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PTOLEMY: OPERATIONS AT 21 LUTETIA AS PART OF THE ROSETTA MISSION AND FUTURE IMPLICATIONS.

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The Rosetta mission and Ptolemy: Rosetta is the European Space Agency 'Planetary Cornerstone' mission intended to solve many of the unanswered questions surrounding the small bodies of the Solar System – the comets, the asteroids and the trans-Neptunians. Launched in March 2004 it is now over halfway through its cruise, leading up to entering orbit around the nucleus of comet 67P/Churyumov-Gerasimenko in mid-2014. To date, this cruise has included three gravitational assist manoeuvres using Earth and one such manoeuvre using the gravity well of Mars, necessary to match the orbit of Rosetta to that of the target comet. In addition, targeted flybys of two asteroids have returned a plethora of data to be compared with the comet observations to come. These flybys were of the 5.3 km diameter E-type asteroid 2867 Šteins on September 5th 2008, and a similar 3,162 km flyby of the 100 km diameter asteroid 21 Lutetia on July 10th 2010, the focus of this work.

Ptolemy is a miniature chemical analysis laboratory aboard the Rosetta lander 'Philae', and is intended to determine the chemical and isotopic composition of cometary material sourced from beneath, on and above the surface of the target comet. Samples are taken from the Sampler, Drill and Distribution system (SD2) and are then processed in a chemical preparation suite before delivery to a three-channel gas chromatograph (GC). Elution products from the GC are passed to a quadrupole ion trap mass spectrometer for detection and quantification [1]. As well as analysing solid samples, Ptolemy can passively adsorb coma material onto molecular sieve (Carbosphere^{TM}) contained within one of the 26 SD2 sample ovens for later thermal release and analysis. Ptolemy can also make direct 'sniff detections of the current spacecraft environment, bypassing the sample inlet and GC system, and analyzing instead the inside of the mass spectrometer, which is connected to space via a vent pipe.

Recent ground based observations of the main belt asteroid 24 Themis have shown this body to have an organic-rich surface with exposed water ice [2], and further studies of other outer main belt objects have observed similar compositions. It is also known that there are at least four main belt comets – comets residing within the main belt, the prototype being 133P/Elst-Pizarro – and there are likely to be many more such bodies undergoing lower levels of cometary activity yet to be discovered [3]. The once clear-cut differentiation between volatile-rich comets and volatile-depleted asteroids has been somewhat eroded by these recent findings.

Ptolemy plans at Lutetia. Based on the demonstrated instrument performance (a sensitivity of one ion count per 1x10^{-11} mbar for a particular mass), and knowing that the state of knowledge concerning the volatile composition and outgassing nature of main belt asteroids is only loosely constraine, it was decided to opportunistically attempt to detect any extant, tenuous exosphere surrounding asteroid 21 Lutetia during the 2010 Rosetta flyby opportunity - understanding the limitations of using a non-optimized instrument. This body was thought to have both carbonaceous material and hydrated minerals on its surface - potential sources of outgassing - and therefore worthwhile of study [4]. The flight-demonstrated mass range of the Ptolemy mass spectrometer (10-140 Da) was particularly suited for detecting volatiles such as water, SO_2 and organics during the flyby. Ptolemy made 'sniff' measurements both several hours either side of 'close approach (CA)' to provide background data, and near to closest approach whilst over the sub-solar point of the asteroid's surface. This area on the surface is of interest for exosphere determination, since it receives the highest insolation and has the highest surface temperature, and is thus the area most likely to show evidence of thermal outgassing of volatiles such as water (Figure 1).

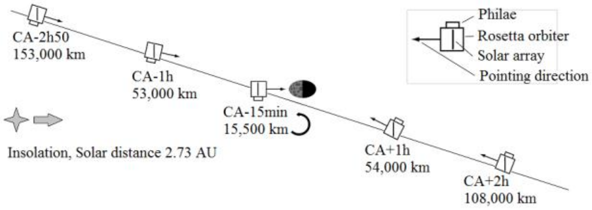

Figure 1. The Ptolemy flyby plan for the 21 Lutetia encounter.

Results and discussion: Summing the total ion counts seen for differing mass spectra ranges (11-90 Da being the low mass range and 20-140 Da the high mass range) and then plotting these against distance to the asteroid does give an interesting rising and falling trend in the apparent pressure of the spacecraft environment, but this cannot be deconvoluted into separate spacecraft and asteroid signals, thus the

Ptolemy results showed no unambiguous detection of an exosphere (Figure 2)[5].

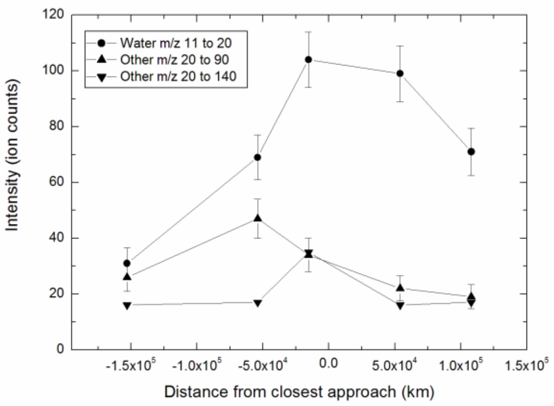

Figure 2. Observed ion counts (a proxy for partial pressure) for three mass ranges observed by Ptolemy during the Rosetta flyby of asteroid 21 Lutetia.

All spacecraft surround themselves with a partial pressure (of the order of $1x10^{-11}$ mbar for Rosetta [5]) of various volatiles; mostly water, but also including organic fractions and other small molecules sourced from surfaces, adhesives, other spacecraft structures and thruster firings. The increase in partial pressure observed during the flyby was of the same magnitude and chemical composition as that to be expected from spacecraft manoeuvres [6]. Such a spacecraft 'exosphere' obscured the *in situ.* detection of any extant tenuous small body exosphere that may have been present.

Lessons Learned: If, in future, a mission were to have the express aim of detecting and characterizing the exospheric properties of a small body, then a number of lessons must be learned from the experiences gained during the opportunistic Ptolemy Lutetia campaign, where a non-optimized instrument was able to take the first steps towards this science goal.

Firstly, spacecraft design must set out to minimize outgassing, through the use of appropriate materials and functional design; since many of the species expected to be seen emanating as thermal outgassing products from small bodies are the same as those commonly found outgassing from spacecraft themselves.

Secondly, sensors intending to determine exosphere presence and composition must be located at as great a distance as possible from the main sources of spacecraft outgassing – such as a position at the end of a boom to create distance between the sensor and spacecraft body.

Thirdly, the spacecraft should pass through the exosphere at a great speed (a few km/s to tens of km/s) to maximize the 'ram effect' of exosphere piling up in front of the spacecraft [7].

Fourthly, during such a flyby, spacecraft orientation and power use must remain constant, to present a constant background outgassing source; in doing so, the task of deconvoluting a transient small body exosphere signal from a hopefully constant spacecraft background pressure is made easier. Any variations in power dissipation or insolation (amount or angle) experienced by the spacecraft will cause fluctuations in spacecraft outgassing.

Conclusion: Although the results obtained by Ptolemy during the Rosetta flyby of asteroid 21 Lutetia were unable to unambiguously deconvolute any tentative, tenuous exosphere from the changing spacecraft local outgassing environment, valuable lessons were learned to inform the design of future experiments to detect the exospheres of small bodies.

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