminent (Sept)

VIPER Ground Development

(Aug-2024)

Aug-2024: VIPER Status

GDS Build-9 released – SW *Features Complete*

Simulations completed:

- Surface Housekeeping
- Rails Driving
- Science Stations
- Transit Housekeeping
- Transit Payload Checkouts & Calibrations
- Science Station ops
- Safe Haven and Hibernation

121 of 128 Ops products completed

A total of 666 team-hours have occurred so far in SIMs, ERTs and MGRU rover testing to date

VIPER Mission Overview & Possibilities

(Dr. Anthony Colaprete)

VIPER Designed to Support a Broad Community

Level 1 Goals:

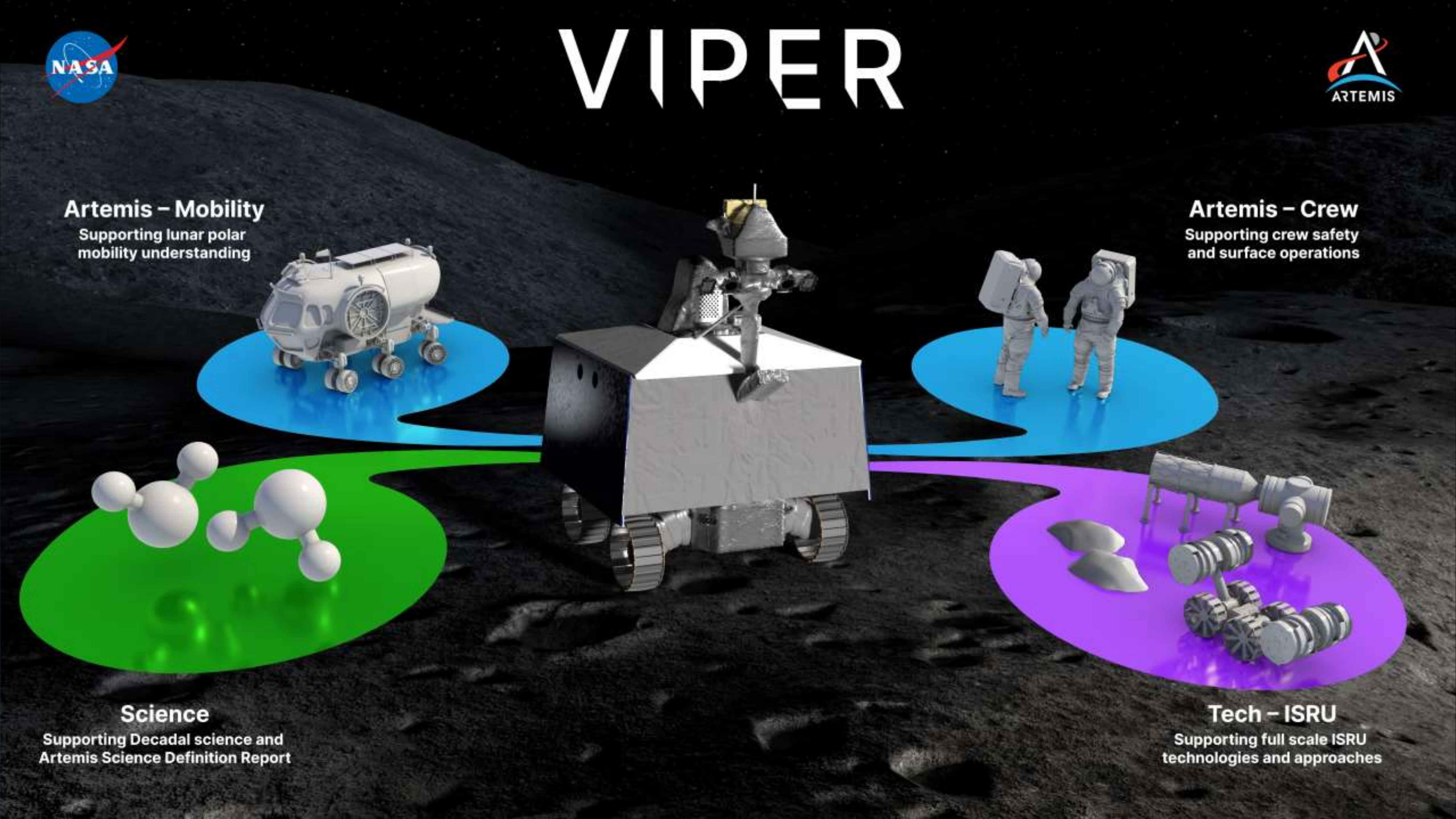
Decadal Survey-Level Science

- 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 “tool box” (rover, instruments, GDS and expertise) can be broadly applied and adapted to meet a variety of goals.



NASA
VIPER
ARTEMIS
Artemis – Mobility
Supporting lunar polar mobility understanding
Artemis – 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

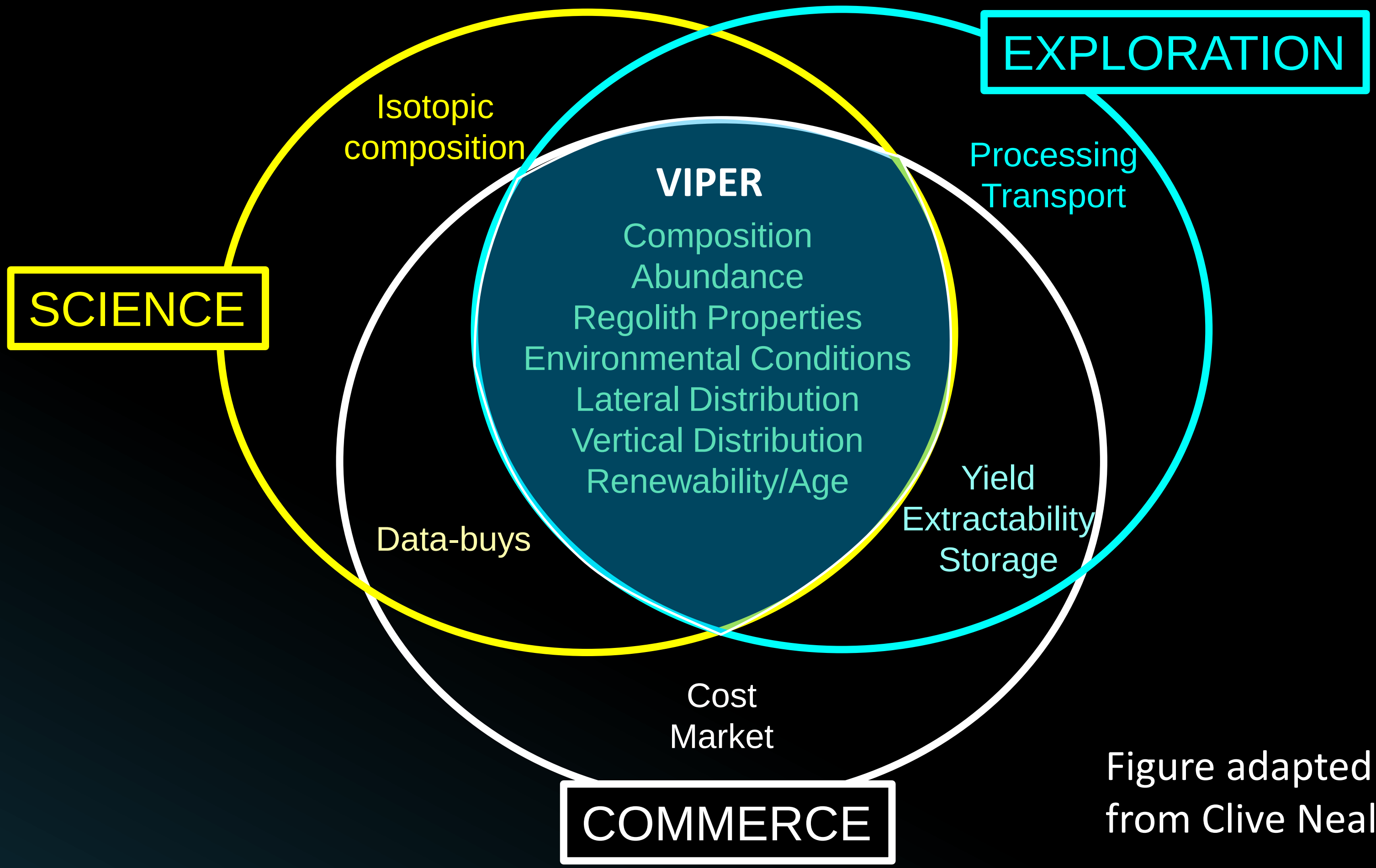


Figure adapted from Clive Neal

VIPER Rover

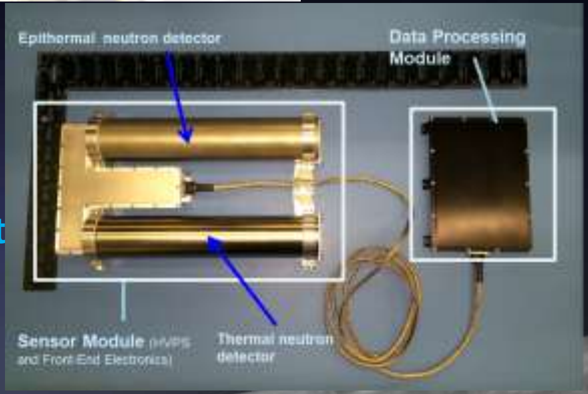
- **Rolling Mass:** ~450kg
- **Power:** ~450W (corner-facing) or 320W per array
- **Communications:** X-band
- **Dimensions:** 1.7m x 1.7m x 2.5m
- **Wheel Diameter:** 0.5m
- **Steering:** Explicit steer; adjustable suspension
- **Top Speed:** 20cm/s (0.5MPH)
- **Prospecting Speed:** 10cm/s (0.25MPH)
- **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

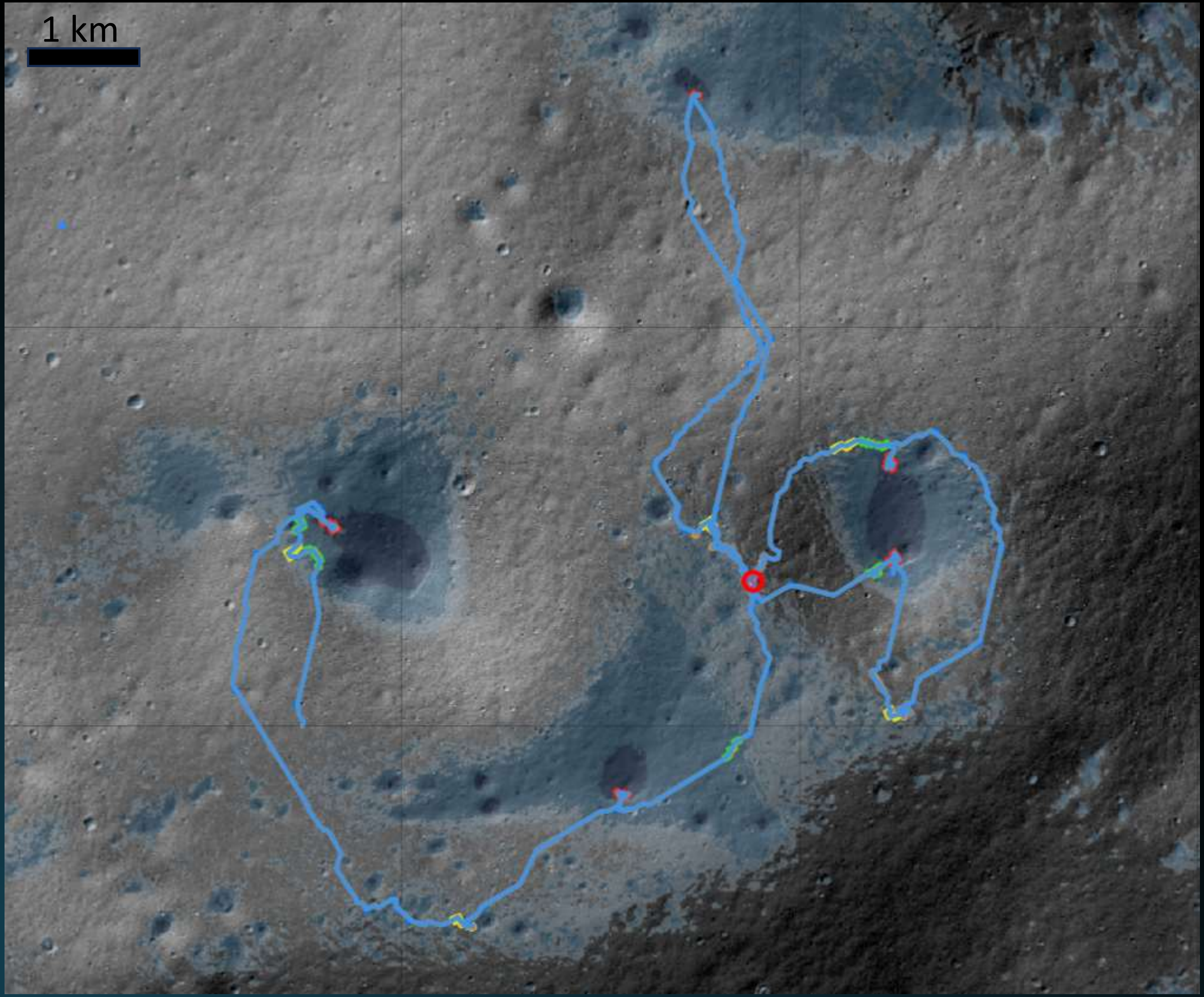


Subsurface Sounding
Rover IMU

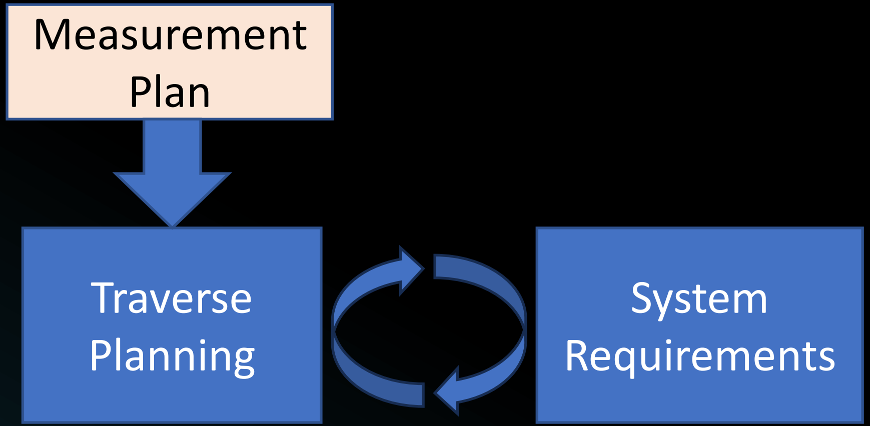
Prospecting & Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS) Instrument

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

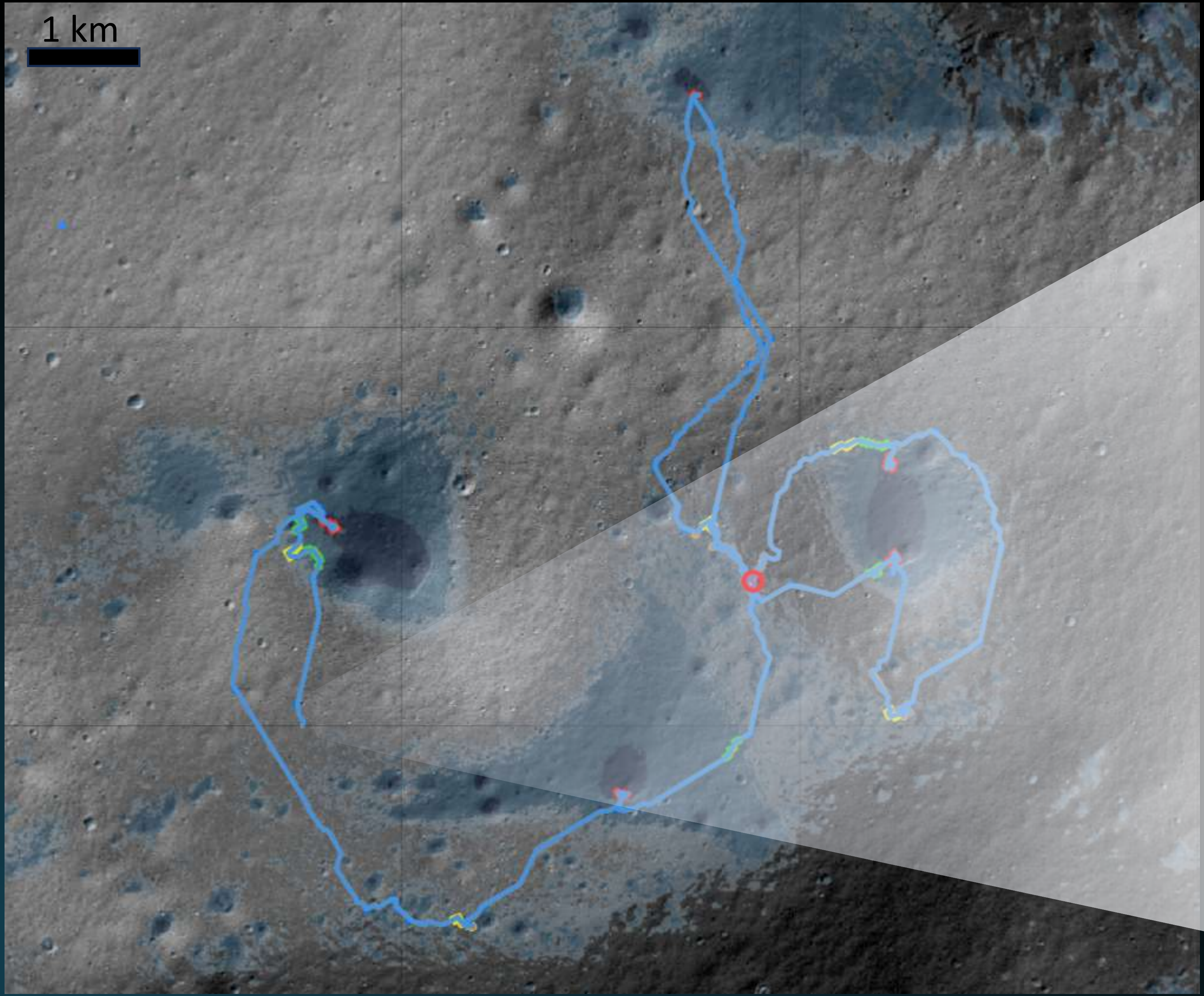
VIPER Mission Capabilities – Mission Summary

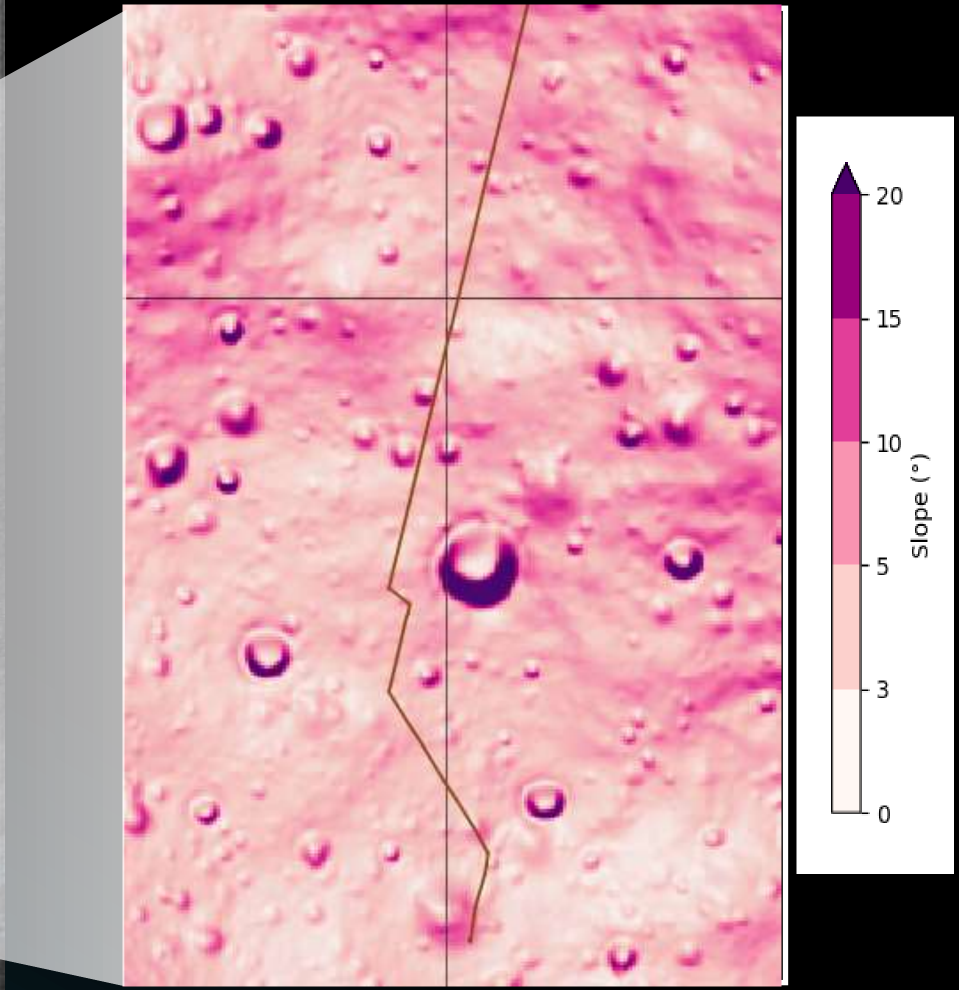


- VIPER's capabilities were motivated through an iterative process of traverse & system development
- Measurement requirements were developed using geostatistical evaluation of necessary coverage, areal density, and number of sample points
- Traverses were built that met these requirements and these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



Rapid Surface Transit

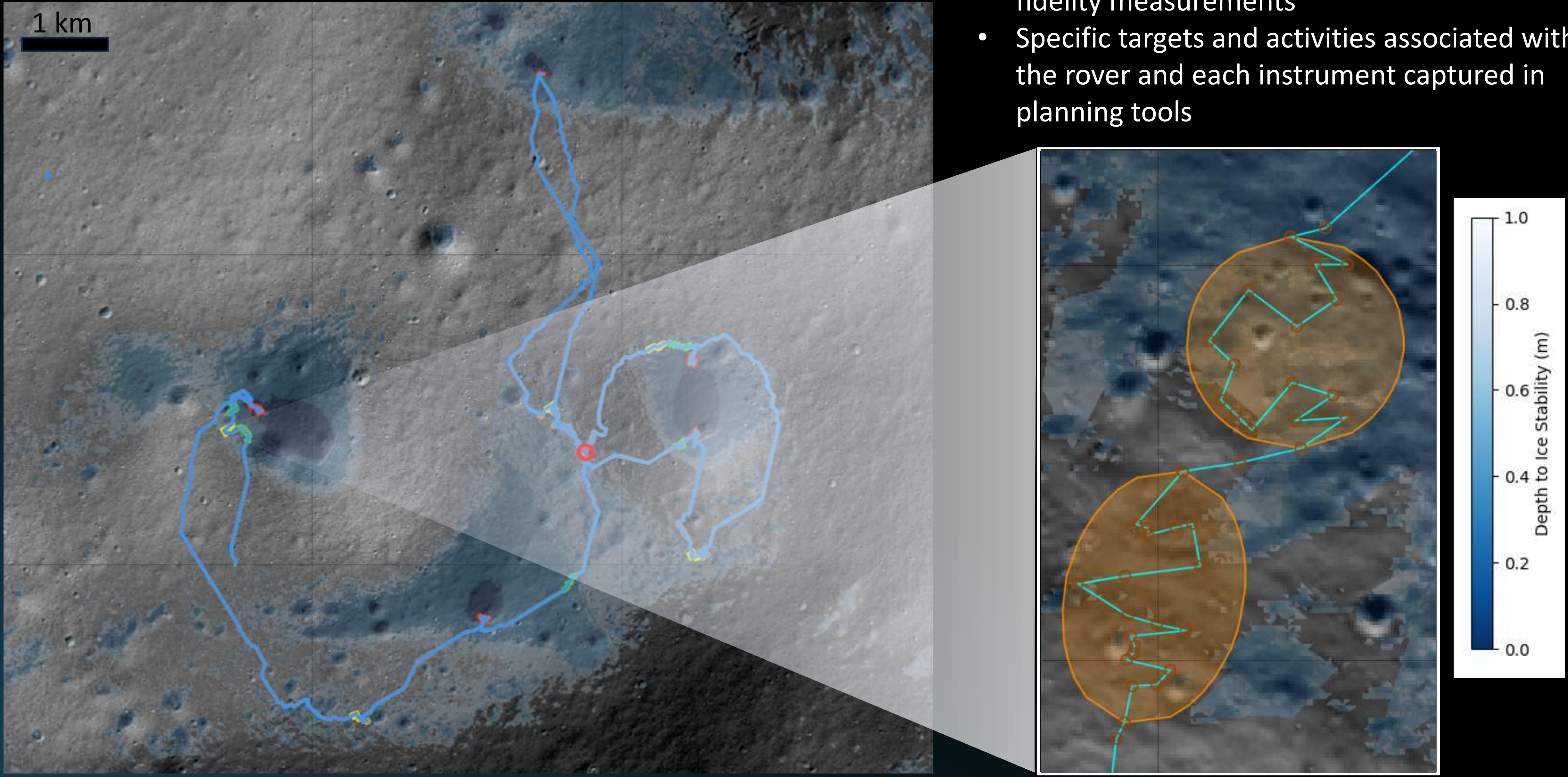




- From landing site, traverse in "Rails" driving mode – quickly and safely get from A to B
- Traverse optimized with AI Tools within hazards, sun and comm constraints

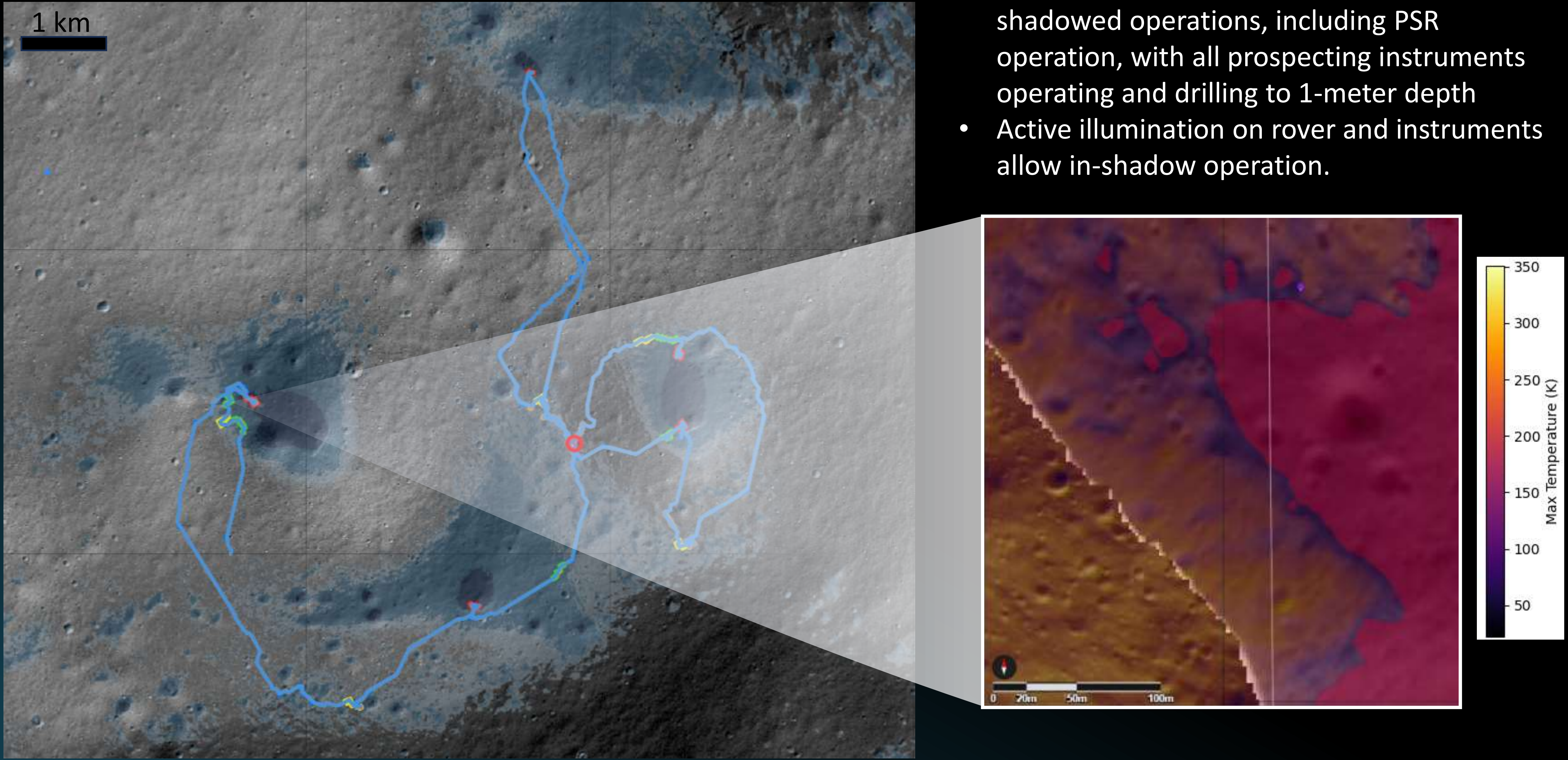
High Fidelity Tactical Planning

- 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

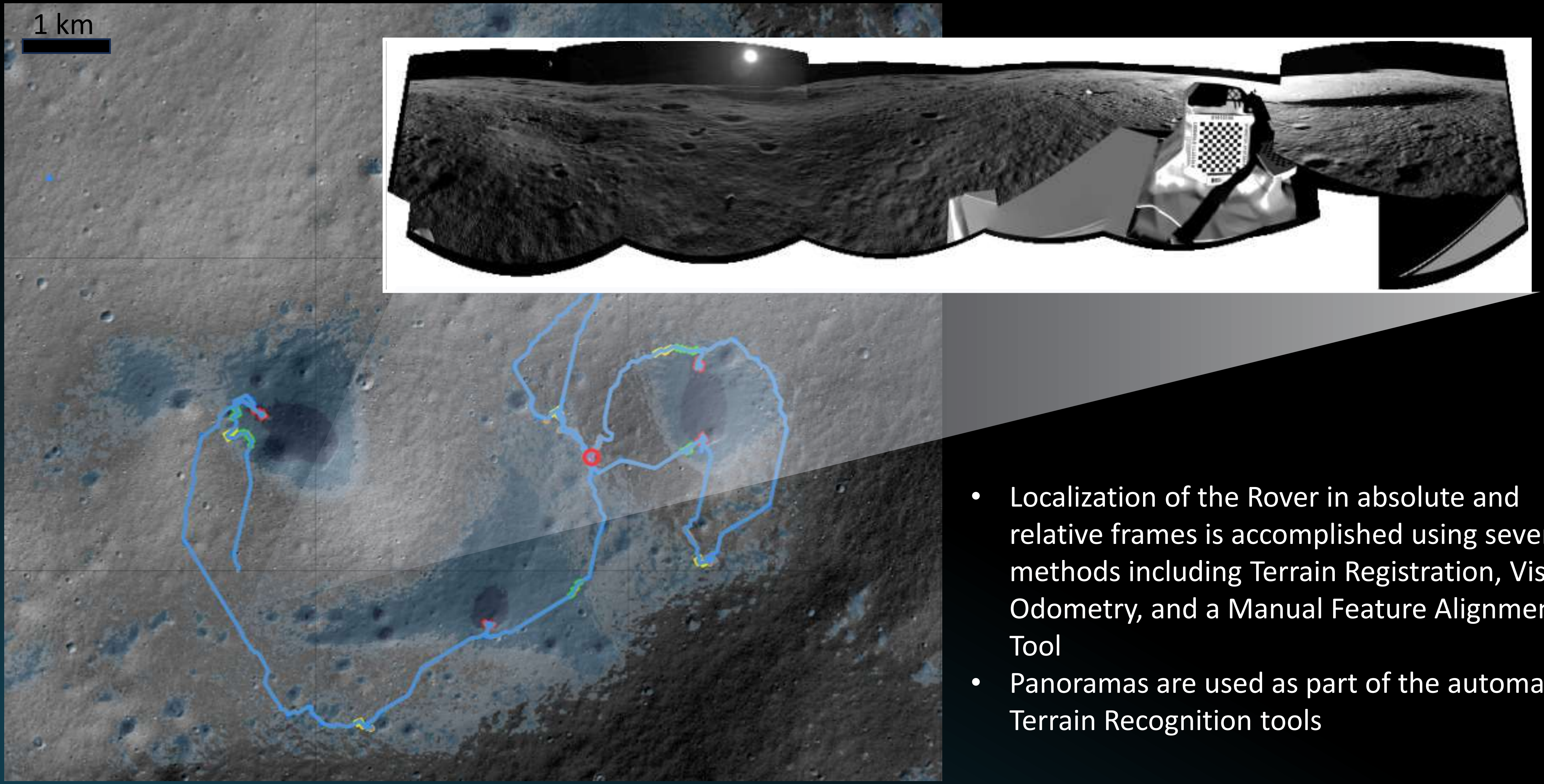


Shadow Operations Endurance

- 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.

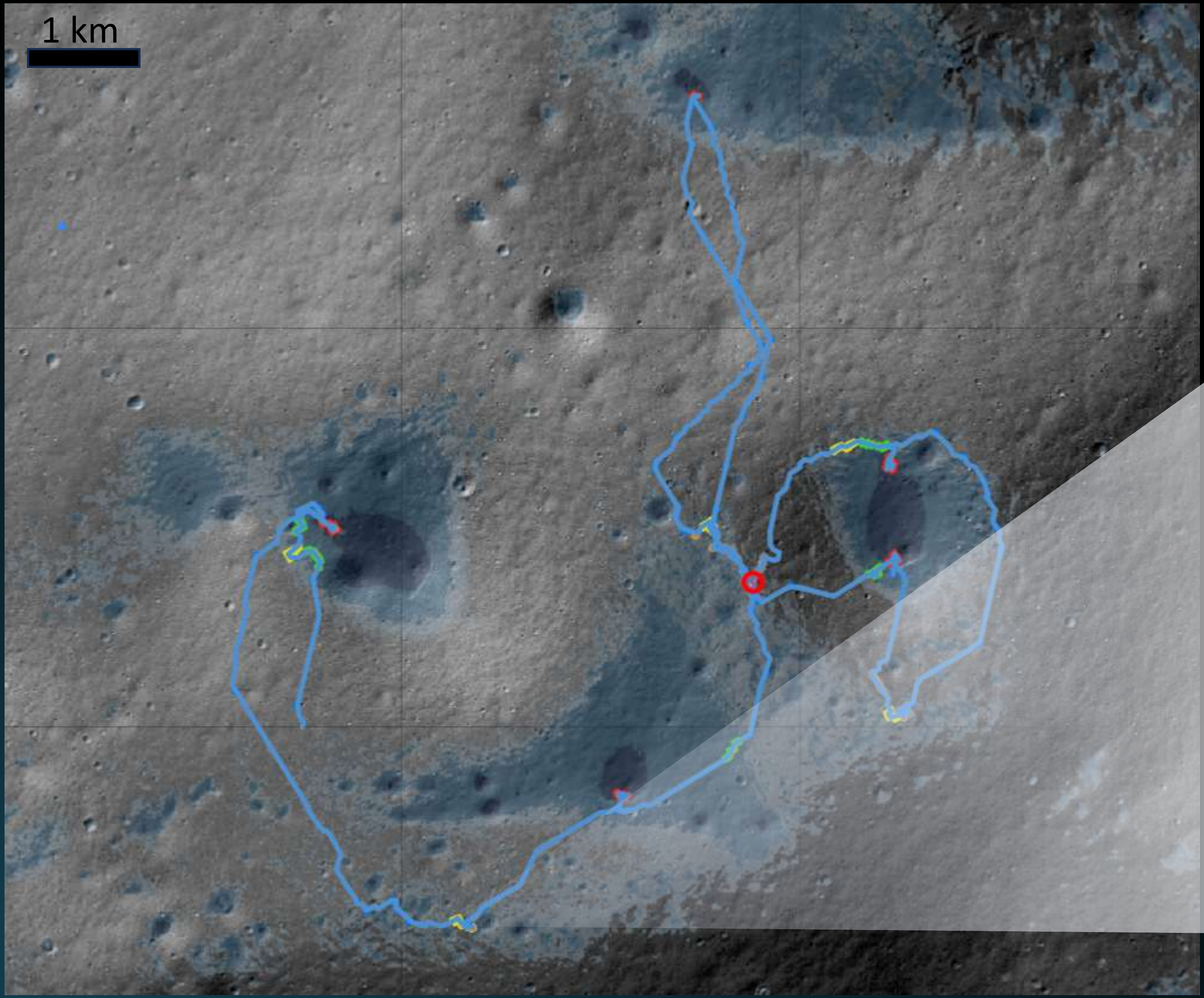


Absolute and Relative Localization

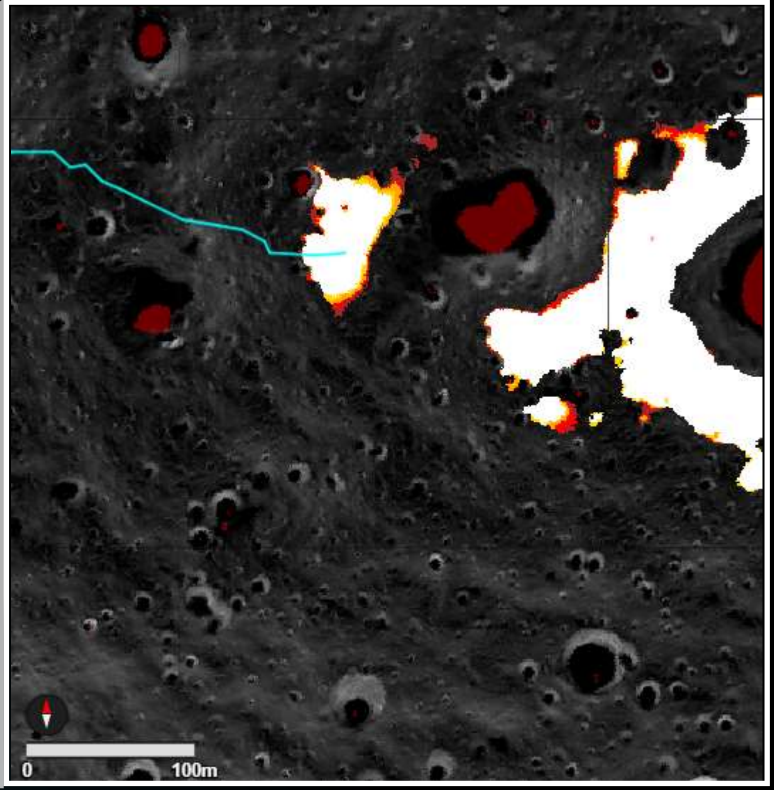


- Localization of the Rover in absolute and relative frames is accomplished using several methods including Terrain Registration, Visual Odometry, and a Manual Feature Alignment Tool
- Panoramas are used as part of the automated Terrain Recognition tools

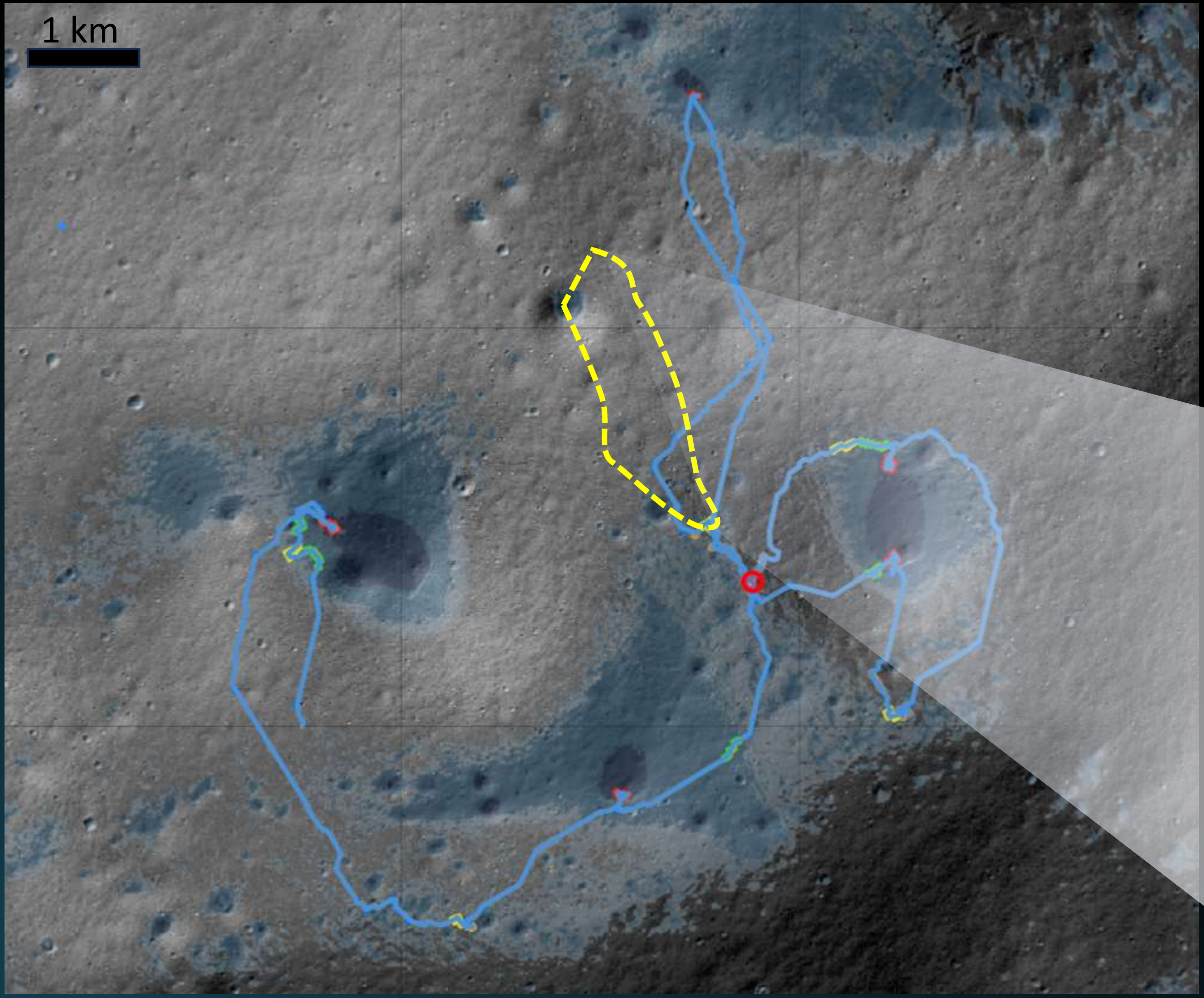
Shadow Period Survival



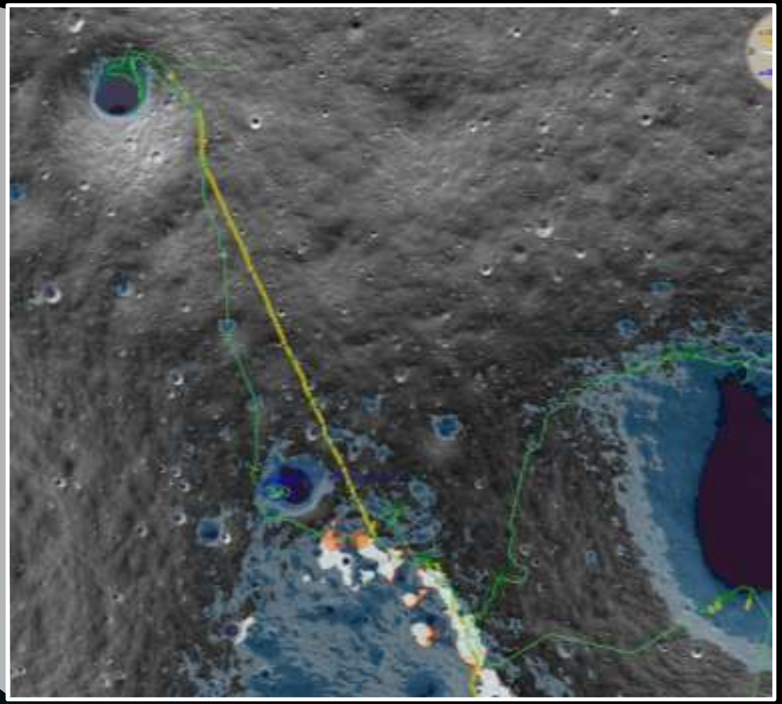
- “Safe Havens”, locations with shadow periods <50 hours long identified with 1-m DEM and illumination modeling
- The Rover is able to park and ”hibernate” at these Safe Havens while Earth is not in view



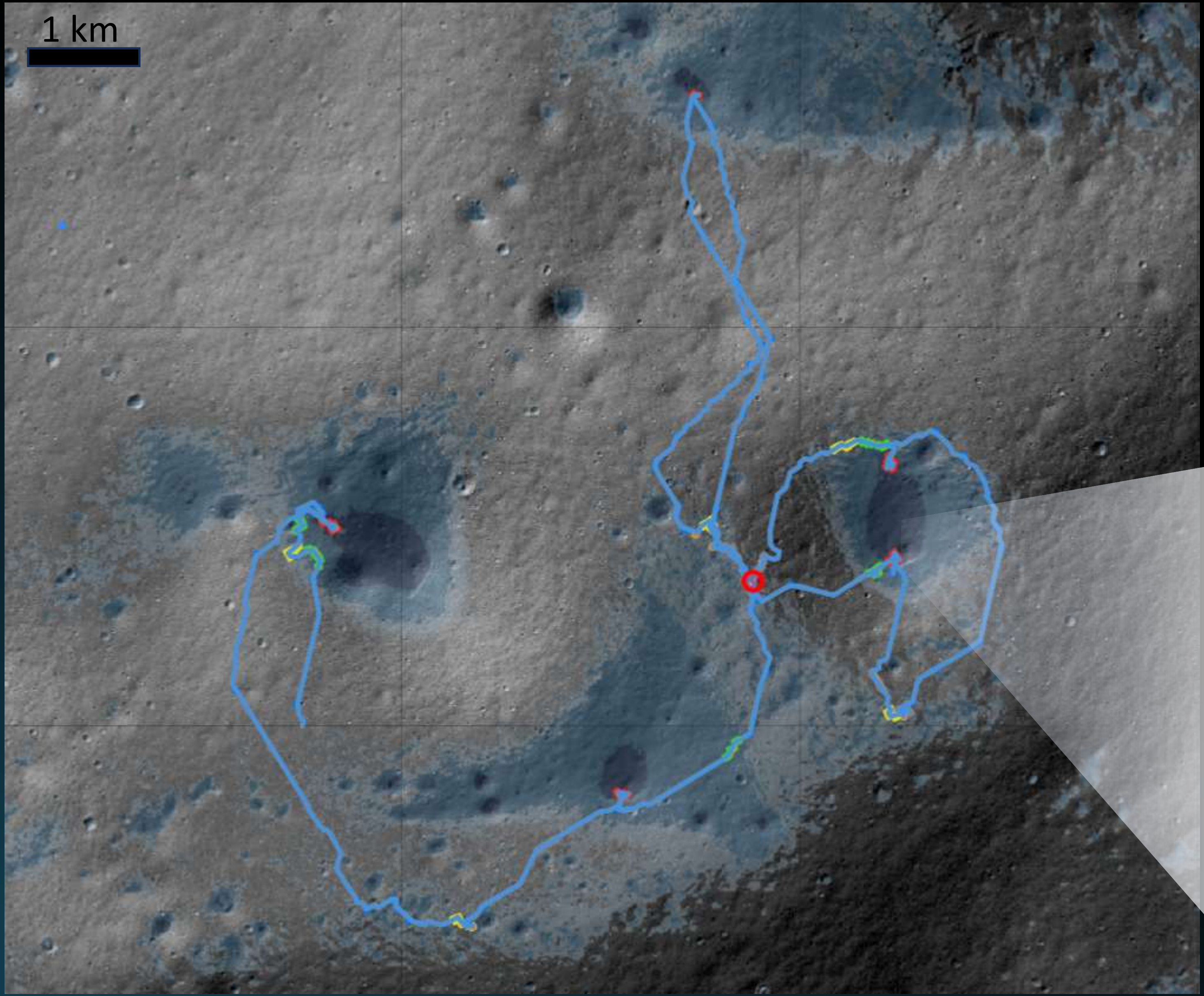
Rapid Replanning



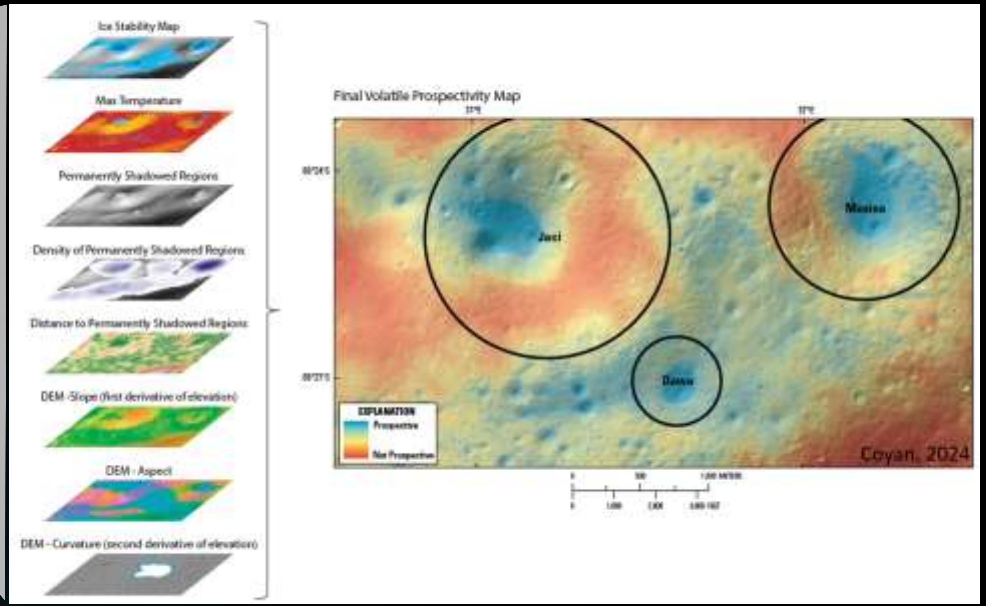
- Replanning is expected and designed for. Tactical planning can occur on time scales of hours, for example moving a drilling location
- During Hibernation Periods between lunar days, the Science Team will update priorities based on what they have learned and work with Mission Systems to update the plan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



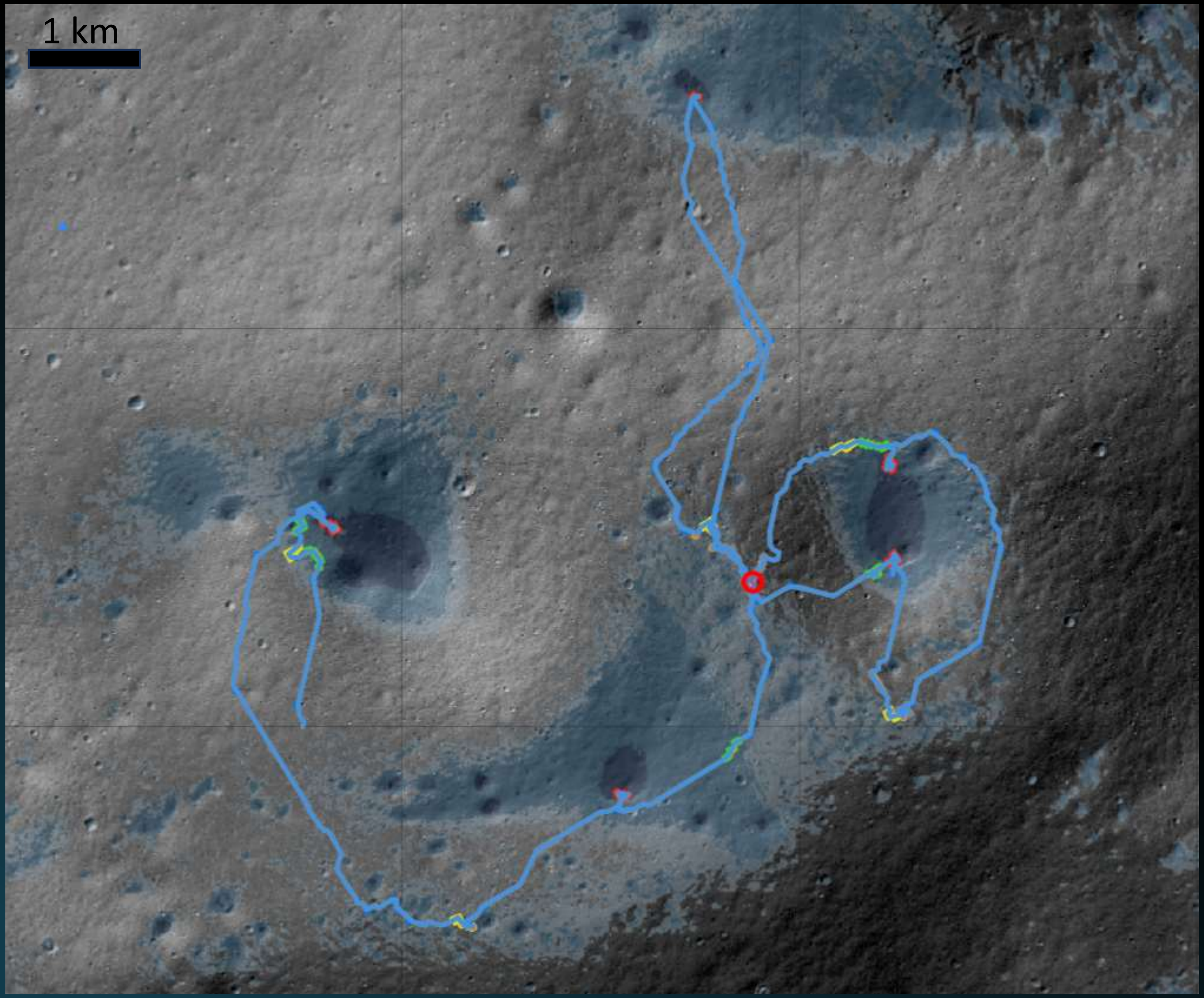
Real-Time Data Processing



- Near real-time data processing and derived data products, including:
  - Resource Map (e.g., Water Favorability Maps & Trafficability Maps)
  - Trend analysis
  - Correlation analysis
- Real-time displays of derived instrument parameters (e.g., Water Equivalent Hydrogen, H_2O 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

VIPER Capabilities and Development

Measurements and Instruments

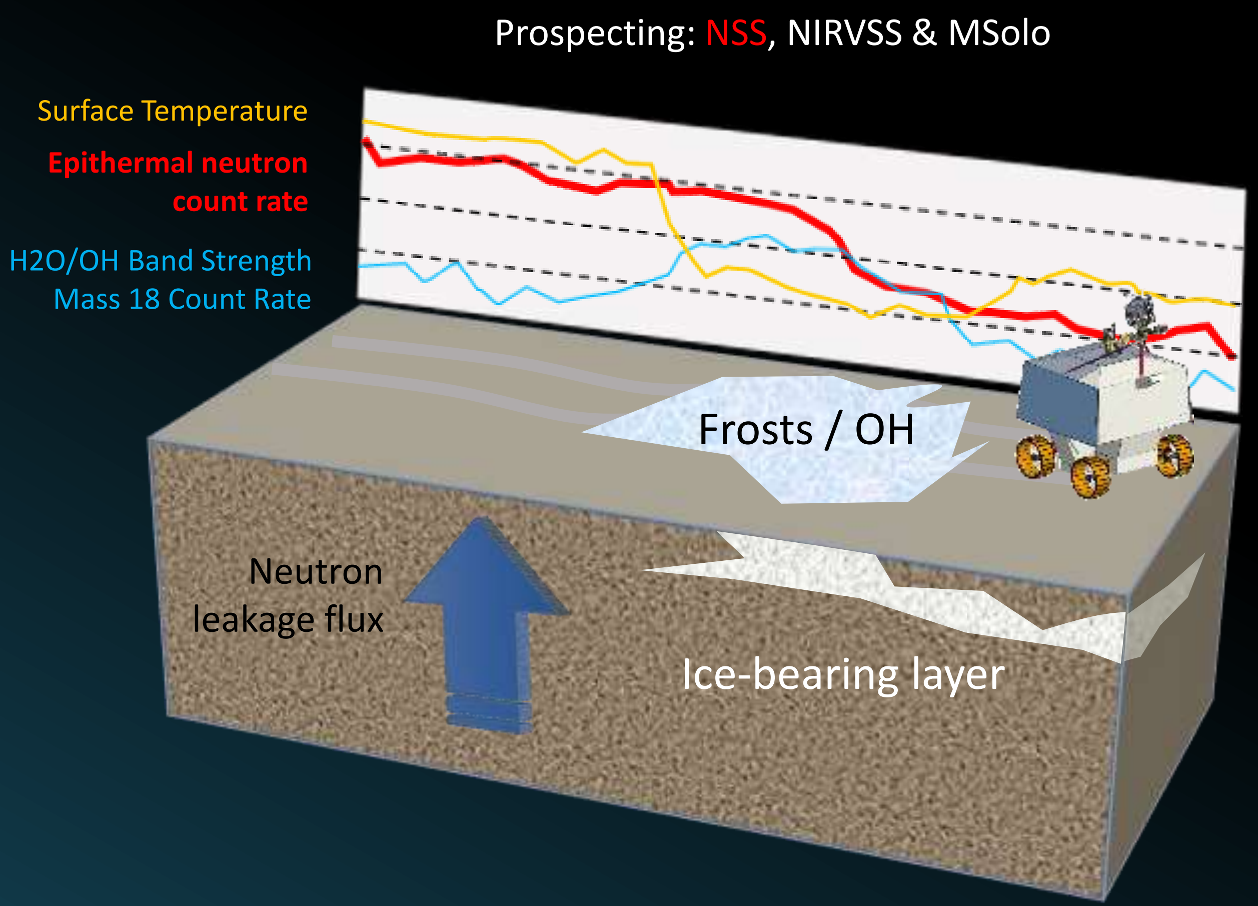
(Dr. Anthony Colaprete)

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*.**

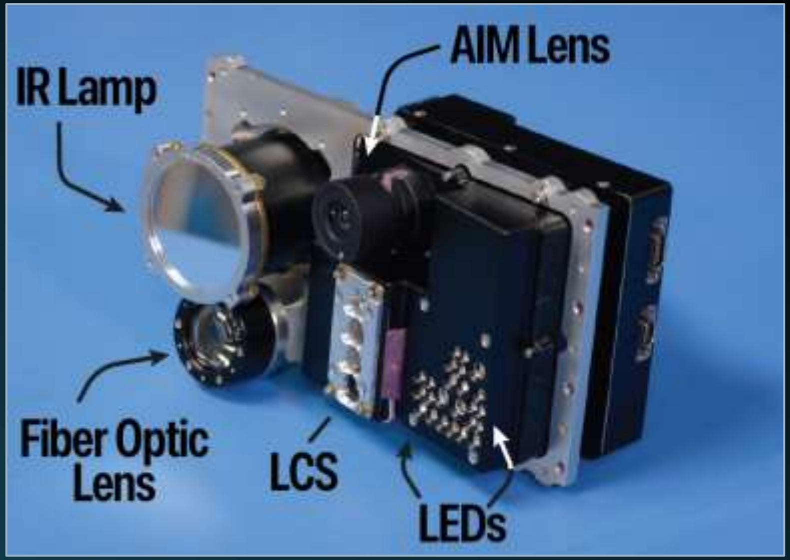
NSS Observation Possibilities



- 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)

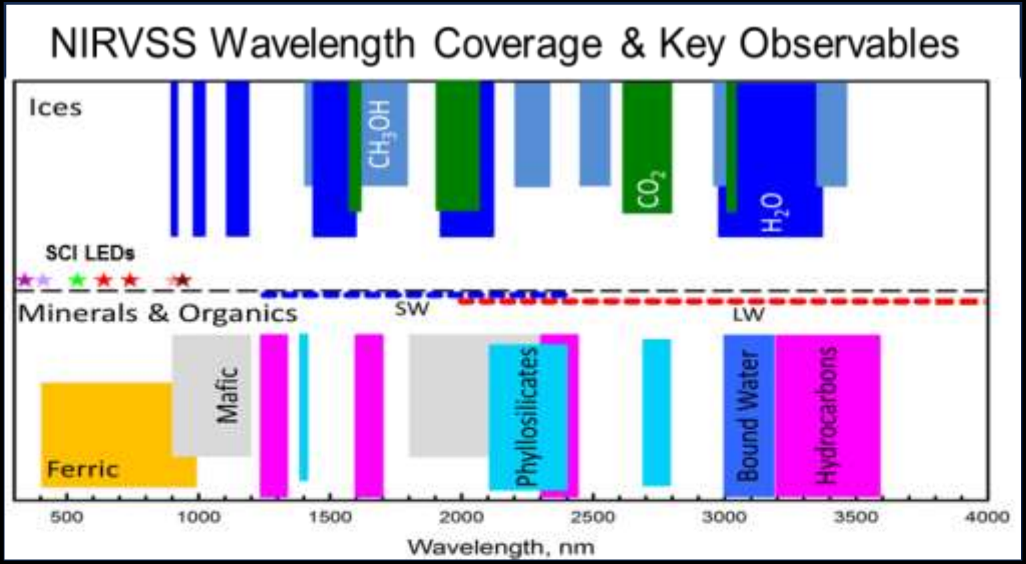
- Provides direct correction for longwave thermal emission contributions to near-infrared observations of the surface.
- Four single-channel thermopile sensors and filters with 36ºC FOV: 6.1-20+ (broadband), 10.5 µm, 13.8 µm, and 14.5-17.5 µm
- Eight gain settings; cycles through one gain setting takes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

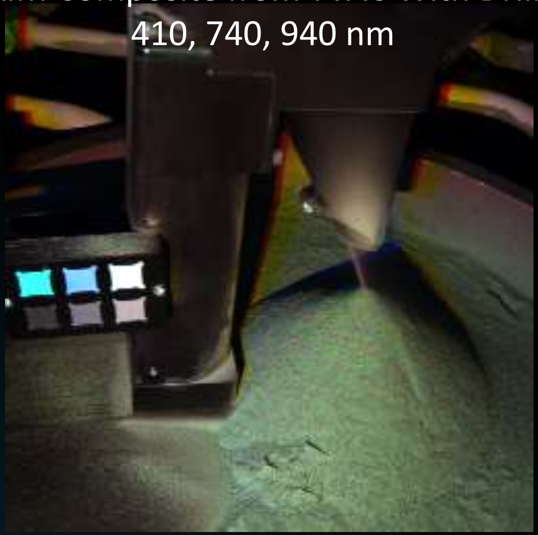
NIRVSS Observation Possibilities

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

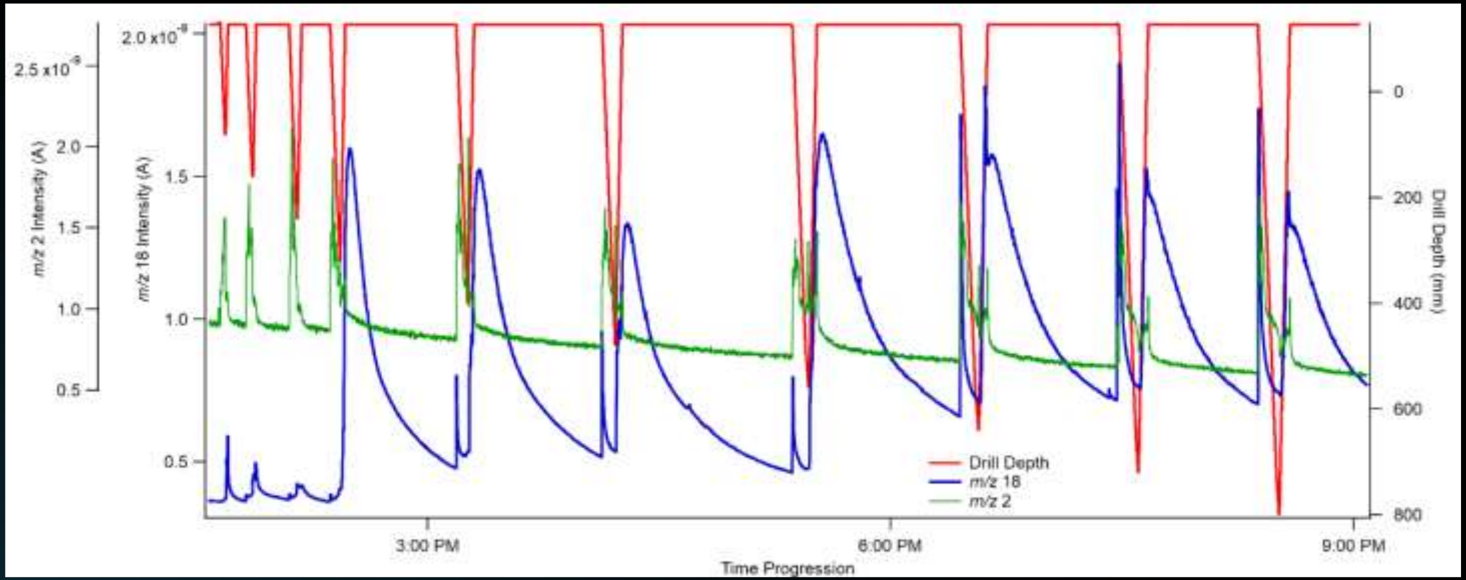
Key Measurements:

- 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)

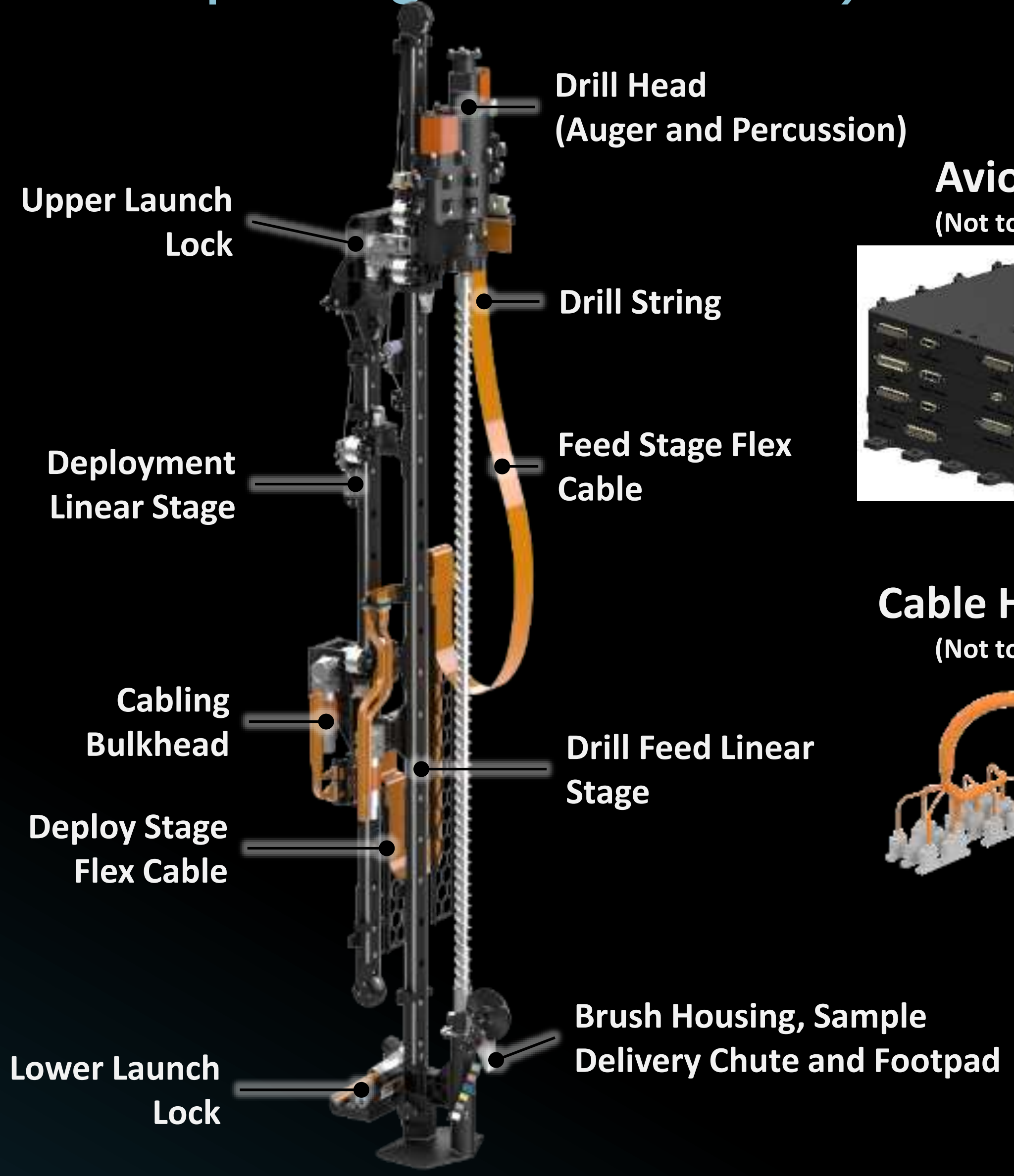
TRIDENT Objectives:

- 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)

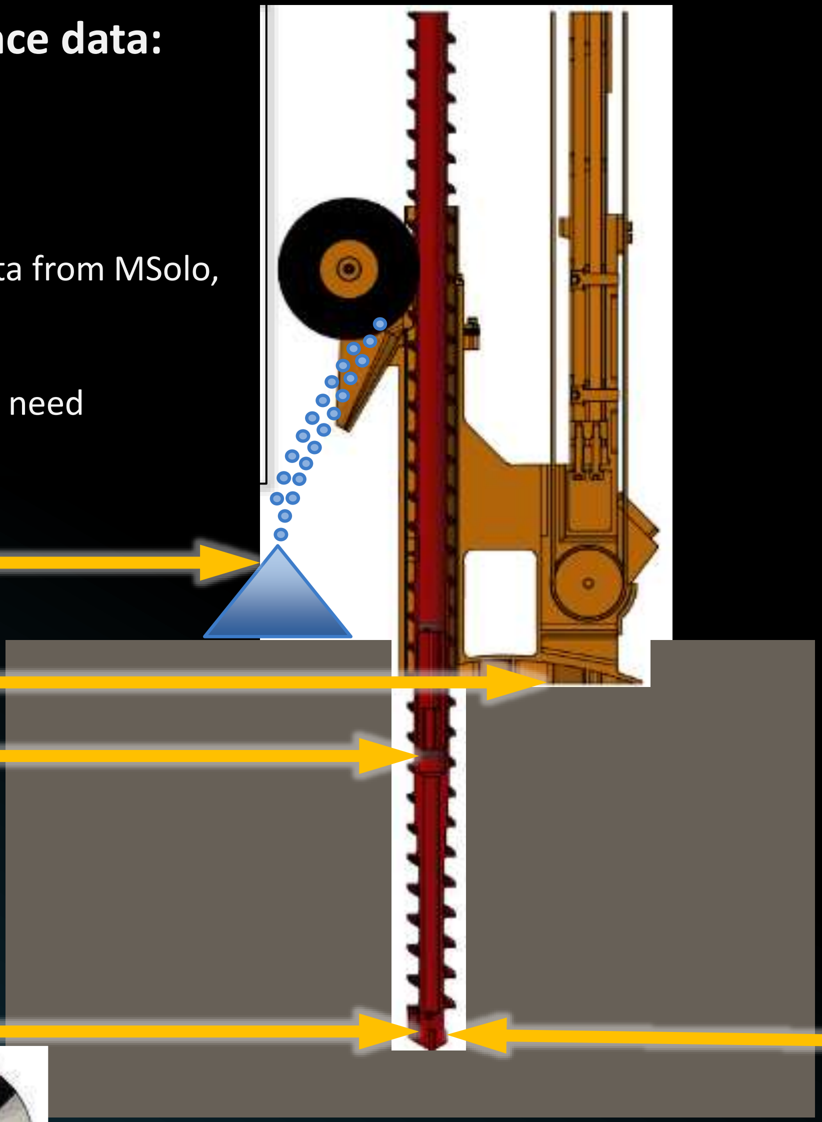
TRIDENT Observation Possibilities

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 (#):

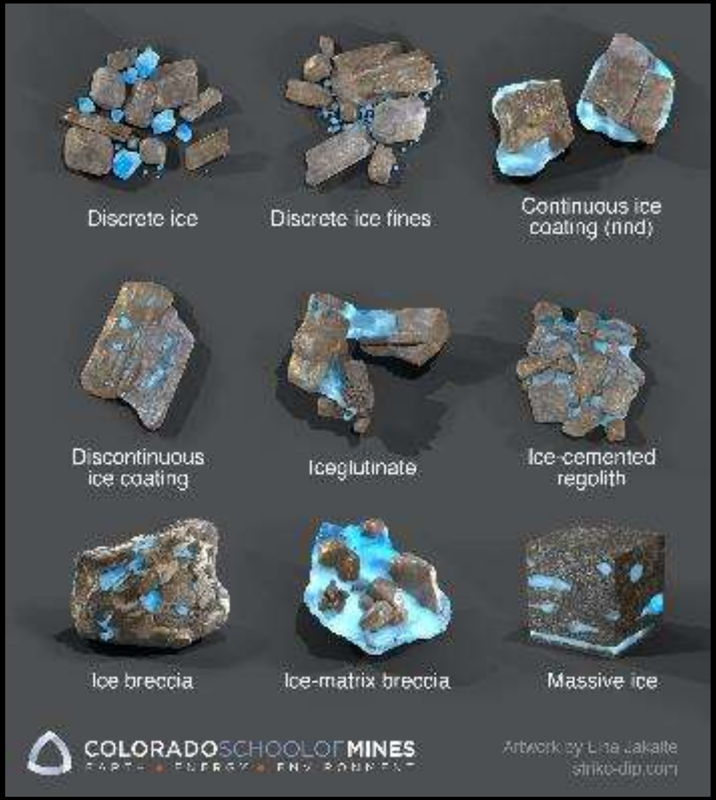
- Bearing capacity

Heater (#):

- Thermal Conductivity (with Temp. Sensor)

Bit Temperature Sensor (#):

- Subsurface Temp vs Depth



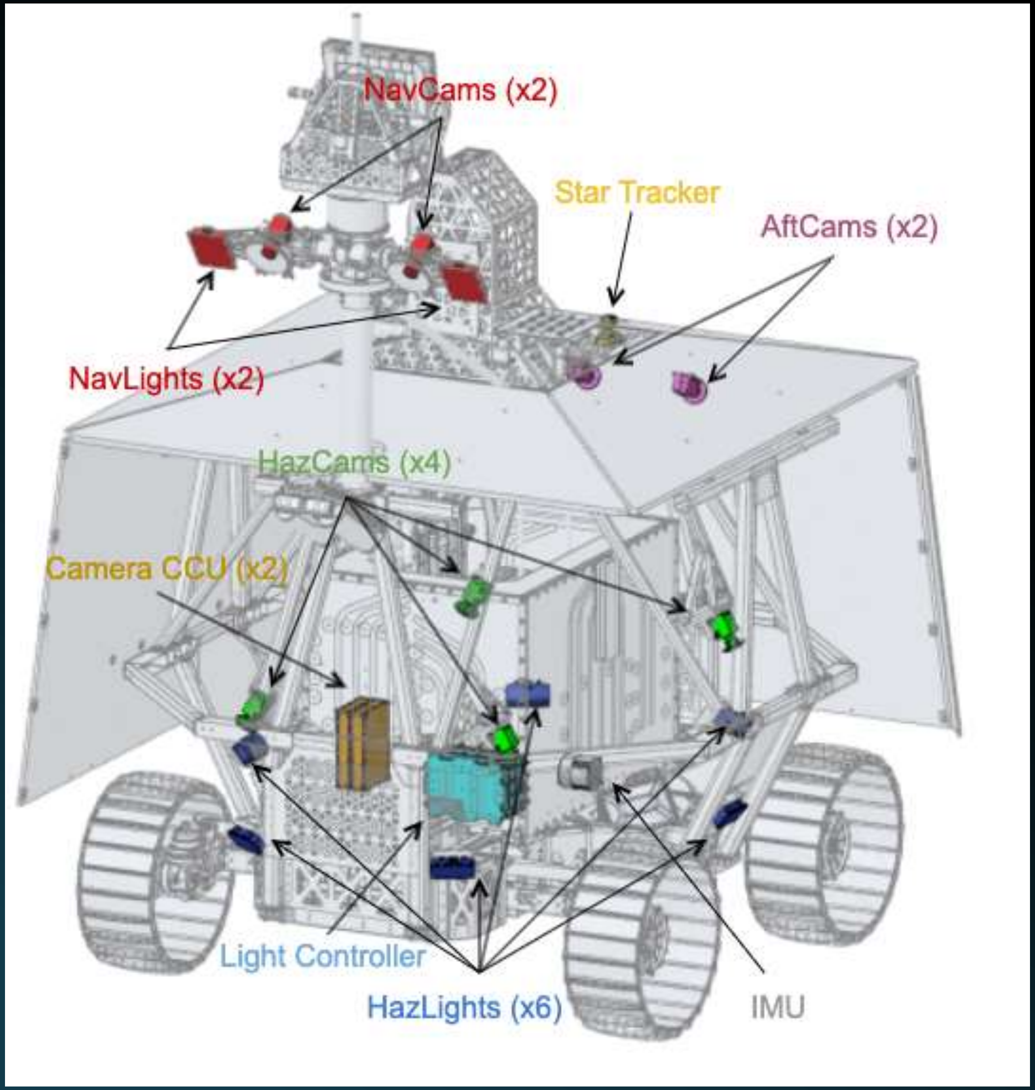
Courtesy Kevin Cannon

Drilling Power (#):

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

VIPER Visible Imaging System (VIS)

Science Lead: Ross Beyer, Hardware Lead: Uland Wong



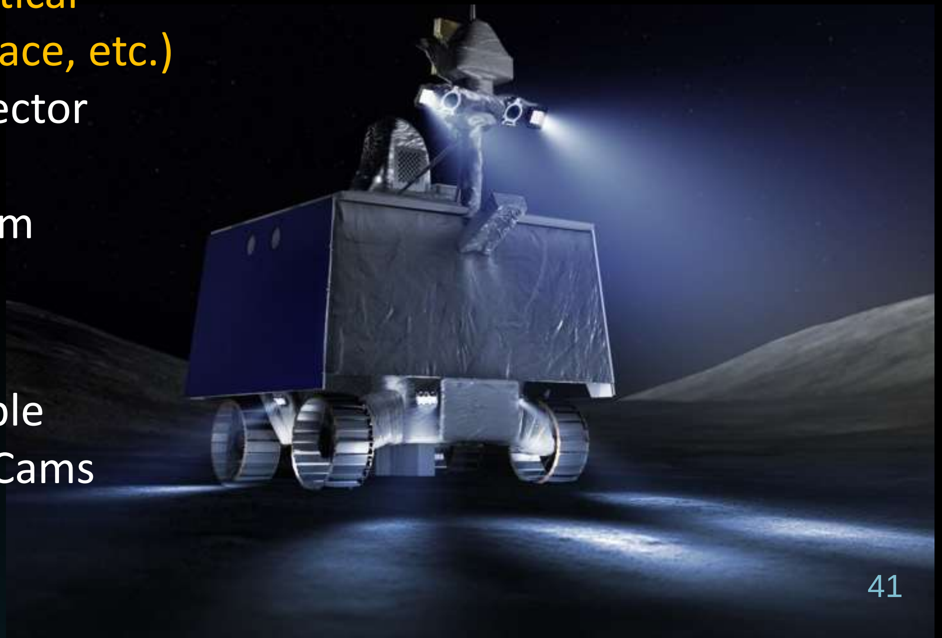
NavCams
- Stereo, PTU-mounted
- 65° FoV
- Can resolve (>= 5 pixels)
    - 10 mm features at 2 m
    - 55 cm features at 20 m

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

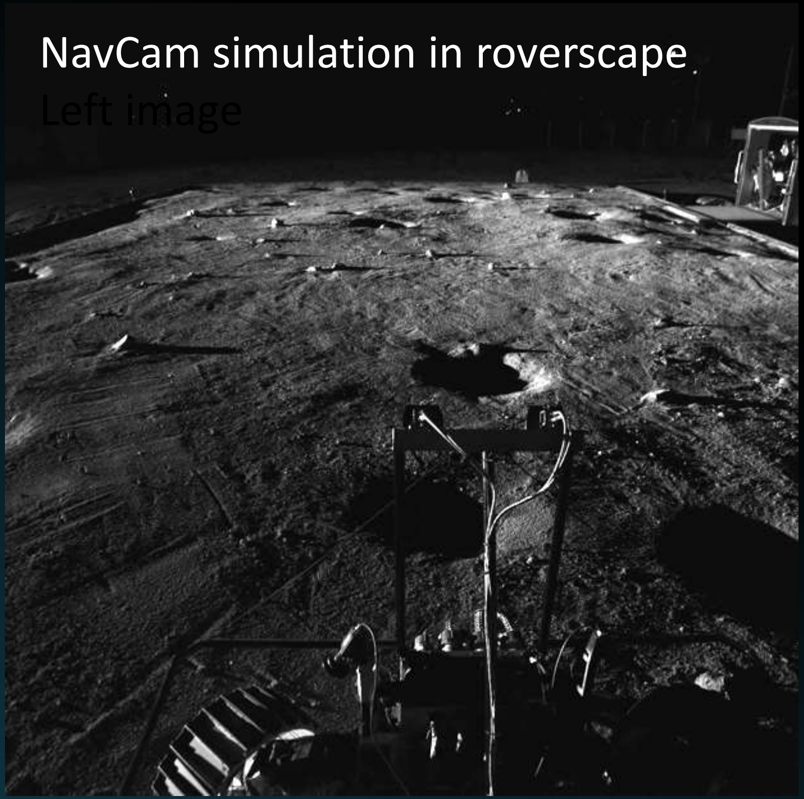
Luminaires (LED lights):
- Independently operatable
- 2 PTU-mounted by NavCams
- 6 around base of rover

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

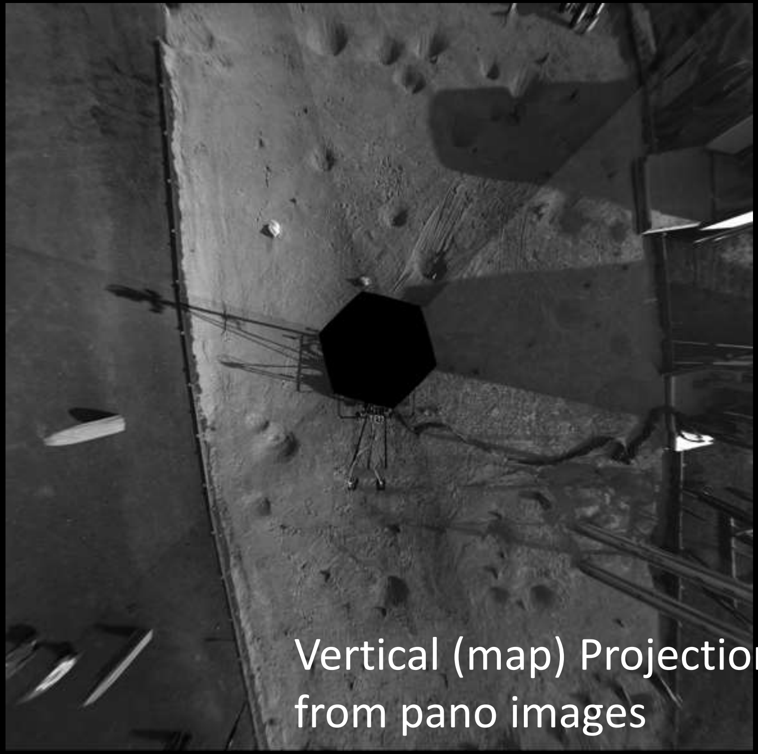
HazCams
- Mono, looking at each wheel
- 110° FoV



VIS Observations and derived products


NavCam simulation in roverscape
Left image


HazCam simulation in Regolith Lab


Vertical (map) Projection from pano images


Panoramic Projection from pano images

Rover Data

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

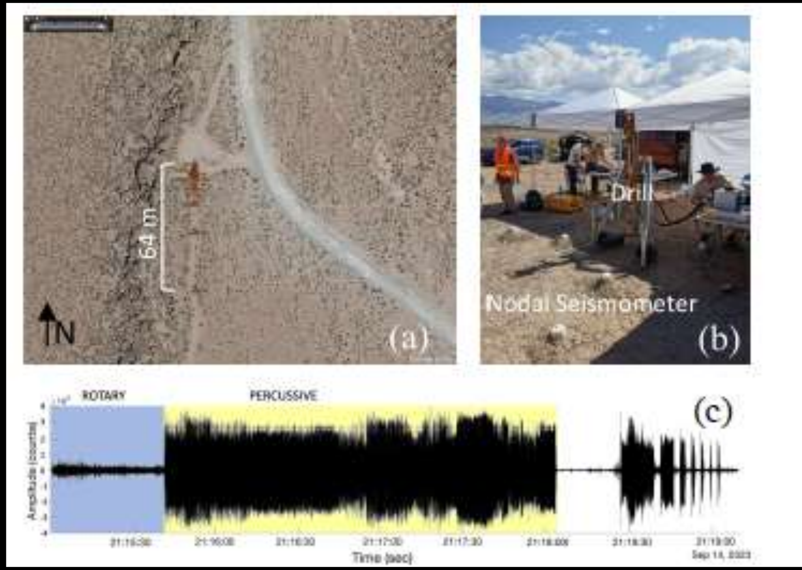
Seismic Measurements

- 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

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

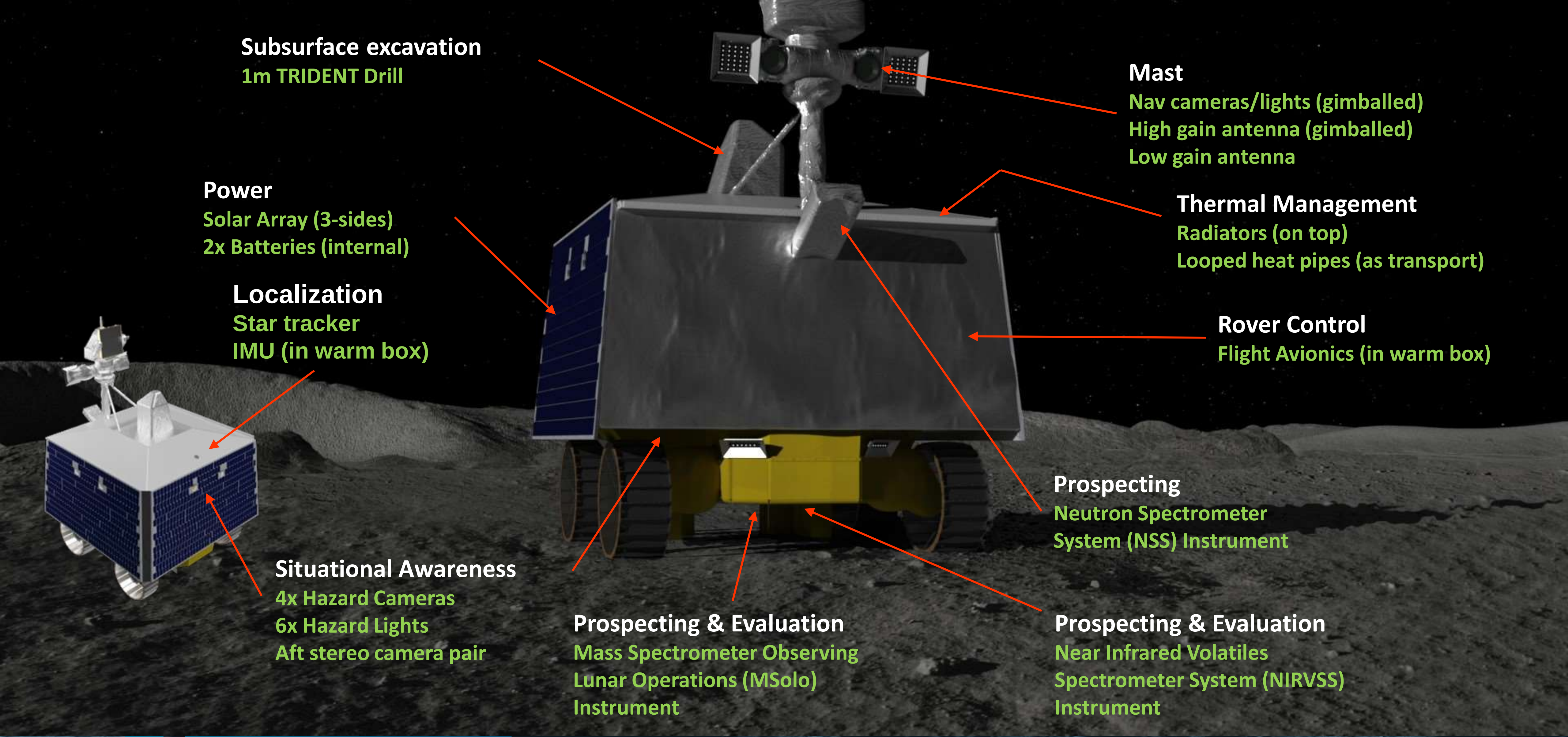


Wheel sinkage vs slope testing at GRC

Roving Platform

(Bill Bluethmann)

VIPER Rover Overview



VIPER Rover Capabilities (1 of 3)

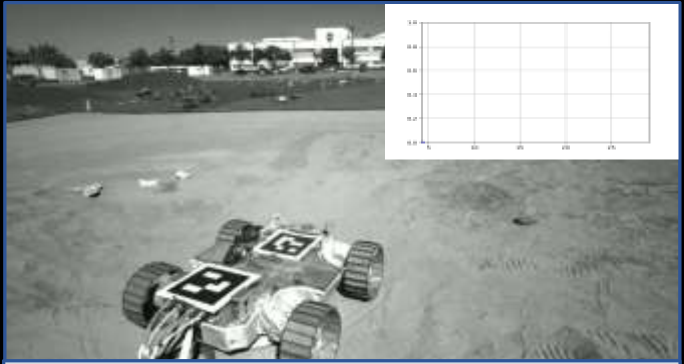
- **Mass:** launched: 490kg, roving: 447kg
- **Dimensions:** 1.7m x 1.7m x 2.5m
- **Power:** solar array generation with battery storage
  - **Solar generation:** 450W (corner-facing) or 320W per array
  - **Battery capacity (beginning of life @ 0C):** 5420 W-hr
- **Communications:** X-band DTE/DFE [1]
  - **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 units in interior
    - Passive looped heat pipes between radiators and warm box
    - Thermal control value on each heat spreader to start/shutdown radiators
  - **Shadow capabilities**
    - 50 hours survival in low power mode
    - 9 hours operational in permanently shadowed region

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

VIPER Rover Capabilities (2 of 3)

- **Mobility System (wheels, wheel modules, motor controllers)**
  - Slopes up to 15 deg, obstacles to 15 cm
  - Adjustable ground clearance from 7- 43cm
  - Waypoint driving with nominal 4-5m commands
    - Commands issued from ground every ~5 min
    - Other drive modes: point turn, entrapment escapement, precision movement
    - Slip/embedding detection
  - Wheel Modules
    - Wheels: diameter 50 cm, with 2.5 cm grousers, spoked
    - Drive: top speed 20cm/s, nominal speed 10 cm/s
    - Steering: explicit with +/-50 deg range
    - Suspension: adjustable with individual wheel downforce control
  - Mobility system qualified to 2x20 km surface life

SLOPE Testing (video)



Slip detection testing (video)

Wheel endurance test (video)

VIPER Rover Capabilities (3 of 3)

- **Imaging**
  - **Navigation Cameras**
    - Gimballed stereo pair on mast with lights
    - Hazard map creation
  - **Hazard cameras**
    - 4x wide angle mono hazard cameras in wheel wells
    - Supported by 6x hazard lights
  - **Aft cameras**
    - **Wide angle stereo pair:** inside aft solar panel
  - **Cameras**
    - 2048 x 2028 imagers
    - 12-bit grayscale
  - **Hazard detection**
    - Up to 8m range for obstacles greater than 10 cm
- **Surface localization**
  - 20m and 0.5 deg accuracy during operations
  - Using visual odometry, wheel odometry, star tracker, and IMU

View from Haz Cam

Testing Lights on Flight Mast

Pointing at moon HGA while roving

VIPER Rover Software Capabilities

Rover Flight Software

- System Services & Applications
- Operational Mode Management
- IAU Power-up and Boot Management
- Fault Management
- Subsystem & Function Management
  - Comm
  - Power
  - Thermal
  - Mobility
  - Egress
  - Navigation
  - Data
  - Mast Gimbal

Rover Ground Software

- Hazard Mapping
- Orthoprojection
- Path Planner
- Pose Corrector
- Rover Motion Predictor
- Stereo Image Processor
- Terrain Registration
- Visual Odometry
- 3D Terrain Map (Digital Elevation Model)
- Coordinate Frame Transformation Library
- Planetary Frame Transformation Library

Rover Simulator

- Lunar Terrain Modeling
- Visual Image Rendering
- Rover Struct/Mech Models
- Rover Dynamics Models
- Rover Payload Models
- Fault Injection
- Rover Navigation HW Models (IMU, Star Tracker, Cameras, Lights)
- Rover Hardware Communication Protocol Models

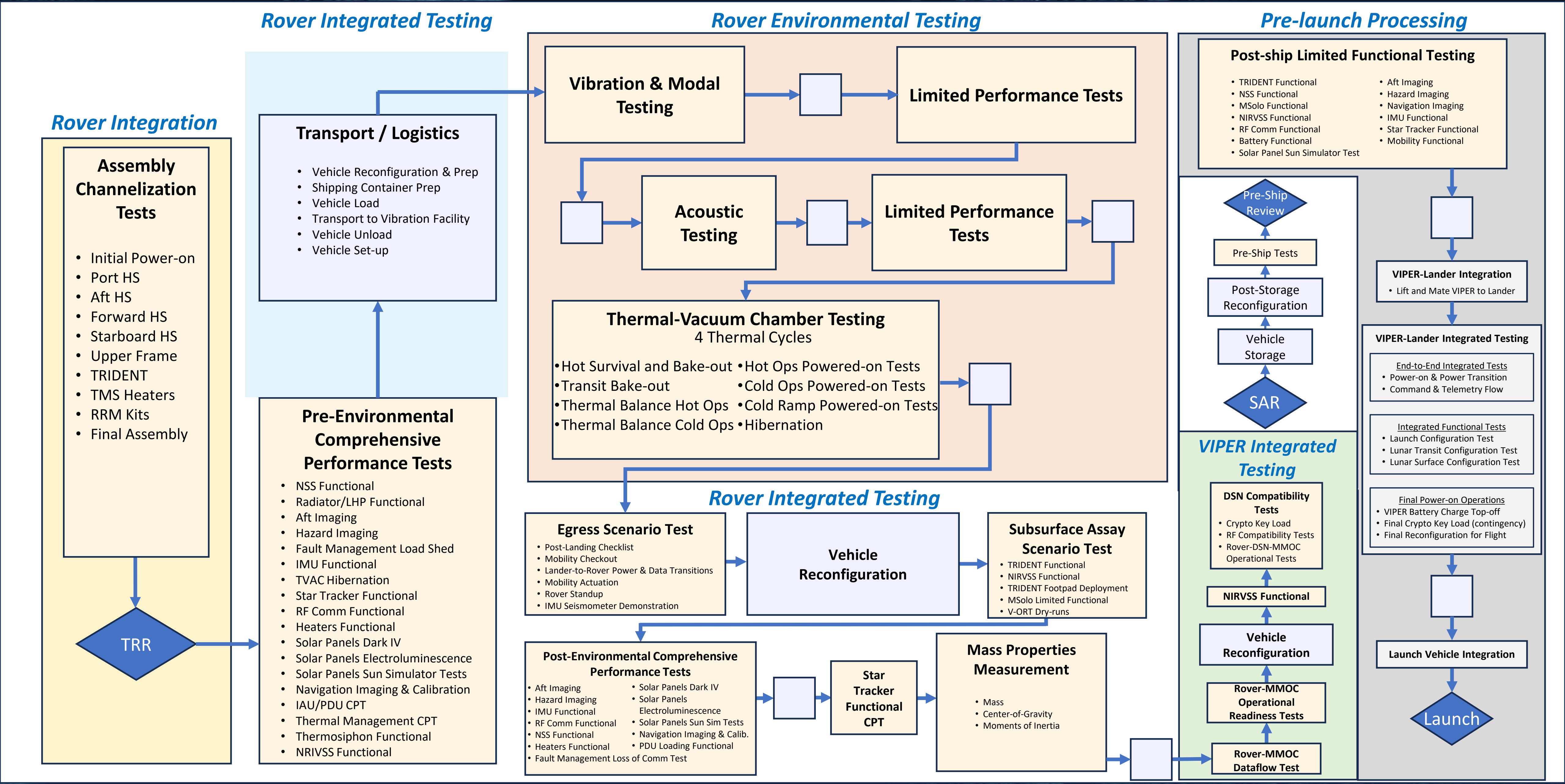
VIPER Rover Integration Complete

ISO 8 Controlled Work Area
Building 9 South
Johnson Space Center

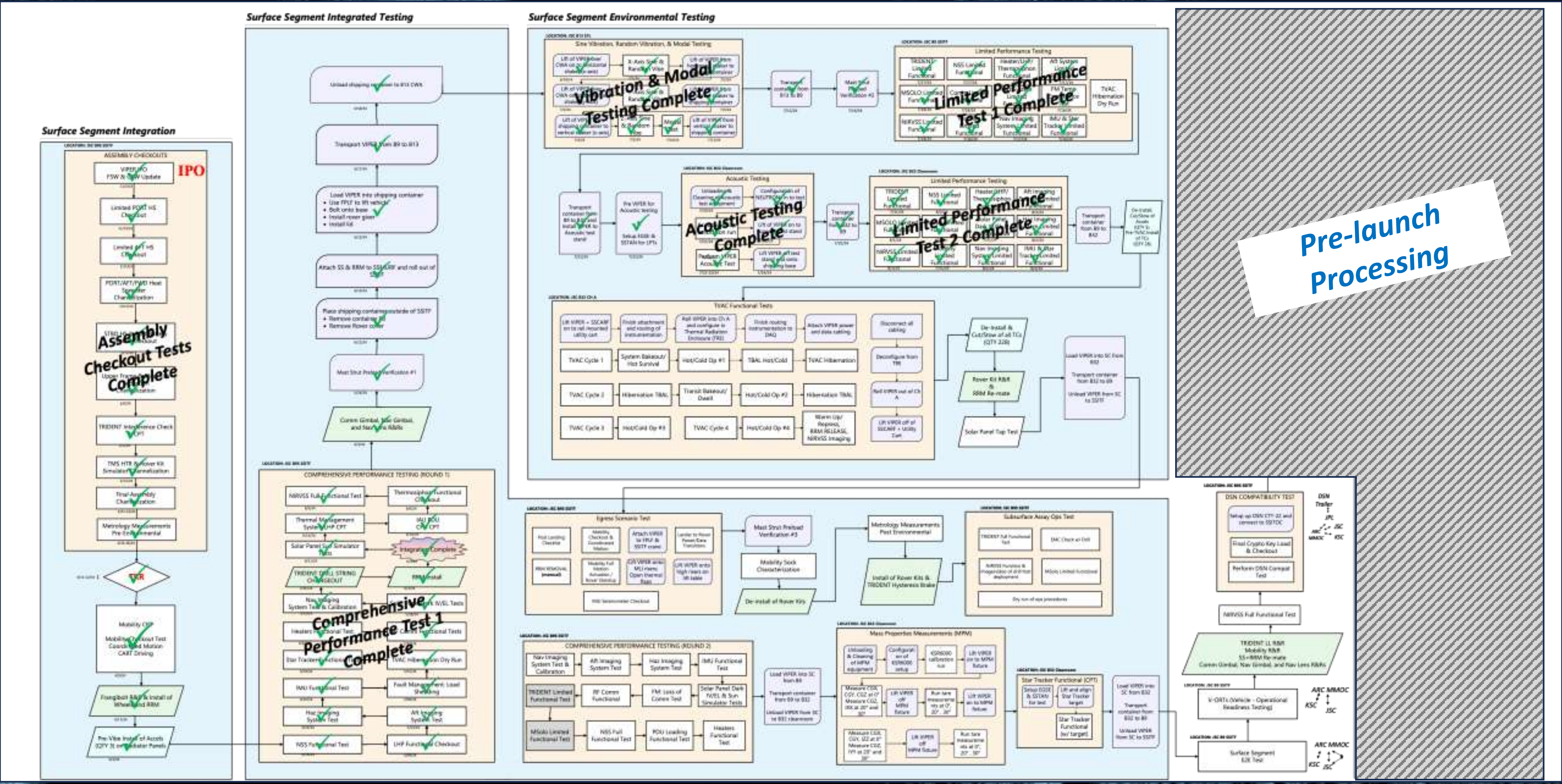
VIPER System Level Testing

(David Petri)

VIPER Flight Vehicle Test Campaign



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

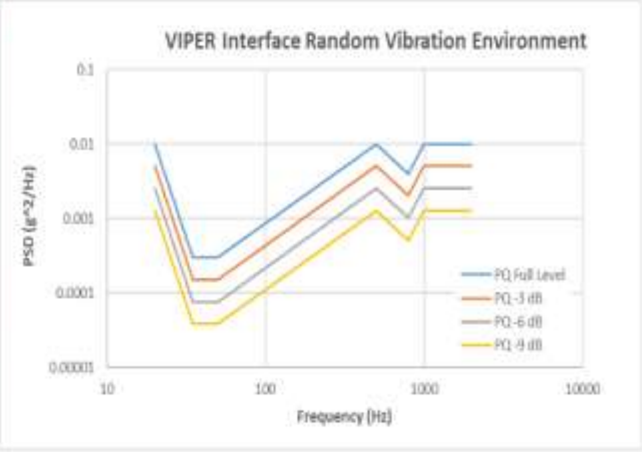
Vibration Test Environments

Note:

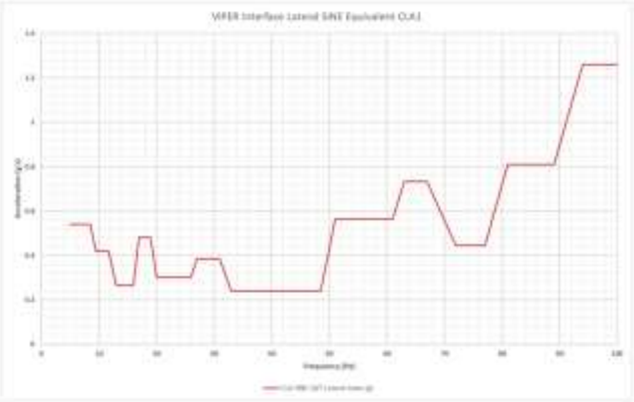
- VIPER rover tested based on previous lunar delivery vendor (CLPS)
- VIPER has further margin beyond what was tested for other partner arrangements

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.



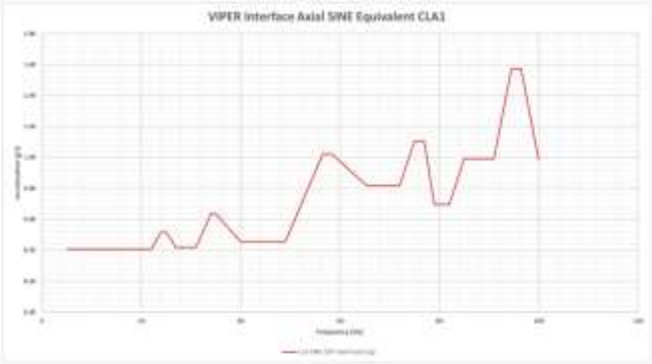
Sine CLA Input – Lateral Axes (X, Y)
Includes 1.2 Factor



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

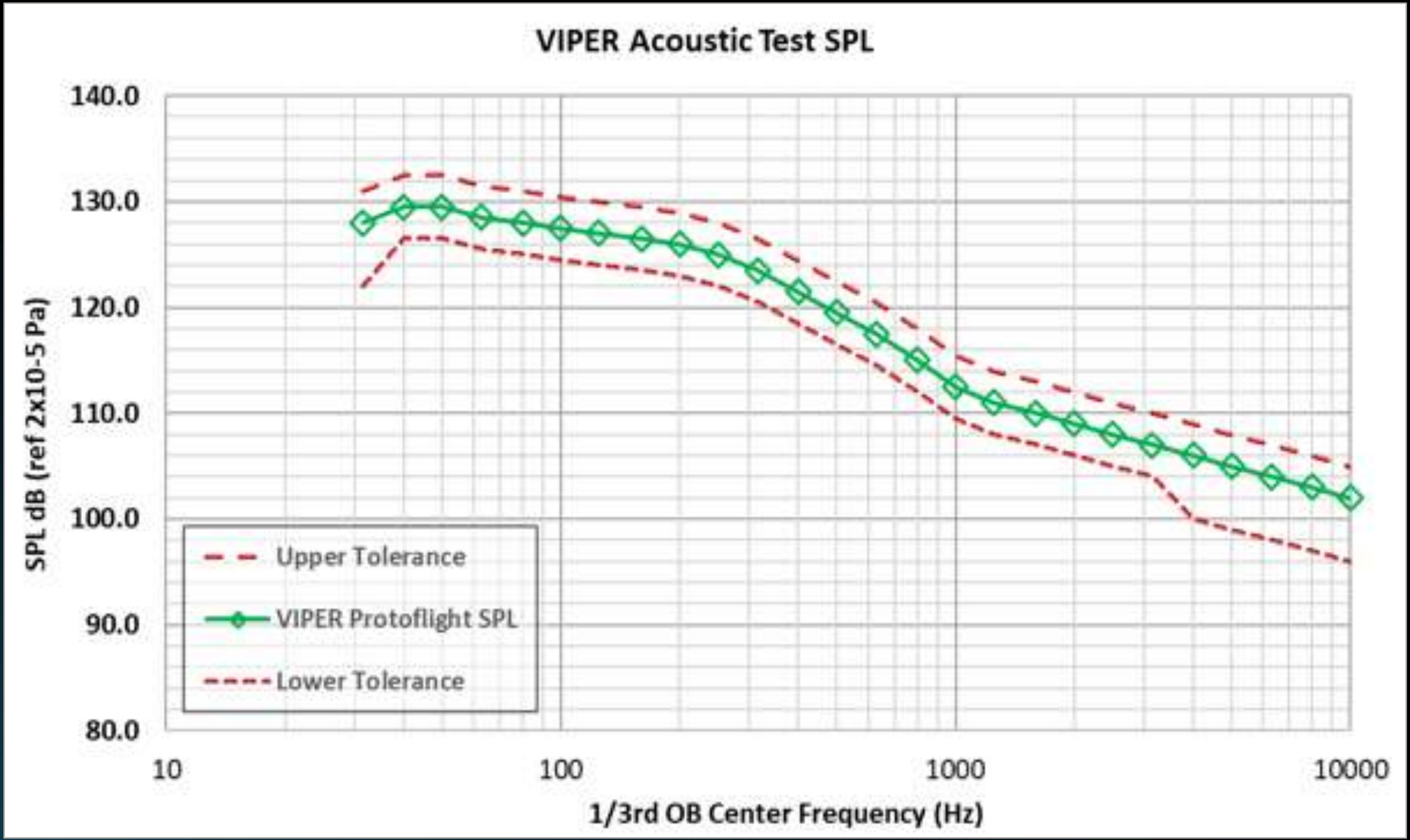
2 oct/min, 2 min 10 secs duration

VIPER Rover Acoustic Testing

July 22-23, 2024

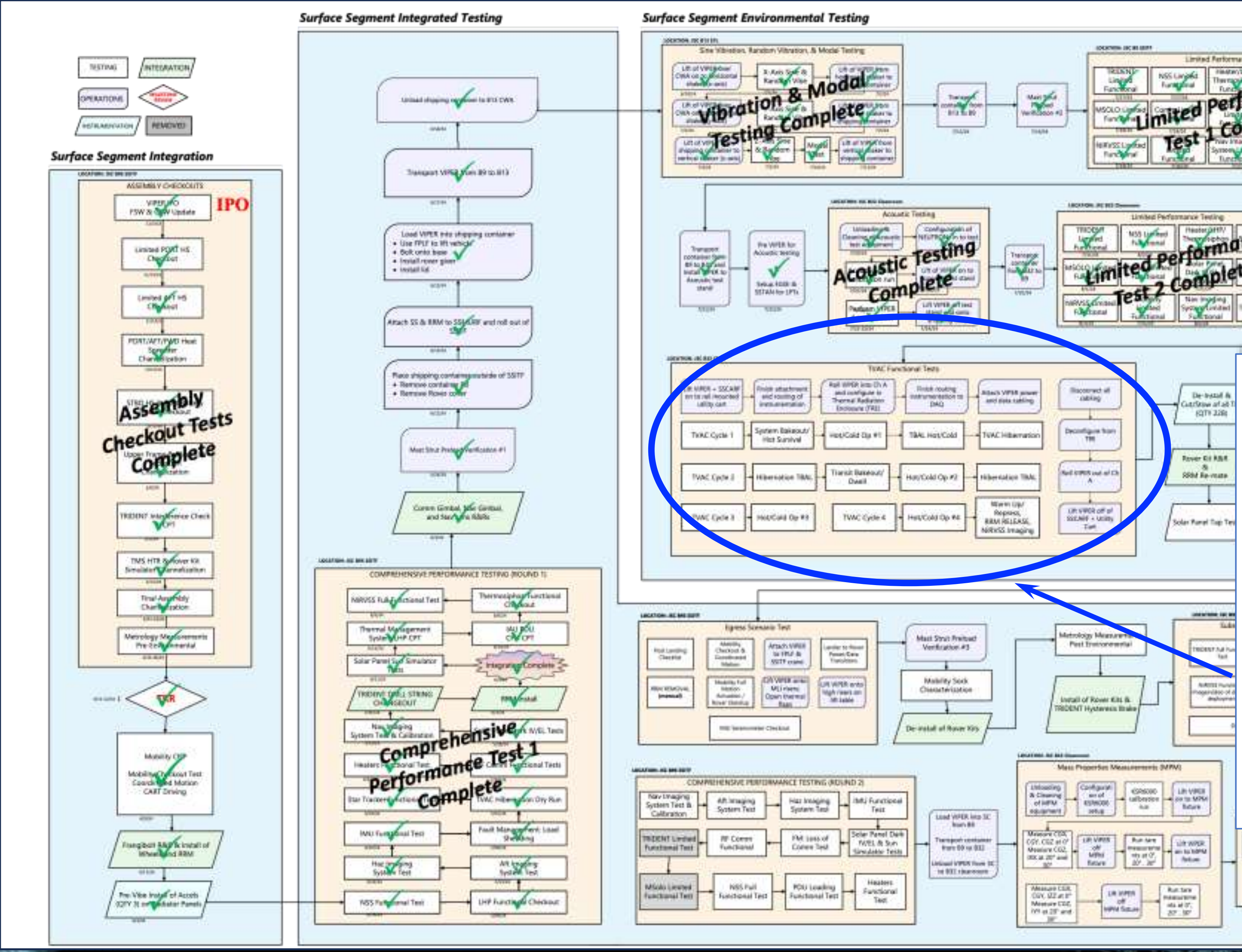
Chamber A Cleanroom
Building 32
Johnson Space Center

Acoustic Test Environment



As Tested Acoustic Profile

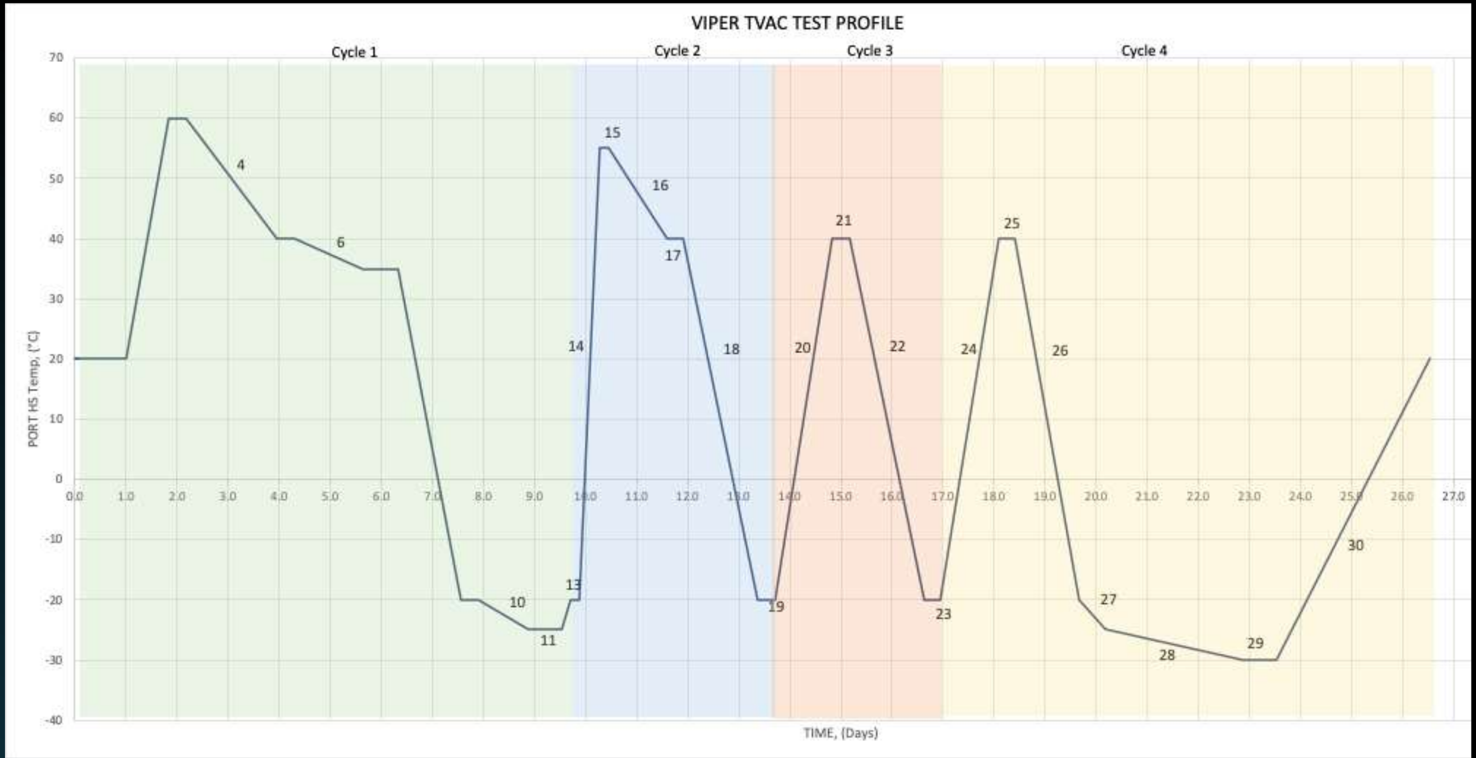
VIPER Flight Vehicle Test Campaign



Upcoming Thermal-Vacuum Chamber Testing

- Chamber A Certification run: 8/12-18
- VIPER TVAC Test: 8/28 – 9/27
  - 4 Thermal Cycles, including
    - Hot Survival and Bake-out
    - Thermal Balance Hot Ops
    - Thermal Balance Cold Ops
    - Cold Ramp Powered-on Tests
    - Hot Ops Powered-on Tests
    - Cold Ops Powered-on Tests
    - Hibernation
    - Transit Bake-out

VIPER Rover Thermal-Vacuum Test



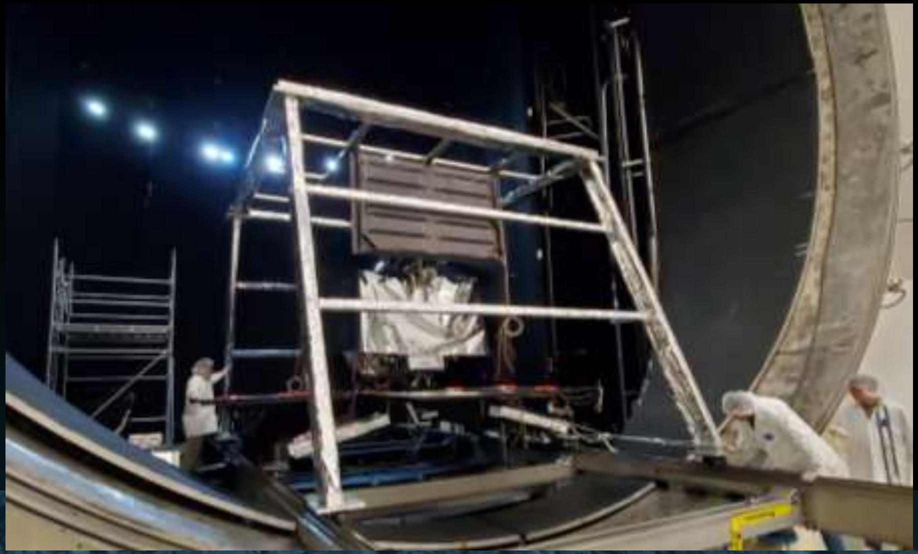
Segment	Segment Time (hr)	Absolute Time (Days)	Description
1		0.0	Start
	24	1.0	Chamber pumpdown
2	20	1.8	Hot ramp #1
3	8	2.2	Hot Surv/Bakeout
4	43	4.0	Cold ramp #1
5	8	4.3	Hot Ops #1
6	32.7	5.7	Cold ramp #2
7	16	6.3	T-Bal Hot Ops
8	30	7.6	Cold ramp #3/RF Comm Functional
9	8	7.9	Cold Ops #1
10	23.3	8.9	Cold ramp #4
11	16	9.6	T-Bal Cold Ops

Segment	Segment Time (hr)	Absolute Time (Days)	Description
20	27	14.8	Hot ramp #4
21	8	15.2	Hot Ops #3
22	35	16.6	Cold ramp #6
23	8	17.0	Cold Ops #3

Segment	Segment Time (hr)	Absolute Time (Days)	Description
24	27	18.1	Hot ramp #5
25	8	18.4	Hot Ops #4
26	30	19.7	Cold ramp #7
27	12.5	20.2	Cold Ops #4
28	64.2	22.9	Hibernate Cold Ramp
29	16	23.5	Hibernation T-Bal
30	72	26.5	Warmup Rover ([illegible] HRS) Start Chamber Warmup

Segment	Segment Time (hr)	Absolute Time (Days)	Description
12	8	9.7	Hot ramp #2 & Charging
13	4	9.9	Cold Dwell/Battery Charging
14	10	10.3	Transit Bakeout Transient
15	4	10.5	Transit Bakeout Dwell
16	27	11.6	Hot Ramp #3
17	8	11.9	Hot Ops #2
18	31	13.4	Cold Ramp #5
19	8	13.7	Cold Ops #2

Thermal-Vacuum Chamber A
Building 32
Johnson Space Center



VIPER Structural Test Article
Simulated Functional Test
August 9-23, 2023

Moon Gravity Representation Unit (MGRU)

- 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

MGRU with Haz/Nav lights on

Egress Testing w/MGRU flight CG

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
  - MGRU 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

Mission Operations and Ground Systems

(Jay Trimble)

VIPER is Operationally Unique

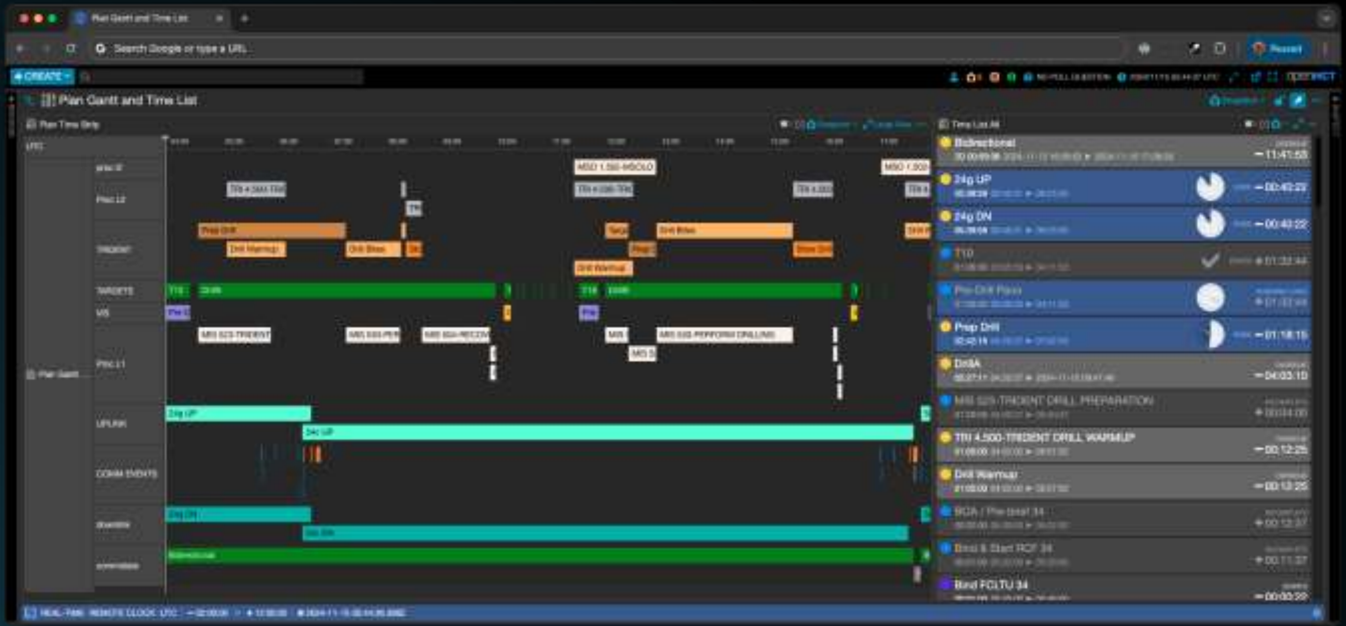
The Lunar South Polar Environment and Vehicle Design

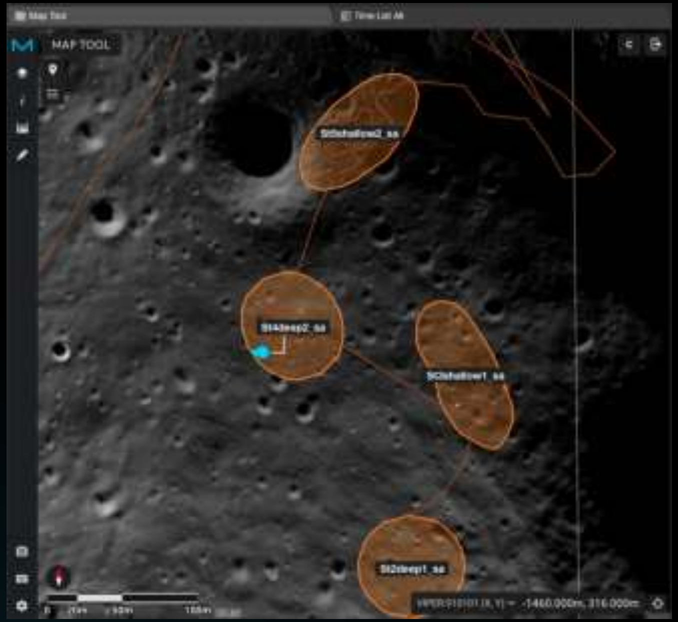
- Operational decisions
  - Vehicle is designed to take advantage of short Earth-Moon distance
  - Operational decisions and many software functions are ground-based
  - Command cycle is minutes
- Vehicle is solar powered and requires sun to operate, with batteries for shadow ops
  - Dynamic lunar polar 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 is Operationally Unique (Cont.)

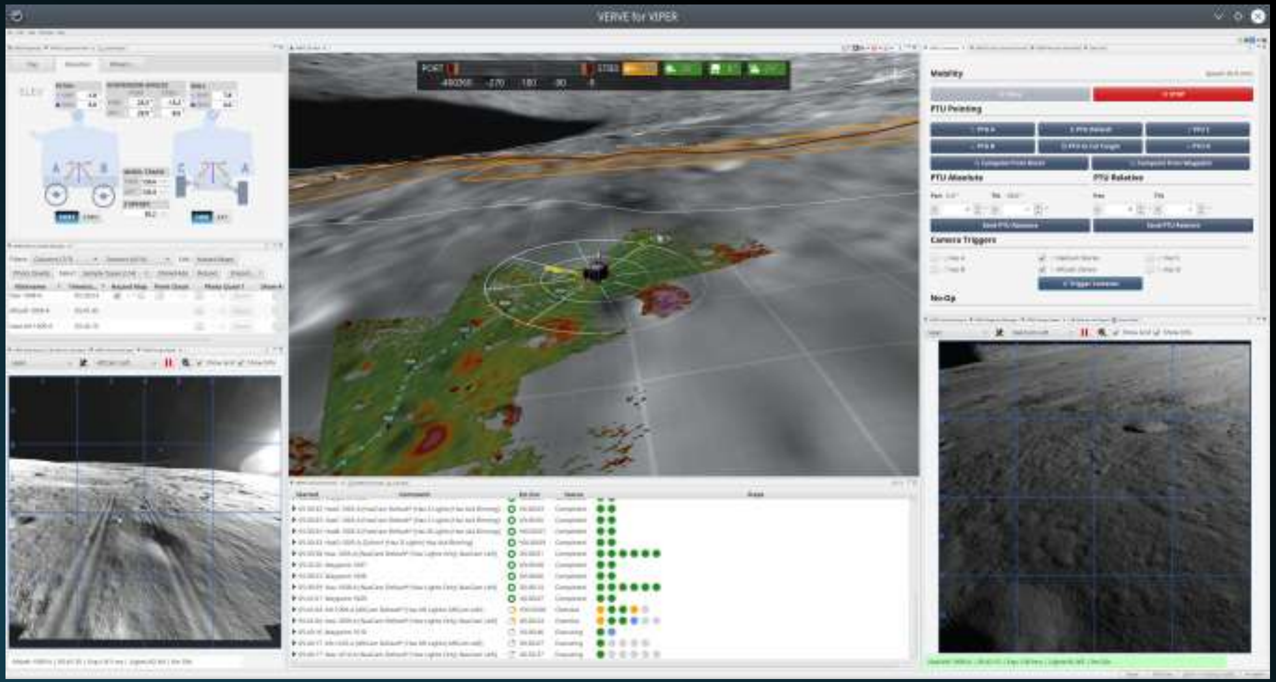
- Real-time surface mission variables and non-determinism make standard mission timelines inadequate
  - Cannot monitor progress v. plan by a traditional mission timeline as you could on a trajectory-driven mission
    - Requires a real-time situational awareness capability
    - Where we are → Map
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

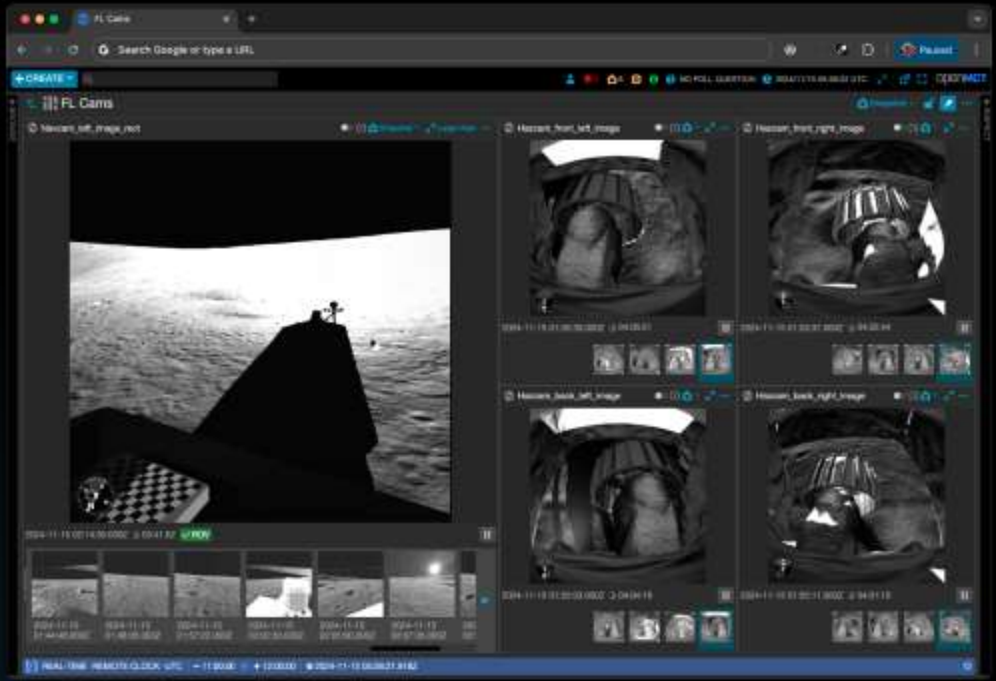




VIPER is Operationally Unique (Cont.)

- 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





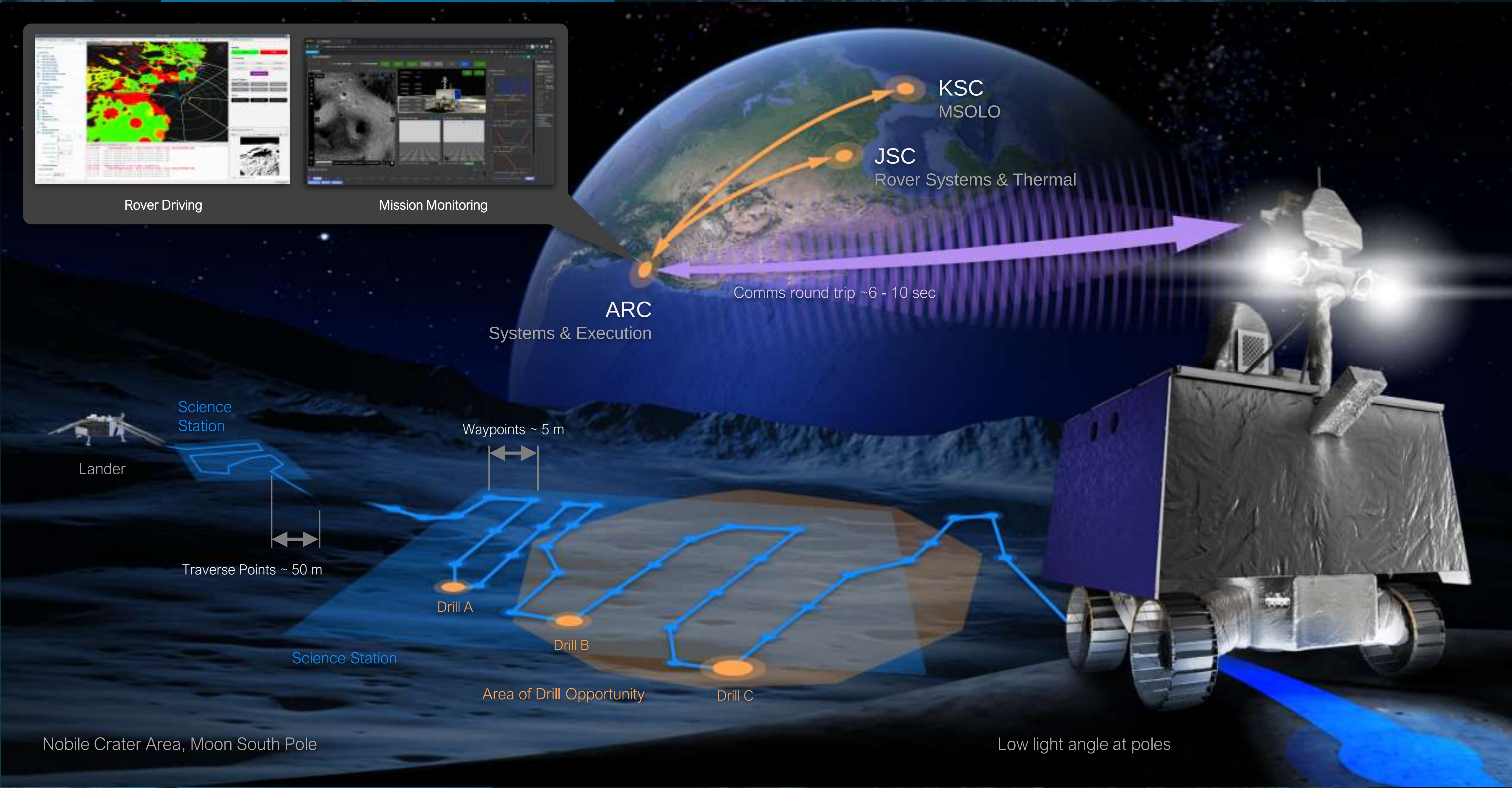
VIPER Operational Characteristics

- 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

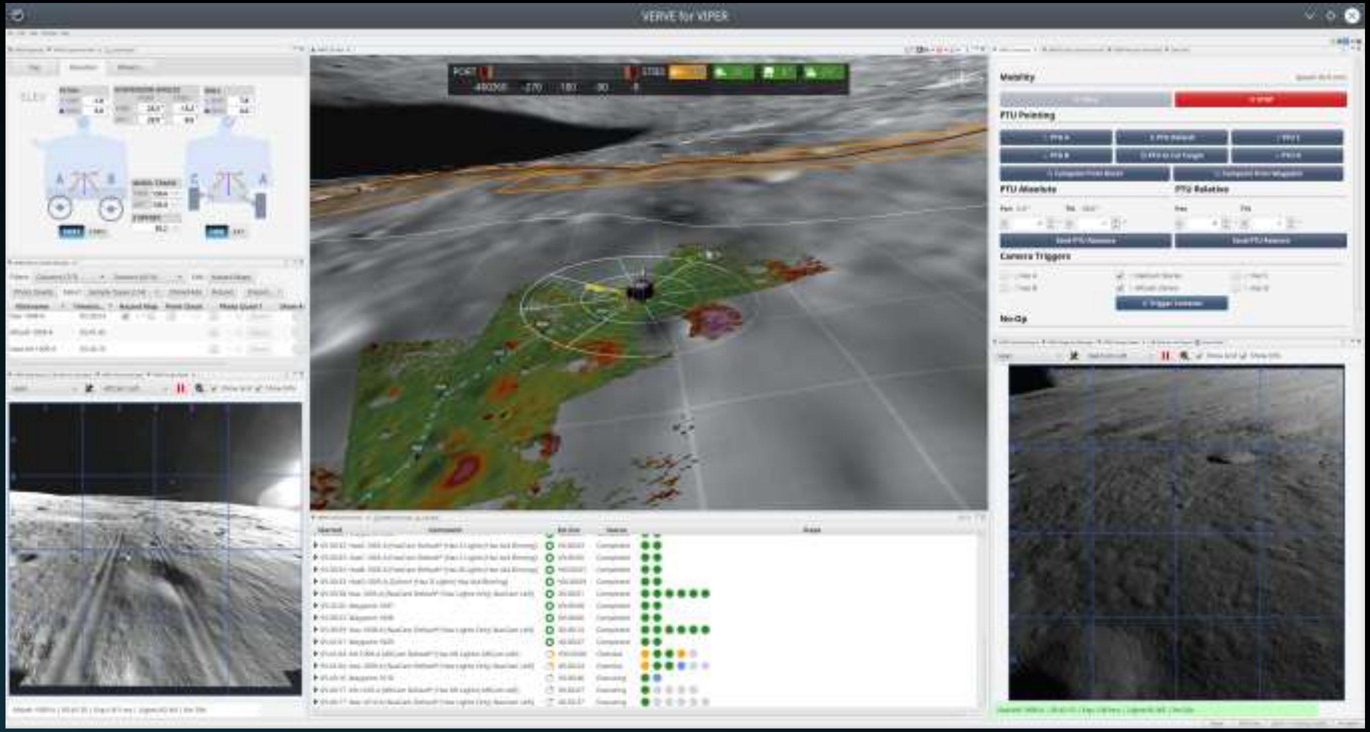
VIPER Mission System – Plan, Train, Drive

- Mission Operations System (MOS)
  - Processes
    - Procedures, Flight Rules, Displays, Scripts, Limits
  - Operations Team
- Ground Data System (GDS)
  - Tools, Control center, Infrastructure
- Mission Planning
  - Traverse Plan, Activity Dictionary
- Training



Rover Driving
Mission Monitoring
KSC
MSOLO
JSC
Rover Systems & Thermal
ARC
Systems & Execution
Comms round trip ~6 - 10 sec
Science
Station
Lander
Waypoints ~ 5 m
Traverse Points ~ 50 m
Drill A
Drill B
Drill C
Science Station
Area of Drill Opportunity
Nobile Crater Area, Moon South Pole
Low light angle at poles

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

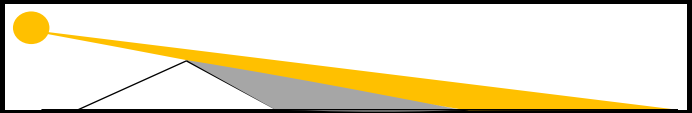
Mission Planning

THE PROBLEM

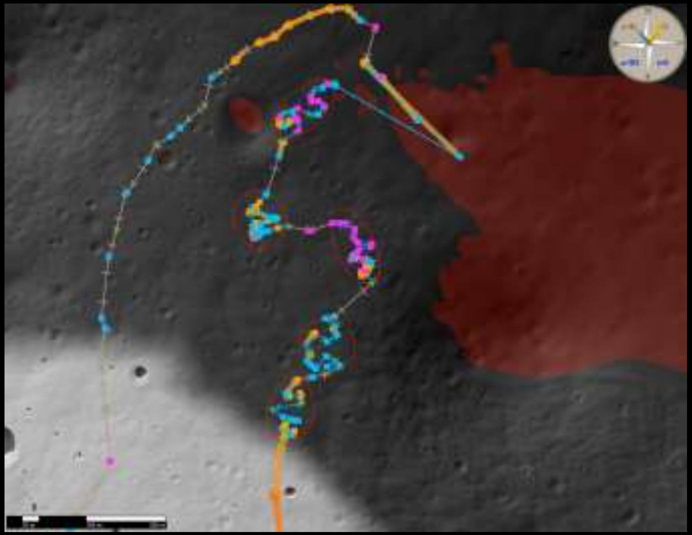
- At the poles, the sun casts long shadows
- Terrain also blocks the direct radio links from ground stations causing radio shadows
- Teleoperation from Earth yields an average speed around 1 cm/sec
- Shadows move from .1 – 1.5 cm/s
- A solar-powered rover must move almost continuously

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 viewshed … (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



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



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

- 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

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)
- Science Stations
  - Govern regions of scientific interest for exploration
  - Traverse focused on distance travelled in region
  - Drill to 1m depth in 10cm bites takes 5hrs including spectrometer measurements
  - Prospecting max speed is 10cm/second

Test and Training

MISSION SIMULATION

Training, Testing Ops Products, Processes and GDS

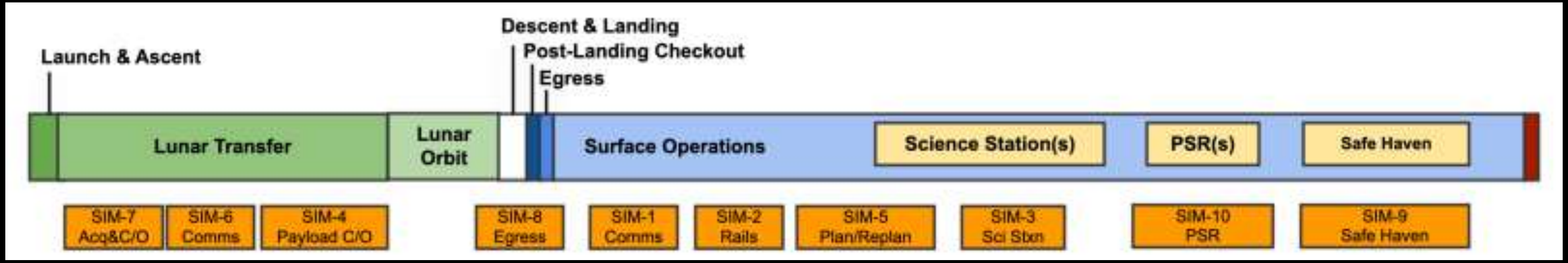
MOON GRAVITY REPRESENTATION UNIT (MGRU)

Egress Testing

Driver Training

Integrated Operations Test and Training

- Operators to train 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



Mission Phase	Activities	Dev Sims	Mini Sims	Integrated SIMs
Launch, Activation, and Checkout	Launch, power-up, initial acquisition, establish transit power configuration, thermal assessment.		✓	Oct '24
Transit: Rover+Comm Checkouts	Rover checkouts via Lander. Transit Comm handover, comm checkouts w/DSN.		✓	Oct '24
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	✓	✓
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.	✓	✓	✓ + Feb '25
Permanently Shadowed Regions	FM configuration, PSR entry, prospecting, drilling, exit, recharge, recovery.	✓	✓	Nov '24
Safe Haven/Hibernation	Localization, assessment, configuration, entry, hibernation, exit, recovery.		✓	✓ + Feb '25

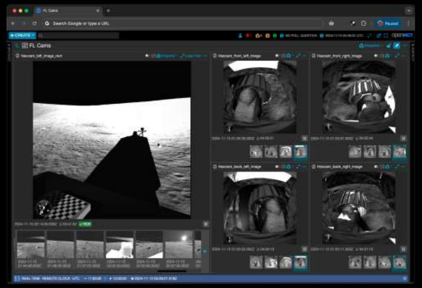
Test & Training Stats	
Team/Processes/Software System Hours	312
MGRU Rover Test Hours	208
Engineering Readiness Test Hours	184
Total Team Training Hours	704
Individual Training Hours	4091

VIPER Operations Overview

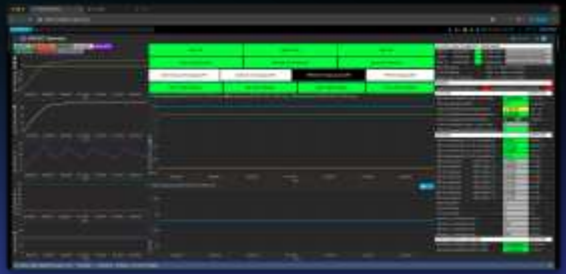
Planning Timeline and Map

Mission Manager Integrated Overview

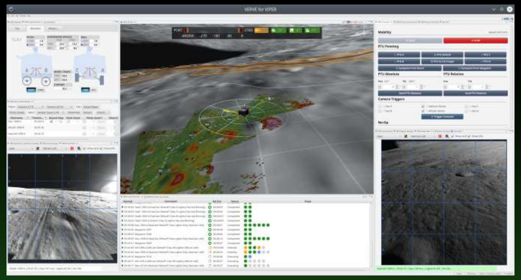
Situational Awareness and Activities



Nav and Haz Cameras



Instrument Health and Status



VERVE Driving Software

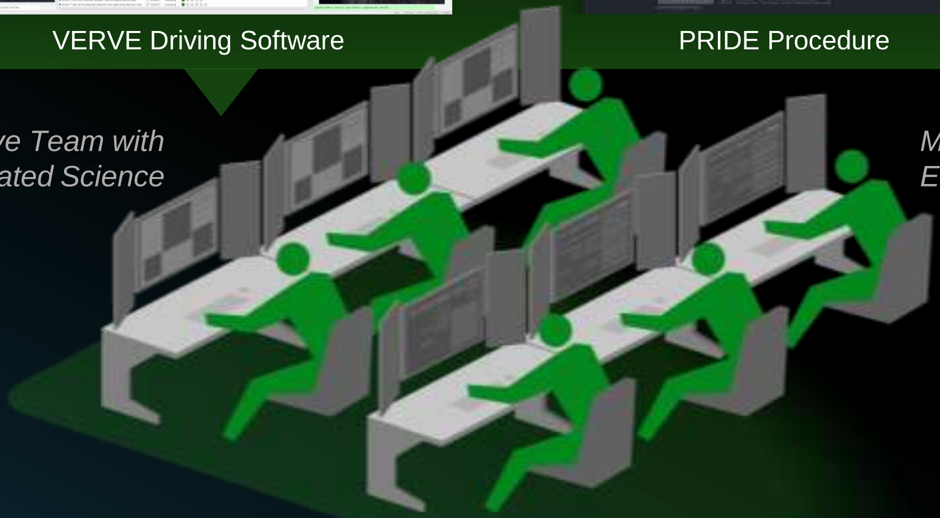
PRIDE Procedure

Instrument and Planning Teams

POC

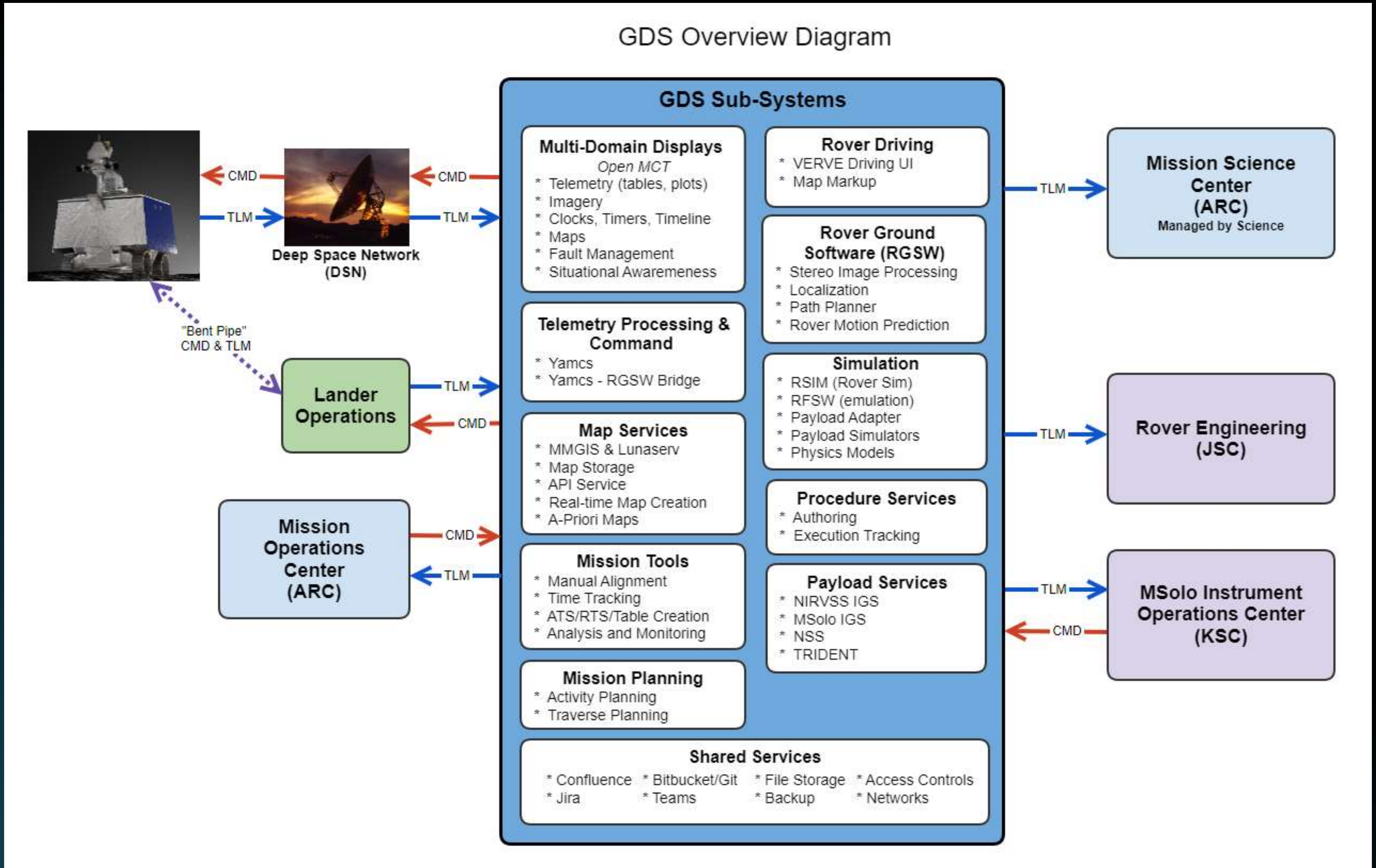
Drive Team with Integrated Science

Mission and Engineering Team



MOC

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

Science Operations

(Dr. Anthony Colaprete)

Science Operations & Integration - Real-time science decisioning systems

The proximity of the Moon to the Earth and the terrain elements (surface characteristics, light/shadow dynamics, communication links) of the lunar South Polar landing site create unprecedented operational conditions for lunar science and exploration with a remotely operated rover.

The integration of real-time scientific support into this operational environment extends and enhances the response capabilities of the VIPER team during surface operations and optimize science.

Extensible to other mission architectures using distributed systems of expertise for remote work.

Effort ensured that science was decisionally prioritized across the mission system.

Science Operations & Integration - Real-time science decisioning systems

The integration efforts focused on employing the following criteria to guide the development of the visualization and mapping tools that are ubiquitously used by the Science and Mission operations teams:

1. Equal access to data and tools for all team members
2. Fluid, interactive exploration of data in real-time (as it is collected)
3. Efficient export, using pre-defined data packages and minimal mouse clicking, of relevant data by mission members co-located in the mission and science operations centers in a format readable by popular tools (e.g., common to the planetary science community - MatLab, ARCGIS, JMP, Excel).

These features are integrated and functional within the Mission Science Center (MSC) in the MMOC.

Science Operations Capabilities and Products

The following components were designed to support the optimization of science return during lunar surface operations:

- MSC-POCC-MOC science roles
- MSC facility and interior design
- MSC workstation software
- MSC workstation hardware
- MSC remote participation hardware
- Instrument data management

Data visualization, access, analysis for rapid decisioning, including real-time data processing and displays (e.g., spectral properties such as water absorption strength and mass spec ion ratios)

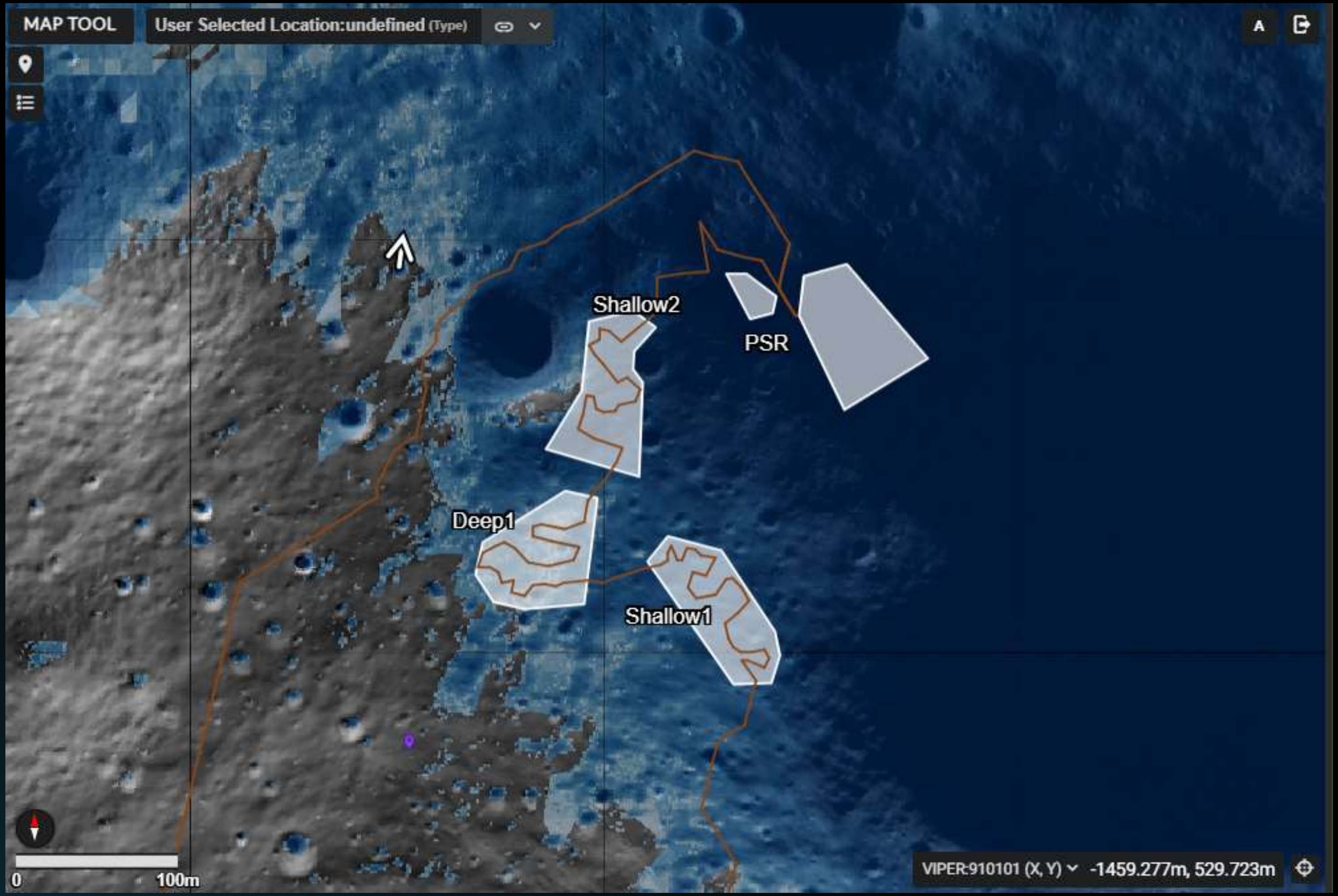
- SOPs (Standard Operating Procedures), SAMs (Standard Analytical Methods) specific to VIPER science objective to characterize the distribution, physical state, and resource potential of water and other volatiles on the Moon; Rapid derivation of resource map products (e.g., Prospectivity and trafficability maps) and other Level 3 data products
- Creation of science planning and timelining for lunar surface operations and real-time science decisioning
- Lunar science objectives management system including a Lunar Dynamic Science Table, TRACKER for real-time management of science objectives, and a Leaderboard for real-time management of science path planning including drill site localization based on evolving science priorities.

Tools, Data Sets, SOPs and Expertise for Developing and Managing Traverse Plans

Integrated systems for moving from mission goals to measurement plans

Methods, Tools and Metrics to:

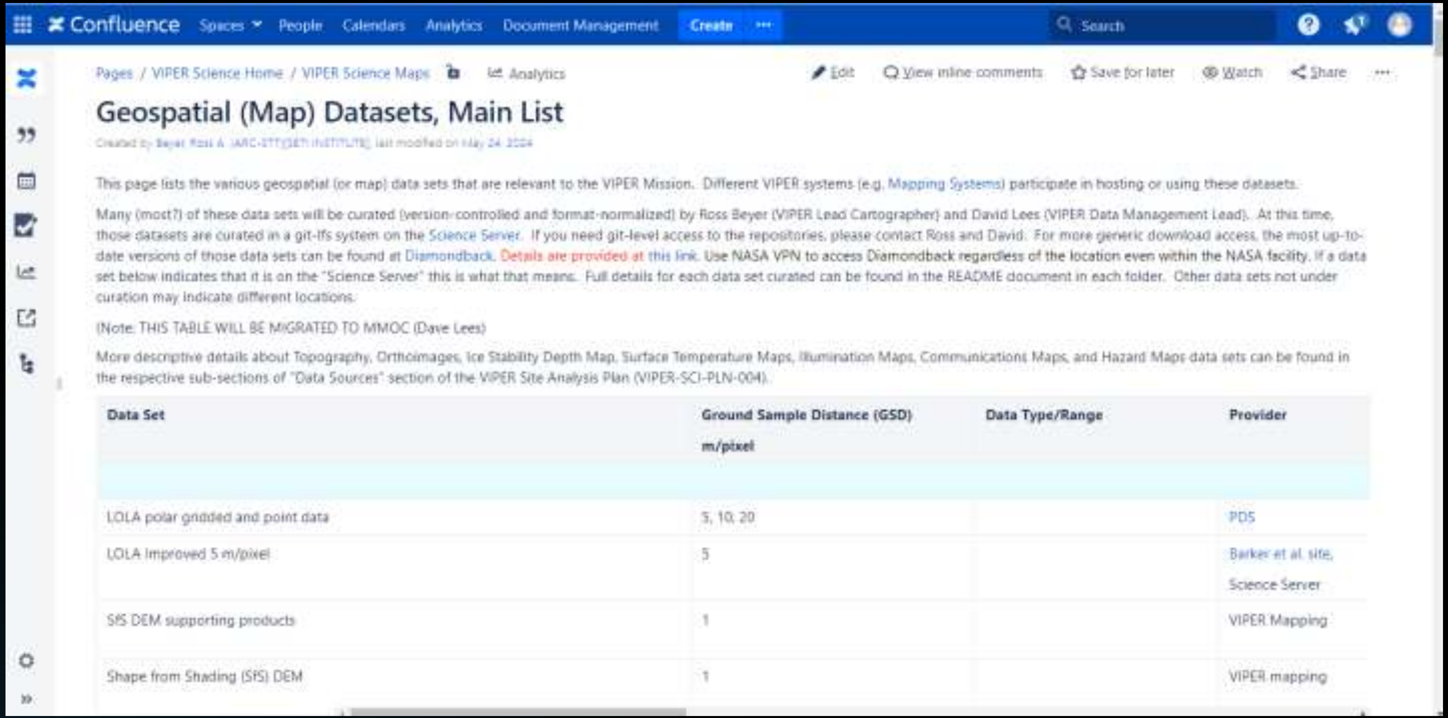
- Assess progress toward planned objectives
- Evaluate new options in near real-time against existing and new goals



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


Confluence Spaces People Calendars Analytics Document Management Create Search

Pages / VIPER Science Home / VIPER Science Maps Analytics Edit View inline comments Save for later Watch Share

Geospatial (Map) Datasets, Main List

This page lists the various geospatial (or map) data sets that are relevant to the VIPER Mission. Different VIPER systems (e.g. Mapping Systems) participate in hosting or using these datasets.

Many (most?) of these data sets will be curated (version-controlled and format-normalized) by Ross Beyer (VIPER Lead Cartographer) and David Lees (VIPER Data Management Lead). At this time, those datasets are curated in a git-lfs system on the Science Server. If you need git-level access to the repositories, please contact Ross and David. For more generic download access, the most up-to-date versions of those data sets can be found at Diamondback. Details are provided at this link. Use NASA VPN to access Diamondback regardless of the location even within the NASA facility. If a data set below indicates that it is on the "Science Server" this is what that means. Full details for each data set curated can be found in the README document in each folder. Other data sets not under curation may indicate different locations.

(Note: THIS TABLE WILL BE MIGRATED TO MMOC (Dave Lees)

More descriptive details about Topography, Orthoimages, Ice Stability Depth Map, Surface Temperature Maps, Illumination Maps, Communications Maps, and Hazard Maps data sets can be found in the respective sub-sections of "Data Sources" section of the VIPER Site Analysis Plan (VIPER-SCI-PLN-004).

Data Set	Ground Sample Distance (GSD) m/pixel	Data Type/Range	Provider
LOLA polar gridded and point data	5, 10, 20		PDS
LOLA Improved 5 m/pixel	5		Barker et al. site, Science Server
SfS DEM supporting products	1		VIPER Mapping
Shape from Shading (SfS) DEM	1		VIPER mapping

Data Products – In Mission

Real-time derivation of resource models, including:

- Trend analysis
- Correlation analysis
- Lunar resource map generation
- 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):

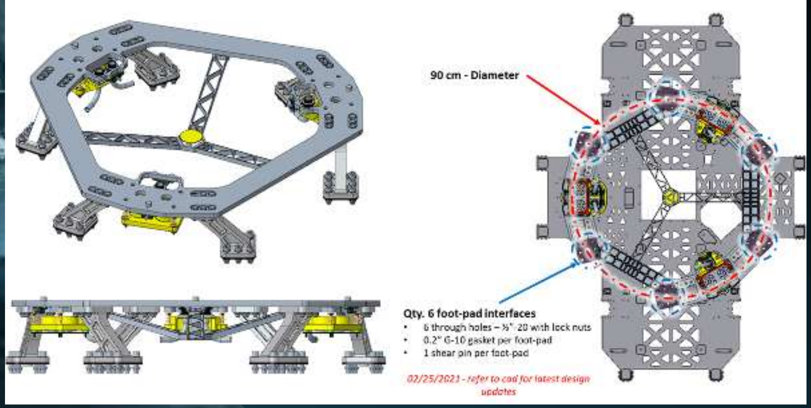
- Surface and subsurface temperatures
- Lighting conditions (validating DEMs and DEM uncertainties)
- Earth visibility (validating DEMs and DEM uncertainties)
- Small scale hazard populations (rocks, craters and slopes) in sunlit areas and PSRs

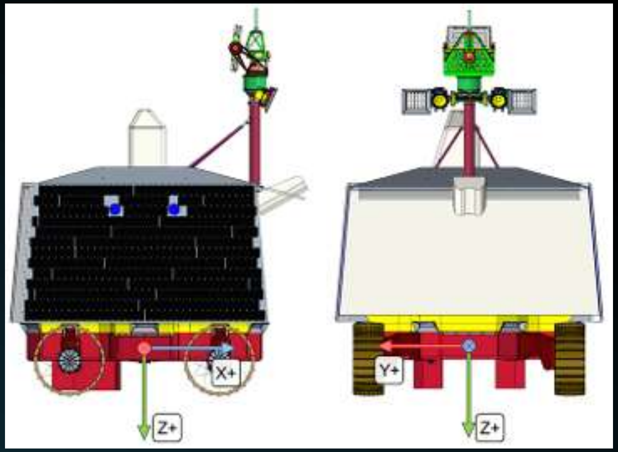
Lander Integration and Launch Site Plan

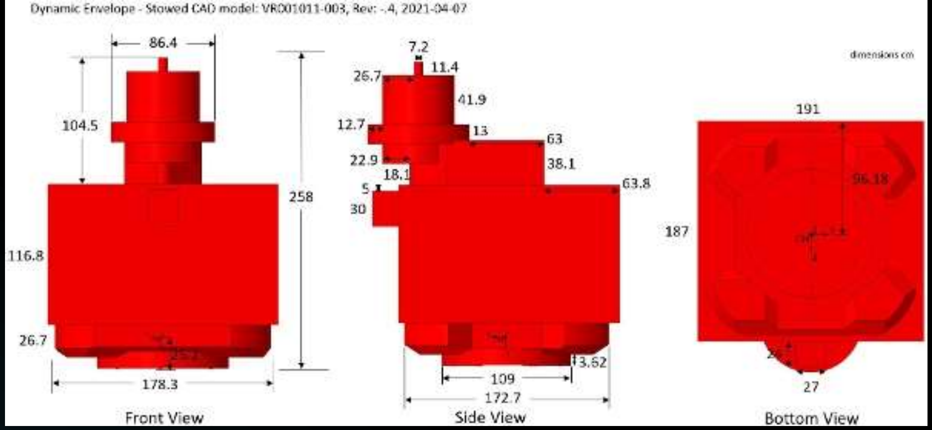
(Tom Luzod)

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)





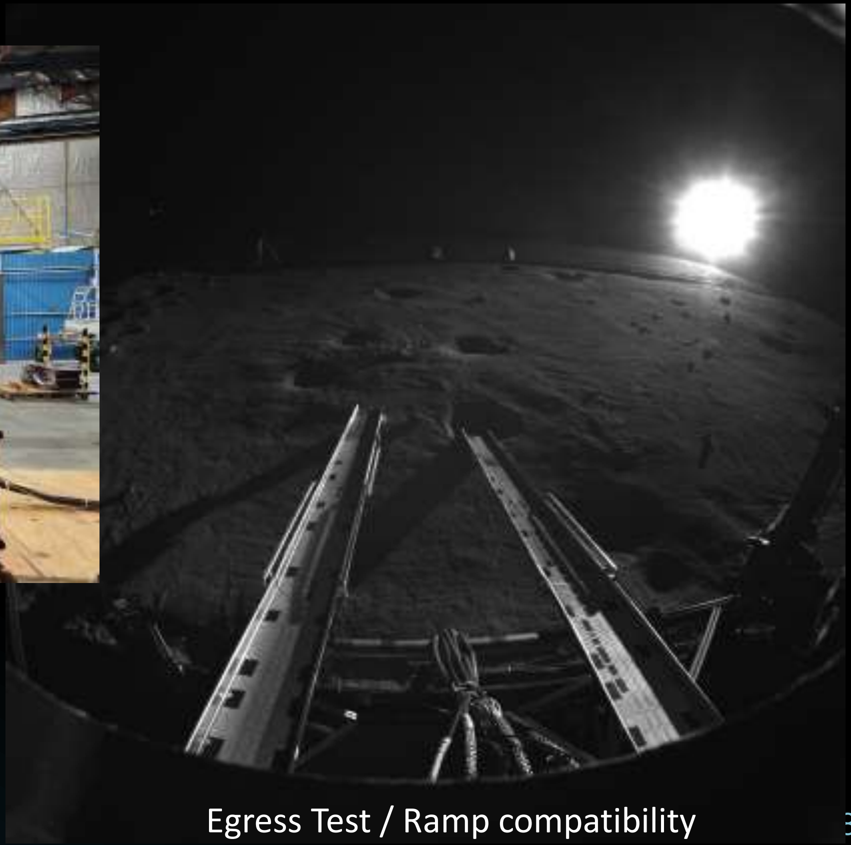


VIPER Team Ready to Collaborate

- 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

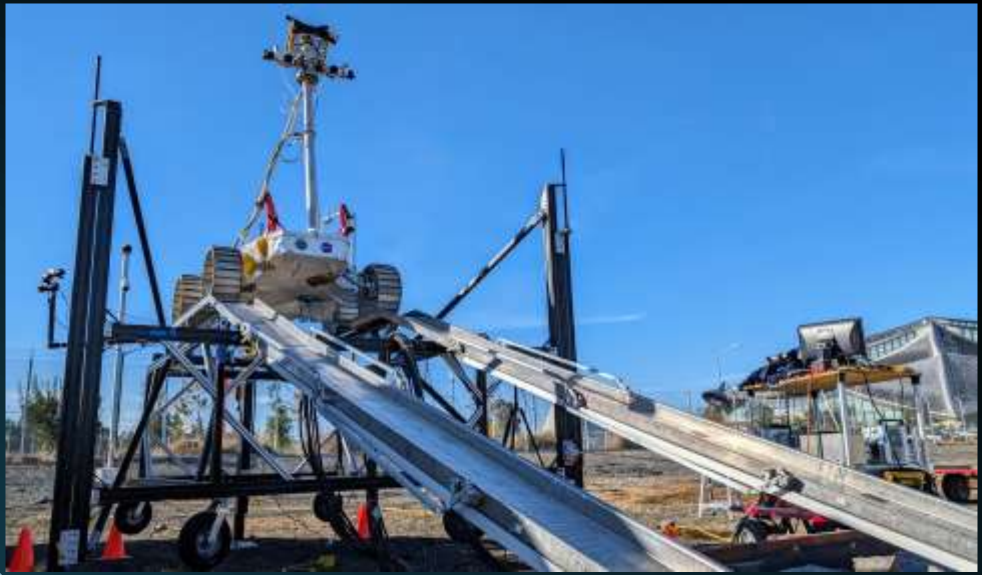
Integration Checks / Lifts



Egress Test / Ramp compatibility

VIPER Collaborative Hardware Capabilities

- VIPER hardware can be used to aid in lander partner interfacing and planning
  - MGRU – 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

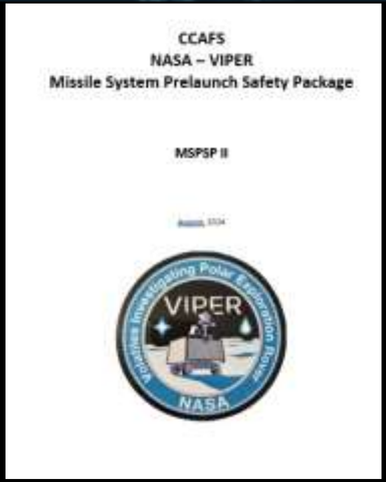
VIPER team stands ready to support your Launch Site process

Launch, Range Safety and Hazards

(Cris Andes)

Safety Deliverables

- 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)



CCAFS
NASA – VIPER
Missile System Prelaunch Safety Package

MSPSP II

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

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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

- Rover 100% built & vibe/acoustic testing complete:
  - TVAC testing imminent
  - High value eng/qual units available for integration work
- Mission Ops software is *features-complete*:
  - 500+ hrs of Ops team test and training
  - 200+ hrs of Ops/rover training in lunar rover-scape
- VIPER team built to be partner-ready:
  - Team well-experienced with lander integration planning/coordinating/testing, with dedicated lead
  - Strong commercial instrument development
- Range-ready:
  - Safety products reviewed and Safety Review II ready
  - MGSE & EGSE have passed Range Safety initial review
- VIPER team cast differently than most NASA missions
  - Focus on forward success and not checking Agency boxes

Information Logistics – Post Event

- Technical documentation can be exchanged via Box
  - Application is approved for sharing with external (non-NASA) partners
- Requests should be submitted to: Christopher.d.Youngquist@nasa.gov
- Suggested Format:
  - Name
  - Association
  - Email Address
  - Area of interest
  - Details of your request
    - Try to use “what”, “how”, and ”why” to start your questions so that the appropriate team member(s) can provide a thorough response.

National Aeronautics and
Space Administration

Thank you.

(Conference-I/O questions)

Q & A

Conference I/O polling