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DYNAMICS OF EJECTA PLUME AFTER THE DART IMPACT ON DIMORPHOS

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Extended Abstract—

The Double Asteroid Redirection Test (DART) is a NASA mission planned to be launched in late 2021/early 2022 and to perform a high-velocity impact on the surface of asteroid Dimorphos, the smaller component of the Didymos binary system, in September/October 2022 (Cheng et al. 2016). DART is part of the Asteroid Impact and Deflection Assessment (AIDA) international collaboration, along with ESA's Hera mission, which is planned to visit Didymos in 2027 (Michel et al. 2018).

We address the problem of dynamical evolution of the ejecta plume shortly after the DART impact on Dimorphos. The goal of this work is to assess the effects of contact and gravitational interactions between ejecta fragments in the gravity regime, using *N*-body simulations. In particular, we are interested in fragments that do not immediately escape the Didymos system after the DART impact. Toward this goal, we focus on "slow" ejecta only, with an upper cut-off at 50 cm/s. This is consistent with current estimates of ejecta captured within the Didymos system after the DART impact (Yu & Michel 2018).

We study the dynamics of ejecta fragments using GRAINS (Ferrari et al. 2017, Ferrari et al. 2020), an *N*-body Discrete Element Method (DEM) code, based on the multi-physics library Chrono (Tasora et al. 2016). The translational and rotational dynamics of each ejecta fragment is integrated as a 6-DOF non-spherical rigid-body. Each fragment interacts within the Didymos environment and with other ejecta particles through gravity, collisions and contact forces. The gravitational environment considers self-gravity between ejecta particles, as well as the gravity of Dimorphos and Didymos (primary asteroid). From a gravitational point of view, asteroids and ejecta fragments are modeled as point masses. The non-spherical shape of fragments and the shape models of the two asteroids (Naidu et al 2020) are used to compute collisions and contact interactions. The non-spherical shapes of fragments are generated randomly for each particle as a convex hull envelope of a cloud of 16 randomly generated points. These points are generated within a spherical domain, resulting in angular fragments with, on average, 10 vertices each. Contact interactions are modeled using SMC (smooth-contact dynamics), a soft-contact approach that models forces at contact points using tangential and normal spring-dashpot systems (Fleischmann et al 2015). Coulomb friction is also modeled at contact points, which are identified at each integration time step between particles of non-spherical shape.

To model the properties of the ejecta plume moments after the DART impact, the DEM simulations start from initial conditions provided by Smoothed-Particle Hydrodynamics (SPH) shock physics simulations. These simulations are performed using the Bern's SPH code (Benz & Asphaug 1995, Jutzi et al. 2008, Jutzi & Michel 2014, Jutzi 2015). The information exchanged between SPH and *N*-body include position, velocity and mass distribution of fragments within the ejecta plume.

SPH: hypervelocity impact and ejecta formation

We study two different cases, each represented by a different set of initial conditions, both related to the DART/Dimorphos scenario. SPH simulations are performed to reproduce DART-like head-on impacts on weak, spherical targets (Raducan & Jutzi 2021).

Table 1: Parameters of SPH simulations

Projectile parameters			**Target parameters**		
Radius	Mass	Velocity	Cohesion	Friction	Density
0.5 m	500 kg	6 km/s	0, 10 Pa	0.6	1.62 g/cm^3

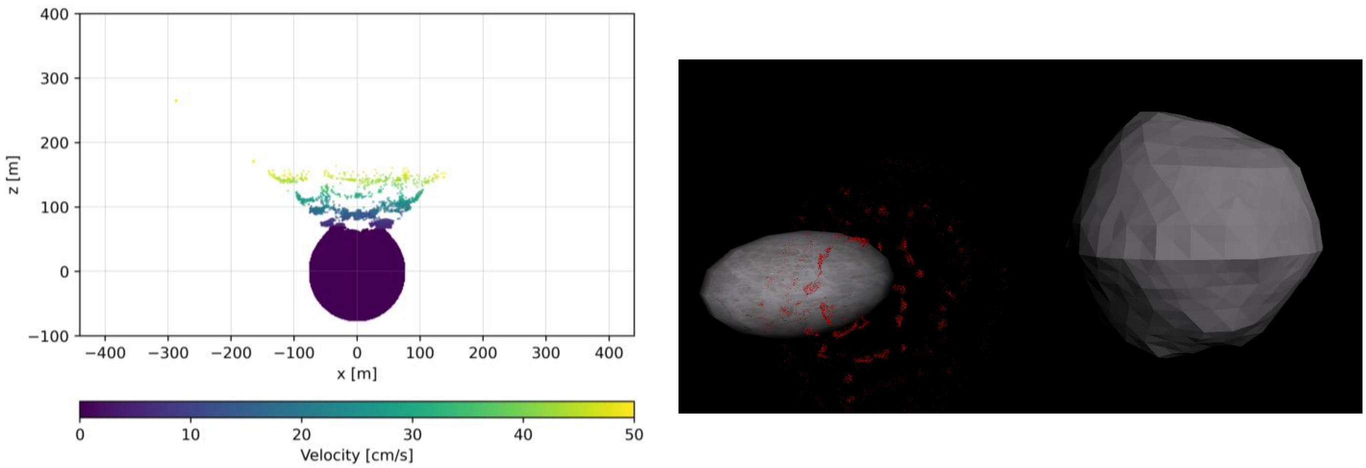

Figure 1: SPH/N-body handoff. Ejecta at the end of SPH simulation (left); ejecta rendered in GRAINS (right).

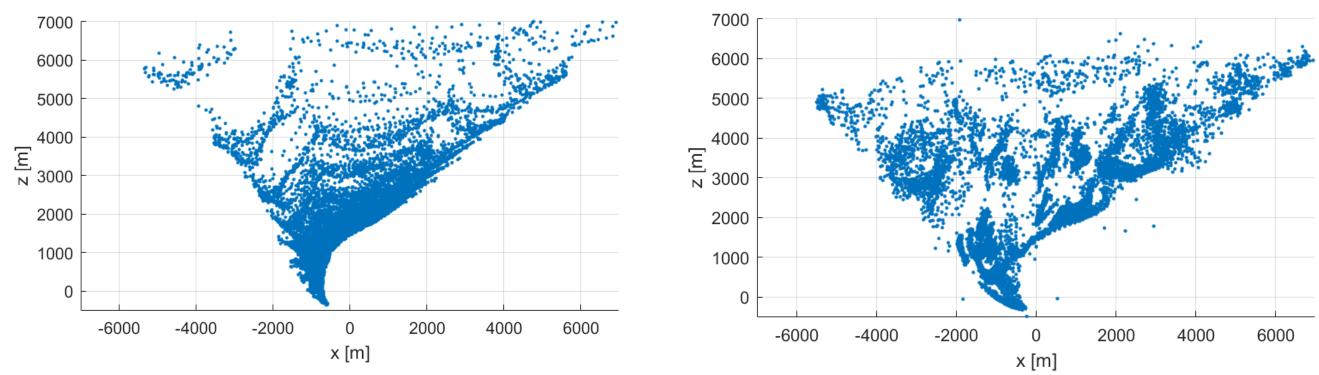

Figure 2: Ejecta evolution 4 h after impact. 0 Pa case (left) and 10 Pa case (right). Both figures shows the projection of the ejecta curtain on the x-z plane, i.e., Dimorphos orbital plane (as well as Didymos equatorial plane). The frame is centered at the barycenter of Didymos system. Asteroids are not shown here: they are located approximately near the origin (Didymos) and at point [x=600m, z=1000] (Dimorphos).

The projectile and target parameters are summarized in **Errore. L'origine riferimento non è stata trovata.**. As for the surface density of the target, we assume basalt (2.65 g/cm^3) and a typical value of 40% for the microporosity. The two simulations differ by the level of material cohesion, which is null in the first case and equal to 10 Pa in the second case.

The handoff between SPH and N-body simulations is performed 5 minutes (10 Pa case) and 15 minutes (0 Pa case) after the DART impact. The handoff time is representative for the transient morphology of the target: in this case it is the time when no more ejecta with velocities higher than 5 cm/s is produced, and the ejected particles are now affected by gravity only. In particular, the 10 Pa case shows clumped structures in the ejecta cone, while the 0 Pa case shows a more uniform density distribution of ejecta. SPH particles are directly transformed into DEM particles, as their mass and density are kept constant. Note that cohesion is not handed over to the *N*-body simulation, where particles are cohesionless in both simulation scenarios. Figure 1 shows the handoff conditions for the case at 10 Pa: the left image shows the SPH ejecta and target, while the right image shows how they are rendered in GRAINS (ejecta are shown in red to improve visibility of small particles).

N-body: ejecta evolution in the gravity regime

Preliminary results show that mutual interactions between ejecta particles have a very relevant effect on their short- to medium-term evolution. In particular, we observe non-spherical particles to have a lower global restitution coefficient, in terms of linear relative velocity, due to non-central collisions. In this case, the translational energy is converted into spin energy of the single fragments (Movshovitz et al 2012, Ferrari & Tanga 2020). In this context, higher density structures are more likely to be formed within the ejecta cone. This affects the evolution of ejecta and might affect their long-term fate. Also, heterogeneous density regions within the ejecta cone affects the optical properties and observability of the plume shortly after the DART impact.

We integrate the dynamics of the ejecta up to several hours after the impact. We observe that initially clumped structures of the 10 Pa simulation case give rise to radially-shaped and randomly distributed features in the ejecta curtain. This is not observed in the 0 Pa simulation case, where the density distribution is more uniform. This is clearly shown in Figure 2 (4 h after impact), where differences between 0 Pa case (left) and 10 Pa case (right) are observed.

In terms of ejecta fate and evolution, both simulation sets show that slower ejecta remains trapped in the system. In particular, we observe material falling onto the Didymos (primary) surface about 5–6 h after the impact (curly structure near the origin of Figure 2).

In summary, we performed a numerical investigation to study of the short- to medium-term evolution of ejecta resulting from the DART impact. We developed the interface and handoff procedure between SPH simulations – used to reproduce impact shock physics – and *N*-body DEM simulations – used to propagate the dynamics of the ejecta in the gravity regime, as they interact with Didymos/Dimorphos gravity field and mutually through self-gravity and contact/collisions. The preliminary test cases show a different behavior of fragments ejected from a target with cohesion compared to a cohesionless one. As follow up study we plan to extend the range of parameters studied, including new target properties.

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