Miniaturised mass spectrometry for future space flight applications.

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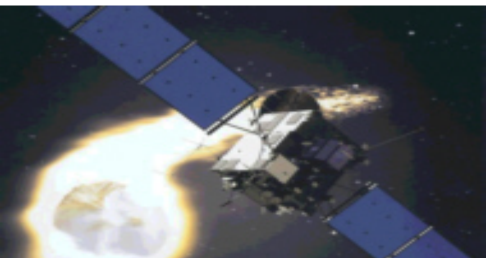
The PSSRI

- Science Faculty at Walton Hall
- 60 plus staff
- Research areas:
  - Development of high sensitivity, high precision, stable isotope instrumentation.
  - Nature and effects of interplanetary dust and its hypervelocity impacts.

Heritage -PSSRI Space based activities (instrumentation)



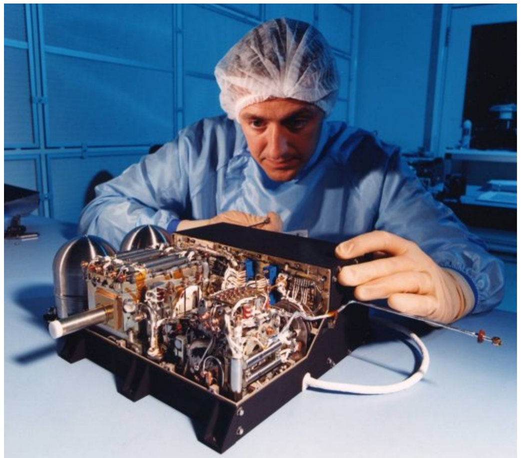

- Rosetta
- Cassini/Hygens
- Beagle 2
- Giotto
- Stone
- Galileo
- ExoMars

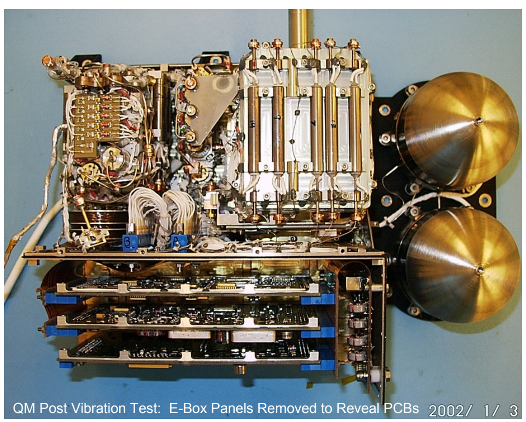


Mass spectrometry in the PSSRI

- Hi-sensitivity mass spectrometers
  - Four in-house designed and built static vacuum mass spectrometer
    - Extraterrestrial sample analysis
    - Isotope measurements of H, C, N and O
  - Organic and inorganic geochemistry groups
    - Commercial GC-IR-MS instruments
- Why the interest in in-situ measurements?
  - Initially interested in comet sample return sample
  - Frustration with in the group
  - ‘if we couldn’t get the sample to our lab then we had to take the lab to the sample’

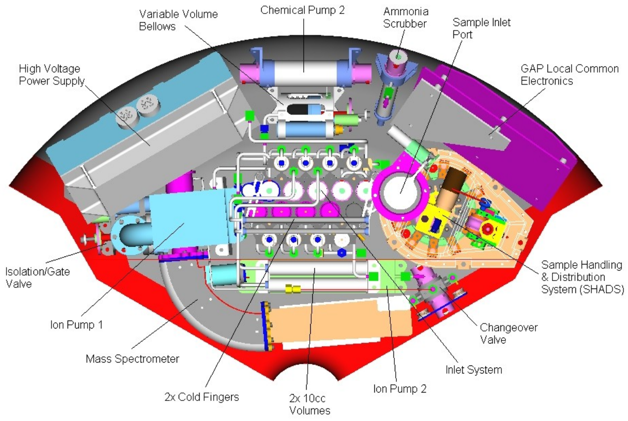
Ptolemy





- Gas chromatograph Isotope Ration Mass spectrometer - miniature chemical laboratory
- Measure the chemical and stable light isotopic composition of cometary material, *in situ*.
- 4.1 kg (30 x 20 x 11 cm)
- Low Power, 4 W nominal (18 W peak)
- Solid sample inlet (carousel, MPAe)
- Sample processing (i.e. drying / combustion)
- 4 channel gas chromatograph
- Ion trap mass spectrometer (500 g, 1 W)
  - MEMS field emission electron source (CCLRC RAL)
  - Digital ion counting (no noise)
  - m/z 10-200
  - C, H, N, O, (S?) isotopes to ± 1 to 5‰

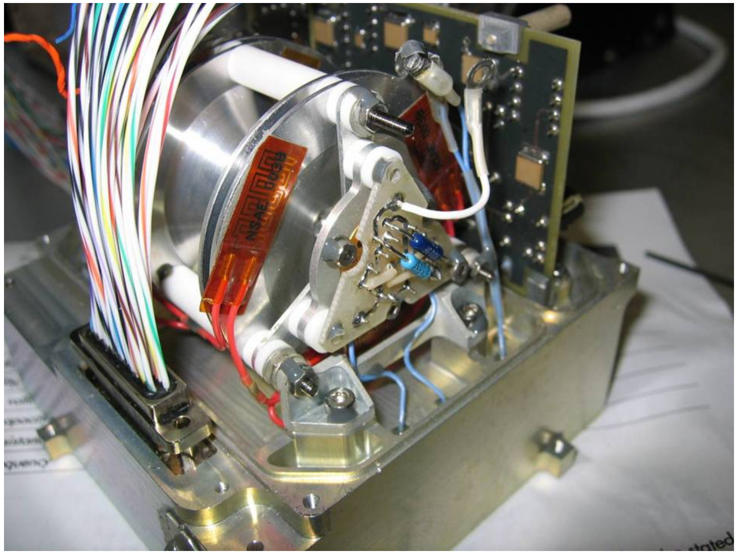
GAP – Beagle 2



- 6 cm radius - Magnetic sector mass spectrometer
- Miniature chemical laboratory
- Quantitative and stable isotopic measurements of:
  - Martian atmosphere and
  - Solid materials (regolith / rock cores)
- C, O, H isotopes, methane, K-Ar dating
- High precision <1 ‰
- 6 kg total mass (30 x 20 x 11 cm)
- 60 W peak, 8 W nominal.
- Solid sample inlet SHADS (carousel, MPAe)
- Chemical sample processing
- Combustion of solid samples

Flight mass spectrometers

- Main criteria for space flight:
  - Low mass
  - Low Power
  - Rugged system
- GAP:
  - Magnetic sector mass spec 2000 g
  - Electronics 500 g
- Ptolemy:
  - Ion trap Mass spectrometer 500 g
  - Electronics 400 g
- The ion trap is suitable for further miniaturisation



Mass Spectrometry Overview

- There are 4 main process involved in mass spectrometry, each entailing a number of possible options:

1 Introduce sample

Sample acquisition

Sample preparation

Get into gas phase

→

2 Create gaseous ions

Ionise with electron beam

→

3 Separate ions

Magnetic field

Time of flight

Quadrupole field

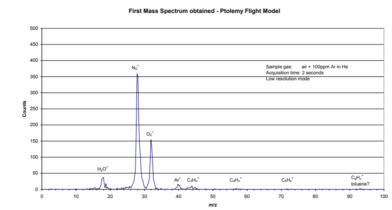
Ion Trap

→

4 Detect ions

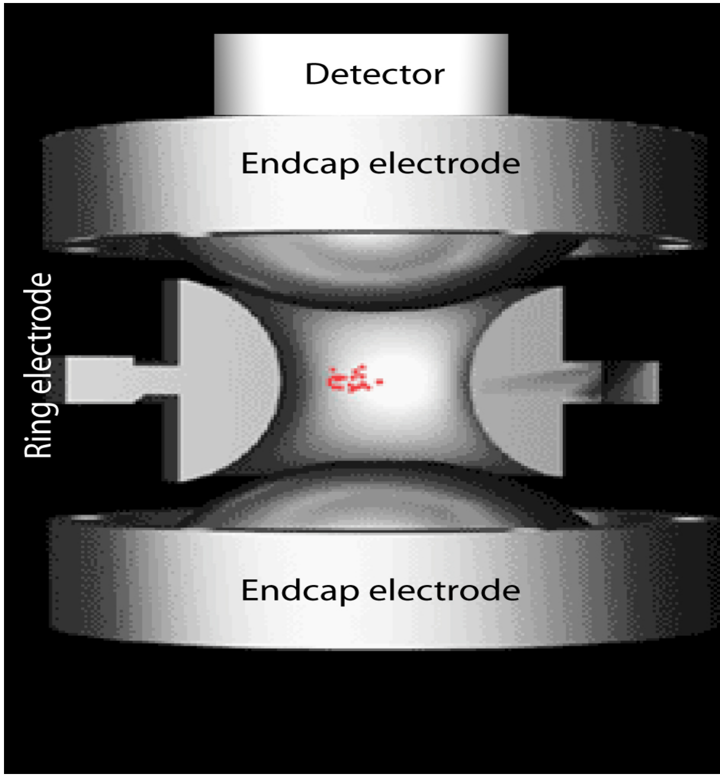
Electron multiplier / MCP output gives m/z ratio and quantity of ions

↓



The Ion trap Mass Spectrometer

- Mechanically simple device:
  - Low mass, low power & inherently rugged
  - 3 electrodes
    - 3D trapping field
    - r.f. (approximately 0.7 MHz)
  - Electron multiplier detector
  - Ion source
- Fast scanning (m/z 10-250 in 100 ms)
- Operates best under poor vacuum (1×10^{-3} mbar)
- Simple software control of one parameter (r.f. amplitude)
- Limitations:
- Requires relatively sophisticated drive electronics and NEEDS a stable rf trapping field.
- 'Normally' there is a loss of isotopic information



Ion trap – a flexible tool

1 Apply RF voltage to ring electrode, creates a trapping field

2 Admit neutrals and ionise by injecting electrons

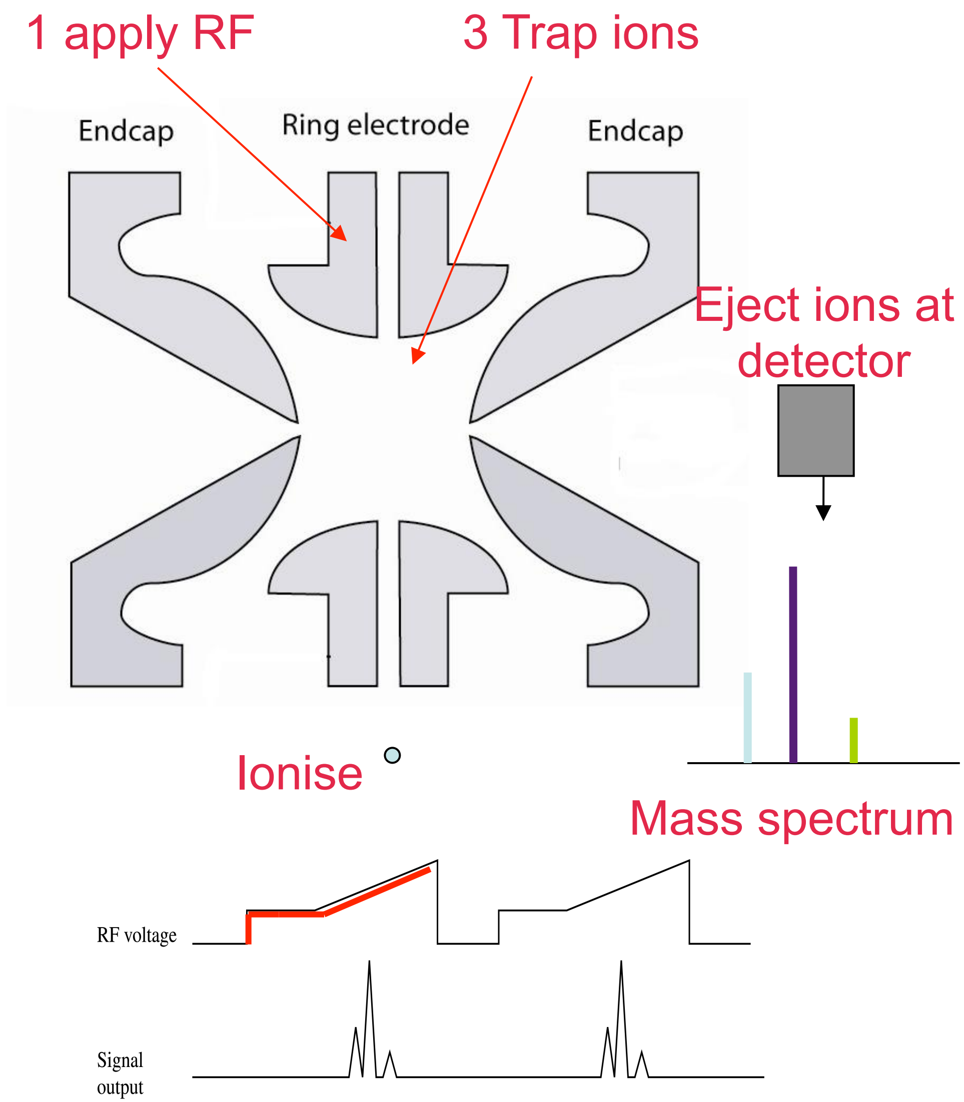
3 All ions (+ve and –ve) stored in stable orbits

4 Once ions are trapped, Eject into electron multiplier to get **mass spectrum**

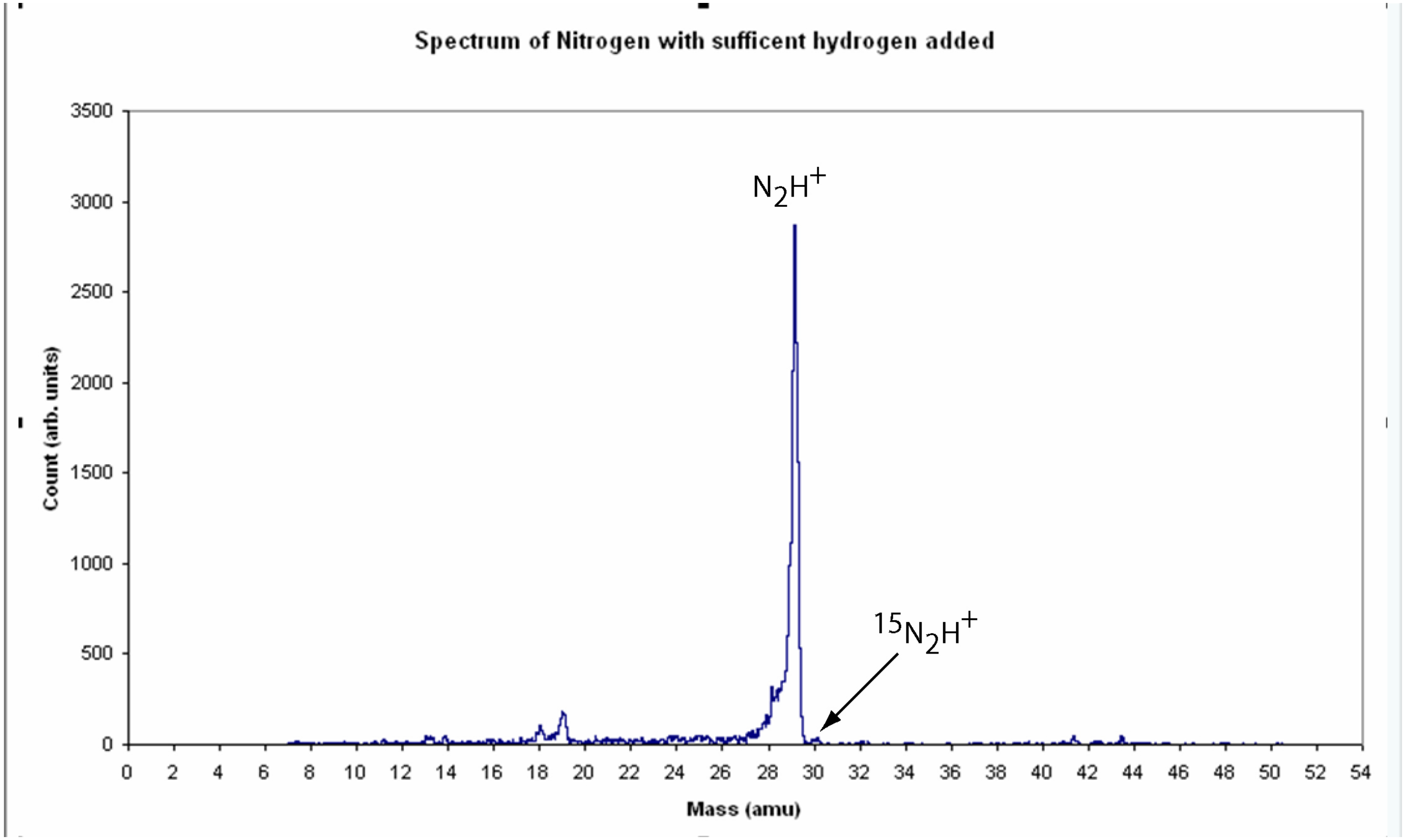
Optionally:

a) Detect ion motions using image current → mass spectrum, improved resolution

b) Fragment ions, trap products, then generate mass spectrum (useful for studying organics)



Recovering isotope information adding Hydrogen

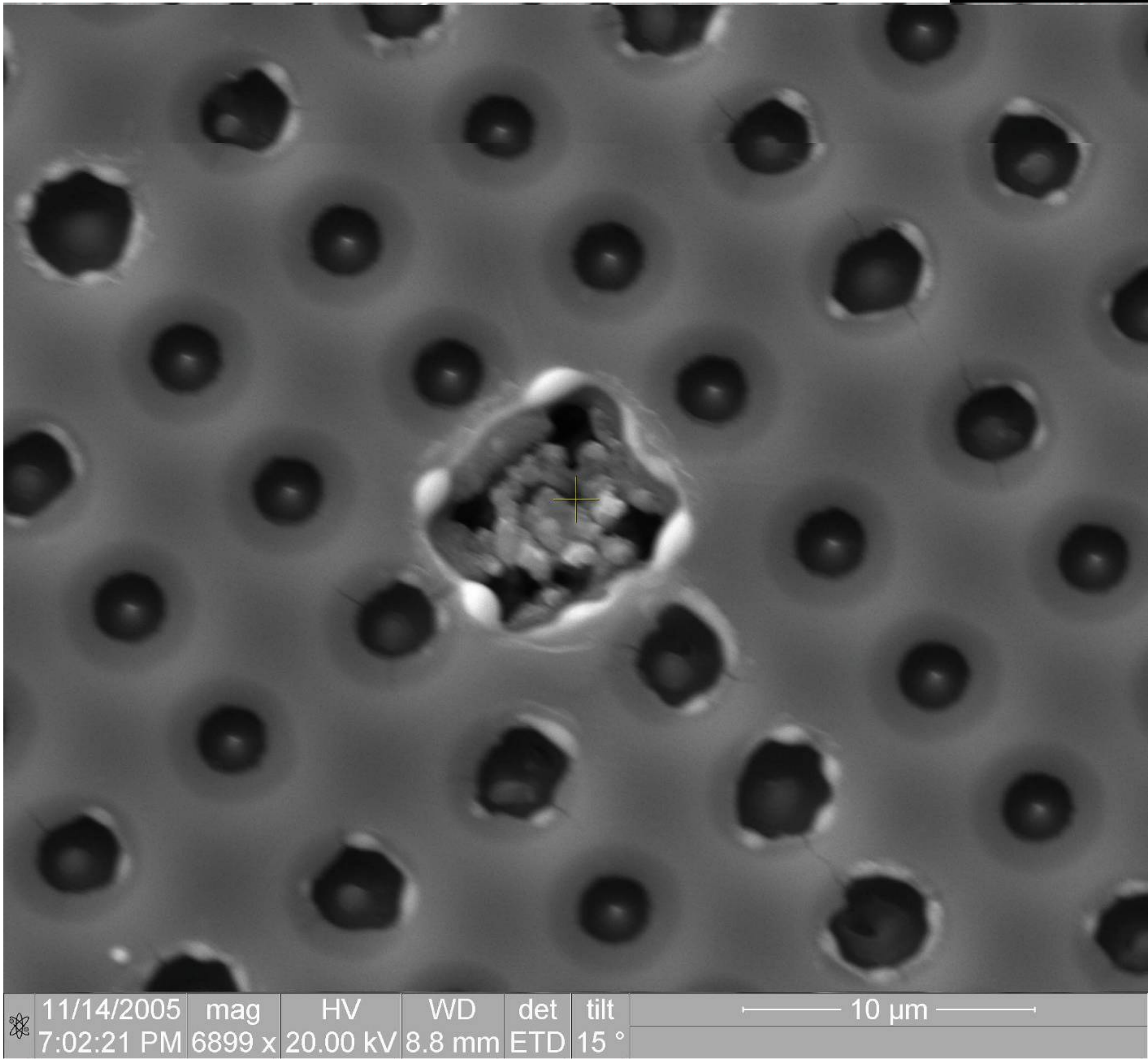


Nano tip source

- Due to the extreme power constraints on the Rosetta lander, The *Ptolemy* instrument uses a silicon nanotip field-effect electron source.
- These electron sources were produced by the CCLRC Rutherford Appleton Laboratory.
- Major problem with these nanotip sources is that they have a short lifetime (approx. 10-20 hours continuous use).
- Contamination and high gas pressures cause arching and damage to tip / gate.
- These issues are consistent with the whole batch (and hence the FM!!!).

SEM imaging of the source

- The electron source was viewed under an SEM
- A large number of emitters are damaged, however more than 50% are still visibly intact.



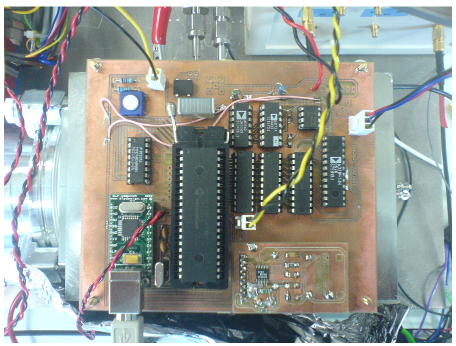
Onwards from the Ptolemy instrument

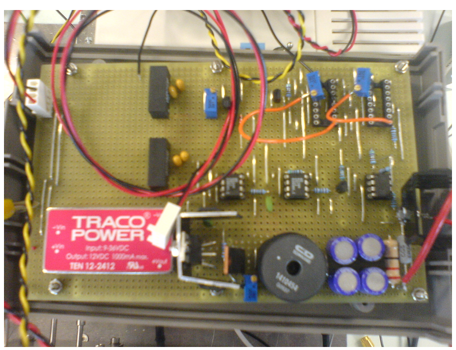
- Simplification – reduction of part count
- Ruggedness – to enable deployment in harsher environments
- Address the electron source problem
- Reduction of the size –
  - Why reduce an already small detector?

- Effect of reducing the size of the trap
  - $V=10.r^2.f^2.$ mass
  - I.e. Ptolemy with a of 8 mm diameter, 0.7 MHz, requires ~ 500 V to scan to m/z = 150
  - To preserve a m/z up to 150, then reducing r to:
    - 5 mm the voltage required drops to ~ 240 v
    - 1mm, the voltage required drops to ~ 8 v
  - Not as simple as that though ☹
    - There are always trade-offs!
    - Smaller r reduces the trapping efficiency so ↑ frequency
    - Less sample stored in the trap compared to larger size
      - Reduced sensitivity

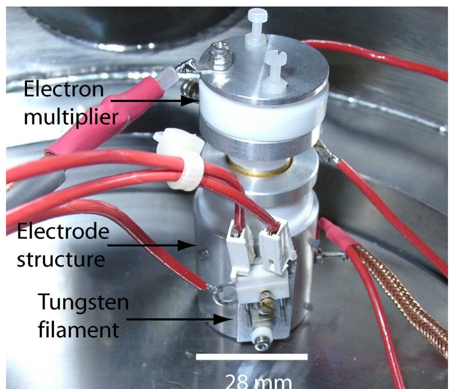
An ion trap for mole deployment

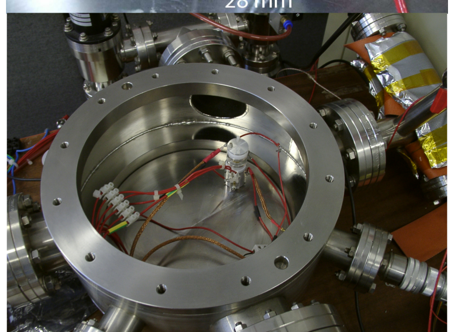
Prototype electronics



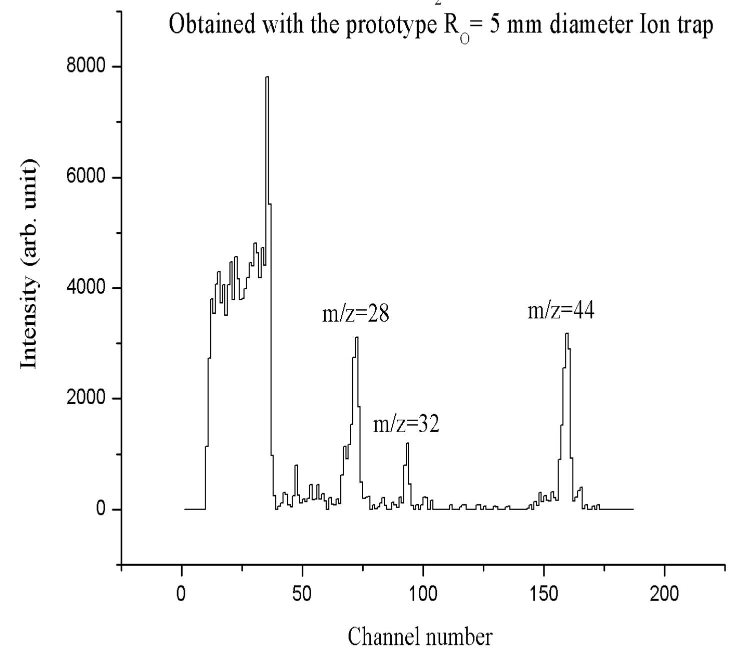


Prototype hardware



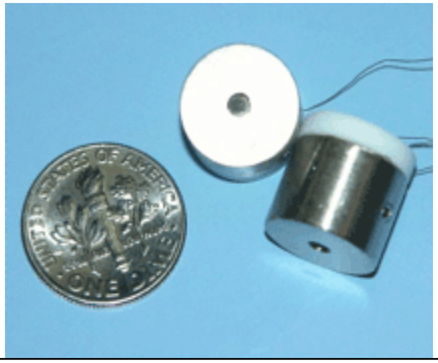


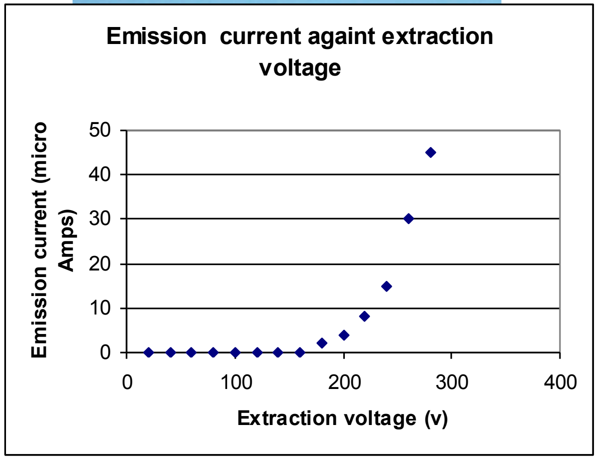
Mass spectra of an air and CO_2 bleed into vacuum chamber
Obtained with the prototype R_O = 5 mm diameter Ion trap



FED Cold Cathode sources

- Commercial Field emission cold cathode
  - Small volume 8 mm (diameter) x 11 mm
- Low voltage extraction achieved
  - 200 V giving 30 micro Amp emission current
- Long life time
  - At least weeks compared to the number of hours for the nano tips
- Issue with stability
  - Design and build a stable power supply to drive the devices





Electronics

- Actively seeking solutions to the drive electronics – area of maximum miniaturisation possible with ASIC / FPGA
- Use of Direct Digital Synthesis (DDS) to give maximum flexibility and control of the r.f. signal

Future mission opportunities

- The PSSRI is currently involved in a number of cosmic vision proposals which involve mass spectrometer instrumentation.
- It is our Intention to develop a ‘generic’ core of mass spectrometer solutions which can be used for a number of different mission opportunities.
- Select sample inlet / preparation system depending on the mission target.
  - Direct inlet / aerosol collection device for atmospheres
  - Membrane inlet for aqueous environments
  - Solid sample handling (i.e. GAP or Ptolemy SHADS)
  - Pumping for atmospheric / sub surface
    - Miniature turbo pumps under investigation (Creare)
      - Low mass 130 g
      - 4 Ls-1 can operate at Martian pressure

Europa dust composition detector

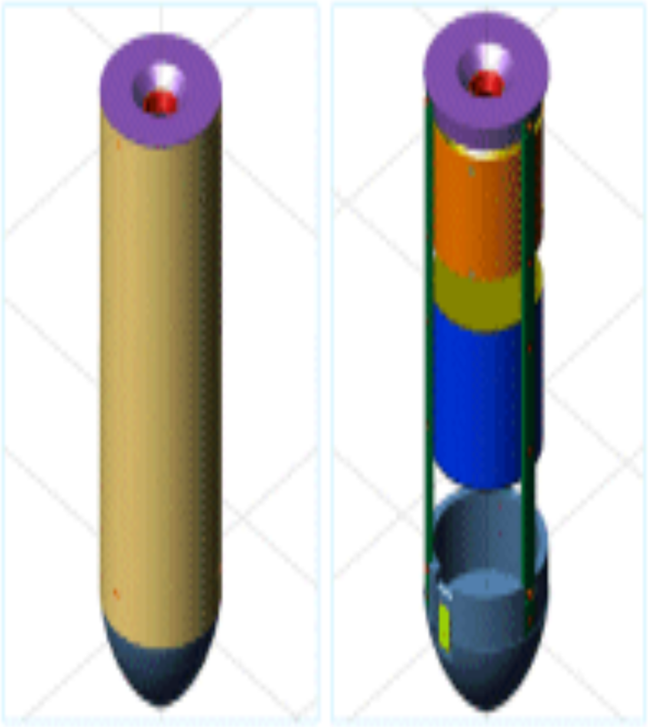
- Particulates (or “dust”) is ejected from surface of Europa by impacts, sputtering… it offers “easy” access to parent body samples
- Detection of particles >~100nm
- Chemical and limited isotopic composition
- m/z 10 to 200 amu
- Resource estimate: <1 kg + electronics
- The Mass spectrometer:
  - High TRL (Ptolemy ion trap & electronics as flown)
- Detector / ionisation stage
  - Low TRL 1/2

Luna water detector

- Low mass ~ 500 g device
- Deployed by a penetrator
- DS2 like sample acquisition system
- Rugged nature of the ion trap lends itself to the impact requirements
- Simple detection of H_20 and other low mass volatiles
- The Mass spectrometer:
  - LOW TRL level 1 or 2

Melting Probe

- Low mass ~ 150 g
- Targets Europa / Mars poles
- Characterisation of volatiles / organics dissolved in melt water
- Membrane inlet system
- To be housed within melting probe (N. Koemle et al.)
  - The OU currently working on a prototype design for lab testing at Institut für Weltraumforschung, Graz (Austria).
- Mass spectrometer system
  - Low TRL 1/2



Instrumented EDLS

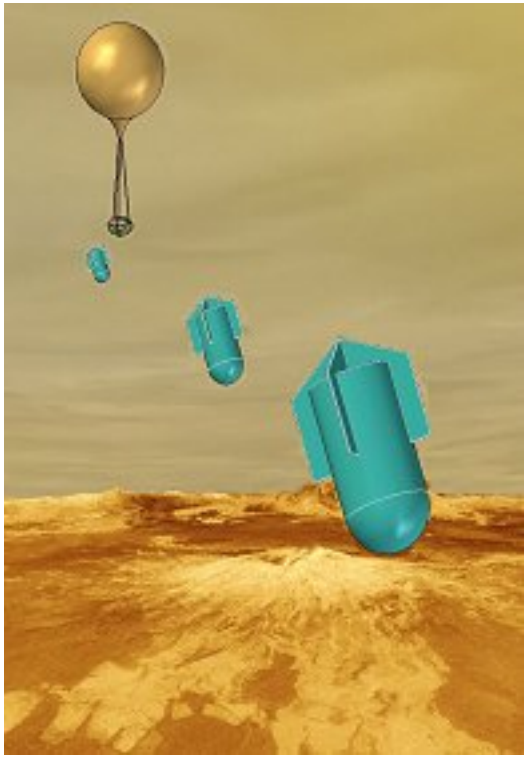
- ESA contract
- For mars entry probe
- Mass spectrometers on the Viking landers obtained a rather incomplete picture of the upper atmosphere (from ca. 200 km to 100 km), due to their slow scanning speed, combined with the fast rate of vertical descent; only one mass spectrum per 6 km descent resolution was obtained. Continuous high resolution data from first entry ($10E^{-8}$ mbar) to ground level (7 mbar) are needed

.

- The OU was unsuccessful.

Venus micro probe

- Very low mass instrument ~ 50 g
- Using MEMS technologies, driving force was the potential to incorporate a MS on instrumented ballast of a balloon.
  - MS profile of atmosphere
- Mass spectrometer system
  - VERY Low TRL <1



Conclusions

- The mass spectrometer is an excellent tool for the space scientists to study planetary environments, icy moons and airless bodies.
- Small, low mass, low power mass spectrometers do exist and they have been flown.
- Further miniaturisation will enable mass spectrometers to be placed on new platforms as long as the resulting compromises in performance can be tolerated.