LUVMI Rover to Characterise Volatile content in Lunar Polar Regions

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The LUVMI project was funded by the European Commission (EC) under the EU Horizon 2020 program
Overview

- Evidence for lunar water
- OU In-situ mass spectrometer instruments
- Possible deployment systems
- Laboratory lunar test chamber
- Water measurement with LUVMI
- Future work – LUVMI-X
The Moon - Volatiles

After the Apollo and Luna era the moon:

‘essentially waterless planet’

from The Lunar Sourcebook (Heiken et al. 1991)
Evidence for a wet moon

Water distribution in regolith according to M³ [USA] data from Chandrayan-1 [India]

Water distribution in regolith according to LPNS data from Lunar Prospector [NASA]

Water distribution in regolith according to data from LEND [Russia] onboard Lunar Reconnaissance Orbiter [NASA]

Possible ice depths according to data from Diviner onboard Lunar Reconnaissance Orbiter [NASA]

Observation of surface ice frost according to data from LAMP onboard Lunar Reconnaissance Orbiter [NASA]

Detection of water vapor during LCROSS impact (NASA)
Current understanding of lunar south pole (1)

Stability of lunar volatiles vs. temperature/locality/depth from LRO data.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Gas</th>
<th>Ice</th>
<th>Dust mass (kg)</th>
<th>Total water %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–23</td>
<td>82.4 ± 25</td>
<td>58.5 ± 8.2</td>
<td>3148 ± 787</td>
<td>4.5 ± 1.4</td>
</tr>
<tr>
<td>23–30</td>
<td>24.5 ± 8.1</td>
<td>131 ± 8.3</td>
<td>2434 ± 609</td>
<td>6.4 ± 1.7</td>
</tr>
<tr>
<td>123–180</td>
<td>52.5 ± 2.6</td>
<td>15.8 ± 2.2</td>
<td>942.5 ± 236</td>
<td>7.2 ± 1.9</td>
</tr>
<tr>
<td>Average</td>
<td>53 ± 15</td>
<td>68 ± 10</td>
<td>2175 ± 544</td>
<td>5.6 ± 2.9</td>
</tr>
</tbody>
</table>

Water inferred by LCROSS NIR and UV/Vis after impact of Centaur stage into Cabeus crater.
Current knowledge of the lunar south pole (2)

What we think we understand:

• Near-IR and neutron data consistent with very small quantities (up to ~100 ppm) H₂O outside the PSRs and at lower latitudes

• UV, visible, and near-IR reflectance data consistent with small quantities (~1%) of H₂O ice intimately mixed and/or patchy at small scales in the PSRs

• LCROSS impact suggests as high as 7% H₂O ice

What we don’t understand fully:

• High concentrations of [H] in regions of thermal instability

• Diurnal variations with magnitude large enough to fill cold traps with ice
We need to know the ground-truth!

- ESA named the moon as the next destination for its human space exploration efforts beyond Low Earth Orbit
- ESA seeks to develop technologies that can enable human presence on the lunar surface
  - both from a technical and from an economic perspective.
- Astronauts on the Moon will need water
  - Take it with them
  - Use water already there
- ISRU – living off the land
  - Make long term habitability possible

- How much water?
  - More than 12 500 km² of PSRs on the moon
  - If top 1 m contains 5% water, maybe $2.0 \times 10^{12}$ litres of water on the moon
  - Real potential for water mining for ISRU in the near future
Prospecting for water with mass spectrometry

**Analytical mass spectrometry - Ion Trap Mass Spectrometer (ITMS) : Philae lander, Rosetta**


**Stable isotope mass spectrometry – Magnetic sector mass spectrometer : GAP, Beagle2**

Magnetic sector stable isotope ratio mass spectrometer, calibration materials for on-board, filament ion source, multiple collectors for simultaneous ion counting, chemical pre-preparations. Mass 6 kg, Power: 15 W, Dimensions: 40x25x12 cm)
Deployment systems – science impact

Different deployment systems:
• Soft landers
• High speed penetrator deployment
• Mobile platforms (rovers)
Deployment systems – trade offs

**Advantages**: Large payloads, complicated systems / instruments, deep drills, potential for long lifetime

**Disadvantages**: Sampling within contaminated zone, no mobility

**Science**: access surface and material at depth, long duration.

**Advantages**: small payloads, simple system, mobility

**Disadvantages**: shallow drills, limited life-time?

**Science**: access surface and near surface material

**Advantages**: Hard to reach places, access to depth, multiple locations

**Disadvantages**: Low mass, simple instrumentation, short life-time, no mobility
PROSPECT Drill / Mass Spectrometer suite Lunar-27

ProSPA = Rosetta Carousel Oven sample inlet + Rosetta Ion Trap MS + Beagle2 MS
Penetrator instrument (MoonLite / L-Dart)

- Target: PSRs at poles
- <100 K
- Water / volatiles present?
- Ground truth water measurement.
- Short life-time
The need for mobility!

• The Lunar Exploration Analysis Group (LEAG):
  – there are enough uncertainties in the distribution of lunar volatiles implying that a non-mobile lander faces a significant risk of not finding volatiles or of “single data point” non-representative discoveries.
  – The scientific priorities can be fully addressed with a mobile payload that has the capability to access depths of 20 cm

‘LUVMI’
LUnar
Volatiles
Mobile
Instrumentation
LUVMI – Mission Goals

Address top priorities established by the Lunar Exploration Analysis Group (LEAG) Volatiles Specific Action Team (VSAT):

• Determining the variability of volatile distribution
• Identification of the chemical phase of volatile elements
• Analysis of physical and chemical behaviour of lunar soil with temperature
• Determining current volatile flux
• Access a PSR
• Use a mass spectrometer - universal detector
• Needs to be low mass / low power as limited resources available

Targets:

• H₂O
• CO₂
• CH₄
• H₂S
• NH₃
• SO₂
• C₂H₄
• CH₃OH
On the lunar surface, the following types of volatiles can be found:

- Volatiles frozen in cold traps (physisorbed)
- Volatiles chemically bound (chemisorbed) to or enclosed in surface particles
- Free volatiles, cosmogenic or produced in-situ
At the last HEMS: The LUVMI rover concept

- **Dynamic Imaging Analytics**
  - Imaging Systems

- **space applications services**
  - Rover Platform

- **The Open University**
  - Mass Spectrometer

- **OHB**
  - Volatile Extraction

- **TUM**
  - Volatile Extraction

**Technical Specifications**

- Rover Mass: < 40 kg
- Instrument mass: < 1.5 kg
- Life time: = 14 days
- Ability to access PSR
At the last HEMS: The VS and VA

Ptolemy ITMS
The LUVMI Rover: Now

October 2018

December 2018 - Noordwijk
Testing the LUVMI rover in Harsh environments

• A real Harsh Environment
  – Noordwijk in December!

[Movie of LUVMI Rover mobility testing]
The LUVMI VS and VA

Refined CAD design

Mass = 1.9 kg
Power = 20 W

As built system

Reference gas system

The VA ITMS

Mass = 1.9 kg
Power = 20 W
Characterisation in the Lunar simulation chamber

VA:
- Mass = 745g
- Power = 5W
Laboratory testing VA & VS

- Volatiles are extraction thermally which give a degree of separation
- Pressure rise measured by the VS
- Volatiles pass into the VA Mass spectrometer for measurement
- On the moon the exosphere is the ‘pump’
Thermal Vacuum Test Setup was designed and built.

WP3.3: Testing
Water extraction experiment
LUVMI Outreach material

- [www.luvmi.space](http://www.luvmi.space)

- Models for 3D printer
- Non-VR driving simulation on the web
- LUVMI VR application
- Outreach material
LUVMI going forward

- Short range ‘penetrators’
- Analogues to Philae lander during ‘bounce’
- Measure Surface properties
- Miniaturised mass spectrometer
- Imaging capabilities
- ‘fire’ into hard to reach locations PSR
- Short life-time
Conclusions

- Simple low mass, low resource mass spectrometers are suitable for in-situ lunar volatiles detection and characterisation

- The LUVMI VS and VA prototype demonstrated H$_2$O extraction in the laboratory

- LUVMI Rover demonstrated autonomous motion and drilling in a very hostile environment

- LUVMI VS and VA concept applicable to other airless bodies for volatile extraction and characterisation

- LUVMI eXtended follow on programme funded and now underway

- LUVMI-X instrumentation offer the possibility of short-range penetrator ‘like’ instruments to access PSRs
Thank you for your attention

"Co-funded by the Horizon 2020 Framework Programme of the European Union, grant agreement 727220"
Back-up penetrator slides
Pendine test range

- Penetrator mounted on a rocket sled
- ¼ mile run to target
- Cut away and ‘fly’ to target
Post impact penetrator
What have we learnt?

• Mass spectrometers can be designed to survive high speed penetrator deployment
• Volatile measurements returned by Ptolemy during a low speed impact

The time is right for a penetrator mission!
BREWSTER ROCKIT: SPACE GUY!

WHAT'RE YOU DOING?
RESEARCH FOR NASA. I'M CRASHING A PROBE INTO THE ASTEROID VESTA.

THE RESULTING EXPLOSION WILL PRODUCE IMPORTANT SCIENTIFIC DATA.

WHAT KIND OF DATA?
WHY MEN LIKE TO BLOW THINGS UP.

THERE IT GOES!
BOOYAH! WOO-HOO!
NICE!

AND WHAT IS YOUR CONCLUSION?
WE NEED MORE DATA!

Thank you for your attention
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