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LUVMI Rover to Characterise Volatile content in Lunar Polar Regions

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13\textsuperscript{th} Workshop on Harsh Environment Mass Spectrometry. Myrtle Beach. Sept 18-21 2017

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.

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) \( \text{H}_2\text{O} \) outside the PSRs and at lower latitudes

• UV, visible, and near-IR reflectance data consistent with small quantities (~1%) of \( \text{H}_2\text{O} \) ice intimately mixed and/or patchy at small scales in the PSRs

• LCROSS impact suggests as high as 7% \( \text{H}_2\text{O} \) 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’
LUunar
Volatile
Mobile
Instrumentation
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
LUVMI Sampling methods

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

Extraction by heating
At the last HEMS: The LUVMI rover concept

- Imaging Systems
- Rover Platform
- Mass Spectrometer
- Volatile Extraction
- Volatile Extraction

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
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

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

Figure 34: Propel system concept with specific (reinforced) payload in a CubeSat-like form factor. 1) propelling system casing; 2) propellable payload 3) retrieving ramp 4) winch 5) spring and spigot system 6) chamber containing the payload.
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 H₂O 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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