Results from End-to-End Testing of the Lunar Capillary Absorption Spectrometer (LuCAS) with the Planetary Volatiles Extractor (PVEx). I. R. King[1], F. J. Sheeran[1], S. Mayne[1], J. Kriesel[2], A. Fahrland[2], Emre Ozen[2], J. Stern[3], M. Kowalewski[3], and the LuCAS team. [1]Honeybee Robotics (iking2@blueorigin.com), Altadena, CA 91001, [2]Opto-Knowledge Systems, Inc. (OKSI), Torrance, CA 90502, [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771.

Introduction: Cold traps in Permanently Shadowed Regions (PSRs) at the lunar poles are known to contain volatiles, including water ice [1]. Locally sourced water is a critical resource for sustaining a human presence on the Moon under NASA's Artemis program, but the source, composition, and distribution of the volatile mixture containing this water ice is not yet well-characterized. To address this, we have developed the Lunar Capillary Absorption Spectrometer (LuCAS): an end-to-end isotope and trace gas analyzer for studying lunar volatiles. LuCAS is paired with the Planetary Volatiles Extractor (PVEx), a 1-meter rotary percussive coring drill that extracts volatiles in-situ by heating regolith contained inside the core. To aid in validating volatile delivery from PVEx to LuCAS and to study the nature of re-condensing lunar volatiles, a camera called "SnowCam" was added to LuCAS to image the Cold Trap onto which volatiles accumulate. Development of these instruments has been funded by NASA SBIR and DALI programs [2, 3]. Here, we present ice accumulation results as part of the end-to-end testing of the TRL 5 LuCAS system with PVEx.

Experimental Setup: The end-to-end testbed has PVEx inside a 3 m × 1 m × 1 m vacuum chamber, with the TRL 5 LuCAS on a benchtop connected via a heated flex hose (Figure 1). The regolith bin is >1 m deep and has a clamshell jacket with liquid nitrogen lines to cool the testbed to cryogenic temperatures; regolith typically reaches −80°C after overnight cooling in a nitrogen backfill. Regolith simulant (LSP-1) water content was varied between 0.2 wt. % (the driest achievable in the lab via bakeout) and 2.5 wt. % (ambient hydration at Honeybee Robotics). For CAS isotope tests, water enriched in deuterium was added to previously dried regolith to increase the expected deuterium signal.

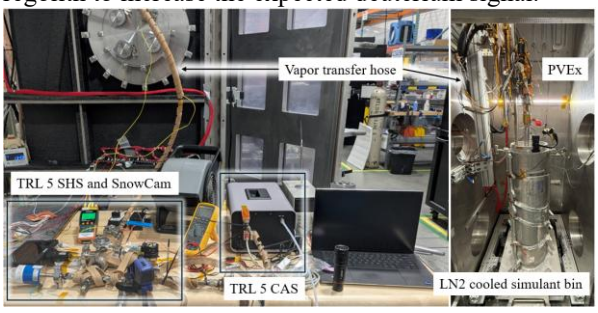

Figure 1: LuCAS TRL 5 end-to-end testbed setup

Collection Results: Volatile accumulation in the instrument was monitored via four independent methods. First, SnowCam directly imaged the Cold Trap to observe ice buildup on the surface, showing the progression from a clean surface, to significant ice accumulation during PVEx heating, to condensation forming when the cold trap was heated prior to vapor delivery to the instrument (Figure 2). Second, a vacuum gauge in the SHS primary volume recorded pressure rises of 6–8 Torr during collection. After the cold trap was warmed back to ambient, pressure rose to the vapor pressure of water (18–22 Torr), indicating that at least ~2 mg of water was collected — with additional liquid condensation that could not be quantified. Third, the cold finger RTD showed temperature increases at constant 15 W power as ice accumulated, reflecting the added thermal load. Fourth, the instrument identified the presence of volatile species by periodically sampling gas from the sample handling system during collection.

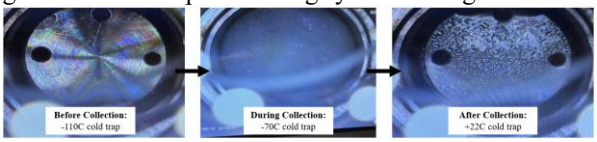

Figure 2: Surface of the Cold Trap imaged by SnowCam at different times in the flight-like concept of operations

Conclusions: This work demonstrates the end-to-end operation of PVEx and LuCAS as an integrated volatile prospecting system. Accumulation of volatiles in this system is limited by the surface area and cooling power of the Cold Trap. This point design is intended to make measurements from potentially very dry (volatile concentrations in the ~ppm range) lunar regolith for species identification and isotopic measurements rather than to harvest volatiles at scale. However, these results establish the technical feasibility of using such a system for lunar prospecting and other scaled operations. Continued development under the DALI program will mature the LuCAS instrument and integrated SnowCam to TRL 6. At the time of writing, the TRL 6 design has passed CDR and hardware build is underway.

References: [1] Colaprete A. et al. (2010) *Science*, 330, 463-468 [2] Sheeran, T. et al., "Planetary Volatiles Extractor (PVEx): Pneumatic Regolith Acquisition and Volatile Extraction for Lunar Prospecting," IEEE Aerospace Conference, 2026. [3] King, I. R. et al., "Lunar Capillary Absorption Spectrometer (LuCAS): A Microfluidic Sensor for Detecting Water and Dissolved Species in Lunar Volatiles," IEEE Aerospace Conference, 2026.