BORE-II SUBORBITAL DEMONSTRATION OF MICROSATELLITE-SCALE MAGNETIC ASTEROID REGOLITH SAMPLE COLLECTION SYSTEM. A. H. Parker[1], D. D. Durda[1], A. D. Whizin[2], K. J. Walsh[1], M. Shoffner[1], and B. Pyke[1] [1]Southwest Research Institute 1050 Walnut Street Suite 300 Boulder CO 80301 (aparker@boulder.swri.edu), [2]Southwest Research Institute 6220 Culebra Road San Antonio TX 78238.

Introduction: The recent successful collection of asteroid regolith by JAXA's Hayabusa2 and NASA's OSIRIS-REx missions will provide a revolutionary glimpse into the physical properties of the surface material of primitive asteroids. For future missions, we consider architectures that enable low cost, low risk multi-site, multi-target sample return to be key to further advancing the physical study of small bodies in the solar system, with the eventual goal of generating returned sample libraries that rival the richness of the meteorite record and astronomical surveys of asteroids.

Under the Project ESPRESSO SSERVI node, we have been developing a framework to enable such future missions: A parent spacecraft carries a large number of very simple micro-landers, each to be deployed to a surface, collect a local sample, and conduct a ballistic "hop" to high altitude where it can be retrieved by the parent spacecraft and stowed for sample return. Such an architecture separates mission risk from sample acquisition risk, as the loss of any individual micro-lander does not impact the mission as a whole.

This concept requires the development and maturation of a simple, inexpensive asteroid surface sample collection system that can be scaled down to very small volume and mass, and one that does not necessitate the generation of large reaction forces that could dislodge the micro-lander from the surface prematurely. In previous work, we have found that magnetic grapples provide an attractive means for collecting asteroid regolith [1] – most, if not all asteroid regoliths are expected to contain substantial enough magnetic compounds [2] that field strengths achieved by common permanent magnets can easily overwhelm local gravity and cohesive forces and act to agglomerate a large volume of material on a collector plate. Laboratory experiments under 1G have also shown that completely non-magnetic pebbles are efficiently entrained by magnetic constituents in the regolith if both are co-located at the sampling site.

In this work, we have integrated the concept of magnetic regolith collection into complete sample acquisition and storage system with a very high volumetric efficiency. We have built fully-functional, free-flying subscale prototypes and launched them on a Blue Origin *New Shepard* capsule for a medium-duration microgravity demonstration of the deployment and sampling process. This demonstration was conducted in the BORE-II environment chambers, which provided a vacuum and regolith environment that simulates an asteroid surface. For details of BORE-II, please see the companion abstract #2265 by Durda et al.

***Clockwork Starfish* Sample Acquisition System:** The *Clockwork Starfish* demonstration samplers (see Figure 1) are simple 3D-printed analog automata designed to be released into the BORE-II environment chambers (see Figure 2), interact with a regolith bed, agglomerate a sample of the regolith onto magnetic collection plates, then finally conduct an "eversion" maneuver to securely store the collected sample through landing and recovery of the *New Shepard* capsule. The eversion process is key to the volumetric efficiency of the *Clockwork Starfish*. When first deployed, all flight systems are stowed inside a tetrahedral volume with a magnetized exterior surface. Once sufficient time has elapsed for a sample to have aggregated on the magnetized surface, a winch system activates to turn the tetrahedron inside-out, everting the exterior panels into a new interior tetrahedral volume and exposing the flight systems to the environment. In a mission context, this action would expose the thruster ports used for the subsequent hop for recovery by the parent spacecraft. The demonstration *Clockwork Starfish* have dry masses of 65 grams each, and contain no flight systems other than those needed to deploy and evert.

Microgravity Demonstration Aboard NS-13: The twin BORE-II vacuum chambers were loaded with beds of a CI chondrite regolith simulant procured from the Exolith Lab. One bed was prepared with a fine-grained sample, with all constituents < 2mm in size, while the second chamber contained a coarse-grained sample with constituents 2-10mm in size.

The payload was carried to space aboard a Blue Origin *New Shepard* capsule on October 13, 2020. After entry into microgravity, the samplers were deployed into the chambers via a spring-launch system. They passively interacted with the regolith agitated by their impact for approximately 30 seconds and both collected large quantities of regolith on their magnetic collection plates. At this point, both samplers attempted eversion. During eversion, three small vibration motors activated to mobilize any regolith grains that may jam between the moving panels of the everting *Starfish*. One of the two samplers successfully performed the complete eversion and confined its collected sample in the sampler interior; the mechanism responsible for unlocking the exterior panels on the second sampler failed to release and it did not complete its eversion. As g-levels increased, both samplers settled to the bottoms of their respective chambers, where they remained through landing and recovery. Video record of the experiment shows that some of the sample collected by both samplers was lost during the g-loads of landing, but for the sampler that successfully inverted this lost quantity was very small.

After recovery of the New Shepard Capsule, the two samplers were extracted from the BORE-II chambers with any attached or confined regolith. The sampler that collected fine-grained material successfully everted and stored 30.6 grams of regolith, ~47% of the sampler's dry mass and nearly entirely filling the sampler volume (see Figure 3). The sampler that failed to evert still retained regolith attached to its magnetic collection plates through the high g-loads of landing, which amounted to approximately 10 grams of material.

Summary and Future Investigations: The demonstration flight of the *Clockwork Starfish* in microgravity and vacuum validated the concept of magnetic collection of asteroid regolith by a free-flying microsatellite-scale lander and confinement of a collected sample through eversion of the lander envelope. The returned sample mass-fraction compared to the sample collection system is remarkably high, approaching 50%, and this returned mass efficiency may be improved further with a larger 1U-scale flight-like lander.

We intend to conduct further tests with other regolith simulants of different size distribution and with a variety of magnetic properties to develop an understanding of system performance in the range of potential asteroid surface environments these micro-landers could be deployed in.

Video of the NS-13 *Clockwork Starfish* deployment in BORE-II is available upon request.

Acknowledgments: BORE is funded through SwRI internal R&D funding and the NASA Flight Opportunities Program, Contract No.: 80NSSC20K0111. The development of the Clockwork Starfish and magnetic sampling systems is funded through the NASA SSERVI node Project ESPRESSO, cooperative agreement number *80ARC0M0008.*

References: [1] Parker A. H. et al. (2019) *LPSC 50,* Abstract #3111. [2] Lodders, K. & Fegley, B. (1998) "The Planetary Scientist's Companion." *Oxford University Press.*

Figure 1: Clockwork Starfish samplers pre-flight. Left panel: Starfish halfway through eversion process, showing pre-deployment interior (left) and exterior (right). Right panel: Starfish in pre-eversion configuration (left) and post-eversion configuration.

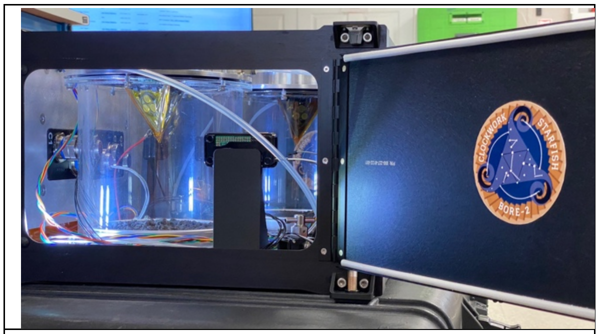

Figure 2: View through the locker door of the BORE-II experiment, showing both acrylic vacuum vessels and the Clockwork Starfish mounted in their spring launchers above the prepared regolith beds.

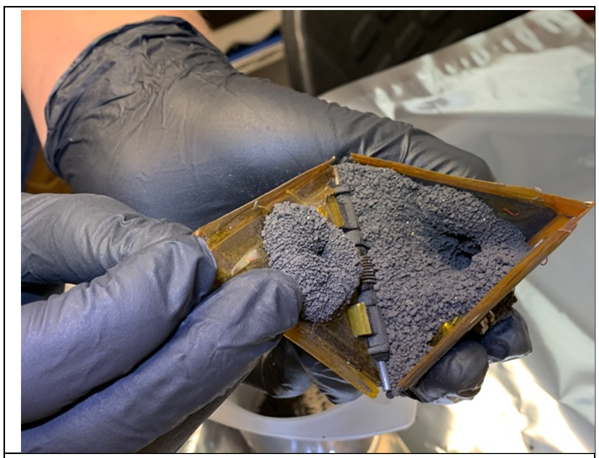

Figure 3: Sampler that completed eversion, shown immediately after capsule recovery. Interior volume almost entirely filled with regolith simulant.