National Aeronautics and Space Administration

EXPLORE SCIENCE

Exploration Science Strategy and Integration Office (ESSIO)

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Planetary Advisory Committee
August 17, 2020

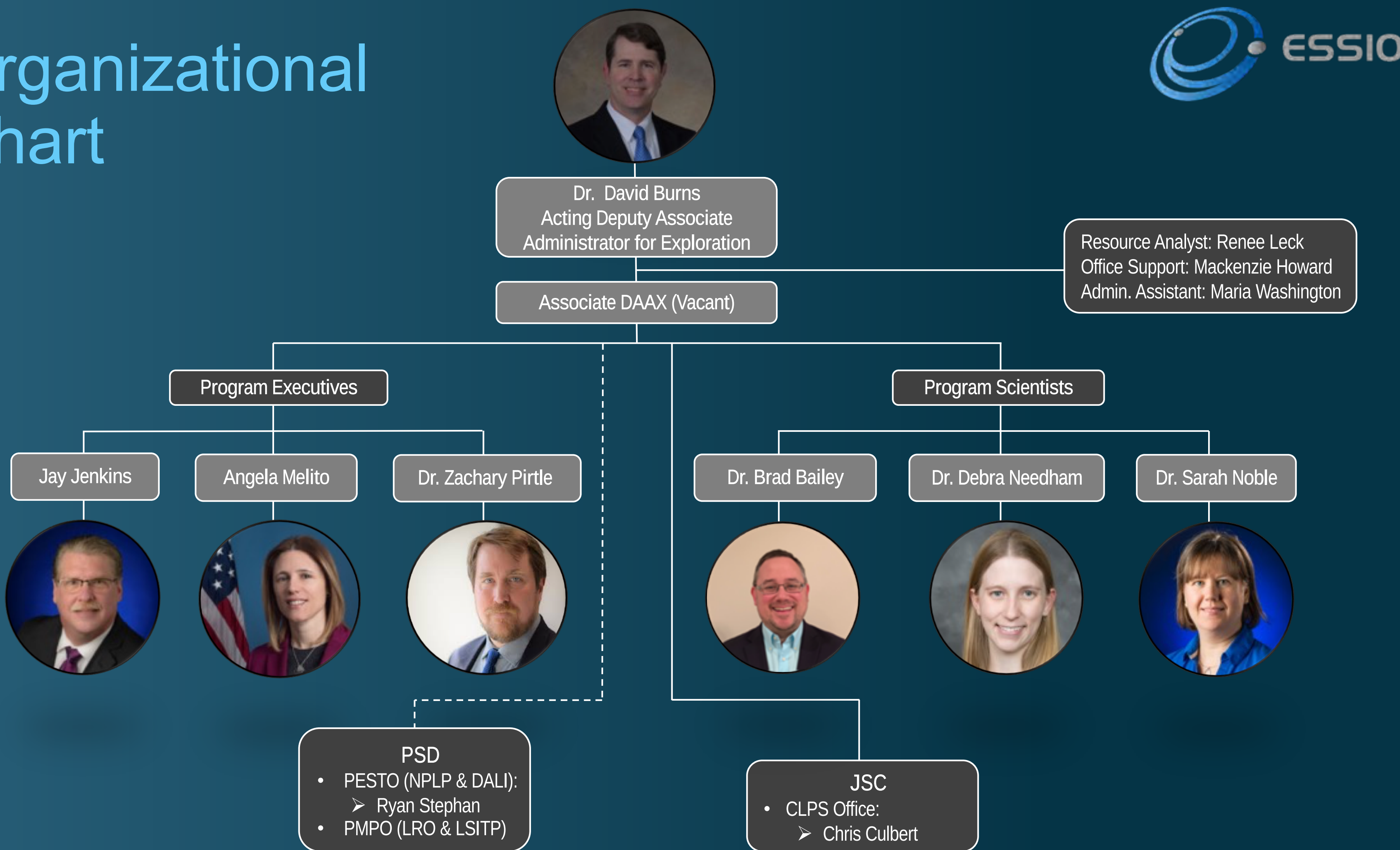
Vision

Define and lead the science strategy for Artemis and Moon to Mars

Exploration science integration between SMD Divisions, SMD/STMD/HEOMD, other government agencies, and international partners

Promote a lunar economy to produce rapid, frequent, and affordable access to the lunar surface and cislunar space

Organizational Chart



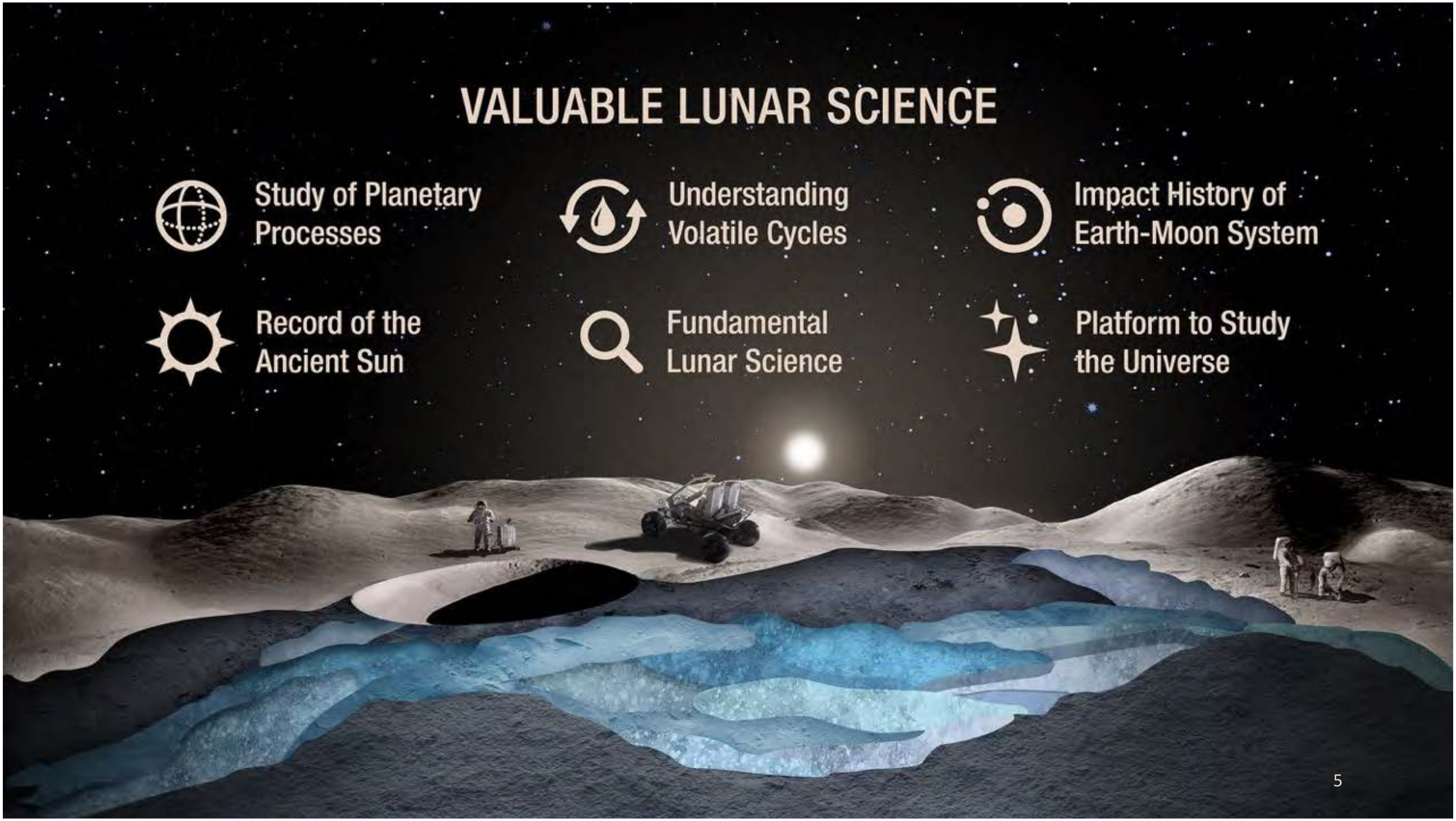
THE MOON ENABLES SCIENTIFIC EXPLORATION

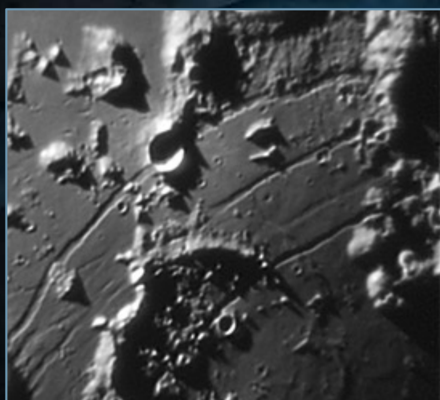
A CORNERSTONE
For Solar System science and exoplanet studies

A NATURAL LABORATORY
To study planetary processes and evolution

A TRAINING GROUND
To learn how to conduct scientific exploration from a planetary surface, working synergistically with crew and robotic explorers

AN OPPORTUNITY
To use infrastructure and resources associated with human exploration to leverage support for autonomous scientific investigations


VALUABLE LUNAR SCIENCE
Study of Planetary Processes
Understanding Volatile Cycles
Impact History of Earth-Moon System
Record of the Ancient Sun
Fundamental Lunar Science
Platform to Study the Universe



STUDY OF PLANETARY PROCESSES

THE MOON: a “mini planet” and prime example for understanding planet formation in our Solar System & around other stars

DIFFERENTIATION
Magma oceans, crust, and mantle

IMPACT
Basins and craters, mixing of the crust

VOLATILES
History, production, and escape mechanisms

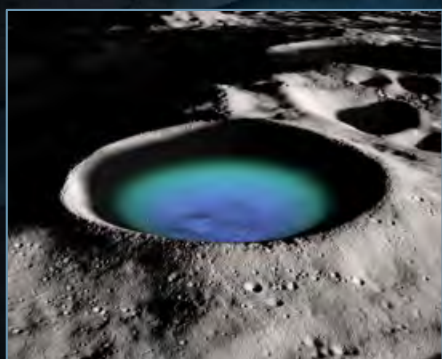
VOLCANISM
Partial melting, eruptions, flow sequence and compositions

TECTONISM
Deformation of the crust and thermal history

EXPLORATION REQUIREMENTS

- *Mobility to visit geologically different features*
- *EVA traverses & suites designed for sample collection*

UNDERSTANDING VOLATILE CYCLES



EXPLORATION REQUIREMENTS

- *Access to persistently shadowed terrain*
- *Sealed collection canisters designed for cold sample curation*

- Moon represents a diversity of sources and sinks of water in the Solar System
- Comets and asteroids impact the lunar surface and leave volatiles behind
- The lunar surface is directly exposed to space, so volatile loss occurs by sublimation, UV ionization, sputtering, and micrometeorite impact
- Solar wind (H) interacts directly with lunar surface (O in silicates), creating water molecules
- Lunar samples contain tiny amounts of primordial volatiles that trace the history of Earth-Moon system formation
- Lunar poles harbor extremely cold environments that may trap water and other volatiles

IMPACT HISTORY OF EARTH-MOON SYSTEM

EXPLORATION REQUIREMENTS

- *Collection of several walnut-sized rocks for chronological analyses*
- *Identification of and collections of rocks from outcrops and boulders*

- Terrestrial impact craters are erased quickly on Earth due to its dynamic surface. The Moon retains a record of the impact flux of the Earth-Moon system
- Age dating lunar rocks associated with specific impacts provides an absolute chronology that anchors the impact history of the inner Solar System
- The Moon’s impact record can be recovered and interpreted in terms of Earth-Moon history. For example, is there Impact Episodicity? An impact 65 My ago wiped out 85% of all fossil species. Evidence suggests such impacts may occur periodically

RECORD OF THE ANCIENT SUN

- The Moon's surface has been bathed in solar wind, cosmic rays throughout its history
- Dust grains retain these particles
- Buried regolith and regolith trapped between lava flows retains the historical record of these fluxes
- Detailed excavation and study by humans can retrieve this record to understand how the Sun has changed through time

EXPLORATION REQUIREMENTS

- *Collection of core tube samples to capture ancient solar wind trapped in regolith layers*
- *Understanding regolith stratigraphy*

FUNDAMENTAL LUNAR SCIENCE

LIFE SCIENCES
Combined effects of fractional gravity & deep space radiation

EXPLORATION PHYSICS
Combustion, fluid dynamics, dust, material sciences

FUNDAMENTAL PHYSICS
General relativity, gravitational physics, quantum information science

FOOD/DRUG DEGRADATION

PLATFORM TO STUDY THE UNIVERSE

EXPLORATION REQUIREMENTS

- *Dexterity to deploy delicate instrumentation*
- *Characterization of the local environment (dust, RF, plasma)*

- The lack of atmosphere allows the full electromagnetic spectrum to be visible from the lunar surface
- The farside of the Moon is the only known place in the Solar System permanently shielded from Earth’s radio noise. This enables more sensitive measurements allowing us to look further back in time, closer to the Big Bang
- Opportunistic astronomy leveraging the surface infrastructure associated with human exploration of the lunar surface

Advancing Beyond the Apollo Paradigm

- Field Geology with Significant Mobility
  - Study the origin and evolution of the Earth-Moon system on the lunar surface.
    - The Moon has experienced geologic processes that shape all terrestrial planets: Impact Cratering, Volcanism, and Tectonism.
    - Mobility on the surface is a key factor for enabling a range of scientific activities (*e.g.*, accessing multiple geologic units, deploying experiments over a broad area).
    - Best achieved as a human/robotic partnership
- New Samples Are Critical
  - The geologic diversity of the Moon coupled with careful selection of samples for return to Earth will address a plethora of science questions.
- Surface Instrumentation
  - Humans facilitate the placement of delicate surface instrumentation.
    - Radio experiment on the radio-quiet farside offers a unique opportunity for sensitive measurements of the early Universe.
- Access to Regions with Cold Temperatures
  - The importance of collecting volatile rich samples requires the ability to explore within extreme cold regions.

A Bold New Era of Human Discovery

- An Opportunity to Study Planetary Processes
  - Mobility to visit geologically different features
  - EVA traverses and suits designed for strategic sample collection
- A Critical Location to Understand Volatiles Cycles
  - Access to persistently shadowed terrain (either robotically or with crew)
  - Sealed collection canisters designed for cold sample curation and volatile sampling
- Impact History of the Earth-Moon System
  - Collection of several walnut-sized rocks for chronologic analyses on Earth
  - Identification of, and collection of rocks from, outcrops and boulders
- Record of the Ancient Sun
  - Collection of core tube samples to capture ancient solar wind trapped in regolith layers
  - Understanding regolith stratigraphy
- A Stable Platform to Study the Universe
  - Dexterity to deploy delicate instrumentation
  - Characterization of the local environment (dust, RF, plasma)
- Experimental Science Enabled by the Lunar Environment
  - Extended human operations in fractional gravity
  - Adequate down mass for experiments

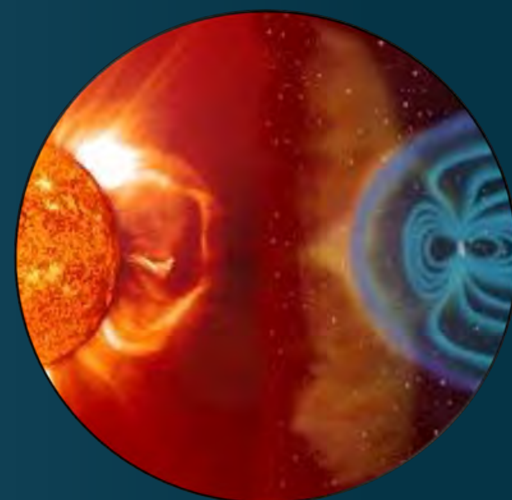
The Artemis Science Objectives

- Study of Planetary Processes
- Understanding Volatile Cycles
- Interpreting the Impact History of the Earth-Moon System
- Revealing the Record of the Ancient Sun
- Observing the Universe from a Unique Location
- Conducting Experimental Science in the Lunar Environment
- Investigating and Mitigating Exploration Risks to Humans

Science Coordination – Strategic Science on Gateway

FACILITATOR

Maintain communication with the Gateway Utilization Office



PROMOTER

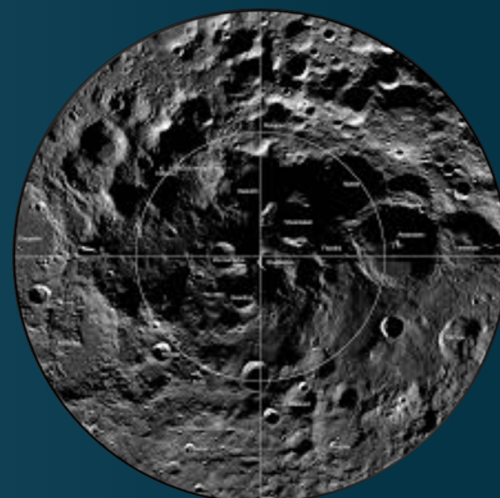
Integral role in communicating Gateway opportunities to SMD and promoting SMD interests to Gateway Utilization – NASA HERMES

STRATEGIZER

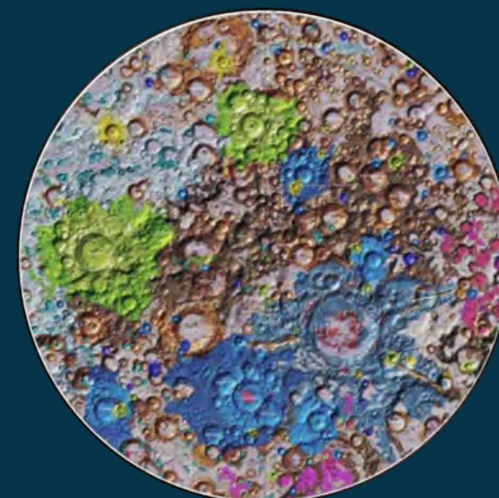
Recruit key expertise within SMD to set SMD strategy and priorities for Gateway Utilization

Science Coordination - Surface Characterization

SURFACE CHARACTERIZATION



LANDING SITE DETERMINATION



MAPPING NEEDS

Working with LRO, the lunar community (SSERVI, LEAG), USGS to define and understand the lunar environment: dust, radiation, temperature, regolith, geotechnical properties, illumination, resources

Lunar Reconnaissance Orbiter

The LRO spacecraft began it's 50,000th orbit of the Moon on August 1, 2020

Still going strong after more than 11 years in orbit!

After starting its life as an Exploration asset under ESMD, then transitioning to a science workhorse that has revolutionized our global understanding of the Moon, LRO is once again being called upon to serve our exploration needs by providing input to landing site characterization for Artemis and CLPS landers.

Science Coordination – Architecture

We are working closely with HEO to define opportunities and needs for science for Artemis 3 and beyond

Instruments and Sensors

Handheld, Walking Stick mounted, Astronaut mounted

LTV mounted

Lander mounted

Astronaut Deployed

Surface Architecture

Pre-deployment Strategy

Foundational Hab

Pressurized Rover

Science Coordination - Surface Ops

TOOLS DEVELOPMENT

Working with the tools folks to get the science input they need to define and produce tools that maximize science and minimize contamination

ASTRONAUT TRAINING

Sarah is on the core training team to develop curriculum for Artemis field and classroom training

SCIENCE TEAM/BACKROOM

Coordinating with HEO to define science team/ backroom support needs and expectations

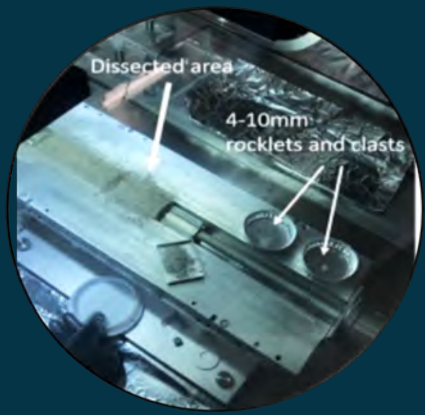
Science Coordination - Sample Return/Curation

Apollo Next Generation Sample Return (ANGSA)

- 73002 (unsealed core)
  - Finished Pass 1 for the first core (73002) at the end of February. Hyperspectral measurements were made the first week of March.
  - The completion of processing sample 73002 will be delayed by at least as long as the telework situation. The team has requested an exception for on-site work, but to date have not received approval.
- 73001 (sealed core)
  - Originally planned to be opened in November, but will be significantly delayed by COVID-19
- Limited samples from 73002 have been distributed. Special Sessions on first results at LPSC (cancelled) and AGU (Dec)

ANGSA 2.0 will likely fall under PSD, when/if the funds are found to execute

Engaging the community to identify and develop cold stowage technology for cryosample return through NASA@Work and a crowdsourcing challenge



Community Engagement

- Lunar Surface Science Workshop – joint with HEO
  - Scheduled for April, but cancelled due to pandemic so we are holding these sessions on a ~monthly cadence, starting with those where we most urgently need input
  - Averaging ~300 participants for each session
  - Talks are recorded, and discussion notes organized into deliverable products: https://lunarscience.arc.nasa.gov/lssw

MAY

Overview and Background

Tools and Instruments

JUNE

SSERVI Exploration Science Forum

JULY

Volatiles

Samples

AUGUST

Dust and Regolith

SEPTEMBER

LEAG annual meeting

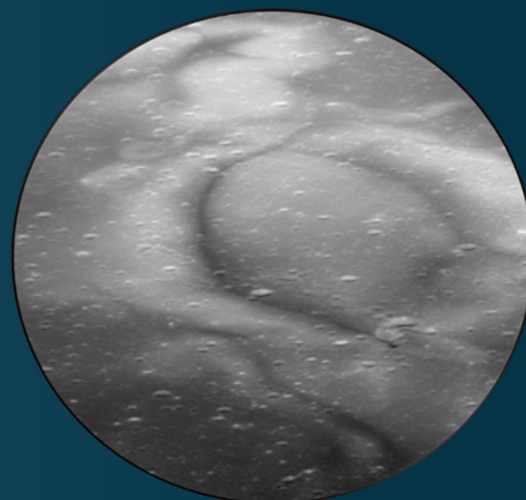
OCTOBER

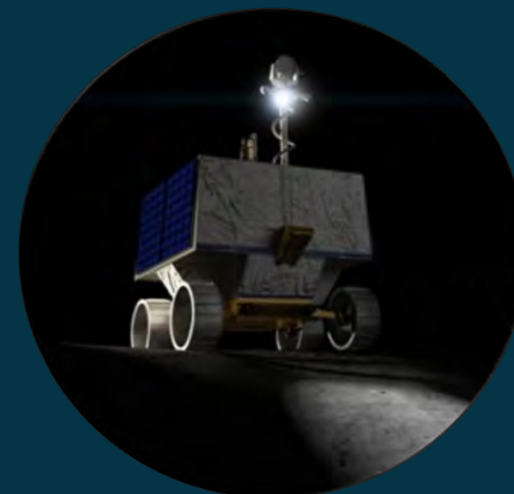
Cartography

The Value of Mobility

- Survive the Night Workshop – joint with HEO and STMD

Innovative Science Deliveries to the Moon





SCHEDULE-DRIVEN

Get to the lunar surface quickly and conduct science

NPLP, LSITP

SCIENCE-DRIVEN

Achieve high-priority science objectives across the lunar surface

DALI, PRISM

DECADAL-CALIBER SCIENCE

Promote development of advanced technology that enhances science return across the lunar surface

ESSIO

CLPS Vendor Pool

ASTROBOTIC

DEEP SPACE SYSTEMS

DRAPER

FIREFLY AEROSPACE

intuitive MACHINES

MOON EXPRESS

LOCKHEED MARTIN

ORBITBeyond

Masten

SPACEX

SNC SIERRA NEVADA CORPORATION

BLUE ORIGIN

ceres robotics

Tyvak

Schedule-Driven Science Deliveries to the Lunar Surface

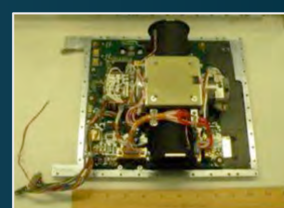
NIRVSS
Detect H_2O/OH

PlanetVac
Acquire and transfer regolith to payloads

LISTER
Investigate the Moon's thermal properties at depth

LEXI X-ray imagery Earth's magnetosphere

LETS Detect GCRs and SEP precursor particles



L-CIRiS
Measure lunar surface properties

Four deliveries for < $450M

25 Instruments selected from NPLP, LSITP programs

Cross-disciplinary: Helio, Astro, Planetary, Tech Demos

Multi-directorate: 2 HEOMD, 1 STMD payloads

$104M in payload procurement, ~$340M in delivery costs

ASTROBOTIC | INTUITIVE MACHINES | Masten ROCKET TECHNOLOGY INNOVATORS | 19D

Science-Driven Deliveries to the Lunar Surface

- Payloads and Research Investigations for the Surface of the Moon (PRISM) Stage-1 RFI
  - Catalog of potential instruments
  - 238 Stage 1 RFI responses received

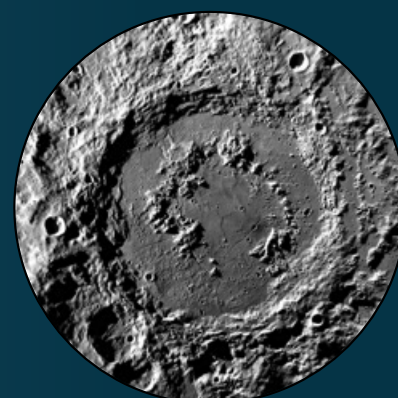
- PRISM Stage-2 solicitations will typically state the location for each delivery, allowing PIs to propose scientific investigations optimized for those locations
  - High-value 'location agnostic' and campaign investigations will be the focus of the next PRISM call
  - PRISM instruments will feed the manifests for Task Orders for deliveries from late 2023 onwards
  - Can be expanded to include orbital payloads
  - Payloads from international partners and other NASA mission directorates may also be identified in a PRISM call to reduce redundancies in proposed science
  - International contributions to PRISM investigations may be included at up to 30% the total cost of the investigation

PRISM 1a/1b – 2023/24 Deliveries

- July 20 community announcement provided a heads-up on the first Stage 2 call and also identified the destinations for the 2 deliveries it will support
- The Schrödinger basin delivery will also include LuSEE, an electromagnetics experiment payload from LSITP

REINER GAMMA

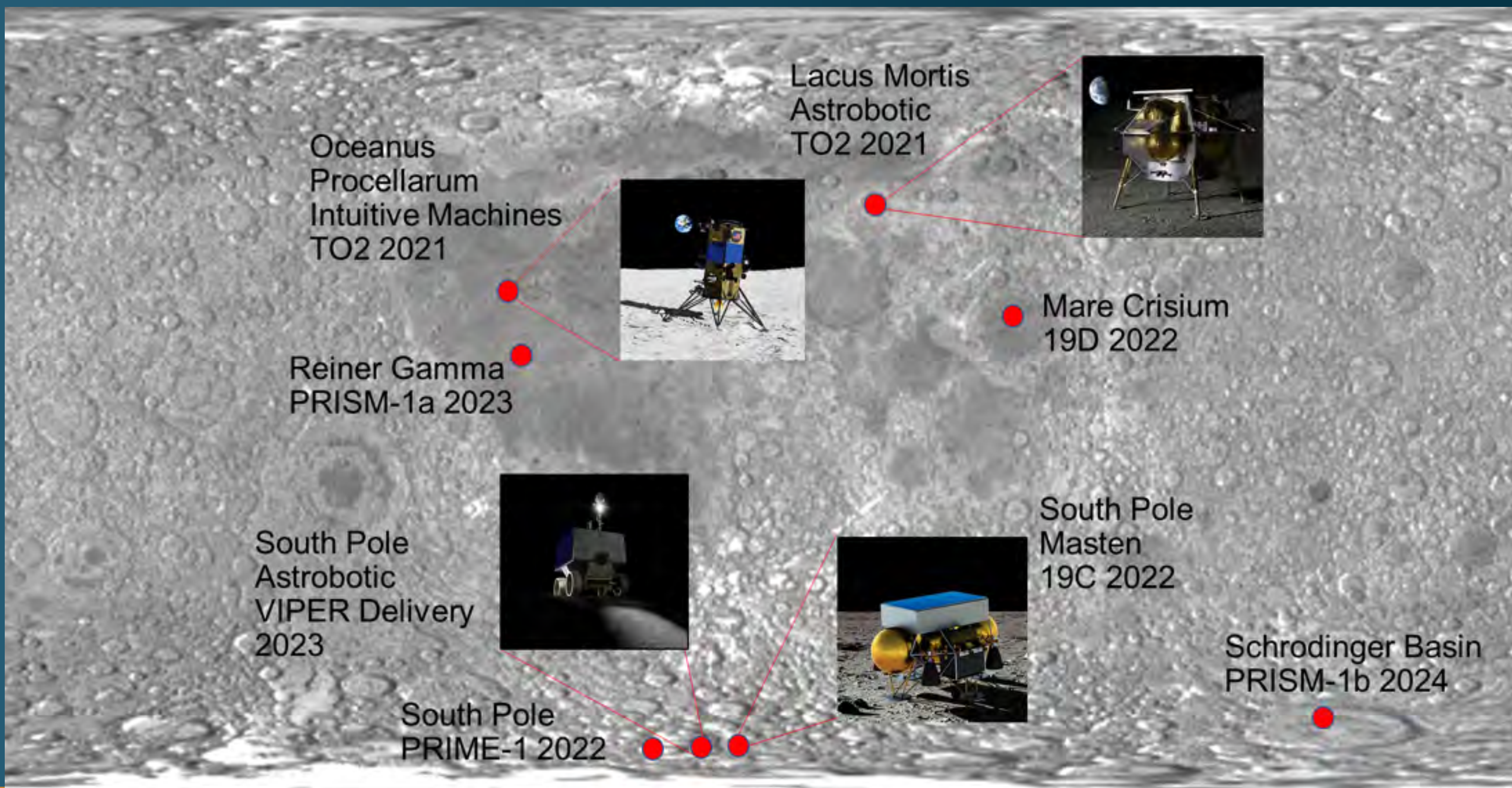
Lunar swirl
magnetic anomaly



SCHRÖDINGER

Young farside
basin impact melt

CLPS Deliveries 2021-2024



Awarded CLPS Delivery Manifests by Benefit Area

Astrobotic - 2

- Surface Exosphere Alterations by Landers (SEAL)
- Photovoltaic Investigation on Lunar Surface (PILS)
- Near-Infrared Volatile Spectrometer System (NIRVSS)
- Mass Spectrometer Observing Lunar Operations (Msolo)
- PROSPECT Ion-Trap Mass Spectrometer for Lunar Surface Volatiles (PITMS)
- Linear Energy Transfer Spectrometer (LETS)
- Neutron Spectrometer System (NSS)
- Neutron Measurements at the Lunar Surface (NMLS)
- Fluxgate Magnetometer (MAG)
- Navigation Doppler Lidar for Precise Velocity and Range Sensing (NDL)

Intuitive Machines – 2/20C

- Lunar Node 1 Navigation Demonstrator (LN-1)
- Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)
- Navigation Doppler Lidar for Precise Velocity and Range Sensing (NDL)
- Low-frequency Radio Observations from the Near Side Lunar Surface (ROLSES)
- Radio Frequency Mass Gauge (RFMG)
- Cryo Methane Propulsion Data Buy

Masten – 19C

- Sample Acquisition Morphology Filtering & Probing of Regolith (SAMPLR)
- Near-Infrared Volatile Spectrometer System (NIRVSS)
- Lunar Compact Infrared Imaging System (L-CIRiS)
- 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)

Key

- Science
- Technology
- Exploration
- HEOMD/STMD In-line tech demo

Astrobotic – 20A

- Volatiles Investigating Polar Exploration Rover (VIPER)

GSFC Laser Retroreflector Array (LRA) included on each lander.

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

Provisional 2022 CLPS Delivery Manifests

Crisium (Task Order 19D)

- Lunar Environment Heliophysics X-Ray Imager (LEXI)
- Next Generation Lunar Retroreflectors (NGLR)
- Radiation Tolerant Computer System (RadPC)
- Sample Acquisition & Delivery System for Instruments & Sample Return (PlanetVac)
- Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER)
- Lunar Magnetotelluric Sounder (LMS)
- Regolith Adherence Characterization (RAC)
- Electrodynamic Dust Shield (EDS)
- Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)
- Lunar GNSS Receiver Experiment (LuGRE)

Key

- Science
- Technology
- Exploration

STMD PRIME1 Task Order

- Polar Resource Ice-Mining Experiment-1 (PRIME-1)
- Mass Spectrometer Observing Lunar Operations (Msolo)

Supporting Other Mission Directorates

- CLPS is a NASA resource and we have been looking at maximizing its value to the agency
  - ➢ MOU with HEOMD and STMD to enable maximum utilization of each SMD-led CLPS delivery
    - ❖ Flying other MDs payloads
    - ❖ Data buys
  - ➢ SMD also receives payload space on CLPS deliveries led by each of the other MDs

- Enabling CLPS deliveries led by other MDs
  - ➢ PRIME-1 (STMD) Task Order for the delivery of STMD's PRIME-1 instrument to a polar region (RFTOP draft released July 31, 2020)

- Partnerships and Payloads with Other Government Agencies
  - ➢ DoD / DARPA
  - ➢ USGS

Summary of International Interest

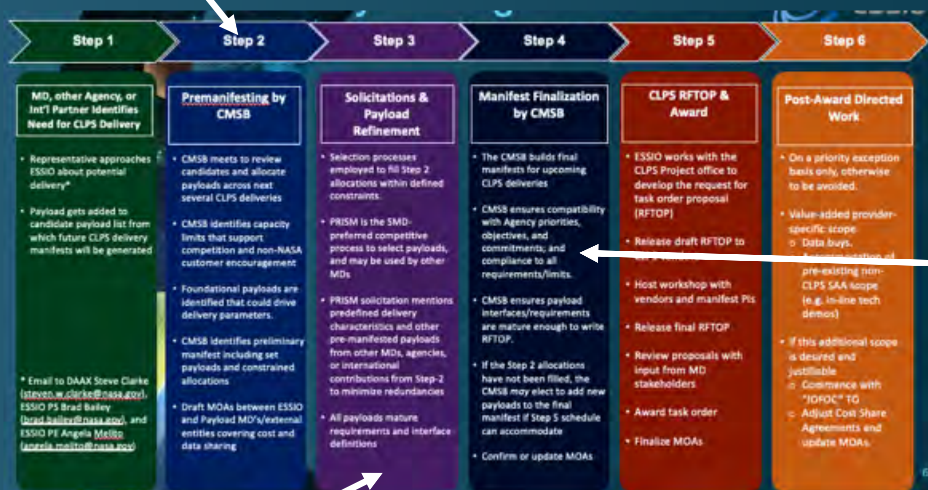
- Australia (Australia Space Agency SoI 9/19 & Curtin University LoS 10/19)
- Canadian Space Agency
- European Space Agency (SoI 3/19)
- Italian Space Agency
- Japan Aerospace Exploration Agency
- Luxembourg
- Korea (Korea Astronomy & Space Science Institute, Exploration Science Working Group Charter 5/19)
- Monaco
- Polish Space Agency
- Swiss Space Office (LoS 12/19)
- United Arab Emirates
- United Kingdom Space Agency (SoI 5/19)

SoI: Statement of Intent
LoS: Letter of Support

International Contributions Ingest

Three methods for ingesting international contributions into a CLPS delivery manifest

#1: Co-manifested with other complementary MD payloads (Step 2)



#3: Remaining lander space may be allocated to int'l contributed payload (Step 4)

#2: PRISM payloads may have int'l contributions (<30%) (Step 3)

Evolving Capabilities for Decadal-Caliber Science

- New capabilities that would enhance science return, ops, and open new avenues for scientific investigations
  - Mobility
  - Orbital Drop-off
  - Comm Relay
  - Sample Return
  - Surviving the lunar night
  - Articulation
  - PSR Operations

- Parallel Development Paths
  - Study task order to existing CLPS providers
  - NASA in-house development (e.g. VIPER, LEMS)
  - Investigate international contribution (e.g., ESA, CSA)
  - RFI to industry to determine potential commercial sources and availability