THE CAESAR NEW FRONTIERS MISSION: 1. OVERVIEW.

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Introduction: The Comet Astrobiology Exploration Sample Return (CAESAR) mission will acquire and return to Earth for laboratory analysis a minimum of 80 g of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (67P). CAESAR will characterize the surface region sampled, preserve the collected sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir.

Comet sample analyses can provide unparalleled knowledge about presolar history through the initial stages of planet formation to the origin of life. CAESAR's sample analysis objectives address questions regarding the nature of Solar System starting materials and how these fundamental components came together to form planets and give rise to life.

To this end, CAESAR will determine the nature and abundances of interstellar dust grains and molecular cloud materials, and characterize the origins and ages of refractory solar nebula condensates. It will trace the history of volatile reservoirs, delineate the chemical pathways that led from simple interstellar species to complex and prebiotic molecules, and constrain the geological and dynamic evolution of the comet. And it will evaluate the potential role of comets in delivering water and organics to the early Earth. CAESAR will achieve these goals by carrying out coordinated sample analyses that will link macroscopic properties of the comet with microscale mineralogy, chemistry, and isotopic studies of volatiles and solids.

Science Implementation: Collection of a sample from the surface of comet 67P is enabled by the CAESAR Camera Suite: A set of cameras that together provide images to support sample site selection, perform optical navigation, and document the sample before, during, and after collection. The Camera Suite also provides geologic context for the sample, and builds on Rosetta results by documenting changes to 67P through the two perihelion passages that will have occurred since it was visited by that mission. Malin Space Science Systems provides the Camera Suite.

The sample is collected by the Sample Acquisition System (SAS), which has been specifically designed for the surface properties of comet 67P observed by the Rosetta/Philae mission. It contacts the comet surface during a touch-and-go (TAG) maneuver at least 5 seconds long, mounted on a three-degree-of-freedom TAG Arm. During surface contact, pneumatic jets direct the sample into a 1.5-liter sample container. Sample collection is verified by direct imaging of the sample container interior, and a load cell in the TAG Arm measures sample mass. An engineering model of the SAS has been tested in zero gravity and vacuum at the NASA Glenn Zero Gravity Research Facility, over a range of adverse surface strength properties, slopes, and particle size distributions. Honeybee Robotics provides the SAS.

Once successful sample collection has been verified, and while the sample is still cold (< -80 °C), the TAG Arm inserts the sample container into the Sample Containment System (SCS), mounted inside the Sample Return Capsule (SRC). The SCS immediately seals the sample, preventing material from escaping into space. The SCS seal uses a stainless steel knife edge driven into a copper gasket, and has been shown via test to substantially exceed leak rate requirements after having been sealed under a range of cold and dirty conditions. Honeybee Robotics also provides the SCS.

The SCS then slowly warms the sample from the cold temperatures at which it was collected to typical comet surface temperatures near perihelion. As gases evolve from the solid sample, they pass from the SCS into a 5-liter passively cooled gas reservoir in the Gas Containment System (GCS), also mounted in the SRC, separating them from the solid sample and thereby protecting the solid sample from alteration. Once H_2O has sublimated from the solid sample, the GCS is sealed to capture the volatiles it contains, and the SCS is vented to space to maintain the solid sample under vacuum. The SCS vent is closed before Earth entry to prevent atmospheric contamination. Continuous records of sample temperature, pressure, and H_2O vapor partial pressure are collected from sealing at the comet until opening on Earth. The interiors of the SCS, GCS, and associated plumbing are coated with high-purity gold to minimize surface reactivity and catalysis. Goddard Space Flight Center (GSFC) provides the GCS.

The pristine nature of the sample is preserved using stringent cleaning protocols during fabrication, and careful mission design during spacecraft operations. Ground and flight witness materials thoroughly document any contamination. The team follows rigorous cleanliness and documentation protocols through all mission phases.

The CAESAR SRC is provided by the Japanese Aerosapace Exploration Agency (JAXA). Its design is based on the SRC flown on the Hayabusa and Hayabusa2 missions. Like its predecessors, the CAESAR SRC drops its heat shield during parachute descent, greatly simplifying thermal control of the comet sample. The aerodynamic stability in the transonic regime of the Hayabusa SRC design allows use of a subsonic drogue parachute, providing ease of flight testing.

The SRC lands at the Utah Test and Training Range (UTTR) and is immediately placed in cold storage. Phase change material sealed in aluminum housings mounted on the GCS assures that no melting of H_2O will occur even if SRC recovery is delayed for hours. All recovered hardware is transported to the Johnson Space Center, where the samples are removed and delivered to the dedicated CAESAR curation facility. After preliminary examination, samples are made available to the worldwide scientific community.

Mission Implementation: GSFC provides CAESAR project management, systems engineering, safety and mission assurance, contamination control, mission operations, and many other important functions. Orbital ATK develops the spacecraft, based on Dawn mission heritage, which like CAESAR uses solar electric propulsion. KinetX Aerospace and GSFC perform mission navigation, the same team of that is navigating OSIRIS-REx.

The CAESAR spacecraft is derived from Orbital ATK's GEOStar-3 electric propulsion spacecraft, with a configuration that emulates the arrangement used for the Dawn mission. It uses three redundant NEXT-C thrusters and power processing strings, supporting operation of two thrusters across the full throttle range. Power is provided by Roll-Out Solar Arrays (30 kW at 1 AU)built by Deployable Space Systems.

CAESAR launches on a high-performance launch vehicle in the summer of 2024 from Cape Canaveral. The ion propulsion system (IPS) is activated after a 60-day commissioning phase, operating with a conservative duty cycle of no more than 90%. The outbound cruise includes an Earth flyby, and can be tailored to include a flyby of the 12-km B-type asteroid 2809 Vernadskij. CAESAR arrives at 67P in December of 2028.

CAESAR enters orbit around 67P, lowering its orbital altitude slowly and sequentially over a period of months. During an initial survey, the color Narrow Angle Camera is used to search for natural satellites, determine changes that have occurred since Rosetta, and produce a global topographic map. Images of increasing resolution are used to downselect to 16 and then 8 candidate TAG sites. A subsequent detailed survey phase provides images that are used to downselect to the final 4 candidate TAG sites. These sites are documented with 7-color stereo images at 2.3 cm/pixel, and monochromatic stereo images at 0.6 cm/pixel. From these images, the team selects a primary TAG site.

CAESAR is capable of executing at least three TAG campaigns (each consisting of 2 rehearsals and 1 TAG), at any solar distance between 3.5 AU and aphelion. The TAG sequence draws significantly from OSIRIS-REx, with modifications to accommodate the physical properties of 67P.

Data for TAG guidance is provided by both optical navigation and laser ranging. After a deorbit burn, three deterministic propulsive maneuvers refined by a closed-loop linear correction from an onboard navigation system deliver the spacecraft to within 25 m (3-σ) of the selected TAG site. Surface contact lasts for at least 5 seconds, with contact force controlled by a constant-force spring in the TAG Arm. After sample collection, the spacecraft automatically executes a backaway burn. The TAGCAM camera, mounted on the spacecraft, images the SAS and surface at five frames/s during TAG, documenting TAG at 1 mm/pixel. The CANCAM camera, mounted within the SAS, images inside the sample container at ten frames/s, documenting sample collection.

After verifying and stowing the sample, CAESAR executes gas transfer to the GCS, and begins a slow drift away from the comet. Proximity operations could be completed in as little as 17 months, but physics dictates that the drift continues until the IPS can be reactivated at 3.5 AU, about 4.6 years after arrival at the comet. Because proximity operations can be performed at any solar distance between 3.5 and aphelion, timeline margin is an ample 3.2 years.

The IPS is re-activated in November of 2033. The inbound cruise includes an Earth flyby, but no asteroid flyby will be conducted. Landing at UTTR takes place at 9:14 AM local time on November 20, 2038.

Summary: CAESAR will return the first sample from a comet nucleus. The payload has been designed to maximize the scientific value of the sample, including both its non-volatile and volatile components. The choice of comet provides substantial risk reduction, achieving the mission within a constrained New Frontiers budget. Most of the sample (≥75%) will be set aside for analysis by generations of scientists using continually advancing tools and methods, yielding an enduring scientific treasure that only sample return can provide.