Lunar Surface Missions for Resource Reconnaissance: NASA's PRIME-1 and VIPER

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1 NASA

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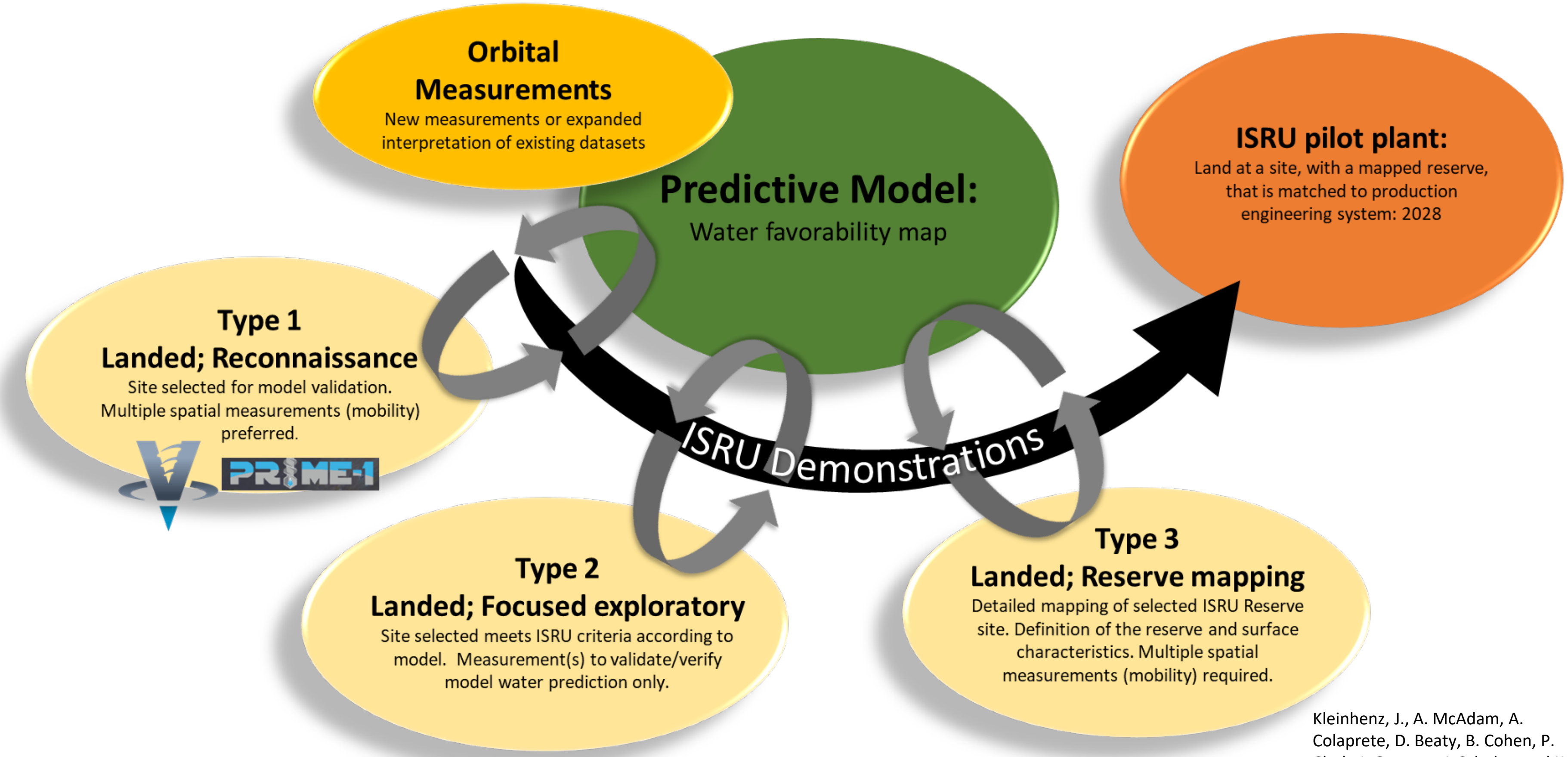
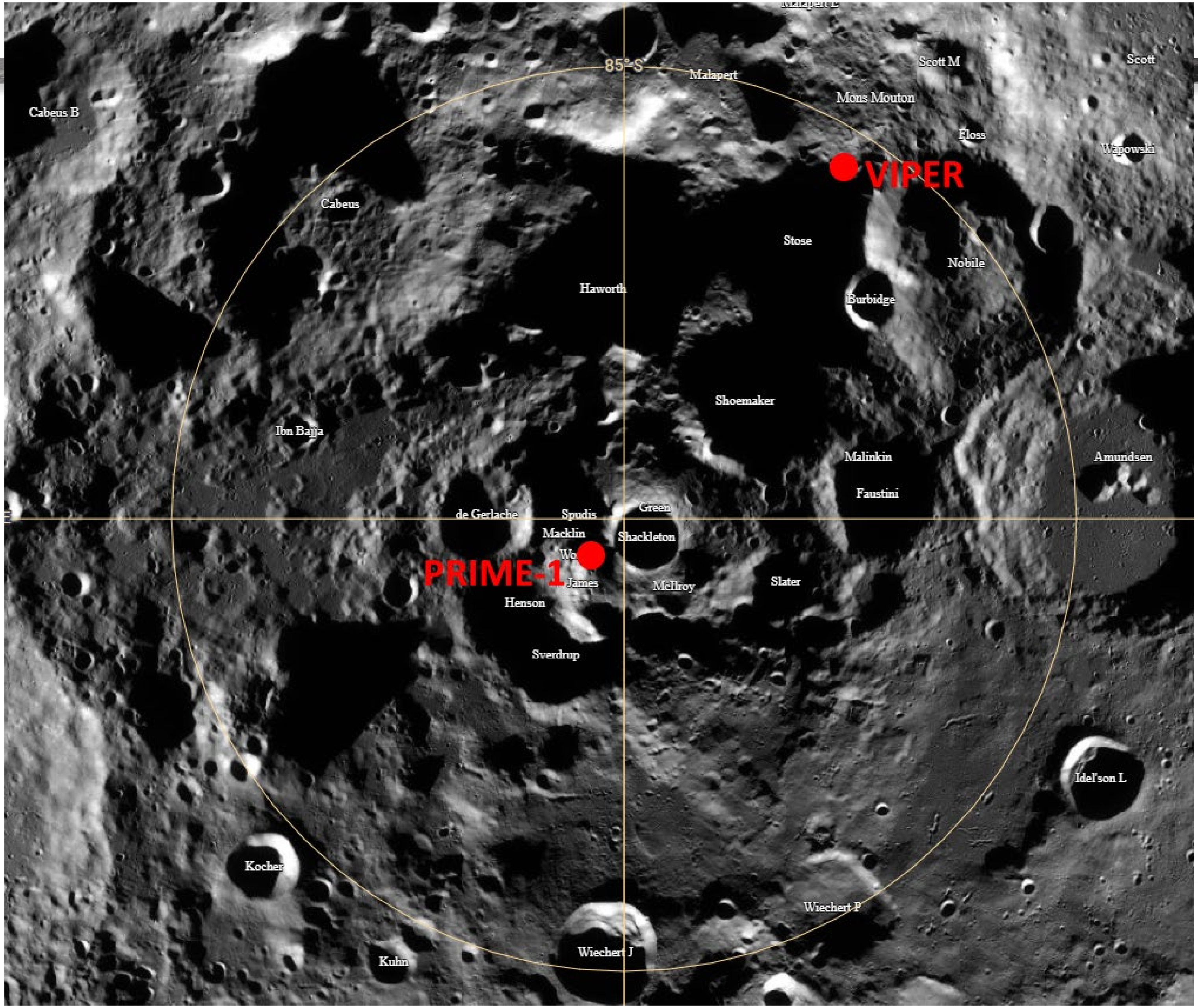
NASA's Resource Reconnaissance

- The Lunar Water ISRU measurement study identified 3 mission types to define the needed reconnaissance to identify an ISRU reserve
- Both PRIME-1 and VIPER missions fall into Type 1 which is about getting information needed to build the models and favorability maps



Kleinhenz, J., A. McAdam, A. Colaprete, D. Beaty, B. Cohen, P. Clark, J. Gruener, J. Schuler, and K. Young, 2020, Lunar Water ISRU Measurement Study (LWIMS): Establishing a Measurement Plan for Identification and Characterization of a Water Reserve. NASA TM-2025008626

PRIME-1 and VIPER are NASA's first steps in performing the resource reconnaissance efforts needed for lunar water ISRU


85°S
Malapert
Scott M
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Mons Mouton
Floss
Wapowski
Cabeus B
VIPER
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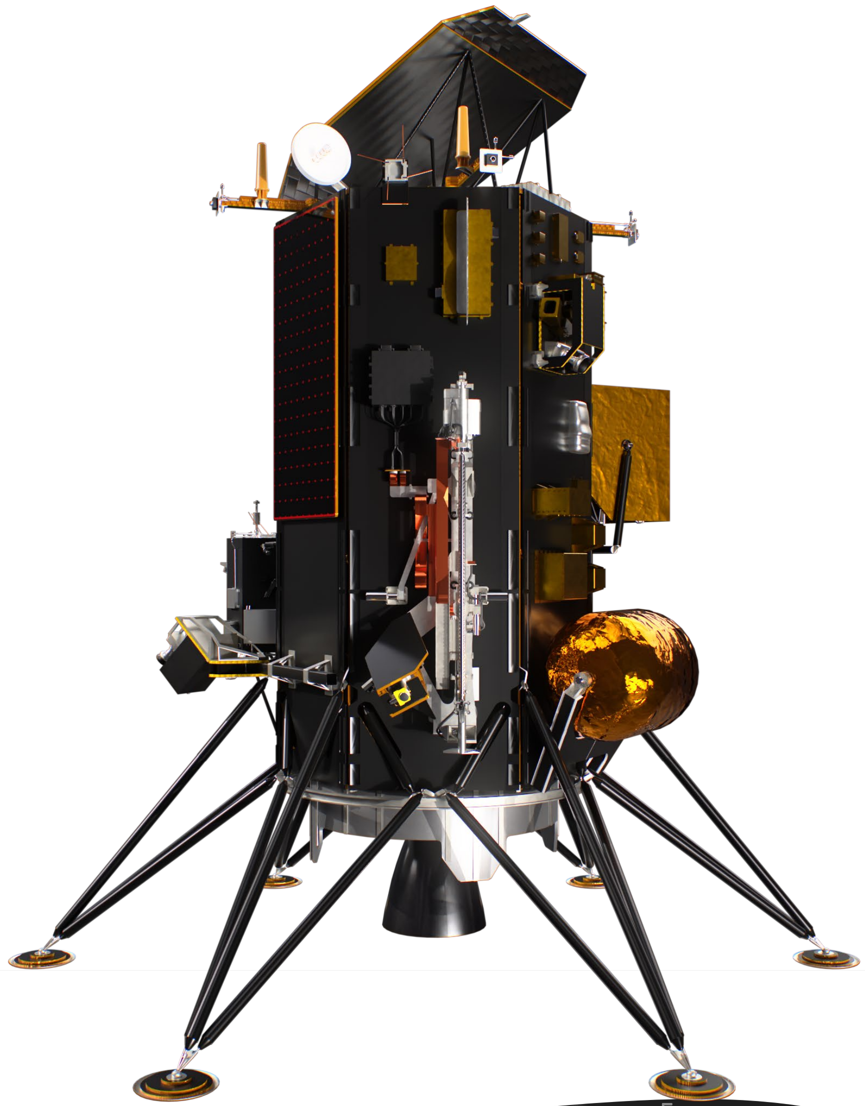
Nobile
Haworth
Burbidge
Shoemaker
Ibn Bajja
Amundsen
Malinkin
Faustini
de Gerlache
Spudis
Green
Macklin
Shackleton
PRIME-1
James
McIlroy
Slater
Henson
Sverdrup
Idel'son L
Kocher
Wiechert P
Kuhn
Wiechert J

PRIME-1

PRIME-1

- Payloads
  - Polar Resources Mining Experiment (PRIME-1)
    - Mass Spectrometer Observing Lunar Operations (MSolo)
    - The Regolith and Ice Drill for Exploring New Terrains (TRIDENT)
    - Visible imager for PRIME-1: 0.1 pix/cm camera to view cuttings pile
  - Micro-Nova Hopper
    - Puli Neutron Spectrometer
    - Nokia 4G/LTE on Lunar Outpost MAPP rover
  - Orbital ride share: Lunar Trailblazer
- Lander Vehicle: Nova-C
  - 4.0 m tall, hexagonal
  - Lox/LCH_4 Propulsion
  - Communication via Lunar Tracking Telemetery and Command Network (LTN): DTE with ground stations



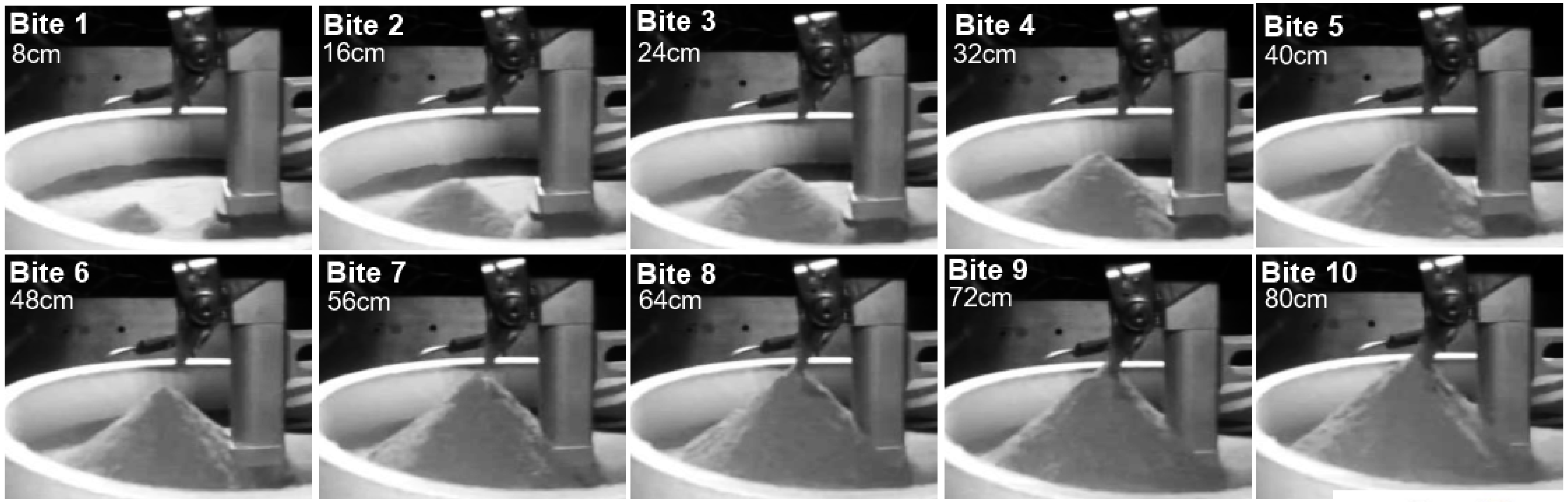
Key Performance Parameters

Performance Parameter	Units	SOA	Threshold value	Project Goal
Regolith sample-depth resolution	Number of linear depths along single drill hole note 1	N/A note 2	3	5
Volatile species identification	Number of volatiles	1 (H_2)	3 (H_2 and H_2O)	>2 (light weight volatiles <70amu)
Water detection accuracy with regolith note 3	% by mass water grade in regolith	N/A note 2	2 note 4	1 note 4

Note 1: Threshold linearly along a depth up to 0.6-m total. Project goal linearly along depth up to 1-m total.
Note 2: No drill samples for SOA. Orbital spatial scale is 10s of km at depth up to 1 meter only for H2
Note 3: Assumes 2.0-5.0% water by mass in regolith which encapsulates ISRU definition of critical grade cutoff
Note 4: Measurement accuracy of ± 50%

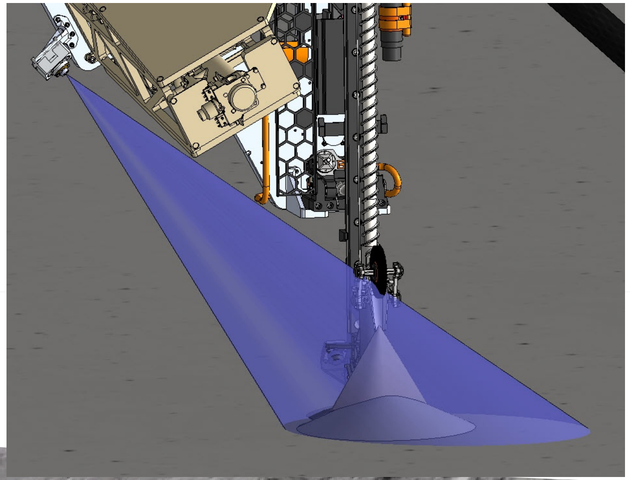
Bite sampling approach

Cuttings Pile increases with each bite, with new material distributed on the pile surface exposing volatiles for sublimation.

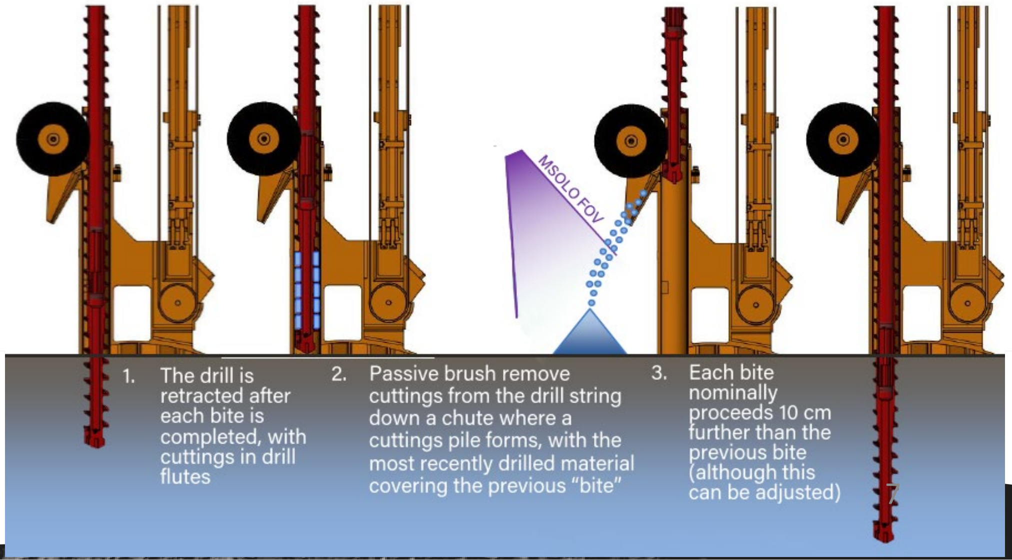


Advantages of Bite Sampling

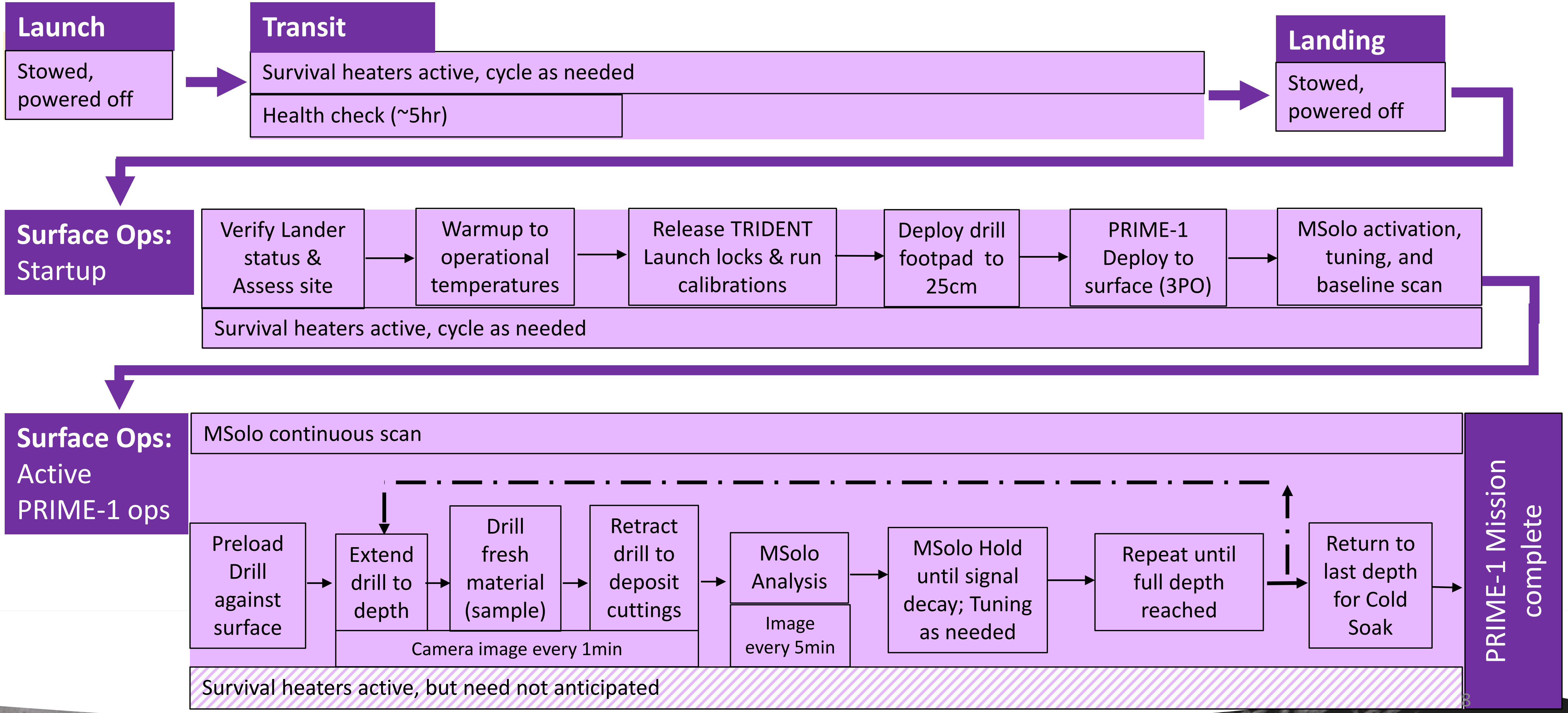
- Lower Power
- Stratigraphy is preserved in 8-10 cm "Bites"
- Accurate material strength determination
- More accurate downhole temperature
- Reduced risk of freezing-in



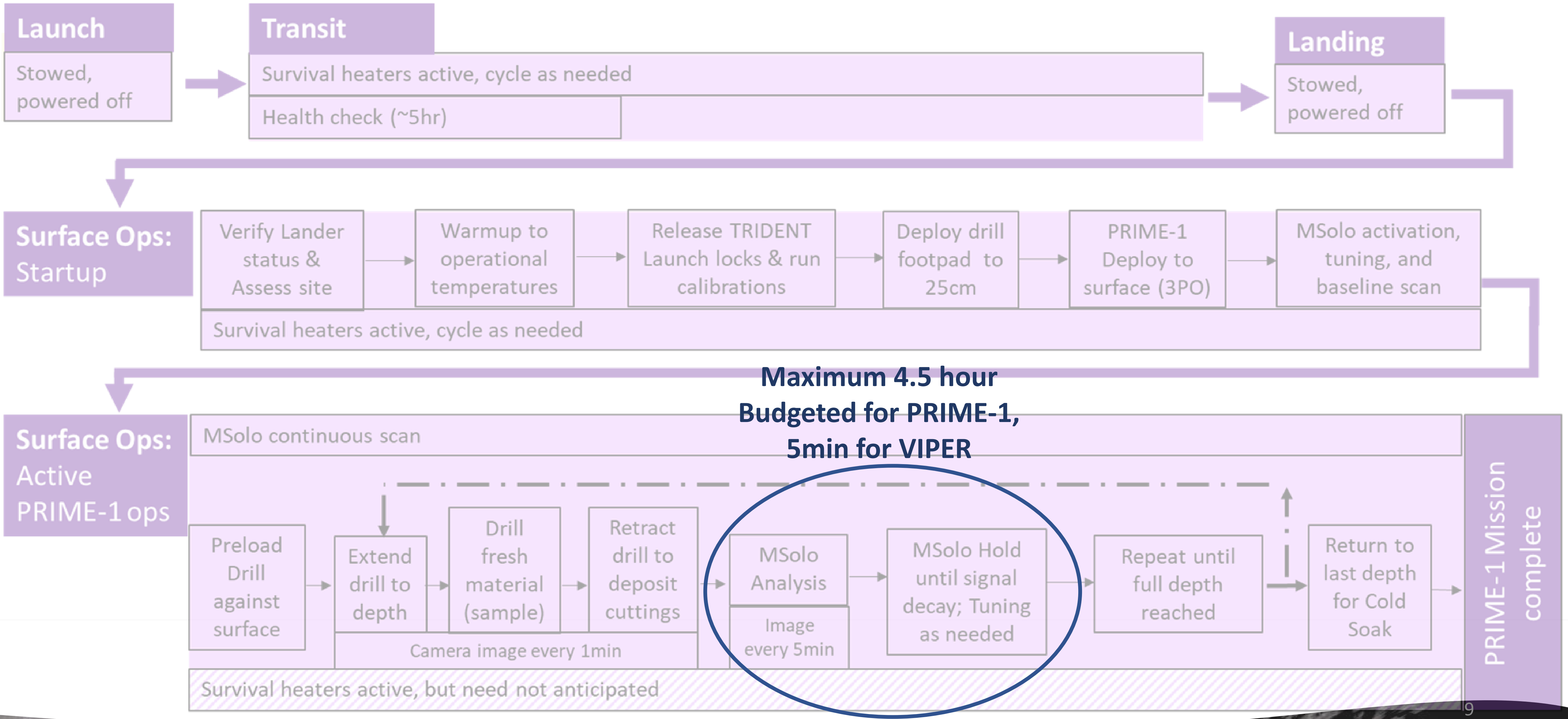
The lander partner provides regular camera imagery of the cuttings pile while operating. Images will be provided every minute during active operations, every 5min during analysis hold periods.



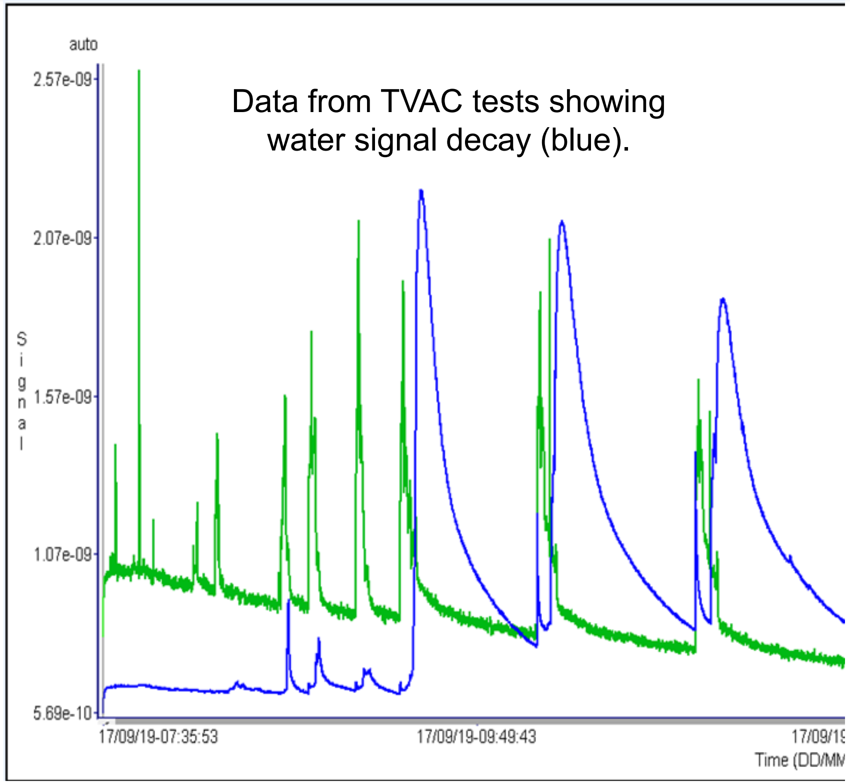
Concept of Operations



Concept of Operations



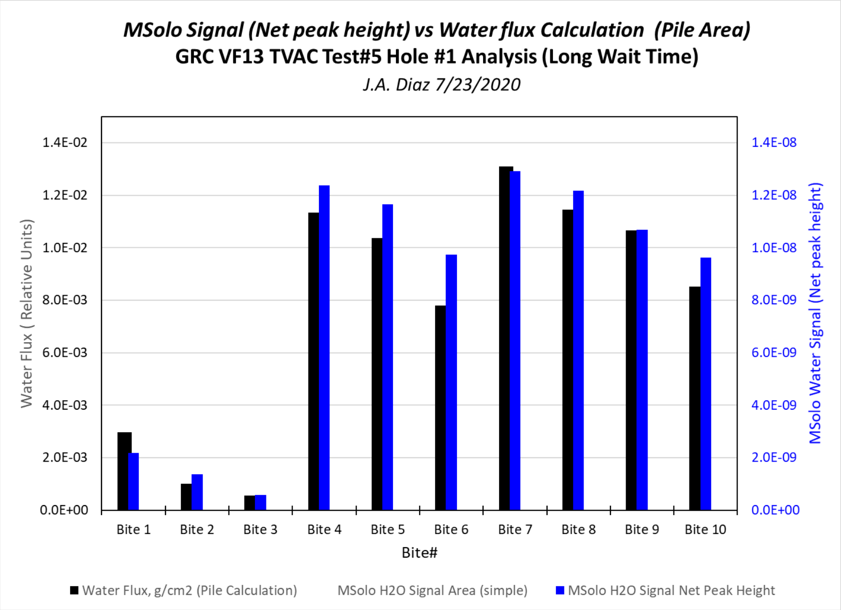
MSolo Analysis time



- PRIME-1 will be able to implement a long MSolo analysis time, looking at the water signal decay which is used to:
  - Understand the volatile diffusion and desorption from regolith which informs ISRU – i.e. desorption during excavation
  - Apply the diffusion model developed using Earth-based TVAC conditions for quantification of PRIME-1 observed lunar water
- In the VIPER mission, the timeline does not allow for the full signal decay
  - The peak intensity will be used to interpret the water estimates using the model developed with PRIME and ground test

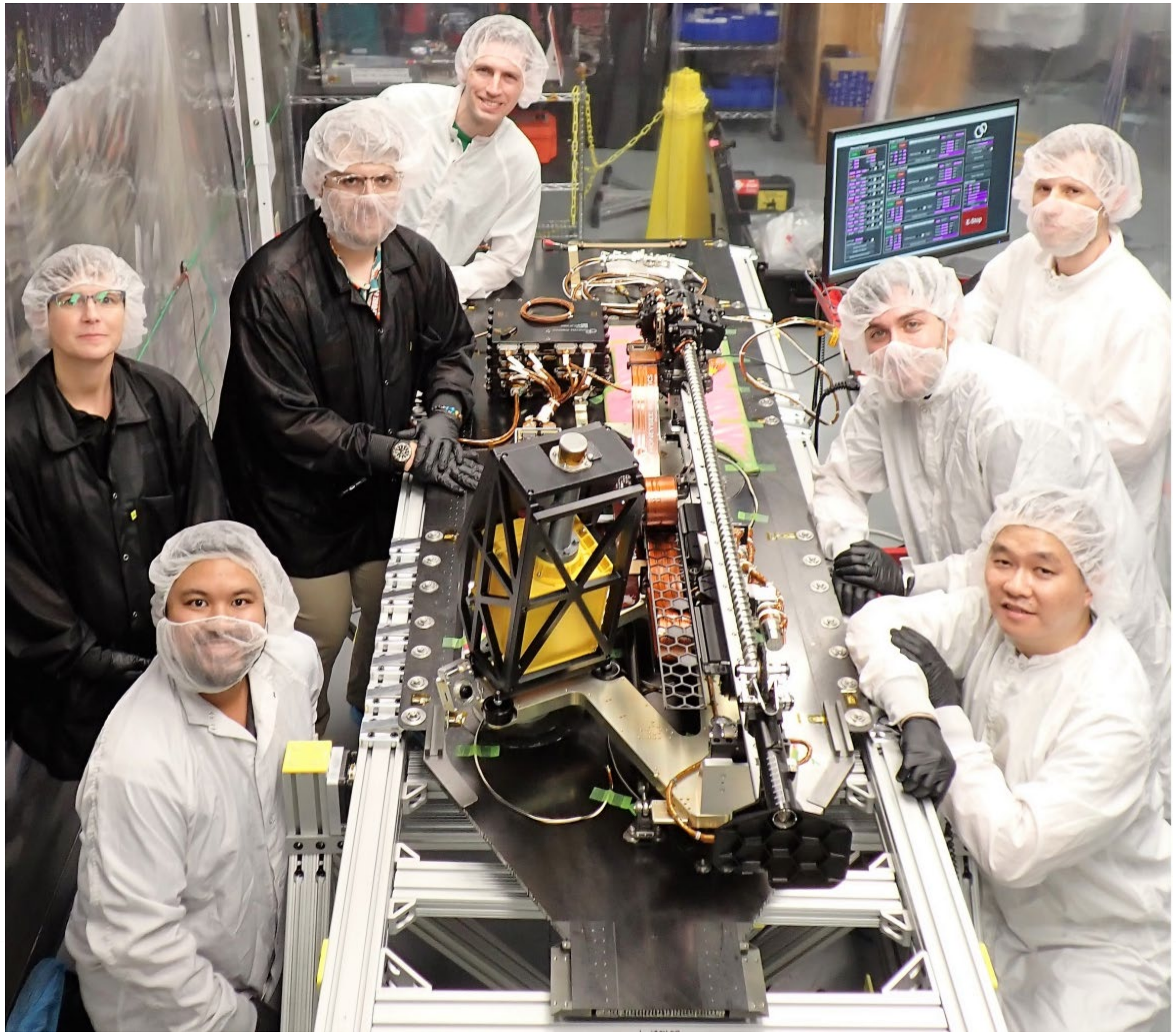
<u>Water Quantification Estimate:</u>

- TVAC tests correlate peak water signal with water flux.
- Water flux is dependent on conical surface area of each bite.



Status

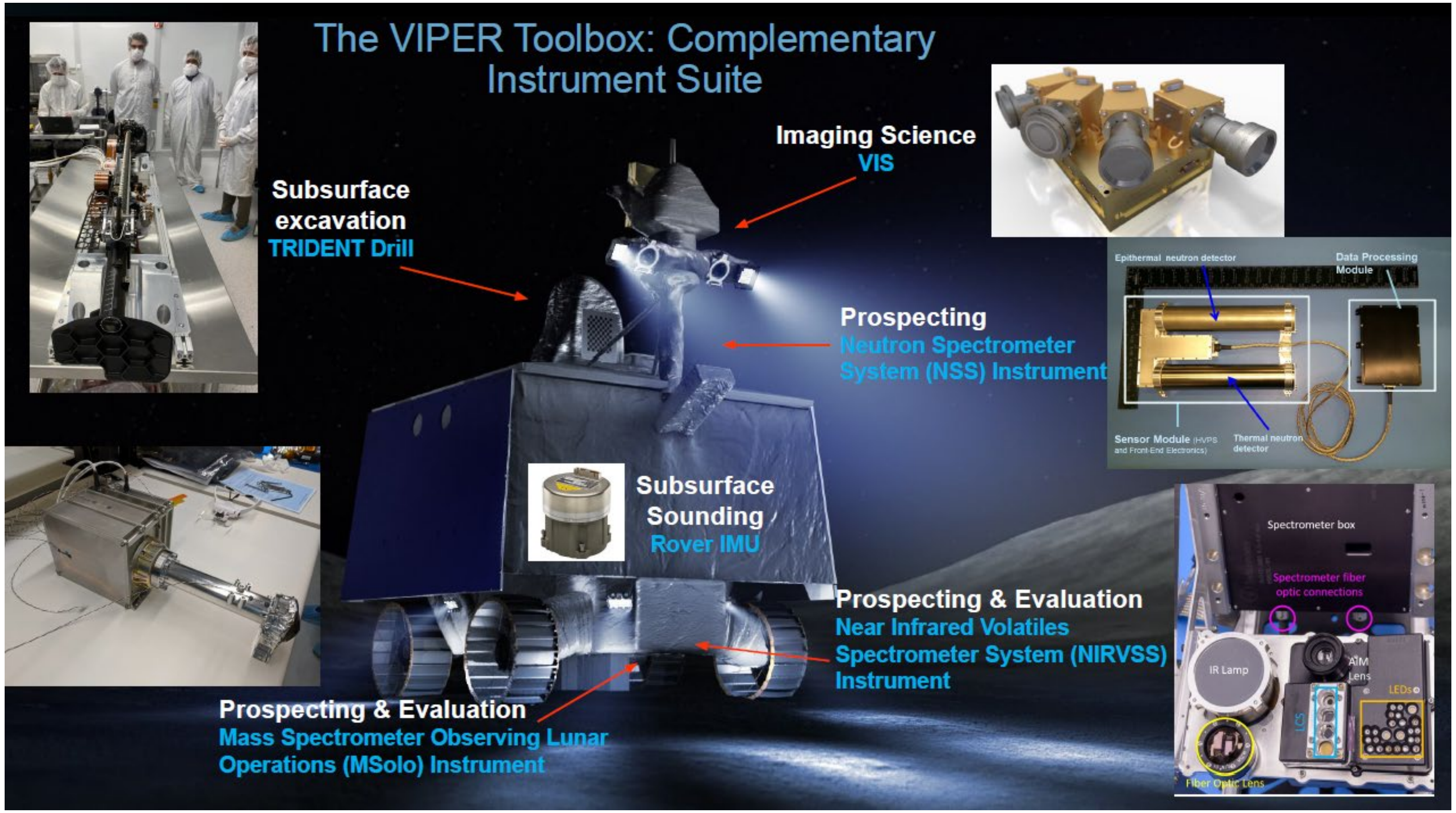
- TRIDENT is integrated onto Nova-C mounting panel
- MSolo is in storage awaiting final lander assembly
  - Fit check performed during TRIDENT to Nova-C panel integration using MSolo model
- Flat Sat testing with instrument engineering units performed in IM's Flat Sat lab (flight computer, software, and power check)



VIPER

VIPER

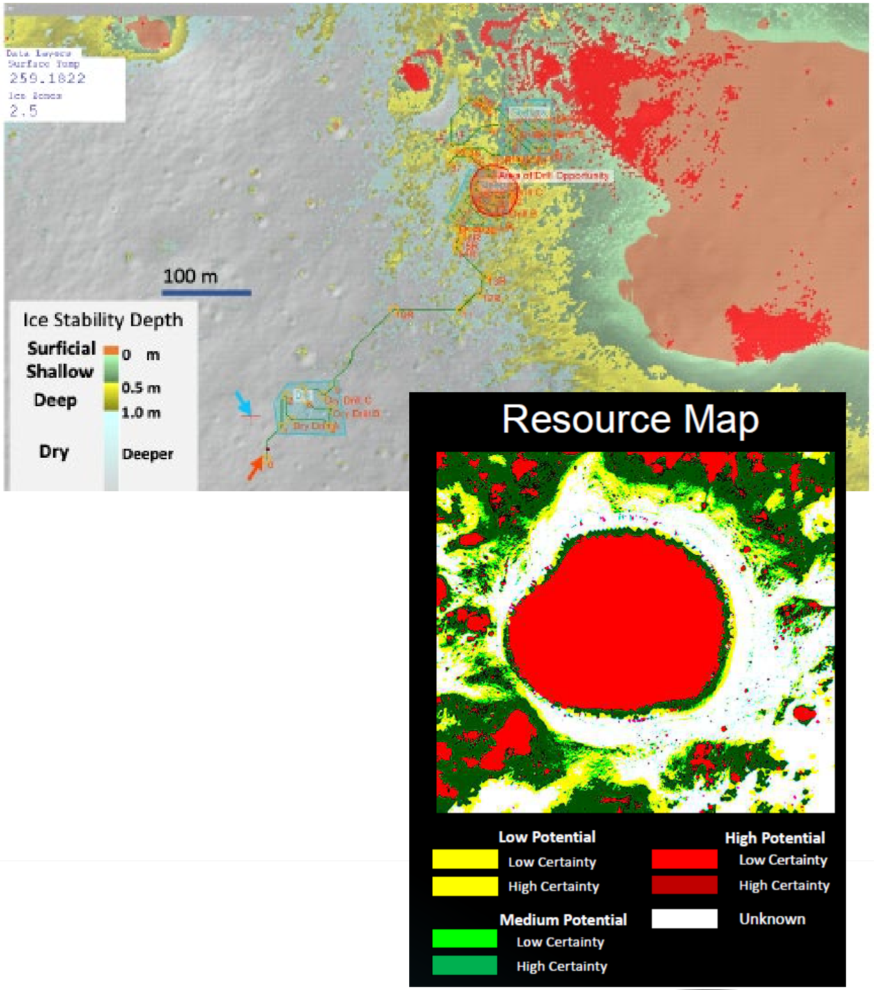
- Instruments:
  - Mass Spectrometer Observing Lunar Operations (MSolo)
  - The Regolith and Ice Drill for Exploring New Terrains (TRIDENT)
  - Near Infrared Volatiles Spectrometer System (NIRVSS)
  - Neutron Spectrometer System, (NSS)
  - Visible Camera suite, 8 cameras (Vis)
  - Inertial Mass Unit (IMU)
- Mass: ~430kg
- Power: 450W peak ; Solar
- Top Speed: 20 cm/s (0.5mph)
- Prospecting Speed: 10 cm/s (0.25mph)
- Total Drive: ~20 km



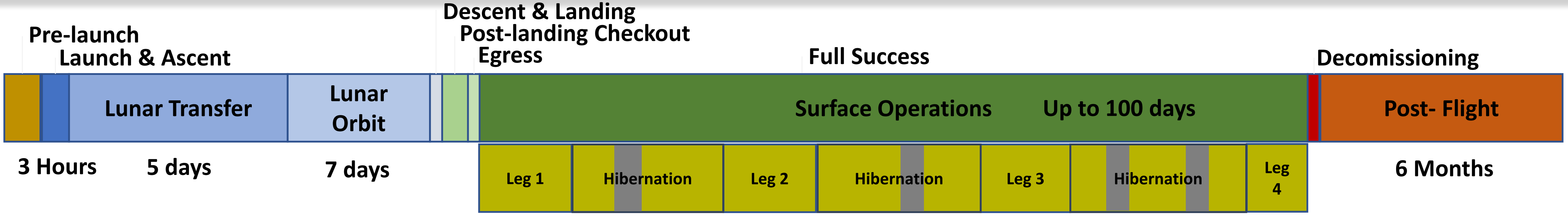
Required Measurements

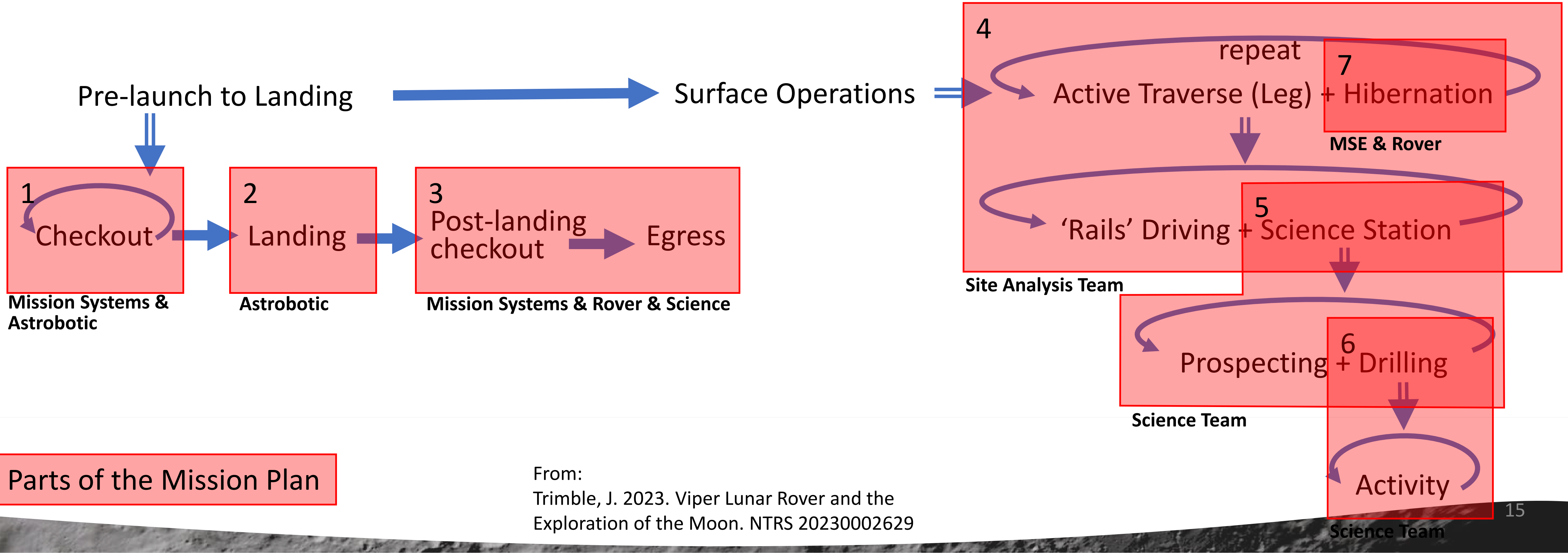
- Determine water distribution and form across defined Ice Stability regions to an uncertainty <50%
  - ISR Area measurement density of >10% for an equivalent area of at least 3800 m2
- Total drive distance in ISR ≥ 190 m (assuming a 2 m sampling width)
- Characterize water (and water equivalent hydrogen) at concentrations as low as 0.5%
  - Measure water physical state and key isotopes
- Measure at scales of <5m and as large as 1000m to account for scales of variability
  - Minimum of 2 ISR repeat measurements separated by 100m
- Minimum of three subsurface characterizations in each ISR separated by 10s of meters
  - Sample across depths 10cm – 80cm with intervals of at least 8cm
- Characterize context, including surface and subsurface temperatures, isotopes, geology, geomorphology/geomechanics and surface composition to inform Resource Models

Notional Traverse path and Resource map (examples)



Mission Plan





Parts of the Mission Plan

From:
Trimble, J. 2023. Viper Lunar Rover and the Exploration of the Moon. NTRS 20230002629

Instrument operations

- During drilling
  - TRIDENT, MSolo, NIRVSS, NSS
  - Bite approach, 10cm increments
  - NIRVSS includes high resolution imager to for cutting pile imagery
  - TRIDENT includes temperature sensors for downhole thermal assay
  - IMU seismic
- During Roving
  - All spectrometers (MSolo, NIRVSS, NSS) operate while roving
  - Visible cameras: Used for navigation, and science targets within a science station

	Measurements	Observations
NSS	Thermal and epithermal neutrons	Water equivalent hydrogen and burial depth along traverse
NIRVSS	Near infrared reflectance spectra from 1300-4000 nm	Surface composition (mineralogy, hydration, frosts) along traverse and from drill cuttings pile
NIRVSS	Imaging (2048x2048 pixel max) with seven color LEDs from 348 to 940 nm	Context imaging below rover along traverse; high resolution imaging (<100 um/pixel) at drill sites
NIRVSS		Imaging of drill cuttings pile
NIRVSS	Thermal radiometry at 10, 14, 18, and 6-25 microns	Surface temperatures under the rover and during drilling down to <100 K
MSolo	Mass spectra between 1-70 amu	Subliming surface volatiles along traverse and from drill cuttings pile
MSolo		Key isotope ratios
TRIDENT	Excavation of subsurface material in 10 cm increments down to 100 cm	Regolith geomechanical properties, including discerning ice-rich from dry regolith
TRIDENT	Subsurface temperatures at two locations (separated by 20 cm)	Subsurface temperatures and thermal conduction
VIS	Resolve terrain and obstacles greater than 10 cm out to 15 m away from rover	Driving and hazard avoidance
VIS		Topography and surface geometry, crater identification
VIS		Rock and grain size frequency distribution
VIS		Rover-surface interaction, regolith photometric behavior

Status

- As of May 2024, VIPER is >90% complete
- Moving into environmental testing, System Test Readiness Review Complete
  - Thermal
  - Acoustic
  - Vacuum (Tvac)

May 14, 2024 https://www.nasa.gov/missions/viper/mission-manager-update-viper-rover-approved-to-move-into-environmental-testing/

Summary

	PRIME-1	VIPER
Location	S. Pole: Shackleton Connecting ridge	S. Pole: Mons Mouton near Nobile crater
Surface Mission Duration	72 Hours	~36 days full mission success ~100 days total (3 lunar day/night cycles)
Instrumentation	TRIDENT (Rotary Percussive Drill, 1m) MSolo (Mass Spectrometer) Visible Camera (1 dedicated to PRIME-1)	TRIDENT (Rotary Percussive Drill, 1m) MSolo (Mass Spectrometer) NIRVSS (Near Infrared Spectrometer) NSS (Neutron Spectrometer) Visible Camera suite IMU
CLPS Lander	Intuitive Machines, IM-2	Astrobotic, Griffin 1
# Drill holes & samples	1 hole (7-10cm bites down to 1m)	35+ holes (10cm bites down to 1m)
Operations	Continuous real time operations Payload from KSC through Nova-Control (IM). DTE via LTN	Continuous real time operations Payload operated direct from ARC DTE via DSN
Objectives	- 1st S. Pole drilling operation - Test operations and science approach - Anchor data set for volatiles & sublimation - Conops test: energy use, timelines (sublimation and operational), molecular definition	- Large data set, Large coverage, Variety of locations - Expanded instrument suite and capabilities - Wide variety of science objectives in addition to exploration goals - Includes geostatistical modeling: before, during, after mission