EPSC Abstracts
Vol. 7 EPSC2012-206 2012
European Planetary Science Congress 2012
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Asteroids, Comets and the Water on Earth - A European Mission to the Main Belt Comets

C. Snodgrass (1), K. Altwegg (2), I. Bertini (3), H. Boehnhardt (1), M.T. Capria (3), A. Coates (4), B. Davidson (5), A. Fitzsimmons (6), M. Hilchenbach (1), G. Jones (4), L. Lara (7), S. Lowry (8), K. Muinonen (9), D. Prialnik (10), B. Schlaeppi (2), H. Sierks (1)

(1) Max-Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, (2) University of Bern, Bern, Switzerland, (3) University of Padova, Padova, Italy, (4) Istituto di Astrofisica Spaziale e Fisica Cosmica, Rome, Italy, (5) Imperial College, London, England, (6) University of Uppsala, Uppsala, Sweden, (7) Queens University, Belfast, Northern Ireland, (8) Instituto de Astrofisica de Andalucia, Granada, Spain, (9) University of Kent, Canterbury, England, (10) University of Helsinki, Helsinki, Finland, (11) University of Tel Aviv, Tel Aviv, Israel

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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. What are 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.

2. What are the MBC Mysteries? The origin of MBCs is still unsolved. The current paradigm sees MBCs as either original or at least early members of the asteroid belt, although cometary origin in the outer solar system cannot fully be excluded. 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 1000km 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.

3. What will an MBC mission explore? The MBC mission will explore one or more members 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, it 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 MBC mission will address three key questions:

(1) What is the nature of the MBC and what triggers MBC activity?

(2) Is water present in MBCs and does it drive the activity?

(3) Is the water in the asteroid belt related to terrestrial water?

Question (1) requires investigating of MBCs either by exploring thoroughly a single object over a longer time interval and/or through shorter encounters with several MBCs, in order to outline and proof the overall picture for the trigger, onset and evolution of activity on this body. Questions (1+2) have immediate implications for the understanding of the formation and evolution of the asteroid belt and the bodies therein. The asteroid belt is the inner region in the solar system where original planetesimals from the formation period have survived. Thus, the bodies therein provide links to the formation and evolution of the terrestrial planets. Question (3) connects to the open issue of water and life on Earth. It is very likely that besides water also organics and other buildings stones for life were delivered to Earth from space. The presence of primitive asteroids in the main belt with organic material on the surface, as it is concluded from telescopic observations, and the extraordinary high impact rate of asteroids on Earth suggest a scenario of extraterrestrial delivery of water and possibly biogenic material to our planet.

4. What instrumentation can contribute to the science questions of the mission? The payload complement shall provide answers to the immediate science goals (1) – (3) of the mission. Significant contributions in answering the key questions of the mission will come from

- a very sensitive mass spectrometer covering a wide mass range from the light elements to heavy organic molecules and high mass resolution for isotopic measurements
- a camera system for the visible wavelength range (0.3-1.0 μm) to image the MBC as a whole, its surface in detail and to assess the spatial and temporal profile of activity
- a thermal spectral mapper (4-30 μm) to measure the temperature profile of the surface, in particular of active areas, and to assess the presence of stony material
- a dust composition analyser and mass detector to determine the dust composition and size distribution
- a radio science investigation using existing spacecraft bus equipment to determine the mass and density of the body

For the exploration of the body interior a penetrating radar or radio sounding system as well as penetrator experiments could ideally complement the science payload. The surface composition and constitution can further be explored through visible and near-IR imaging spectroscopy. Very accurate shape estimations could come from a laser altimeter system onboard.

5. What is the mission profile? For a single target mission, after launch from Earth and the cruise to the MBC, a science phase at the MBC of several months is required in order to allow enough time for data collection for the fulfillment of the science goals. The exploration of the MBC by the remote sensing instrumentation will be done in phases starting at larger distances (100-1000km) to a close distance between a few ten to a few km. Dust and gas collection requires extended periods at closest possible distances to the surface (order one object radius). The radar/radio sounding system and laser altimeter work best from a stable orbit that allows multiple scans of the body from different directions. It is important to explore the MBC in both, the active and the inactive state, ideally arriving before onset of activity and continuing over the start to the end of the period. Since this 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. Alternatively, a multi-flyby mission at several MBCs can serve to achieve the science goals.
It is planned to perform a mission study to explore and evaluate the scientific and engineering profile of an MBC mission further with the goal to arrive at a solid and competitive mission proposal for a possible future M4 mission call of the European Space Agency ESA or to be prepared for alternative national and international calls of similar mission classes.