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A Comprehensive Model for Activation of Main Belt Comets

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Abstract

Main Belt Comets (MBCs) are asteroidal bodies with tails similar to those of comets. It has been suggested that the comet-like activity of these *activated asteroids* is due to the sublimation of sub-surface water-ice that is exposed when these objects are impacted by meter-sized bodies. We have developed a comprehensive model for this scenario where using a 3D SPH approach, we simulate collisions between m-sized and km-sized bodies, and determine the probability of ice exposure. Results show that ice is exposed in the bottom and surface of impact craters, and also accrete on the surface of the MBC. Impact craters have depths of ~ 15 m, implying that ice has been located within the top 15 m of the object. This has strong implications for models of ice longevity in the asteroid belt. Results also suggest that the activities of current MBCs are most probably from multiple impact sites. We present the details of our simulations and discuss their implications for the origin of Earth's water.

1. Introduction

Main-belt comets have attracted a great deal of interest since their identification as a new class of bodies by Hsieh & Jewitt in 2006 [1]. Much of this interest is due to the implication that MBCs activity is driven by the sublimation of volatile material (presumably water-ice). Analysis of the orbital evolution of MBCs suggests that these objects are native to the asteroid belt and formed in-situ as the remnants of the break-up of large icy asteroids [2,3]. The latter strongly argues in support of the idea that water-carrying planetesimals and planetary embryos from the outer part of the asteroid belt provided the majority of Earth's water during its formation.

Studies of the mass-loss in MBC 133P, combined with the observation of its recurrent activity from 1996 to 2004 [1,4] suggest that the impact crater(s) on this MBC must have been created by small 1–10 m-sized objects. These impacts excavate sub-surface ices, causing ice to sublimate and create a thin atmosphere and a tail when an MBC comes close to the Sun. In order to understand the nature of the activation of MBCs, and more importantly, to determine where ice is located in these bodies and in their parent asteroids, we have studied these collision processes and their outcomes by simulating impacts between km-sized bodies and m-sized objects using a smooth particle hydrodynamics (SPH) approach. Our SPH code includes material strength, fracture models, and porosity. We have carried out simulations for a large range of parameters allowing m-sized impactors to erode enough of an MBC's surface to trigger its activation. In the following, we discuss our methodology and present the results of our simulations.

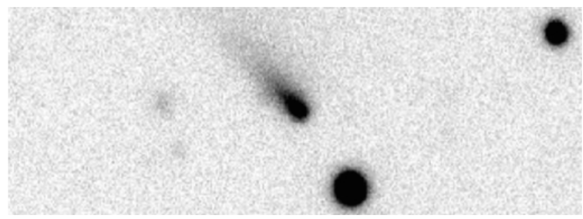

Figure 1: R-band, 90 s image of the MBC P/2008 R1(Garradd) taken UT2008 September 30 at the Keck telescope. A tail of material extends to the northeast from the nucleus of the object [5].

2. Simulations and Results

We have developed a full 3D SPH code capable of accurately simulating collisions of bodies of different sizes [5,6]. Our code includes material strength and self-gravity, and implements full elasto-plastic continuum mechanics. Fracture and brittle failure are treated using the Grady–Kipp fragmentation prescription. Our code also includes the p-alpha model for porosity with a time-varying α [7], and accounts for evaporation during the impact as well as the re-accretion of scattered materials.

To simulate collisions, we considered targets ranging from very soft (e.g., tuff) to very hard (e.g., basalt) with water contents varying from 0 to 50%. Given that

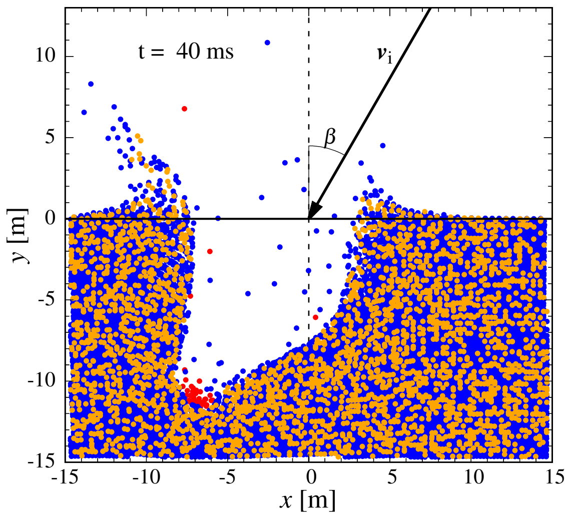

Figure 2: Impact crater for 4.4 km/s impact velocity.

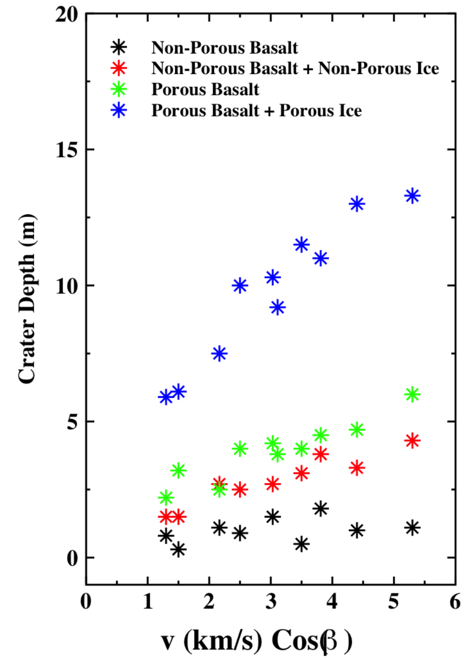

Figure 3: Graph of the depths of impact craters in terms of impact velocity for porous and non-porous targets, and with different water contents [9].

both the target and the projectile originate from the asteroid belt, we considered impact velocities in the range of 2.5 km/s to 5.3 km/s with the most probable value being around 4.4 km/s. The impact angle was varied between 0° (head-on) and 60°. We resolved the combined system of the impactor and target into ∼500,000 SPH particles. Because compared with the time of the influence of the gravitational force of the target body, the impact timescales are very short, we simulated collisions without self-gravity [8]. To analyze the evolution of the system during each impact, we took 100 snapshots every 1 ms. In between snapshots, time integration was continued with an adaptive step-size.

Figure 2 shows a snapshot of the final crater for an impact velocity of 4.4 km/s and an impact angle of 30°. The target is a mixture of 50% porous basalt (orange) and 50% porous water-ice (blue), and has a 50% water-mass fraction. As shown here, water-ice is exposed in the interior part of the impact crater and is also scattered out due to the impact [9,10].

Figure 3 shows the depth of impact craters for different material and water contents. As shown here, for the range of impact velocities corresponding to those in the asteroid belt, the depth of an impact crater is slightly below 15 m [9,10]. This indicates that in these bodies and in their parent asteroids, water-ice is located in the top 15 m, and as suggested by [11], has survived for the age of the solar system.

3. Conclusions

1) Impacts of small bodies present a viable mechanism for exposing sub-surface volatiles. 2) Water-ice is within the top 15 m. 3) The loss of ice due to the heat of impact is negligible. 4) Most of the ejected ice particles are lost and not re-accreted. 5) Activation of MBCs is most probably from multiple impact sites. 6) The water content of MBCs has to be larger than 20% in order be able to account for the observed activation of MBCs [9,10].

4. References

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