Resource Prospector (RP)
A lunar volatiles prospecting and In-Situ Resource Utilization (ISRU) demonstration mission

Briefing to IEEE Robotics and Automation Society
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2016-07-20
http://www.nasa.gov/resource-prospector  @NASAexplores

No Export Controlled materials (ITAR/EAR)
The Hunt for Lunar Volatiles

Clementine (1994):  
Bi-static radar tests with Arecibo could indicate water-ice in permanently shadowed craters

Lunar Prospector (1998):  
Permanently-shadowed polar craters contain elevated Hydrogen levels

LCROSS/LRO (2009):  
There is water-ice and other volatiles in the permanently-shadowed regions

“Could that Hydrogen be trapped as water-ice?”

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“How are the volatiles distributed and can we make use of them?”

RP (2020): “Land and prospect for the water-ice. Experiment with ISRU to extract water from the soil…”

LCROSS not only confirmed presence of water-ice in a permanently-shadowed region, but showed there may be enough to be economically viable.
RP will provide water-ice distribution on human-scales [m-km], and will explore if areas of temporary sunlight might also retain water ice, making water potentially much more accessible.
The Top Strategic Risk: we don’t know exactly how much water is in the moon or how deep, or how plentiful it is. This is a key strategic issue we need to understand… and if there is one thing we should do soon, it is to send soon a resource prospector to the moon.

Charles Miller - Study PI & President of NexGen Space LLC
Evolvable Mars Campaign
A Pioneering Approach to Exploration

Earth Reliant

Proving Ground

Earth Independent

The Trade Space
Across the Board
- Solar Electric Propulsion
- In-Situ Resource Utilization (ISRU)
- Robotic Precursors
- Human/Robotic Interactions
- Partnership Coordination
- Exploration and Science Activities

Cis-lunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

AIAA SPACE-2014 Conference
Crusan presentation, 2014-08-07
RP Mission Animation
Site Selection Criteria

- Likely subsurface volatiles
  - Sustained low subsurface temperatures conducive to volatile retention
  - Orbital neutron spectrometer hydrogen signature

- Sufficient daylight illumination
  - More than 4 Earth days of solar power for rover operations
  - Clement surface temperature for rover survival

- Suitable for Direct to Earth (DTE) communication
  - DSN stations clear the horizon

- Traversable terrain
  - Slopes < 10 deg
  - Limited density of rocks

2011-10-18, “RESOLVE Sun & Shadow DRM 2.2”, RESOLVE Architecture Team
NSS Subsurface Hydrogen (Ice) Sensing

- Galactic cosmic rays shatter nuclei in the lunar soil.
- The shattered nuclei release neutrons, creating a “flux” of neutrons leaking to space.
- Those leaked neutrons tell us about near-subsurface composition.
- Variations in that Neutron flux while roving, tell us about the abundance and burial depth of hydrogenous materials in subsurface.

The RP NSS measures neutron flux for prospecting, able to sense hydrogen-bearing materials (e.g. water-ice) up to 1 meter depth, enabling mapping while roving.
Landing sites under discussion

- RP Team is working with candidate partners to optimize landing site
  - Many possibilities exist trading volatiles concentration, terrain, lighting, Direct-To-Earth Comm, and mission duration
RP15 Field Testing
RP Neutron Spectrometer (NSS) & NIR Spectrometer (NIRVSS) field tests (2014-08)

NSS in the NASA-ARC Roverscape
- The NSS is located on the rover and in front of that is a neutron source holder for Earth testing only (simulating lunar radiation activity)
- The team has driven across rock patches and an ice proxy for testing

NIRVSS in the NASA-ARC Roverscape
- The team drove across rock patches and an ice proxy for testing
RP Drill & NIRVSS testing
2013-09 & 2015-07

Drill & NIRVSS testing in TVAC chamber at NASA-GRC (-80°C)

RP15 Rover-hosted Drill testing in doped simulant tube at NASA-JSC
• RESOLVE ISRU payload systems undergoing engineering test
  – Subsystem TVAC and vibe testing, drilling in relevant environment, etc
• Prototyped a cost-efficient lander
  – Novel aluminum riveted structure concept reduces complexity and cost
  – NASA looking for international partner to provide the lander
Payload & Drill subsystem

Regolith filling the crucible

Crucible processing

Material capture
Rover Frame/Chassis

Heat spreaders

Batteries
Rover Suspension/Drive Subsystem

Suspension assembly

1g wheels
RP15 Rover/Payload integration
2015-07

Rover Assembly
RP15: Surface Segment (Payload/Rover)

- Subsurface Sample Collection
  - Drill

- Operation Control
  - Flight Avionics

- Resource Localization
  - Neutron Spectrometer System (NSS)

- Sample Evaluation
  - Near Infrared Volatiles Spectrometer System (NIRVSS)

- Heat Rejection
  - Radiator (Simulated)

- Vision & Comm
  - Camera/Antenna Mast

- Volatile Content/Oxygen Extraction
  - Oxygen & Volatile Extraction Node (OVEN)

- Volatile Content Evaluation
  - Lunar Advanced Volatile Analysis (LAVA)

- Power
  - Solar Array (simulated)

- Surface Mobility/Operation
  - Rover
Rover Dimensional Comparison (approx.)

- 1.5m x 1.5m x 2.0m (LxWxH)
- Weighs about 300kg

Sojourner (1996):
- 0.6m x 0.5m x 0.3m (LxWxH)
- Weighs about 11kg

Spirit/Opportunity (2004):
- 1.6m x 2.3m x 1.5m (LxWxH)
- Weighs about 180kg

Curiosity (1996):
- 3.0m x 2.8m x 2.1m (LxWxH)
- Weighs about 900kg
RP15 First Prospecting/Processing in the Field

2015-08-18

Crucible awaiting sample inside the rover

RP15 drilling in the JSC Rock Yard
RP15 Drilling on a slope in the Field
2015-08-24

Sloped Drilling at JSC

Sand Captured in Drill Brush Housing & Flutes
Mother Nature rebelling. Building sand barriers to flowing water.

Heading back to the highbay to do a systems check.
"VERVE" driving tool funded by STMD...

…. how we drove RP15 at JSC from ARC
Distributed Operations Test testing

2015-08-21

NASA-ARC Mission Control room driving RP15 rover @ NASA-JSC

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

3-D Image Viewing of NIRVSS Camera Images During DOT

NASA-KSC Payload Control room
RP15 Environmental Testing
RP15 in ARGOS gravity offload facility (1/6g) (VIDEO)

Mobility, Lander Egress, Drilling
Wheel grouser studies: Obstacle climbing @ 1/6g
RP15 Undergoing TVAC testing
2016-03

TVAC chamber testing of RP15 rover subsystems

RP15 wheels & steering assemblies undergoing TVAC test
RP15 Undergoing Vibe testing
2016-03

TVAC chamber X/Y-axes testing of RP15 rover

TVAC chamber Z-axis testing of RP15 rover

OVEN in vibe

Drill in vibe
Drill testing at NASA-GRC’s VF-13 TVAC chamber measuring lunar volatiles loss when drilling a meter deep into lunar soil and transferring materials into the RP rover.

Testing the flight-like RP system, including spectrometers, a drill, and sample-handling system at lunar conditions, with engineered lunar-like soil conditions, doped with 5% water and chilled to -100°C.
Stereo Vision testing in lunar polar contexts

2016-06

Studying stereo camera effectiveness with different rocks sizes/distributions and low-angle sunlight (long shadows)
RP Education and Public Outreach Activities

• Full assault on Social Media!
  – Actively putting RP’s message our there
  – Ranking member Rep Mike Honda’s Chief staffer requested an RP briefing @ NASA-ARC because of what he “and other techie staffers” read on Twitter
Resource Prospector (RP) Overview

Mission:
• Characterize the nature and distribution of water/volatiles in lunar polar sub-surface materials
• Demonstrate ISRU processing of lunar regolith

RP Specs:
• Mission Life: 6-14 earth days (extended missions being studied)
• Rover + Payload Mass: 300 kg
• Rover Comm: X-band 600kbps directional / 4kbps omni downlink
• Rover Dimensions: 1.4m x 1.4m x 2m
• Rover Power (nom): 300W
• Max speed: 25cm/s. Prospecting: 10cm/s
• Cost: <$350M (excl LV)
• Mission Class: D-Cat III
• Launch Vehicle: Falcon 9 v1.1

Project Timeline:
✓ FY14: Phase A (Formulation)
✓ FY15: Phase A (Demonstration: RP15)
• FY16: Phase A (Environmental testing: RP15)
• FY17: Phase B SRR/MDR
• FY18: PDR (Implementation)
• FY19: CDR (Critical design)
• FY20: SIR/I&T
• FY21/22: RP launch
Let’s go.