INFLUENCE OF TARGET HETEROGENEITY ON CRATER FORMATION: INSIGHT FROM LABORATORY AND NUMERICAL STUDIES. J. Ormö[1], S.D. Raducan[2], R. Luther[3], M.I. Herreros[1], G.S. Collins[4], A. Losiak[5,6], K. Wünnemann[3,7], M. Jutzi[2] and M. Mora-Rueda[1]. [1]Centro de Astrobiologia CSIC-INTA, Spain (ormoj@cab.inta-csic.es); [2]Space Research and Planetary Sciences, University of Bern, Switzerland; [3]Museum für Naturkunde Berlin, Leibniz Institute for Evolution and Biodiversity Science, Germany; [4]Department of Earth Science Engineering, Imperial College London, UK; [5]WildFire Lab, University of Exeter, UK; [6]Institute of Geological Sciences, Polish Academy of Sciences, Poland; [7]Freie Universität Berlin, Germany.

Introduction: NASA's Double Asteroid Redirection Test (DART) will impact the smaller component of the 65803 Didymos asteroid system, 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 characterization of the impact outcome, including the morphometry and morphology of the crater. Recent impact experiments and numerical studies [3–5] have shown that the kinetic impact efficiency depends strongly on the target properties and structure, and is non-unique (i.e., impacting asteroids with the same properties can result in different deflection). Therefore, for a successful interpretation of the DART impact outcome it is important to understand the influence of asteroid properties on the cratering process. Moreover, the DART impact outcome analysis will be based on numerical models, which require extensive and accurate prior validation.

Most previous impact experiments and the subsequent validation work of numerical models have focused on homogeneous targets [e.g., 6, 7]. However, it is unlikely that Dimorphos is homogeneous at the scale of DART impact. Here we present preliminary results from impact experiments and numerical simulations specifically designed to mimic asteroid surface materials and structures (e.g., layered targets, rubble piles). The experiments are performed at the Experimental Projectile Impact Chamber (EPIC) at Centro de Astrobiología CSIC-INTA, Spain.

Methods: The EPIC utilizes a 20 mm calibre compressed N_2 (300 bar) cannon that launches projectiles at velocities up to ≈420 m/s and at angles of 20– 90◦ from horizontal [8]. The experiments, half- or quarter-space, are recorded with high-speed cameras and the resulting crater profiles are scanned in 3D with 0.5 mm resolution. Here we use the iSALE-2D [9] and the Bern SPH [10] shock physics codes to simulate the laboratory experiments. Both iSALE-2D and SPH include material models suitable for geological materials, various equations of state and porosity compaction models. Here we compare numerical models with impact experiments into targets with three different structures: homogeneous, layered and heterogeneous.

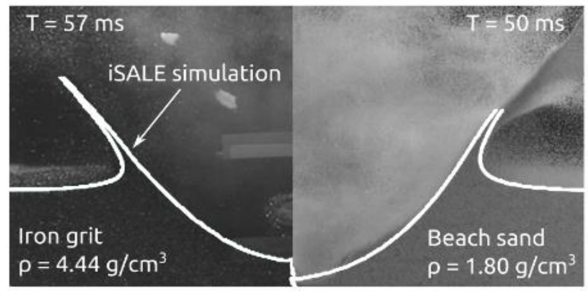

Figure 1: Crater profiles captured during crater formation after impacts of EPIC shots at ≈400 m/s into iron grit sand (left) and beach sand (right). iSALE-2D simulation profiles are plotted on top (white line) and show good agreement with the experiments.

Results and discussion:

1. Vertical impacts into homogeneous targets. These impact experiments were performed into dry beach sand and iron grit targets and the results are used to validate the ejecta curtain formation and crater size from 2D numerical models into homogeneous targets (Fig. 1). This setup is also used as reference for comparison with more complex target settings.

2. Layered targets. Recently visited asteroids (e.g. Itokawa, Ryugu) have been observed to have a layered structure (i.e., a layer of regolith overlying a much stronger and denser substrate). The effects of target layering on impact cratering in the strength regime have been studied extensively through laboratory experiments [e.g., 11] and simulations [e.g., 12]. However, it is possible that Dimorphos has a granular cohesionless upper layer and that cratering in this layer is gravity-controlled, much like Hayabusa2's SCI experiment [13]. Little is known of the effects of layering in the gravity regime, however it is likely that the momentum transferred from the DART spacecraft can be both amplified or reduced, depending on Dimorphos's layering configuration [12]. We carry out experiments with layers of different density (i.e., beach sand over iron grit) to simulate gravity-controlled cratering in layered targets. While much of the kinetic energy of the projectile is released in the weaker upper target, this material also requires relatively less energy to be cratered resulting in a concentric crater morphology. This crater morphology is well reproduced by iSALE-2D numerical models (Fig. 2).

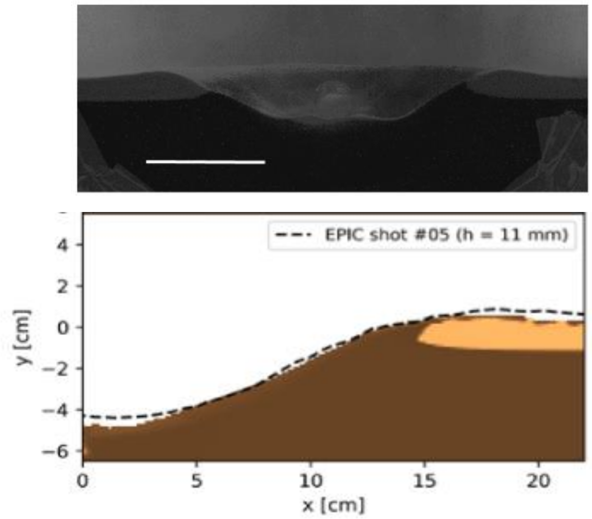

Figure 2: Top: Final crater morphology from EPIC impact experiment into beach sand layer (light shade) of thickness h = 11 mm, over iron grit substrate (dark shade). Scale bar is 10 cm. Bottom: Crater morphology from iSALE-2D simulation compared to the surface profile from the EPIC experiment (dashed line).

3. Complex target structures/Rubble piles. Variations in strength and density also occur in greatly heterogeneous objects such as 'rubble-pile' asteroids. An irregular crater growth and, consequently, irregular ejection of material affect the asteroid deflection (e.g. unpredictable motions). Such irregularities are difficult to model numerically and require full 3D geometry, which is computationally expensive. Nevertheless, efforts to model rubble pile geometries in the context of DART are undertaken [14] and laboratory experiments are highly needed to validate such models. We have performed a shot into a target of porous ceramic balls (simulating "boulders") of approximately equal size and weight as the projectile in a matrix of beach sand. This 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 projectile hit straight on a ball, which was crushed to dust. Balls placed in immediate proximity to the impact point were ejected and 'rays' were created in the ejecta blanket (Fig. 3A&B). Balls placed at about 3 ball diameters away from the impact point were displaced towards the crater rim (Fig. 3B). This impact experiments represents the first step towards understanding the importance of heterogeneities in the cratering process and impact momentum transfer. SPH simulations aimed at reproducing this impact experiment are underway and preliminary results of the early cratering process show good agreement with the experiment.

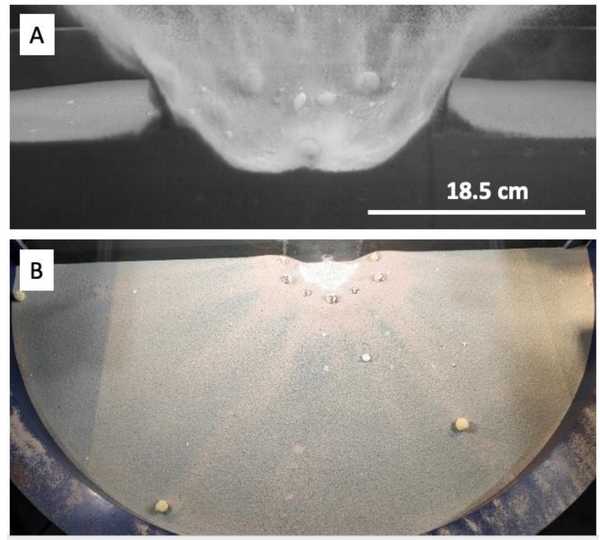

Figure 3: EPIC 'rubble pile' experiment. A) Transient crater. Note interaction between balls and ejecta curtain. B) Final crater, view from above. The ball placed at the impact point gets crushed, the balls next in line get ejected (near border of tank), and the balls next in line get excavated to the crater rim. Note the ejecta 'rays'

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References: [1] Cheng, A. F. et al. (2018) Planet. Space Sci, 157:104–115. [2] Michel, P. et al. (2018) Adv Space Res. 62:2261–2272. [3] Housen, K. R. & Holsapple, K. A. (2011) Icarus, 211:856–875. [4] Jutzi, M. & Michel, P. (2014) Icarus, 229:247–253. [5] Raducan, S. D. et al. (2019) Icarus, 329:282–295. [6] Wünnemann, K. et al. (2016) Meteorit. Planet. Sci, 51:1762–1794. [7] Luther, R. et al. (2018) M&PS 53 (8), 1705-1732. [8] Ormö, J. et al. (2015) Meteorit. Planet. Sci, 50:2067–2086. [9] Wünnemann, K. et al. (2006) Icarus, 180:514–527. [10] Jutzi, M. et al. (2008) Icarus, 198:242–255. [11] Quaide, W. L. & Oberbeck, V. R. (1968) J. Geophys. Res. 73:5247–5270. [12] Raducan, S. D. et al. (2020) PSS, 180:104756. [13] Arakawa, M. et al. (2020) Science, 368:67–71. [14] Stickle, A. M. et al. (2018) LPSC XLIX, 49:1576.