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Ptolemy operations at the surface of a comet, from planning to reality

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ABSTRACT

Ptolemy is a Gas Chromatograph–Isotope Ratio–Mass Spectrometer (GC–IR–MS) aboard the Philae lander element of the Rosetta mission to comet 67P/Churyumov-Gerasimenko. Developed to determine the chemical and stable light isotopic composition of cometary material, Ptolemy was conceived as a highly flexible instrument able to accommodate changes in operational functionality via software modification. This was considered essential to allow for different modes of operation not only in response to rapid/unexpected changes and opportunities, but also to longer-term shifts in priorities as the overall mission plan (and indeed cometary science in general) changed during the decades from initial concept to landing. Against the backdrop of events of the Philae landing, this paper describes the methods of instrument operation and rational behind them used to achieve the Ptolemy scientific results during the period 12–14th November 2014. In particular we demonstrate the importance of a flexible modular approach to the instrument architecture enabling complex instrument operations, especially in a situation where the environment of exploration is effectively unknown and some of the engineering solutions were being tested in the field for the first time.

1. Introduction

During the Rosetta spacecraft's journey from its launch on the 2nd March 2004 until its arrival at comet 67P/Churymov-Gerasimenko (hereafter 67P) in August 2014, a nominal mission plan was developed to cover the period from touchdown until depletion of the Philae batteries. The aim of this plan, known as the First Science Sequence (FSS), was to achieve all of the primary science goals of the Philae instruments, making the most of the limited resources available, such as time, energy and data volume. The FSS was estimated to last 55 h at which point Philae would enter hibernation whilst the secondary batteries recharged. The Long Term Science (LTS) operations would commence over a period of several months intermittently operating instruments whenever the lander had sufficient power.

On 12th November 2014 the Philae lander made contact with the surface of comet 67/P [1] and the FSS started executing automatically. Included in the lander payload was the Ptolemy instrument, a Gas Chromatograph–Mass Spectrometer (GC–IR–MS), designed to measure the chemical and isotopic composition of material containing the light elements, carbon, hydrogen, oxygen and nitrogen (CHON) [2]. Once the non-nominal nature of the landing became apparent

Abbreviations: CDMS, Command and Data Management System (of the Philae Lander); COSAC, COmetary SAmpling and Composition (instrument); CSS, Chemistry Set Simulator (software development test equipment for Ptolemy); EEPROM, Electrically Erasable Programmable Read Only Memory; EGSE, Electronic Ground support equipment; FM, Flight Model (of Ptolemy); FSS, First Science Sequence; GC–IR–MS, Gas Chromatography–Isotope Ratio–Mass Spectrometer; GRM, Ground Reference Model; LCC, Lander Control Centre; MS, Mass Spectrometer; POM, Polyoxymethylene – a $[CH_2–O]_n$ polymer; RAL, Rutherford Appleton Laboratory, a facility of the Science and Technology Facilities Council; RF, Radio Frequency; SD2, Sampler Drill and Distribution System; SONC, Science Operations and Navigation Centre; TC, Tele-Command; TIC, Total Ion Count; QM, Qualification Model (of Ptolemy)

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and the subsequent impact on resources characterised, the lander FSS operations required significant modification. Therefore, Ptolemy's operations were re-configured to recover as much science as practical within the short time frame of the Philae FSS campaign. This paper describes the features of the Ptolemy control process that enabled modification of the nominal instrument sequences and the scientific results obtained, whilst the instrument was located on a comet 500 million km from Earth. This 3-day period of intense activity required, in addition to the well-designed operating protocols of the instrument, an esprit de corps among the wider Philae Science and Operation teams developed through liaisons between individuals over several years.

1.1. Overview of the Ptolemy instrument

The Ptolemy instrument, built collaboratively by The Open University and RAL Space (Rutherford Appleton Laboratory), is comprised of five main sub-systems; instrument electronics, sample inlet system, gas processing system, gas chromatography columns and a mass spectrometer as the detector. An image of the Ptolemy Flight Model (FM) instrument is shown in Fig. 1 and a more detailed description in Morse et al. [3]. The electronics section of Ptolemy included power conversion, drive and sensor electronics along with its own dedicated Central Processing Unit (CPU) to monitor and control the Chemistry sub-systems. The instrument specifications are shown in Table 1.

The sample inlet system interfaces with the Sampler Drill and Distribution System (SD2, [4]) which can collect solid material up to a depth of 58 cm from the Lander balcony and deliver it to a set of 26 ovens on a carousel. Ptolemy controlled the tapping station to seal an oven, the oven heater and temperature sensor, whereas SD2 controlled carousel rotation as well as the drilling. The software control interface between SD2 and the carousel instruments (Ptolemy, COSAC and ÇIVA) was maintained by the Lander CDMS with each instrument having write access to status flags in its own area of RAM and read access to the status flags of RAM belonging to other instruments. To use the Tapping Station Ptolemy software would check that SD2 indicated the carousel was ready and the desired oven was in position. Ptolemy would then set its status flag to indicate that the carousel was in use before docking the Tapping Station. Ptolemy would clear the status flag when the undocking had successfully completed. The ovens are heated and sample gases thus evolved are transferred to the gas processing system. The gas processing system contains chemical reagents to process the sample into forms suitable for isotopic analysis [5]. It also contains reference gases to allow direct comparison of the isotopic ratio of the cometary C, H, O and N with that of terrestrial materials carried on-board. The analyte (sample or reference) can then be injected into one of three Gas Chromatography (GC) columns to separate the individual molecular components to be analysed by the quadrupole ion trap mass spectrometer for mass-selective identification at unit mass resolution. Alternatively the analyte can be injected directly into the mass spectrometer, a much simpler process but resulting in a more complicated mass spectrum to interpret.

The coma gas can be analysed by two methods; Direct or Pre-concentration. Direct analysis, commonly referred as "sniffing", is achieved by not activating the helium carrier gas system and allowing gases to diffuse back into the mass spectrometer through the vent pipe, which exits the lander on the upper surface. Alternatively, cometary gases are passively trapped and concentrated onto a cold molecular sieve reagent (Carbosphere™) contained within one of the Ptolemy ovens on SD2. Heating this oven releases the concentrated coma gas for analysis, as per solid samples. This "CASE" (Comet Atmosphere Sample Experiment) oven offers the potential of a more sensitive and comprehensive approach but at the cost of time resolution.

2. Material and methods

2.1. Ptolemy software

With the length of the Cruise phase of the Rosetta mission being over 10 years, it was recognised that an element of flexibility needed to be incorporated into the design and implementation of the operational sequences. It was also acknowledged that other cometary space missions were scheduled to be launched and return data before Rosetta

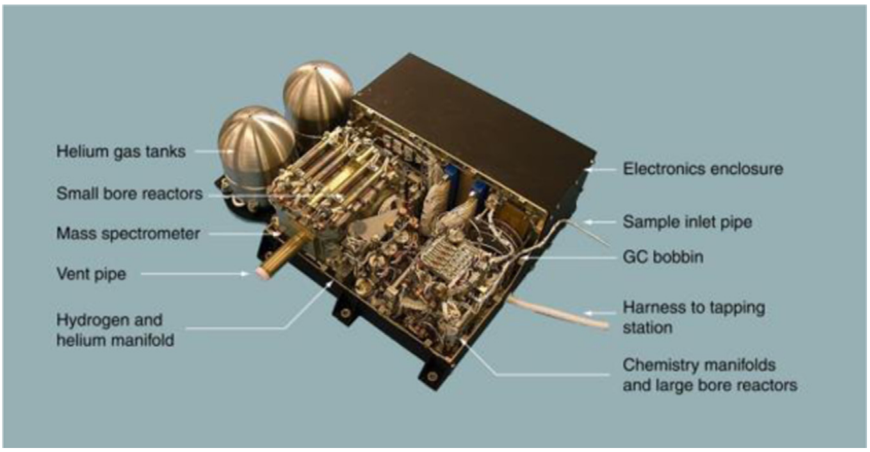

Fig. 1. The Ptolemy flight instrument with the outer cover removed to show components of the Ptolemy hardware.

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