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L-DART: DIRECT ANALYSIS OF RESOURCE TRAPS WITHIN LUNAR PERMANENTLY SHADOWED REGIONS BY A PENETRATOR MISSION.

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Introduction: Lunar Direct Analysis of Resource Traps (L-DART) addresses many current knowledge gaps concerning lunar volatiles and permanently shadowed regions (PSRs), providing in-situ ground truth data to calibrate existing remote datasets.

It builds on UK expertise in developing and testing penetrator system concepts for the Moon and Europa (e.g. MOONLITE [1]). Following release of a Penetrator Descent Module in lunar orbit (Figure 1), its Penetrator Delivery System performs de-orbit and orientation before releasing the instrumented Penetrator to penetrate a few meters into target lunar surface at ~300 m/s. The penetrator itself serves as the sampling tool and an on-board mass spectrometer analyses in-situ the volatiles released both in the impact and in the subsequent thermal soak from lander to surrounding regolith. A pair of 3-axis accelerometers measure regolith structure during landing and constrain penetrator final location. Temperature sensors enable deduction of regolith thermal properties. Pre- and post-impact imagery provides context. Science is complete and data relayed to Earth within 1-2 hours, minimizing system mass and lifetime requirements.

Possible landing sites include Cabeus (for comparison with LCROSS) or Shoemaker which exhibits excess hydrogen, or areas indicated by LRO to exhibit putative surface frost. Alternatively, L-DART could target the hypothesised ancient (paleo) south pole [2] and hence potentially ancient volatiles.

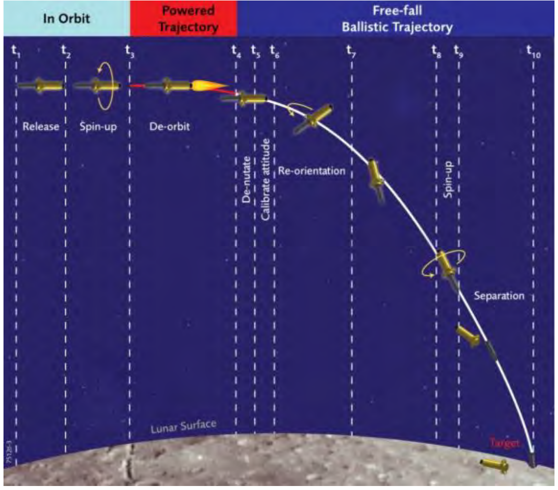

Figure 1: Typical events during penetrator delivery (credit Airbus Defence and Space)

Lunar polar volatiles and knowledge gaps: After the lull that followed the Apollo and Luna era, many spacefaring nations are preparing new lunar missions. Many such missions target high latitudes, now understood to be very different to the largely equatorial areas sampled previously. Orbital data have revealed an extraordinary near-polar thermal environment, with the Moon's low angle of tilt meaning that topography dominates illumination conditions and temperatures in PSRs are among the lowest of any solar system body. These areas act as cold traps where a range of volatiles are thermally stable on geological timescales [3] offering a scientific treasured trove of time-integrated volatile inventory. These potentially abundant supplies of volatile resources including water, could represent a source of materials for in-situ resource utilization (ISRU). Together with nearby raised areas that offer near-constant illumination (e.g. [4]), these potentially enable sustained exploration and even a permanent human presence.

The search for lunar polar water is therefore a highly active research topic. Although a variety of instruments on orbiters have indicated the presence of hydrogen or water at or near the surface, unequivocal interpretation of orbital datasets can be problematic. The most direct evidence for lunar polar volatiles comes from the Lunar Crater Observation and Sensing Satellite (LCROSS) mission launched together with Lunar Reconnaissance Orbiter (LRO) in June, 2009 [5]. This culminated in the impact of the spacecraft's spent upper rocket stage into the permanently shadowed Cabeus crater near the lunar south pole. The impact was observed by a suite of instruments on the LCROSS shepherding spacecraft, and led to the deduction that the concentration of water ice at the impact site was 5.6 ± 2.9% by mass [6]. In addition to water, a number of other volatile species were detected by instruments on both the shepherding spacecraft and LRO (including near-infrared, visible and ultraviolet spectrometers; [6], [7]). Many of these were consistent with calculations on thermal stability [8], [9].

But still L-CROSS leaves questions unanswered. The amount of material excavated in the impact is uncertain (at least in part due to uncertainties in mechanical properties of the landing site regolith) and this propagates into uncertainties in the inferred concentrations of volatiles in the regolith. There is some suggestion of a delayed flash implying porosity in the target material; the sub-surface thermal environment was not measured directly. And because the observations on chemical composition of the plume were made remotely, these are subject to chemical processing that may occur within the plume hence measurements may not be fully representative of the original source materials. Notably, not only do current uncertainties relate to fundamental scientific questions, but they also involve many of the physical parameter inputs demanded by engineers seeking to design future missions.

Arguably, a rare consensus concerning lunar polar volatiles is that new landed missions are necessary, carrying suites of instruments to extract and analyze volatiles and characterize the source environment. An example is ESA's PROSPECT package [10]. At its heart is an ion trap mass spectrometer weighing only ~500 g yet capable of detecting a wide range of volatiles with high sensitivity, and with heritage of successful analogous measurements on the Rosetta comet lander [11], [12]. But its samples are supplied by a ~25 kg drill, and hence this is only suitable for deployment on a large static platform such as Luna-27 or perhaps a 250 kg-class rover. Smaller rovers in the ~25 kg class may also house such compact analysis instruments but direct regolith sampling depth may be limited to the upper ~10 cm [13].

Penetrators mission such as L-DART therefore present an ideal or even unique means through which to directly sample and analyze at depths analogous to those probed by remote sensing (i.e. the upper ~2 m), in lunar regions such as PSRs inaccessible to conventional spacecraft. Moreover, by using miniaturized and ruggedized hardware such as mass spectrometers [14] similar to those planned for landers such as Luna-27 [11], L-DART can provide valuable ground truth to aid the interpretation of remote data-sets.

Science Objectives and Instrumentation:

The science objectives of L-DART are summarized in its Science Traceability Matrix (to be presented). The focused payload of complementary and high TRL instruments comprises accelerometers, mass spectrometer, temperature sensors and imager(s). The acquired data provide unique in situ measurements of PSR volatiles and geotechnical/thermal properties. This ground truth greatly enhances existing and future remote datasets and informs future mission design. The descent imager provides wider geological context (local topography, geology, illumination) as well as images of high value for public engagement and outreach. The post-landing imager (if implemented) will provide complementary micro-scale imagery.

Current Status: The L-DART consortium is currently conducting a payload definition exercise to refine the reference payload. This will enable the updating of key payload parameters such as mass and volume to reflect recent developments in technology readiness level. In addition, preliminary results may be presented on a study by The Open University and QinetiQ (funded by UK Space Agency) aimed at increasing the understanding of the attenuation of the penetrator's UHF communications signal by any regolith overlying the onboard antenna post-landing.

The outcomes of the above activities will generate outputs ready for input to a Phase A type study in which the system design feasibility can be assessed and realistic estimates of the all-up penetrator system mass can be generated for input to more detailed mission design and cost estimating activities.

Conclusions: L-DART targets key scientific and exploration knowledge gaps concerning lunar polar volatiles, by making in situ measurements of volatiles and regolith thermal and geotechnical properties supported by contextual imaging at macro- and micro-scale. Many technological aspects have been matured in the last decade, and international partners are now actively being sought to exploit this significant potential and make the mission a reality.

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