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Cratering processes on rubble-pile asteroids: insights from laboratory experiments and numerical models

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NASA's Double Asteroid Redirection Test (DART) will impact the moon of Didymos, Dimorphos, and alter its orbital period around the primary, thus demonstrating the controlled deflection capabilities of near-Earth asteroids by a kinetic impactor [1, 2]. ESA's Hera mission [2] will arrive at Dimorphos several years after the DART impact and provide a detailed characterisation of the impact outcome, including the morphology of the DART impact crater.

Recent impact experiments and numerical studies [3, 4, 5] have shown that the kinetic impact efficiency strongly depends on the target properties, and is non-unique (i.e., impacting asteroids with different properties can result in the same deflection). Therefore, for a successful interpretation of the DART impact outcome, it is important to understand the influence of asteroid properties to the cratering process. Moreover, small asteroids, of less than about 10 km in diameter, are believed to be rubble-pile objects, aggregates held together only by self-gravity or cohesive forces [6]. It is also likely that Dimorhpos is not homogeneous at the scale of the DART impact and the target structure will influence the momentum enhancement and the crater morphology resulted from the impact.

Here we present new modelling results aimed at assessing the momentum transfer and the crater morphology resulted from DART-like impacts on rubble-pile asteroids.

We use Bern's Smoothed-particle hydrodynamics (SPH) shock physics code [7, 8], which is well suited to model high velocity impacts on heterogeneous asteroids. The code includes material models

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relevant for geological materials, various equations of state and a porosity compaction model, the $P-\alpha$ model.

Efforts to model rubble-pile geometries in the context of DART are undertaken [9], however these results have not yet been validated against laboratory experiments. To increase the confidence in our numerical model, we first performed validation tests of impacts into heterogeneous targets, against recent laboratory experiments performed at the Experimental Projectile Impact Chamber (EPIC) at Centro de Astrobiología CSIC-INTA, Spain [10, 11]. The EPIC facility was used to perform a vertical shot into a target of porous ceramic balls in a matrix of beach sand, at about 400 m/s. The EPIC utilises a 20 mm calibre compressed N2 (300 bar) cannon and here it used a quarter-space geometry.

The impact generated a crater about half the diameter of a reference crater in a homogeneous beach sand target. However, the reduced cratering efficiency may be also enhanced by the fact that the project hit straight on the boulder placed at the centre of the target. Boulders placed in immediate proximity to the impact point were ejected and created ‘rays’ in the ejecta blanket. Boulders placed more than about 3 boulder diameters away from the impact point were displaced towards the crater rim.

SPH simulations were able to accurately reproduce the crater formation and the ejecta curtain evolution. Our validated SPH rubble-pile structure model will be applied in simulations of global scale effects of DART-like impacts on small asteroids with heterogenous interiors.

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