ROBOTIC SURFACE ELEMENTS OF A LUNAR SAMPLE RETURN MISSION COORDINATED WITH CREW IN AN ORBITING ORION VEHICLE.

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Introduction: Exploration Flight Test One (EFT-1) launched the first Orion vehicle on a Delta IV Heavy in December 2014. The Orion was propelled ~15 times higher than the International Space Station, producing a return speed that was 80% of the speed of a spacecraft returning from the Moon in a successful test of its atmospheric re-entry and recovery capabilities. The success of EFT-1 is the first step in a revitalized and integrated robotic and human exploration program beyond low-Earth orbit.

The best and most accessible target for the integrated exploration program is the Moon. The next Orion mission will be Exploration Mission One (EM-1) launched on the Space Launch System (SLS), which will be an uncrewed flight to a Distant Retrograde Orbit (DRO) around the Moon in 2018. Exploration Mission Two (EM-2) will be the first test of a fully functional SLS and Orion and send crew around the Moon. That mission will set the stage for Orion to support lunar surface activities.

The international community has already developed a well-defined set of scientific and exploration objectives for the lunar surface (e.g., [1,2]). To adequately address those objectives, surface missions need to collect and return samples to Earth. The Global Exploration Roadmap (GER) [3] outlines plans for a human-assisted sample return mission circa 2024 and for a human presence on the lunar surface circa 2028.

In this paper, we examine some of the issues associated with human-assisted sample return missions. We outline two examples of robotic surface traverses and discuss how the robotic asset would interact with crew in an orbiting Orion vehicle. That type of integrated activity is particularly attractive for missions on the lunar farside (an area completely unexplored during the Apollo era), because the Orion vehicle will provide a communication link and, thus, access to a part of the Moon that is otherwise unavailable to an Earth-based mission control.

Potential Landing Sites: Following a review of lunar science objectives [1], a global study of lunar landing sites where those objectives could be addressed was initiated. The outcome of that study [4] included the following findings: (i) the Schrödinger basin, along the margin of the South Pole-Aitken (SPA) basin, is the best target for addressing the largest number of objectives; and (ii) the Amundsen crater, also along the margin of SPA, is a good target for a mission with a narrower focus on volatile deposits and the processes that generated them. The latter finding was recently addressed elsewhere [5] and will not be discussed further here, where we instead focus on missions to the Schrödinger basin within the SPA basin.

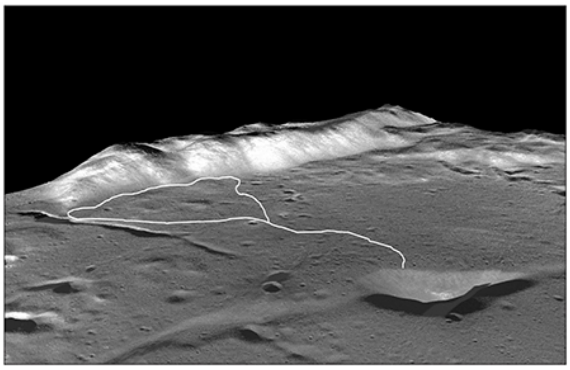

Fig. 1. *Conceptual traverse in the vicinity of a pyroclastic vent and the basin peak ring which would provide a diverse array of samples to address a large number of science objectives. See [8] for details of different traverse options.*

Traverse Options: Several landing sites for both crew [6,7] and robotic assets [8,9] have been investigated within the Schrödinger basin. This basin is nearly 320 km in diameter, up to 4.5 km deep, with a peak ring that rises 1 to 2.5 km above the basin floor. One of the most interesting landing sites is located between a pyroclastic vent (with ISRU potential) and the basin's peak ring (Fig. 1).

A sample return mission to this part of the basin would (a) produce samples of the Schrödinger basin impact lithologies, from which the age of one of the last basin-forming impact events could be measured, and (b) potentially SPA impact lithologies, from which the age of the oldest basin-forming event could be measured. Those samples would help test the lunar cataclysm hypothesis. The nearby peak ring would (c) provide samples of the deep lunar crust, allowing tests of both the giant impact hypothesis and the lunar magma ocean hypothesis. Because Schrödinger basin is the best preserved basin of its size on the Moon (and exquisitely preserved compared to any basin on Earth), impact lithologies collected within that geologic context would (d) provide insights into the types of impact processes that shaped early planetary surfaces. Volcanic processes modified small regions of the basin, producing (e) lava flows and a pyroclastic vent that can be sampled to investigate the thermal and magmatic evolution of the lunar interior. Finally, that pyroclastic vent and nearby permanently shadowed regions would (f) provide an opportunity to examine the volatile cycle on the Moon and the deposition of those types of materials in deposits with in situ resource potential. A study of landing sites and sampling strategies in Schrödinger [8] has developed an optimal traverse lasting 9-10 days; descoped traverse options last 7.9 and 6.5 days.

Another potential landing site is located in the southern portion of the basin (Fig. 2), where outcrops containing the largest fraction of SPA-melt samples are predicted to occur [9]. A mission to this site would produce samples that could be used to determine both the age of SPA and that of the Schrödinger basin. The basin walls at this site would also provide an opportunity to investigate the stratigraphy of the SPA basin where it was punctured by the Schrödinger-forming event.

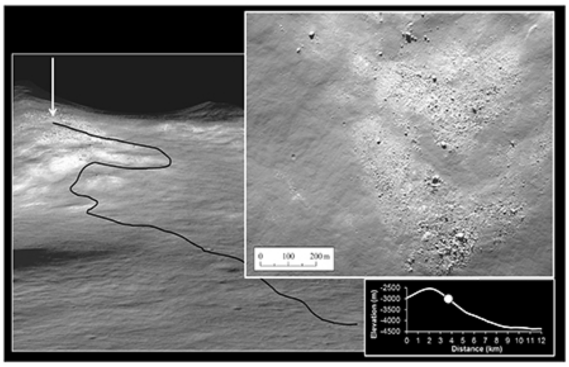

Fig. 2. *Conceptual traverse from the basin's floor to its walls, which could potentially provide samples for determining the ages of both Schrödinger and the South Pole-Aitken (SPA) basins. After [9].*

In the simplest mission scenario, the robotic asset would conduct its traverse and collect samples within a single lunar daylight period. Extended missions are possible if the robotic assets are designed to survive a period of lunar darkness.

Mission Concept: We propose to coordinate those robotic surface activities with crew on an Orion vehicle in orbit [10]. In that type of mission, astronauts in NASA's Orion vehicle (potentially supported by ESA's service module) would either be in orbit in the vicinity of the Earth-Moon L2 point (EM-L2) or in a distant retrograde orbit (DRO). In the case of an EM-L2 orbit, crew would be nearly 60,000 km above the lunar far side surface. Mission Control on Earth could maintain contact and operate the lander and rover through Orion. Moreover, for portions of the mission, astronauts on Orion could teleoperate the rover, in near real time, to reduce mission risk, enhance scientific return, and test operational concepts for future missions to Mars. An ascent vehicle on the robotic asset could return samples to the Orion vehicle for return to Earth or, with the addition of a capsule, directly to Earth.

Studies of potential Orion orbits [10,11] found that an EM-L2 orbit provides more mission capability than a DRO orbit. In missions of 26 to 30 days, crew could maintain contact with the robotic asset without any communication gaps (Fig. 3). In this type of mission scenario, the robotic asset would make its descent only after Orion successfully launched and communication was assured. After 13 days of surface operations, an ascent vehicle on the robotic lander would lift off to rendezvous with crew on Orion. That amount of contact time between Orion and the robotic asset would be sufficient for the optimal traverse of [8].

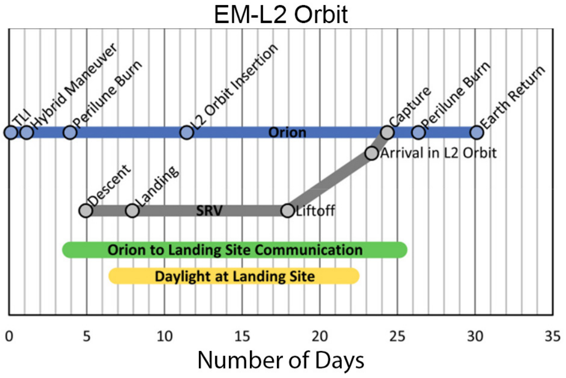

Fig. 3. *Timeline of critical events in an integrated robotic sample return vehicle (SRV) and human sample return mission utilizing Orion in an L2 orbit [12]. The interval during which communication between Orion and the SRV is shown in green and the interval of daylight on the surface is shown in yellow.*

References: [1] National Research Council (2007) *The Scientific Context for Exploration of the Moon*. [2] Crawford I.A. et al. (2012) *Planet. Space Sci., 74*, 3-14. [3] International Space Exploration Coordination Group (2011) *The Global Exploration Roadmap*. [4] Kring D. A. and Durda D. D. (2012) *LPI Contrib*. No. 1694, 688 p. [5] Lemelin M. et al. (2014) *Planet. Space Sci., 101*, 149-161. [6] O'Sullivan K. M. et al. (2011) *GSA Spec. Pap., 477*, 117-127. [7] Bunte M. K. et al. (2011) *GSA Spec. Pap., 483*, 533-546. [8] Potts N. J. et al. (2015) *Adv. Space. Res., 55,* 1241-1254. [9] Hurwitz D. M. and Kring D. A. (2014) *Lunar Planet. Sci. XLV*, Abstract #1398. [10] Burns J.O. et al. (2013) *Adv. Space Res.*, 52, 306-320. [11] Hopkins J. B. et al. (2013) *International Astronautical Congress, 64th*, paper A5.1.4, 22 p. [12] Pratt W. et al. (2014) *International Astronautical Congress, 65th*, paper IAC-14-A5.1.7, 18 p.