National Aeronautics and Space Administration

EXPLORE MOON to MARS

Volatiles Science Objectives Addressed by CLPS Deliveries

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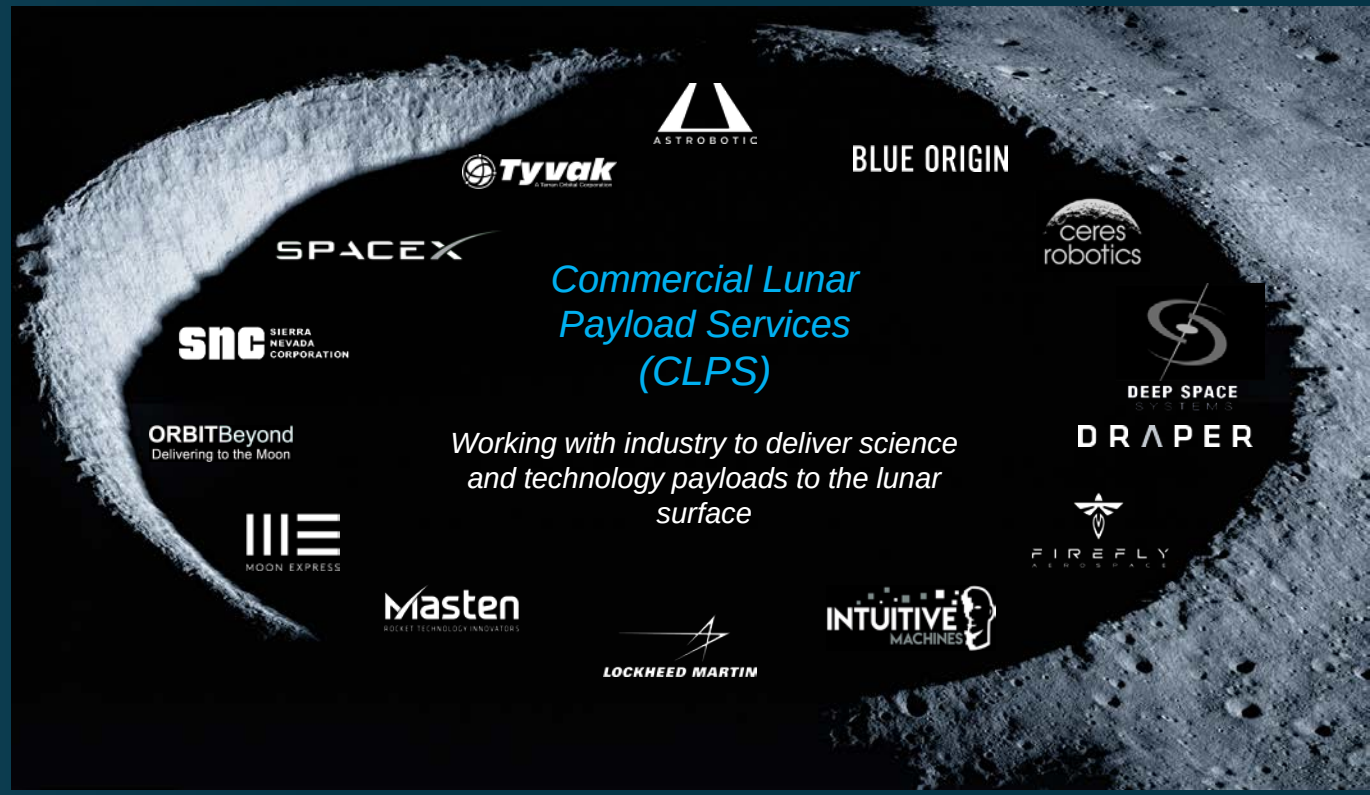
November 20, 2020

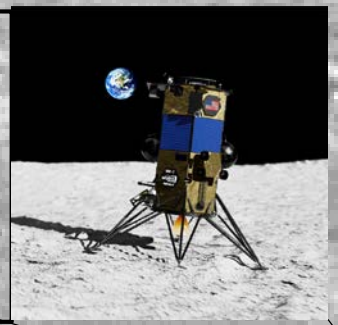
Commercial Lunar Payload Services (CLPS)

Goal: Use commercial end-to-end delivery services to enable access to the lunar surface

- Deliveries initiated using a Task Order
  - Any of the 14 companies on the catalog can respond to a Task Order (TO)
  - Expected cadence of 2 TO per year
- Task Orders list what NASA wants delivered, and any constraints
  - E.g., landing site, specific needs of instruments
- First 5 lunar surface delivery task orders awarded, deliveries beginning in 2021
  - 2021: Non-polar deliveries (Astrobotic and Intuitive Machines) – TO 2A & 2B
  - 2022: Polar delivery (Masten) – TO 19C
  - 2022: Polar delivery (IM) – PRIME-1
  - 2023: Polar delivery (Astrobotic) – Volatiles Investigating Polar Exploration Rover (VIPER) TO 20A



Delivery Site:
Mare Serenitatis
Provider:
Intuitive Machines
Task Order (TO) 2 | 2021



Delivery Site:
Lacus Mortis
Provider:
Astrobotic
TO2 | 2021

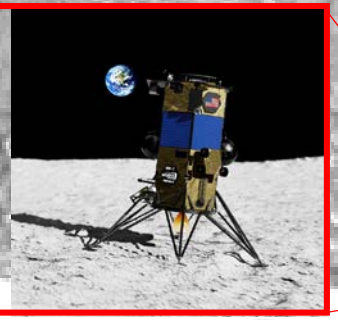
Delivery Site:
Lunar Pole
Provider:
Astrobotic
VIPER | 2023

Delivery Site:
Reiner Gamma
Provider: TBD
PRISM-1a | 2023

Delivery Site:
Mare Crisium
Provider: TBD
TO19D | 2023

Delivery Site:
Schrödinger Basin
Provider: TBD
PRISM-1b | 2024

Delivery Site:
South Pole
Provider:
Intuitive Machines
PRIME-1 | 2022

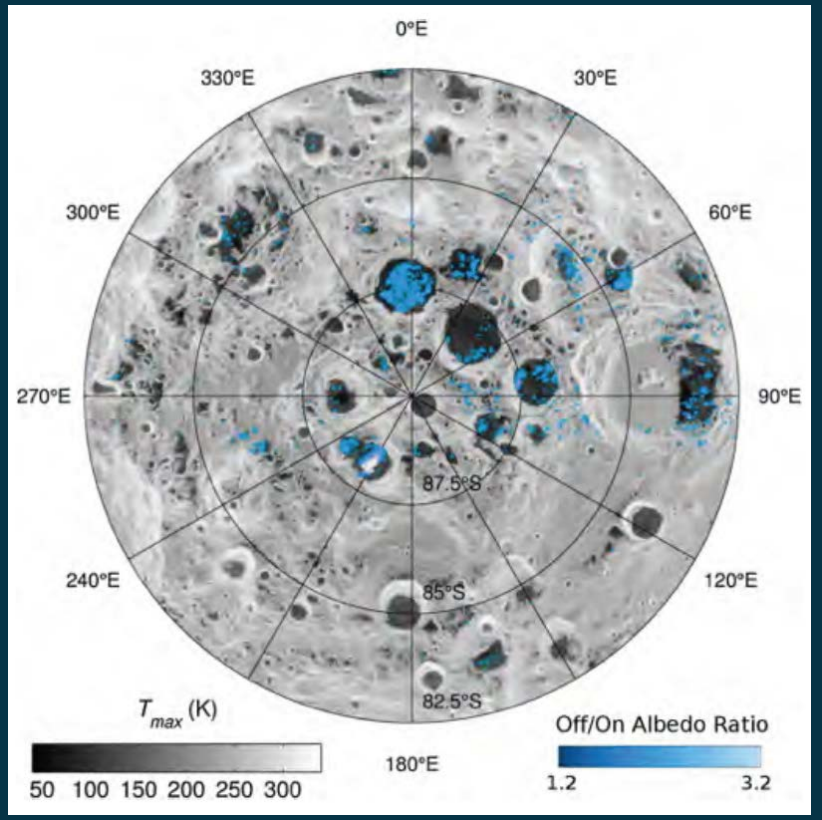


Delivery Site:
South Pole
Provider:
Masten
TO19C | 2022

Volatiles Science Objectives

Goal 4: The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history *SCEM Report, 2007, 2018*

- 4a: Determine the compositional state and compositional distribution of volatile components
- 4b: Determine source(s) of lunar polar volatiles
- 4c: Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions
- 4d: Understand physical properties of the very cold (possibly volatile rich) polar regolith
- 4e: Determine what the cold polar regolith reveals about the ancient solar environment
- 7c: Deposition of volatiles by the solar wind.
- 8d: Migration of surficial water to cold traps.



Locations of anomalous UV albedo consistent with water ice. From Hayne et al., 2015.

2022 CLPS 19C Polar Delivery Manifest

ESSIO

Payloads largely selected from Lunar Surface Instrument and Technology Payloads (LSITP)

Masten Space Systems

SAMPLR
PI: Sean Dougherty
Baseline Mass: 18 kg

NIRVSS
PI: Tony Colaprete
Baseline Mass: 5 kg

L-CIRiS
PI: Paul Hayne
Baseline Mass: 9 kg

Retroreflector
PI: Xiaoli Sun
Baseline Mass: 0 kg

MSolo
PI: Jackie Quinn
Baseline Mass: 7.5 kg

Sample Acquisition, Morphology Filtering & Probing of Regolith (SAMPLR)

Near-Infrared Volatile Spectrometer System (NIRVSS)

Lunar Compact Infrared Imaging System (L-CIRiS)

Laser Retroreflector

Mass Spectrometer Observing Lunar Operations (MSolo)

Camera System for lunar science on commercial vehicles (Heimdall)

Linear Energy Transfer Spectrometer (LETS)

Moon Rover with Exploration Autonomy (Moon Ranger)

Neutron Spectrometer System (NSS) – Deployed on Moon Ranger

Heimdall
PI: Aileen Yingst
Baseline Mass: 6.1 kg

LETS
PI: Eddie Semones
Baseline Mass: 1.5 kg

Moon Ranger + NSS
PI: Andrew Horchler
Baseline Mass: 18 kg

Key

- Science
- Technology
- Exploration

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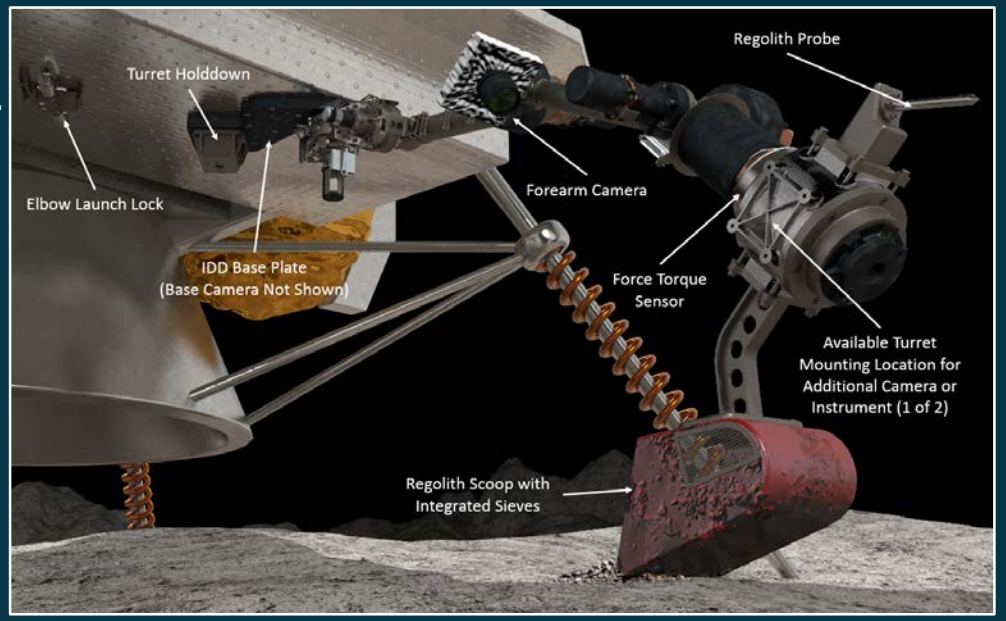
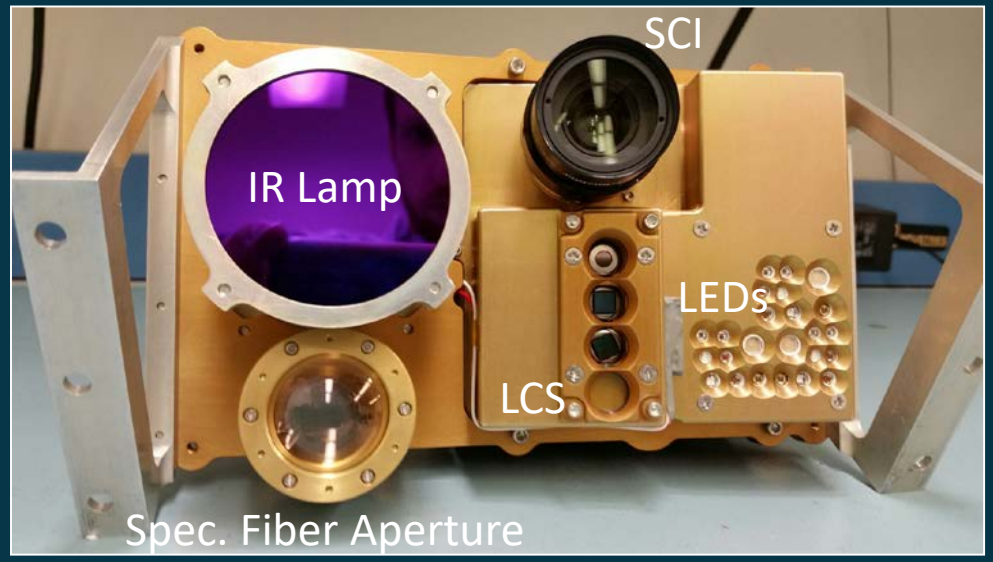
Sample Acquisition Morphology filtering, and Probing Lunar Regolith (SAMPLR)

- **Payload Specifications:**
  - Lead Development Organization: MDA Info. Sys.
  - Payload PI: Sean Dougherty
  - Payload Mass: 12.6 kg
  - Payload Dimensions: 19 x 50 x 30 cm
- **Payload Description:**
  - SAMPLR will leverage an existing MER flight-spare robotic arm to provide a flight-proven lunar payload platform.



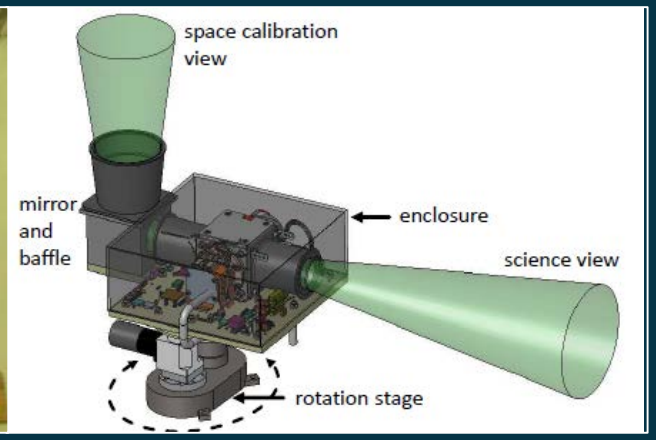
- **Payload Objectives:**
  - SAMPLR will demonstrate operation on the lunar surface to qualify the mechanisms and topology for use in future missions with additional payloads.
  - SAMPLR will capture regolith geotechnical data with a penetrometer by leveraging an existing cone probe and force-torque sensor.
  - SAMPLR will demonstrate the use of a regolith scoop design with integrated sieves to acquire regolith samples and filter them to isolate size distributions of particles.

Near-InfraRed Volatile Spectrometer System (NIRVSS)



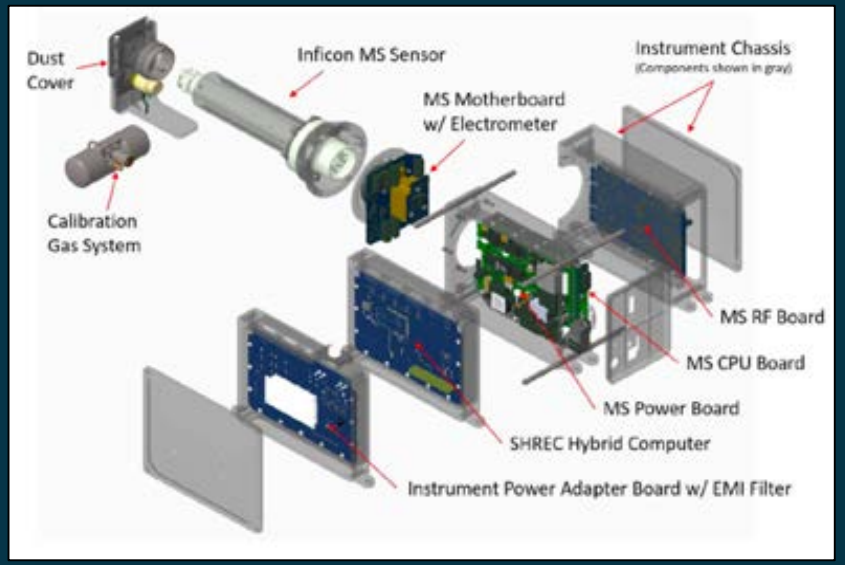
- **Payload Specifications:**
  - Lead Development Organization: NASA ARC
  - Payload PI: Anthony Colaprete
  - Lander Partner: Astrobotic
  - Payload Delivery Date: March 2020
  - Payload Mass: 4.4 kg
  - Payload Dimensions: 21 x 18 x 16 cm
- **Payload Description:**
  - NIRVSS is a two-channel near-infrared point spectrometer.
  - The NIRVSS payload includes a spectrometer context imager and a longwave calibration sensor.
- **Payload Objectives:**
  - NIRVSS will measure surface and subsurface hydration (H_2O and OH).
  - NIRVSS will also measure CO_2 and CH_4 while simultaneously mapping surface morphology and surface temperature.

Lunar Compact InfraRed Imaging System (L-CIRiS)



- **Payload Specifications:**
  - Lead Development Organization: U. CO
  - Payload PI: Paul Hayne
  - Payload Mass: 6.5 kg
  - Payload Dimensions: 20 x 20 x 10 cm
- **Payload Description:**
  - L-CIRiS is a multispectral, long-wave infrared imaging radiometer that will be developed using parts that are already on-hand including all of the optical parts, the focal plane assembly and motor, and the carbon nanotube sources.
- **Payload Objectives:**
  - L-CIRiS will measure surface mineralogy, temperature, and thermophysical properties of the lunar surface < 1 cm
  - L-CIRiS will image the lunar surface to determine the lunar surface composition and demonstrate the facility of the instrument for future lunar ISRU activities.
  - L-CIRiS will also map the lunar surface temperature distribution for 360 degrees in azimuth and scene distances from 10 meters to the horizon.

Mass Spectrometer Observing Lunar Operations (MSolo)

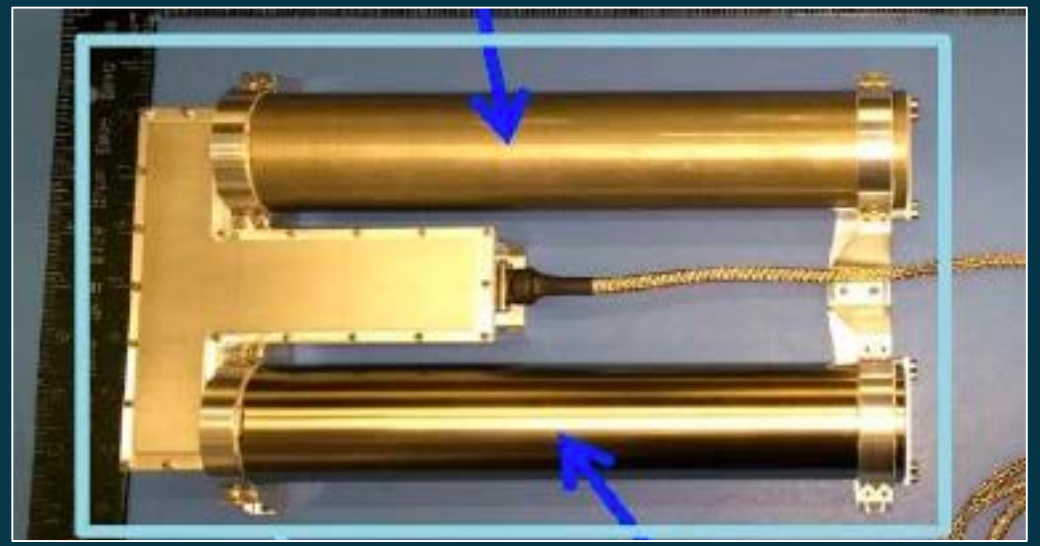


- **Payload Specifications**
  - Lead Development Organization: NASA KSC
  - Payload PI: Jackie Quinn
  - Lander Partners: Masten, Astrobotic
  - Payload Mass: 5.3 kg
  - Payload Dimensions: 45 x 18 x 19 cm
- **Payload Description:**
  - The MSolo instrument is a commercial mass spectrometer that is ruggedized for space applications.
- **Payload Objectives:**
  - The MSolo payload will identify low-molecular weight volatiles with unit mass resolution to measure isotopes including D/H and O18/O16.
  - MSolo can be installed to either measure the lunar exosphere or the spacecraft outgassing and contamination.

Heimdall

- **Payload Specifications:**
  - Lead Development Organization: PSI
  - Payload PI: Aileen Yingst
  - Payload Mass: 3.9 kg
  - Payload Dimensions: 7.8 x 5.8 x 4.4 cm
- **Payload Description:**
  - The Heimdall payload consists of four 5 Megapixel, color CMOS cameras plus an on-payload data recorder:
    - Descent imager, regolith imager, and two panoramic imagers.
  - The payload has extensive flight heritage from OSIRIS-REx and other classified missions.
- **Payload Objectives:**
  - Heimdall will characterize and map the landing site at multiple scales and perspectives for a contextual understanding of the geology.
  - Heimdall will also characterize the regolith and provide useful data for science, engineering risk, and resource utilization.
  - The included cameras will record the regolith/plume interaction during descent.

Neutron Spectrometer System (NSS)



- **Payload Specifications:**
  - Lead Development Organization: NASA ARC
  - Payload PI: Richard Elphic
  - Lander Partner: Astrobotic
  - Payload Delivery Date: March 2020
  - Payload Mass: 3.2 kg
  - Payload Dimensions: 21 x 32 x 7 cm
- **Payload Description:**
  - NSS is a neutron spectrometer that measures cosmic ray-generated neutrons using two helium gas-proportional counters to detect thermal and epithermal neutrons with less than 0.1% uncertainty.
- **Payload Objectives:**
  - NSS will determine the abundance of hydrogen-bearing materials and the bulk regolith composition at the landing site.
  - NSS will also measure any time variations in hydrogenous volatile abundance during the diurnal cycle.
  - Indirectly detect potential water present in the soil, up to 3 feet below the surface

19C Summary

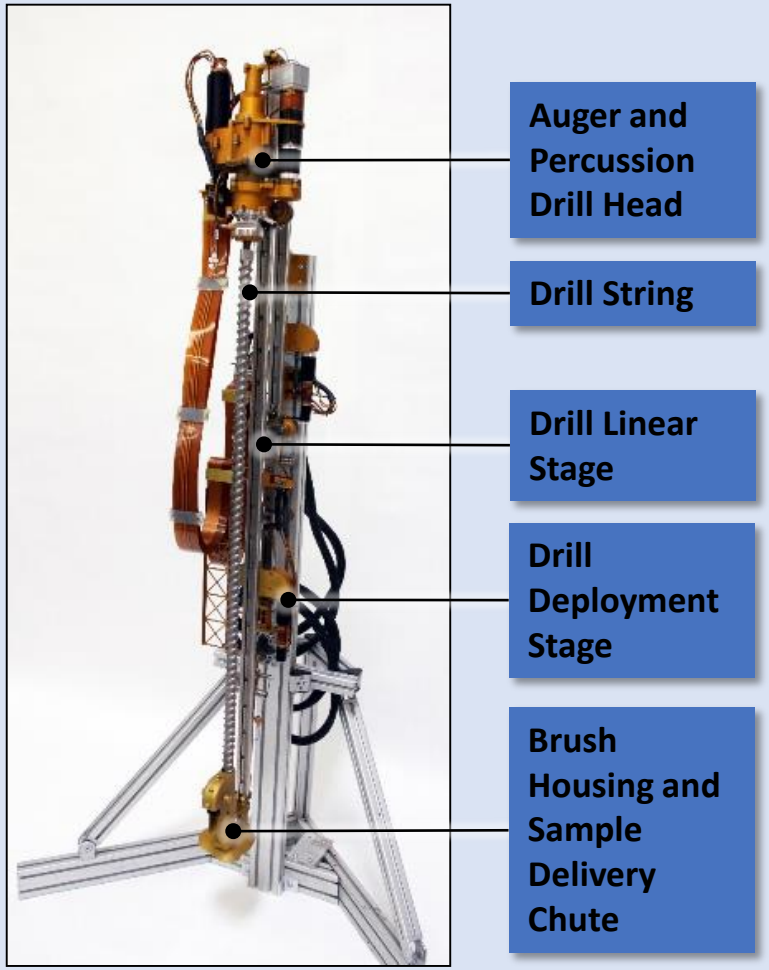
- **Overall Delivery Science Addressed:**
  - Assess the composition, geotechnical properties, and distribution of volatiles in the exosphere, regolith, and substrate
    - 4a: Determine the compositional state and compositional distribution of volatile components
    - 4c: Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions
    - 4d: Understand physical properties of the very cold (possibly volatile rich) polar regolith
  - Demonstrate technologies for VIPER
  - Characterize the radiation environment in preparation for the arrival of crew

- **Status of Delivery:**
  - Payload ICDs to be baselined this month
  - Initial thermal models and CAD model provided to payloads
  - Masten has evaluated primary landing sites; alternate site under evaluation

2022 Polar Resources Ice Mining Experiment (PRIME-1)

- **Payload Specifications:**
  - Lead Development Organization: NASA ARC
  - Project Manager: Jackie Quinn
  - Lander Partner: Intuitive Machines
  - Payload Mass: 34.5 kg
- **Payload Description:**
  - TRIDENT will capture lunar regolith in 10-cm increments down to 1 meter depth
  - TRIDENT will measure the strength of lunar regolith
  - TRIDENT's embedded temperature sensor will measure subsurface temperatures
  - MSolo will identify volatiles including D/H and O^{18}/O^{16}
- **Payload Objectives:**
  - Drill into the lunar subsurface 1 m and deliver regolith to the surface for water, volatiles evaluation.
  - Measure the composition of gasses emanating from exposed regolith before, during, and after drilling.
  - Demonstrate capability to identify volatile variation and relative concentration within the first meter of regolith

Intuitive Machines

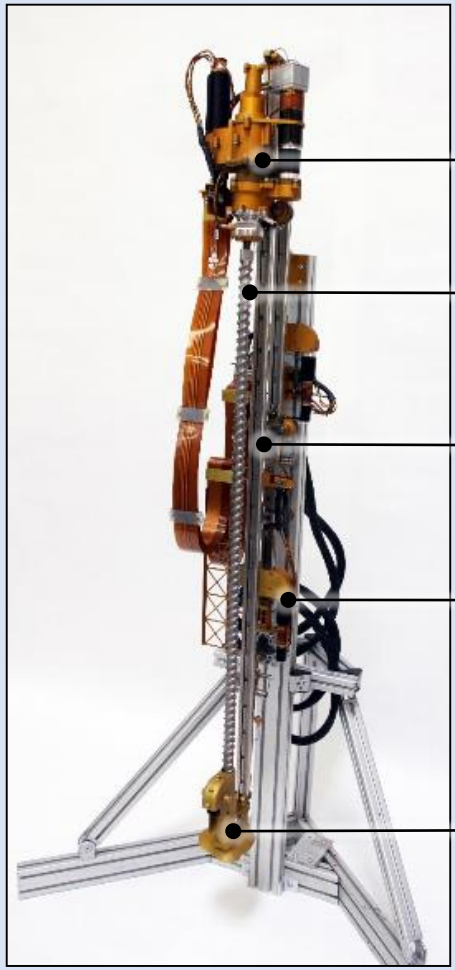


TRIDENT Drill

PRIME-1 Summary

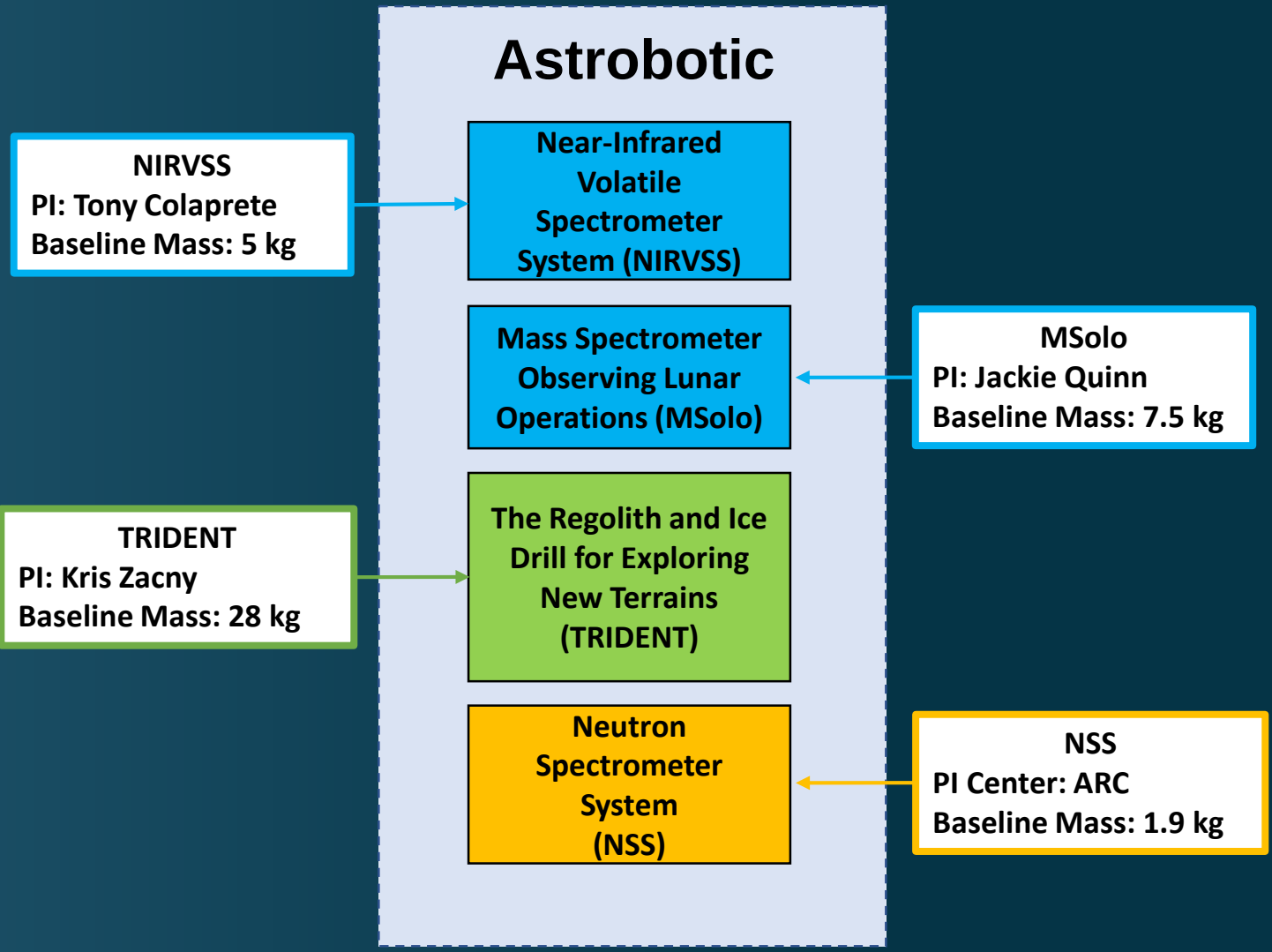
- **Overall Delivery Science Addressed:**
  - Measure the composition of gasses emanating from exposed regolith before, during, and after drilling to 1m depth
    - 4a: Determine the compositional state and compositional distribution of volatile components
    - 4d: Understand physical properties of the very cold (possibly volatile rich) polar regolith
- **Status of Delivery:**
  - Completed Mission Architecture Review
  - Completed first Payload Integration Working Group (PIWG)

Intuitive Machines



2023 VIPER

Payloads selected from both NPLP and LSITP Programs



VIPER

- **Key Facts About NASA's VIPER Mission**
  - Launch: Late 2023, to a lunar pole
  - Mission duration: 100 Earth days, 3 cycles of lunar day and night
  - Distance goal: 12 miles (20 kilometers)
  - Rover size: Similar to a golf cart: 1.5 m x 1.5 m x 2.5 m and 430 kilograms
  - Power: Solar-charged battery, peak power of 450 W
  - Top speed: 0.5 mph (0.8 kph)
  - Communications: X-band direct-to-Earth (no relay) over the Deep Space Network

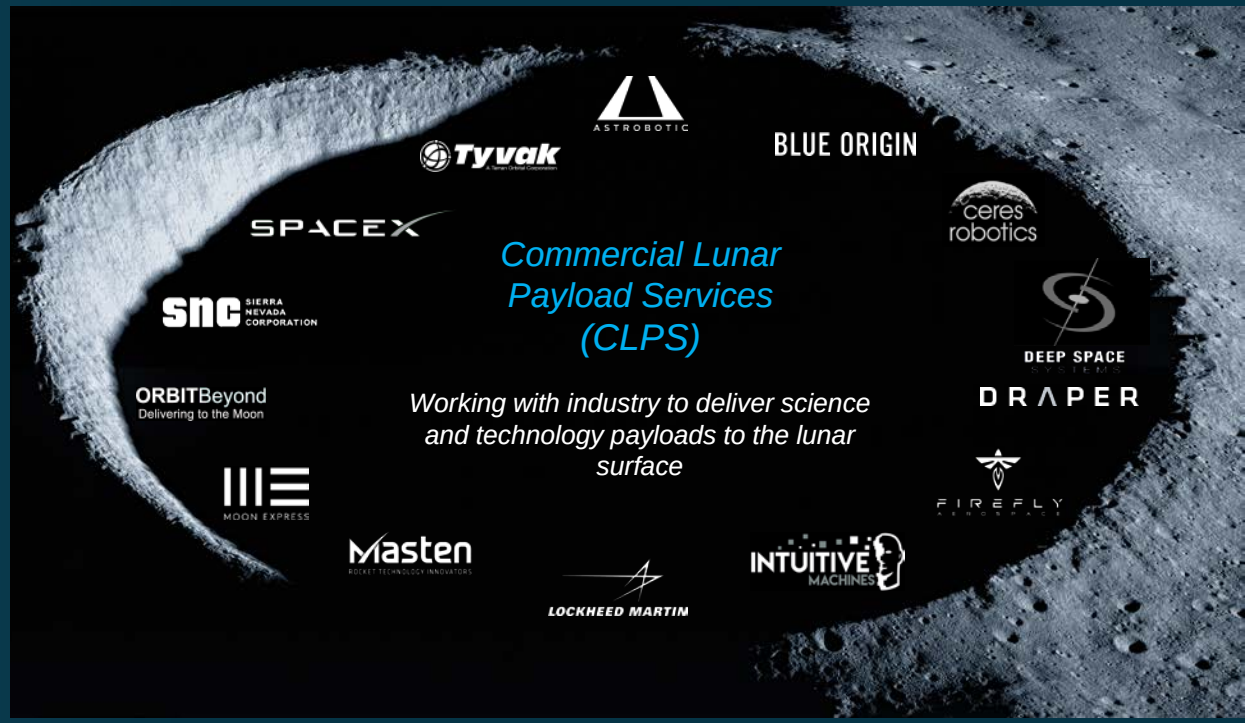
- **VIPER's Drill and Science Instruments**
  - NSS: Neutron Spectrometer System
  - TRIDENT: The Regolith and Ice Drill for Exploring New Terrains, 1 m drill
  - NIRVSS: Near-Infrared Volatiles Spectrometer System
  - MSolo: Mass Spectrometer Observing Lunar Operations

VIPER Summary

- **Overall Delivery Science Addressed:**
  - Assess the composition, geotechnical properties, and distribution of volatiles in the exosphere, regolith, and substrate
    - 4a: Determine the compositional state and compositional distribution of volatile components
    - 4c: Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions
    - 4d: Understand physical properties of the very cold (possibly volatile rich) polar regolith
  - Leverage instrument demonstrations from earlier delivery of 19C
  - Acquire data from same instruments in new location.

Summary of CLPS Volatiles Measurements

- **Three CLPS deliveries planned to the lunar polar regions**
  - 2022: Masten, 19C
  - 2022: Intuitive Machines, PRIME-1
  - 2023: Astrobotic, VIPER
- **Payloads will address primarily three high-priority science objectives:**
  - Determine the compositional state and compositional distribution of volatile components
    - NIRVSS, L-CIRiS, MSolo, NSS, PRIME-1
  - Understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shaded lunar regions
    - MSolo
  - Understand physical properties of the very cold (possibly volatile rich) polar regolith
    - SAMPLR, Heimdall



Future Plans for CLPS

CLPS is fostering decadal caliber science on the lunar surface

- **Regular cadence of two TO per year planned**
  - Offers regular, global access to the surface of the Moon
  - Upcoming opportunities expected to solicit network science and site-agnostic science
  - Future opportunities will aim to promote mobility and survive/operate through the night
  - Demonstrate and use advanced technologies that promote scientific endeavors
  - Enables achievement of high priority science objectives
- **Payloads and Research Investigations on the Surface of the Moon**
  - PRISM-1a: Reiner Gamma lunar swirl
  - PRISM-1b: Schrödinger basin impact melt
  - Call for instrument suites released Nov. 5, 2020
  - Step 1 due Dec. 11 2020, Step 2 due Feb. 3, 2021