EXPLORING THE SOLAR SYSTEM WITH AN INTEGRATED HUMAN AND ROBOTIC DEEP SPACE PROGRAM. David A. Kring, Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd., Houston, TX 77058 USA (kring@lpi.usra.edu).

Introduction: NASA is developing the Orion crew vehicle and Space Launch System (SLS). Those vehicles, along with an ESA service module, provide new capabilities for exploring deep space. A series of Exploration Missions (EMs) are being designed for cis-lunar space to validate spacecraft performance and evaluate crew health performance. During that validation phase and after the systems are fully operational, opportunities to explore Solar System processes will be greatly enhanced. Here I expand on activities [1] that can occur through 2030 with a forward look at how they may shape opportunities circa 2050.

Initial Mission Capabilities: In the initial EMs, Orion could be outfitted with a high-definition camera to image the Moon during 100 km altitude passes over the lunar surface (Fig. 1), an additional camera to detect impact flashes on the farside and/or in the nighttime hemisphere to complement ground-based measurements of the nearside, radiation detectors for measurements external to and within the Orion crew capsule to test crew exposure models, and a receiver to make modern measurements of radio noise on the lunar farside for comparison with an RAE-2 occultation of Earth in 1973. In addition to CubeSats already planned as secondary payloads, a communication asset could be deployed into orbit for future farside relay.

Human-assisted Robotic Sample Return: More complex missions that follow can integrate humans in orbit with robotic assets on the lunar surface in a development path consistent with the Global Exploration Roadmap (GER [2]). The feasibility and productivity of an Orion L2-farside sample return mission involving a 30 km traverse [3] and an astrophysical mission that deploys a radio antenna [4] have already been studied. Those scenarios will be enhanced if Orion has sufficient bandwidth to accommodate high data rates, including high-definition video from the lunar surface. Once an orbiting facility at the Earth-Moon L2 position is available, then longer duration farside sample return missions [5,6] can be implemented, with 100 to 300 km-long traverses and 30 to 60 kg of material returned to Earth for geologic and in situ resource studies.

Initial Destinations: Historically, two dozen successful missions have explored the lunar nearside surface. None have landed on the farside, so that vast region of unexplored territory is an obvious target of interest. A global landing site study [7] found that the Schrödinger basin, within the South Pole-Aitken basin, has the greatest potential for scientific return (Fig. 2). Multi-element missions can subsequently target other farside destinations within the South Pole-Aitken basin, either robotically or with humans using Lunar Electric Rovers (LERs) or Space Exploration Vehicles (SEVs) (Fig. 3). Crew on the surface would greatly accelerate scientific discovery while also testing methods for in situ resource utilization (ISRU) and sustainable exploration. Robotic assets, such as the LERs, could be used to survey additional areas (e.g., for resource volatiles), in between those crew landings. An existing concept [8] suggests crew land sequentially at Malapert massif, the South Pole, Schrödinger basin, Antoniadi crater, and the center of the South Pole-Aitken basin.

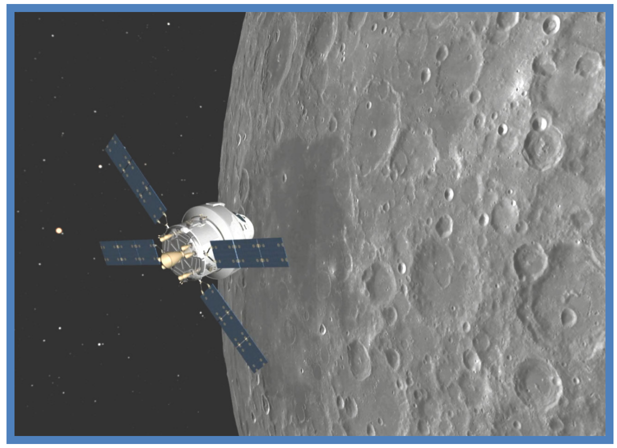

Fig. 1. Concept illustration of the NASA Orion crew vehicle and ESA service module passing over the lunar surface en route to a halo orbit about the Earth-Moon L2 position. Alternative orbits include distant retrograde orbits (DROs) or near-rectilinear orbits (NROs).

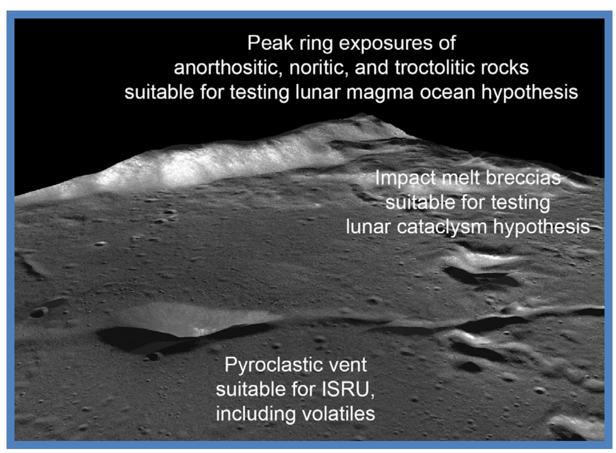

Fig. 2. Schrödinger basin is a high-priority target for both robotic and human missions.

While those initial missions target the Moon, they will address processes relevant to the entire Solar System, such as the accretion of planets, delivery of biogenic material, and the dynamical evolution of orbits. The Moon is the best and most accessible destination to address fundamental questions about the origin and evolution of the Solar System.

Demonstrating Capabilities & Retiring Risk: Human-assisted robotic missions will revalidate our ability to land on and traverse the lunar surface, ascend to and rendezvous in lunar orbit, and return samples to Earth, all of which are essential capabilities to be developed for the GER. In addition, the installation of an orbiting facility and assembly of robotic elements at L2 will validate deep space assembly operations (a Mars-forward capability), while developing the capability for crew to tele-operate surface assets (a Mars-forward technology) and demonstrating a series of crew health performance capabilities (e.g., deconditioning countermeasures, space radiation protection and monitoring, habitation systems) needed for exploration beyond the cis-lunar environment. The eventual deployment of crew on the surface will validate a capability for long-duration activities in relatively low gravity geologic settings while encumbered with pressurized suits, vehicles, and habitats (which are elements of any Mars-forward architecture).

Distribution of Assets: In general, human and robotic assets will need to be integrated to maximize productivity and safety. Asymmetrical distribution of those assets should, however, be strategically applied. To address lunar exploration objectives identified by the National Research Council [9], the best results will be obtained by a trained crew on the surface. Incremental progress can be made with a human-assisted robotic architecture until the capability to land crew exists. Those robotic assets will continue to be useful after crew are able to access the surface, either by providing additional analyses of a landing site after a crew has returned to Earth or by exploring regions not initially targeted by human missions.

Different destinations may also require an asymmetrical distribution of assets. For example, many geologically and compositionally simple asteroids are ideal targets for robotic assets, whereas complex planetary surfaces, such as the Moon, favor human assets with their observational skills, ability to reason, and ability to rapidly adapt to encountered conditions.

Technological Development Phasing: Technological capabilities to be developed include a communication relay for global access to the lunar surface; a voice, video, and data bandwidth (>1 Mbps) that exceeds current Deep Space Network capabilities; an Earth-Moon L2 orbiting platform; robotic and human lunar landers with ascent vehicles; and a crew rover. These capabilities are tractable and, in the case of the crew rover, already exists in proto-type form (Fig. 3).

Fig. 3. A proto-type LER that has been tested extensively in simulations of 3-, 14-, and 28-day-long missions with (inset) a concept SEV.

Training: While developing those technological capabilities, the program needs to develop its human assets. General geologic training of astronauts will be necessary, followed by mission-specific training. In parallel, scientists in the planetary science community will need to be trained in mission operation procedures that involve crew, building on the success of mission simulations conducted through the Desert Research and Technology Studies program.

Discussion and Conclusions: The opportunities available to planetary science will be greatly enhanced with an integrated human and robotic deep-space exploration program. It will change how the planetary science community functions. Human-assisted sample return and humans to the lunar surface are feasible in the 2020's and early 2030's. While those capabilities are being developed, the launch capabilities of the SLS will be able to routinely deploy robotic assets to both the inner and outer Solar System. The data returned from the human and robotic missions will be immense and will require a workforce able to digest that information. That transformation will be essential for a subsequent exploration phase, which may carry crew to more distant destinations, such as Phobos, Deimos, and the surface of Mars as we approach 2050.

References: [1] Kring D. A. (2016) *LEAG Mtg.*, Abstract #5020. [2] International Space Exploration Coordination Group (2013) *The Global Exploration Roadmap*, NASA NP-2013-06-945-HQ, 42p. [3] Potts N. J. et al. (2015) *Adv. Space Res.*, *55*, 1241–1254. [4] Burns J. O. et al. (2013) *Adv. Space Res.*, *52*, 306–320. [5] Landgraf M. et al. (2015) *LEAG Mtg.*, Abstract #2039. [6] Steenstra E. S. et al. (2016) *Adv. Space Res.*, *58*, 1050–1065. [7] Kring D. A. and Durda D. D., eds. (2012) *A Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon*, LPI Contrib. 1694, 688p. [8] Hufenbach B. (2015) 66th IAC (IAC-15,A5,1,1,X30756), 11p. [9] National Research Council (2007) *The Scientific Context for Exploration of the Moon*, 107p.