Ptolemy: An instrument aboard the Rosetta lander Philae, to unlock the secrets of the solar system

Conference or Workshop Item

Ptolemy: An Instrument aboard the Rosetta Lander Philae, to Unlock the Secrets of the Solar System.

D. J. Andrews[1], S. J. Barber[1], A. D. Morse[1], S. Sheridan[1], I. P. Wright[1], G. H. Morgan[1], [1] Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, MK7 6AA, UK.

Comets and Light Elements: Small bodies, such as asteroids and comets, represent the 'leftovers' of Solar System formation, and as such provide us with a repository of material that is essential for studying the early Earth. In particular, the comets contain largely pristine materials including those volatile species (which are depleted in small bodies that formed nearer to the Sun) that are essential for life. Studying the nature and isotopic composition of these volatiles, which are composed of the light elements carbon, hydrogen, oxygen and nitrogen (CHON), may provide answers to many of the fundamental questions surrounding the origins of life on the early Earth, and possibly elsewhere in the Solar System.

Past cometary space missions: A number of space missions have visited comets in the last two decades, from the 68 km/s *Giotto* flyby of 1P/Halley in 1986 [1], to the recent and spectacular encounter between *Deep Impact* and 9P/Tempel 1 [2], which possibly raised as many questions as it answered [3]. These space missions, combined with ground-based observations [4], have unveiled a vast amount of information concerning the composition and structure of comets. Observations by imaging spectrometers on board the flyby bus of *Deep Impact*, and observations of the plume of material thrown off the surface of the nucleus by the impact, seem to indicate that the comet is largely refractory dust in bulk composition, with relatively lesser levels of volatile material than expected. In short, the nucleus was an 'icy dirtball' rather than a 'dirty snowball' [3]. However, the only way to get 'ground truth' is either to return samples of comets to Earth, or to make detailed *in situ* analyses. The NASA *Stardust* mission will return refractory and volatile samples to the Earth for analysis, collected from the coma of comet 81P/Wild 2 [5]. These samples are due to be returned to the Earth at 10:00Z on January 15th 2006, in what will be the fastest ever entry of a vehicle into the Earth's atmosphere [6]. If the entry, descent and landing onto the Utah desert is successful, then humankind will have its hands on the first samples of cometary material available in the laboratory, indeed the first ever samples returned from outside of Earth's sphere of influence. At the time of writing, the outcome from preliminary investigations is not known, however much more may be known by the time of presentation.

The Rosetta mission: *Rosetta* is an ESA cometary mission with a difference. Whereas all prior cometary space missions have flown past their targets at many km/s, or in the case of Deep Impact, interacted with the cometary nucleus for the briefest of instants, *Rosetta* will be delicately placed into orbit around the nucleus of comet 67P/Churyumov-Gerasimenko. From an orbital height of only a few km, *Rosetta* will not only be able to map the nucleus in unprecedented detail, including probing the internal structure, but it will also deposit a lander onto the surface, which will then conduct *in situ* analyses of the cometary body. This will be the first controlled, survivable landing of a space probe onto the nucleus of a comet [7].

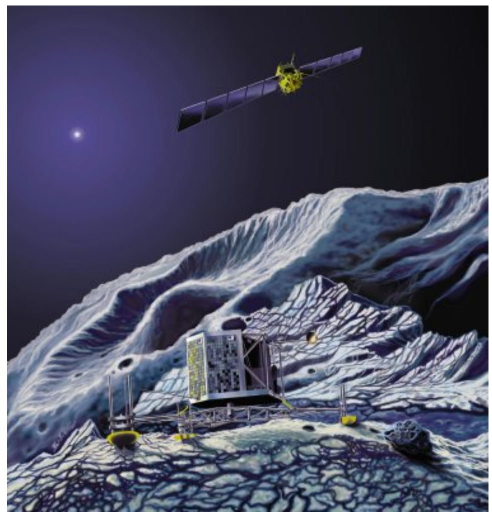

Fig 1 *shows an artist's concept of the 100 kg Rosetta lander 'Philae' anchored to the surface of its target comet, with the 3000 kg Rosetta orbiter arcing overhead. Credit Astrium / Erik Viktor.*

One of the ten instruments on board the *Philae* lander is *Ptolemy*; a miniature chemical analysis suite designed and built in the UK by the Open University and the CCLRC Rutherford Appleton Laboratory. *Ptolemy* is a gas chromatograph-isotope ratio mass spectrometer (gc-irms), using a quadrapole ion trap as a detector. The 4.5 kg instrument will provide chemical and isotopic analyses of both volatiles (including water) and refractory materials drilled from the comet nucleus, and will also conduct the same analyses on volatile compounds collected from the cometary coma.

These samples will be provided to the *Ptolemy* instrument by the *Sample Drill and Distribution System (SD2)* which includes 26 sample ovens, some of which are able to heat samples to 800°C. The sample gas thus provided, will be passed through a set of valves and manifolds, and reacted with a number of reagents to 'clean up' the sample, prior to injection into one of three gas chromatography columns to effect separation of the sample mixture. The column effluent is finally admitted to the ion trap mass spectrometer for quantification and chemical and isotopic characterisation.

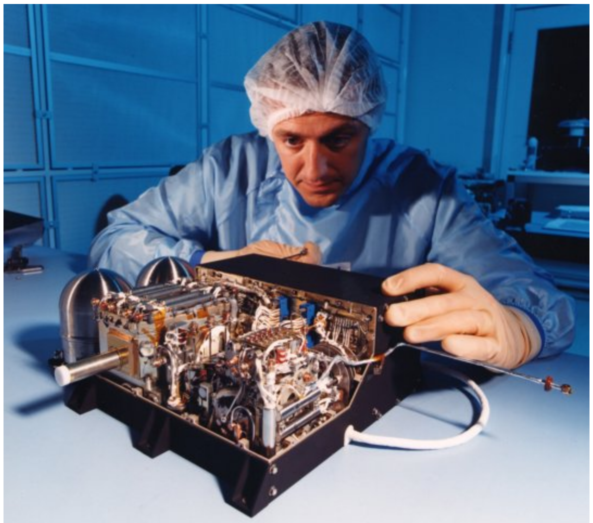

Fig 2 *shows an Open University scientist working on 'Ptolemy', the advanced and miniature chemical and isotopic analysis laboratory currently flying on board the ESA Rosetta lander Philae. Credit The Open University / CCLRC Rutherford Appleton Laboratory.*

Ptolemy will provide chemical and isotopic data for a number of extant species, for atomic masses 10 Da to 140 Da, including the D/H, $^{13}C/^{12}C$, $^{15}N/^{14}N$ and $^{18}O/^{16}O$ ratios, present in volatile and refractory materials in the upper 250 mm of the nucleus' surface [8].

This information will increase greatly humankind's depth of knowledge concerning conditions in the early Solar System, and may also help to shed light on the fundamental question of life's origins. For instance, some hypotheses propose the existence of a pre-biotic chemical 'soup' as the cradle of life; it is entirely possible that the complex organic materials themselves were sourced from the radiatively altered crusts of cometary nuclei.

Ground based test programme: The *Ptolemy* flight spare instrument has been comprehensively tested inside a thermal vacuum chamber under conditions which simulate the operational environment on board *Philae*. The chamber is able to provide a vacuum of 5.0×10^{-7} mbar over the entire thermal range expected to be experienced on the surface of comet 67P. The flight spare instrument has been used to test various modes to be used on the flight instrument during the comet phase, using sample gases admitted directly to the ion trap enclosure via thin capillary tubing.

The Ptolemy flight spare ion trap mass spectrometer has successfully generated mass spectra in a flight representative condition, using silicon nanotips as an ionisation source. This ionisation source has now been replaced with a thoria coated thin wire filament, whilst the properties of silicon nanotips are experimented with in parallel.

The Ptolemy flight spare instrument has demonstrated a mass range of 14 Da to 140 Da, and has shown the possibility of unit mass resolution over this range.

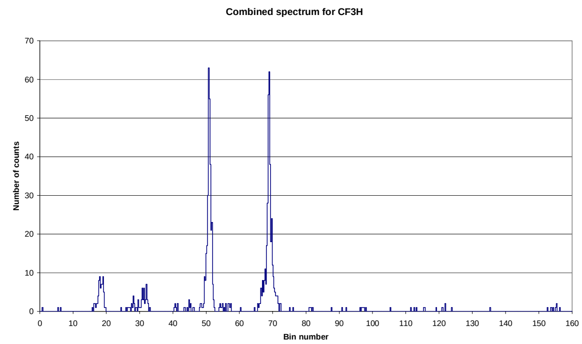

Fig 3 *shows a combined calibration spectrum taken of CF_3H admitted via the direct channel immediately into the Ptolemy ion trap mass spectrometer at 1 nmol/s.Peaks of water, and the three cracking products of CF_3H are seen from left to right at masses 18, 31, 50 and 69 respectively. Credit The Open University*

A total of in excess of 500 separate mass spectra have been generated thus far, and the results of these, along with a breakdown of *Ptolemy*'s operation will be presented in a poster session.

References:

[1] R. Reinhard, *J.Phys. E: Sci. Instrum.* 20 (1987)

[2] M.F. A'Hearn *et al.* Deep Impact: a large-scale active experiment on a cometary nucleus, *Space Sci. Rev.* 2005

[3] M. Küppers *et al.* A large dust/ice ratio in the nucleus of comet 9P/Tempel 1, *Nature* 437, 987-990

[4] N. Biver *et al*. Chemical Composition Diversity among 24 Comets Observed at Radio Wavelengths, *Earth, Moon and Planets* 90, 323-333. 2002

[5] S. F. Green *et al*. Stardust Wild 2 Dust Measurements, *Workshop on dust in Planetary Systems*, 2005

[6] P. N. Desai *et al*. Entry Dispersion Analysis for the Stardust Comet Sample Return Capsule, *GNC, AFM and MST Conference and Exhibit*, August 11-13, 1997, New Orleans, LA

[7] R. Bertrand *et al*. Rosetta Lander Descending Phase on the Comet 67P/Churyumov-Gerasimenko. *18th International Symposium on Space Flight Dynamics*, 11-15 October 2004, Munich, Germany

[8] A. D. Morse *et al*. In-Situ Chemical and Isotopic Analysis of a Comet Body by Ptolemy. *EGS XXVIII* General Assembly, Nice, France, 6 - 11 April 2003.