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Castalia: A European Mission to a Main Belt Comet

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Abstract

Main Belt Comets (MBCs) are a newly found population in the main asteroid belt. A spacecraft mission to MBCs can provide key insights into the formation and evolution of the planetary system and the early evolution of Earth. The scientific key questions of the mission, its instrumentation and mission profile is studied with the goal to prepare for future mission calls of international space agencies.

1 Main Belt Comets (MBCs)

MBCs are minor bodies with asteroid like orbits and an appearance like comets. They orbit the Sun mainly in the outer part of the main asteroid belt. When active – most likely during several revolutions, they emit micron-size dust, although at low production rate (order 1000 tons/revolution). Sizes (order km) and albedos (< 0.1) are small. The first MBC (133P/Elst-Pizarro) was discovered in 1996, and more than 1000 MBCs are expected in the asteroid belt at a time.

The origin of MBCs is still unsolved. The current paradigm sees MBCs as either original or at least early members of the asteroid belt. It is believed that they survived in the belt in a dormant state and that their activity occurred only recently and may not last very long. What drives the activity in MBCs is unknown. Cometary-like sublimation of ices is best compatible with the observed phenomenology and very likely the reason for MBC activity. If so, only water ice is expected to be the major volatile that can survive long enough in a body in the asteroid belt, and only when deeply covered under an insulating surface. Excavation by impact could bring the water ice (closer) to the surface and trigger the start of MBC activity. The presence of water (ice) in the asteroid belt is very important for the presence of water on Earth. Nowadays, water up to the volume of a 1000 km diameter body exists on Earth. However, the origin of water on Earth is unsolved. A likely scenario is that water did not survive from the formation phase of the planet, but was imported to Earth thereafter. At about 4 billion years ago, liquid water existed (again) on a solid terrestrial surface. Re-import of water could have happened by means of impacts of planetesimals during the clean-up process of the planetary debris disk. The asteroid belt has by far delivered the most impactors to Earth, compared to the outer solar system where the comets reside. Isotopic measurements of water and possibly minor species can help to illuminate the role of MBCs for the existence of water on Earth. Related is the possible import of organics and even biogenic material from extraterrestrial space. A Main Belt Comet mission has the potential to address and solve scientific key questions related with the asteroid belt and the early evolution of the terrestrial planets.

2 The Castalia mission

The Castalia mission will explore a member of a new class of small bodies that can provide unique insights into the distribution of volatiles in the early stages of planet formation. In exploring an MBC, the mission will advance our understanding of the origin and evolution of the family of terrestrial planets. Seeking the processes whereby habitable environments were created and finding where resources are located is of central importance for the exploration of the solar system. The specific science goals of the Castalia mission are:

1. Characterise a new Solar System family, the MBCs, by in-situ investigation
2. Understand the physics of activity on MBCs
3. Directly detect water in the asteroid belt
4. Test if MBCs are a viable source for Earth's water
5. Use MBCs as tracers of planetary system formation and evolution

To achieve these goals, a number of measurement objectives have been defined. These in turn define the necessary instrumentation and mission profile. These goals can be achieved by a spacecraft designed to rendezvous with and orbit an MBC for some months, arriving before the active period begins to map both the surface and interior with remote sensing instrumentation before directly sampling the gas and dust released during the active phase, using in-situ instruments mounted on the orbiter. Given the low level of activity of MBCs, and the expectation that their activity comes from only a localised patch on the surface, the orbiting spacecraft will have to be able to maintain a very close orbit over extended periods – the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC.

3 Instrumentation

The straw-man instrument payload is defined as those necessary to characterise a MBC, locate its active area(s), and measure isotopic ratios of water. It is made up of:

Remote sensing measurements:

- Visisble and near-infrared spectral imager
- Radar (deep interior)
- Radar (shallow subsurface)
- Thermal infrared imager
- Radio science

In-situ measurements:

- Dust impact detector
- Dust composition analyser
- Neutral/ion mass spectrometer
- Magnetometer
- Plasma package

In addition to this, the option of a surface science package is being considered. While the primary science goals of the Castalia mission can be achieved by the orbiter alone, there are valuable extra experiments that can be carried out by either a simple lander (similar to the MASCOT lander which will be taken on the Hayabusa 2 mission) or a penetrator experiment (where instruments are included inside of a 'bullet' fired a few metres into the surface of the comet.

4 Mission

The mission requires a-priori knowledge of the activity profile of the object, at the moment MBC 133P/Elst-Pizarro is the best known target for such a mission. In preparation for a possible future M4 mission call of the European Space Agency ESA a design study for the Castalia mission has been carried out in partnership between the science team, DLR and OHB Systems. This study looked at possible missions to 133P with launch dates around 2025, and found that this (and other MBC targets as backups) are reachable with an M-class type mission. All proposed instruments and mission scenarios, including the necessary 'hovering' operations, appear to be feasible for such a mission.

The Castalia mission will explore a new population of solar system body, identifying buried ice that has remained in the inner solar system, unchanged since the formation of the planets. Given the importance of such ice for planet system formation, and potentially for life on Earth, this should be a high priority for future missions; we have studied and shown that this can be done at the next M-class call.