ARNE - SUBLUNAREAN EXPLORER. M.S. Robinson, J. Thanga, R.V. Wagner, V.A. Hernandez, School of Earth and Space Exploration, Arizona State University, 1100 S. Cady Mall, 85287, robinson@ser.asu.edu

Introduction: Lunar mare "pits" are key science and exploration targets. The first three pits were discovered within Selene observations [**1,2**] and were proposed to represent collapses into lava tubes. Subsequent LROC images revealed 5 new mare pits and showed that the Mare Tranquillitatis pit (MTP; 8.335°N, 33.222°E) opens into a sublunarean void at least 20-meters in extent [**3,4**]. Additionally more than 200 pits were discovered in impact melt deposits [**4**]. A key remaining task is determining pit subsurface extents, and thus fully understanding their exploration and scientific value. We propose a simple and cost effective reconnaissance of the MTP using a small lander (<130 kg) named Arne that carries three flying microbots (or pit-bots) each with mass of 3 kg [**5,6,7**]. Key measurement objectives include decimeter scale characterization of the structure of wall materials, 5-cm scale imaging of the eastern floor, determination of the extent of sublunarean void(s), and measurement of the magnetic and thermal environment.

Why Arne?: Rationale: The future of the human race lies in space. The first step in extending our current pitiful knowledge and capabilities in our transition to a space-faring species requires lunar exploration. First step - discover a sustainable architecture for lunar exploration. Need: Enable sustainable crewed lunar exploration (reduce mass, cost, risk) Goals: 1) Investigate suitability of void(s) at MTP for exploitation (radiation shield, micrometeorite shield, benign thermal conditions). 2) Technology demonstration (Autonomous precision landing and hazard avoidance, flying payload with autonomous navigation). 3) Investigate nature of mare flood volcanism (thickness of flows, nature of void. 4) Engage the public (Explore the voids! What else can we find? What lies beneath?) Objectives: Land safely and accurately, under autonomy, image pit wall during descent, fly autonomous pit-bots into void, measure extent of voids, characterize roughness of voids, high resolution mapping of pit floor for future landing planning, characterize magnetic and thermal environment of pit floor and void(s).

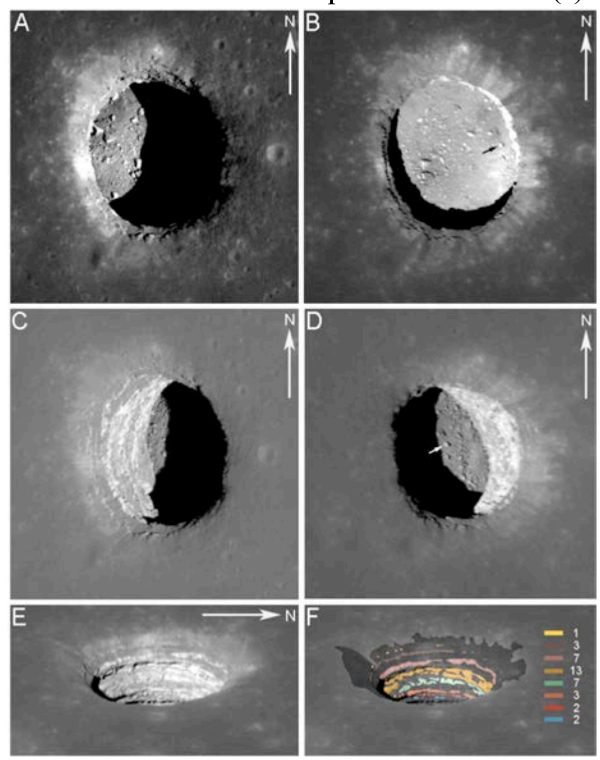

Figure 1. (A, B) MTP in two near nadir images with opposite Sun azimuth angles, both images are approximately 175 m wide. Oblique views: (C) layering in west wall and a portion of pit floor beneath overhanging mare (29° ema); (D) A significant portion of the illuminated area is beneath the eastern over hanging mare in this image (26° ema), white arrow indicates same boulder marked with black arrow in B. Detailed layering is revealed in (E) and (F). Outcropping bedrock layer thickness estimates are presented in (F) in meters, ±1m.

Arne Concept of Operations: Arne will make a noontime descent and optically lock onto the MTP rim and floor shadow, 100 meters above the surrounding mare Arne will descend vertically (~1 m/s). At the top of the pit Arne will determine the position of boulders on the floor known from LROC images [**3**], and then maneuver to a relatively smooth spot in view of the Earth.

After initial surface systems check Arne will transmit full resolution descent and surface images. Within two hours the first pit-bot will launch and fly into the eastern void. Depending on results from the first pit-bot the second and third will launch and perform follow-up observations (continue exploring same void or head west, north, and/or south). The primary mission is expected to last 48-hours, before the Sun sets on the lander there should be enough time to execute ten flights with each pit-bot.

Arne will carry a magnetometer, thermometer, 2 high –res cameras, and 6 wide angle cameras. The pit-bots are 30-cm diameter spherical flying robots [**5,6,7**]. Lithium hydride [**5,6**] and water/hydrogen peroxide power three micro-thrusters and achieve a specific impulse of up to 400 s. The same fuel and oxidizer is used for a fuel cell (energy density 2,000 Wh/kg) [**5,6**]. Each pit-bot flies for 2 min at 2 m/s for 100 cycles; recharge time is 20 min. The pit-bots are equipped with a flash camera, magnetometer, thermometer and obstacle avoidance infrared sensors. Once on the ground and initial check out is complete the exploration begins!

- Launch PB-1, 120 second flight into void, 1-m/s at an altitude of <3 meters
- 75 seconds to characterize topology of unseen void, send data to lander
- 5 seconds to touch down
- 30 minute pressurize H and O reservoirs, image, temperature, magnetics measurements
- Second flight - transmit remaining data from 1st flight and data collected on surface, collect additional ranging and images
- Lander transmits PB-1 data to Earth between flight 1 and flight 2
- During PB-1 second repressurization period plus 1 hr pause while flight team evaluates returned data and plans further PB-1 activities and PB-2 first flight (**Fig. 2**)
- If void terminus not found PB-2 launches and serves as relay for PB-1
- If void terminus found PB-1 continues mapping east void and PB-2 heads west
- PB-3 launches follows up on discoveries from PB-1 and PB-2
- PB-3 explores third direction (N, S?), or…
- PB-3 relay data for PB-1 and 2, or …
- PB-3 ascends and images pit walls, or …
- PB-3 acquires detailed imaging of lander and surroundings

Due to the short ground operations time (<72 hours) the ground science support team must be nimble and plan final operations in real time.

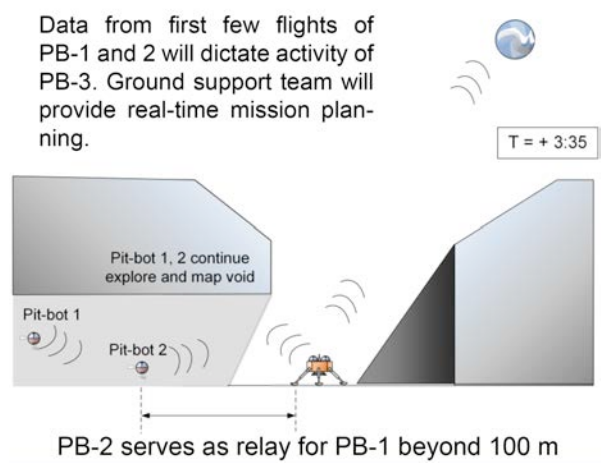

Figure 2. Basic Arne ConOps during mid-mission.

References: [**1**] Haruyama et al. (2010) *41st LPSC*, #1285 [**2**] Haruyama et al. (2010) *GRL*, 36, dx.doi.org/10.1029/2009GL0406355 [**3**] Robinson et al (2012) *PSS*, 69, dx.doi.org/10.1016/j.pss.2012.05.008 [**4**] Wagner and Robinson (2014) *Icarus*, dx.doi.org/10.1016/j.icarus.2014.04.002 [**5**] Thangavelautham et al. (2012) *IEEE ICRA* [**6**] Strawser et al. (2014) *J. Hydrogen Energy* [**7**] Dubowsky et al. (2007) *Proc. CLAWAR*.