THE ESA PROSPECT PAYLOAD FOR LUNA 27: SCIENCE ACTIVITIES AND DEVELOPMENT STATUS.

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Introduction: The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is a payload in development by ESA for use at the lunar surface. Current development is for flight on the Russian-led Luna-Resource Lander (Luna 27) mission, which will target the south polar region of the Moon.

Additional flight opportunities for PROSPECT related hardware are also now in development. These include flight of the full PROSPECT package on a NASA CLPS mission in 2025, and two flights of the Exospheric Mass Spectrometer (EMS) element, one on the Astrobotic Peregrine-1 mission (scheduled for flight in mid-2022) [11], and a second on JAXA's LUPEX rover, for flight around 2024/2025.

PROSPECT Overview: PROSPECT will perform an assessment of the volatile inventory in the near surface lunar regolith (down to ~ 1 m), and complete elemental and isotopic analyses to determine the abundance and origin of any volatiles discovered [1]. PROSPECT also has ISRU capabilities, and will aim to complete in-situ extraction of oxygen (and solar wind implanted volatiles) from lunar minerals, which will constitute potential science return from anywhere on the Moon. PROSPECT is comprised of the ProSEED drill module and the ProSPA analytical laboratory plus the Solids Inlet System (SIS), a carousel of sealable ovens for evolving volatiles from regolith (Fig. 1).

The drill is capable of collecting two icy samples of different sizes and mechanical properties in a single sampling operation, one of up to 45 mm^3 and a second up to 8 cm^3, with the smaller sample delivered to ProSPA. The drill rod also has integrated temperature sensors and a sensor to measure the electrical permittivity of the lunar soil along the borehole.

The ProSPA laboratory will receive samples from the drill, seal them in miniaturized ovens, and process them via ramped (EGA), stepped (isotopic) or single step (ISRU) heating up to 1000 °C, completing physical and chemical processing of released volatiles, and analysing the obtained constituents via Ion Trap or Magnetic Sector mass spectroscopy.

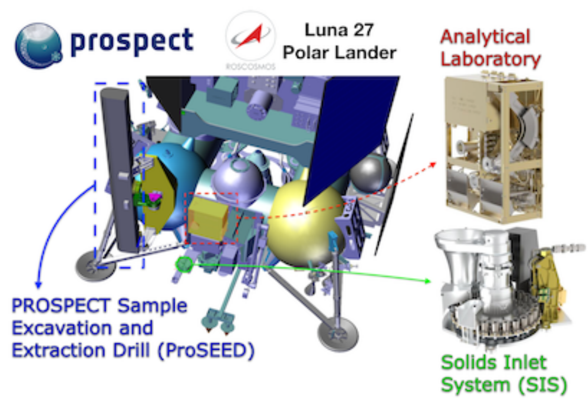

Figure 1: *Rendering of PROSPECT onboard Luna 27 polar lander, including the ProSEED drill module (left), and ProSPA (right). ProSPA comprises 1) the Solids Inlet System (lower right), and 2) the analytical laboratory (upper right).* Credit: IKI

ProSEED and ProSPA will also each carry small cameras. The ProSEED Camera has multispectral capabilities via 6 LEDs, which can illuminate the surface with wavelengths ranging from 451 to 970nm. This will provide images of the drill working area to monitor activities and deliver contextual scientific information. ProSPA's Sample Camera (SamCam [2]) has its own specific illumination unit (with similar capabilities to the ProSEED Camera), and will provide images of the samples in the ovens, providing information on their morphology, grain size, volume and mineralogy.

Development status: For Luna 27, PROSPECT Phase C (detailed definition) began in December 2019. In parallel to the industrial schedule undertaken, an associated plan of research activities has been formulated to gain from and guide ongoing development, build strategic scientific knowledge, and to prepare for operation of the payload. Recent developments include the construction of an EM of the p-sensor and of the ProSEED Imaging System, and their successful testing in representative environments. Details of further activities are described below

Drill Testing. Testing of the ProSEED Development Model was carried out in December 2019 as part of the final Phase B activities. Test procedures were formulated to demonstrate drilling and sampling functionality in ambient, cold and thermal vacuum (TV) laboratory conditions (at CISAS, University of Padova). Tests included drilling into, and sampling from, well-characterized NU-LHT-2M simulant mixed with anorthosite inclusions of various sizes [3] covering a plausible range of lunar regolith characteristics [e.g. [4]]. For tests in thermal vacuum, material was prepared for cases with water content representative of regolith that ranged from 'dry' to 'saturated' (0 - ≲12 wt. %). The main functionalities of the drill system were successfully demonstrated and required performances were achieved in these tests.

ProSPA Bench Development Model (BDM). The BDM of the ProSPA analytical lab at the Open University has been tested to demonstrate science performance against measurement requirements. Dedicated efforts in 2020/21 focused on verification of evolved gas analysis (EGA) via measurement of meteorite standards, constraint of oxygen yield via demonstration of ISRU capabilities [5, 6] improving understanding of sensitivity of science requirements to regolith volatile abundance and possible contamination, and understanding the performance of oven seal materials [7].

Science Activities: a number of science activities are being pursued alongside and in support of the technical development.

Volatile Preservation: Efforts continue on understanding the capability of PROSPECT to sufficiently preserve the volatile content in regolith throughout the sampling-analysis chain for the range of expected volatile contents, e.g. [8] (Figure 2). Detailed modelling and experimental work is ongoing to better understand water sublimation rates in realistic lunar surface operational environments, regolith structures, and geometries [9], and to better constrain the potential effect on measured D/H of sublimation of lunar water ice (for example, elaborating from [10]). Results from this work will help ensure that even in a 'hot operational case', the original volatile inventory can be determined with sufficiently small uncertainties.

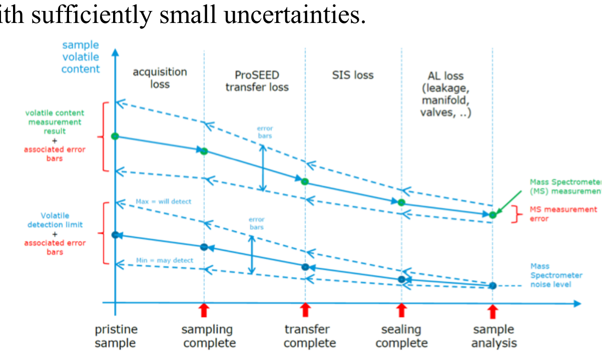

***Figure 2:** Tracking sublimation throughout sample-chain to reduce measurement uncertainty.* Credit: Mortimer et al.

ProSEED Imaging System Testing: In June/July 2021, members of the Science Team at IAPS in Italy have successfully tested the Engineering Model of the ProSEED Imaging System. Testing included measuring the spectral profile of each of the LEDs, characterizing the geometric, radiometric and spectral response of the camera, and assessing the impact that dust deposition may have on the camera sensitivity. Images taken of samples during the testing are now being analysed by the broader Science Team to see what can be ascertained from the multispectral data alone.

CAPTEM sample analysis: In 2020, PROSPECT Science Team members successfully requested two samples of lunar regolith (2 g each) from the Apollo collections (14163 and 69921). The samples were finally delivered in late summer 2021 and the team are working on detailed plan for their analyses. The proposed experiments will investigate loss of water ice through sublimation and the effects that the bulk properties and the ice-regolith coupling have on the sublimation process.

Isotope measurement requirements: The Science Team are currently revisiting the science requirements related to isotopic measurements for ProSPA to allow for testing of instrument performance in line with the expected cleanliness and contamination parameters. This will allow us to enter the Critical Design Review with some confidence in the instrument's ability to return good scientific results.

Landing site analyses: The landing site for Luna 27 is not yet known, but there are 8 candidate sites already selected. Work is ongoing to study each of these, mapping them in detail and looking at several critical parameters that will allow for instrument survival / operation and provide the best potential for the presence of volatiles [12].

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