Extreme Mapping:
Looking for water on the moon

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What are the exploration challenges we face?
You cannot easily fly surveys over the moon.
Scientists prefer to go into the field. Dr. Darlene Lim sampling basalt, Hawaii Volcanoes National Park.
It is not often we have astronauts on Extra-Vehicular Activity (EVA)
Why should we look for water on the moon?
Human space exploration

People need to drink almost 2 liters of water per day.
Today it costs $450 to launch one kg.

Photo: Pat Corkery
United Launch Alliance
Yes, we recycle urine on the ISS Water Recovery System.
We can use water to make fuel.

Apollo 11 lunar module returning from the moon.
Finding water ice on the moon helps us learn about the moon’s history.

Image: NASA / JPL - Caltech
What do we already know?
Moon facts:

- 384,400 km (238,900 mi) from Earth
- Temperatures from 123 °C (253 °F) to -233 °C (-387 °F)
- The same side of the moon is always facing the earth.
Lunar Reconnaissance Orbiter (LRO) gathers high resolution maps and data
Nearside reflectance map built of mosaic strips
We can stitch together images to form map layers

Lunar North Pole
Floor and eastern wall of Antoniadi crater
Copernicus crater central peak
Slope map from LOLA
LRO’s LOLA measures topography using lasers

LOLA topography of LCROSS landing
LRO’s DIVINER measures surface temperature
GRAIL built a gravity map
We know that there is water ice on the moon.
Lunar Crater Observation and Sensing Satellite (LCROSS) measured hydrogen on the moon.
Simulation of LCROSS deployment
LCROSS plume
What is the proposed Resource Prospector Mission?
Solar powered Batteries
No nuclear power

RP Engineering Prototype Rover
RP Engineering Prototype Rover in action
How do the instruments work to detect water?
Near Infrared Volatile Spectrometer System
NIRVSS

Detects surface elements

Hydrogen spectrum
Neutron Spectrometer System
NSS

Detects subsurface elements
Oxygen and Volatile Extraction Node (OVEN) & Lunar Advanced Volatile Analysis (LAVA)
RP Engineering Prototype Rover

- Subsurface Sample Collection
  - Drill
- Operation Control
  - Flight Avionics
- Resource Localization
  - Neutron Spectrometer System (NSS)
- Vision & Comm
  - Camera/Antenna Mast
- Volatile Content/Oxygen Extraction
  - Oxygen & Volatile Extraction Node (OVEN)
- Heat Rejection
  - Radiator (Simulated)
- Volatile Content Evaluation
  - Lunar Advanced Volatile Analysis (LAVA)
- Sample Evaluation
  - Near Infrared Volatiles Spectrometer System (NIRVSS)
- Power
  - Solar Array (Simulated)
How do we plan where to send the rover?
Sun shadow crossing a candidate site, calculated from topography

NASA/ Mark Shirley | Images: Andy McGovern / APL
Build map layers and mark up maps

Multi-temporal illumination map of the lunar south pole

NASA/GSFC/Arizona State University
Create simple sequential route plans in xGDS on OpenLayers 3 (Exploration Ground Data Systems)

Duration estimates based on average speed
How much time does the rover have left in each area?

dark red = 4h
red = 8h
orange = 8-16h
yellow = 16-24
other colors = additional days

NASA/ Matthew Deans | Images: Andy McGovern / APL
Prototype planner: can the rover follow the proposed route?
Prototype planner: How much margin is there at each point?
How do we communicate with a rover on the moon?
We communicate with the Deep Space Network (DSN)

Goldstone Antenna
DSN covers the whole planet.

- **Goldstone view**
- **Madrid view**
- **Canberra view**

**Moon is 10x further away than GEO**

- Geosynchronous orbit
- 30,000 km from Earth
- Low Earth Orbit (600 km)
It can take 2 minutes to communicate one way between the Earth and the Moon over the DSN.
How do we remotely operate a rover on the moon?

NASA / Bill Anders / Apollo 8
Rover Operator Interface (VERVE)
In VERVE, we customize tabular views to show diagnostics.
VERVE shows 3D terrain with overlays for rover operators.
VERVE can adjust our terrain models with new data.
2011 Mars Science Laboratory (MSL) & Antares for Curiosity

NASA/ Laurence Edwards
Hazard Detection with lasers
Hazard detection test
How do we prepare for a lunar mission?
We practice at our facilities.

NASA ARC Mission Control driving RP15 rover at NASA JSC, August 2015

NASA JSC Rock Yard from the rover (left) stereo camera

NASA KSC Payload Control
We practice in the field with “Analog Missions”

Mojave Volatile Prospector (MVP) 2014 KReX2 rover with RESOLVE instruments
Prospecting Payload on K-REX Rover

Sample Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS)

Resource Localization
Neutron Spectrometer System (NSS)
Making sure we will find water
MVP sampling
How do scientists work with the rover?
The science team for MVP works in the back room at NASA Ames
Plan
Monitor & Archive
Explore

Pre-Mission
During Mission
Post-Mission

Exploration Ground Data Systems (xGDS) for rapid remote science
Scientists can customize their own views of the data.
Each person in the back room has a particular job.
Scientists must also monitor the rover.
Scientists take geolocated notes within xGDS
Scientists can search for data within xGDS and use it for planning.
Scientists can monitor rover position, tracks, notes and other events in xGDS.
xGDS aggregates plot data

Drilling:
- 28cm – 50cm
- 50cm - 60cm
- Drill Extraction

Contact with ground

Drill position at contact

Water signal
- No water signal
- Water signal

Drill Depth Baseline
Band Depth Baseline
Plots correlated with images

Drill position at contact

Drill Depth Baseline

Band Depth Baseline

Water signal

No water signal

Water signal

Contact with ground

Drilling: 28cm – 50cm

Drilling: 50cm – 60cm

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20120718-002137

20120718-002207

20120718-002207
xGDS can compare instrument readings with reference spectra
xGDS can aggregate instrument readings into heat maps
MVP Mission Analog monitoring
What will this mission accomplish?
We will have expanded human knowledge about the moon.
NASA builds our tools on open source software.

When you contribute to open source software, you may be helping NASA explore our universe.
NASA releases open source software.

software.nasa.gov
code.nasa.gov
github.com/nasa
ti.arc.nasa.gov/opensource/projects/
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