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Europe's future exploration of Main Belt Comets

C. Snodgrass (1), G. H. Jones (2), N. Bowles (3), A. Gibbings (4), M. Taylor (5), I. Franchi (1), S. Sheridan (1),
(1) The Open University, UK (colin.snodgrass@open.ac.uk) (2) MSSL/UCL, UK (3) Oxford University, UK (4) OHB System AG, Germany (5) ESA, ESTEC, The Netherlands

Abstract

We discuss options for the future exploration of Main Belt Comets (MBCs) using European spacecraft. MBCs are objects with asteroid-like orbits in the main belt, but comet-like appearances. They are an important 'missing link' in our understanding of the small bodies of our Solar System, and a high priority population to explore with spacecraft, but so far no mission to visit a MBC has been selected. We briefly review previous proposals to ESA, before considering future options to either visit a MBC or study them via space-based remote observation.

1. Main Belt Comets

MBCs were only recently identified as a population in their own right [1], following the discovery of additional objects like the puzzling 133P/Elst-Pizarro, which was first seen active in 1996 and caused some debate over whether it was a comet or collisional debris. It has not yet been possible to obtain direct confirmation that MBC activity is comet-like, i.e. driven by sublimating ice, via detection of a gas coma [2]. The question has been convincingly settled for 133P and four other MBCs, as they have returned to activity after each perihelion passage since discovery, meaning that sublimation of ice is the only reasonable explanation [3]. Direct study of the volatile component of MBCs, and remaining questions about their nucleus structure, composition, and history, will require spacecraft exploration, or more sensitive telescopic observations.

2 Previous proposals

2.1 Caroline

Proposed at the ESA M3 call, Caroline [4] was a sample return MBC mission, making use of aerogel capture of dust released from the MBC in a similar way to the Stardust comet mission [5]. Although this would not be sensitive to volatiles at the MBC, returning a sample of dust from the main belt to apply the full range of techniques possible in Earth-based laboratories would be very valuable, and would allow comparison with results from NEO sample return missions (Hyabusa, OSIRIS-Rex).

2.2 Castalia

Castalia was proposed to the ESA M4 and M5 calls [6]. It would rendezvous with and orbit an MBC for a time interval of some months, arriving before the active period for mapping and then sampling the gas and dust released during the active phase. Given the low level of activity of MBCs, the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC, allowing in situ sampling of gas and dust in sufficient quantities to measure composition and isotopic ratios. The payload comprises vis/NIR cameras, thermal cameras, radars and radio science, mass spectrometers for gas and dust, a dust counter, plasma instruments and a magnetometer. The instruments are based on heritage from Rosetta, including the ROSINA, COSIMA and GIADA instruments (the latter two combined into a single dust instrument for Castalia). Various optional elements, including a simple surface science package, could also be considered. At the moment, MBC 133P is the best-known target for such a mission. A design study for the Castalia mission, carried out in partnership with OHB System AG found that a mission to 133P, or backup MBC targets, is achievable by an ESA M-class mission.

2.3 CASTAway

CASTAway is a mission concept, proposed for M5, to explore the diversity of the main asteroid belt [7], by combining a long-range (point source) telescopic survey of thousands of objects, targeted close encounters with 10 - 20 asteroids, and serendipitous searches for very small asteroids. The science payload consists of three linked instruments: a 50 cm diameter telescope feeding a CCD camera for narrow angle imaging and a moderate resolution spectrometer with spectral coverage from 0.6-5 μm; a thermal infrared imager for temperature, albedo and composition mapping during flybys; asteroid detection cameras, based on star trackers, to detect new objects in the 1-10 m size range. Ideally, CASTAway would include one MBC in its flyby target list, although the relatively small population of known MBCs make this a challenge when selecting a trajectory optimised for the largest number of targets. Even without a flyby, CASTAway would be valuable for MBCs in performing remote observations, including searches for outgassing, and in giving a better comparison between MBC and asteroid properties.

3 Future missions

3.1 ESA future missions study

In 2016 ESA released a call for ‘new ideas’ for future missions. From this, and following a discussion with representatives of the European planetary science community at ESA headquarters in 2017, an ESA concurrent design facility study looked at various concepts. These included the possibility of using multiple small satellites instead of (or in combination with) one larger one to explore asteroids or comets. This was partially inspired by the ‘CubeSats’ that have become increasingly common in Earth orbit in recent years, although operation in deep space presents its own challenges. The case of a mission to a MBC was considered, with similar science goals to Castalia, but instruments spread between a series of small satellites.

3.2 Involvement in non-ESA missions

Proteus is a MBC rendezvous mission with similar goals to Castalia, which was proposed to the last NASA Discovery round [8], and will likely be proposed again, potentially with European payload involvement. Conceptually similar to the ESA-China proposal for Marco-Polo at the ESA M4 call, a proposal from the China Academy of Space Technology would see a mission visit a NEO, return a sample to Earth, and then send the main spacecraft on to a MBC [9]. If selected it would arrive at the MBC (expected to be 133P) in the late 2020s. Discussions with international partners are ongoing, but European institutes could provide extra instruments, releasable CubeSat-sized probes, or even a penetrator to sample the subsurface and measure its composition [10].

4 Remote observations

Although the most detailed information on MBCs will only be obtained by visiting them, telescopic observations can look at composition, and have the advantage of being able to study the whole population. The big challenge is detecting outgassing water. Attempts were made using the ESA Herschel space telescope, which was sensitive to water emission at 557 GHz. Upper limits for 176P and 358P found $Q(H_2O) < 4$ and 8×10^{25} molecules s^{-1}, respectively [11, 12].

JWST will have excellent sensitivity to faint emissions that could enable direct detection of water outgassing [13]. To perform a broader survey than will be possible with JWST, a small telescope could be launched to perform a dedicated water search. Collecting various comet observations to assess the sensitivity of current technology suggests that the most sensitive searches, for a given telescope size, could be performed in the far UV, where the hydrogen Ly-α line is a strong emitter [2]. Such a telescope would have to be placed in an orbit away from Earth’s geocorona, e.g. in heliocentric or lunar orbit, but could be a useful mission for MBC science on a budget smaller than M-class, e.g. for the anticipated F-class ESA call.

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