DEFORMATION OF SMALL ASTEROIDS BY IMPACTS AND IMPLICATIONS FOR NASA'S DART MISSION

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Introduction: NASA's Double Asteroid Redirection Test (DART) impact [1, 2] on asteroid Dimorphos (the smaller component of the 65803 Didymos system) will occur on September 26th, 2022. The aim of the mission is to alter the orbital period of Dimorphos around Didymos, which will demonstrate the capabilities of the kinetic impactor as an asteroid mitigation strategy. ESA's Hera mission [3] will arrive at Dimorphos about four years after the DART impact and will perform a detailed characterisation of Dimorphos and of the DART impact outcome.

Past studies of the outcome of small-scale impacts on asteroid surfaces [e.g., 4–7] have shown that the impact outcome strongly depends on the surface, subsurface and internal properties. Small asteroids are often considered to be rubble-pile objects, aggregates held together only by self-gravity or small cohesive forces [8, 9]. Moreover, recent results from the SCI impact on Ryugu [10] suggest that impacts on its surface might be controlled to a large extent by its weak gravity rather than strength. These findings might also be applicable to the DART impact.

The aim of this work is to numerically simulate DART-like impacts on small asteroids with varying realistic surface material properties and interior structures. We study the consequences of such impacts on the physical evolution of small asteroids and make predictions of the outcome of the DART impact (e.g., ejecta formation, deflection efficiency, crater morphology or degree of global deformation).

Numerical Model: We use the Bern SPH impact code [11, 12] to model DART-like impacts (≈ 500 kg projectiles at 6 km/s) on spherical asteroid targets and track the evolution of the target for up to 2 hours after the impact. Recently, the code has been validated against laboratory experiments of impacts into heterogeneous, rubble-pile-like targets [9].

To quantify the effects of the target properties and structures on the post-impact morphology and degree of shape change, we considered the following target scenarios: 1) Homogeneous spherical targets with varying cohesion (Y_0 = 0 to 50 Pa) and varying coefficient of internal friction (f = 0.4 to 1.0); 2) Rubble-pile spherical targets with different distributions of boulders, embedded into a cohesionless (Y_0 = 0 Pa) matrix material.

Results and discussion: The size and morphology of the DART crater is of paramount importance for determining the asteroid's near-surface properties and structure. We find that the mechanical strength properties of small asteroids are crucial for their physical evolution. With decreasing target cohesion, more material is displaced or ejected above escape speed. Our results show that even a small amount of cohesion (10 Pa) can dramatically affect the outcome of an impact on a small body in terms of the post-impact target morphology and the production of low velocity ejecta. DART-like impacts into both cohesionless homogeneous targets and rubble-pile targets scenarios produce morphologies that are dissimilar to cratering. The cratering efficiency is so large that the impact changes the global shape of the asteroid.

Initial results from our impact simulations into rubble-pile targets suggest that large boulders (up to ≈ 10 m in diameter, corresponding to $\approx 10^4\times$ projectile's mass) can be ejected from the target, mostly intact. In the case of the DART impact on Dimorphos, such boulders either leave the asteroid system, either orbit the system, or land on Didymos or back on Dimorphos. The ejection of large intact boulders by small scale sub-catastrophic collisions may have important implications for the structure of small asteroids (i.e., the abundance of rubble-pile vs. monolithic objects among the small asteroid population). Our modelling results together with future observations by the Hera mission will provide constraints regarding the evolution of the shapes and structures of small asteroids by sub-catastrophic impacts.

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