AEGIS: AEROGEL EXPERIMENT GATHERING IMPACTOR SAMPLES. D. P. Moriarty III[1,2], N. E. Petro[1], B. A. Cohen[1], P. Metzger[3], M. E. Zolensky[4], R. N. Watkins[5], S. N. Valencia[1,6], N. M. Curran[1,2], K. E. Young[1], J. D. Kendall[1], T. J. Stubbs[1], H. Yano[8], M. E. Evans[4], and A. J. Westphal[9] [1]NASA GSFC (8800 Greenbelt Rd, Greenbelt MD 20771; Daniel.P.Moriarty@NASA.gov), [2]USRA, [3]UCF, [4]NASA JSC, [5]PSI, [6]UMCP, [7]UMBC, [8]JAXA, [9]UCB.

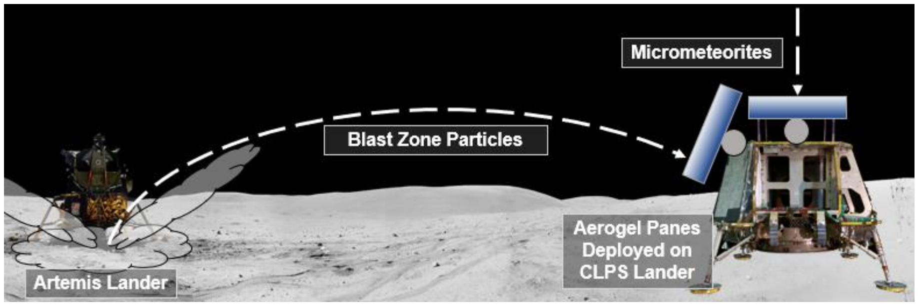

Fig. 1: Aerogel panes deployed on a CLPS lander will capture small, high-velocity particles at the lunar surface. These panes will be collected by Artemis astronauts and analyzed to better understand the flux, energies, trajectories, and physical properties of these particles. These measurements are relevant to several fundamental lunar and solar system science goals, and are important for better understanding the hazards associated with long-lived human and robotic activity at the lunar surface.

Introduction: NASA's Artemis Program encompasses sustained human and robotic activity near the lunar south pole, presenting a unique set of opportunities and challenges. A key consideration with implications for both science and safety is the flux of impactors impinging mission hardware and personnel. Regardless of the location selected, the Artemis site will be subject to two primary types of impactors: (1) micrometeorites (including interplanetary dust, interstellar dust, and solar wind particles) and (2) lunar regolith particles accelerated by rocket exhaust during spacecraft landing and takeoff. The basic principles of these processes are understood through models, laboratory experiments, and analyses of lunar and orbital mission data. However, the Artemis architecture is unprecedented in terms of its duration and complexity, and the actual particle environment may differ significantly from predictions. Key differences from previous missions expected to influence exhaust plume ejecta include the landing/takeoff cadence, lander size, engine configuration and thrust pattern, and the local terrain roughness and slopes[1,2].

AEGIS (Aerogel Experiment Gathering Impactor Samples) is an instrument concept that would greatly improve our understanding of the micrometeorite and blast zone particle environment. Briefly, the AEGIS concept employs aerogel collectors at the lunar surface, optimized to capture both micrometeorites and blast zone particles (Fig. 1). Intended for south polar CLPS deployment prior to Artemis 3, aerogel panes would be collected by Artemis astronauts for return to Earth, allowing detailed analyses of physical and dynamical properties. Installation of replacement panes (for collection during subsequent human exploration) enables assessment of the evolution of the landing zone through the repeated landings comprising Artemis 4-7 (including support missions), and offers longer collection times to capture relatively rare particles such as interstellar dust.

In Greek mythology, the *aegis* is a fearsome shield wielded by Athena and Zeus. Traditionally, operating under an *aegis* is associated with protection by a powerful, knowledgeable, or benevolent source. Fittingly, the primary science and exploration-enabling goals for AEGIS are as follows:

1. Assess the flux and composition of micrometeorites impacting the lunar surface to better understand the reservoirs of these impactors (**constraining models of NEO origin and depletion as well as the elemental and isotopic compositions of interplanetary dust, interstellar dust, and solar wind particles**).
2. Determine the energies and trajectories of micrometeorites to better understand their **role in space weathering** and **the hazards posed to human and robotic lunar surface operations**.
3. Determine the flux, trajectories, energies, physical properties (including grain size), and compositions of blast zone particles to better understand blast zone processes (*i.e.*, the **energy coupling between lander exhaust and the lunar surface**) and the **hazards posed to surface activity**.
4. Understand the **evolution of the blast zone particle load through repeated landings** of variable spacecraft sizes, engine configurations, and locations.

Aerogel Collector Optimization: Work is ongoing to mature the AEGIS concept, specifically focused on the implementation of aerogel impactor sample collectors. Aerogel is specifically engineered to capture and preserve the trajectory of small, high velocity particles while minimizing thermal and other alterations. Therefore, aerogel is ideally-suited to

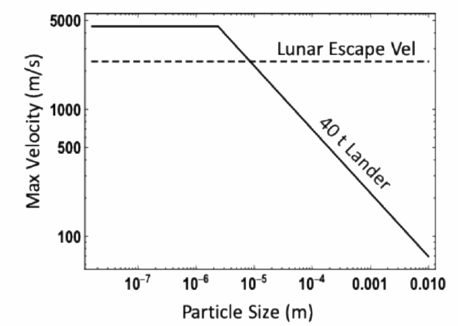

Fig. 2: Modeled maximum blast zone particle velocities as a function of particle size for a 40 ton lander.

capture the dynamical and physical characteristics of the particle environment within the Artemis site. Numerous aerogel compositions and densities are available, optimized for different particle sizes, densities, and velocities. Therefore, it may be beneficial to leverage several aerogel compositions (as well as metal foils similar to the Apollo SWCs[3]) to assess a greater diversity of samples. Although some thermal and other alteration of captured particles is expected, previous experience from the Stardust mission aid future interpretations[4]. In particular, use of tantala aerogels are recommended for sensitive elemental analyses[5].

Where and when aerogel panes are deployed is also critical for mission optimization. Micrometeorites are most likely to impact at ~45° from the surface[6], whereas particles are typically ejected from the rocket exhaust plume at much lower angles (typically ~3°)[7]. It may therefore be beneficial to deploy aerogel panes in multiple orientations to separately target micrometeorites and blast zone particles.

However, multiple aerogel panels may not be necessary to differentiate between micrometeorites and blast zone particles, based on our current understanding of their inherent differences. Blast zone particles are predicted to exhibit lower velocities (<5 km/s), with velocities related to particle size (Fig. 2). Micrometeorites exhibit no such dependency and typically exhibit velocities >10 km/s[8]. While it can be challenging to reconstruct velocities from aerogel track morphology, use of uniform density aerogel of certain compositions or inclusion of momentum sensors can improve the reliability of these determinations[5].

The average flux of micrometeorites on the lunar surface is far lower than the blast zone particle flux during a landing/takeoff event. Based on data from various lunar orbiters[9,10], a 1 m^2 aerogel pane on the lunar surface would be subject to ~3 impacts per year of µg-mass micrometeorites. This number increases exponentially with decreasing impactor mass. In contrast, analysis of Surveyor III spacecraft materials (which were subject to particles accelerated by the Apollo 12 Lunar Module exhaust plume at a distance of 155 m) exhibit significant damage consistent with complete saturation by dust-sized particles[11]. To preserve captured micrometeorite tracks, and limit saturation of aerogel collectors by blast zone particles, it may be prudent to deploy articulated shielding to control the timing and duration of exposure to incident particles. Such an approach, while increasing the complexity of the instrument, would also enable particles corresponding to specific landing events or phases within individual events to be targeted. Aerogel saturation may also be prevented by deployment at greater distances from the location of the largest landing vehicles, as the size of the blast zone is strongly dependent on the dry mass of the lander[1].

The model illustrated in Fig. 2 demonstrates that particles lofted by exhaust plumes can be accelerated above the lunar escape velocity. Initial calculations estimate that an orbital vehicle such as the Gateway will be subject to >2000 dust-scale blast zone particle impacts/m^2. Coordinated orbital aerogel deployment (similar to the GIDC[5] or Tonpopo[12]) would be of high scientific value for further characterizing the implications of energy coupling between rocket exhaust and the lunar surface.

Resources: This concept represents a relatively simple, low-cost option to enrich and diversify the science return of the Artemis Program while refining assessments of risks to crew and equipment. The collector is entirely passive, with the exception of optional momentum sensors and articulated shielding or deployment mechanisms. Aerogel is a very low-density substance, so the mass is nearly all in the mounting hardware. Previous estimates for the GIDC (an accordion-style collector with collecting area of ~1 m^2) estimate a furled volume of ~65 cm^3 and mass <20#. Expected crew interaction is nominally brief (collecting and optional replacing of collectors). Mounting configuration on the host lander is flexible to accommodate other instruments. Further maturation of the concept (including costing and engineering constraints) is currently being pursued at NASA GSFC.

References: [1]Clegg-Watkins, R N. et al.. (2016). *Icarus*, *273*, 84-95. [2]Metzger, P. T. (2020) *Lunar Dust* #2141. [3]Geiss, J. et al (2004) *Space Science Reviews*, *110*(3-4), 307-335. [4]Brownlee D. (2014) *Ann. Rev. Earth Planet. Sci.* 42:179-205. [5]Evans, M. E. et al. (2019) *LPSC 50* #2132. [6]Shoemaker, E. M. (1962). *Physics and Astronomy of the Moon*, 283-359. [7]Lane, J. E., & Metzger, P. T. (2012). *Partic. Sci. and Tech.*, *30*(2), 196-208. [8]Bottke Jr., W. F.et al.. (1996). *Icarus*, *122*(2), 406-427. [9]Hörz, F., et al. (1971). *J. Geo. Res. 76*(23), 5770-5798. [10]Anders, E., et al. (1973). *The Moon*, *8*(1-2), 3-24. [11] Immer, C.,et al. (2011). *Icarus*, *211*(2), 1089-1102. [12] Kawaguchi, Y. et al. (2016). *Astrobiology*, *16*(5), 363-376.