Main Belt Comets

Asteroid belt's new class of objects and possible source of water and volatiles for the Earth

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Observations of cometary activity in four icy asteroids 7968 Elst-Pizzaro, 118401, P/2005 U1, and P/2008 R1 (also known by their cometary designations as 133P/Elst-Pizzaro, 1999 RE_{70}, P/Read, and P/2008 R1 Garradd) have revealed a new population of objects in the asteroid belt (Figures 1 and 2, Hsieh & Jewitt 2006; Jewitt, Yang & Haghighipour 2009). Known as Main Belt Comets (MBCs), the dual characteristic of these objects (i.e., their asteroidal orbits and their cometary activity) has raised many questions regarding their origin and activation mechanism. Observations of the dusty tail of 133P/Elst-Pizzaro by Hsieh, Jewitt & Fernandez (2004) have shown that MBC tails contain small dust grains that have been ejected from their surfaces by gas drag produced by sublimation of near-surface water ice. The survival of ice on these objects is a major surprise, and opens exciting new science possibilities. The goal of this white paper is to address the importance of studying and characterizing MBCs (through both ground- and space-based telescopes as well as space missions) and to show the immediate relevance of the results to the formation and evolution of our solar system, in particular to understanding the sources of Earth's volatiles and water.

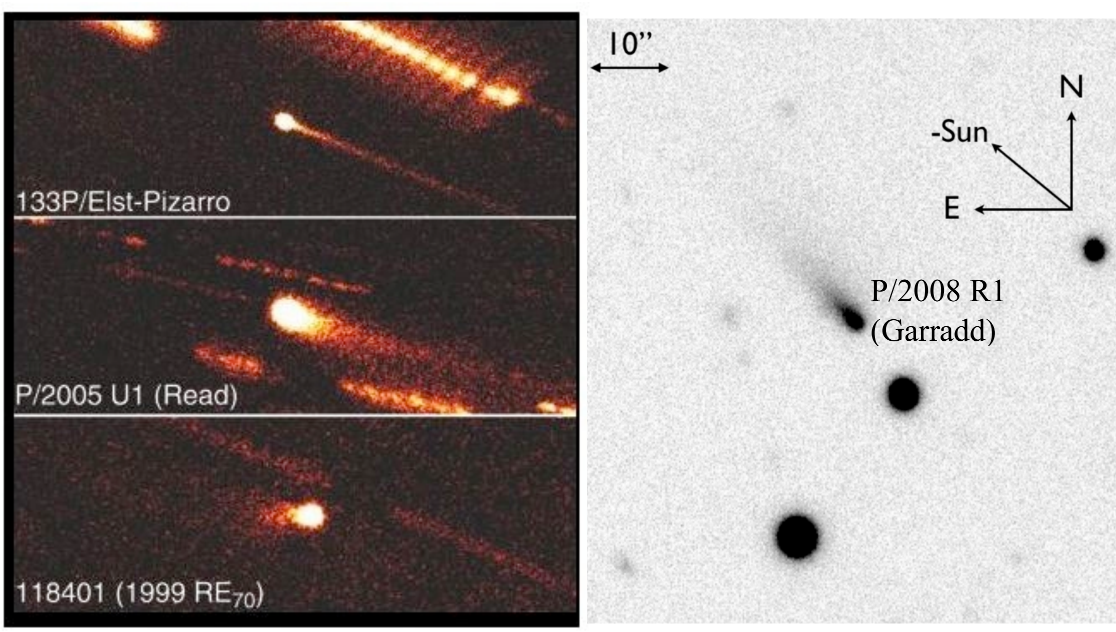

Fig. 1 Pictures of the four known MBCs (Hsieh & Jewitt 2006, Jewitt, Yang & Haghighipour 2009).

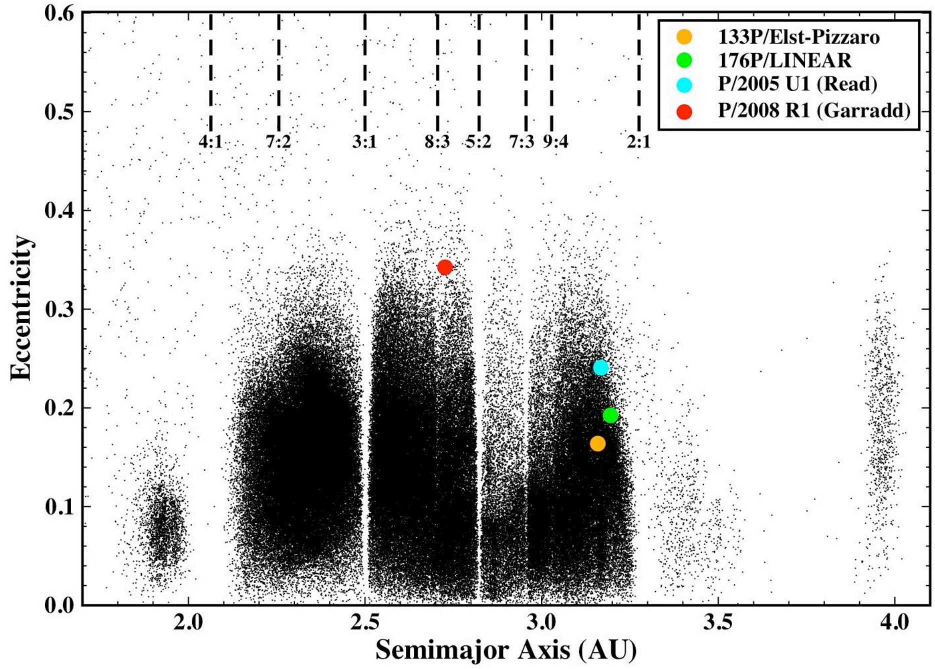

Fig. 2 Graph of the location of the four currently known MBCs in the asteroid belt (Jewitt, Yang & Haghighipour 2009).

One of the long-standing issues in our solar system is the source of water for Earth. It is likely that during its formation, Earth was too hot to contain much water. Instead, water might have been delivered to Earth, probably by the impact of ice-carrying solid bodies. The ice-rich comets are obvious candidates, however, spectroscopic measurements of their isotopes indicate that water ice in comets is more deuterium rich than are the Earth's oceans. Independently, dynamical simulations of the formation of terrestrial planets suggest that the outer asteroid-belt may be a stronger source of impactors on the Earth than are comets. The MBCs are a new class of ice-rich objects in the outer region of the asteroid belt that represent a plausible category of small bodies capable of contributing water and other volatiles to the terrestrial planets. The study of the dynamics and characteristics of these objects will shed light on the formation of these bodies, their origins, activation mechanisms, and their contributions to the formation and water contents of Earth. In this respect, the necessary research on these objects can be categorized as in the following.

Key Research Topics on Main Belt Comets

- **Origin and Formation** While the physical appearance of MBCs suggests a cometary origin as part of an inward scattering of comets from the outer regions of the solar system and their subsequent capture in orbits in the asteroid belt, (Levison et al. 2008a,b,c; Morbidelli et al. 2008; Bottke et al. 2008), the asteroidal orbits of these objects (combined with the proximity of 133P/Elst-Pizzaro, 1999 RE_{70}, and P/2005 U1 to the Themis family of asteroids) suggests that MBCs formed in or around their current orbits

(Haghighipour 2009). Detailed computational simulations (of the collisions and scattering of small bodies), and measurements of the spectra of MBCs are required to portray a comprehensive picture of the origin and history of these objects.

- **Activation Mechanism** Observations of 133P/Elst-Pizzaro suggested that sublimation of sub-surface water ice was the driver of activity and the source of the dust tail for this MBC (Hsieh et al. 2004. Two mechanisms may account for exposing the ice: collision of an MBC with a small (e.g., meter-sized) object, and a small perihelion distance as in the case of P/2008 R1 (Garradd). While the latter is a dynamical characteristic of an object, the former scenario requires a detailed study of the probability of collisions between km-sized MBCs and m-sized bodies. Assuming a size distribution of $N \propto D^n$, $n = -2.5$ for the objects in the asteroid belt, where N is the cumulative number of an object with a diameter D, the number of m-sized projectiles throughout the asteroid belt would be 10^6 times larger than the number of MBCs. In other words, computational simulations of the collision of an MBC with a m-sized object requires extensive integrations of several million objects for tens of millions of years—an outstanding challenging task that requires availability of numerous fast computers.

- **Thermal Modeling** To understand the stability of water ice in MBCs, it is necessary to develop models of the stability of ice for billion years in asteroids throughout the asteroid belt as a function of their orbital parameters and physical properties. This work is needed to show that we have a quantitative grasp on the ice physics, and also on the mechanism by which ice is exposed to space to begin sublimation (e.g., collisions with smaller objects). Such thermal models will also enable us to discuss the depth of the ice, the longevity of the out-gassing, and other crucial factors.

- **Large Scale Surveys** The currently known MBCs are a few km in size. Hsieh et al. (2004) and Hsieh & Jewitt (2006), infer that these objects lose ~ 1 meter per year from their cometary activity. Although the activity is episodic (i.e., at perihelion), this rate of size-reduction suggests a short lifetime for MBCs. In other words, the current MBCs must have started their activities not too long ago. It also suggests that many MBCs might have existed in the past and became inactive, and many more MBCs may exist in the outer asteroid belt that may be on their ways to approach their perihelion distances (where their activity intensifies). Large-scale surveys with telescopes that have the capability of continuously monitoring the sky (e.g., Pan STARRS1) will play an important role in the detection of these objects.

- **Space Mission to an MBC** While MBCs are clearly out-gassing, they are faint targets and unlikely to yield compositional information even to spectrographs on the world's largest telescopes (e.g. Keck 10-m on Mauna Kea). Key insight relevant to gaining an understanding of the role these objects may have played in the origin of volatiles on the terrestrial planets will be best made with in-situ exploration.

References

Bottke, W. F., Levison, H. F., Morbidelli, A., & Tsiganis, K. 2008, LPI Contribution No. 1391, p.1447

Haghighipour, N., 2009, M&PS, Submitted

Hsieh, H. H., Jewitt, D., Fernandez, Y. R. 2004, AJ, 127, 2997

Hsieh, H. H., & Jewitt, D. 2006, Science, 312, 561

Jewitt, D., Yang, B., & Haghighipour, N. 2009, Submitted

Levison, H. F., Morbidelli, A., Van Laerhoven C., Gomes, R., & Tsiganis, K. 2008a, Icarus, 196, 258

Levison, H. F., Bottke, W. F., Gounelle, M., Morbidelli, A., Nesvorn y, D., & Tsiganis K. 2008b, 39 Annual Meeting of DDA, 12.05

Levison, H. F., Bottke, W. F., Nesvorn y, D., Morbidelli, A., & Gounelle, M. 2008c, Asteroids, Comets, Meteorites Conference, Abstract 8156

Morbidelli, A., Levison, H. F., Tsiganis, K., Gomes, R. 2005, Nature, 435, 462