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
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
  - Deep Space Systems
  - Draper
  - Firefly Aeronautics, Inc.
  - Intuitive Machines, LLC
  - Lockheed Martin Space
  - Masten Space Systems, Inc.
  - Moon Express
  - 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.
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
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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

ASTROBOTIC SELECTS UNITED LAUNCH ALLIANCE VULCAN CENTAUR ROCKET TO LAUNCH ITS FIRST MISSION TO THE MOON

Pittsburgh, Penn., and Centennial, Colo., Aug. 19, 2019 – Astrobotic announced today that it selected United Launch Alliance’s (ULA) Vulcan Centaur rocket in a competitive commercial procurement to launch its Peregrine lunar lander to the Moon in 2021.
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

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

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

<table>
<thead>
<tr>
<th>Instrument Name</th>
<th>NSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass [kg], CBE</td>
<td>1.9*</td>
</tr>
</tbody>
</table>
| 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 ≥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\textsubscript{2}O, OH, and CO\textsubscript{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

<table>
<thead>
<tr>
<th>Instrument Name</th>
<th>NIRVSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass [kg]</td>
<td>3.57 kg (not including Fiber)</td>
</tr>
<tr>
<td>Spectrometer Module:</td>
<td>18x18x8.5</td>
</tr>
<tr>
<td>Observation Bracket:</td>
<td>20.4x13x15.1</td>
</tr>
<tr>
<td>Dimensions [cm]</td>
<td>Spectrometer = 12</td>
</tr>
<tr>
<td></td>
<td>Bracket Assembly = 5.26</td>
</tr>
<tr>
<td></td>
<td>Lamp = 12.3</td>
</tr>
<tr>
<td>Power [W], Avg</td>
<td>Range: 1.2 to 4.0 μm</td>
</tr>
<tr>
<td></td>
<td>SNR&gt;100 at 2 and 3 μm</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Water Ice to &lt;0.25%</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Radiance to &lt;25%</td>
</tr>
</tbody>
</table>
**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 O_{18}/O_{16}

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

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

*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.

<table>
<thead>
<tr>
<th>Instrument Name</th>
<th>TRIDENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass [kg], CBE</td>
<td>18 (includes launch locks). Can be reduced for lander deployment.</td>
</tr>
<tr>
<td>Dimensions (stowed) [cm]</td>
<td>27 x 22 x 177 (for 1-m depth). Can be reduced for lander deployment.</td>
</tr>
</tbody>
</table>
| Power [W]                        | Idle: < 5  
Augering: ~20 nominal, 175 max  
Percussion: 0 nominal, 150 max |
| Telemetry (while operating)      | ~3.4 kbits/s |
SIMPLEEx-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 (HVM₃): 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 as 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.
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