MICRO-ROVER EXPLORATION OF LUNAR PITS DEPLOYABLE BY COMMERCIAL LANDER.

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Introduction: Commercial moon landers have, for the first time, made regular, affordable, lunar surface missions realities. However, since their payloads are currently limited in mass, volume and bandwidth, these constraints beg the question of whether such missions can possibly achieve purposeful, high-return pit exploration. This paper conceives high-return pit explorations achievable by the technologies of our time that can be delivered by these commercial landers and economical missions.

Former and current counterparts to the "Skylight" missions presented here include descending into or landing directly onto pit floors. Our own earliest concept envisioned a heavier lander as a flyover explorer, then landing to deploy a rover for modeling from the pit's rim [1,2,3,4]. The missions presented here embrace the small but existing landers of our day and smaller micro-rovers that they can deploy. Subsequent concepts by others have a spacecraft land directly in a pit [5], or land hardware massive enough to anchor for tethered pit descent [6]. These mission concepts require significant precision landing capability and landers that do not exist. They also rely on robot developments and technology maturation that are beyond immediate timeframe.

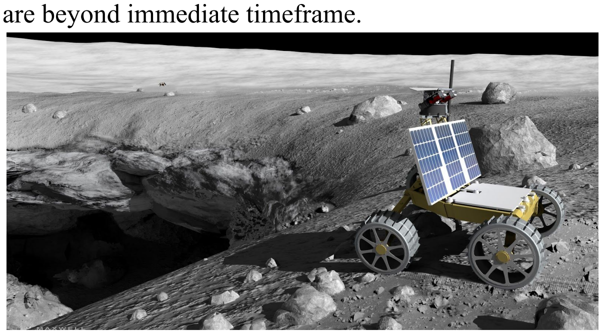

Figure 1. Pit exploration mission concept

Purposeful Near-Term Missions: We conceive "Skylight" missions to explore and model lunar pits. We constrain to landers, rovers and technologies that exist or are underway in current maturation programs. The missions seek to map pits and discover caves with merits advantageous to human presence. Beyond cave discovery, Skylight missions will determine pit morphology, rim geomechanics, the unique issues of rim navigability, rim terramechanics, and the existence of overlooks and rappel routes for future initiatives. The primary science products from which the studies and observations derive will be vast, high-fidelity, high-coverage models of pits and their surrounding terrains as viewed by rover from the rim. Additionally, the missions will evaluate and evolve performance of the landings, micro-rovers, exploration autonomy and pit modeling technologies that make the missions possible.

Skylight missions compute pit models from imagery acquired by micro-rovers while circumnavigating lunar pits. The landers and rovers of these missions are solar-powered without isotopes to survive a night. Hence, robot traverse and model computation must proceed at high cadence to complete operations within a single lunar illumination period. The mission elements and their technologies include precision landing, micro-roving, pit exploration autonomy, in-situ pit modeling, and the aggregate of all these to complete mission-in-a-week..

Peregrine Lander: Peregrine is characteristic of commercial landers that are tracking for first lunar touchdowns in 2021, then repeated landings thereafter. Although small, Peregrine is capable of deploying one or more pit exploration micro-rovers per mission. Pit missions are distinct from all rover missions to date that target regions versus a point feature. Pit missions require some degree of precision. Precision landing capability is under development for landing Peregrine reasonably near lunar pits, but without the ultra-precision suggested for landing in or exactly on the rim per alternate scenarios. Reasonable pit proximity is advantageous for minimizing rover driving distance and comm range rover-to- pit.

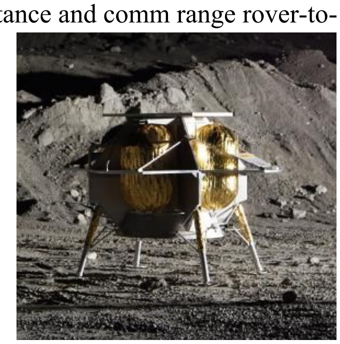

Figure 2. Peregrine Lander

Pitranger Micro-Rover: PitRanger is under development as a small, fast, autonomous solar rover. It must be small by virtue of lander volume and mass constraints. Such a small rover cannot carry or power a direct-to-Earth radio, so that compels autonomy when out of wireless comm range for data downlink via the lander. Since these "missions-in-a-week" limit time, and this class of pit modeling requires substantial driving range. For such range, these rovers must exhibit unprecedented speed and cadence relative to priors. Prior rovers are myopic to view for safeguard and navigation. PitRangers must additionally provide telescopic optics to acquire long cross-pit and down-pit views for modeling. These rovers must feature large tipover stability margins and high egress mobility for acquiring plunging views from precipitous pit rims.

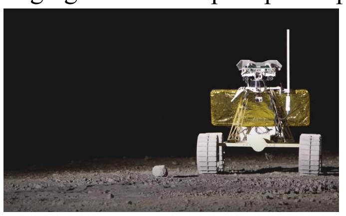

Figure 3. PitRanger Micro rover prototype

Pit Exploration Autonomy: Pit exploration autonomy consists of the behaviors and intentions to occupy vantage points, acquire imagery essential for pit modeling, scallop and encircle a pit, and make judgements like tradeoff of detail for coverage. This is achieved by layering methodologies like next-best-view planning, energy-maximizing sun-synchrony, brinkmanship precipice approach and exposure bracketing over conventional robotic sense-plan-act navigation.

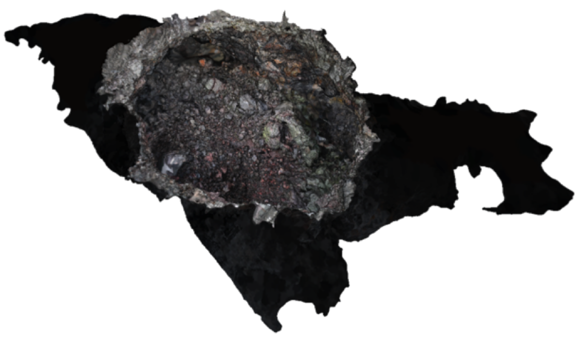

Figure 4. 3D reconstruction of a terrestrial skylight using images taken from pit rim [7].

In-situ Pit Modeling: Pit modeling processes imagery with structure-from-motion and simultaneous localization and mapping to generate vast, high-fidelity, highly three-dimensional pit models. The technology concurrently determines the poses from which each image was acquired and performs multi-pose stereo to model the geometry. The process is extremely process-intensive. For that reason this computation is performed aboard the lander. The raw imagery is massive data and couldn't possibly be conveyed to Earth by this class of lander during the short duration of these missions. The model resulting from the vast data and computation is, however, compact and viable for Earth transmission along with many raw images.

Mission economy and way forward: Skylight is presented as a class of micro-rover pit exploration that is deployable by lander, precision landing, rover, autonomy and modeling technologies that are all exist, are in flight development or are underway in technical maturation programs. The paper sets forth the scenario in which these can be combined serendipitously to accomplish highly-economical, high-value, near term missions. There is no representation that such mission or missions are chartered or commissioned.

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