Mass Spectrometry

for analysis of lunar polar volatiles

Simeon Barber

simeon.barber@open.ac.uk

Mass Spectrometry (MS) basics

Ionisation

Electron impact ionisation:
- Heated filament
- Field Effect

Chemical ionisation
Thermal ionisation
Laser ablation/ionisation/ICP

Mass separation

Method:
- Using electric fields
- Using magnetic fields

Domain:
- Separate in space
- Separate in time

Ion detection

Destructive:
- Electron multiplier
- Micro channel plate
- Faraday cup

Non-destructive:
- Image current

- Advantages:
  - A “universal” detector – measures anything that can be introduced into it
  - Can optimise the technique for a vast range of measurement challenges, e.g.:
    - Laser ablation / Time of Flight / SEM detection for stand-off elemental analysis
    - Electron impact (filament) / Magnetic sector / Faraday cup for precise stable isotopic analysis
    - Electron impact (filament) / Quadrupole mass filter / SEM for cheap, wide range Residual Gas Analysis
- Disadvantages
  - Can be heavy, complex – though not always: see later
  - It’s the “*getting the sample into it*” that can be the challenge: see later

Choosing a MS: figures of merit

- Performance
  - Sensitivity
  - Signal to noise
  - Accuracy/Stability
  - Dynamic range
  - Mass resolution (Resolving Power)
  - …

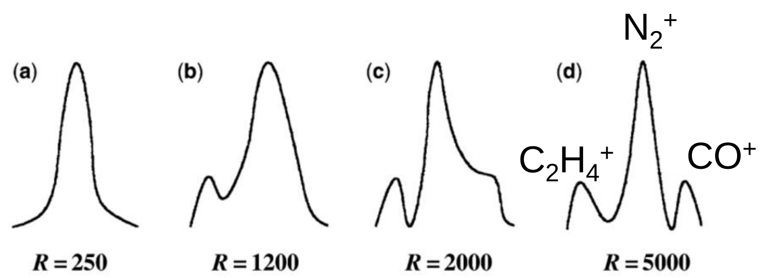


Figure 5.18. The peak shape of the background ions of m/z 28 versus resolving power R of a mass spectrometer.

Adapted from: Lebedev (2009) in Mass Spectrometry, Ekman et al. (eds.), Wiley

- For space applications, with limited resources (mass, power etc), a simple MS can have benefits
- Most lunar polar volatiles can be separated with unit mass resolution
- For CO/N_2, we can use chemistry to help us:

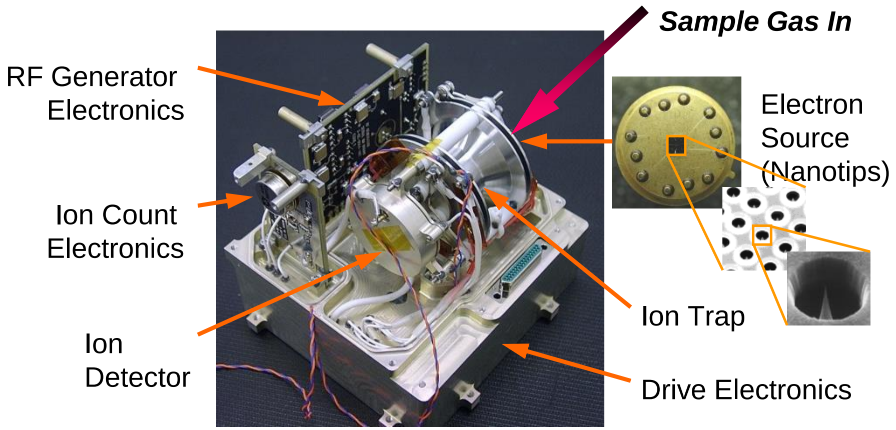
$$N_2/CO \xrightarrow{[O]} N_2 + CO_2$$

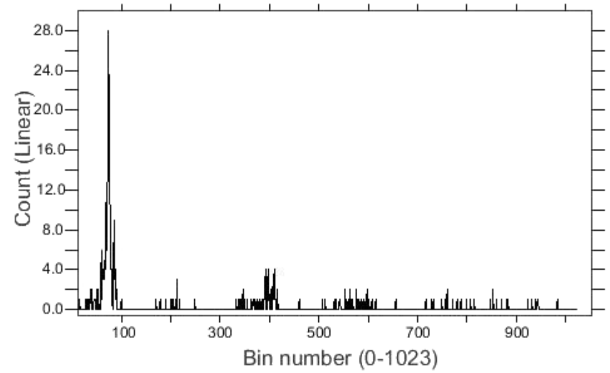
28 → 28, 44

- Exceptions: organics give complex spectra

Two space MS for volatiles analysis

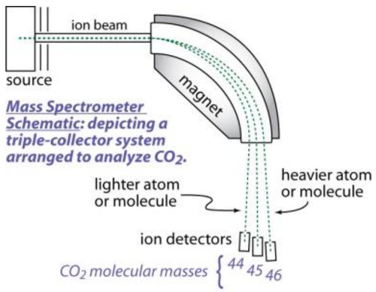
- Analytical MS through quadrupoles (QIT/QMF) (Rosetta Philae – Ptolemy)

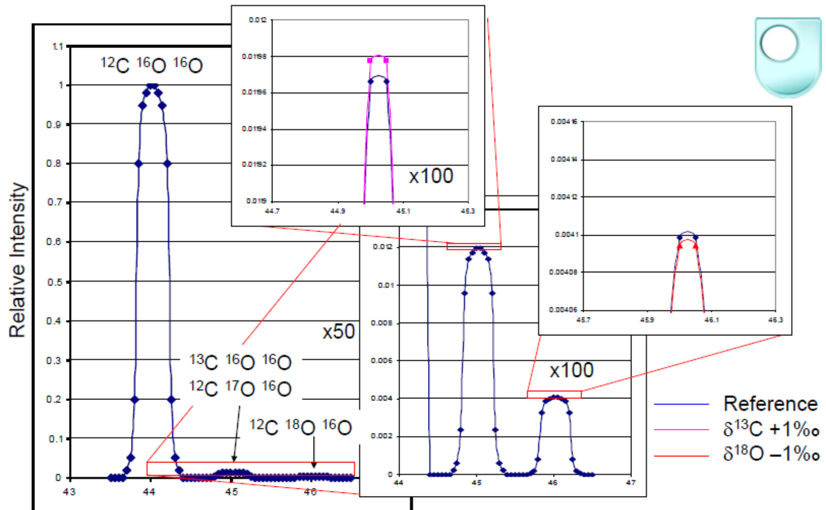




Gas-Chromatograph / Ion Trap MS, FED ion source, serviced by drill/carousel/ovens, chemical pre-preparations, 10 - ~200 amu, ~20 full scans per sec. MS is 500 gram of total of 4.5 kg, 15 W, 30x20x10 cm). Wright et al. Science Vol. 349, Issue 624, 2015 DOI: 10.1126/science.aab0673

- Stable isotope MS through Magnetic Sector (Beagle 2 Gas Analysis Package)





Require 10^6 ions of minor peaks to achieve 1‰

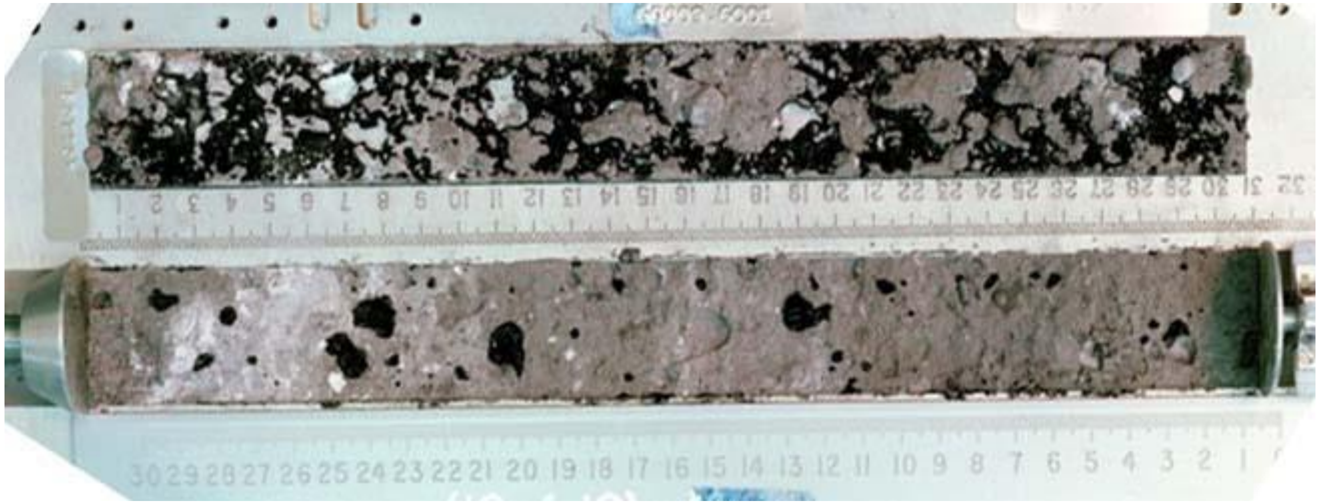
Magnetic sector stable isotope ratio mass spectrometer, on-board isotopic reference materials for in-situ calibration, filament ion source, multiple collectors for simultaneous ion counting. Serviced by mole/carousel/ovens, chemical pre-preparations. 6 kg, 15 W, 40x25x12 cm)

Sample acquisition and preparation

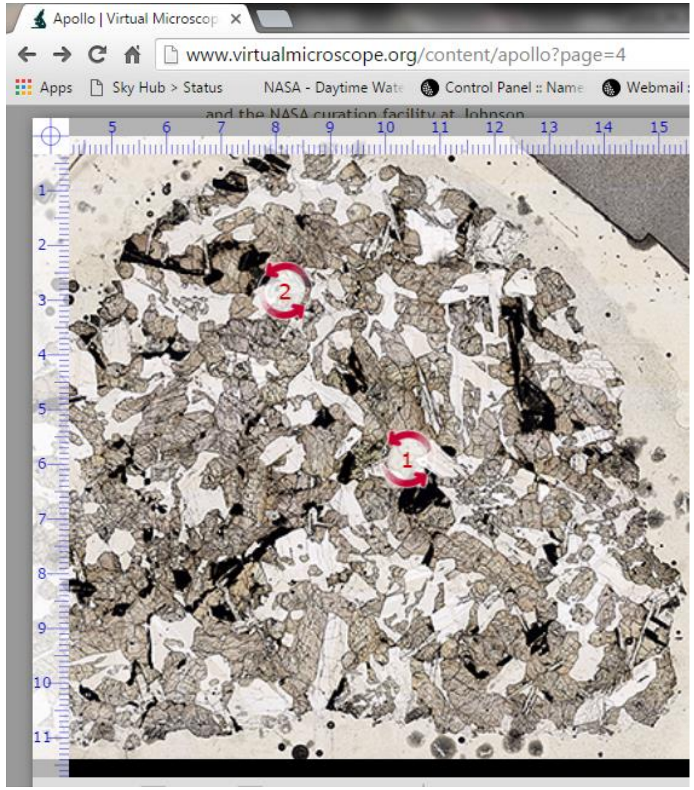
- Unless using a system such as a laser which gives extraction of volatiles and ionisation in one step, need to first extract the sample and prepare it for the chosen MS
- Volatiles are typically analysed through thermal techniques which give a degree of separation during release
- Gas chromatograph – a useful intermediate stage to separate complex mixtures in time before introduction into MS
- 3 example sample extraction systems follow:
  - PROSPECT: drill for Luna-27 with ESA/Roscosmos
  - LUVMI: Lunar Volatiles Mobile Instrumentation
  - EVITA: Evolved Volatiles Ion Trap Analyser for an Instrumented Mole

The analyses that we (I) would like to do at the lunar pole…

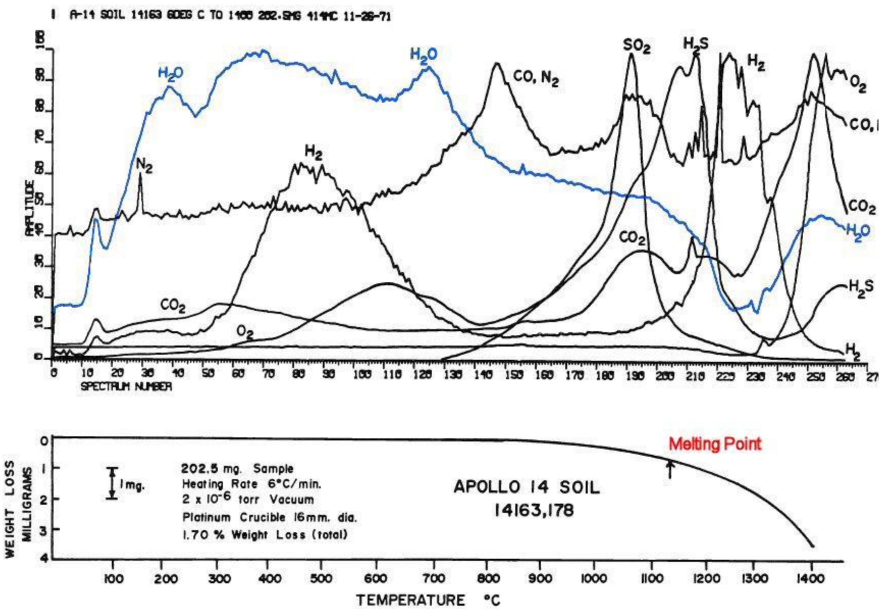
…reproduce Apollo/Luna era datasets in-situ at the poles



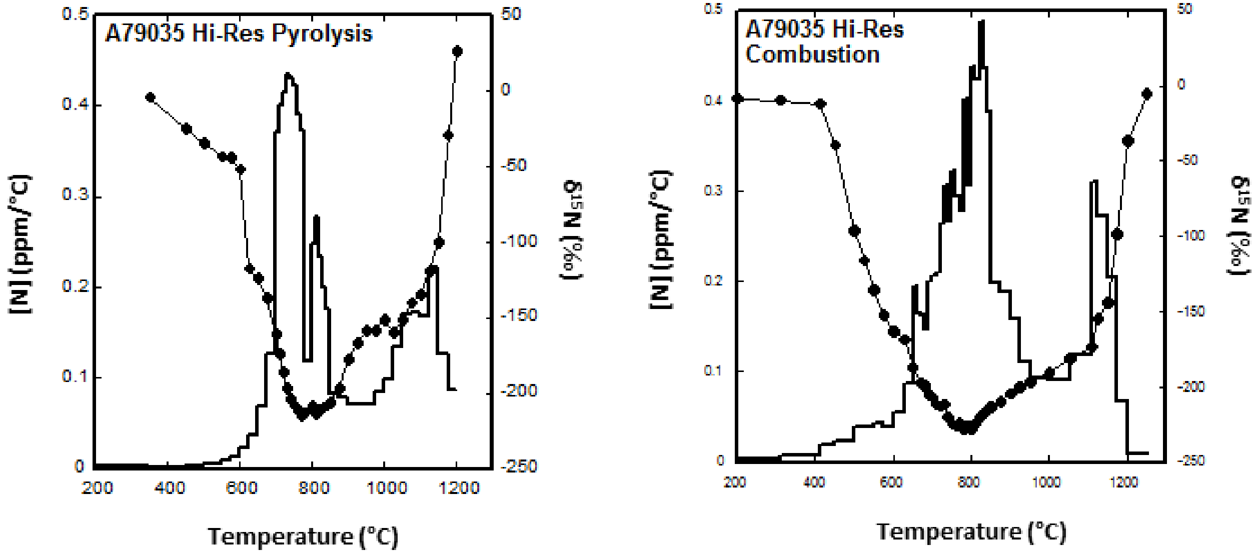
Core 60009 (NASA)



www.virtualmicroscope.org

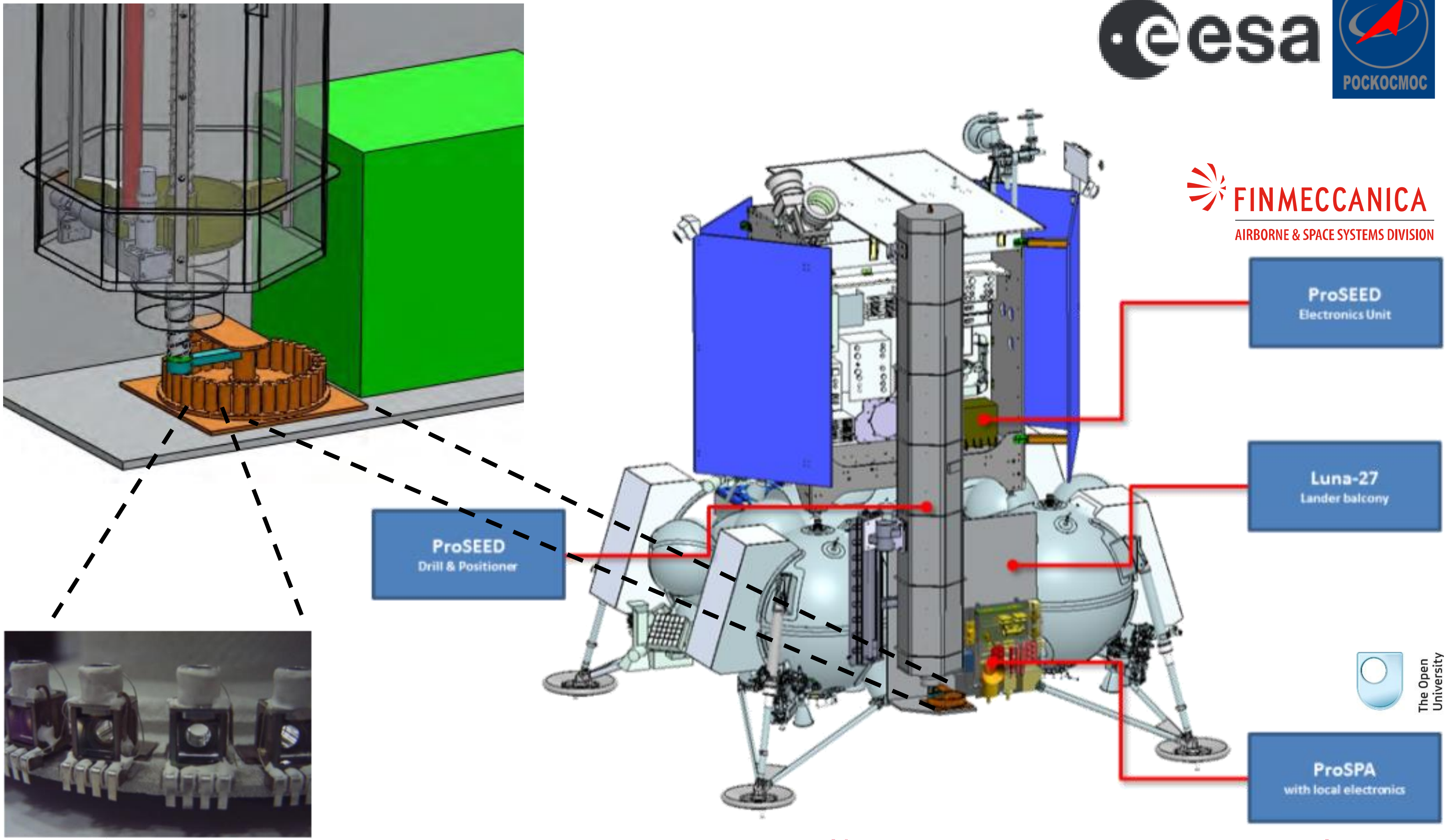


Thermal release of volatiles from Apollo 14 soil.
Gibson E.K., Jr. et al. (1972) *Proc. Lunar Sci. Conf.* 2029-2040



Stepped pyrolysis (left) and combustion (right) of Lunar Breccia A79035 (CT Pillinger).

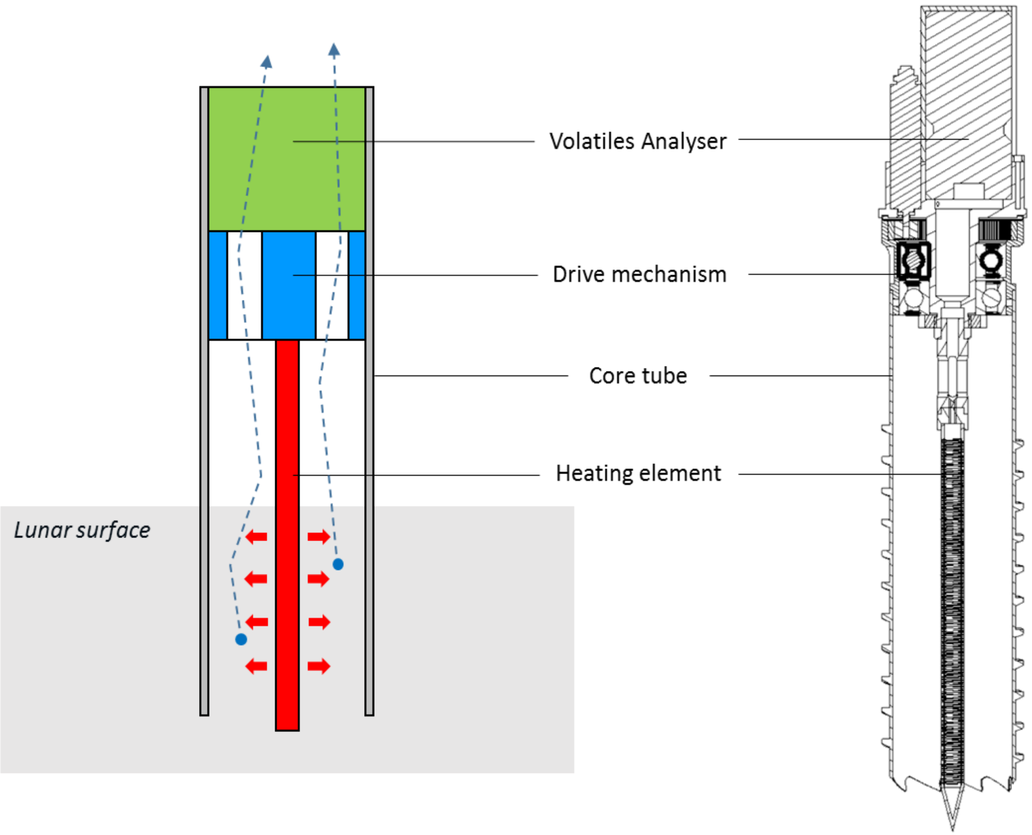
PROSPECT drill / MS suite for Luna-27

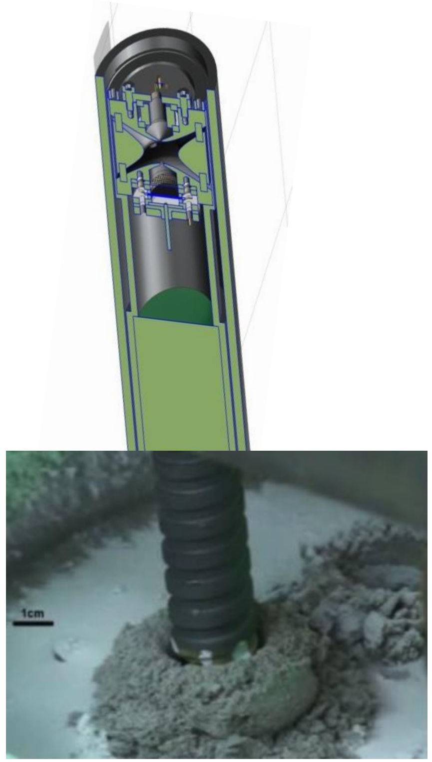


ProSPA = Rosetta Carousel/Ovens + Ion Trap MS + Beagle2 MS

Lunar Volatiles Mobile Instrumentation

- LUVMI: Horizon 2020 SPACE project about to start
- Integrates a mass spectrometer with a sampling tool to create a versatile/powerful/flexible (mobile) system for a ~40 kg rover with 50 km range
- Targeted at meeting 4 ½ of the top 5 LEAG recommendations
- Complements planned missions and open to accommodate international partner instruments
- The scientific advisory board will be formed in the next few weeks…

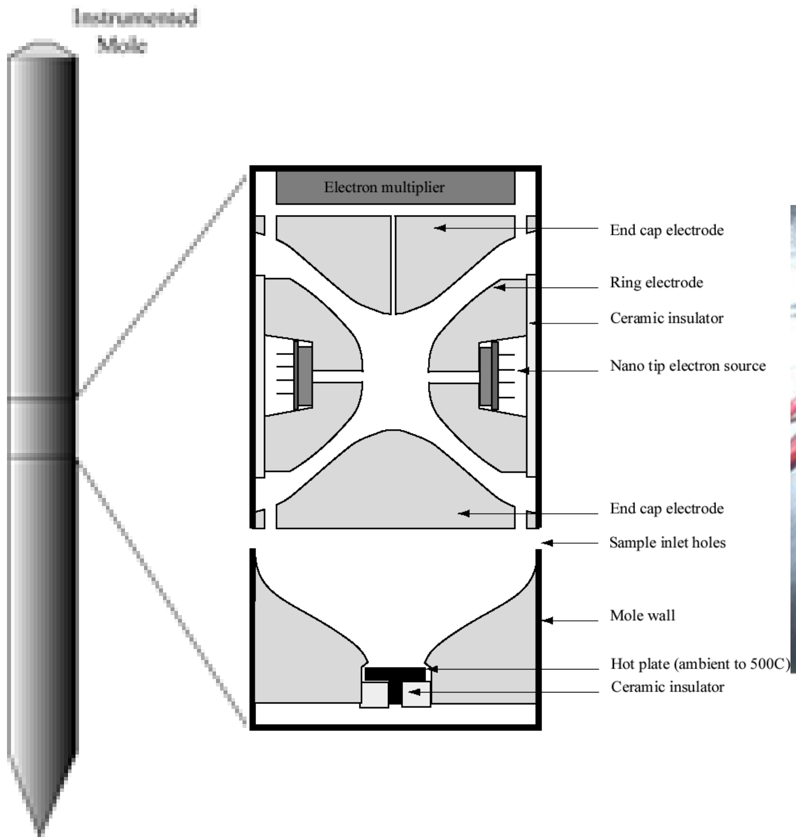


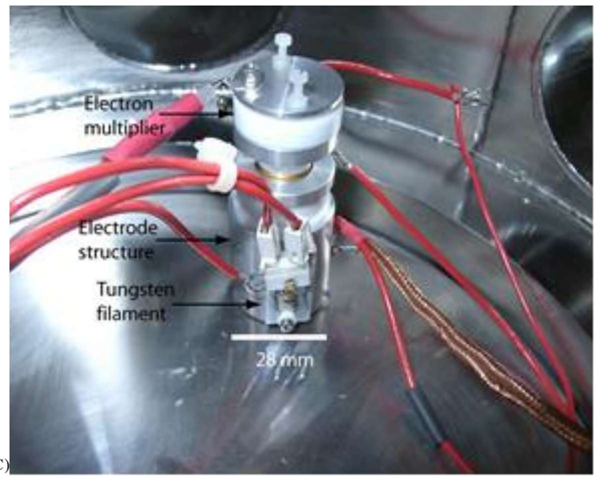


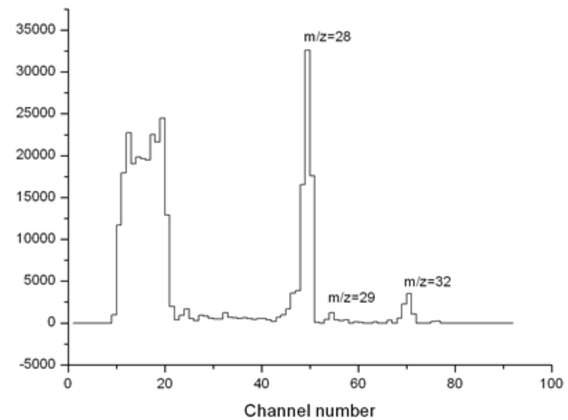
Consortium: Space Applications Services NV (coordinator), The Open University, Dynamic Imaging Analytics Ltd., Technical University of Munich, OHB System AG

Instrumented mole

- Ultra-miniature ion trap mass spectrometer for deployment within an instrumented mole
- Diameter 28 mm; integrated sampling “hot plate”







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ProSEED

Lead: Finmeccanica, Italy

Subcontractors:

Astronika, Poland

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Kayser Italia, Italy

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Politecnico di Milano, Italy

RUAG, Switzerland

Sener, Spain

ProSPA

Lead: The Open University, UK

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