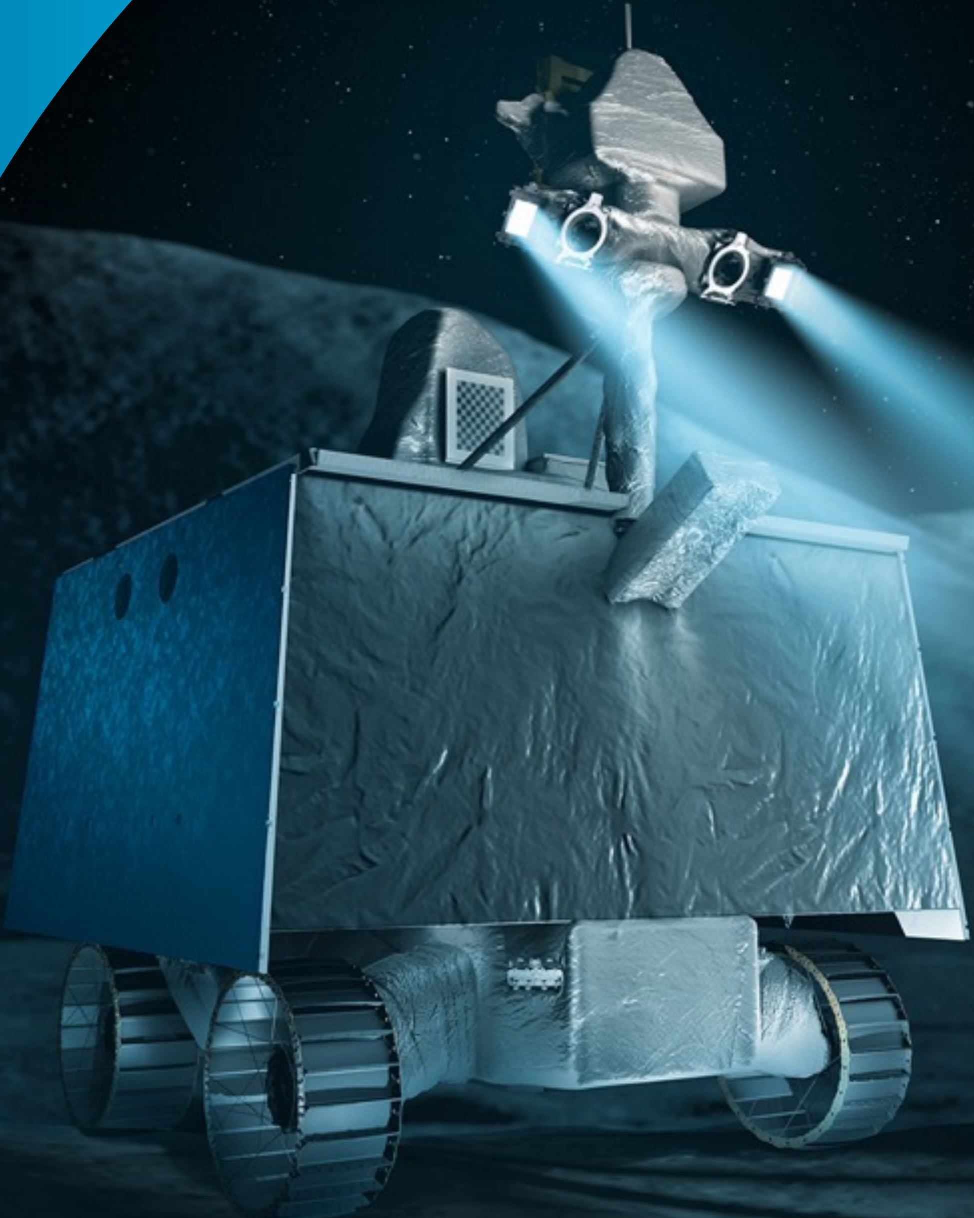


National Aeronautics and Space Administration

VIPER Mission Traverse Planning – Strategies, Design, Dynamics

Dr. Kimberly Ennico-Smith
VIPER Deputy Project Scientist
NASA Ames Research Center
on behalf of the VIPER Planning Team

Space Resources Roundtable XXIII June 6, 2023

VIPER Planning Team

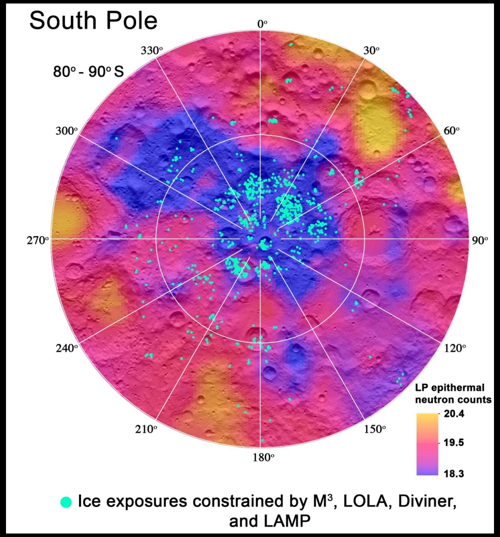
M. Shirley[1], E. Balaban[1], L. Falcone[2], K. Bradner[1], A. Colaprete[1], R. Beyer[1,3], R.C. Elphic[1], J. Coyan[4], C. Fassett[5], D. Lees[1], D.S.S. Lim[1], Z. Mirmalek[1,6], A. Nefian[1], M. Siegler[7]

[1]NASA Ames Research Center, [2]KBR Wyle Services, [3]SETI, [4]USGS, [5]APL, [6]BAERI, [7]Planetary Science Institute

Why VIPER?

Lunar Polar Volatiles

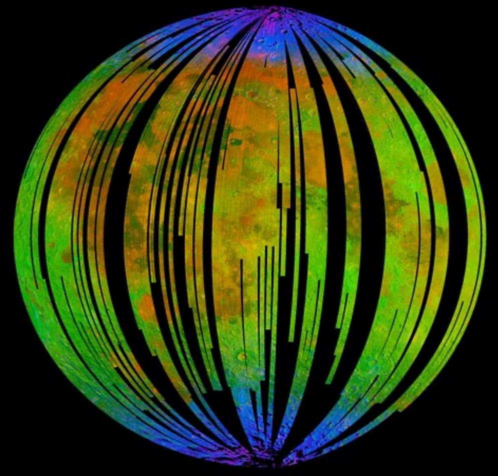
- Frozen water, methane … (liquid or gas at room temp)
- Detected from orbit by remote sensing Clementine, Lunar Prospector, LRO, LCROSS, Chandrayaan-1 …



Li, S. et al. 2018

VIPER's primary mission goal is to characterize the distribution of water and volatiles across a range of thermal environments

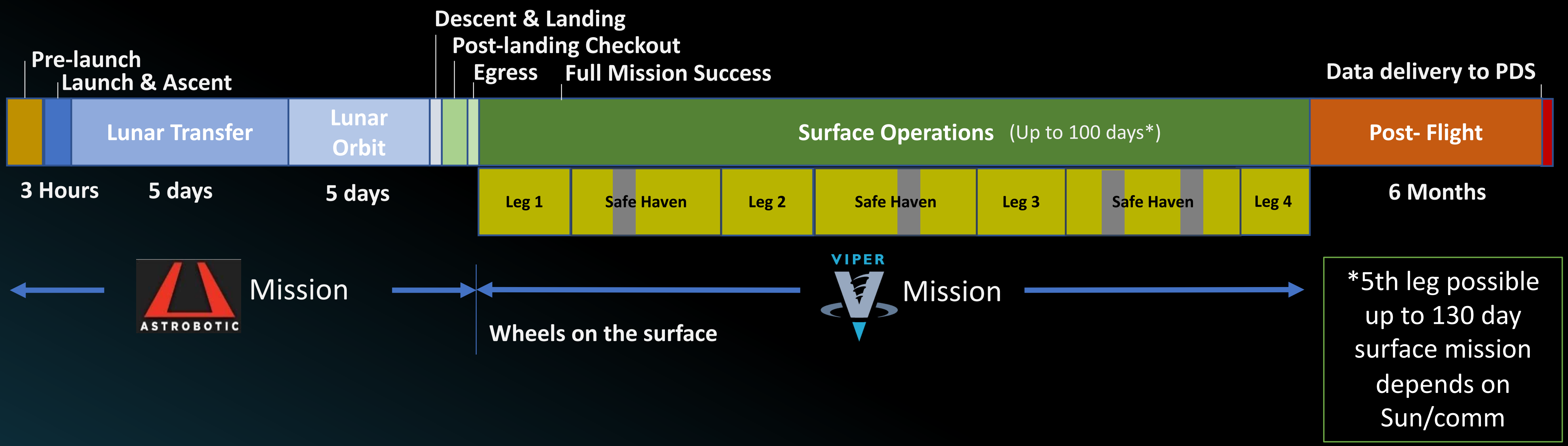
- Make direct measurements of polar volatiles
- Characterize their physical state and composition
- Characterize horizontal and vertical distribution at scales relevant to potential extraction processes
- Provide ground truth for orbital datasets used to create lunar resource maps



Pieters, C. et al. 2009

Colaprete, A. et al. 2023 LPSC #2910, 2022 LPSC #2675, 2021 LPSC #1523

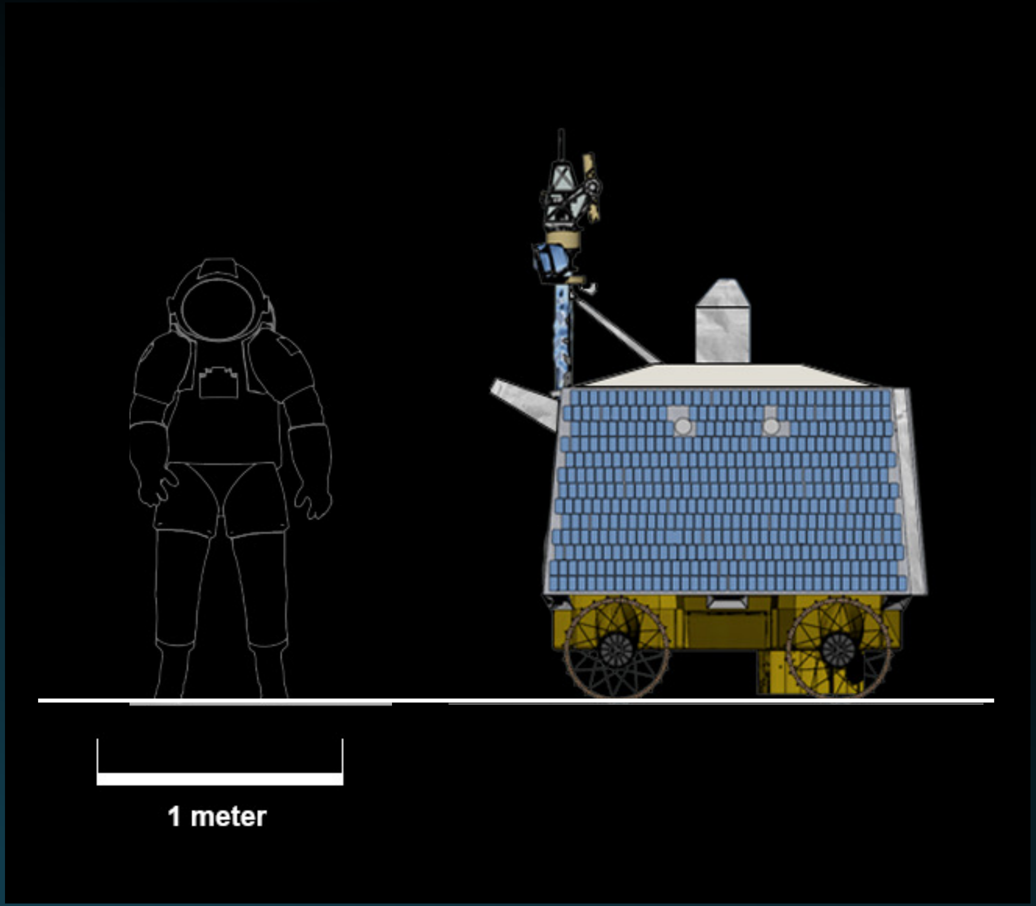
VIPER Mission Phases



VIPER is delivered to Moon under a Commercial Lunar Payload Services (CLPS) contract

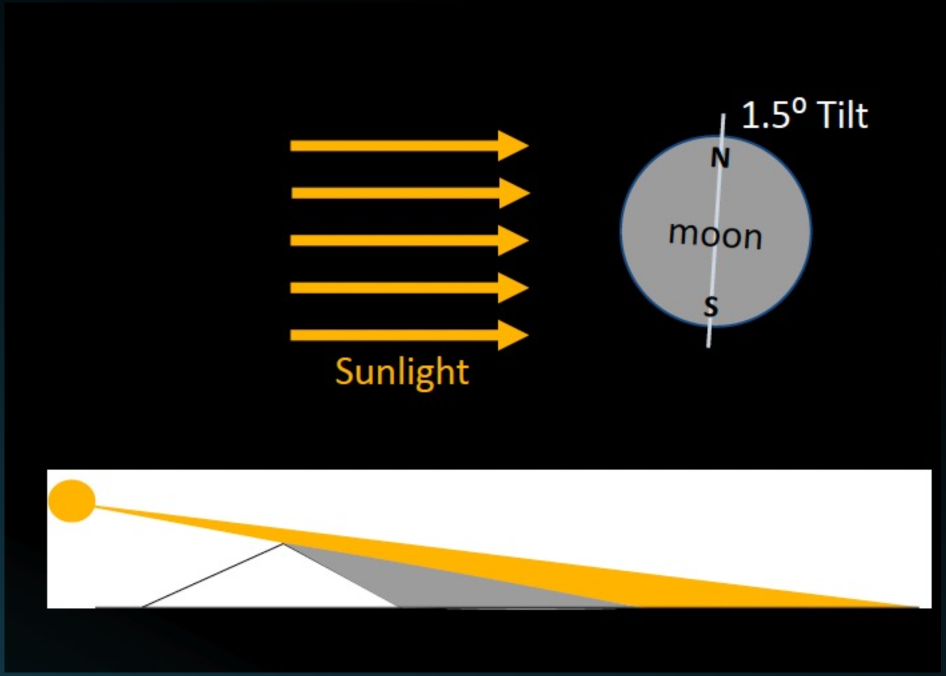
- Astrobotic’s Griffin lander to launch on Falcon Heavy
- VIPER is a payload until it is on the surface

VIPER's key engineering specs …



- Solar-powered rover
  - Working endurance in shadow (w/drill): ~9.5 hrs
  - Endurance in min power mode: 50 hrs
- Line-of-sight to Earth radio comms
  - Teleoperated from the ground
- Mission Duration: 100+ Earth days
- Driving
  - Distance Travelled (goal): 20 km
  - 1 cm/s average speed ("Speed made good")
  - 10 cm/s when moving (waiting 90% of time)
  - 15 deg slope limit
  - Can negotiate 20 cm obstacles

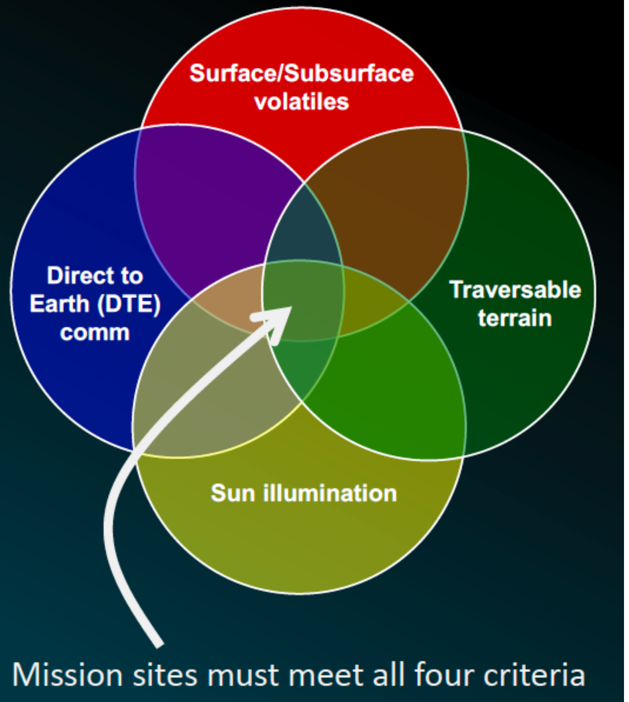
… Lead to constraints on traverse designs



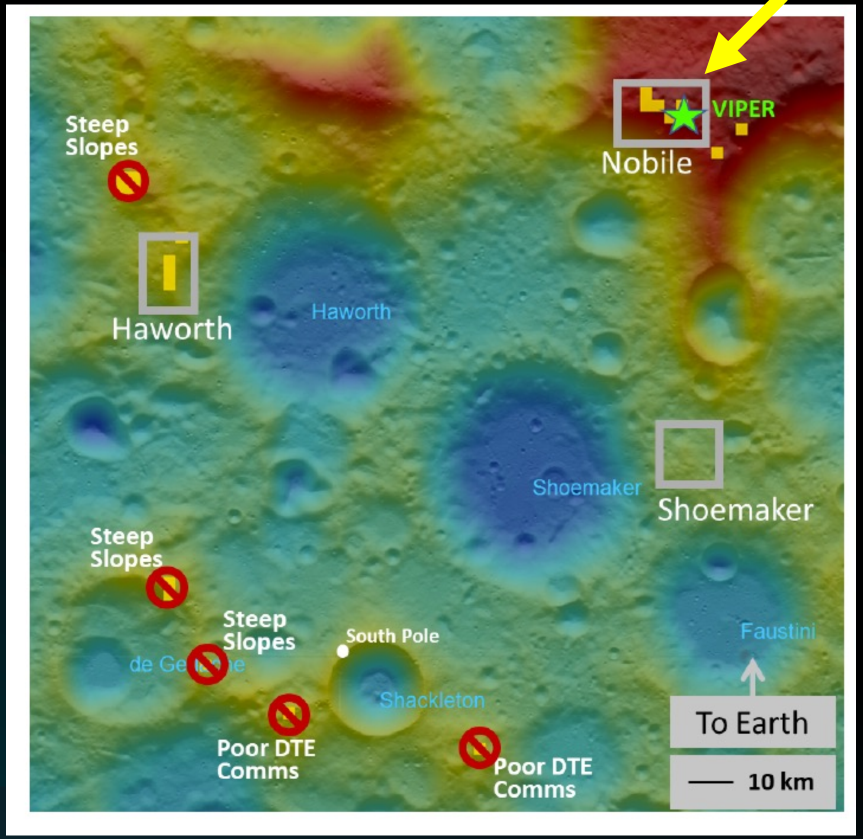
- At the poles, the Sun casts long shadows
- Similar radio shadows are cast from line-of-site radio link to ground stations
- Sun and radio shadows move at speeds similar to VIPER's “average speed”

Traverses must be timed to avoid moving shadows

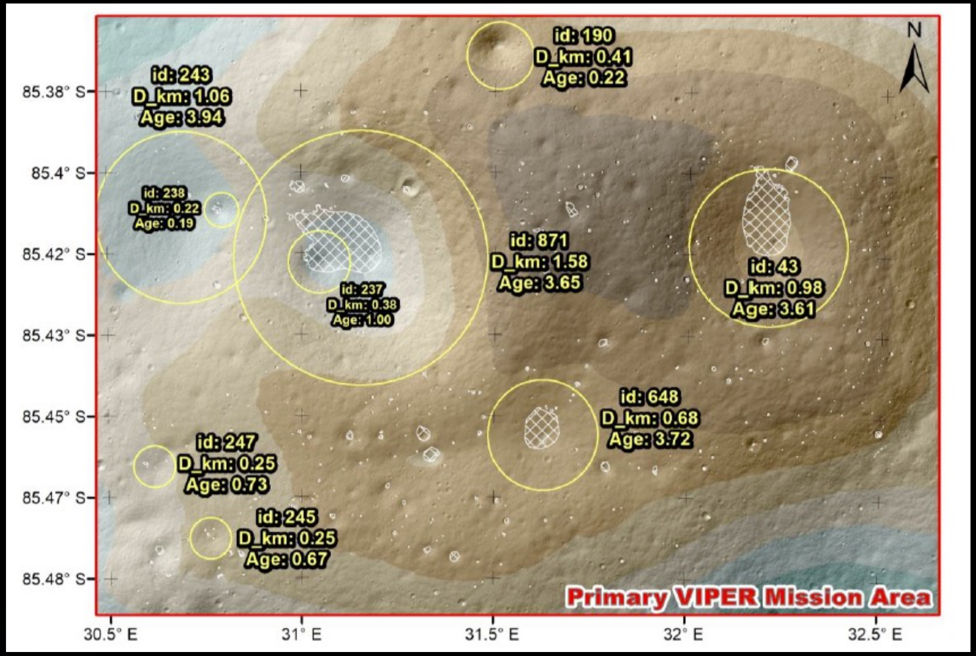
Traverse planning started with Site Selection



Colaprete A., PAC, 2020



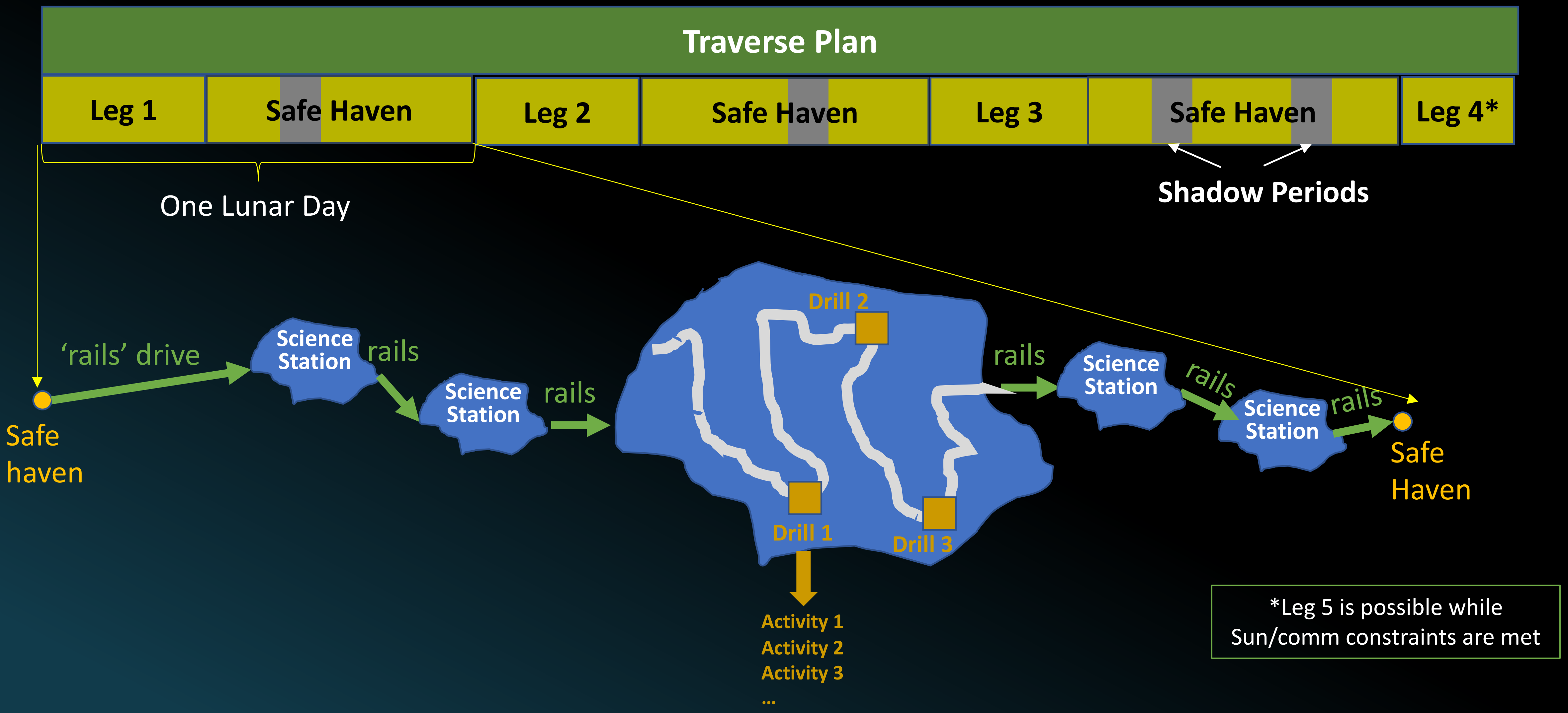
Beyer, R. et al. 2022 LPSC #2479



Fassett, C. et al. 2022 LPSC #2027

VIPER is landing in late 2024 on Mons Mouton, high mountain, west of Nobile crater, near Lunar South Pole

Traverse plan is structured at multiple levels

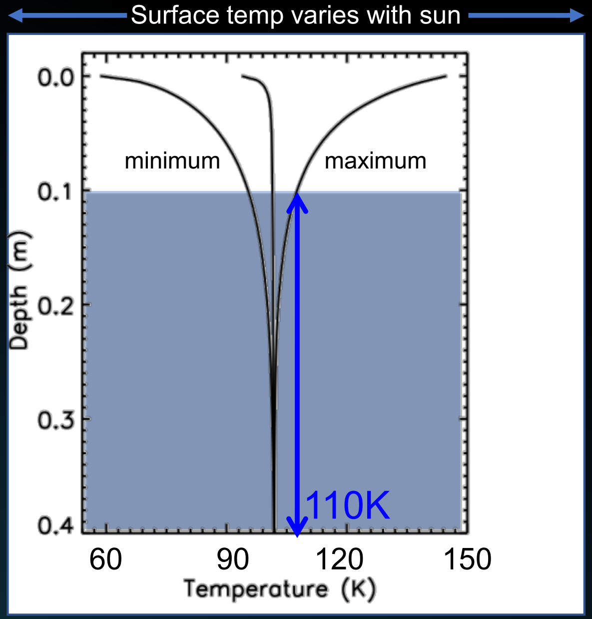


Traverse Planning Strategies

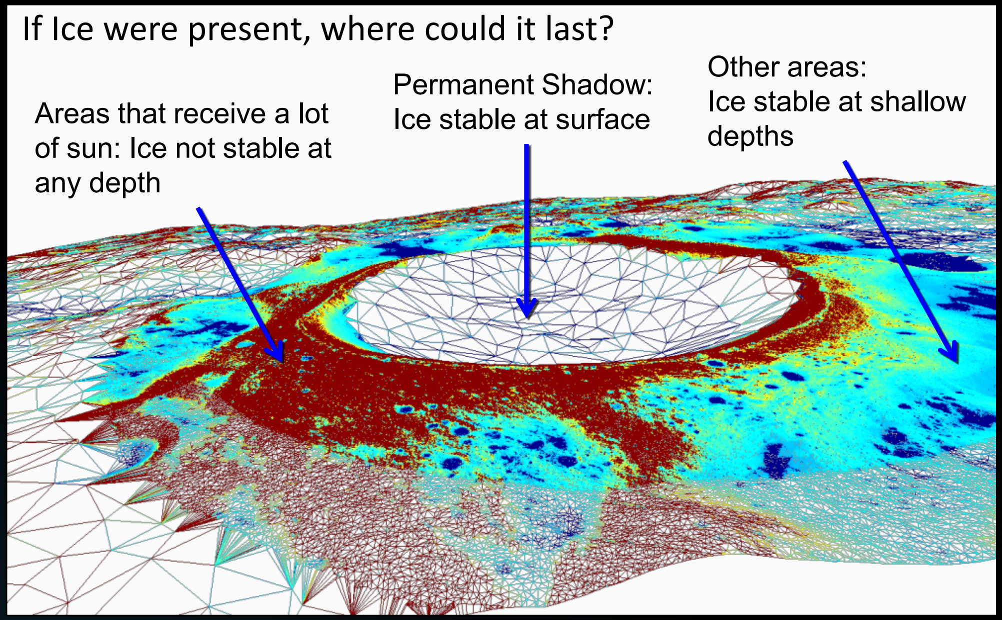
	Strategic	Tactical
	Designed for optimizing mission productivity and minimizing risk	*Designed to optimize information gain by planning inside smaller areas*
Scope	Over Full Mission; specifies route and timing	Current lunar day (up to ~14 Earth days)
Detail	Selected: includes activities that impact critical resources (e.g., power, data storage)	Full: includes comm passes/handovers, maintenance activities, ground activities, deadlines
Ready Date	Launch -1 year	Launch -1 year
Updates	Goal: next lunar day; Capability: next Earth day	Max of 1 per shift
Contingencies	Major contingencies (e.g. low battery storage, SEP events, DSN outage)	Strategic contingencies produce multiple tactical plans
Change Process	Drive by Science Measurement Plan	Flight-rule driven
Update Cadence	Before launch: frequent After launch: once per month during safe haven, or as per contingency needs	Up to 1 release per shift Formal but quick review process based on mission ops practices

Both use automated route planning approaches

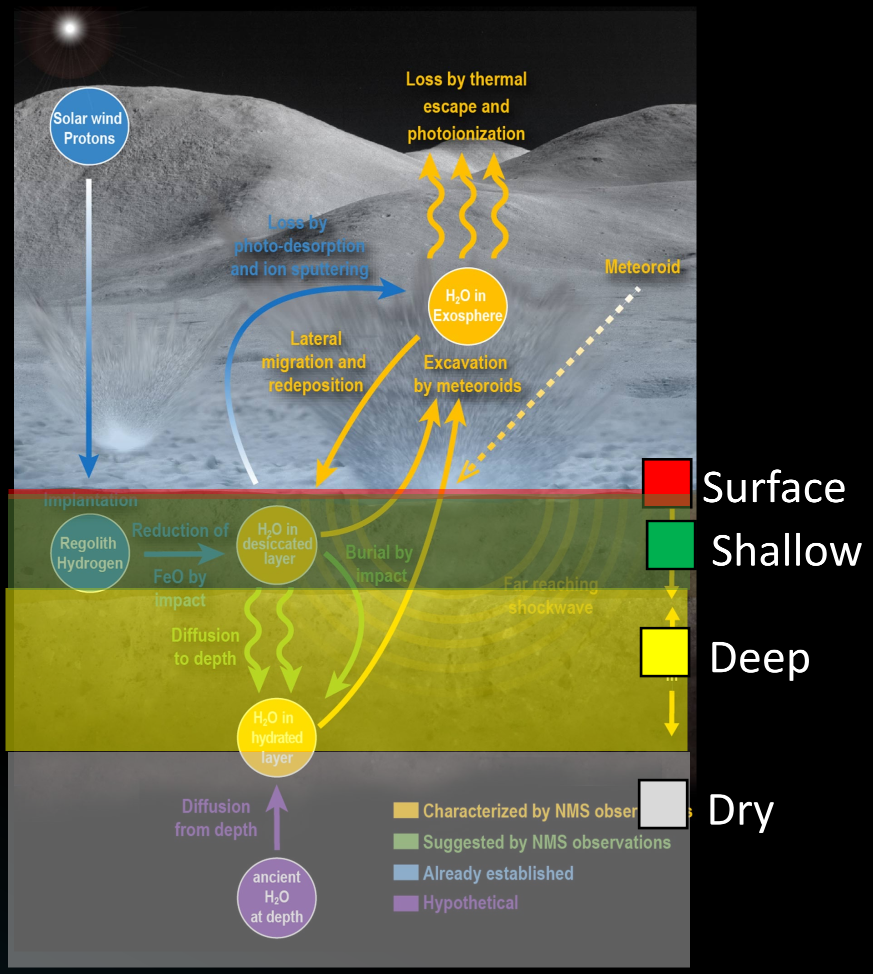
Using thermal history as a proxy for volatiles
Concept of Ice Stability Regions



Temp at depth ~constant
Ice can be stable below the monthly and seasonal thermal wave.



Maps generated by Matt Siegler (PSI) and Dave Paige (UCLA)



Benna, M. et al. 2019

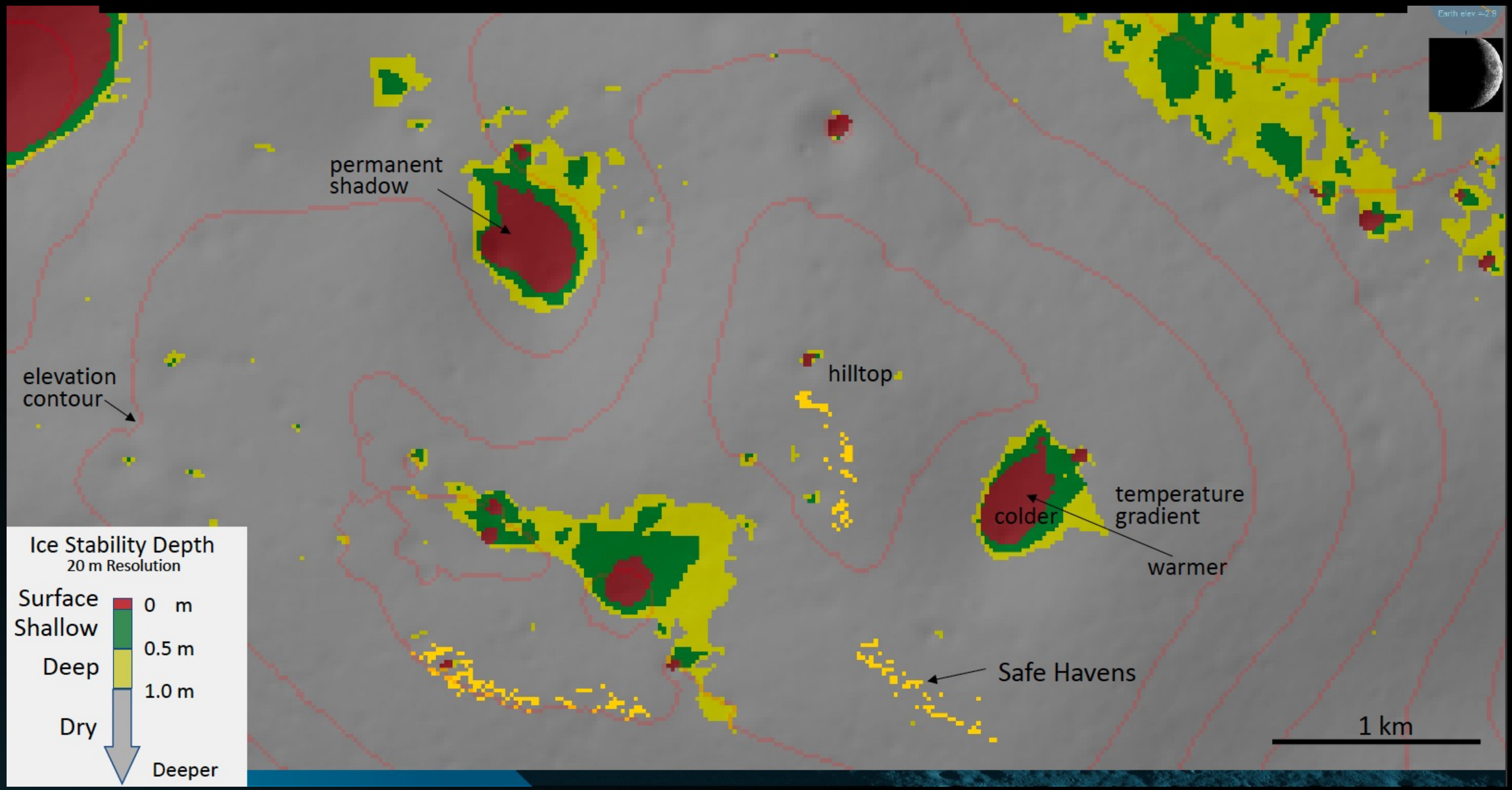
- Temperatures that remain <107 K are necessary for long-term (Gyr) ice stability
- Where does it stay this cold over long periods of time?
  - Surface: Permanent Shadow
  - Below Surface: Depends on transient surface heating by Sun
- How deep is summarized as Ice Stability Depth
  - Function of terrain shape and can be calculated at scales down to a few meters -> Ice Stability Region

Science Station concept drives design

Science Station: 3800 m^2 area dominated by specific Ice Stability Region (ISR) type

To estimate total volatiles in top meter in a Science Station:

- 10-15% area coverage to estimate water with <50% uncertainty
- Corresponding linear coverage is 224-335 m of driving
- Drill 3 times to 1m depth to ground truth prospecting data, separation of drill sites by 10s of meters
- Full mission success requires 6 science stations (one each per type, plus 2 repeats separated by 100 m)



Core planning problem is the placement of these science stations

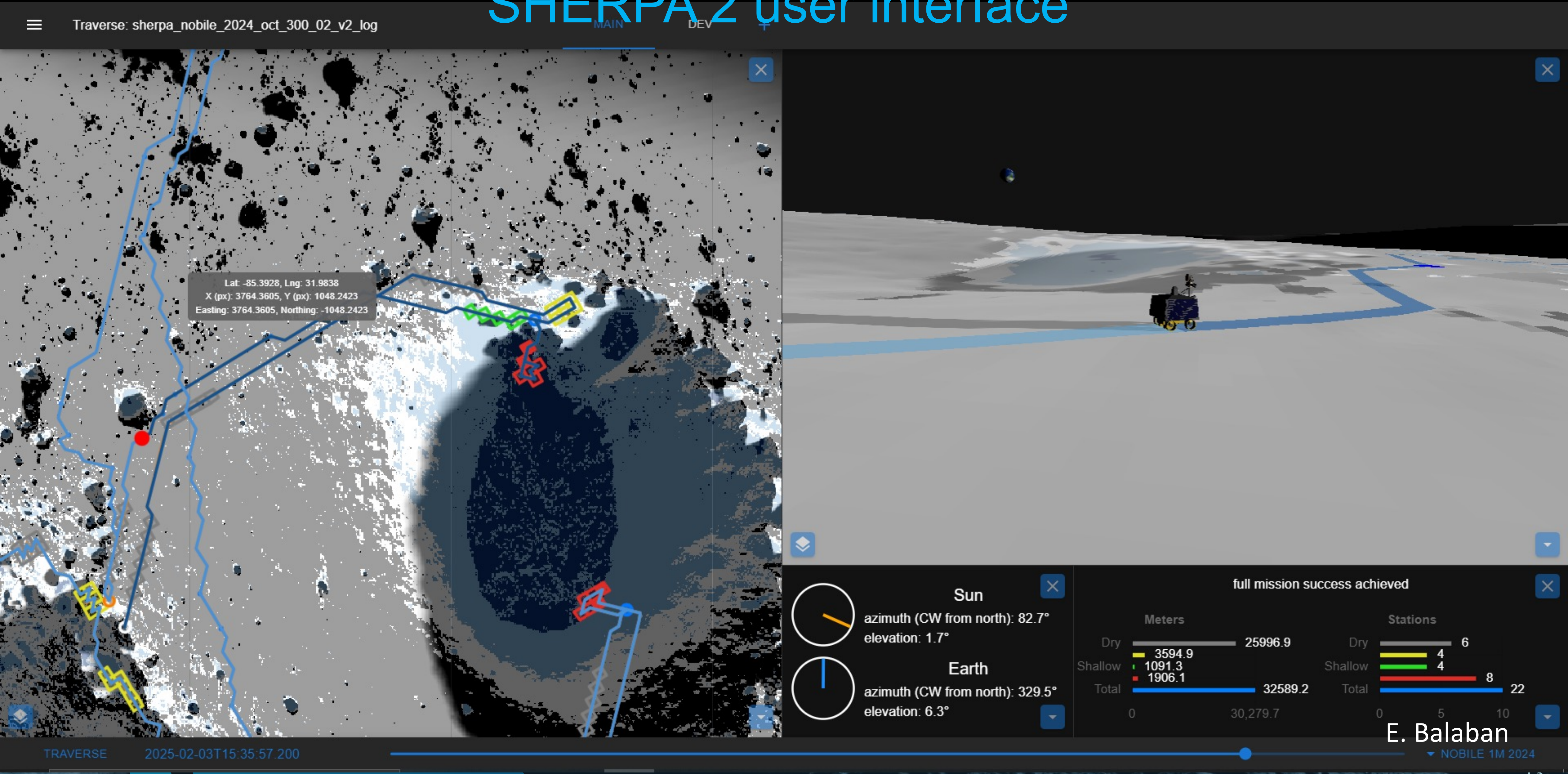
SHERPA Planning Tool
(traverse generation and evaluation)

SHERPA (**S**ystem **H**ealth **E**nabled **R**eal-time **P**lanning **A**dvisor) is an artificial intelligence (AI) decision support system for robotic space missions that is based on formal decision making under uncertainty.

Provides

- Interfaces to solvers / policies
- Use case infrastructure
- Model, telemetry and data products management
- Unit and end-to-end testing framework
- Visualization tools
- Benchmarking and statistics

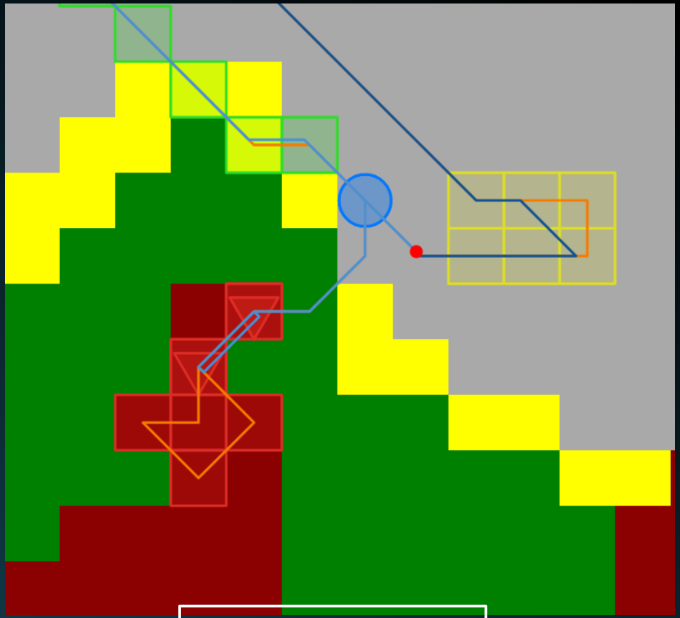
SHERPA 2 user interface



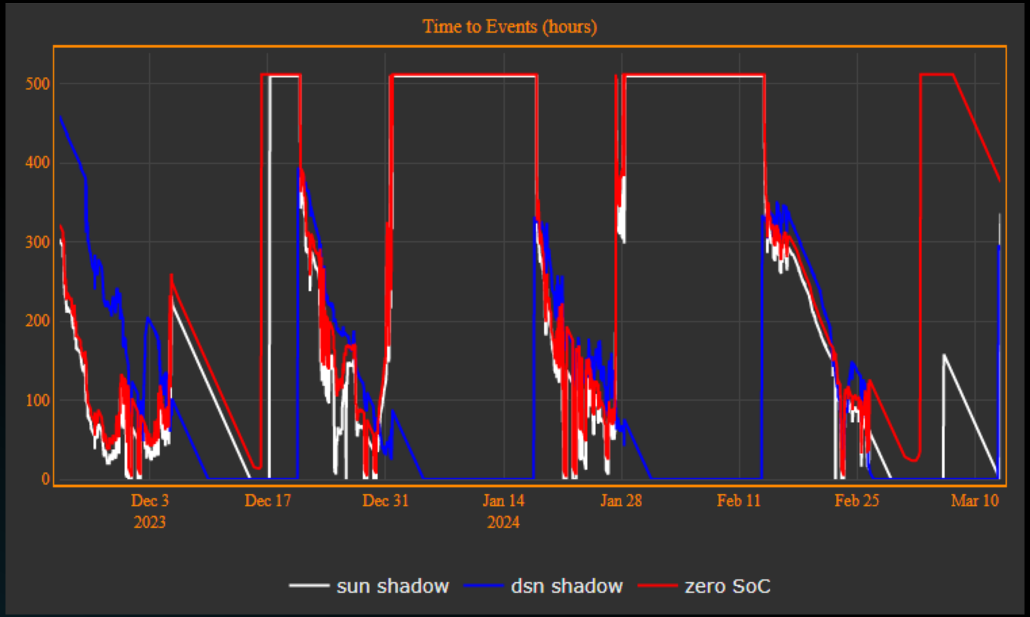
E. Balaban

Mission evaluation use case

- In this use case, Monte-Carlo simulations are used to stress-test candidate mission plans.
- SHERPA injects stochastic delays and faults during a mission scenario execution and collects performance statistics.
- Scenario execution policies are intended to represent human operator decisions (including on deviations from the nominal plan).

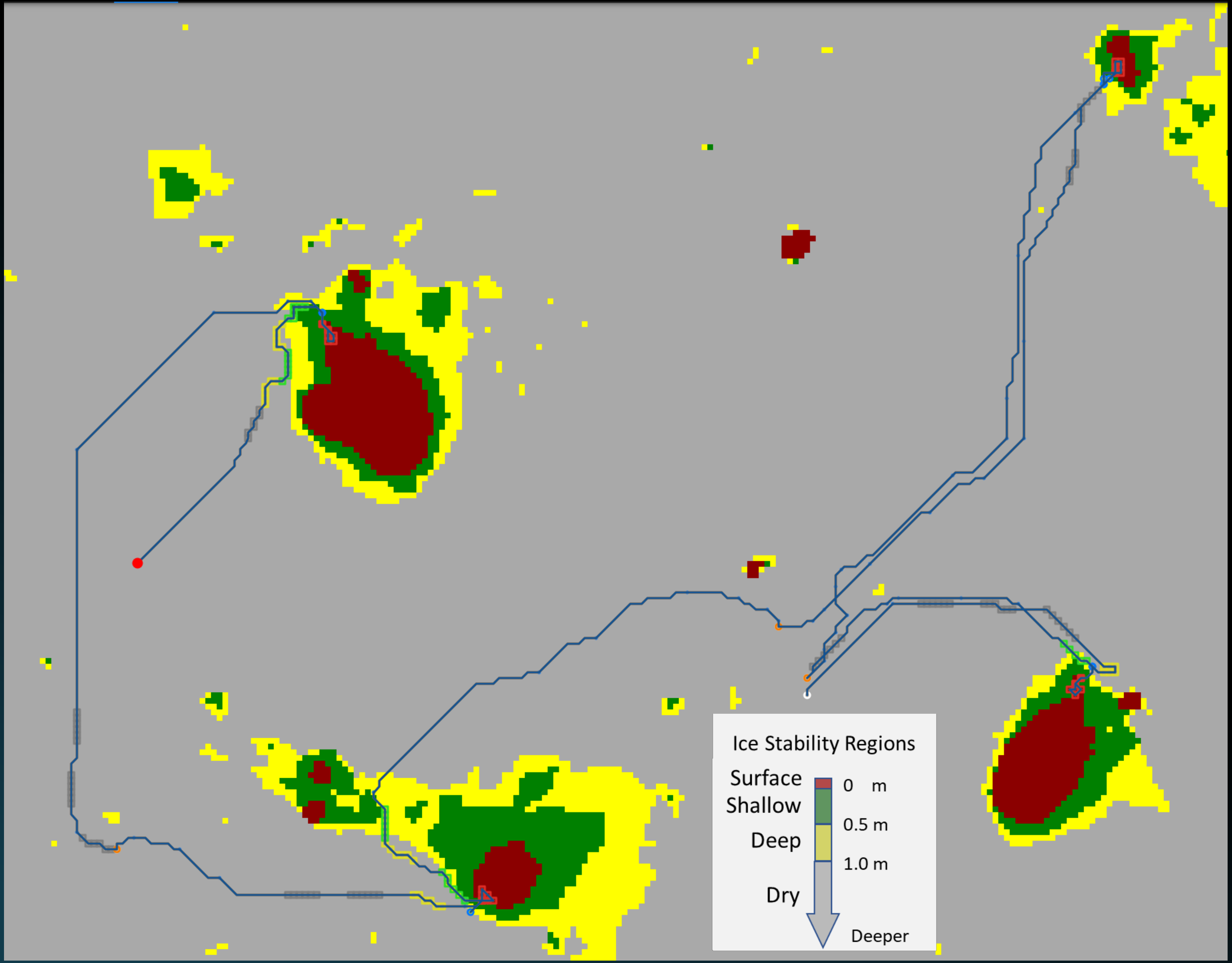


orange – planned
blue – executed



Example of performance statistics collected during mission evaluation

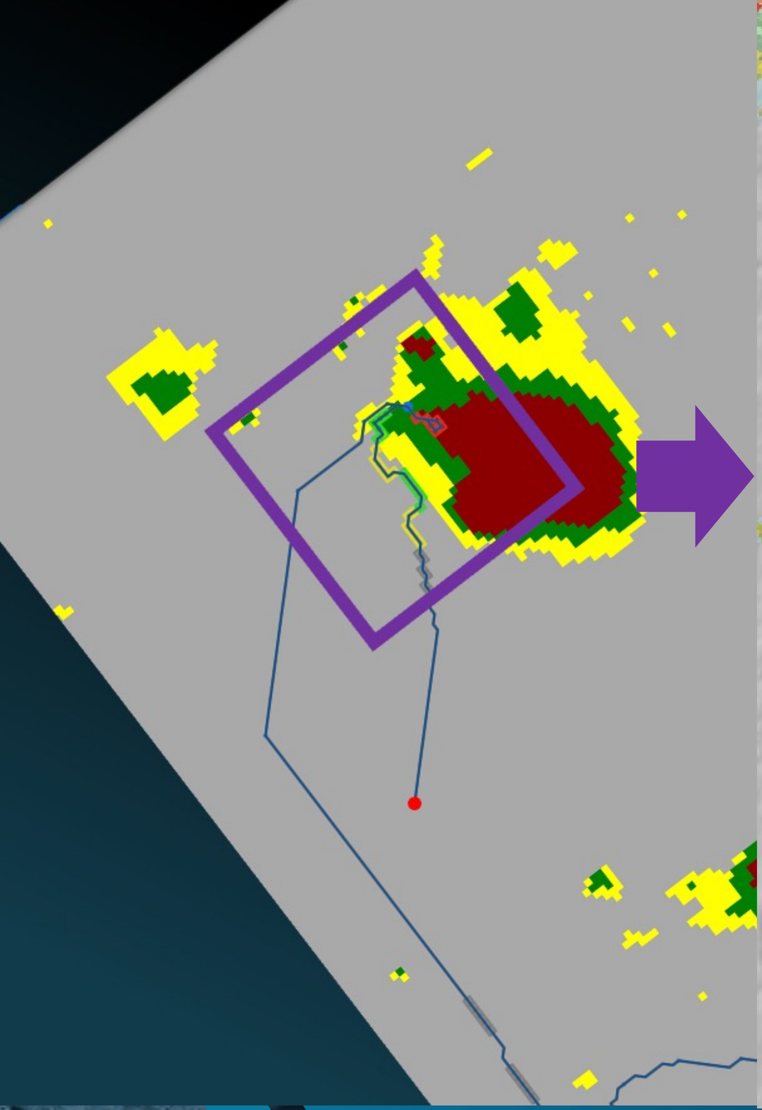
SHERPA November 2024 traverse example

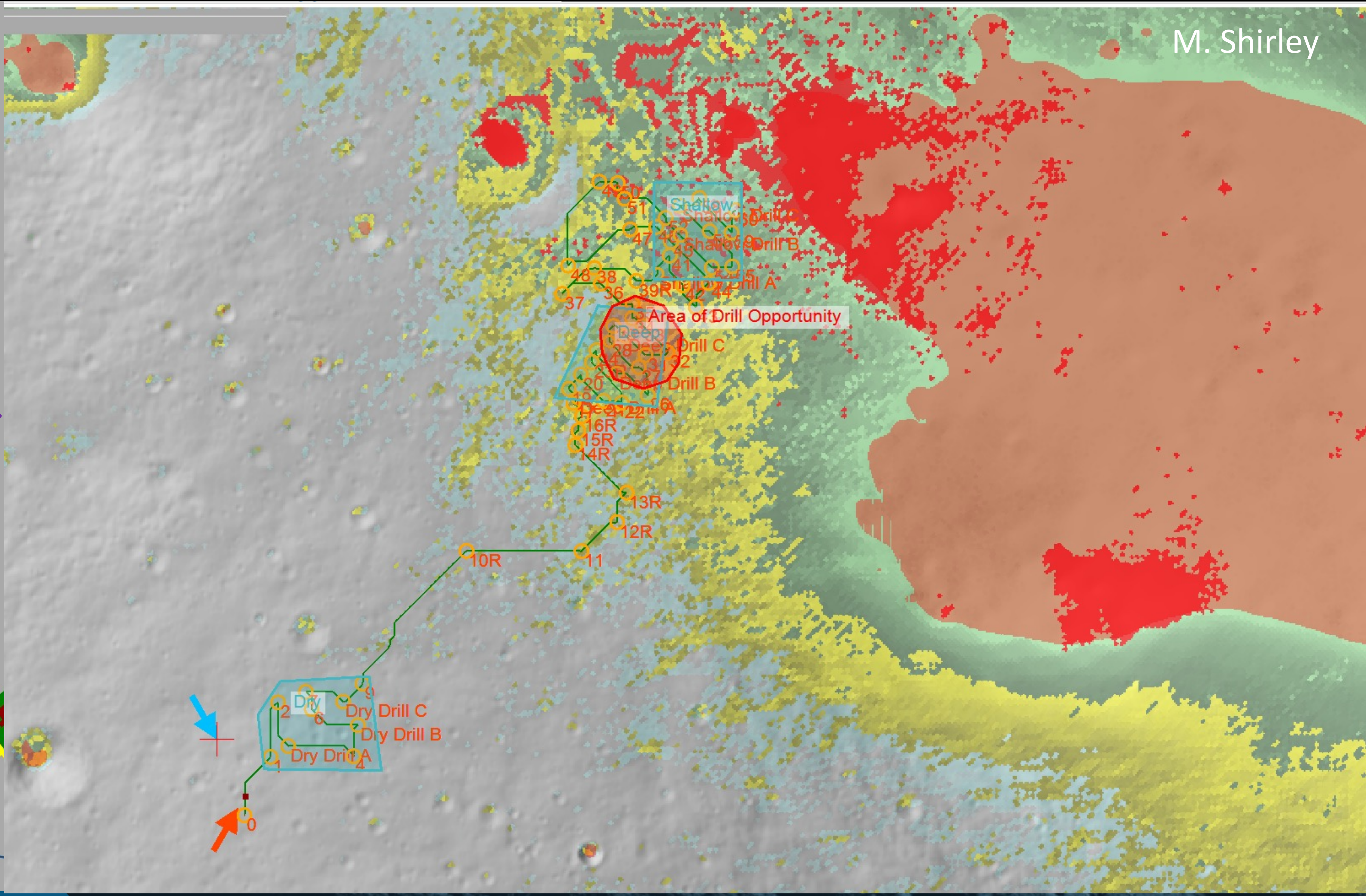


Landing time	2024-11-10T16:00:00
Duration (Earth days)	112.17
FMS (lunar day)	1
FMS (Earth days)	7.74
FMS (m)	3444
Odometry, total (m)	29809
Dry (m)	25193
Deep (m)	1638
Shallow (m)	1063
PSR (m)	1914
Science stations, total	30
Dry	12
Deep	5
Shallow	5
PSR, prospecting	4
PSR, drilling	4

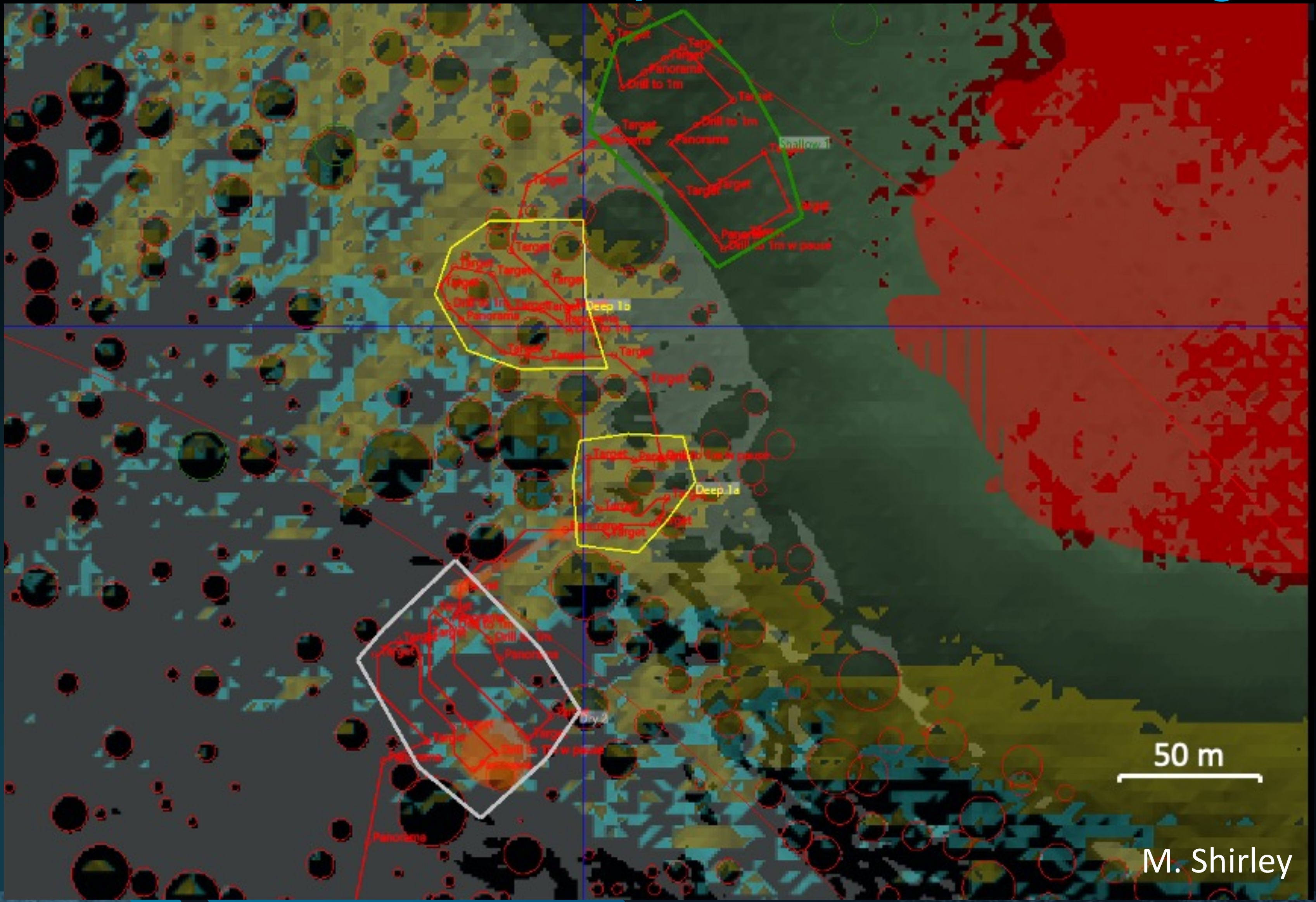
Convert Strategic Traverse -> Tactical Traverse

SHERPA Output





Tactical plans provide guidelines, enable flexibility, optimize information gain



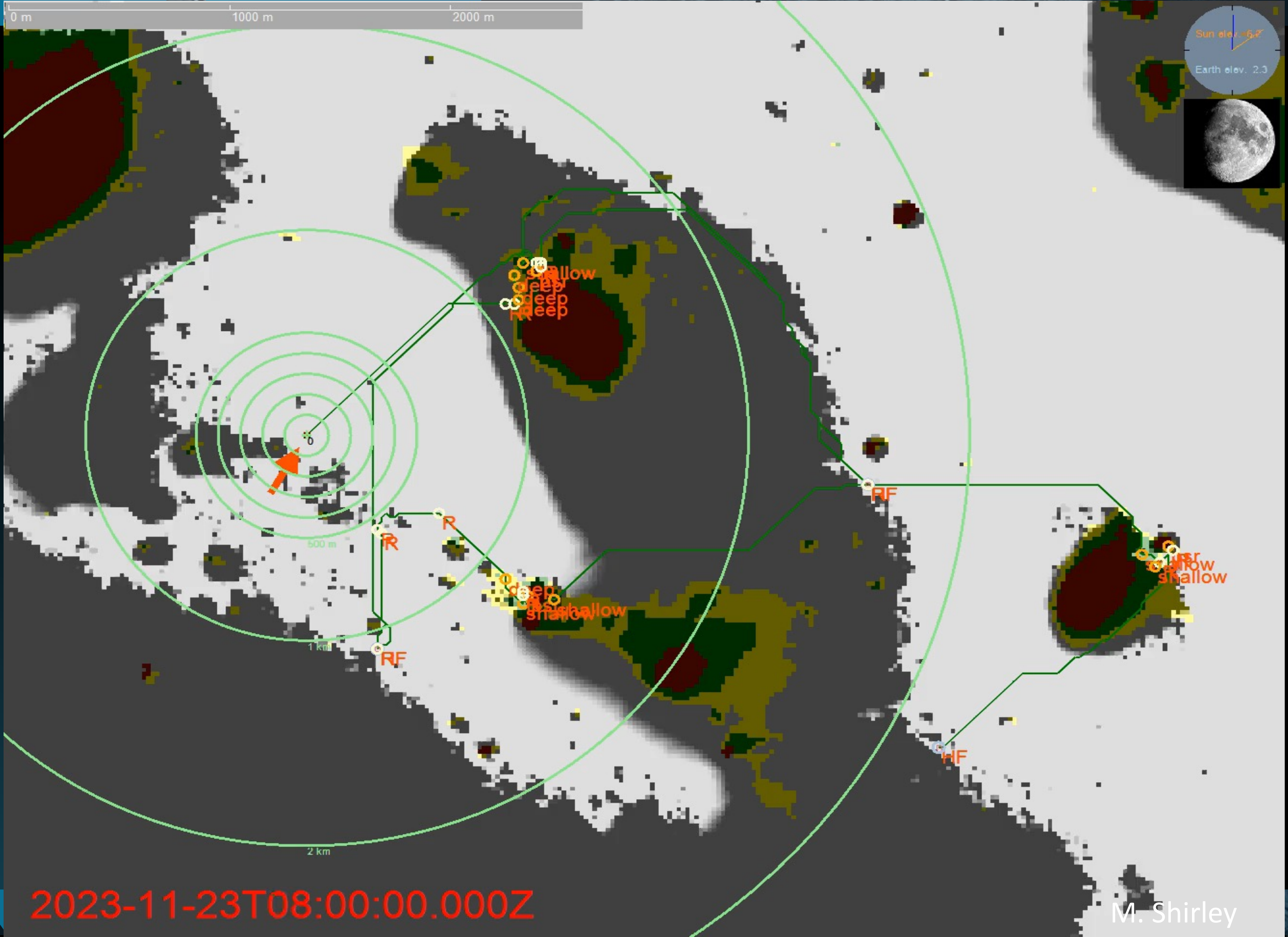
Optimize information gain
Examples

1. Geostatistical analysis techniques (e.g., trend analysis, kriging, linear regression) are applied in response to prior measurements while maintaining the required coverage density.
2. Third drill site in a Science Station is not *a priori* fixed. VIPER Science Team advises drill placement and subsequent sample analysis activities which is, in turn, folded back into the Tactical Plan.

Summary

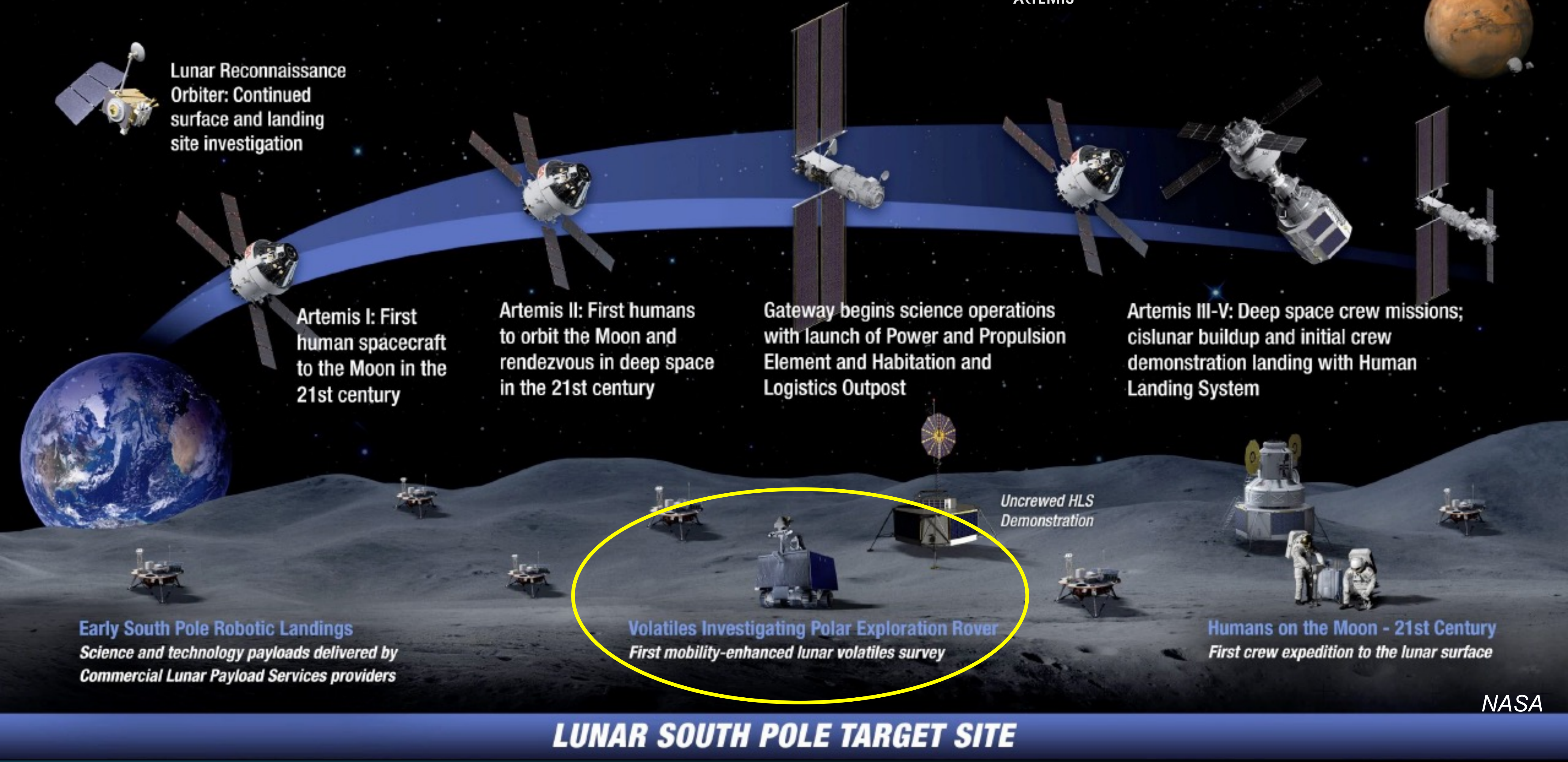
- Innovative and automated route planning approaches for lunar polar conditions have revealed the right places for VIPER to optimize its science return.
- VIPER planners can deliver baseline and contingency traverses over a range of landing dates and locations.
- These plans can be compared to mission performance metrics and allow for adjustments for science preferences and/or program risk levels.
  - Site Selection provided the mission area canvas for multiple traverse possibilities.
  - Traverse Strategic Plans give the scope and options for entire mission.
  - Traverse Tactical Plans, made over smaller areas, offer opportunities to feed forward near-real time science interpretation of this unexplored land to optimize further science return.
- VIPER planning has been and continues to be an iterative process between science and operations.

https://www.nasa.gov/viper


0 m
1000 m
2000 m
Earth elev. 2.3
500 m
1 km
2 km
RF
RF
HF
2023-11-23T08:00:00.000Z
M. Shirley

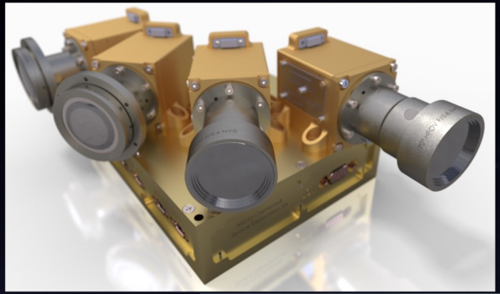
Backup

Artemis: Landing Humans On the Moon

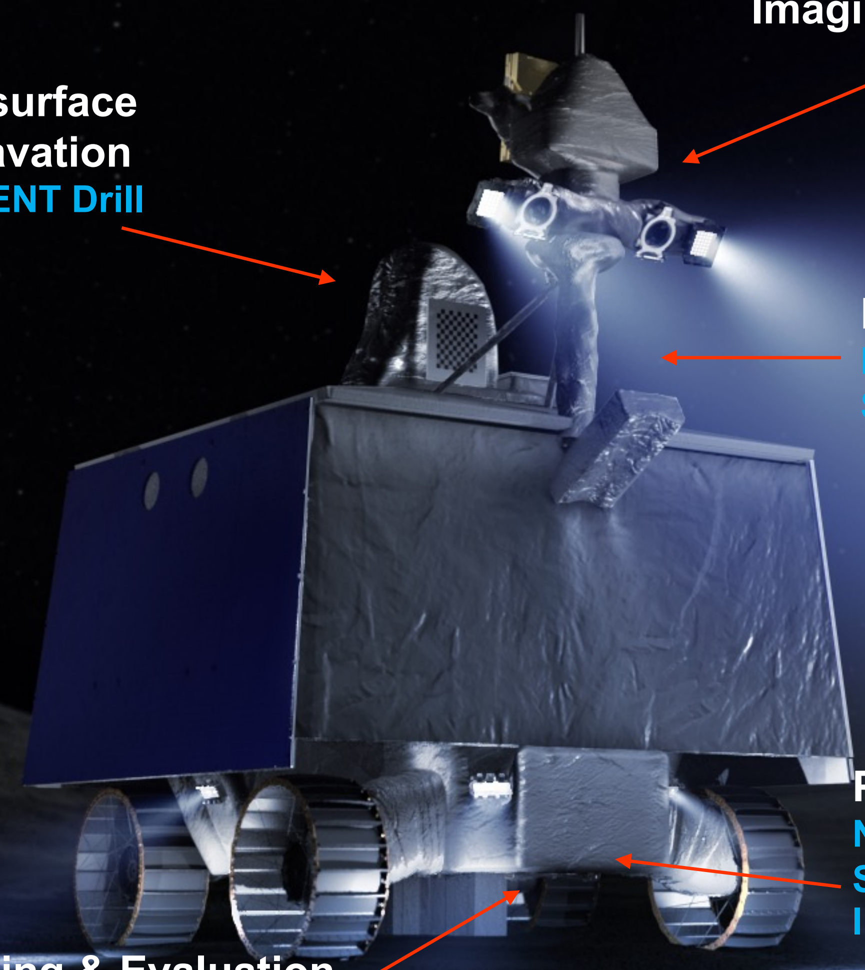


VIPER Science Instruments

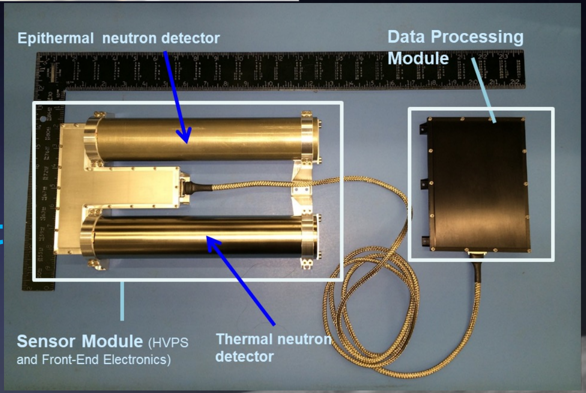
Subsurface excavation
TRIDENT Drill

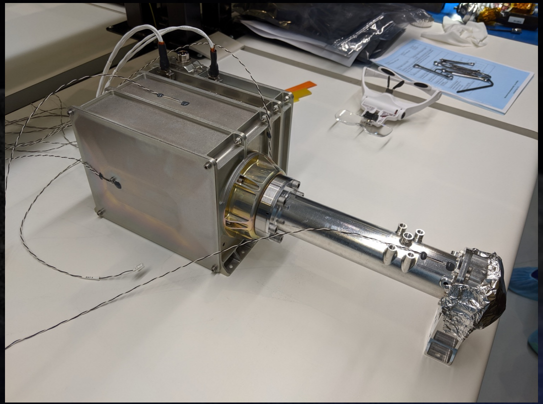


Imaging Science
VIS



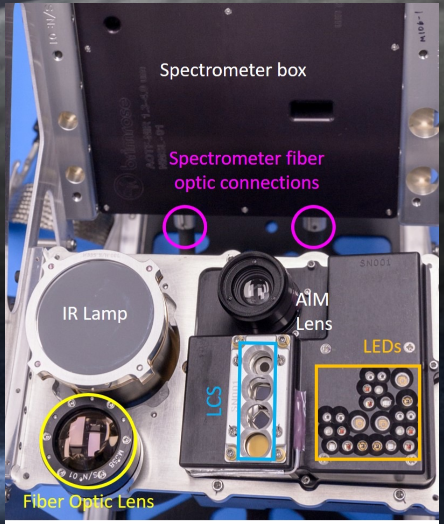
Prospecting
Neutron Spectrometer System (NSS) Instrument





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

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



VIPER payload is integrated and analytically powerful