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COmet Nucleus Dust and Organics Return (CONDOR): a New Frontiers 4 Mission Proposal

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Abstract

CONDOR would collect and return a ≥ 50 g sample from the surface of 67P/Churyumov-Gerasimenko for detailed analysis in terrestrial laboratories. It would carry a simple payload comprising a narrow-angle camera and mm-wave radiometer to select a sampling site, and perform a gravity science investigation to survey changes of 67P since Rosetta. The proposed sampling system uses the BiBlade tool to acquire a sample down to 15 cm depth in a Touch-and-Go event. The Stardust-based sample return capsule is augmented with cooling and purge systems to maintain sample integrity during landing and until delivery to JSC's Astromaterials Curation Facility. Analysis of rock-forming minerals, organics, water and noble gases would probe the origin of these materials, and their evolution from the primordial molecular cloud to the 67P environment.

Introduction

Astronomical observations show that synthesis of both simple and complex organic molecules occurs in the interstellar medium, through various pathways including ice chemistry under ultraviolet irradiation. Links between these materials and Earth's prebiotic organic matter are unknown, and can only be probed on samples that contain pristine organic material. No well-preserved samples from the outer solar system exist to test ideas regarding solar system formation, and accretion of rocky planets with habitable surface environments. Current micro-analytical techniques have reached the point where the limiting factor in understanding the most primitive solar system materials is not instrument precision but instead is the lack of availability of less-processed, undamaged material that accreted in the outer solar system.

ESA's Rosetta mission makes 67P the best characterized comet to date. Water outgassed from the nucleus exhibits a high D/H ratio [1], suggesting a significant contribution of molecular cloud material to the isotopic budget. The surprising abundance of highly volatile species (e.g., O_2 and S) corroborates that 67P is a pristine sample of material accreted in the Kuiper Belt [2]. The surface of 67P is rich in organics, whose composition is partially understood from VIRTIS [3] and ROSINA data. Thus, 67P is an exceptional target for the first return of macroscopic, pristine cometary nucleus material to the Earth.

Overview of proposed mission

The CONDOR concept uses a Lockheed-Martin A2100 bus with a commercial solar-electric propulsion system to encounter and sample 67P at large heliocentric distances, when comet activity is minimal. The sample would be returned to Earth within 12.4 years, and curated at ≤ -80 °C.

Table 1: Proposed mission timeline

Event	Date (Sun distance, AU)
Launch	Jun. 16, 2024
67P Arrival	Apr. 25, 2029 (3.6)
Reconnaissance and Site Selection	Apr. 25, 2029 – Mar. 31, 2030 (3.6 – 5.1)
Sample acquisition	Mar. 31, 2030 – Sep. 9, 2030 (5.1 – 5.6)
67P Departure	Dec. 10, 2033 (3.3)
Earth Return	Nov. 8, 2036

Reconnaissance and Site Selection

We would follow 67P during its aphelion passage to survey changes since Rosetta and select a sampling site of high scientific value that is safe for the spacecraft. The proposed remote sensing payload (Figure 1) consists of a narrow-angle camera (NAC) from Malin Space Science Systems and a mm-wave radiometer (CONRAD) from JPL. The NAC is used to produce a global shape model with < 1 m resolution, as well as local digital elevation maps of candidate sampling sites at < 4 cm resolution. NAC narrow-band color imaging determines surface albedo and visible slope that is a proxy for ice. CONRAD is a three-channel radiometer that is sensitive to thermal properties, and enables CONDOR to see below the surface of 67P and find areas where primitive materials are accessible beneath a thin dust layer of < 10 cm thickness. The mass of the 67P nucleus is measured via X-band coherent Doppler radiometric tracking for 8 hrs/day, to determine total mass loss since 2016.

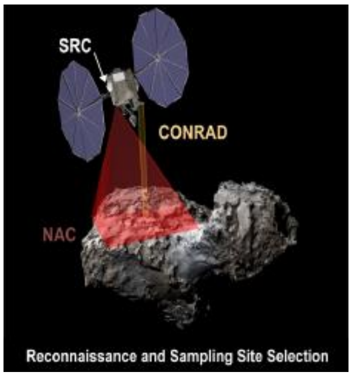

Figure 1: The site selection phase of CONDOR concept would last 340 days and consist primarily of mapping local topography with the NAC and thickness of surface dust cover with CONRAD.

Sample Acquisition

The BiBlade sampling tool [4], designed by JPL and constructed by Honeybee Robotics, would acquire up to 590 cc of comet material when filled to capacity (Figure 2). This is more than sufficient to return ≥ 50 g. It deposits the sample in a vault within the CONDOR sample return capsule (SRC), from Lockheed Martin, and releases a lid. The SRC contains two sample vaults, allowing return of up to two samples from 67P. Molecular sieves are integrated in the lids of the sample vaults to capture volatiles potentially released by the sample(s). Temperature inside the blades remains below -80°C.

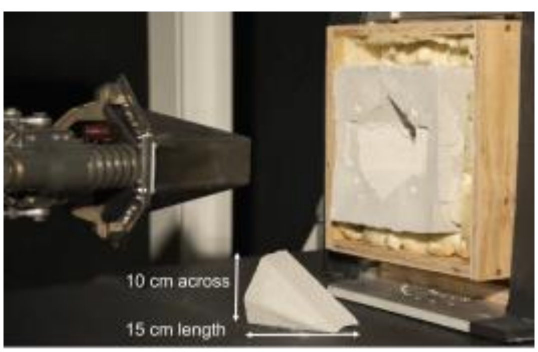

Figure 2: The BiBlade (TRL6) acquires a sample in materials up to 18 MPa cone penetration resistance, as hard as terrestrial permafrost.

Proposed Earth return and preliminary examination

After sample acquisition, CONDOR would stay at 67P until close enough to the Sun to allow departure and return to Earth. The SRC would be released on Nov. 8, 2036, and use an ammonia cooling system to maintain the capsule ≤ -20 °C until recovery. The SRC would also be purged with ^{40}Ar to prevent contamination from terrestrial atmosphere. After recovery, the sample(s) and hardware for contamination monitoring would be transported to JSC's Astromaterials Curation Facility at ≤ -20 °C, where < 25% of the sample is used for PE and > 75% of the sample is preserved for legacy at ≤ -80 °C.

The PE phase is projected to span the two-year period following sample recovery. A sample catalog would be produced within the first six months. Mineralogic and petrologic analyses inventory the materials to sub-micron scale. Elemental techniques determine the chemical composition of constituent materials. Analyses of the isotopic compositions of minerals, organic matter, and volatiles (H_2O and noble gases) determine their origin (presolar, formed in the outer/inner protoplanetary disk, mixed components) and evolution in the environment of 67P.

Acknowledgements

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