# ProSPA: Analysis of Lunar Polar Volatiles and ISRU Demonstration on the Moon

## Conference or Workshop Item

**ProSPA: Analysis of Lunar Polar Volatiles and ISRU Demonstration on the Moon.**

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**Introduction:** The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is in development by the European Space Agency (ESA) to support international lunar surface exploration missions. It comprises a drilling element (ProSEED – PROSPECT Sample Excavation and Extraction Drill) 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 both 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:** The first anticipated implementation is within the Luna-27 mission (Roscosmos-ESA) planned to visit the south polar region of the Moon in 2022. The accommodation of PROSPECT on the Luna-27 platform is shown in Figure 1. The functions of ProSPA are distributed across 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 (37 x 27 x 13 cm) chemical analysis laboratory incorporating two mass spectrometers and associated ancillary and control systems (Figure 1).

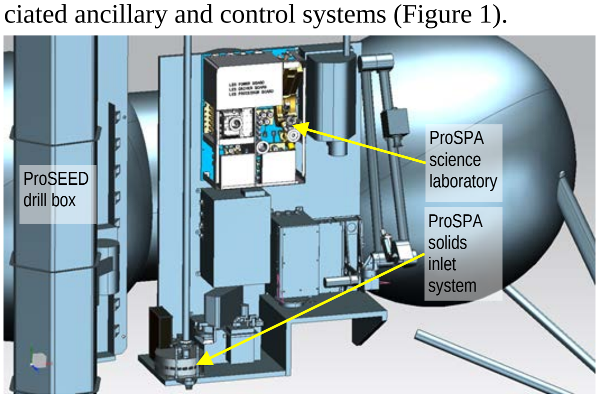


*Figure 1: Location of ProSPA units and ProSEED drill box on Luna-27 lander (credit IKI/Roscosmos)*

**Volatiles Preservation:** The local regolith temperature at the sampled site is assumed to be ~120 to 150 K. A wide range of volatiles may be present 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 grain size in lunar regolith [2]. Various measures are employed to minimize the uncontrolled loss of volatiles before the sample is hermetically sealed within the ProSPA oven (the overall strategy is to "do things quick and cold"). The landing event will be controlled such that the instruments involved in volatiles analysis (including PROSPECT) are located on the anti-sun side of the lander. Thus sample drilling, extraction and transfer to the ProSPA ovens occurs in the shade of the lander (though reflected heat must also be considered). 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 directly transferred into it from the drill. After sample transfer the carousel is rotated to place the sample-containing oven under an imager to confirm the presence of sample and also enable an estimation of its volume (10-60 mm$^3$). Then the sample oven is rotated to the "tapping station" position where an actuator is used to seal the oven to a pipe that runs to the chemical analysis laboratory.

**Volatiles Extraction:** Volatiles are extracted from the sample through heating the sealed oven in specific modes to accomplish a variety of analyses (Figure 2).

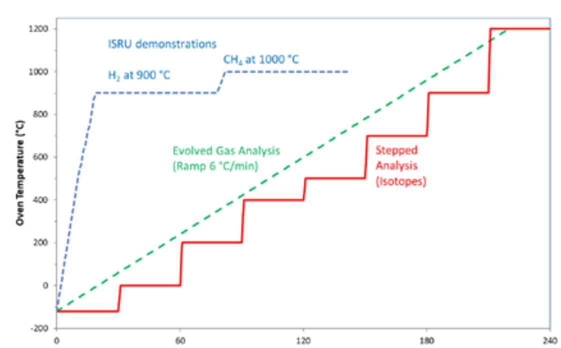


*Figure 2: Example sample oven heating profiles*

*Evolved gas analysis:* the oven is heated at a ramp rate of 6°C/min and the released gases are continuously analyzed by mass spectrometry to afford 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. Subsequently or alternatively, methane feed gas can be used for 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 sequentially 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 subsystems of the chemical laboratory are shown in Figure 3.

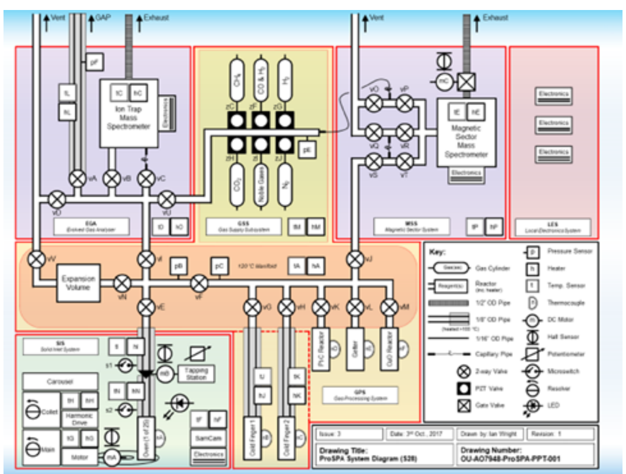

*Figure 3: Schematic diagram of ProSPA Solids Inlet System (lower left) and Science Laboratory*

**Instrument Heritage:** To minimize development timescales in line with the schedule of the Luna-27 mission, the ProSPA instrument draws extensively upon European heritage in flight hardware. The Solids Inlet System is based upon similar systems flown on Rosetta Philae [4] and in development for ExoMars rover [5], 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 lander [6]. The magnetic sector instrument for isotopic analysis is based upon that developed for the Gas Analysis Package on the Beagle 2 Mars lander [7]. Further gas processing components, electronics and software share similar heritage and the team developing ProSPA is based on previous successful missions.

The anticipated science output is the identity, quantity and isotopic composition of volatiles as a function of depth within the first 1.2 m of the lunar surface.

**Current Status:** ProSPA is undergoing its Preliminary Design Review at the end of Phase B. A number of key technical challenges have been addressed through theoretical 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). Present 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 data-sets. ProSPA will provide ground truth for remote sensing data and inform future plans for lunar exploration and ISRU.

**Acknowledgement:** ProSPA is being developed by a consortium led by The Open University, UK, under contract to the PROSPECT prime contractor Leonardo S.p.A., Italy, within a program of and funded by the European Space Agency.

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