

**Searching for lunar water: The Lunar Volatile Resources Analysis Package.** A. D. Morse<sup>1</sup>, S. J. Barber<sup>1</sup>, K. R. Dewar<sup>1</sup>, J. M. Pillinger<sup>1</sup>, S. Sheridan<sup>1</sup>, I. P. Wright<sup>1</sup>, E. K. Gibson<sup>2</sup>, J. A. Merrifield<sup>3</sup>, C. J. Howe<sup>4</sup>, L. J. Waugh<sup>5</sup> and C. T. Pillinger<sup>1</sup>, <sup>1</sup>Planetary & Space Sciences, The Open University, Walton Hall, Milton Keynes. MK7 6AA UK. ([a.d.morse@open.ac.uk](mailto:a.d.morse@open.ac.uk)), <sup>2</sup>Astromaterials Research Office, NASA Johnson Space Center, Houston, TX 77058, USA, <sup>3</sup>Fluid Gravity Engineering, 1 West Street, Emsworth, PO10 7DX, UK, <sup>4</sup>RAL Space, Didcot, Oxfordshire, OX11 0QX, UK, <sup>5</sup>EADS Astrium Ltd., Gunnels Wood Rd., Stevenage SG1 2AS, UK.

**Introduction:** The ESA Lunar Lander has been conceived to demonstrate an autonomous landing capability. Once safely on the Moon the scientific payload will conduct investigations aimed at preparing the way for human exploration. As part of the provisional payload an instrument known as The Lunar Volatile Resources Analysis Package (L-VRAP) will analyse surface and exospheric volatiles. The presence and abundance of lunar water is an important consideration for ISRU (In Situ Resource Utilisation) since this is likely to be part of a strategy for supporting long-term human exploration of the Moon.

**Lunar water:** Immediately following the Apollo era the Moon was considered a volatile-poor body. Samples collected from the Apollo missions contained only ppm levels of water formed by the interaction of the solar wind with the lunar regolith [1], in addition to larger quantities of water assumed to arise from terrestrial contamination. However, more recent orbiter observations have indicated that water may exist as ice in cold polar regions buried within craters at concentrations of a few wt. % [2]. Infrared images from M3 on Chandrayaan-1 have been interpreted as showing the presence of hydrated surface minerals with the ongoing hydroxyl/water process feeding cold polar traps. This has been supported by observation of ephemeral features termed “space dew” [3]. Meanwhile laboratory studies indicate that water could be present in appreciable quantities in lunar rocks [4] and could also have a cometary source [5]. The presence of sufficient quantities of volatiles could provide a resource that would simplify logistics for long-term lunar missions.

**ESA Lunar Lander:** The Lunar Lander is a European Space Agency (Directorate of Human Spaceflight and Operations) robotic mission concept planned for launch in 2018 to demonstrate key technology to enable human exploration [6]. The primary mission aim is to demonstrate soft, precise, automated landing, with hazard avoidance. Potential target areas are zones of almost constant illumination (e.g. at the edge of the Shackleton crater at the lunar south pole). Such landing sites fulfill the requirement to demonstrate accurate navigation (~200m) and enable the solar-powered craft to survive for long periods (~ 6 months) enabling detailed scientific investigations of the surface environment.

**L-VRAP:** The Lander payload includes provision for a Lunar Volatile Resources Analysis Package (L-VRAP). The authors have been commissioned by ESA to evaluate suitable technology and provide a provisional design of L-VRAP.

Although landing in an illuminated area these zones are in close proximity to permanently shadowed, and potentially, volatile-rich cold traps. Scientific aims are to demonstrate effective extraction of volatiles and to determine the volatile inventory of the Moon (with a view for future In Situ Resource Utilisation). Surface samples will be collected by a robotic arm with the possibility of a rover to collect more distant samples. The concentration, chemical and accurate isotopic ratios (D/H, <sup>13</sup>C/<sup>12</sup>C, <sup>15</sup>N/<sup>14</sup>N, <sup>18</sup>O/<sup>16</sup>O and noble gases) of liberated volatiles will be determined, possibly using similar technology to the Philae comet lander of the Rosetta mission [7]. An additional aim is the monitoring of the chemical and isotopic composition of the tenuous lunar atmosphere [8] to establish a baseline measurement prior to active human exploration (which will presumably be accompanied by contaminating effects). The lunar atmosphere will provide information on the processes involved in forming lunar volatiles and their concentration mechanisms.

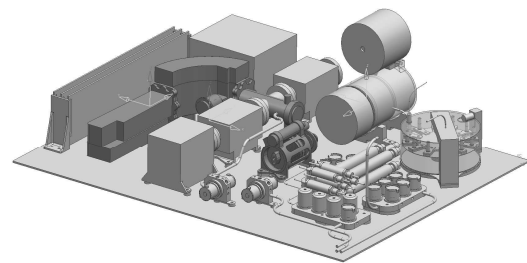


Fig. 1 Layout of L-VRAP instrument.

**Contamination:** An important consideration for this study is the effects of contamination from the Lander. The landing sequence will use about 1000 kg of propellant, with a large fraction directed onto the landing site. Initial modelling indicates that uncontaminated samples will be accessible by the robotic arm at depths of several centimetres. Knowledge of the contamination composition and distribution will allow the

identification of surface volatiles, either by subtracting the contamination or by identifying protected areas such as surface shielded by boulders.

**References:** [1] Pillinger C. T. (1979) *Rep.Prog.Phys*, 42, 897–961. [2] Mitrofanov I. G. et al. (2010) *Science*. 330, 483–486. [3] McCord T. B. et al. (2011) *J.Geophys.Res.*, 116, E00G05. [4] Boyce J. W. et al. (2010) *Nature* 466, 466–469. [5] Greenwood, J. P. et al. (2011) *Nature Geosci*, 4, 79–82. [6] Fisackerly R. et al. (2011). The European Lunar Lander: Robotic Operations in a Harsh Environment. *Moon*,. [7] Morse A. D. et al. (2009) *In: Rosetta: ESA's mission to the origin of the solar system*, 19.6, 669–686. [8] Hofmann J. H. (1975) Lunar Atmospheric Composition Experiment, NASA report.