

## PENETRATOR SCIENCE OBJECTIVES FOR THE MOON AND ARTEMIS.

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**Brief Presenter Biography:** Dr. Ahrens is a NASA Postdoctoral Program Fellow at NASA Goddard Space Flight Center. She is a member of the LRO Diviner Science Team researching on volatile stability and morphology at the lunar poles.

**Introduction:** Some key decadal-scale mission goals at the Moon have been proposed [1], these include sample return, the establishment of a lunar geophysical network, and exploring extreme environments, such as the permanently shadowed regions at the lunar poles [2 – 4]. These environments present accessibility challenges, though contain significant rewards for science return. Small penetrator experiments have great potential for precursor and survey missions for the exploration of these environments, producing early science data and later mission planning.

Penetrators have been conceptualized for planetary exploration for several decades but have yet to be operated successfully [5]. Penetrators are designed to be self-contained vehicles with a suite of instruments designed to survive and function after achieving certain depth into the regolith using the kinetic energy of impact, or designed to measure mechanical (or compositional) properties as part of a much larger vehicle [6].

**Penetrator Designs:** The basic design and technology for penetrators has existed for several decades through military design, though only recently have penetrator concepts been applied to Solar System exploration [5, 7 – 8]. Unfortunately, these early concept designs lacked technological and budgetary means for completion, or lacked robustness of deployment – landing (e.g., survivability of instruments). While there may be limited volume and high g-loading, these penetrators have low mass and low development cost, with flexible options for multiple deployments, especially for extreme environments.

“Piggyback” penetrators (those that are part of a larger mission) would ballistically be emplaced downrange from a main lander mission and be targeted into extreme environments (e.g., deep, hazardous craters, lava tube pits, or permanently shadowed regions). These ballistic-type penetrators could last ~1 week and target up to ~10 km downrange from the lander [6]. “Dedicated”-type penetrators could be available through NASA’s Discovery-type programs to provide larger-

scale science-driven explorations that may include more sophisticated penetrator arrays traversing across larger regions, lasting for several weeks – months. Penetrators can act as a precursor or complementary mission to a lander to allow for targeting of a future landing site, or an array could bring more science detail on a larger area, such as lunar swirls or large PSR craters, all at relatively low risk and cost (*i.e.*, 3 out of 6 can succeed and complete the primary mission).

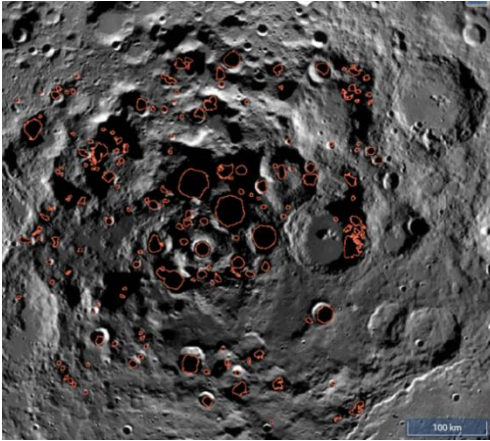
**Payload Science Objectives:** Penetrator science objectives can address key issues related to the origin and evolution of the lunar surface, as well as astrobiologically-important possibilities, for example the possible containment of organics [9, 10]. Potential penetrator instruments include dielectric probes, thermal and heat sensor probes, seismometers, spectrometers (neutron, APX, tunable diode lasers, Raman, etc.), and magnetometers [5, 6]. For volatile science objectives, these instruments can assist in identifying volatile abundance, chemical compounds, and distribution of H-bearing species.

**Permanently Shadowed Regions:** There are several observations of volatiles present at the lunar poles (Figure 1) [2 – 4,; 11 – 12], however the nature and distribution of these volatiles are uncertain. Sampling of these volatiles could yield fundamental insights regarding the origin and evolution of the lunar volatiles, their spatial and depth profiles, and the discovery of enabling resource utilization for future exploration efforts [6].

Deployment of penetrators into a PSR would immediately provide geochemical information within the upper 1-2 m of regolith [6]. Such regolith information would be provided by the deceleration profile of the penetrator and its depth of penetration. This process would heat the regolith and information about the thermal characteristics of the upper regolith would be provided by the instrument suite onboard the penetrator [6].

A suite of sensors and instruments that provide data on the temperature, pressure, conductivity, and hardness include accelerometer sensors, temperature sensors, thermal pulses for temperature profiles, pressure sensors for ice/soil compression, infrared tunable diode lasers (IR-TDL) and other laser wavelengths for detection of gases in the volatiles (e.g., H<sub>2</sub>, He, O, CH<sub>4</sub>, etc.), and

dielectric electrodes can perform bulk chemistry measurements to identify minerals and organics [6, 10].



**Figure 1:** Permanently shadowed regions (outlined in orange) at the South Pole of the Moon. PSR locations and outlines created by [13] and mapped in LROC Quickmap.

**Artemis:** Future Artemis crewed missions are planned to explore the lunar south pole. Small cold traps to adjacent illuminated terrain may provide access to rovers and landers. However, larger PSRs may prove to be inaccessible to crews, rovers, and landers. Penetrators with a suite of instruments prior to human exploration would be extremely useful in this regard. Penetrators can also prove useful for plasma experiments, such as with magnetometers and charged particle detectors, for hazard assessment of these PSRs and the overall lunar south pole region. An array of penetrators (with solar or nuclear batteries) could be set up in advance of an Artemis crew.

With technology development for the penetrators themselves and for their instrument payloads, it will be possible to build upon the work of past penetrator concepts to create full-scale engineering models capable of realistic end-to-end testing and eventual deployment. During the next decade, we envision that penetrator systems will take their place along with orbiters, landers, and rovers in NASA's suite of lunar exploration.

**Acknowledgements:** The authors would like to thank our cohorts from Magellan Aerospace, Canada, on technological discussions. C. Ahrens' research was supported by an appointment to the NASA Postdoctoral Program at NASA Goddard Space Flight Center, administered by Oak Ridge Associated Universities under contract with NASA.

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