

TRIGGERING THE ACTIVITY OF MAIN BELT COMETS. T. I. Maindl¹, N. Haghighipour², C. Schäfer³, R. Speith⁴, and R. Dvorak¹, ¹Department of Astrophysics, University of Vienna, Austria (thomas.maindl@univie.ac.at), ²Institute for Astronomy, University of Hawaii-Manoa, HI, USA (nader@ifa.hawaii.edu), ³Institut für Astronomie und Astrophysik, Eberhard Karls Universität Tübingen, Germany, ⁴Physikalisches Institut, Eberhard Karls Universität Tübingen, Germany.

Introduction: Main-belt comets (MBCs) have attracted a great deal of interest since their identification as a new class of bodies by Hsieh and Jewitt in 2006 [1]. Much of this interest is due to the implication that MBC activity is driven by the sublimation of volatile material (presumed to be water-ice) presenting these bodies as probable candidates for the delivery of a significant fraction of Earth's water. Results of the studies of the dynamics of MBCs suggest that these objects formed in-situ as the remnants of the break-up of large icy asteroids. Simulations also show that collisions among MBCs and small objects could have played an important role in triggering the cometary activity of these bodies. Such collisions might have exposed sub-surface water-ice which sublimated and created thin atmospheres and tails around MBCs. Earlier dynamical studies established collision statistics of km-sized objects such as MBC candidates with m-sized boulders in the asteroid belt [2]. In order to drive the effort of understanding the nature of the activation of MBCs, we have investigated these collision processes by simulating the impacts in detail using a smoothed particle hydrodynamics (SPH) approach that includes material strength and fracture models. We have carried out simulations for a range of impact velocities and angles, allowing m-sized impactors to erode enough of an MBC's surface to trigger its activation. In the following, we present the results of our simulations and discuss their implications for the activation of MBCs.

Water Distribution Inside MBCs: While the source of the activity of MBCs is presumed to be the sublimation of water-ice, the distribution of water inside these bodies is still not entirely understood. [3] suggest that H₂O can only exist at a depth of about 50 to 150 m beneath the surface of an MBC whereas [4] has shown that water ice can actually stay within the top few meters just under a thin dusty surface layer. A possible mechanism to trigger the activation of MBCs is the micro-impacts of meter-sized bodies onto water-rich kilometer-sized asteroids (e.g., [5], [1]). In that respect, two fundamental questions arise:

1) What is the typical depth of an impact crater in a collision between a meter-sized object and a km-sized body for typical impact energies in the asteroid belt?

2) Can such impacts result in the exposure of sub-surface water-ice?

Simulations: We simulated the collision of a meter-sized rocky projectile with a km-sized target. To explore the dependence of the depth of the produced crater on the water content of the target, we considered two different scenarios: a target with a water-mass fraction of 5%, similar to those considered by Raymond et al. ([6], [7]) and Izidoro et al. ([8], [9]) in their simulations of terrestrial planet formation, and a target consisting of only solid rock.

Given that both the target and the projectile originate from the asteroid belt, we consider impact velocities in the range of 2.5 km/s to 5.3 km/s following [10] who found the mean impact velocity to be 5.3 km/s with the most probable value being around 4.4 km/s. The impact angle α is varied between 0° (head-on) and 60°.

For the simulations we use a 3D smoothed particle hydrodynamics (SPH) code that includes material strength. Our code ([11], [12]) implements the full elasto-plastic continuum mechanics and includes the Grady-Kipp fragmentation model for treating fracture and brittle failure ([13], [14]). A tensorial correction warrants first-order consistency [15]. The subjects were resolved into approximately 500,000 SPH particles and 250–500 snapshots were taken every 0.4 ms per scenario. Projectile and target material constants were those for basalt (rock) and water-ice (Tillotson equation of state and Weibull flaw distribution, see [12] and references therein).

Results: Figure 1 shows snapshots of a typical simulation of a rocky projectile colliding with the surface of an asteroid. Across the scenarios, the velocities were varied between 2.5 km/s and 5.3 km/s, and the projectile radii were chosen to be 0.5 and 1 m. Accordingly, the resulting impact energies Q were in the interval of $\sim 4.4 \times 10^7$ J (1 m projectile @ 250 m/s) to $\sim 1.6 \times 10^{11}$ J (2 m projectile @ 5.3 km/s).

As expected, we observe significantly different crater depths depending on the impact energy and the impact angle. Figure 2 shows the aggregated crater depth data from our simulations with blue diamonds representing impacts on targets with 5% water-ice and red crosses those on pure rocky targets. There is a clearly notable spread due to different impact angles

and evidence of higher water ice content causing deeper craters due to less overall material strength.

Conclusions: Our simulations show that for all values of impact velocity and angle, crater depths are only a few meters. None of our simulations produced craters 50 m or deeper. Our results imply that if the activity of MBCs is due to the sublimation of water-ice, water has

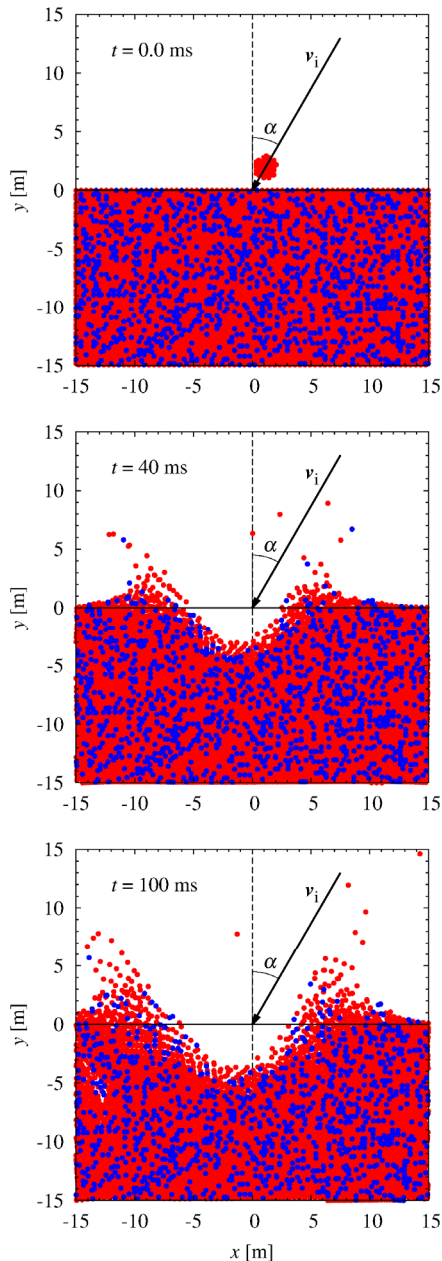


Figure 1. Simulation snapshots of a rocky (basalt) 2 m projectile colliding with the surface of an asteroid with 5% water uniformly distributed throughout its volume as ice inclusions (blue dots). The impact velocity and

angle are $v_i = 5.3$ km/s and $\alpha = 30^\circ$, respectively. This is a 2D section of a 3D simulation.

to be no deeper than a few meters. This is consistent with the model by [4]. Future studies will include carrying out simulation for different values of water/rock ratio, including water-loss due to the energy of impact, and tracing ejected material with respect to both possible escape from the target and re-accretion of especially eroded water ice.

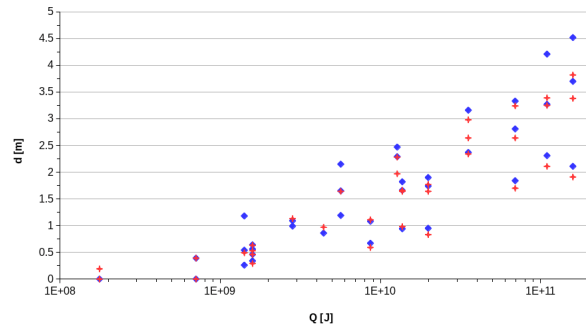


Figure 2. Variations of crater depth (d) in terms of the energy of impact (Q) due to different impact angles, impact velocities, and the size of the target. Depending on Q , uncertainties due to the SPH method are about 0.6 m ($Q \leq 5 \times 10^{10}$ J) or 0.9 m ($Q > 5 \times 10^{10}$ J). Red crosses and blue diamonds correspond to pure rock and 5%-water targets, respectively. Crater depths for $Q < 10^8$ J are below resolution.

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