Research-Grade 3D Virtual Astromaterials Samples: Novel Visualization of NASA's Apollo Lunar Samples and Antarctic Meteorite Samples to Benefit Curation, Research, and Education. E. H. Blumenfeld[1,2], C. A. Evans[3], E. R. Oshel[2], D. A. Liddle[2], K. R. Beaulieu[2], R. A. Zeigler[3], K. Righter[3], and R. D. Hanna[4], R. A. Ketcham[4,] [1]Transdiscplinary Artist (www.erikablumenfeld.com), [2]JETS, NASA Johnson Space Center, Houston TX 77058 (erika.h.blumenfeld@nasa.gov), [3]NASA JSC, Houston TX 77058, [4]UTCT Facility, Jackson School of Geosciences, University of Texas at Austin, Austin TX, 78712.

Introduction: NASA's vast and growing collections of astromaterials are both scientifically and culturally significant, requiring unique preservation strategies that need to be recurrently updated to contemporary technological capabilities and increasing accessibility demands. New technologies have made it possible to advance documentation and visualization practices that can enhance conservation and curation protocols for NASA's Astromaterials Collections. Our interdisciplinary team has developed a method to create 3D Virtual Astromaterials Samples (VAS) of the existing collections of Apollo Lunar Samples and Antarctic Meteorites. Research-grade 3D VAS will virtually put these samples in the hands of researchers and educators worldwide, increasing accessibility and visibility of these significant collections. With new sample return missions on the horizon, it is of primary importance to develop advanced curation standards for documentation and visualization methodologies.

Objectives: Our objective is to create virtual 3D reconstructions of Apollo Lunar and Antarctic Meteorite samples that are a fusion of two state-of-the-art data sets: the interior view of the sample by collecting Micro X-ray Computed Tomography (XCT) data and the exterior view of the sample by collecting High-Resolution Precision Photography (HRPP) data. These new data offer the research community an information-rich visualization of both compositional and textural information prior to any physical sub-sampling.

Having established and reported our evolving methodology for achieving a 3D model of both the exterior of the sample using HRPP and the interior of the sample using XCT data sets [1] [2] [3], we aim to refine and advance these methods in order to improve our model's resolution, and to achieve higher fidelity in the scaling of the models for fusion of the data sets.

Method: We are an interdisciplinary team that brings together expertise in the fields of professional photography, heritage conservation practices, geoscience, astromaterials curation, photogrammetry, imaging science, x-ray computed tomography, application engineering, and data curation. Since 2013 we have been working to establish new curation protocols to create 3D models of astromaterials samples to benefit the research community and curation practices. Initial results demonstrated the successful creation of the first image-based 3D reconstruction of an Apollo Lunar Sample (60639) correlated to a 3D reconstruction of the same sample's XCT data, illustrating that this technique is both operationally possible and functionally beneficial. In May of 2016 we began a 3-year NASA-funded project to produce Virtual Astromaterials Samples for 60 high-priority Apollo Lunar and Antarctic Meteorite samples and serve them on NASA's Astromaterials Acquisition and Curation website.

Our method uses three primary existing technologies: High-Resolution Precision Photography (HRPP), Structure-From-Motion Photogrammetry (SFM) and Micro X-Ray Computed Tomography (XCT). We have also designed and built new hardware and developed methods to achieve a singular coordinate system to fuse the resulting two data sets into one 3D VAS.

HRPP provides exceptional detail and reliable fidelity of the sample being photographed, and allows for calibration of the equipment to eliminate distortion. Our first results [1] [2] used a Nikon D700, which is a 12.1-megapixel camera with a 36.0 x 23.9 mm CCD Sensor. We have now advanced our equipment system to the Hasselblad H4D, which is a 60-megapixel camera with a 40.2 x 53.7mm CCD Sensor. A relative comparison of the resolution between the cameras using a Koren chart indicates that our new image resolution and subsequent models will improve by at least 43%. This improved resolution allows us to meet the quality demands of both today's and future users.

Astromaterials curation protocol requires that the samples to be stored in a multi-clean room facility and kept in nitrogen cabinets during the photographic process [4]. As such, the camera remains outside the cabinet and images are taken through the optical glass of the Scientific Observation Port. Each sample is imaged at 15-degree intervals at several elevations using our specialized registration and rotation stage that holds the astromaterials samples during the photography procedure (see Figure 1).

SFM provides off-the-shelf software to produce 3D reconstructions of the HRPP images using photogrammetric principles. In our first reporting we used the Agisoft PhotoScan Standard version. We have since advanced our system to the Agisoft PhotoScan Pro version, greatly improving functionality and command during the modeling process, and allowing us to work with targets graphics to improve alignment.

XCT provides a complete volume data set of the sample, where brightness of textural features is related to its density and composition [5]. We have collaborated with the UTCT Facility at UT Austin's Jackson School of Geosciences for the XCT scanning of the samples, and all Research Year 1's sample selections were scanned at UTCT. With NASA's Astromaterials Acquisition & Curation Office at Johnson Space Center (JSC) bringing online an in-house state-of-the-art Micro-XCT scanner, the samples selected for subsequent research years will be scanned onsite at JSC.

Our initial efforts in aligning the coordinate system and combining these two data sets in order to achieve the 3D VAS have been successful, and first results can be found in the forthcoming LPSC publication by Beaulieu K. R. et al. [6]. The process computes and applies the six degrees-of-freedom transformation of the SFM-derived date of a sample into the XCT data coordinate system of the same sample. As a result, simultaneous visualization of the sample's exterior texture and internal composition can be achieved using the SFM high-fidelity textured model and XCT data products. Evaluation of these first results gave us initial error margins that can be improved, and prompted us to revise our registration and rotation stage, in order to achieve more accurate scaling of the model for co-registration of the data sets, as well as improved recognition of the sample by providing signal targets on the rotation platform.

Our new 3D Astromaterials Sample Rotation Platform uses Agisoft PhotoScan's ring code targets in an intuitive layout that covers the diameter of the platform. Target sizes were dependent on final resolution constraints and were placed according to the average sizes of samples, and can accommodate samples ranging from ~3 cm to 25 cm. The platform remains inside the cabinet and holds the astromaterials samples during the photography procedure. The platform, constructed from 6100 series aluminum, allows us to maintain scale and orientation for 3D reconstruction, and facilitates incremental sequencing during photography. We also designed and fabricated an in-cabinet photographic backdrop for better lighting control and cleaner separation of the sample from the background.

Results: Our research continues to demonstrate that research-grade Virtual Astromaterials Samples are beneficial in preserving for posterity a precise 3D reconstruction of the sample prior to sub-sampling. This protocol greatly improves documentation practices by providing unique and novel visualization of the sample's interior and exterior features. As we continue to improve the fidelity and resolution of our system in advance of the creation of the final models, we are assured that we will be offering scientists an unprecedented research tool for preliminary investigation and targeted sub-sample requests. Additionally, this project yields 3D models that are a visually engaging and interactive tool for bringing astromaterials science to the public. All 3D VAS models and original data will be served on NASA's Astromaterials Acquisition and Curation website (https://curator.jsc.nasa.gov) and is set to launch in 2019.

Figure 1: HRPP equipment setup in Lunar Laboratory, Johnson Space Center.

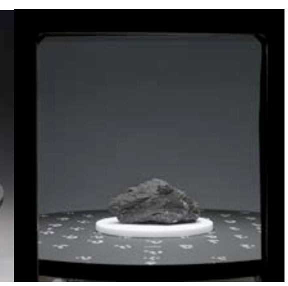

Figure 2 (left): 3D Astromaterials Sample Rotation Platform.
Figure 3 (right): HRPP of Apollo Lunar Sample 79115,0 used for SFM reconstruction.

Figure 4: XCT-derived 3D model of Apollo Lunar Sample 79115,0

References: [1] Blumenfeld E. H. et al. (2014) *Metsoc 77*, Abstract #5391. [2] Blumenfeld E. H. et al. (2015) 46th *LPSC*, Abstract #2740. [3] Blumenfeld E. H. et al. (2016) *AGU Fall Meeting*, Abstract #190585. [4] Allen C. et al. (2011) *Chemie der Erde, 71*, 1-20. [5] Ketcham R. A. et al. (2001) *Computers and Geosciences, 27,* 381-400. [6] Beaulieu K. R. et al. 48th LPSC.