ADVANCED CURATION ACTIVITIES AT NASA: PREPARING FOR THE NEXT WAVES OF ASTROMATERIALS SAMPLE RETURN. R. A. Zeigler, J. H. Allton, C. A. Evans, M. D. Fries, F. M. McCubbin, K. Nakamura-Messenger, K. Righter, M. Zolensky, and E. K. Stansbery, NASA Johnson Space Center, 2101 NASA Parkway, Mail Code XI2, Houston, TX 77058. ryan.a.zeigler@nasa.gov.

Introduction: Astromaterial sample return missions from other planetary bodies (e.g., the Moon, asteroids, the Sun) and astromaterial sample collection missions here on Earth (e.g., Antarctic Meteorites, Cosmic Dust) have been a vital part of NASA's science vision since nearly its inception. Beginning with the Apollo missions to the Moon and extending to the recent launch of the OSIRIS-REx asteroid sample return mission, these astromaterials collections have been an invaluable resource to scientists and educators around the world. Sample studies continue to provide fundamental insight into how our solar system and its constituent bodies formed and evolved over the past 4.5 billion years. As evidence of their utility, there are currently over 19,141 samples on loan to 433 Principal Investigators in 24 countries.

As we plan for exploration missions through 2050, sample return missions will continue to play a vital role in NASA's science vision. Returned samples truly are the gift that keeps on giving. Having the samples accessible on Earth allows new generations of scientists and new generations of instrumentation to answer ever evolving scientific questions. For example, the Apollo samples were collected ~50 years ago, yet recent studies of these samples have fundamentally changed our view of how the Earth-Moon system formed, the role of volatiles in the early inner solar system, and even the positions of the gas giants in the outer solar system.

Vital to the long term viability of any sample return mission is the careful curation of the samples. Curatorial efforts need to begin early; not with the return of the samples, but rather at mission conception. The Astromaterials Acquisition and Curation Office at NASA Johnson Space Center (hereafter JSC Curation) is responsible for curating all of NASA's current and future extraterrestrial samples. Looking at possible sample return missions over the next 35+ years [1], many samples would require curation efforts a step beyond our current capabilities, e.g., cold or cryogenic curation, organically and biologically clean curation, curation of gases and ices, and curation of samples with extreme pressure, temperature, or redox requirements. Below we discuss the current curatorial efforts in JSC curation, as well as efforts that are underway (or need to be undertaken) to prepare for the challenging curation conditions required by future sample return missions.

Present Curation: Currently, JSC Curation curates all or part of nine different astromaterial collections, with two more on the way soon: 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), (8) Hayabusa asteroid Itokawa particles (2010), Hayabusa 2 asteroid Ryugu particles (2021), and OSIRIS-REx asteroid Bennu particles (2023). We also curate spacecraft coupons and witness plates for multiple missions (e.g., OSIRIS-REx). Thus, we currently curate large rock samples (Apollo, Meteorites), bulk regolith and core samples that are intimate mixtures of particles ranging from submicron to 1 cm (Apollo), micron-scale individual particles (Cosmic Dust, Hayabusa), micron-scale particles embedded in aerogel (Stardust), atoms of the solar wind implanted in various materials, physical pieces of spacecraft that have astromaterials embedded in them (Microparticle Impact Collection), and materials that capture contamination knowledge for returned extraterrestrial samples (Genesis, Stardust, OSIRIS-REx).

The samples are stored in eight different clean room suites containing 22 different rooms, ranging from ISO class 4 to 8 (i.e., Class 10 to Class 100,000). Most samples are stored under dry nitrogen conditions, and the larger samples (e.g., Apollo, meteorite) are processed in isolation cabinets under dry nitrogen conditions. The smaller samples requiring fine manipulation are processed in air on flow benches (e.g., Cosmic Dust, Stardust). The majority of the samples are stored and processed under room temperature conditions (~20º C), although a subset of the meteorites and lunar samples are stored frozen at -5º C, though they are not processed at that temperature (Fig. 1).

In addition to the labs that house the samples, a wide variety of facilities and infrastructure are required to support the clean-rooms and centralized curation takes advantage of the economies of shared resources for more than 10 different HEPA-filtered air-handling systems, ultrapure dry gaseous nitrogen systems, an ultrapure water (UPW) system, and cleaning facilities to provide clean tools and equipment for the labs. We also have sample preparation facilities for making thin sections, microtome sections, and even focused ion-beam (FIB) sections to meet the research requirements of scientists across the globe.

In order to ensure that we are keeping the samples as pristine as possible, we routinely monitor our clean rooms and infrastructure systems. This monitoring includes measurements of inorganic or organic contamination in processing cabinets [2-3] and weekly airborne particle counts in most labs. Each delivery of liquid N_2 is monitored for contaminants (typically <6 ppm Ar, and <1 ppm all others combined), and the stable isotope composition of the gaseous N_2 is measured monthly. The quality of our UPW system is monitored daily.

In addition to the physical maintenance of the samples, resources are pooled to achieve economies in documenting detailed handling histories and physical states of samples and subsamples. Databases record the current and ever changing characteristics (weight, location, destructive analysis spots, etc.) of >250,000 individually numbered samples across our various collections. Similarly, there are 100s of thousands of images associated with the samples that are stored on our servers. Collectively, these digital and paper records contain each sample's history in curation, information that could be of vital importance to future researchers.

Advanced Curation: As each new sample collection is returned, new facilities are added to accommodate them. The next missions returning samples to JSC are Hayabusa 2 and OSIRIS-REx, in 2021 and 2023 respectively (the Hayabusa 2 samples are being provided as part of an international agreement with JAXA). Two large suites of ISO class 5 clean rooms to house these samples are currently in the planning stages and should be completed in 2020.

In addition to adding clean-rooms to house samples, we are augmenting our analytical facilities as well. A micro-CT 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) for retroactive PET-style analyses of our existing collections, and (4) for periodic assessments of the existing sample collections.

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 collections as envisioned by NASA exploration goals. 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. In the relatively near term, these efforts will be useful for Mars Sample Return (including Phobos samples), sample return from a cometary surface, and volatile-rich samples from the lunar poles, all of which were named in the NRC Planetary Science Decadal Survey 2013-2022. Looking farther out, these advanced curation efforts will begin to lay the groundwork for other challenging samples that might be returned: (1) mercurian or venusian surface sample return (requiring extremes in pressure, temperature, and redox); or (2) ice and/or volatile samples from outer solar system locations like Ceres, Saturn's Rings, Enceladus, or Europa.

Concluding Remarks: We are fully committed to pushing the boundaries of curation protocol as humans continue to push the boundaries of space exploration and sample return. However, we must never forget our founding principle that curation begins at the conception of a sample-return mission or campaign (in the case of Mars 2020), not at the time of sample collection or return. The return of every extraterrestrial sample is a scientific investment. Our primary goals are to maintain the integrity of the samples and ensure that the samples are distributed for scientific study in a fair, timely, and responsible manner.

References: [1] McCubbin F. M. et al. (2017) *Planetary Science Vision 2050 Workshop*. [2] Calaway, M.J., C.C. Allen, and J.H. Allton (2014, NASA TP-2014-217393, July 1, pp. 108. [3] Allen, C. et al., (2011). Chemie Der Erde-Geochemistry, 71, 1-20.

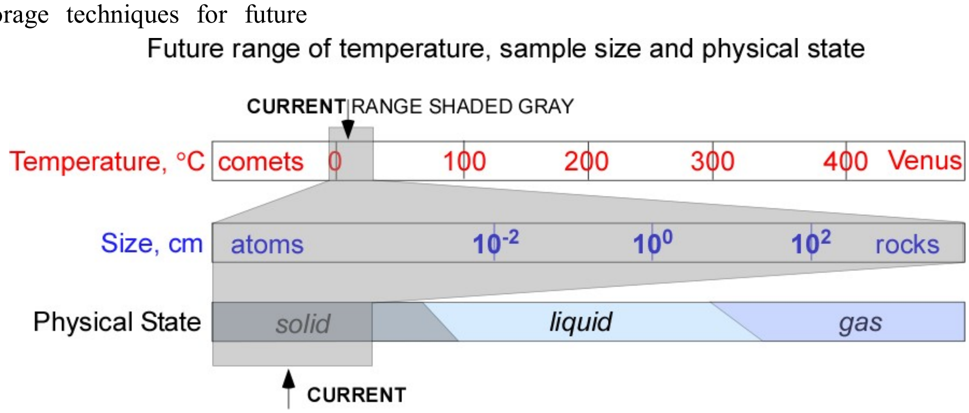

Figure 1: Schematic diagram showing the current conditions that astromaterials are stored at in JSC Curation, as well as likely future conditions that will be required.