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AMBITION, the Comet Nucleus Cryogenic Sample Return mission for ESA Voyage 2050 program

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Since the 1980s, ESA has played a leading role in cometary space science with Giotto and the Rosetta/Philae missions to comets 1P/Halley and 67P/Churyumov-Gerasimenko, respectively. These missions have greatly improved our knowledge of comets and placed Europe in an ideal position for the preparation of future cometary missions. After a cometary flyby mission (Giotto) and an orbiter (Rosetta) with a nucleus lander (Philae), and the selection of F-class Comet Interceptor ESA mission, the next major step in cometary science would be a cryogenic sample return mission as studied in the AMBITION proposal [1] which was submitted to ESA in the context of the future Voyage 2050 program. Despite the success of previous missions, a number of high priority scientific questions are still debated within the cometary community:

- How did cometary materials assemble? What are the building blocks of cometary nuclei?
- Which post-planetesimal evolutionary paths need to be considered? Are comets collisional fragments or primordial planetesimals?
- Which cometary components originate from the time before the formation of the Solar System? What is the nature of the refractory organic materials? How and where did these components form?
- Are there differences in physical/chemical properties in the comet populations? What are the commonalities and differences between comets and primitive asteroids? Are these distinct populations? Do comets, Main Belt comets and active asteroids have different primordial reservoirs?
- How does comet activity work? How do surface and coma observations reconnect with the pristine, deep interior?
- How are the dusty coma, the surrounding plasma, and the nucleus interacting together? Do interactions with the solar wind influence the activity and evolution of comets?
- What contributions did comets make to reservoirs of volatiles and prebiotic compounds on early Earth?

The best approach to answer these questions is to return a pristine and volatile rich cometary sample to Earth. Such a sample, preserved at cryogenic temperature, will be transferred to a state-of-the-art curation facility, where it will be investigated in great detail.

In this scenario part of the sample will be studied by means of different analytical techniques in laboratory-controlled conditions while the remaining sample will be stored at cryogenic temperature

for future investigations. Laboratory analyses of the returned sample can achieve much higher precision and resolution measurements as compared to in-situ measurements.

The AMBITION study has considered different mission targets (see Figure 1), including Centaurs, Jupiter family comets and its extinct members, returning Oort cloud comets, dynamically new comets, main belt comets and interstellar comets as possible candidates. Among them, Jupiter family comets are the ones which offer the best characteristics, in terms of orbital parameters, evolutionary history, composition and activity, to be selected for an L-class cryogenic sample return mission. The other targets could be explored by more consolidated (orbiters, landers) small and medium class missions.

The selection, collection and storage of the sample at controlled cryogenic temperature and pressure during the return flight, Earth re-entry and landing phases will require significant technological advancement to guarantee maintenance of the optimal environmental conditions for the collected sample. Several options are identified for pristine sample collection from the cometary nucleus, including subsurface corers able to extract carrots up to 3 m depth as well as grabbers and manipulator arms to collect ice-rich, semi-buried boulders from the surface.

The AMBITION mission is the “Holy Grail” in the field of cometary exploration and Solar System formation. For its implementation it will need a strong commitment from the scientific community, industrial partners, ESA and national space agencies.

Comet type	Fly-by	Rendezvous	Landing	Sample return	Cryogenic SR
Centaur	M	M/L	L+		
Jupiter Family	DI, DS1, EPOXI etc.	Rosetta	Philae	Stardust	L++
Extinct JFC	F/M	M/L	L	L	
Returning OCC	Giotto etc.	L+	L++		
Dynamically new	Comet Interceptor				
Main Belt Comet	M	ZhengHe-A	L	M (Stardust-like) L (surface)	
Interstellar comet	M				

Figure 1: Approximate mission classes for different mission and comet types, in increasing complexity from left to right, and covering varying evolution stages of comets from the four possible reservoirs (Kuiper Belt, the Oort cloud, the Main Belt, and other planetary systems). Shading indicates approximate cost from yellow (F-class) through orange (M-class) to red (L-class or multiagency flagship missions). Hatched boxes indicate that such a combination is unfeasible, mostly due to excessive Δv requirements. Past and planned missions are shown. From [1].

[1] Bockelée-Morvan, D. et al., AMBITION, Comet Nucleus Cryogenic Sample Return (2019), eprint, 2019arXiv190711081B

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