ProSPA: An instrument for lunar polar volatiles prospecting and in situ resource utilization proof of concept

Conference or Workshop Item

PROSPA: AN INSTRUMENT FOR LUNAR POLAR VOLATILES PROSPECTING AND IN SITU RESOURCE UTILIZATION PROOF OF CONCEPT.
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Introduction: Many missions are in preparation for in-situ prospecting for lunar polar volatiles and by extension the assessment of such materials as potential resources to support future exploration missions. In this context, the European Space Agency (ESA) is developing the Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT). It comprises a drilling element (ProSEED – PROSPECT Sample Excavation, Extraction and Delivery) and a Sample Processing and Analysis element – ProSPA. PROSPECT is designed for high-latitude landing sites, to investigate volatiles and other resources from the perspectives of science (e.g. nature, abundance, distribution and processing of lunar volatiles) and of exploration (e.g. availability and extractability of materials for In-Situ Resource Utilization – ISRU).

Instrument Implementation: PROSPECT is part of the Roscosmos Luna-27 lander (Figure 1) planned to visit the south polar region of the Moon in 2022-3. ProSPA comprises two physical units – (1) a Solids Inlet System (SIS) comprising a series of single-use sample ovens on a rotary carousel together with a sample imager, and (2) a miniature chemical analysis laboratory incorporating two mass spectrometers and associated ancillary / control systems.

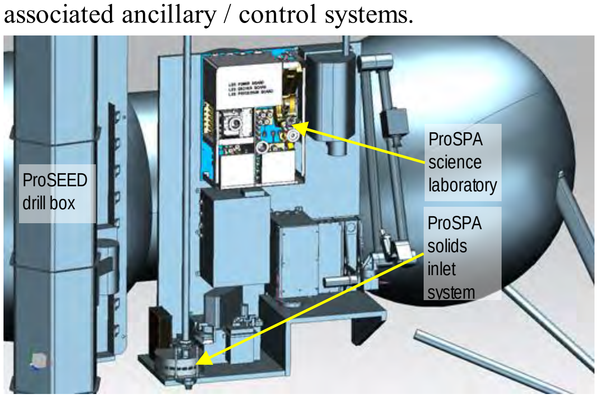

Figure 1: Location of ProSPA and ProSEED drill box on Luna-27 lander (IKI/Roscosmos)

Volatiles Preservation: At the low temperatures expected in the sampled lunar regolith (~120 to 150 K), a wide range of volatiles may exist in a variety of forms, including physically (loosely) bound and chemically (more strongly) bound species. The stability (hence rate of loss) of lunar volatiles is a strong function of temperature [1] as well as particle size [2]. To minimize the loss of volatiles before the sample is hermetically sealed within the ProSPA oven, the landing event is controlled such that instruments involved in sample acquisition and analysis face away from the Sun. Thus sample drilling, extraction and transfer to the ProSPA ovens occurs in the shade of the lander (though reflected heat is a necessary consideration). The SIS is thermally isolated from the "warm" enclosure of the chemical analysis unit, allowing the oven to be at 150 K or colder when the sample is received from the drill. After sample transfer, the carousel is rotated to place the sample-containing oven under an imager which confirms the presence of sample and enables estimation of the sample volume (up to ~60 mm^3). Then the sample oven is rotated to the "tapping station" position where an actuator seals the oven to a pipe which runs to the science laboratory.

Volatiles Extraction: Volatiles are extracted from the sample through heating within the sealed sample oven. A variety of heating profiles are envisaged to accomplish a variety of analysis modes (Figure 2).

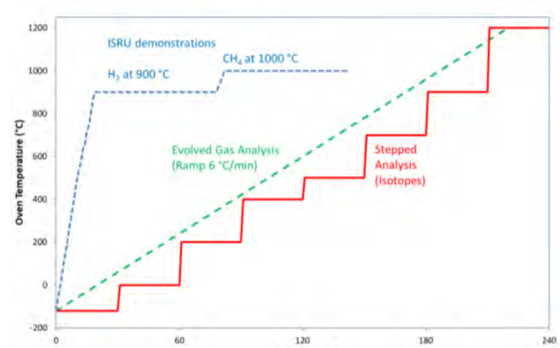

Figure 2: Example sample heating profiles

Evolved gas analysis: the oven is heated at a ramp rate of 6°C/min and the released gases are continuously analyzed by mass spectrometer to generate evolved gas analysis plots of the type previously presented for analysis of Apollo samples [3].

ISRU demonstration: the oven is heated to 900°C in the presence of added hydrogen feed gas to extract oxygen through reduction of mineral phases [4, 5]. Subsequently or alternatively, methane feed gas can effect gas-phase carbothermal reduction at 1000°C.

Stepped pyrolysis or combustion: gases released at a series of fixed temperatures from samples in vacuum or in oxygen respectively are isotopically analyzed in a magnetic sector mass spectrometer.

Volatiles Analysis: Volatiles released through the previously described extraction processes are passed to the ProSPA chemical laboratory for analysis. This comprises an ion trap device for analytical mass spectrometry (target m/z range 2-200 amu) and a magnetic sector instrument for stable isotopic analysis (~per mil level precision), together with the associated gas handling and processing components including open/closed valves, metering valves, micro-reactors, pressure sensors, reference materials etc. The chemical laboratory subsystems are shown in Figure 3.

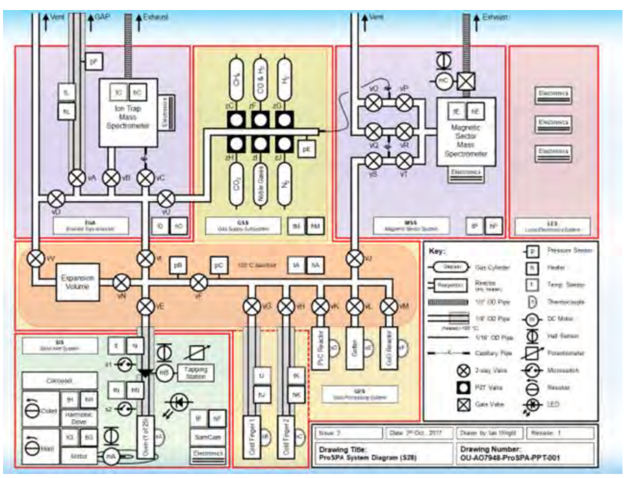

Figure 3: Schematic diagram of ProSPA Solids Inlet System (lower left) and Science Laboratory

Instrument Heritage: To minimise development timescales in line with the schedule of the Luna-27 Roscosmos-ESA mission to the lunar south pole in 2022, the ProSPA instrument draws heavily upon European heritage in flight hardware. The Solids Inlet System is based upon similar systems flown on Rosetta Philae [6] and in development for ExoMars rover [7], adapted for the lunar environment and sample nature. The ion trap mass spectrometer is based on the lightweight (<500 gram all-in) device which made the first chemical analyses on the surface of a comet on board Rosetta Philae [8]. The magnetic sector instrument for isotopic analysis derives from that developed for the Gas Analysis Package on Beagle 2 Mars lander [9]. Further gas processing components, electronics and software share similar heritage.

The anticipated science output is the identity, quantity and isotopic composition of volatiles as a function of depth (up to 1.2 m) in the lunar surface.

Current Status: ProSPA is undergoing a Preliminary Design Review at the end of Phase B. Various technical challenges have been addressed through modelling and/or laboratory work in areas such as oven sealing in the lunar thermal and dust environments, volatiles preservation, sample imaging and volume estimation. Recent results will be presented. A prototype instrument is in construction to enable testing of the extraction profiles shown in Figure 2 and optimization of resource requirements (power, time, energy). Current predictions are that ProSPA requires 10 kg including margin and peak power of ~70 W.

Conclusions: ProSPA is a powerful and versatile scientific laboratory for analyzing lunar volatiles and testing thermo-chemical extraction processes relevant to ISRU. Using techniques developed in the laboratory and refined in previous missions it will identify, quantify and isotopically characterize (D/H, $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) samples extracted from up to 1.2 m depth by the ProSEED drill. The acquisition of contextual images of the samples and the use of on-board reference materials will enable the results from ProSPA to be interpreted in the context of existing lunar datasets. ProSPA will provide ground truth for remote sensing data and inform future plans for lunar exploration and ISRU.

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