THE SNOW BADGER MISSION CONCEPT: TRENCHING FOR ICE WITH HUMANS AND ROBOTS.

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Introduction: Trenching is an established and effective technique for obtaining rich, direct information about subsurface geology. It was used during the Apollo missions [1-3], by Mars Phoenix [4], and accidently by the MER Spirit rover [5], all to great effect. The advantage of a trench compared to a drill hole is that it gives a 3-dimensional understanding of the subsurface, compared to a 1-dimensional data point. This is especially important for regolith strata on the Moon that tend to be very heterogeneous in terms of composition and physical properties, and are difficult to trace even over short distances.

Some of the most important science questions to be answered at the lunar south pole involve the history, nature, and distribution of volatile ices expected to be present there [6-8]. Even though the Artemis astronauts are unlikely to descend into large permanently shadowed regions (PSRs) like Shackleton or Amundsen, they will have access to micro PSRs at numerous locations [9], and to smaller PSRs in select locations (Fig. 1). Additionally, ices are stable in the shallow subsurface peripheral to the larger PSRs [10]. Some of the biggest unknowns about lunar water (and other volatiles) can therefore be addressed by Artemis: What are the sources of volatiles and how have fluxes changed over time? How does water content vary as a function of depth? What is the physical nature of the ice-regolith mixtures? How has impact gardening affected the icy regolith? Here, we propose Snow Badger, a joint human-robotic investigation to trench into icy regolith at the lunar south pole to help address these outstanding questions.

Snow Badger Concept: Snow Badger leverages the RASSOR platform (Fig. 2), a highly innovative and capable robot developed by the KSC Swamp Works Group [11]. RASSOR autonomously digs trenches by using counter-rotating bucket drums that cancel out reaction forces. In Earth-based regolith bins, RASSOR can perform slot trenching to >1 m deep and can excavate up to 2.7 tons of regolith per day [11]. Material excavated from the trench is dumped out on the surface and is available for sampling and analysis.

Concept of Operations. Using the Artemis astronauts' time to dig trenches is inefficient, and it is

likely only one or two shallow trenches could be dug during surface operations. However, RASSOR can trench without assistance, and can work tirelessly when the astronauts are inside their lander. The ConOps for Snow Badger involves one or more RASSOR robots trenching in select locations and transects around the Artemis landing site. These can be selected based on pre-landing remote sensing data, by instruments on the lander during descent, and/or by the astronauts during their first EVA. The robot(s) dig while the astronauts are not on EVA, maximizing efficiency and minimizing dust hazards. RASSOR(s) could also be pre-deployed via a NASA Commercial Lunar Payload Services (CLPS) task order, increasing the number and size of trenches available when the astronauts arrive. If pre-deployed, instruments integrated onto the rovers could carry out initial measurements before human landings.

During EVA, the RASSOR robot(s) recharge at the lander while the Artemis astronauts investigate the finished trenches and tailings piles using hand-held instruments, tripod-mounted instruments, and/or direct sampling. A particularly effective instrument set would include a portable hyperspectral imaging camera with an active light source for use in shadows. Hyperspectral cameras are increasingly being deployed in terrestrial field studies [12,13], and small instruments like the Ultra Compact Imaging Spectrometer (UCIS) have been developed for flight [14]. Imaging spectroscopy pairs perfectly with trenches because stratigraphy is preserved, and it allows for 3-dimensional, quantitative information for how ices are concentrated and distributed in the subsurface.

Estimates of Resources. Currently the mass of the RASSOR 2.0 being tested at KSC is 67 kg (target mass = 50 kg), its dimensions are 1.93×0.85×0.43 m, and it is powered by a 1410 Whr Li battery [11]. However, the overall design can be scaled up or down, as has been done for the roughly half-scale "Mini-RASSOR" variant. The cost to boost maturation of RASSOR from its current TRL 4 to flight readiness is estimated at approximately $10M. An additional flight-ready instrument can be used for the hyperspectral imaging system: for reference, UCIS is <2 kg, and has a power consumption of ~ 5 W [14].

Crew interaction with the robot(s) will be minimal, and will consist mostly of supervision, monitoring, and maintenance tasks in case of breakdown. The majority of the crew time is spent on tasks uniquely suited to human explorers: investigating, imaging, interpreting, and sampling the freshly dug trenches during EVA.

In theory the Snow Badger concept can be deployed anywhere in the south polar region, relying on the presence of micro cold traps for access to ices. However, there are strategic locations inside small, shallow PSRs, or on the periphery of larger PSRs that have low slopes leading into them. These locations (<6° from the pole) are highlighted in Fig. 1.

Conclusions: Snow Badger is a concept for an investigation where Artemis astronauts work together with autonomous robots that trench while they sleep and charge while they explore on EVA. Placed in micro cold traps or in/near larger PSRs, this investigation will maximize the ability of Artemis to study the history and nature of lunar volatiles. It will also constitute the first 3-dimensional prospecting campaign for eventually mining ice to support a permanent human presence on the Moon.

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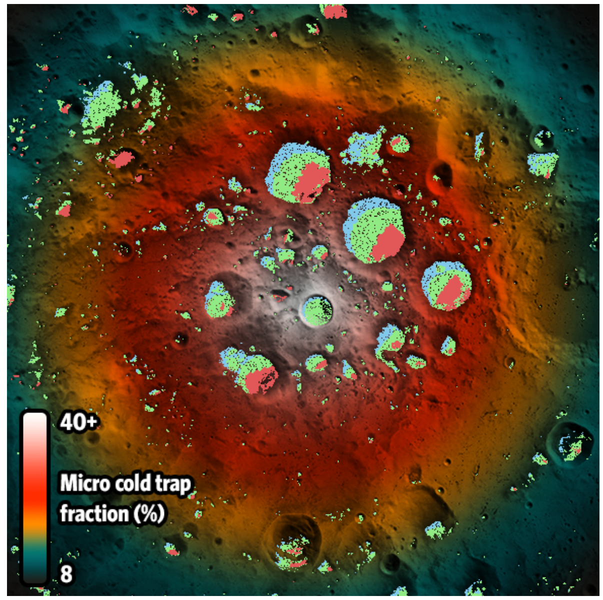

Fig. 1. Map of the south pole (<6°). Background color gradient is the modeled fraction of surface micro cold traps from [9]. Superimposed cyan, green, and red areas (in order of increasing favorability) are promising terrain types [15] for macro cold traps that may host significant amounts of volatiles.

Fig. 2. The RASSOR robot digging a 1-meter deep trench in the Swamp Works regolith bin. Image credit: NASA/KSC.