

National Aeronautics and
Space Administration



EXPLORE SCIENCE

Exploration Science Strategy and Integration Office (ESSIO)

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Planetary Advisory Committee
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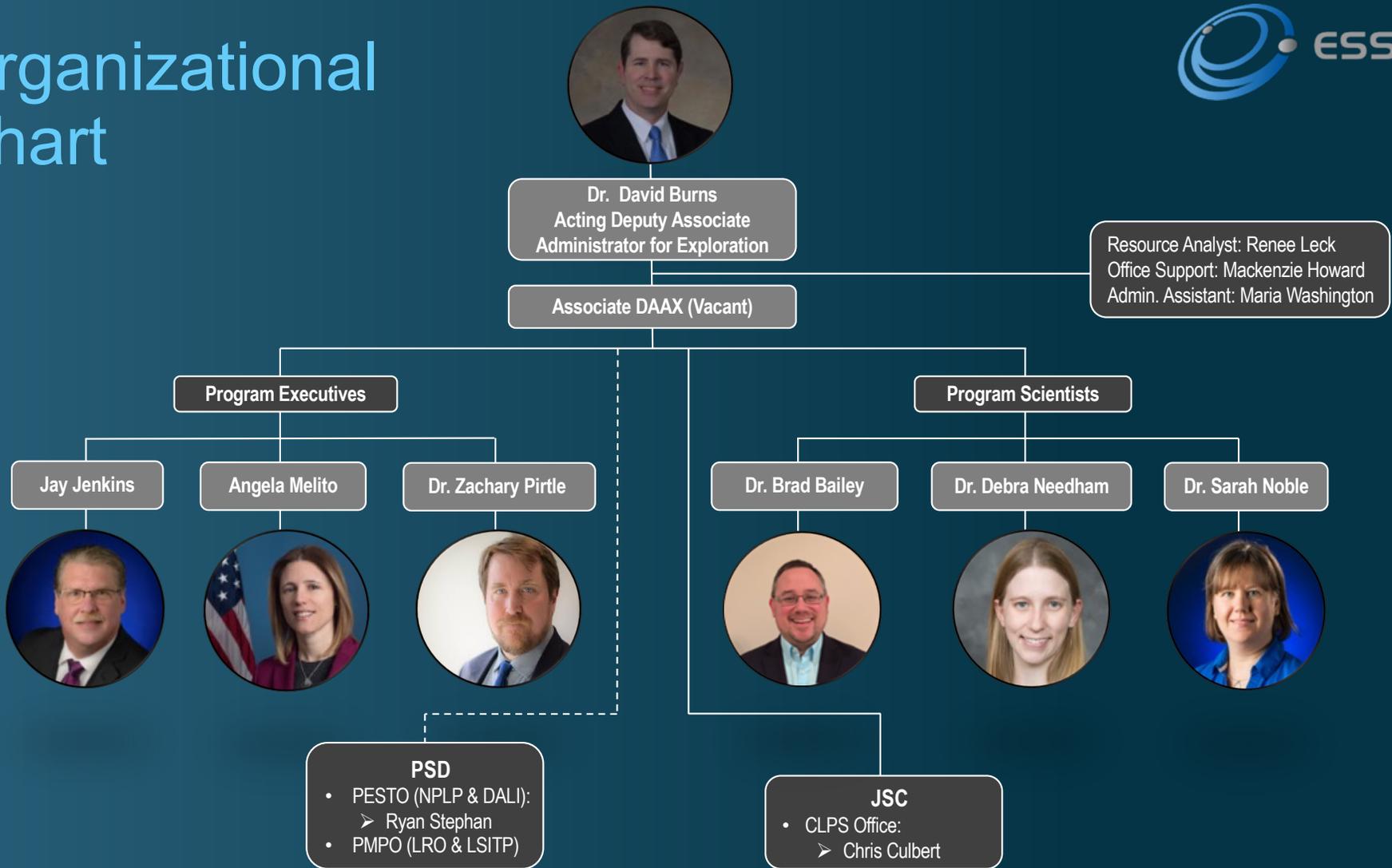
Vision

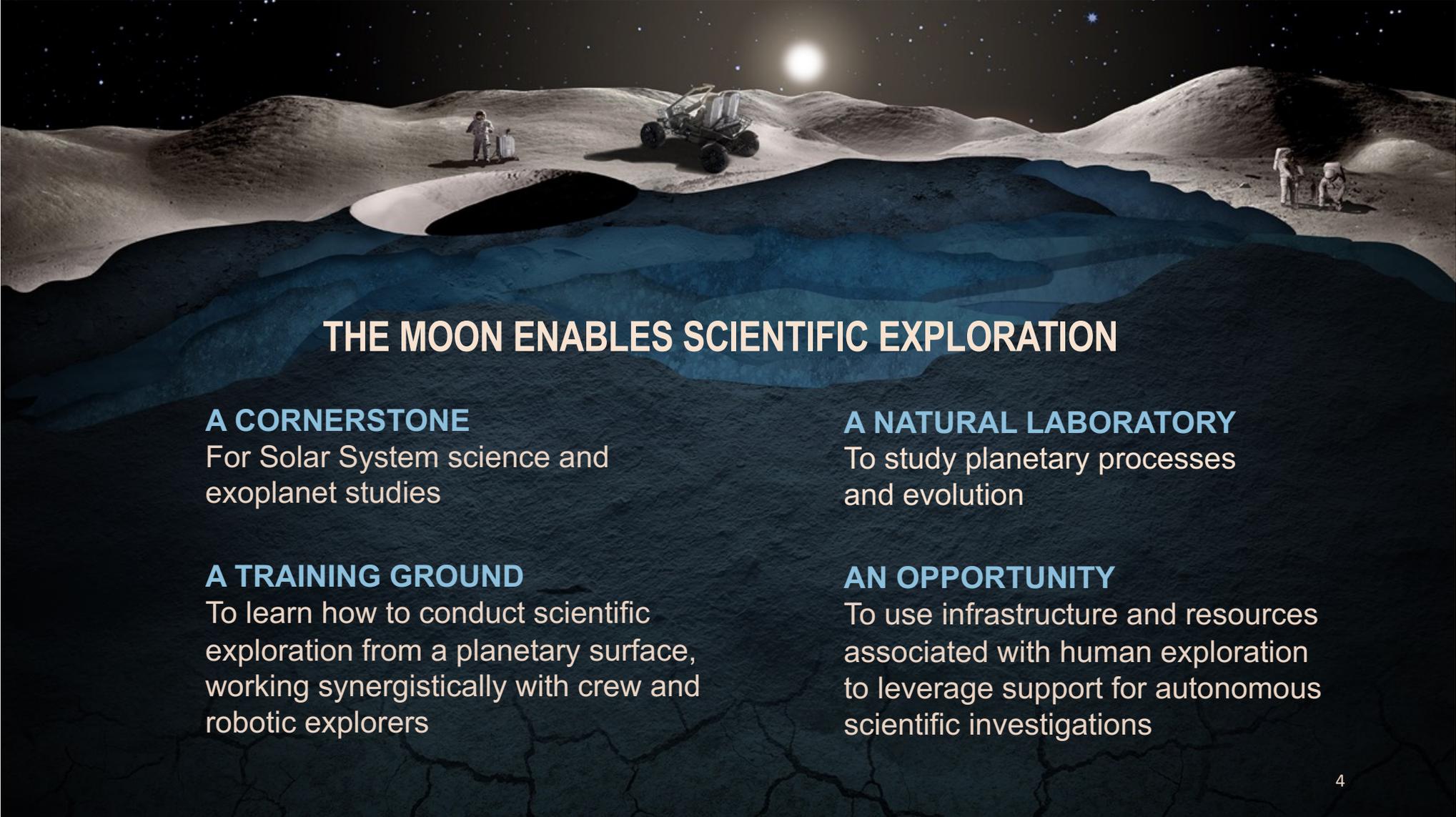
Define and lead the science strategy for Artemis and Moon to Mars

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 TRAINING GROUND

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

A NATURAL LABORATORY

To study planetary processes and evolution

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



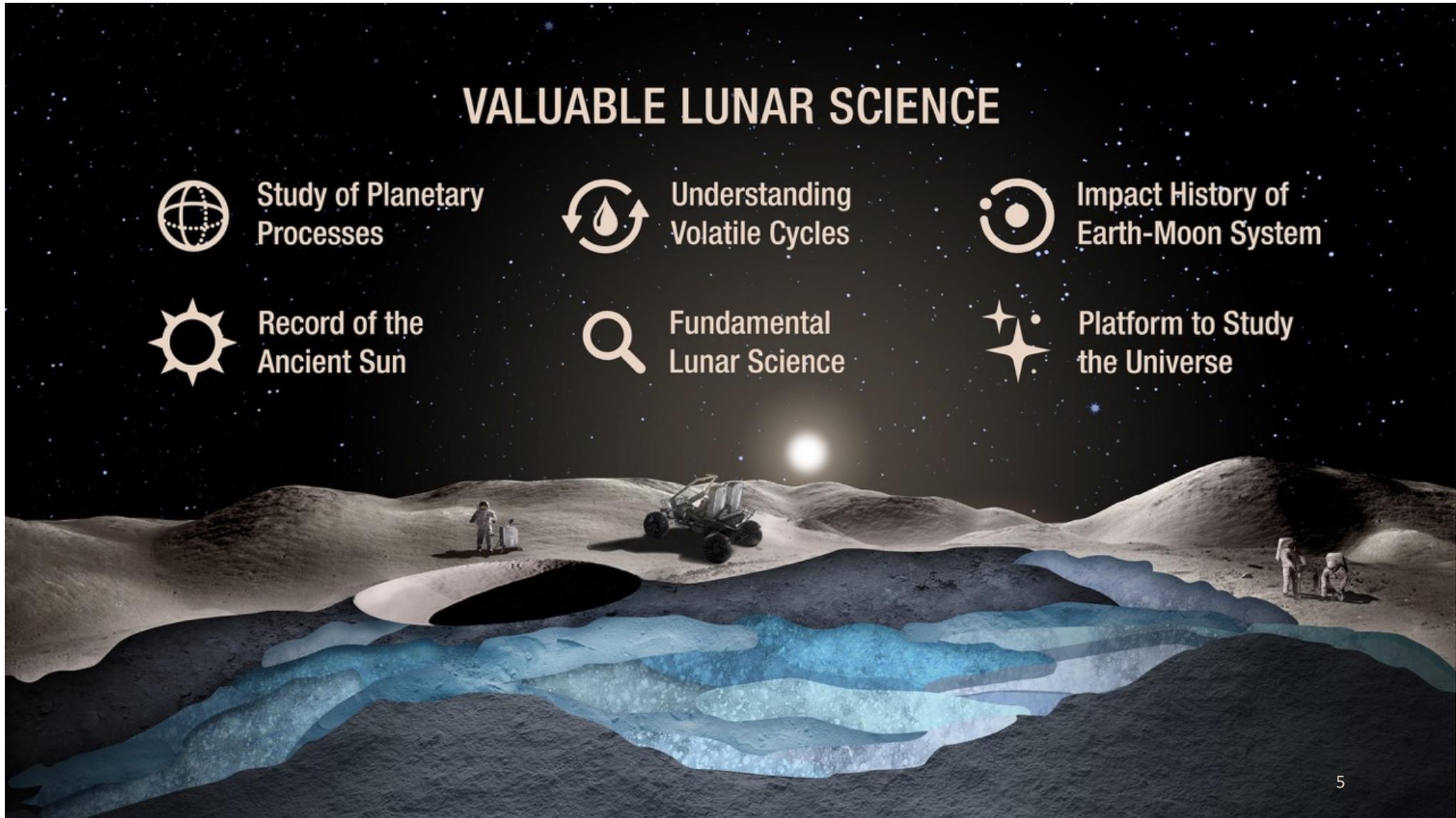
Record of the Ancient Sun

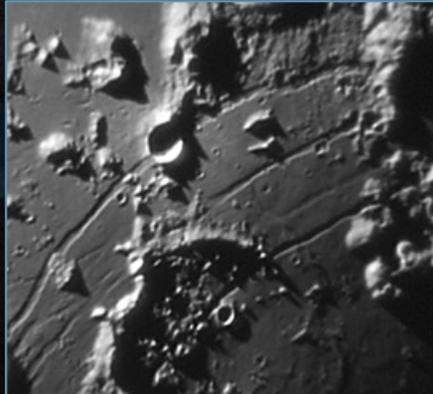


Fundamental Lunar Science



Platform to Study the Universe





EXPLORATION REQUIREMENTS

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

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

+ VOLCANISM

Partial melting, eruptions, flow sequence and compositions

+ IMPACT

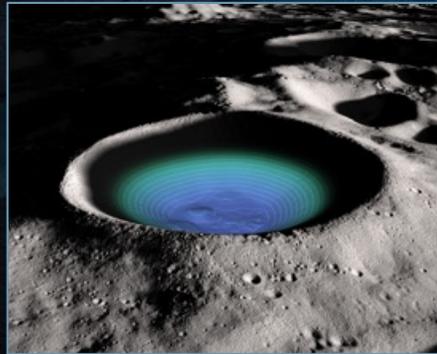
Basins and craters, mixing of the crust

+ TECTONISM

Deformation of the crust and thermal history

+ VOLATILES

History, production, and escape mechanisms



EXPLORATION REQUIREMENTS

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

UNDERSTANDING VOLATILE CYCLES

- + 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



EXPLORATION REQUIREMENTS

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

IMPACT HISTORY OF EARTH-MOON SYSTEM

- + 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



EXPLORATION REQUIREMENTS

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

+ 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



FUNDAMENTAL LUNAR SCIENCE

LIFE SCIENCES

Combined effects of fractional gravity & deep space radiation

FUNDAMENTAL PHYSICS

General relativity, gravitational physics, quantum information science

EXPLORATION PHYSICS

Combustion, fluid dynamics, dust, material sciences

FOOD/DRUG DEGRADATION



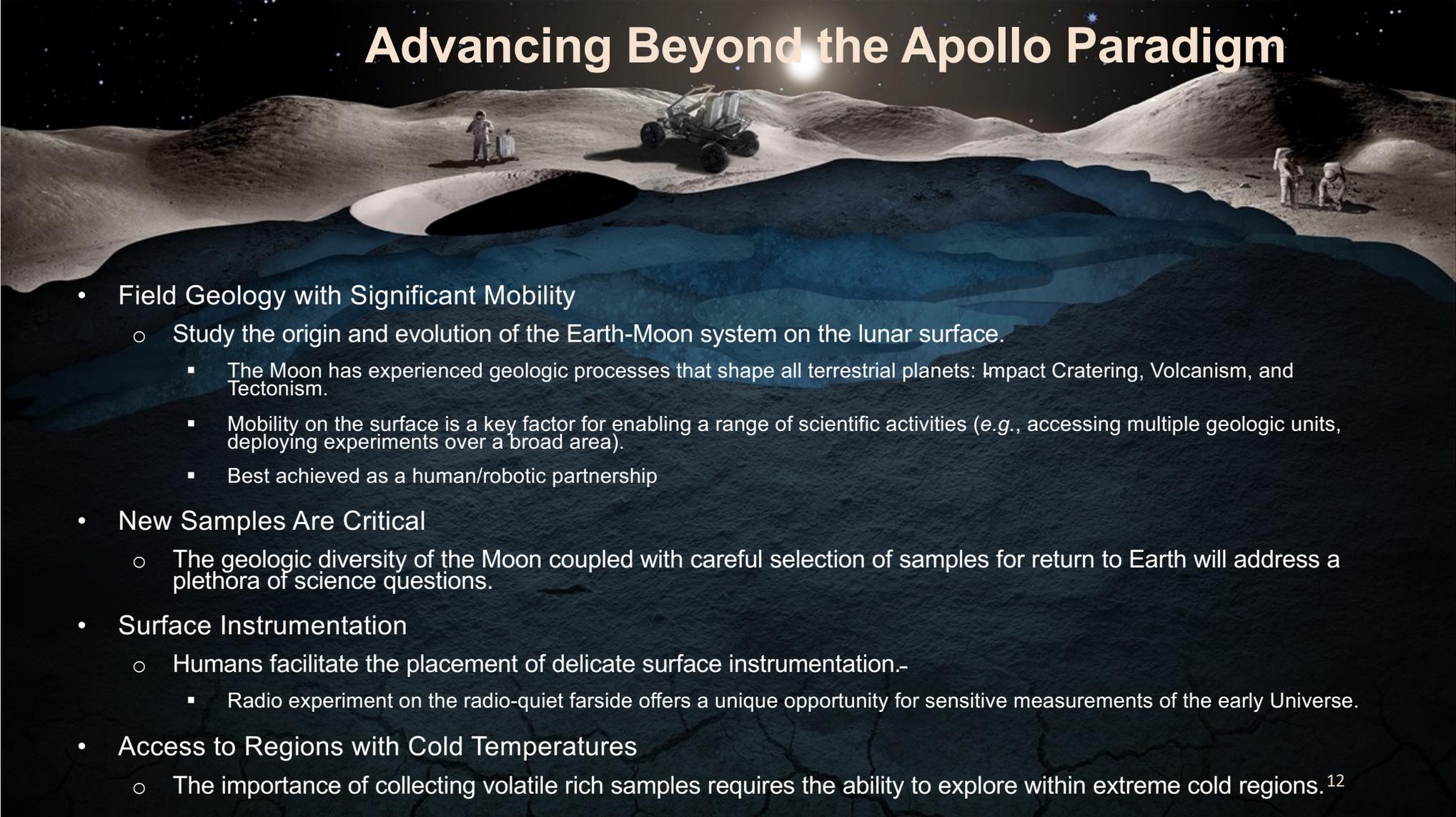
PLATFORM TO STUDY THE UNIVERSE

- + 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

EXPLORATION REQUIREMENTS

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

Advancing Beyond the Apollo Paradigm

A futuristic lunar landscape with a rover, astronauts, and a crater. The scene is set on the moon's surface, featuring rolling hills, a large crater, and a rover. Two astronauts are visible, one near the rover and another further away. The sky is dark with stars and a bright sun or moon in the distance.

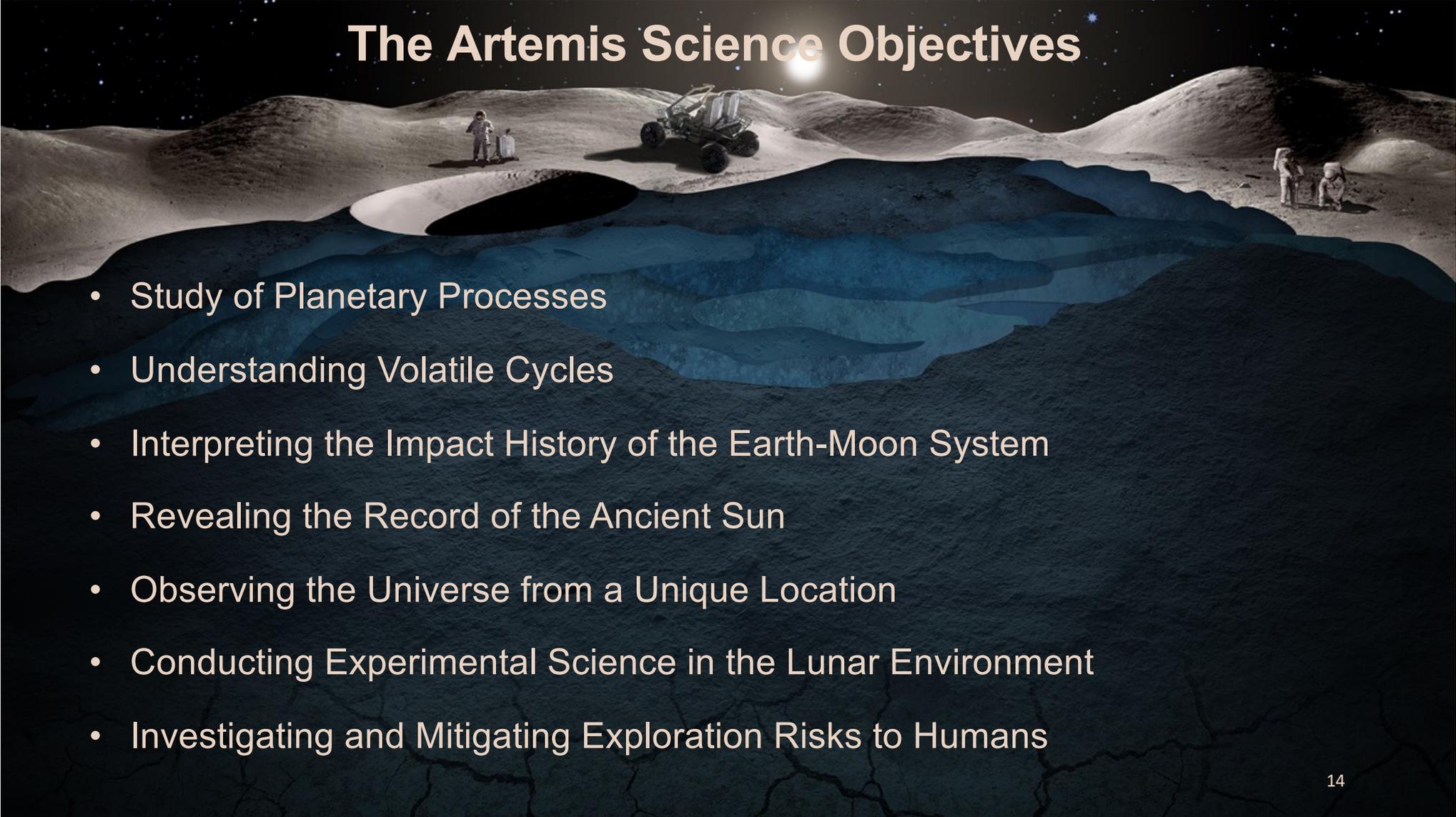
- **Field Geology with Significant Mobility**
 - Study the origin and evolution of the Earth-Moon system on the lunar surface.
 - The Moon has experienced geologic processes that shape all terrestrial planets: Impact Cratering, Volcanism, and Tectonism.
 - Mobility on the surface is a key factor for 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.¹²

A Bold New Era of Human Discovery



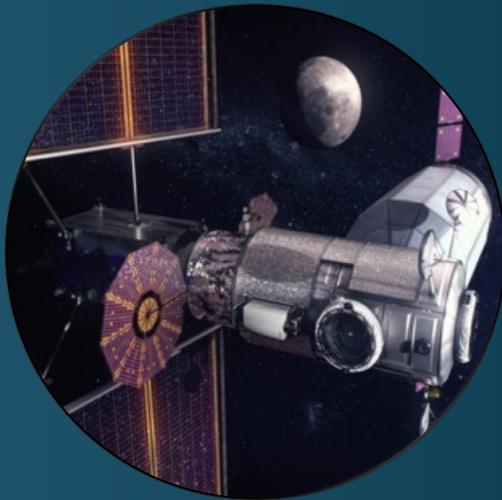
- **An Opportunity to Study Planetary Processes**
 - Mobility to visit geologically different features
 - EVA traverses and suits designed for strategic sample collection
- **A Critical Location to Understand Volatiles Cycles**
 - Access to persistently shadowed terrain (either robotically or with crew)
 - 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



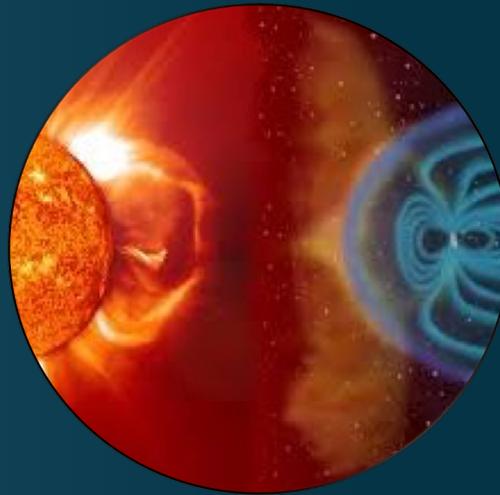
- Study of Planetary Processes
- Understanding Volatile Cycles
- Interpreting the Impact History of the Earth-Moon System
- Revealing the Record of the Ancient Sun
- Observing the Universe from a Unique Location
- Conducting Experimental Science in the Lunar Environment
- Investigating and Mitigating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

Science Coordination – Strategic Science on Gateway



FACILITATOR

Maintain communication
with the Gateway
Utilization Office



PROMOTER

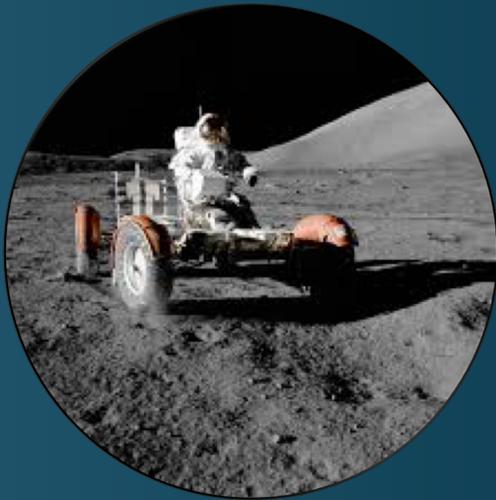
Integral role in communicating
Gateway opportunities to SMD
and promoting SMD interests
to Gateway Utilization –
NASA HERMES



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 its 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.



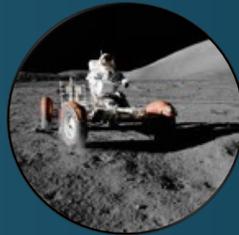
Science Coordination – Architecture

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

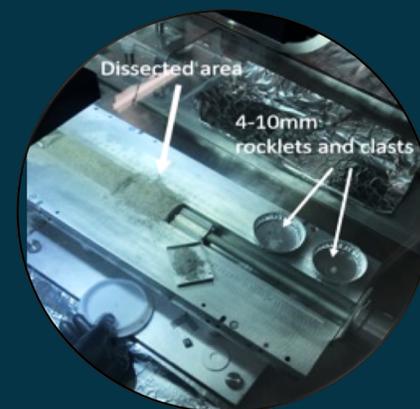
Science Coordination - Sample Return/Curation

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

CLPS Vendor Pool



Schedule-Driven Science Deliveries to the Lunar Surface

NIRVSS
Detect H₂O/OH



PlanetVac
Acquire and transfer regolith to payloads



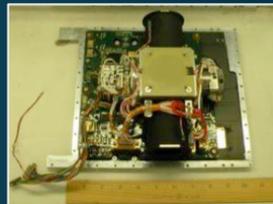
LEXI X-ray imagery
Earth's magnetosphere



LETS Detect GCRs and
SEP precursor particles



LISTER
Investigate the
Moon's thermal
properties at depth



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



19D

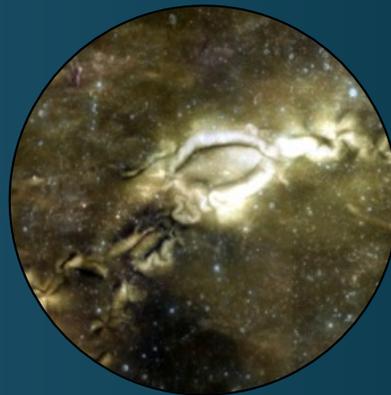
Science-Driven Deliveries to the Lunar Surface

- 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

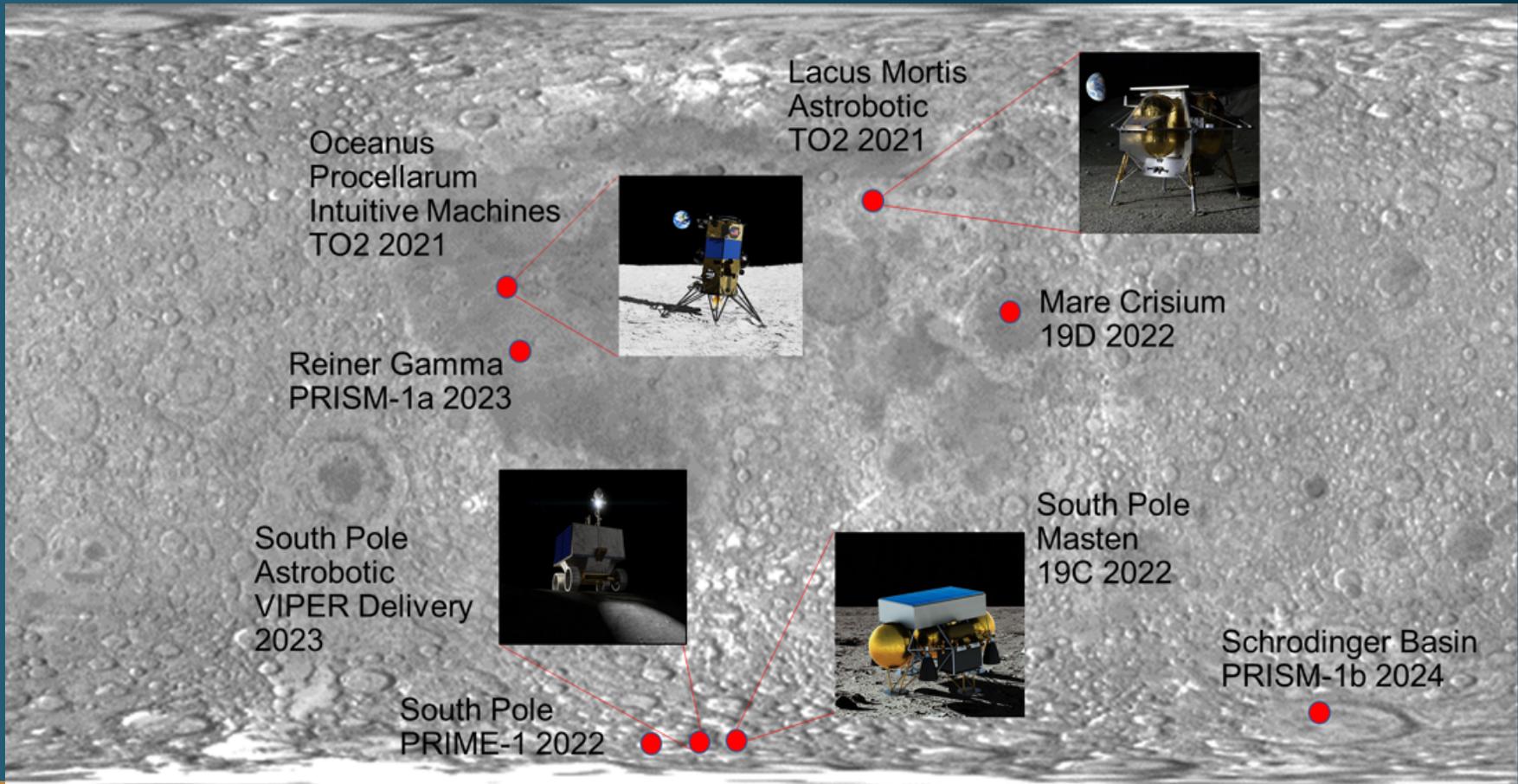
Lunar swirl
magnetic anomaly



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

Intuitive Machines – 2/20C

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

Key

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

Astrobotic – 20A

Volatiles Investigating Polar Exploration Rover (VIPER)

Masten – 19C

Sample Acquisition Morphology Filtering & Probing of Regolith (SAMPLR)	Camera System for lunar science on commercial vehicles (Heimdall)
Near-Infrared Volatile Spectrometer System (NIRVSS)	Linear Energy Transfer Spectrometer (LETS)
Lunar Compact Infrared Imaging System (L-CIRiS)	Moon Rover with Exploration Autonomy (Moon Ranger)
Mass Spectrometer Observing Lunar Operations (Msolo)	Neutron Spectrometer System (NSS)

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

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 Sol 9/19 & Curtin University LoS 10/19)
- Canadian Space Agency
- European Space Agency (Sol 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 (Sol 5/19)



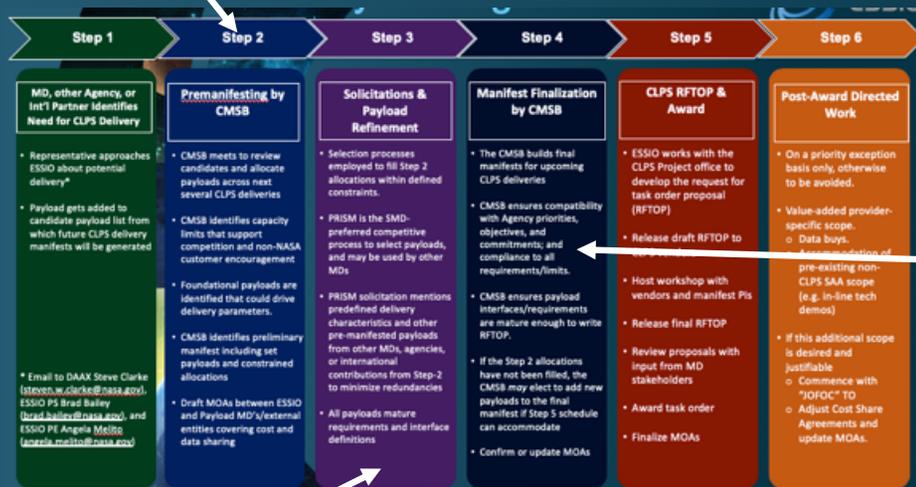
Sol: Statement of Intent
LoS: Letter of Support

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

