Characterizing Lunar Water
Resource Prospector: A rover mission to the Lunar polar region

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History of Water on the Moon

Chandrayaan-1 radar data consistent with water ice in PSRs and M3, Deep Impact HRIIR, and Cassini VIMS data indicate presence and variability of surface OH/H₂O.

Clementine bi-static radar suggests water ice in polar permanently shadowed regions (PSRs).

1961 - Watson, Murray & Brown theorize Lunar cold traps may contain water ice.

1969-1972 Apollo samples suggest a dry moon.

1994

2008

2009

2010 ...

Integrated data from instruments on LRO support large quantities of water ice in PSRs and partially sunlight regions.

Lunar Prospector Neutron Spectrometer detects elevated hydrogen levels correlated with PSRs.

LCROSS impacts Cabeus A and detects significant quantities of water in the ejecta.
History of Water on the Moon

Polar Temperatures and Volatiles

Modeled annual mean temperature

Long-term vacuum stability temperatures for observed volatiles

Only volatiles with T>80 K (above red dashed line) expected below surface in sunlight regions.
Moving Forward – What Must Be Done

Given: There are potentially substantial hydrogen rich resources on the Moon…

Then: We must gain the necessary knowledge to guide future mission architectures to allow effective utilization of in-situ resources to their fullest extent and optimum benefit.

- Understand the resources – Resource Prospector (RP)
  - What resources are there (minerals, volatiles, water/ice)?
  - How abundant is each resource?
  - What are the areal and vertical distributions and hetero/homogeneity?
  - How much energy is required to locate, acquire and evolve/separate the resources?

- Understand environment impact on extraction and processing hardware
  - What is the local temperature and illumination environment?
  - What are the physical/mineralogical properties of the local regolith?
  - Are there extant volatiles that are detrimental to processing hardware or humans?
  - What is the impact of significant mechanical activities on the environment?

- Design and use hardware to the maximum extent practical that has applicability to follow-on ISRU missions
  - Can we effectively separate and capture volatiles of interest?
  - Can we execute repeated processing cycles (reusable chamber seals, tolerance to thermal cycles)?
RP is being pursued within NASA to prospect for volatiles in the polar regions of the Moon.

RP addresses using lunar resources to produce oxygen and propellants that enable new mission architectures for human exploration.

RPM is targeted for launch in 2021/22.

Mission elements include:

**Launch vehicle** – TBD, Potentially SLS, EM-2

**Lunar lander**
- Commercial
- International Cooperation, possibly Taiwan

**Rover** - NASA

**Payload** – NASA

**Surface and sub-surface characterization**
- neutron spectrometer – sub-surface
- near-infrared spectrometer, camera, radiometer – surface & sub-surface

**Sample collection, delivery, analysis**
- drill - collect and deliver sample(s)
- oven - heats sample(s)
- gas chromatograph / mass spectrometer - characterizes sample volatiles

RP - “Big Picture”
RP– The Tools

Drill
• Subsurface sample acquisition
• Near-surface assay
• Detailed subsurface assay

NIR Volatiles Spectrometer System (NIRVSS)
• Surface composition and H₂O/OH identification
• Near-subsurface sample characterization
• Drill site spectroscopy, imaging, and temperatures

Neutron Spectrometer System
• Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

Oxygen & Volatile Extraction Node
• Volatile Content/Oxygen Extraction by warming
• Total sample mass

Lunar Advanced Volatile Analysis (LAVA)
• Analytical volatile identification and quantification using GC/MS
• Measure water content of regolith at 0.5% (weight) or greater
• Characterize volatiles of interest below 70 AMU

Rover
• Mobility system
• Cameras
• Surface interaction
**Landing Site Requirements**

**RPM Polar Landing**

Must meet the following four criteria

1. **Surface/Subsurface Volatiles**
   - High hydrogen content (LRO LEND & LPNS instruments)
   - Constant <100 K temperatures @ 10 cm below surface (LRO Diviner instrument)
   - Surface OH/H$_2$O ($M^3$, LRO LAMP & Diviner)

2. **Reasonable terrain for traverse**
   - Slopes $< 10^\circ$
   - Limited density of rocks

3. **Direct Earth view for communication (DTE)**

4. **Sunlight for duration of mission for power**
A Potential S. Pole Landing Sites

**LEND Results**

- **Site Analysis**
  - **Site:** A | B | C
  - **Shallow “Frost Line”**<0.1 m | <0.2 m | <0.1 m
  - **Slopes**<10° | <15° | <10°
  - **Neutron Depletion** 4.5 cps | 4.7 cps | 4.9 cps
  - **Temporary Sun** 4 days | 2-4 days | 5-7 d
  - **Comm Line of Sight** 8 days | 17 days | 17 days
  - *may not coincide

**Very short duration mission**

**Predicted Volatile Stability**

**Solar Power Potential**
Step #1: Get there…

- **Cruise Phase (Depends on launch vehicle):**
  - 5-day direct Earth to Moon transfer w/DSN S-band
  - Spin up to 1 rpm using Attitude Control System (post-TLI)
    - No de-spin during TCMs
  - Perform system checkout
  - Perform two TCMs (nom.)
  - Perform two Neutron Spec calibrations (nom.)

- **Contingency / Off nominal**
  - Allows for two (2) additional TCMs
  - Propellant margin for spin / de-spin for thermal anomalies
Step #2: Land there…
Details depend on launch vehicle)

Cruise

Braking Burn

Descent & Landing

Separation

Final Descent

Landed

Surface Operations

Payload/rover powered on during descent

Landing images transmitted during descent via 84 kbps fan antenna

Initial Altitude: 16.6 km
Initial Velocity: 2.5 km/s

Initial Altitude: 3 km
Initial Velocity: 0.105 km/s

Touchdown Velocity: <.001 km/s

Payload & rover checkout + NS cal, prior to release & roll-off of rover.

Rover DTE comm. during surface ops

Lander power down upon landing

TCMs w/Spin stabilized attitude perpendicular to Sun

DTE Comm via omni antenna

During cruise, comm link is used for payload calibration & bake-out operations

Assume power up post separation (after shroud jettison)
Step #3: Prospect & Excavate there...

Landing site candidate areas (green):
- No slopes > 15° in 200 m diameter landing ellipse
- Must have sun & communication for 48 hrs
- Must have lit terrain on approach during powered descent

Traverse path:
- No slopes > 15° (using 20-m LOLA gridded product)
- Sun/comm corridors with margin

White circles near surface assay
- blue circles deep, 1m, drilling

Site Overview
Plan: noble-i v 3
Time: 1/13/2022 11:49:40 PM
Science Goals

1. **Monitor** the surface during rover traverses and at excavation sites for water and other volatiles.
   - Identify surface bound H$_2$O/OH
   - constrain mineralogical/geological context
   - measure surface temperatures

2. **Observe** the immediate vicinity of the drill site before and during drill operations to look for real-time changes in the properties of the materials exposed during drilling.
   - Identify volatiles, including water form (e.g., ice vs. bound) at all depths drill exposes at surface
   - Constrain the volatile presence in top ~20-30 cm of regolith: provides constraints on NSS measurements of hydrogen abundance
   - Constrain surface/subsurface temperatures
Spectrometer Box

- Two spectrometers to achieve wavelength range and resolution to identify key volatiles (solids)
- Shortwave (SW): 1590-2400 nm
- Longwave (LW): 2300-3400 nm

Bracket Assembly

**Lamp** - Enables spectral observations in illuminated and shadowed terrain

**Drill Observation Camera (DOC) & LEDs**

- Image drill area with sufficient FOV to observed ~20 cm of tailings
- Sufficient resolution to identify regolith structure at scales ~500 µm
- Using multiple-wavelength LEDs for surface mineral composition

**Longwave Calibration Sensors (LCS), 7.8, 10.6, 14, and 25 µm**

- Surface temperatures
- Correct thermal emission contamination in 3 µm band → required for determining concentrations of OH/H2O
NIRVSS designed for minerals and ices

Ices

Minerals & Organics

DOC LEDs

SW range

LW range

Minerals & Organics

Ferric

Mafic

Phyllosilicates

Bound Water

Hydrocarbons

HCN

Wavelength, nm

1000

2000

3000

4000

5000

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NIRVSS Components

- Spectrometers
- Fiber inputs
- Lamp
- Fiber Viewports
- DOC
- LCS
- NIRVSS Components
- LEDs
NIRVSS Testing

Glenn Research Center VF-13
Vacuum Chamber
NIRVSS Testing

From Ames we command data collection by NIRVSS and monitor DOC imaging and spectral data
NIRVSS Testing

DOC Unsaturated Color Composite

Phone camera Image during assembly, color not correct bottom row are gray scales 10, 20, 30 percent reflectance

scale = 1
B = 410 nm LED
G = 540 nm LED
R = 650 nm LED
Spectral parameters to monitor water ice during drilling

Water ice, \(\sim 80 \mu m\) [6]

\[ BD2000 = 1 - \frac{a}{b} \]

\[ BD3000 = 1 - \frac{c}{d} \]
Monitor band parameters as drilling progresses

BD2000 and BD3000 as drilling proceeds
Show the movie