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**NEOSHIELD: THE FATE OF EJECTA FROM A KINETIC IMPACTOR STRIKE ON
A NEAR-EARTH OBJECT**

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ABSTRACT

The study of motions of granular material lofted at low speeds from the surface of a small body as the result of a hypervelocity impact has been left largely unexplored to date. The speeds of such material might be comparable to the escape speed of the body, e.g., five orders of magnitude below the impactor speed for a 150-m diameter target with bulk density 1.3 g/cm³ impacted at 6 km/s. The NEOShield Project, funded by the European Commission in its FP7 program, is primarily, but not exclusively, a European consortium of research institutions that aims to analyze promising mitigation options and provide solutions to the critical scientific and technical obstacles involved in confronting threats posed by small bodies that cross Earth's orbit. An important component of the work packages is the design a general NEO defense strategy based upon momentum transfer via kinetic impact (Harris et al., 2013, *Acta Astronautica* 90, 80). Relatedly, AIDA is a joint NASA-ESA mission in Phase A/B1 study comprising the NASA Double Asteroid Redirection Test (DART) mission, which is to act as a test of our ability to deflect the small natural satellite of the binary near-Earth asteroid (65803) Didymos using a kinetic impactor, and the ESA Asteroid Impact Monitor (AIM) rendezvous mission, an observer spacecraft that would characterize the target and the impact outcome. In order to address concerns over potential observational and mechanical effects of lingering dust and debris, information about the ejecta produced by such an impact is of particular importance to the mission profile of an observer satellite (e.g., AIM). Here we discuss some of the details of the numerical issues involved in assessing the ejecta fate in the framework of a hypervelocity kinetic impactor approach to NEO threat mitigation as part of a specific work package of NEOShield, and with the AIDA framework in mind.

We thus define a set of procedures to assess numerically ejecta fates in the framework of hypervelocity kinetic impactors. The approaches we explore are

varied, allowing for comparisons between our methodologies. We use the *N*-Body code PKDGRAV (Stadel, 2001, *Ph.D. thesis*, U. of Washington; Richardson et al., 2000, *Icarus* 143, 45) outfitted with a soft-sphere collisional routine (Schwartz et al., 2012, *Granul. Matter* 14, 363) to perform the bulk of the numerical work. Ultimately, we will construct a database outlining the effects of different impact conditions and gravitational environments on ejecta outcome. These results may be used in space mission studies to examine the fate of certain-sized ejected grain fragments and regolith based on impact conditions in order to assess the risks posed to the spacecraft and the expected momentum transfer efficiency to the asteroid target.

In order to generate an ejecta field, the late-stages of the impact phase must be solved; we do so in three different ways and compare the results: by using a hydrocode to compute the impact outcome (Jutzi & Michel, 2014, *Icarus* 229, 247; Figs. 1 & 2), solving for the initial ejecta positions and velocities using known scaling laws (Housen & Holsapple, 2011, *Icarus* 211, 856; Fig. 3), and by using an *N*-Body approach to compute the impact (Schwartz et al., 2014, *Planet. Space Sci.* 103, 174; Fig. 4) as well as the resulting ejecta field. Each approach has its own unique strengths and limitations, which will be addressed. In each case, self-gravitating particles are used with a massive particle embedded in the center as proxy for the asteroid mass.

Between the European Commission-funded NEOShield consortium (EC-FP7, #282703) and the AIDA concept study, approved by both ESA and NASA for Phase A, there exists great international interest in performing a deflection study. Results will be shown in the context of an impact into a single asteroid (NEOShield). It will also be shown how this work is being applied in the context of an impact into the secondary of a binary asteroid system (AIDA).

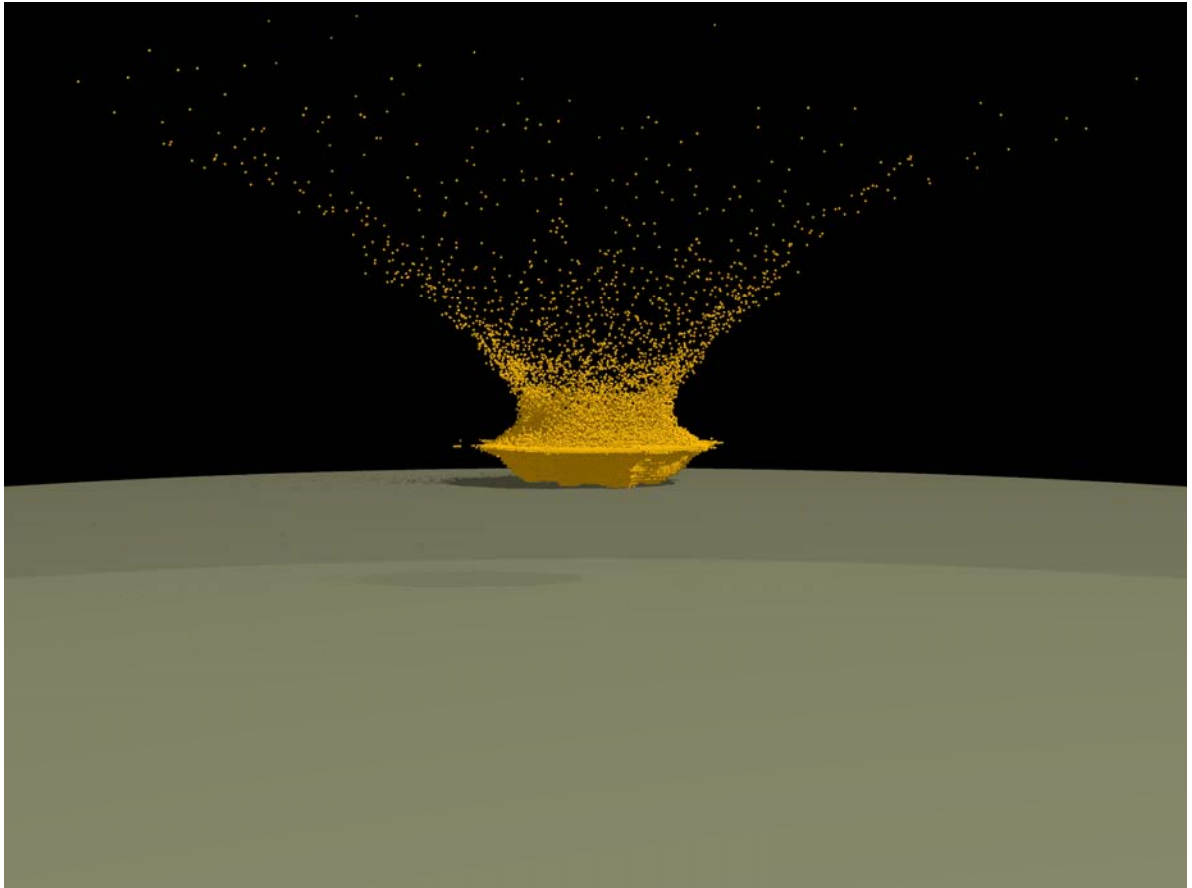


Fig. 1. Initial positions of those particles moving with +z velocity and with initial angles of trajectory above 10° from the surface after the hypervelocity impact phase for one of the ejecta-evolution simulations involving a 7.5 km asteroid target. We place the ejecta material just above a large sphere that represents the asteroid surface. Although in reality, the impact surface should be flush to the surface of the sphere, we take care that the material remains realistically close to the surface.

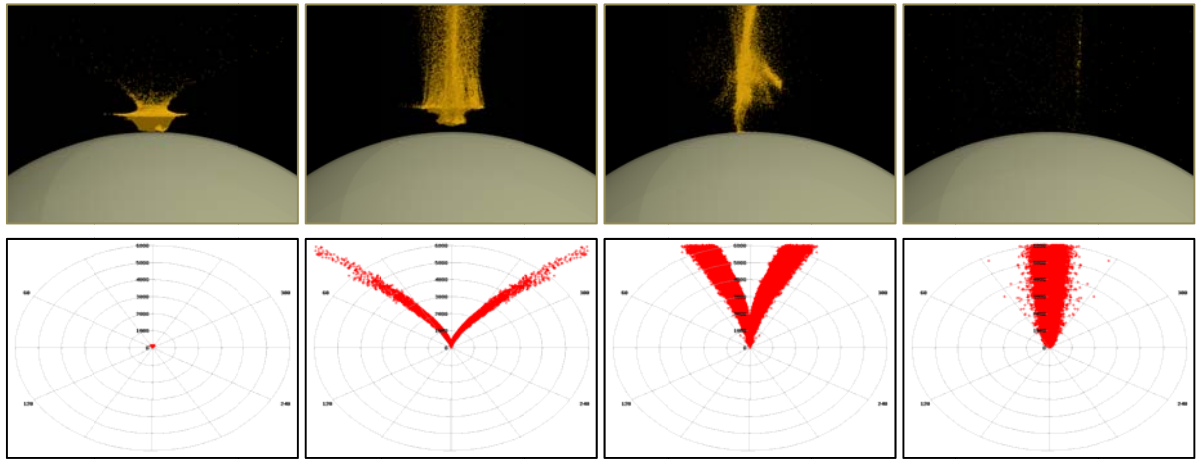


Fig. 2. Positions of individual ejecta grains after a simulated hypervelocity impact on a 150-m bounded target (notice the curvature of the target compared with the 1.5-km target of Fig. 1). Top row: ray-traced images near the impact point; the images are centered on the point of impact. Bottom row: corresponding polar plots showing particle positions (red points) with concentric circles every 1 km of simulated space; azimuthal positions are not shown and the plots are centered on the asteroid center. In all images, the impact trajectory is downward (z-axis points up). Snapshots progress in time from left to right, with the first frame corresponding to the SPH/PKDGRAV handoff 0.16 s post-impact; the second frame is taken at 100 s; the third at 1 ks; and the final frame depicted here at 10 ks.

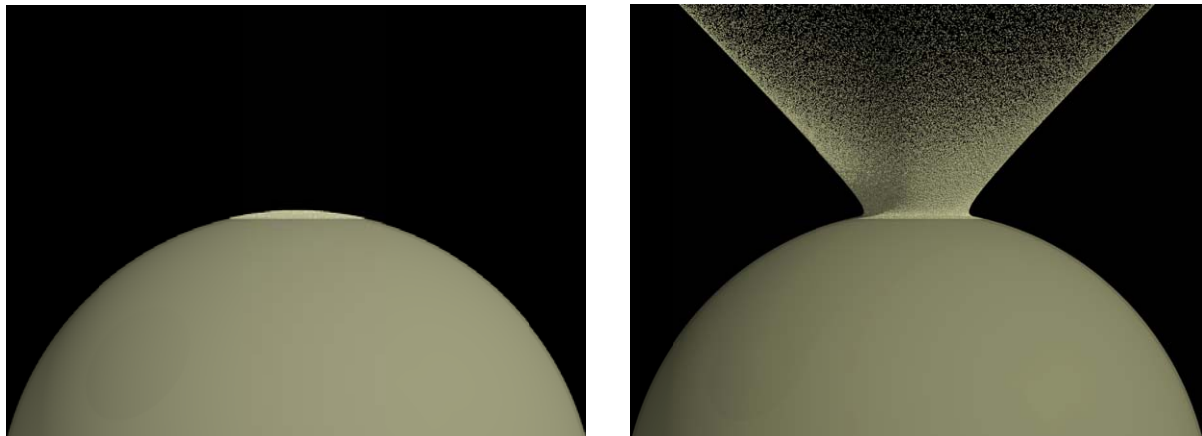


Fig. 3. The start (left frame) of an N -body simulation using ejecta particle velocities solved for with scaling laws from Housen & Holsapple (2011): a bowl of 641,586 particles representing a portion of the surface of an asteroid that suffers a kinetic impactor strike is embedded into the surface of a sphere that represents the entire asteroid; the particles are then ejected (right frame).

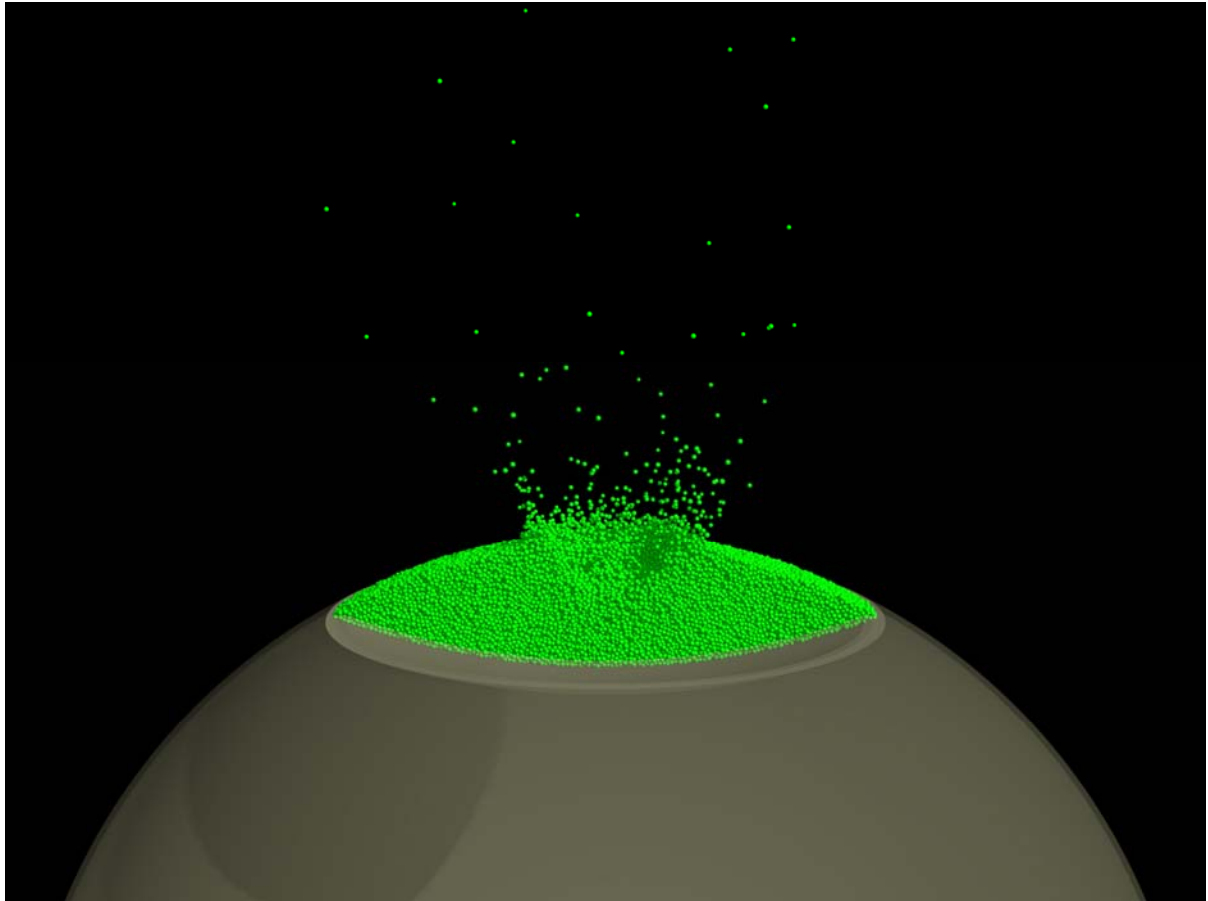


Fig. 4. Positions of particles 2.26 seconds after impact. Impact is performed with PKDGRAV using the SSDEM collisional routine. Foreground particles removed for visualization. Particles are bi-layer, with the outer 10% of their radii defined by softer layer of material. Full simulation has 186,184 particles.

This study is performed in the framework of the NEOShield Project funded under the European Commissions FP7 program agreement No. 282703. Most of the computation was performed using the Beowulf computing cluster (YORP), run by the Center for Theory and Computation at the University of Maryland's Department of Astronomy. For data visualization, the authors made use of the freeware, multi-platform ray-tracing package, Persistence of Vision Raytracer (POV-Ray).
