Resource Prospector Instrumentation for Volatile Analysis

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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

Project Timeline:
- FY13: Pre-Phase A: MCR (Pre-Formulation)
- FY14: Phase A (Formulation)
- FY15: Phase A (Demonstration: RP15)
- FY16: Phase A (Risk Reduction)
  - FY17: L2 Requirement Lockdown (July 11)
  - FY18: MRD and PDR (Implementation)
  - FY19: CDR (Critical design)
  - FY20: I&T
  - FY21: RP launch

RP Specs:
- Mission Life: 6-14 earth days (extended missions being studied)
- Rover + Payload Mass: 300 kg
- Total system wet mass (on LV): 5000 kg
- Rover Dimensions: 1.4m x 1.4m x 2m
- Rover Power (nom): 300W
- Customer: HEOMD/AES
- Cost: ~$250M (excl LV)
- Mission Class: D-Cat3
- Launch Vehicle: EM-2 or ELV
Resource Prospector – The Tool Box

**Sampling**
- Drill
  - Subsurface sample acquisition
  - Auger for fast subsurface assay
  - Sample transfer for detailed subsurface assay

**Prospecting**
- Neutron Spectrometer System (NSS)
  - Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth
- NIR Volatiles Spectrometer System (NIRVSS)
  - Surface H2O/OH identification
  - Near-subsurface sample characterization
  - Drill site imaging
  - Drill site temperatures

**Mobility**
- Rover
  - Mobility system
  - Cameras
  - Surface interaction

**Processing & Analysis**
- Oxygen & Volatile Extraction Node (OVEN)
  - Volatile Content/Oxygen Extraction by warming
  - Total sample mass
- Lunar Advanced Volatile Analysis (LAVA)
  - Analytical volatile identification and quantification in delivered sample with GC/MS
  - Measure water content of regolith at 0.5% (weight) or greater
  - Characterize volatiles of interest below 70 AMU

Presentations:
- 11:30 Ted Roush -- Water Ice in Lunar Simulants: NIRVSS Drilling Observations
- 2:35 Julie Kleinhenz -- Characterization of Volatiles Loss from Soil Samples at Lunar Environments

Posters:
- Colaprete: Traverse and Observation Planning for the Resource Prospector Mission (#66)
- Zacny: The Resource Prospector Drill (#79)
RP15: Surface Segment (Payload/Rover)

- Subsurface Sample Collection
- Operation Control
- Resource Localization
- Sample Evaluation
- Vision & Comm
- Heat Rejection
- Power
- Volatile Content/Oxygen Extraction
- Volatile Content Evaluation
- Surface Mobility/Operation

- Drill
- Flight Avionics
- Neutron Spectrometer System (NSS)
- Near Infrared Volatiles Spectrometer System (NIRVSS)
- Camera/Antenna Mast
- Oxygen & Volatile Extraction Node (OVEN)
- Lunar Advanced Volatile Analysis (LAVA)
- Solar Array (simulated)
- Rover
Volatile analysis demonstration measured increasing water concentration as simulant sample temperature increases.
OVEN (Oxygen and Volatile Extraction Node)

Multiple functions

- Receive sample from drill
- Confine sample to a known volume
- Weigh sample
- Heat sample, build pressure from volatiles
- Transfer volatile sample to LAVA Subsystem
- Discard sample

**REACTOR STATION**
Seals and heats sample up to 450 °C

**STORAGE STATION**
Locks two crucibles in place during launch

**ARM**
Has three degrees of freedom to move crucible to different stations

**SAMPLE REMOVAL STATION**
Inverts crucible to remove sample

**WEIGH STATION**
Measures mass of sample

**CRUCIBLE** (Shown at sample acceptance location)
Holds 12 ccs of sample delivered from drill
OVEN Subsystem

- Completed testing to understand temperature distribution of regolith during heating profiles to compare to modeling results
- Completed testing of required sealing forces and dust tolerance of seals to minimize volatile loss during heating

Trade Studies
- Crucible chiller – To reduce sublimation losses
- Weigh and Dump Stations – May be removed
- Integrated RTD in crucible- Provides sample temperature but adds complexity
- Active vs passive gripper
Lunar Advanced Volatile Analysis (LAVA)

• Purpose: Identify and quantify water as well as other low molecular weight species of interest to ISRU and Science community

  - Volatiles are transferred from the OVEN reactor to the LAVA Surge Tank where the pressure & temperature are measured

  - Gas sample is diluted and analyzed by GC-MS to identify and quantify constituents.

  - Gases of interest are H\textsubscript{2}O, CO, CO\textsubscript{2}, H\textsubscript{2}, H\textsubscript{2}S, NH\textsubscript{3}, SO\textsubscript{2}, CH\textsubscript{4}, and C\textsubscript{2}H\textsubscript{4} (1-70 amu)

  - Water that is evolved will be condensed and photographed, demonstration of resource storage (as well as public engagement).
Volatile Identification and Quantification

**Drill and Regolith Transfer**
- Near Surface Assay located sample of interest
- Regolith from depth captured on drill flutes and transferred into OVEN crucible

**Seal and Heat**
- Regolith filled crucible manipulated in OVEN and sealed in reactor station
- Crucible is heated to user defined setpoints to drive volatiles into gas phase

**Quantify and Identify**
- Gas phase volatiles transferred to known volume held at temperature to prevent condensation, number of moles calculated with ideal gas law
- Gas sample diluted and analyzed with GC-MS for species identification and quantification
RP LAVA GC-MS Summary

- Inficon Fusion MicroGC module
  - Single Plot-Q column (8m), separate inert components from CO₂ and H₂O
  - Isothermal operation, ~2min runtime
  - microTCD with auto-ranging capability

- Inficon Transpector MPH
  - Quadrupole mass spectrometer
  - Open ion source and cross beam ion source configurations
  - ~3.5kg, ~20W

<table>
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<th>Factor</th>
<th>Requirement</th>
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<tr>
<td>1.1 Scan rate</td>
<td>Collect 1-70 amu at 6Hz</td>
</tr>
<tr>
<td>1.2 Water detection</td>
<td>1000ppm at above scan rate</td>
</tr>
<tr>
<td></td>
<td>limit</td>
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### Integrated System

<table>
<thead>
<tr>
<th>Low water range average uncertainty</th>
<th>70 ppm</th>
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</thead>
<tbody>
<tr>
<td>High water range average uncertainty</td>
<td>1725 ppm</td>
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\[
y = 0.0002x^2 + 274.72x + 140267 \\
R^2 = 0.9988
\]

\[
y = 310.5x - 249461 \\
R^2 = 0.9982
\]
Detection Limits for Water

- Detection limit for water with worst case assumptions is 1.3% water in the vapor phase

- Instruments have demonstrated detection limits of 1000ppm

- Lower limit of detection required for isotope analysis, this work is still in progress

Assumptions

- 12g lunar regolith sample (lowest density sample)
- 50% loss of water ice due to sublimation during drilling
- OVEN and LAVA volumes were volatiles are generated are 100cc each
- SDS dilution is 1:5 (sample to helium diluent) based on the assumption that the sample is all water (worst case assumption)
- Total pressure generated by water and other volatiles is 65psia (max operational pressure with current concept of operations)
- All of the water present in the sample is in the vapor phase
- Gas temperature is 150C (423K), i.e. the temperature of the LAVA system
Flight forward design – modified Commercial Off the Shelf (COTS)

- Modification areas for flight driven by environment
  - Thermal considerations
  - Vibration considerations
  - Radiation considerations
  - Command/control interface

- Utilize components from other missions where possible within schedule/cost (valves, port connectors)

- Testing in thermal vacuum chamber and radiation testing of avionics
Current Status and Future Work

LAVA
- Instruments developed in partnership with Small Business Innovative Research (SBIR) at NASA - Creare, LLC has history of flight hardware development and delivery
- Software development in concert with hardware development – new command and control flight compatible software is under development
- ETU hardware build in progress for manifold and water droplet demonstration

OVEN
- Continue to investigate trade space and contribute to payload investigation on volatile loss
- ETU hardware build in progress for testing with avionics

Payload
- Continue to work towards understanding integrated set of measurements
- Requirements development