APPLICABILITY AND UTILITY OF THE ASTROMATERIALS X-RAY COMPUTED TOMOGRAPHY LABORATORY AT JOHNSON SPACE CENTER.

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Introduction: The Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center is responsible for curating all of NASA's astromaterial sample collections (*i.e.* Apollo samples, Luna Samples, Antarctic Meteorites, Cosmic Dust Particles, Microparticle Impact Collection, Genesis solar wind atoms, Stardust comet Wild-2 particles, Stardust interstellar particles, and Hayabusa asteroid Itokawa particles) [1-3]. To assist in sample curation and distribution, JSC Curation has recently installed an X-ray computed tomography (XCT) scanner to visualize and characterize samples in 3D. [3] describes the instrumental set-up and the utility of XCT to astromaterials curation. Here we describe some of the current and future projects and illustrate the usefulness of XCT in studying astromaterials.

Instrumentation and Methodology: The XCT lab at JSC is equipped with a Nikon XTH 320 micro-XCT system uniquely suited for imaging a wide variety of sample types ranging from ~ 0.5 mm up to 15 cm at high spatial resolutions. Optimal imaging for a particular sample is achieved by utilizing one of four interchangeable X-ray sources: 180 kV nano-focus transmission source, 225 kV reflection source with multi-metal target (Mo, W, Ag, Cu), 225 kV rotating target reflection source, and a 320 kV micro-focus reflection source. The modular source design, a 2000 x 2000 pixel 16-bit CCD detector, and a stage that can accommodate large samples (up to 30 cm and 100 kg) makes this system well-suited for studying the various materials housed at JSC.

Utility and Applicability of XCT in Astromaterials Research and Exploration Sciences (ARES) : A review of XCT in planetary science, as well as an explanation of the background and principles of XCT are provided by [4] and [5], respectively. Below is a brief explanation of some of the current and future projects in the XCT lab. These projects demonstrate the curation, research, and mission support capabilities of the XCT lab at JSC.

Comparing X-ray and neutron CT. Dr. Andrew Needham (Jacobs-JETS) imaged two chondrite meteorites (Parnallee and Murchison) using neutron CT at the Oak Ridge National Laboratory with the goal of mapping hydrogen-rich regions. These data were complemented with X-ray CT imaging to further understand the nature of the H-rich phases. A companion abstract describes this work [6]. The reconstructed X-ray CT data for Parnallee and Murchison have a voxel size of 15.67 and 13.03 µm, respectively. The neutron data have voxel sizes of 37.5 µm and were scanned at different orientations to the X-ray data. To compare the datasets on a slice-by-slice basis, the volumes were aligned and resampled using Avizo™ 3D rendering software (Figure 1).

High-resolution imaging of small meteorites. Dr. Marc Fries (NASA-JSC) collected mm-sized magnetic particles from sediments off the coast of Washington state. These particles were imaged at < 2 µm/voxel resolution and reveal a terrestrial coating around a metal- and silicate-bearing micrometeorite (Figure 2).

Multi-resolution imaging of Apollo regolith core. Lunar regolith core 73002 was XCT imaged at the University of Texas High-Resolution X-ray CT Facility (UTCT) to map the structure of the core and characterize clasts within the lunar regolith prior to its opening, as part of NASA's Apollo Next-Generation Sample Analysis (ANGSA) initiative. Having a 3D map of the core has allowed the processors to make more informed decisions during dissection and removal of clasts. Large clasts removed during dissection can then be scanned at higher resolutions at JSC to confirm their location and reveal even further mineralogical and textural features (Figure 3).

Analyzing charred spacecraft reentry materials. Benton Greene (Jacobs-JETS) charred fiber-reinforced plastic materials (carbon-fiber and fiber glass) at low pressures to simulate the effects of spacecraft reentry. To measure the depth of charring and structural changes, two samples (80 mm x 25 mm x 10 mm) were scanned at 24.44 µm/voxel. Lateral variations in charring are visible within samples and the type and degree of charring varies between the two materials (Figure 4).

3D shergottite characterization. 3D petrographic descriptions of shergottites will allow for more representative sample characterization. Additionally, 3D crystal size distributions and mineral fabric analyses can elucidate information about their petrogenesis, including magma storage processes and lava emplacement styles. This work is part of the primary author/new lab manager's ongoing Ph.D project. Quantitative fabric analysis in 3D is a promising field for better understanding physical processes that affected astromaterials.

Conclusion: The Astromaterials XCT lab is capable of imaging a wide range of sample types and sizes, as well as providing assistance in data processing and interpretation. Little, if any, sample preparation is necessary, and samples can be scanned inside Teflon bagging with a nitrogen atmosphere to maintain their pristine nature. Future projects include but are not limited to: cold-curation scanning methods, developing procedures for XCT-based informed sample chipping and sectioning, and multi-modal analyses (XCT +/- EMPA/SEM, µXRF, TEM, SIMS, etc.). Further, scans of curated samples will be made available to the scientific community via an online database. Additionally, instrument time will be made available to investigators funded to do studies on astromaterials.

Acknowledgments: We thank UTCT and the ANGSA team for the XCT images of the Apollo regolith core and the opportunity to image removed clasts and Benton Greene for charred spacecraft material.

References: [1] Allen, C. et al., (2011). *Chemie Der Erde-Geochemistry*, 71, 1-20. [2] McCubbin, F. M. et al., (2016) 47th LPSC, abstract #2668. [3] Zeigler, R. A. et al., (2017) 48th LPSC, abstract #2772, [4] Hanna, R. D. and Ketcham, R. A. (2017). *Geochemistry*, 77.4, 547-572. [5] Ketcham, R. A. and Carlson, W. D. (2001). *Computers and Geosciences*, 27, 381-400. [6] Needham A. W. et al. (2020), *LPSC.*

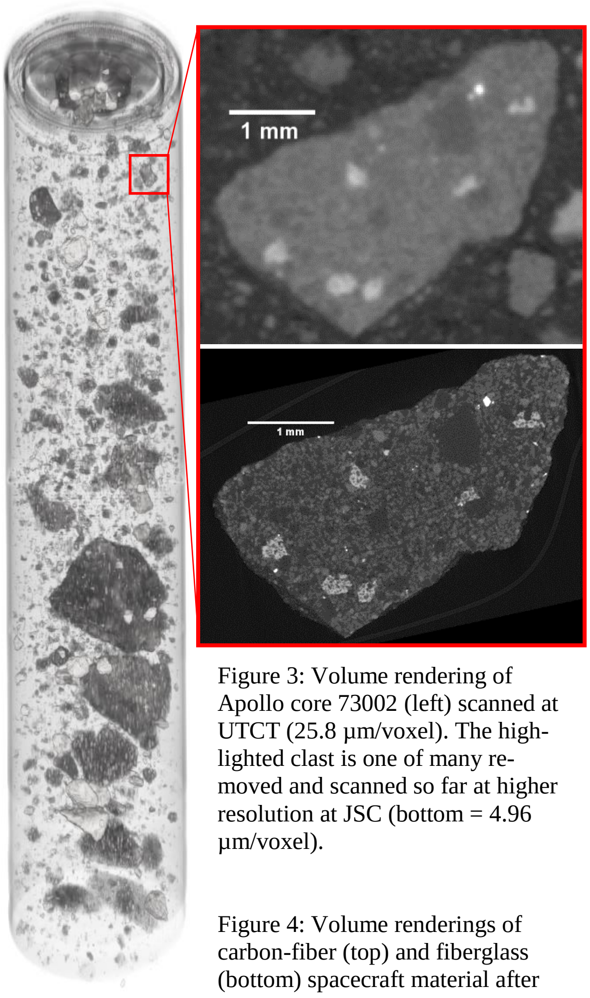

Figure 3: Volume rendering of Apollo core 73002 (left) scanned at UTCT (25.8 µm/voxel). The highlighted clast is one of many removed and scanned so far at higher resolution at JSC (bottom = 4.96 µm/voxel).

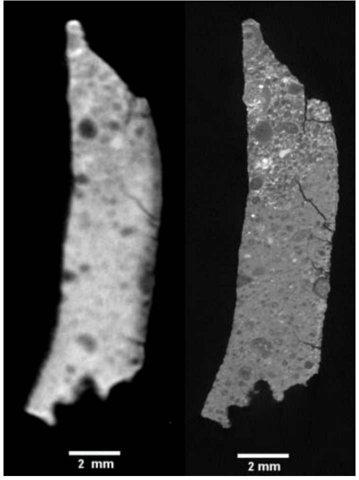

Figure 1: Neutron (left) and X-ray (right) computed tomography slices of Murchison (37.5 and 13.03 µm/voxel, respectively)

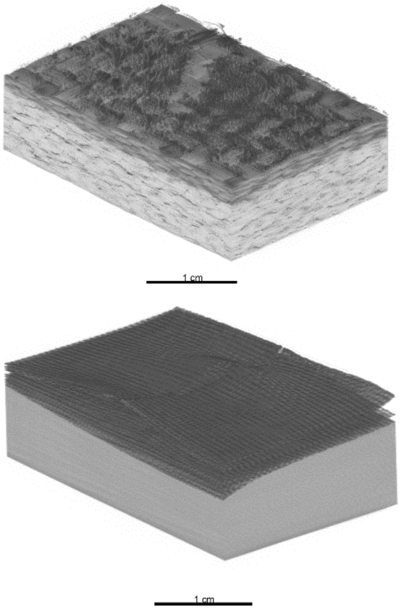

Figure 4: Volume renderings of carbon-fiber (top) and fiberglass (bottom) spacecraft material after being charred at low pressures to simulate reentry (24.44 µm/voxel).

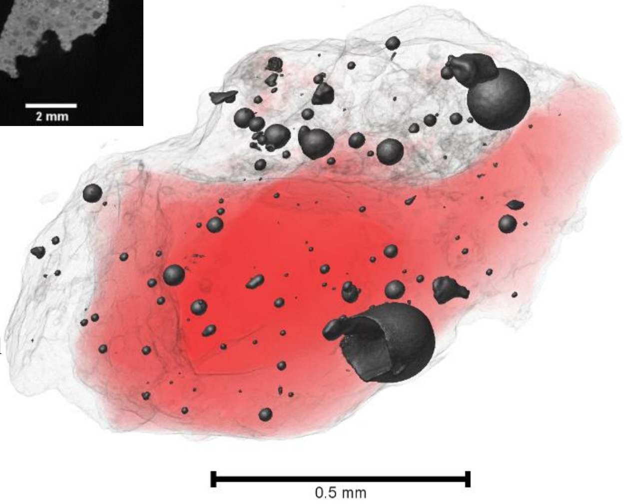

Figure 2: Micrometeorite volume rendering. Terrestrial rind is transparent, meteorite mass is transparent red, and metal phases are dark gray (1.82 µm/voxel).