THE CAESAR NEW FRONTIERS MISSION: 1. EXPECTED NATURE OF THE RETURNED COMET SAMPLE. D.S. Lauretta[1], S.W. Squyres[2], L. Bermúdez[3], G. Blake[3], J.S. Canham[3], P.C. Chu[5], S. Clemett[6], J. P. Dworkin[7], Y. Furukawa[8], P.A Gerakines[7], D.P. Glavin[7], C.D.K. Herd[9], M.B. Houghton[7], Y. Kimura[10], C.C. Lorentson[7], J.M. Makowski[3], S. Messenger[11], S. Milam[7], M. Mumma[7], K. Nakamura-Messenger[11], T. Nakamura[8], A. Nguyen[6], D. Oberg[3], L.F. Pace[11], J.W. Spring[5], A. Takigawa[12], M. Violet[3], K. Zacny[5], T.J. Zega[1], and the CAESAR Project Team. [1]University of Arizona, Tucson, AZ, USA. [2]Cornell University, Ithaca, NY, USA. [3]Orbital ATK, Inc, Dulles, VA USA. [4]California Institute of Technology, Pasadena, CA, USA. [5]Honeybee Robotics, Brooklyn, NY USA, [6]JETS, NASA Johnson Space Center, Houston, TX, USA. [7]NASA Goddard Space Flight Center, Greenbelt, MD, USA. [8]Tohoku University, Sendai, Miyagi Prefecture, Japan. [9]University of Alberta, Edmonton, AB, Canada. [10]Hokkaido University, Sapporo, Hokkaido, Japan. [11]NASA Johnson Space Center, Houston, TX, USA. [12]Kyoto University, Kyoto, Kyoto Prefecture, Japan. Email: lauretta@lpl.arizona.edu

Introduction: Comets are time capsules from the birth of our Solar System that record presolar history, the initial stages of planet formation, and the sources of prebiotic organics and volatiles for the origin of life. These capsules can only be opened in laboratories on Earth. CAESAR's sample analysis objectives are to understand the nature of Solar System starting materials and how these components came together to form planets and give rise to life [1]. Examination of these comet nucleus surface samples in laboratories around the world will also provide ground truth to remote observations of the innumerable icy bodies of the Solar System.

The CAESAR Sample Analysis Plan: We developed an initial version of the *CAESAR Sample Analysis Plan* as part of our Phase A Concept Study. The purpose of this plan is to ensure that analyses of the returned samples and associated hardware are optimized to achieve the scientific objectives of the mission. CAESAR's driving sample analysis objective is to *Analyze returned volatile and non-volatile material to determine the origin and history of the comet and Solar System starting materials*. This objective maps to the Level 1 Requirement to *Analyze the returned sample to determine the presolar history, formation age, nebular and parent-body alteration history, relation to known extraterrestrial materials (meteorites, asteroids, and comet samples), organic history, volatile history, space weathering, and resurfacing history of 67P*. Sample analyses thus provide knowledge about presolar history through the initial stages of planet formation to the origin of Earth's oceans and life.

Expected Nature of the Returned Sample: CAESAR will return four primary types of cometary material:

- Solid samples in the Sample Containment System
- Volatile samples in the Gas Containment System
- Solid particles on the sampling pads
- Solid particles and volatile residues on other elements of the returned sample hardware

We base the sample analysis plan on the assumption that CAESAR will collect a sample during a single Touch-and-Go (TAG) sampling of the smooth terrain on comet 67P Churyumov-Gerasimenko (67P), the mission target. We further assume that volatiles sublimated from the solid sample after sealing in the Sample Containment System (SCS) will be collected and isolated in a separate Gas Containment System (GCS). 67P's smooth terrain is both well suited to TAG sampling and scientifically compelling. This terrain is likely composed of loose particles that have been liberated from the more rugged terrain by sublimation and fell back on the surface, accumulating in gravitational lows [2,3]. The fact that particles in the smooth terrain originated from elsewhere on the nucleus means that our sample may contain materials derived from many locations.

The properties of 67P's smooth terrain are known particularly well at the Philae lander's first touchdown point. Philae observations show that the uppermost surface of 67P's smooth terrain is composed of granular inorganic and organic materials. Solid particles in the ~cm and larger size range are typical. The CAESAR Sample Acquisition System (SAS) acquires particles up to 4.5 cm in size, and these particles are expected to preserve primordial structures and textures on cm and sub-cm scales. In the 1 – 100 µm size range, cometary materials are expected to resemble stratospheric IDPs and comet 81P dust returned by the NASA Stardust mission. These samples are mostly fine-grained (0.1 – 50 µm) assemblages of anhydrous minerals. The properties of coarse-grained comet nucleus materials (1mm – 1cm+) are unconstrained because Stardust did not sample these materials, and such large materials do not survive the high-velocity atmospheric entry typical of cometary debris. However, there is evidence suggesting that some carbonaceous meteorites derive from comets [4]. If this is true, then the 67P regolith may contain solid material, similar to CI carbonaceous chondrites, in addition to the loose aggregates of fragile materials. The minimum required mass of the solid sample is 80 g, but with a volume of 1.5 liters, the SCS is capable of collecting a maximum of 800 g of material with the same density as the measured bulk density of 67P [5].

The smooth terrain of 67P is rich in organic materials and ices. At 15-30 m/pixel, all smooth terrain shows a strong 2.9-3.6 μm absorption interpreted to result from organics [6]. Philae's brief touchdown in smooth terrain showed that a range of volatile organics was present. Ices are widely distributed on and near the surface [7]. H_2O outgassing from smooth terrain indicates the presence of ice in the ~1 cm-thick diurnal thermal layer [8, 9], easily accessible to TAG sampling. Bluish regions in Rosetta images are interpreted to be more abundant in icy materials [10], a conclusion supported by VIRTIS observations [7, 11]. As sublimation increases near perihelion, smooth terrains take on a bluer spectral slope [10], indicating exposure of ice-rich material. Newly developed, very shallow scarps in smooth terrain show bluer scarp faces, again consistent with exposure of near-surface ice [12]. Thus, ice is abundant just beneath the surface of the whole nucleus and the smooth areas are covered with water-ice-rich material.

The Rosetta instruments ROSINA, Ptolemy, and COSAC detected most previously known comet volatiles [13-15]. ROSINA also discovered new volatiles including P (likely from PH_3), O_2, and N_2. Outgassing rates of H_2O, HCN, and NH_3 are correlated. Importantly, the COSAC mass spectrometer identified sixteen volatile organic species in sniffing mode including many N-bearing species and four compounds (acetone, acetamide, methyl, and ethyl isocyanate) not previously found in comets [13]. These volatiles sublimated directly from particles excavated by Philae's impact in smooth terrain that entered the warm COSAC exhaust tubes. For sample analysis planning, we assume 100 g of collected volatiles in the GCS, assuming 500 grams of total collected sample and 20 wt.% water ice.

The CAESAR SAS will penetrate as much as 10-20 centimeters into the surface of the 67P nucleus surface. Therefore, the samples collected by the contingency sampling pads will sample particles from various depths as well as the immediate surface of the nucleus. The contingency pads will acquire a multitude of particles in the <100 μm size range upon contact with the comet surface. These particles are expected to resemble IDPs and 81P particles. This range of samples present many unprecendented challenges in astromaterials curation. We have also developed a *CAESAR Curation Plan* to outline our approach to meeting these challenges.

CAESAR Curation: The overarching objectives of CAESAR curation are to preserve and protect the returned 67P samples and space exposed hardware to maximize the science return. To this end, the sample recovery, storage, and handling procedures and facilities have been designed to protect the samples from contamination, temperature excursions, and moisture that could result in alteration or modification of the sample. CAESAR sample scientists and the Curation Office have been integrated with mission engineering from the outset to identify requirements on contamination and sample environmental controls. CAESAR Curation is led by the Curator of Ices and Organics within the Astromaterials Curation Office at Johnson Space Center (JSC). They partner with cold curation experts and space suit designers for cold glovebox development.

The CAESAR Sample Collection will include cometary samples and flown spacecraft surfaces of the sample containers to support investigations related to the space environment. Therefore, even areas of the CAESAR SRC free of any cometary materials will be separately curated at JSC as part of the CAESAR Sample Collection. All of the CAESAR Sample Collection including cometary returned samples, flight hardware, curation interface hardware, and contamination knowledge samples (ATLO archival, witness coupons, and UTTR soil samples) will be curated at JSC.

Samples for the Community: After Earth return, samples are available to the CAESAR science team who perform precise analyses in terrestrial laboratories. The current sample analysis plan is based on existing laboratories led by science team members with extensive experience in these techniques. However, advances in instrumentation over the next two decades will undoubtedly lead to lower detection limits, lower sample-mass requirements, and higher resolution data. Ongoing analysis by generations of scientists using techniques not yet invented guarantees an enduring scientific treasure that only sample return can provide. The CAESAR Sample Analysis Plan will be updated regularly as the nature of the returned sample and the available analytical techniques become apparent.

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