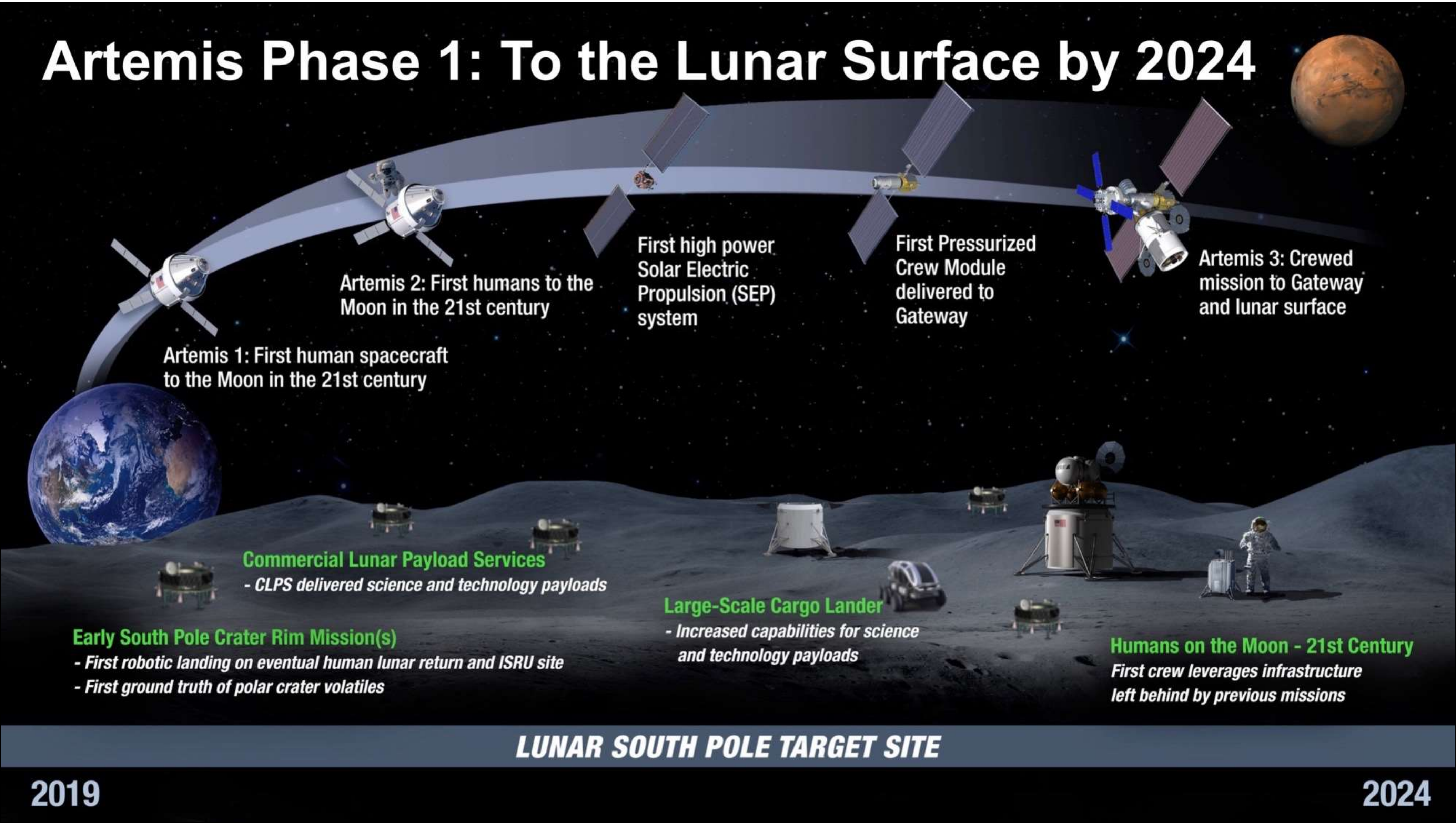
National Aeronautics and Space Administration

NASA

EXPLORE SCIENCE

Lunar Discovery & Exploration Program Status

Steve Clarke
Deputy Associate Administrator for Exploration
Science Mission Directorate, NASA


Artemis Phase 1: To the Lunar Surface by 2024
Artemis 1: First human spacecraft to the Moon in the 21st century
Artemis 2: First humans to the Moon in the 21st century
First high power Solar Electric Propulsion (SEP) system
First Pressurized Crew Module delivered to Gateway
Artemis 3: Crewed mission to Gateway and lunar surface
Commercial Lunar Payload Services
- CLPS delivered science and technology payloads
Early South Pole Crater Rim Mission(s)
- First robotic landing on eventual human lunar return and ISRU site
- First ground truth of polar crater volatiles
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2019
2024

Lunar Discovery and Exploration Program

- **Commercial Lunar Payload Services (CLPS)**
  - Two deliveries per year
  - Drive to enable community-driven science
- **Instrument Development and Delivery**
  - Instruments for CLPS
  - Maturation of instrument concepts (DALI)
- **VIPER Polar Rover**
  - NASA-built rover to the lunar surface in late CY2022
    - Delivery by CLPS provider via on-ramp for enhanced capability
- **Follow on missions (commercial rovers) approximately every 24 months**
- **Long Duration Rover Investments**
- **Lunar Reconnaissance Orbiter Mission Operations**
- **Lunar SmallSats**
  - SIMPLEX
  - CubeSats/SmallSats delivered into lunar orbit by CLPS
- **Apollo Next Generation Sample Analysis (ANGSA)**

Commercial Lunar Payload Services (CLPS)

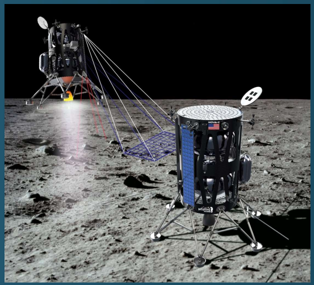
- Contract awards announced November 29, 2018:

Astrobotic Technology, Inc	Firefly Aeronautics, Inc.	Masten Space Systems, Inc.
Deep Space Systems	Intuitive Machines, LLC	Moon Express
Draper	Lockheed Martin Space	Orbit Beyond

- Services will be acquired through Task Orders
- First Lunar Surface Transportation Task Order awarded May 2019
- Expected Task Order cadence of 2 per year
- Future on-ramps for additional providers and as more capabilities are needed
    - ➢ On-ramp RFP for enhanced lander services capability.

CLPS Delivery Task Order Selections

Astrobotic



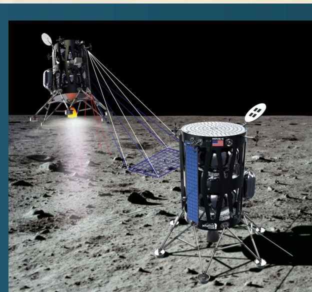
Intuitive Machines

Orbit Beyond

- On May 31, 2019, NASA selected the first Commercial Moon landing delivery services for Artemis Program to deliver science and technology to the Moon
  - Astrobotic of Pittsburgh awarded $79.5 million to fly as many as 14 payloads to Lacus Mortis, by July 2021
  - Intuitive Machines of Houston awarded $77 million to fly as many as five payloads to Oceanus Procellarum by July 2021
  - Orbit Beyond of Edison, New Jersey, awarded $97 million to fly as many as four payloads to Mare Imbrium, by September 2020

Commercial Lunar Payloads Services Update

Astrobotic



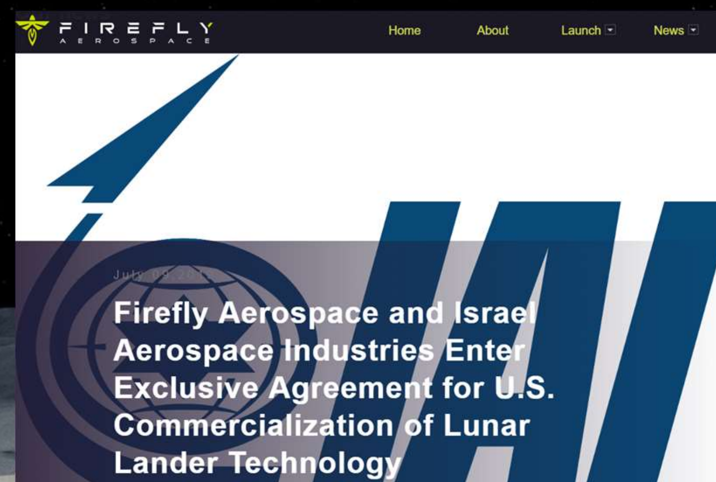
Intuitive Machines

Orbit Beyond

- On May 31, 2019, NASA selected the first Commercial Moon landing delivery services for Artemis Program to deliver science and technology to the Moon
  - Astrobotic of Pittsburgh awarded $79.5 million to fly as many as 14 payloads to Lacus Mortis, by July 2021
  - Intuitive Machines of Houston awarded $77 million to fly as many as five payloads to Oceanus Procellarum by July 2021
  - Orbit Beyond of Edison, New Jersey, awarded $97 million to fly as many as four payloads to Mare Imbrium, by September 2020

Commercial Lunar Payloads Services Update

- **On-ramp for enhanced lander services capability**
  - June 20 – Synopsis released
  - July 29 – RFP released
  - Aug 15 – Industry Day
  - Aug 29 – Proposals Due; *extension granted to Sept 11*
  - Oct 8 – Source Selection Meeting



Instruments to Fly on CLPS Deliveries

- NASA conducted two calls for instruments to fly on CLPS surface deliveries
  - Both were for near ready to fly experiments
  - NASA Provided Lunar Payloads (NPLP) was a NASA-internal call
    - 13 instruments selected
    - Mixture of science, technology & exploration
  - Lunar Surface Instruments & Technology (LSITP) was a call to the external community
    - 12 instruments selected July 1
  - Future calls (internal and external combined) planned approximately annually
  - Goal is to head towards a PI-led science payload suite model
  - Opportunities for internationally provided payloads

NASA Provided Lunar Payloads (NPLP)

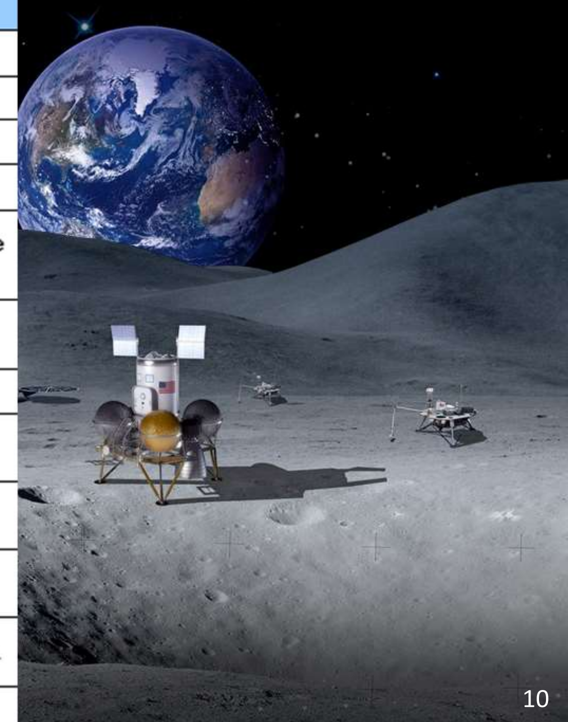
- **13 payloads selected on Feb 21, 2019**
  - ➢ Near-ready or ready-to-fly payloads
  - ➢ Open to science, technology and exploration type payloads

Instrument Name	Payload Classification	Lead Organization
SEAL: Surface and Exosphere Alterations by Landers	Entry, Descent, & Landing	NASA GSFC
Linear Energy Transfer Spectrometer	Instrument - Spectrometer	NASA JSC
Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)	Entry, Descent, & Landing	NASA LaRC
Solar Cell Demonstration Platform for Enabling Long-Term Lunar Surface Power	Power Technology Demonstration	NASA GRC
Near-Infrared Volatile Spectrometer System	Instrument - Regolith Properties	NASA ARC
Neutron Spectrometer System	Instrument - Neutron Spectrometer	NASA ARC
Lunar Node 1 (LN-1) Navigation Demonstrator	Navigation	NASA MSFC
Neutron Measurements at the Lunar Surface	Instrument - Neutron Spectrometer	NASA MSFC
PROSPECT Ion-Trap Mass Spectrometer (PITMS) for Lunar Surface Volatiles	Instrument - Mass Spectrometer	NASA GSFC
Development of NASA Provided Lunar Payload: Fluxgate Magnetometer	Instrument - Magnetometer	NASA GSFC
Low-frequency Radio Observations from the Near Side Lunar Surface	Instrument - Radio Frequency	NASA GSFC
Navigation Doppler Lidar (NDL) for Precise Velocity and Range Sensing	Entry, Descent, & Landing	NASA JSC
Mass Spectrometer Observing Lunar Operations (M-SOLO)	Quadrupole Mass Spectrometer	NASA KSC

Lunar Surface Instrument and Technology Payload (LSITP)

- **12 payloads selected on July 1, 2019**
  - Near-ready or ready-to-fly payloads
  - Open to science, technology and exploration type payloads

PI First Name	PI Last Name	Title	Org
Johnnie	Engelhardt	Regolith Adherence Characterization (RAC) Payload	Alpha Space Test and Research Alliance, LLC
Robert	Grimm	Lunar Magnetotelluric Sounder	Southwest Research Institute
Stuart	Bale	The Lunar Surface Electromagnetics Experiment (LuSEE)	University of California, Berkeley
Brian	Walsh	Lunar Environment heliophysics X-ray Imager (LEXI)	Boston University
Douglas	Currie	NEXT GENERATION LUNAR RETROREFLECTORS (NGLR) for Lunar Physics, Gravitation and General Relativity and Cartography	University of Maryland, College Park
R. Aileen	Yingst	Heimdall: A flexible build-to-print camera system for conducting lunar science on commercial vehicles	Planetary Science Institute
Paul	Hayne	Lunar Compact InfraRed Imaging System (L-CIRiS)	University Of Colorado, Boulder
Brock	LaMeres	Lunar Demonstration of a Reconfigurable, Radiation Tolerant Computer System	Montana State University, Bozeman
Seiichi	Nagihara	Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER)	Texas Tech University, Lubbock
Kris	Zacny	PlanetVac: Sample Acquisition and Delivery System for Instruments and Sample Return	Honeybee Robotics, Ltd.
Sean	Dougherty	SAMPLR: Sample Acquisition, Morphology Filtering, and Probing of Lunar Regolith	MDA Information Systems, Inc.
Andrew	Horchler	MoonRanger: Flight-Forward Moon Rover with Exploration Autonomy	Astrobotic Technology, Inc.



Lunar Mobility Strategy

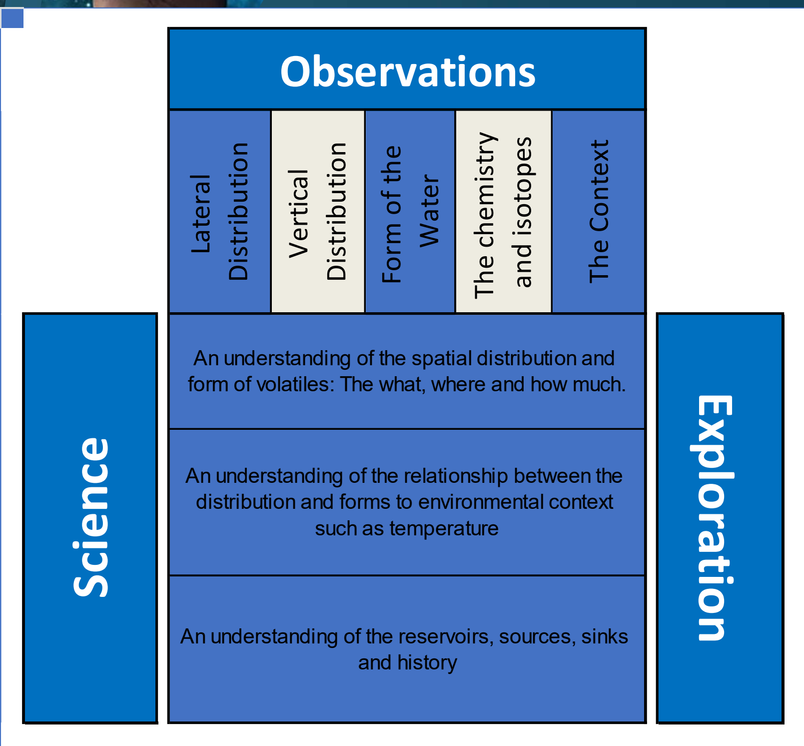
- Primary drivers include science and human exploration objectives and soonest landing; target is late 2022 in the South Pole region
- Primary objectives:
  - ➢ Ground truth of volatiles (horizontal and vertical distribution, composition, and form)
  - ➢ Long duration operation (months)

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

Lunar Discovery and Exploration Program (LDEP)

- **Commercial Lunar Payload Services (CLPS)**
  - Two deliveries per year
  - Drive to enable community-driven science
- **Instrument Development and Delivery**
  - Instruments for CLPS
  - Maturation of instrument concepts (DALI)
- **VIPER Polar Rover**
  - NASA-built rover to the lunar surface in late CY2022
    - Delivery by CLPS provider via on-ramp for enhanced capability
- **Follow on missions (commercial rovers) approximately every 24 months**
- **Long Duration Rover Investments**
- **Lunar Reconnaissance Orbiter Mission Operations**
- **Lunar SmallSats**
  - SIMPLEX
  - CubeSats/SmallSats delivered into lunar orbit by CLPS
- **Apollo Next Generation Sample Analysis (ANGSA)**

VIPER: The Intersection Between Exploration and Science



Common Objectives

- The spatial distribution and form of volatiles: The what, where and how much
- The relationship between the distribution and forms to environmental context, such as temperature
- The reservoirs, sources, sinks and history

Mission Features

- Multi-lunar day duration at South Pole (for Dec. 2022 launch)
- Designed to traverse 10s of kilometers
- Provides feed forward to follow-on missions and resource maps of visited sites and extrapolation to orbital data sets

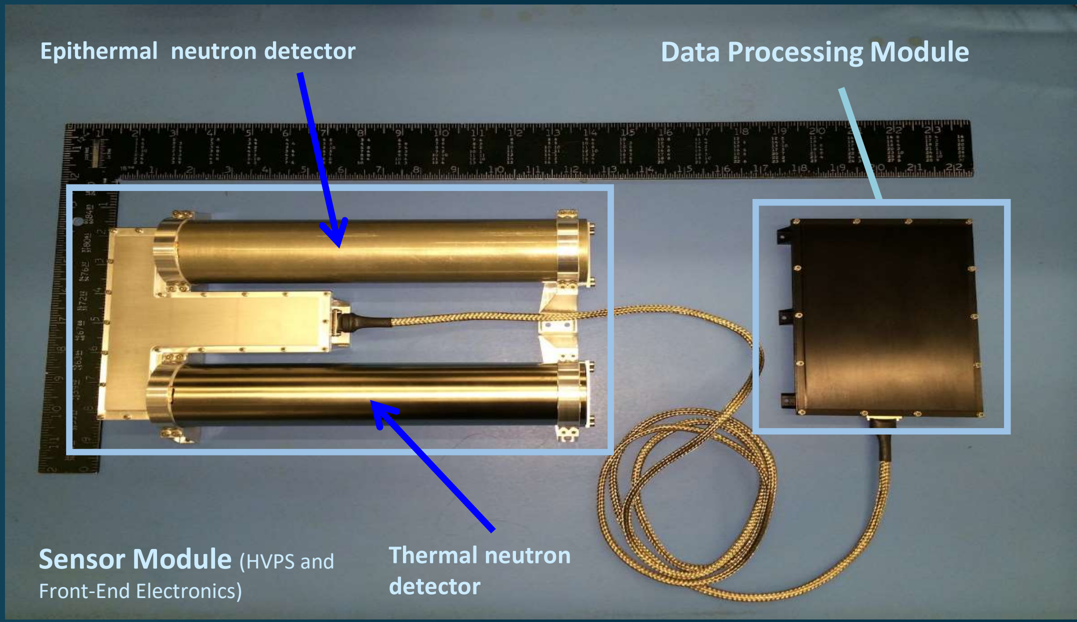
VIPER Payload: Neutron Spectrometer System (NSS)

NSS (NASA ARC/Lockheed Martin ATC)
PI: Rick Elphic (NASA ARC)

Instrument Type: Two channel neutron spectrometer

Key Measurements: NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring down to 0.5% (wt) WEH to 3σ while roving

Operation: NSS is on continuously while roving



Instrument Name	NSS
Mass [kg], CBE	1.9*
Dimensions [cm]	Sensor Module: 21.3 x 32.1 x 6.8 Data Processing Module: 13.9 x 18.0 x 3.0
Power [W]	1.6
Sensitivity	WEH to $\geq$0.5 wt% water-equivalent at 10 cm/s
Accuracy	5 – 10% absolute

*Total Mass Breakdown:
- Sensor Module: 1284g
- Data Processing Module: 287g
- 2-m cable harness, DPM-SM: 147g
- Heaters and misc.: 170g

VIPER Payload: Near InfraRed Volatiles Spectrometer System (NIRVSS)

NIRVSS (ARC, Brimrose Corporation)
PI: Anthony Colaprete (NASA ARC)

Instrument Type: NIR Point Spectrometer, 4Mpxl Panchromatic Imager with 7 LEDs, four channel thermal radiometer

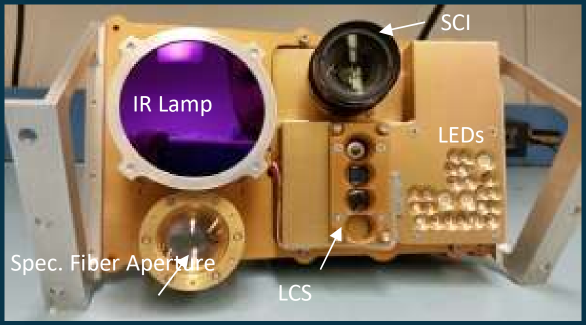
Key Measurements: Volatiles including H_2O, OH, and CO_2 and, minerology, surface morphology and temperatures

Operation: On continuously while roving and during drill operations

Primary Measurements:
Components
- *AOTF NIR Point Spectrometer:* 1300-4000nm
- *Spectrometer Context Imager (SCI):* 4Mpxl imager with seven LEDs between 340-940nm
- *Longwave Calibration Sensor (LCS):* IR flux and surface temperature down to <100K to ± 5K
- *Lamp*: Dual filament tungsten lamp provides even, calibrated light source when in shadow

Spectrometer

Bracket Assembly



Instrument Name	NIRVSS
Mass [kg]	3.57 kg (not including Fiber)
Dimensions [cm]	Spectrometer Module: 18x18x8.5 Observation Bracket 20.4x13x15.1
Power [W], Avg	Spectrometer = 12 Bracket Assembly = 5.26 Lamp = 12.3
Sensitivity	Range: 1.2 to 4.0 μm SNR>100 at 2 and 3 μm Water Ice to <0.25%
Accuracy	Radiance to <25%

VIPER Payload: Mass Spectrometer Observing Lunar Operations (MSolo)

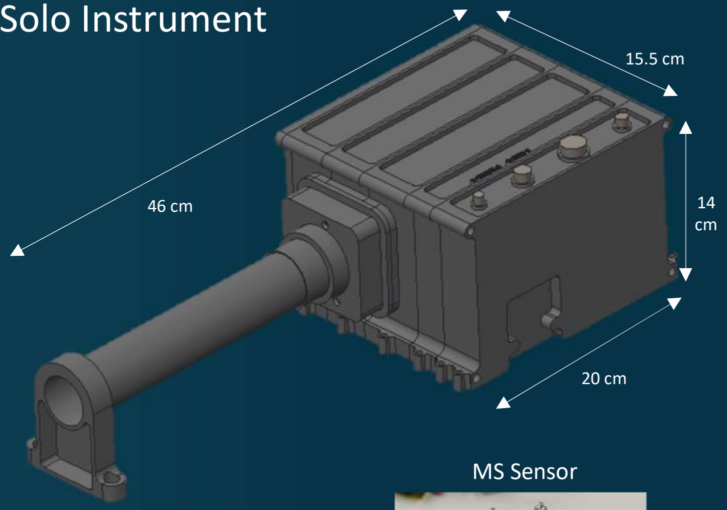
MSolo (KSC, INFICON, NSF– SHREC Space Processor, & Blue Sun – Virtual Machine Language)
PI: Janine Captain (NASA KSC)

Instrument Type: Quadrupole mass spectrometer

Key Measurements: Identify low-molecular weight volatiles between 2-100 amu, unit mass resolution to measure isotopes including D/H and $0^{18}/0^{16}$

Operation: Views below rover and at drill cuttings, volatile analysis while roving and during drill activities

MSolo Instrument



MS Sensor

Instrument Name	MSolo
Mass, CBE	6 kg
Dimensions	15.5 x 20 x 46 cm
Power	Average 35 W while scanning
Detectors	Faraday Cup (MDPP* 1.5e-12 Torr)
	Electron Multiplier (MDPP* 2e-15 Torr)

*MDPP – minimum detectable partial pressure @ m/z 28 with open ion source

VIPER Payload: The Regolith and Ice Drill for Exploring New Terrain (TRIDENT)

TRIDENT (Honeybee Robotics)
PI: Kris Zacny

Instrument Type: 1-meter hammer drill

Key Measurements: Excavation (and potential delivery) of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth (info on ice-cemented ground vs. ice-soil mixture).

Operation: Performs subsurface assays down to 100 cm in <1 hr, depositing cuttings at surface for inspection by other instruments.

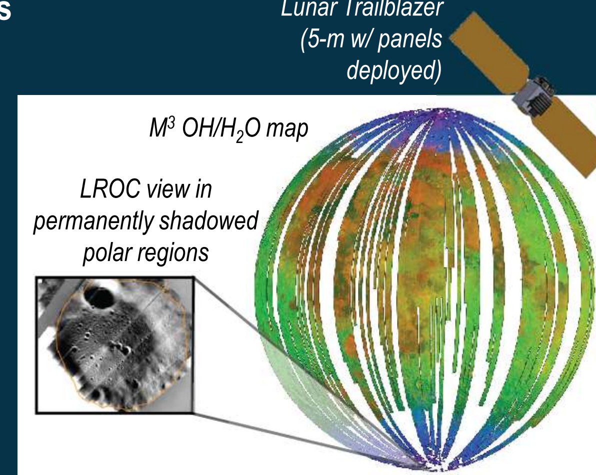
Instrument Name	TRIDENT
Mass [kg], CBE	18 (includes launch locks). Can be reduced for lander deployment.
Dimensions (stowed) [cm]	27 x 22 x 177 (for 1-m depth). Can be reduced for lander deployment.
Power [W]	Idle: < 5 Augering: ~20 nominal, 175 max Percussion: 0 nominal, 150 max
Telemetry (while operating)	~3.4 kbits/s

TRL6 Drill

Lunar cryo-chamber tests at GRC

SIMPLEx-2: Lunar Trailblazer (PI: Ehlmann, Caltech | DPI: Klima, APL)

- **Trailblazer addresses major scientific questions about the Moon and water cycles on airless bodies directly from the Planetary Science Decadal Survey.**
- **Trailblazer also forges a path for future exploration by evaluating locations of the operationally useful deposits of water and providing compositional basemaps of landing zones**

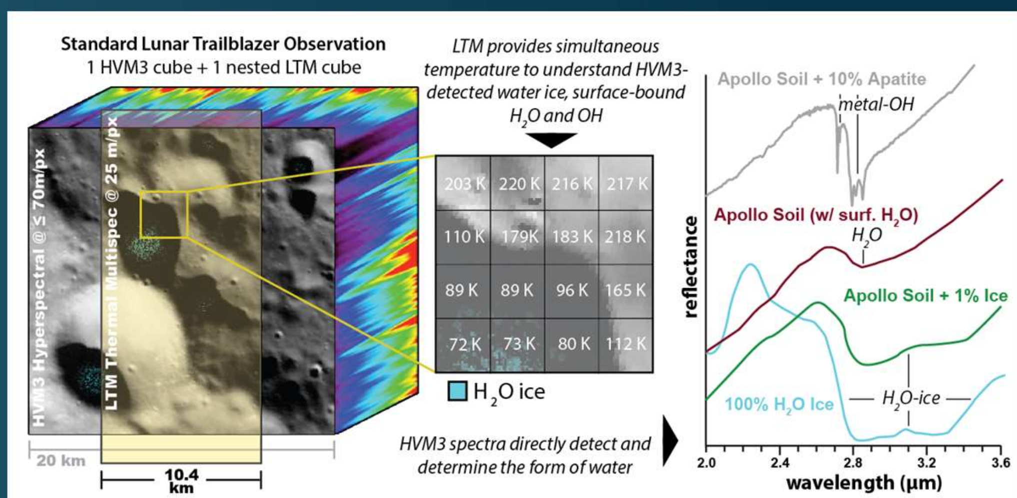


An **ESPA-Grande sized craft**, deployable from any GTO orbit, Trailblazer uses nested measurement sets from

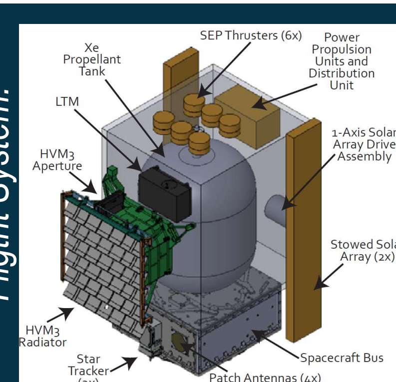
1) **High-resolution Volatiles and Minerals Moon Mapper (HVM^3):** a JPL-built imaging spectrometer (0.6-3.6 μm)
2) **Lunar Thermal Mapper (LTM):** University of Oxford-built multispectral thermal camera (7-100 μm)

to **determine the form, abundance, and distribution of water on the Moon**. Distribution is mapped a function of latitude, time-of-day, soil maturity, and lithology. Terrain-scattered light is used to map in permanently shadowed craters. Bonus science: compositional maps of igneous lithology

Example dataset:



Flight System:



ANGSA: Apollo Next Generation Sample Analysis

- Nine teams selected to analyze untouched Apollo samples
- Samples returned by Apollos 15 & 17 have been stored in pristine condition
- Will use techniques not available in the 1970s

Lunar Reconnaissance Orbiter

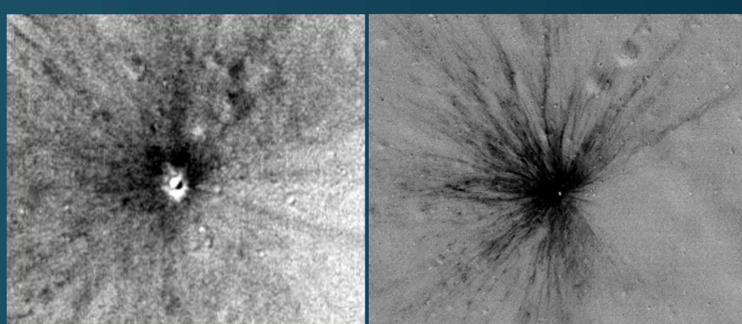
- **LRO now funded under LDEP**
- **Will be available to characterize potential landing sites for CLPS providers and international partners**

- **LRO coming up on a decade of observations**
- **Still providing new science**

Discovered hundreds of impact related changes since start of mission (NAC Before/After pairs)

Significance

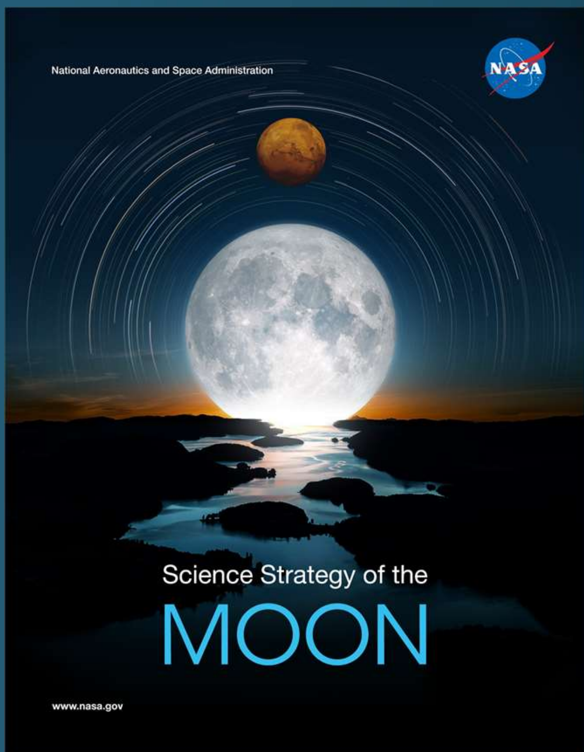
Refine flux of >0.5 m bolides inner Solar System
Seeing new complex ejecta patterns
Secondaries from small craters are extensive
Engineering constraints for future long lived assets



17 March 2013 impact, 18 m crater, secondaries found >30 km distant

Robinson et al., New crater on the Moon and a swarm of secondaries, Icarus, 2015
Speyerer et al., Quantifying crater production and regolith overturn on the Moon with temporal imaging, Nature, 2016

Science Strategy of the Moon



Implementation Strategy Using Precursor Robotics

- Use Commercial Lunar Payload Services (CLPS) contract to deliver instruments on and near the Moon
  - Volatile measurements are a priority
  - Science at both polar and non-polar locations
  - Drive increased capability including mobility and sample return
- Release and award science instrument development opportunities on an annual basis
- Include CLPS and Gateway opportunities in SMD AOs
- Develop an international strategy to enable partner scientific contributions

Science by 2024: CLPS

Polar Landers & Rovers

- First direct measurement of polar volatiles, improving our understanding of their lateral and vertical distribution, as well as their physical state and chemical composition
- Information on the geology of the South-Pole Aitken basin, the largest impact in the Solar System, potentially discovery of lunar mantle material

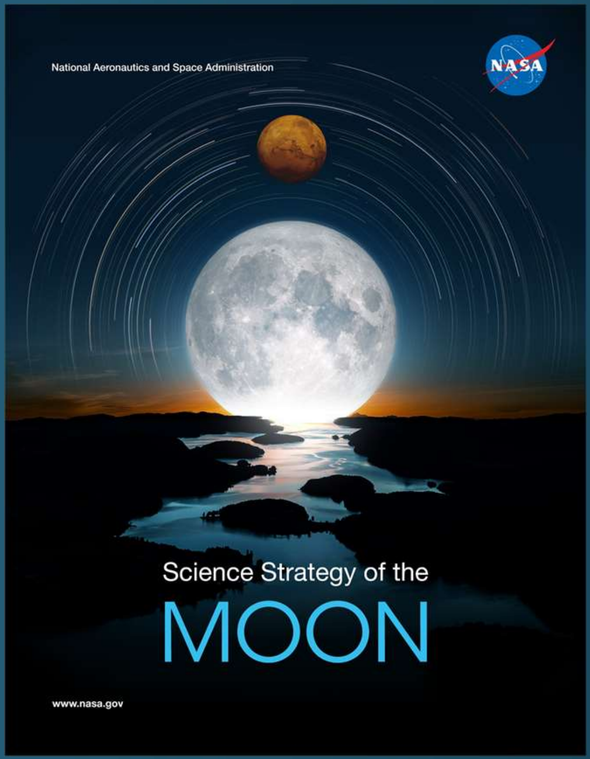
Non-Polar Landers & Rovers

- Ability to explore scientifically valuable terrains not explored by Apollo, examples could include:
  - ➢ Land at a lunar swirl and make the first surface magnetic measurement to help understand how these enigmatic features form
  - ➢ Visit young volcanic features such as Ina to understand the volcanic evolution of terrestrial planets
  - ➢ Far-side radio silent region
- PI-led instrument suites for Discovery-class science

Orbital Data

- CubeSats (Artemis-1 & delivered by CLPS providers), or comm/relay spacecraft could acquire new scientifically valuable datasets
  - ➢ Global mineral mapping (including resource identification), global elemental maps, improved volatile mapping

Science Strategy of the Moon



Implementation Strategy with Crew

- Develop an exploration science mission plan for the first human return mission
  - ➢ Engage the community to develop ideas for science to conduct on the lunar surface
  - ➢ Coordinate with HEOMD to prioritize surface science objectives, develop the necessary tools and terrestrial training to conduct that science
  - ➢ Provide potential landing sites analysis including new data acquisition
  - ➢ Consider potential pre-deployment of science experiments for the crew to set up
  - ➢ Provide surface reconnaissance of the landing site environs to help plan surface operations
  - ➢ Organize a science backroom to provide real time scientific guidance to the crews on the surface
  - ➢ Ensure that curation is prepared to accept new samples, including a preliminary examination team to catalog and organize those samples


NASA
EXPLORE MOON to MARS
MOON LIGHTS THE WAY