THE ASTROMATERIALS X-RAY COMPUTED TOMOGRAPHY LABORATORY AT JOHNSON SPACE CENTER. R. A. Zeigler[1], D. M. Coleff[2], and F. M. McCubbin[1], [1]NASA, Johnson Space Center, Mail Code XI2, Houston TX, 77058, ryan.a.zeigler@nasa.gov. [2]Jacobs Technology, Johnson Space Center, Houston TX 77058.

Introduction: The Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center (hereafter JSC curation) is the past, present, and future home of all of NASA's astromaterials sample collections [1-2]. JSC curation currently houses all or part of nine different sample collections: Apollo samples (1969), Luna samples (1972), Antarctic meteorites (1976), Cosmic Dust particles (1981), (4) Microparticle Impact Collection (1985), (5) Genesis solar wind atoms (2004); (6) Stardust comet Wild-2 particles (2006), (7) Stardust interstellar particles (2006), and (8) Hayabusa asteroid Itokawa particles (2010). Each sample collection is housed in a dedicated clean room, or suite of clean rooms, that is tailored to the requirements of that sample collection. Our primary goals are to maintain the long-term integrity of the samples and ensure that the samples are distributed for scientific study in a fair, timely, and responsible manner, thus maximizing the return on each sample.

Part of the curation process is planning for the future, and we also perform fundamental research in advanced curation initiatives. Advanced Curation is tasked with developing procedures, technology, and data sets necessary for curating new types of sample collections, or getting new results from existing sample collections [2]. We are (and have been) planning for future curation, including cold curation, extended curation of ices and volatiles, curation of samples with special chemical considerations such as perchlorate-rich samples, and curation of organically- and biologically-sensitive samples. As part of these advanced curation efforts we are augmenting our analytical facilities as well. A micro X-ray computed tomography (micro-XCT) laboratory dedicated to the study of astromaterials will be coming online this spring within the JSC Curation office, and we plan to add additional facilities that will enable non-destructive (or minimally-destructive) analyses of astromaterials in the near future (micro-XRF, confocal imaging Raman Spectroscopy). These facilities will be available to: (1) develop sample handling and storage techniques for future sample return missions, (2) be utilized by PET for future sample return missions, (3) be used for retroactive PET-style analyses of our existing collections, and (4) for periodic assessments of the existing sample collections. Here we describe the new micro-XCT system, as well as some of the ongoing or anticipated applications of the instrument.

Methodology: We are installing a Nikon XTH 320 micro-XCT system in JSC curation. It has four interchangeable X-ray sources: 180 kV nano focus transmission source, 225 kV reflection source with multi-metal target (Mo, W, Ag, Cu), a 225 kV rotating target reflection source, and a 320 kV reflection source. The system also has a 16-bit, 400 mm^2 (2000 x 2000 pixel) CCD detector, as well as a heavy duty stage that will accommodate large (up to 30 cm) and heavy (up to 100 kg) samples.

The multiple sources, high-resolution detector, and large stage will allow the flexibility to analyze a wide range of sample sizes. The 180 kV transmission source will allow for high resolution (submicron) scans on small samples (less than ~5 mm), whereas the 225 kV and 320 kV sources will allow scans of larger samples at resolutions on the order of 10s or 100s of microns per voxel depending on the sample size. (The resolution on a scan is largely determined by the diameter of the sample being scanned divided by ~2000.) The maximum size high-density rock sample that can be scanned has yet to be determined, but test scans on basalt samples >15 cm in diameter have been successful.

Discussion: High-intensity XCT scanners have been used to study astromaterials (and other geologic samples) for over 15 years, and the practice is becoming ever more prevalent [3-5]. They have a wide range of scientific uses, including (but certainly not limited to) measuring porosity, determining the modal abundance and 3D distribution of phases inside samples, and identification of fabrics or strain patterns in samples. In addition to their use for research, XCT scans have increasingly been utilized as a part of the astromaterials curation process, beginning with meteorites [6-7], and more recently with the Apollo samples [8].

Their utility in curation lies in their ability to non-destructively map out the phases and voids within a sample. As an example, we have scanned several large Apollo polymict breccias, and we were able to identify and tentatively classify the lithologies in these clasts (Fig. 1). The samples can then be subdivided, either through sawing or careful chipping, and those "new" clasts made available to scientists. Similar reconnaissance XCT scans on igneous samples can find regions of interest, e.g., mafic-rich regions within anorthosites, xenoliths within basalts, or zircons within granites, which again will be cataloged and made available to investigators for more in depth study.

The penetrative nature of the XCT scans allows for astromaterials samples to be analyzed within sealed low density containers, preserving the pristinity of the samples (Fig. 2 – Picture of Apollo samples in Teflon bags, immobilized within cardboard tubes). The XCT technique is not completely non-destructive, however. A recent study by [9] has shown that XCT scans of meteorites can alter the natural radiation dose of the sample. The number of techniques where this is applicable (e.g., thermoluminescence) is limited, however. Nevertheless, XCT scans could cause damage for other types of studies (e.g., organics), and we plan to undertake extensive studies to fully characterize the impact XCT scans have on the samples [10]. In the meantime, the percentage of any one sample that is studied by XCT will be limited to ensure that no irreparable damage is done to an entire sample.

The use of XCT alone is a powerful tool for curation, but combining XCT with other techniques, such as micro-XRF or confocal laser Raman spectroscopy, will add more quantitative chemical or mineral (respectively) information, and will allow for a more robust classification of new samples. Similarly, we have recently undertaken a project to combine micro-XCT scans with high resolution visual 3D images of the surface of samples into a single integrated data product [11]. This will allow investigators an unprecedented ability to examine samples to determine if they are applicable to their study.

The Astromaterials XCT lab in JSC curation should be online by early Spring 2017, and we expect to begin scanning Apollo and meteorite samples shortly thereafter. These scans will be made available to the scientific public via the curation website, and advertised via newsletters emailed to the community. Additionally, instrument time will be available to investigators funded to do studies on astromaterials where XCT would be of benefit to the study.

References: [1] Allen, C. et al., (2011). Chemie Der Erde, 71, 1-20. [2] McCubbin, F. M. et al. (2016) *47th LPSC*, abstract #2668. [3] Kuebler, K. E. et al. (1999) *Icarus 141*, 96-106. [4] McCoy et al (2002) *EPSL 246*, 102-108. [5] Zolensky M. et al. (2014) *MAPS* 49, 1997-2016. [6] Almeida N. V. et al. (2014), *MAPS 77* abstract #5033. [7] Smith C. L. (2013) *MAPS 76*, abstract #5323. [8] Zeigler R.A. (2014) *45th LPSC*, abstract #2665. [9] Sears, D. et al. (2016) *MAPS 51.4*, 833-838. [10] Welzenbach, L. C. et al. (2017) *48th LPSC*, #2112. [11] Blumenfeld. E. H. et al. (2017) *48th LPSC*, #2874.

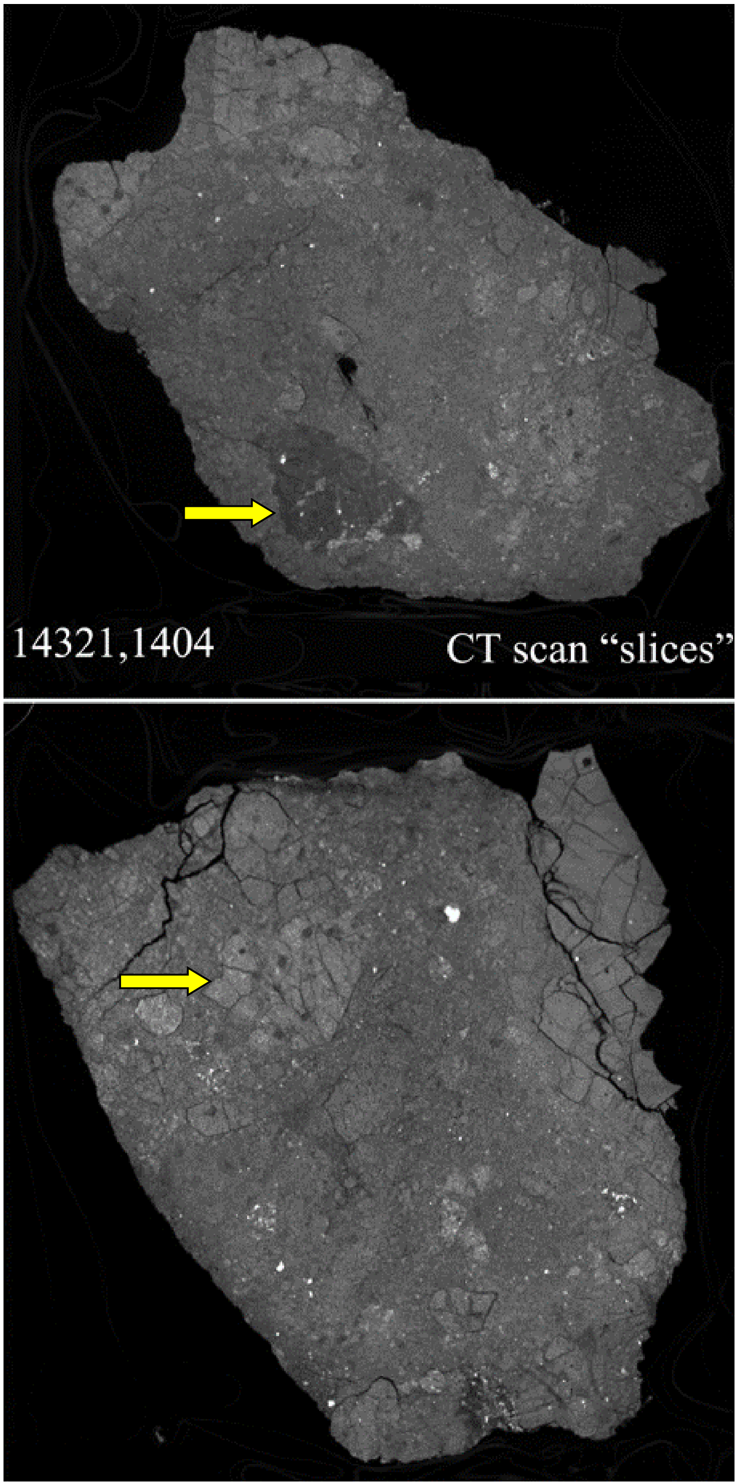

Figure 1: Slices of the micro-CT scan of sample 14321,1404. Brightness of the phases are proportional to x-ray attenuation. Yellow arrows highlight interesting feldspathic (top) and mafic (bottom) clasts. Sample is ~ 6 cm in diameter.