PASSIVE RETROREFLECTOR ARRAYS FOR POLAR NAVIGATION IN THE DARK. D. R. Cremons[1], D. E. Smith[2], X. Sun[1], E. Mazarico[1], and J. Head[3], [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771 daniel.cremons@nasa.gov, [2]Massachusetts Institute of Technology, Cambridge, MA 02139, [3]Brown University, Providence, RI 02912.

Introduction: Laser retro-reflector arrays (LRAs) consisting of corner cube retroreflectors (CCRs) can act as fiducial markers for decades of laser ranging on the Moon and other planetary bodies. Upcoming CLPS missions as well as missions from government space agencies (JAXA, ISRO) will carry small LRAs on their landers. Placement of a small LRA on the deck of a lander or rover enables tracking with an orbital laser altimeter with a precision on the order of centimeters. In addition, LRAs can support precision autonomous navigation and landing regardless of lighting conditions, a valuable feature for lunar polar exploration. These LRAs will soon arrive on the lunar surface, and their ruggedness makes them ideal for locating ISRU depots, sample caches, positions of interest, or waypoints during the lunar night when visual navigation is not feasible.

Array Design	Hemispherical
Array Diameter	5.11 cm
Array Height	1.65 cm
CCR Clear Aperture	1.27 cm
Number of CCRs	8
Mass	20 g

Figure 1. Small LRA after integration with SpaceIL Beresheet lander deck in Nov. 2018.

LRAs on CLPS and International Landers: We have designed, fabricated, and tested 13 small LRAs under the Commercial Lunar Payload Services (CLPS) program [1,2]. These 20-gram LRAs are designed to provide a high-gain optical target which can be ranged to with a laser altimeter from any azimuth angle above 30° in elevation from the mounting plane (60° from zenith). These small instruments (Figure 1) were designed and tested for decades of lifetime on the lunar surface, including radiation testing to 19 Mrad (Si). The arrays can operate over the entire lunar day and night and are completely passive; they require no power, communication, or thermal control, and can survive in the darkest, coldest PSRs.

LRAs as Navigation Markers for Polar Exploration: The ubiquitous long shadows and rapidly changing illumination conditions of the lunar South Pole present navigation challenges for both autonomous and human missions. The high phase angle near the poles present challenges for entry, descent, and landing (EDL) systems that rely on camera-based optical navigation, perhaps supported by a single-beam laser rangefinder. If such missions are required to land in illuminated terrain this will impose limitations on both landing locations and the precise timing of those landings (as well as other orbit maneuvers to prepare for EDL).

LRAs for Entry, Descent, and Landing.

We suggest that LRAs such as those flown on upcoming CLPS landers can be used as fiducial target markers to enable EDL within shadowed terrain (temporary or permanently shadowed). A triangle (or other shape) of LRAs placed by robotic means around a targeted landing zone would form a unique reference frame with which a laser-based landing navigation system could triangulate the lander position and safely complete the landing sequence. Since the retroreflector arrays are alignment insensitive within 60° of zenith, there would not be any site preparation or stringent placement requirements besides an open sky view. The arrays could be set down with a robotic arm or even dropped from a rover bay [3]. The high optical gain of the LRAs means that a laser-based landing navigation system could begin tracking this landing zone from tens of kilometers in range, potentially on previous orbits to refine the approach vector.

Traverse Mapping in Shadowed Terrain.

Small LRAs could also enhance human or robotic surface traverses. We envision a traverse through shadowed terrain where LRAs are placed at line-of-sight intervals along the traverse to form a “trail of breadcrumbs” from the lander or habitat. Navigating back along the trail would then involve scanning the scene with a laser or focused LED to look for the “flash” when illuminating the retroreflector. The LRAs would act as “lighthouses on demand”, identifying the heading and potentially the range (based on signal strength) from the observer to the reference point. Such waypoint navigation would allow for quick egress into and out of dark terrain to maximize time spent in the scientifically rich dark terrain. Finally, LRAs could be placed at sample or equipment caches for later retrieval without the need for high-resolution imaging.

References: [1] Sun X. et al. (2019) *Appl. Opt.*, *58*, 9259-9266. [2] Cremons D. R. et al. (2020) *Appl. Opt.*, *59*, 5020-5031. [3] Tsuda, Y. et al. (2013) *Acta Astronaut.*, *91*, 356-362.