NASA Lunar Robotics for Science and Exploration

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Robotic lunar missions

RACE TO THE MOON
What started as a contest between the US and the USSR has become the scene of international collaboration.

Kaguya (orbiter)
Chang'e 1 (orbiter)
LRO (orbiter)
Luna Glob (lander)
Chang'e 2 (lander)
GRAIL (orbiter)
LADEE (orbiter)
Chandrayaan-2 (lander)
MoonLITE (lander)
Moon Next (lander)
International Lunar Network 362 (lander)
International Lunar Network 364 (lander)

US
9 orbiters
11 landers
3 impactors
1 fly-by

USSR
6 orbiters
7 landers
1 impactor
6 fly-bys

Uncrewed
Crewed

China
1 orbiter
Europe
1 orbiter
Japan
1 orbiter
1 impactor

SUCCESSFUL MOON MISSIONS PRIOR TO 2008

D. Mackenzie, New Scientist, July 11 2008
Robotic lunar missions at MSFC

- **Lunar Precursor Robotics Program (LPRP)**
  - Robotic missions to gather lunar environmental data to advance U.S. exploration objectives earlier and with less cost
  - LRO and LCROSS

- **Discovery Program**
  - Small PI-led science missions, competed among all science
  - M3 and GRAIL

- **Lunar Science Program**
  - Robotic missions to accomplish key lunar scientific objectives
  - LRO, which will transition after one year of operations to SMD for a 2-year nominal science mission, LADEE, and two landed payloads as part of the International Lunar Network (ILN)
LRO (2009)

- Lunar Reconnaissance Orbiter (LRO) – initiated in 2004 as the first step back to the Moon in the Vision for Space Exploration
- Exploration Systems Mission Directorate (ESMD) – focus is on datasets to help plan human activities
- Goddard project, managed under LPRP at MSFC
- **Objectives:**
  - Characterization of the lunar radiation environment, biological impacts, and potential mitigation
  - High resolution global topography necessary for selecting future landing sites
  - Assess resources and environments of lunar polar regions
  - High spatial resolution visible imagery
## LRO Instruments

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>Measurement</th>
<th>Exploration Benefit</th>
<th>Science Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRaTER (BU+MIT)</td>
<td><em>Tissue equivalent response to radiation</em></td>
<td>Safe, lighter weight space vehicles that protect humans</td>
<td>Radiation conditions that influence life beyond Earth</td>
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<tr>
<td>Diviner (UCLA)</td>
<td><em>300m scale maps of Temperature, surface ice, rocks</em></td>
<td>Determines conditions for systems operability and water-ice location</td>
<td>Improved understanding of volatiles in the solar system - source, history, migration and deposition</td>
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<tr>
<td>LAMP (SWRI)</td>
<td><em>Maps of frosts in permanently shadowed areas, etc.</em></td>
<td>Locate potential water-ice (as frosts) on the surface</td>
<td></td>
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<tr>
<td>LEND (Russia)</td>
<td>Hydrogen content in and neutron radiation maps from upper 1m of Moon at 5km scales, Rad &gt; 10 MeV</td>
<td>Locate potential water-ice in lunar soil and enhanced crew safety</td>
<td></td>
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<tr>
<td>LOLA (GSFC)</td>
<td>~50m scale polar topography at &lt; 1m vertical, roughness</td>
<td>Safe landing site selection, and enhanced surface navigation (3D)</td>
<td>Geological evolution of the solar system by geodetic topography</td>
</tr>
<tr>
<td>LROC (NWU+MSSS)</td>
<td>1000 of 50cm/pixel images (125km²), and entire Moon at 100m in UV, Visible</td>
<td>Safe landing sites through hazard identification; some resource identification</td>
<td>Resource evaluation, impact flux and crustal evolution</td>
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LCROSS (2009)

- Lunar Crater Observation and Sensing Satellite, chosen as a secondary payload on LRO vehicle
- Ames project under LPRP management
- **Objectives:** to reveal the presence & nature of water ice on the Moon
- Shepherding S/C directs the Centaur into a permanently-shadowed crater
- The S-S/C observes the ejecta cloud, and then enters the cloud using several instruments looking for water
- Lunar-orbital and Earth-based assets will also be able to study both clouds (LRO, Chandrayaan-1, HST, etc)
LCROSS Instruments

1 Visible Context Camera:
4 color, 6 degree FOV, <0.5 km resolution at T-10 min to S-S/C impact

2 NIR Cameras
1.4 μm water ice band depth maps
1 km resolution at T-10 min

2 mid-IR Cameras
7 and 12.3 μm
< 0.5 km resolution

1 Visible Spectrometer
0.25 to 0.8 μm, ~0.002 μm resolution

2 NIR Spectrometers
1.35 to 2.45 μm, 0.012 μm resolution

1 Total Visible Luminance Photometer
Broadband from 0.6 – 1.2 μm, sample rate >1000 Hz, < nW NEP @ 1000 Hz
**GRAIL (2011)**

- Gravity Recovery and Interior Laboratory, an SMD PI-led mission by Dr. Maria Zuber at MIT, managed by Discovery program
- Based on GRACE on the Earth - twin spacecraft with mutual microwave ranging to very precisely map the moon's gravity field
Moon Mineralogy Mapper (2008)

- Discovery PI-led instrument by Carle Pieters at Brown University on Chandrayaan-1
- Imaging spectrometer (VIS-NIR) to map the lunar surface at high spatial and spectral resolution
- Objectives: characterize and map the mineral composition of the lunar surface to gain information about the Moon's geologic evolution
LADEE (2011)

- Lunar Atmosphere, Dust and Environment Explorer, Ames/GSFC project, managed by Lunar Science Program at MSFC
- Instruments: Neutral Mass Spectrometer, UV/VIS spectrometer, Dust counter
  - **Goals:**
    - Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity
    - Determine if the Apollo astronaut sightings of diffuse emission at 10s of km above the surface were Na glow or dust
    - Document the dust impactor environment (size-frequency) to help guide design engineering for the outpost and also future robotic missions
ILN (2014)

- International Lunar Network—a geophysical network to accomplish high priority science, but difficult for any single agency to accomplish on its own
- US and international landed missions, 2-4 US Landers planned, project at MSFC/APL, managed by Lunar Science Program at MSFC
- **Goals**: understand the interior structure and composition of the moon
  - Determine the thickness of the lunar crust (upper and lower)
  - Characterize the chemical/physical stratification in the mantle
  - Determine the size, composition, and state (solid/liquid) of the core of the moon.
  - Characterize the thermal state of the interior
• US Science Definition Team recommended seismometers, heat flow probes, electromagnetic sounding, laser ranging (active or passive)

• International Core Instruments Working Group chartered July 2008 to define core ILN instruments

• International Communications Working Group also chartered July 2008 to coordinate communication and navigation needs to support ILN and beyond, including spectrum, standardized communication protocols standardized data and networking protocols
Summary

• NASA is undertaking a sustainable yet comprehensive approach to robotic investigation of the moon to support science and exploration objectives.

• The lunar flight projects being undertaken by NASA provide a robust robotic lunar flight program for the next decade, complement lunar R&A initiatives to rebuild a lunar science community, and increase international participation in NASA’s exploration plans.