ASTEROID IMPACT AND DEFLECTION ASSESSMENT (AIDA) MISSION: MODELING AND SIMULATION OF IMPACT OUTCOMES—EJECTA PROPERTIES AND EVOLUTION. S. R. Schwartz[1], E. Asphaug[2], A. Cheng[3], K. R. Housen[4], P. Michel[1], P. Miller[5], A. Stickle[3], G. Tancredi[6], J.-B. Vincent[7], K. Wünnemann[8], Y. Yu[1], and The AIDA Impact Simulation Working Group; [1]Labratoire Lagrange, Univ. Nice, CNRS, Observatoire de la Côte d'Azur, Boulevard de l'Observatoire, CS 34229, 06304 Nice Cedex 4, France (srs@oca.eu), [2]SESE, ASU, Tempe, AZ, [3]JHU/APL, Laurel, MD, USA, [4]The Boeing Co., Seattle, WA, USA, [5]LLNL, Livermore, CA, [6]Departamento de Astronomía, Facultad de Ciencias, Iguá, Montevideo, Uruguay, [7]Max Planck Institut für Sonnensystemforschung, Planets, Göttingen, Germany, [8]Museum für Naturkunde Berlin, Leibniz Institute for Research on Evolution and Biodiversity, Germany.

Introduction: The Asteroid Impact Deflection and Assessment (AIDA) mission is the first actual deflection test currently under study by two main space agencies [1–2]. Comprising AIDA are the NASA Double Asteroid Redirection Test (DART) mission, which began its Phase-A study in October 2015, and the ESA Asteroid Impact Monitor (AIM) rendezvous mission, which began its Phase-A/B1 study in March 2015 [3]. The AIDA target is the near-Earth binary asteroid 65803 Didymos, which will make an unusually close approach to Earth in October, 2022. The ~300-kg DART spacecraft is designed to impact the Didymos secondary at 7 km/s and demonstrate the ability to modify its trajectory through momentum transfer.

The ejecta fate resulting from a kinetic impactor is poorly understood; to date, only a few studies have been devoted to it, e.g., [4–6], however it is of great importance: (i) it contributes to the understanding of the spacecraft's working environment for better risk management; (ii) it provides crucial information for the ground-based observation of the impact outcome, which is planed for AIDA; (iii) it contributes to the theoretical understanding of small binary formation mechanisms with a wealth of empirical data; (iv) it can be used to estimate the momentum transferred to the impacted body.

Here we present distinct aspects of the ejecta fate study. Within the parameters defined by observational and experimental data, different assumptions about the physical properties of the Didymos secondary component will lead to different initial ejecta properties. Such properties include, e.g., particle densities, velocities, and sizes. We also explore the possibility that in the microgravity environment considered, loose regolith far from the impact site may loft due to impact-induced seismic waves propagating through the body. Based on these varied initial ejecta properties, analytical and numerical studies can be performed to extrapolate the ejecta fate. What is the evolution of the resulting ejecta cloud? Is a tail produced? Answers to these questions are crucial to addressing the three points listed above, involving spacecraft maneuvering, observational strategies, and long-lasting science questions involving the characteristics of small bodies and their formation scenarios.

Ejecta properties: Models of the fate of material ejected during the DART impact, and the associated impulse imparted to Didymoon, require estimates of the velocity distribution of the ejecta. The velocity distribution depends on the properties of the target material, which are largely unknown for the Didymos system. However, useful bounds on the ejection velocities can be made by conducting impact experiments in the lab using a variety of target materials.

The porosity of the target is known to have a strong effect on ejection velocities. Figure 1 shows the ejecta velocity distribution in nondimensional form [7] for materials with porosity ranging from 0% (water) up to 85% (granular pumice). Other materials, with intermediate porosities, are shown as well. The y-axis is the ejection speed divided by the impact speed. These experimental results clearly show that, for a given launch position, the ejection speed steadily decreases with increasing target porosity. This general trend should hold in different gravitational regimes.

In support of this conclusion, and exploring ejecta properties based on additional target parameters (different forms of friction, cohesion), we have used distinct types of numerical tools, e.g., the shock physics code iSALE [8], smoothed particle hydrodynamics codes, e.g., [9], and the granular code PKDGRAV [10–13]. The iSALE models show that under 1-g conditions, the ejection angle tends to be steeper for the early ejecta, although certain SPH/PKDGRAV simulations suggest that this this latter result may not hold in microgravity [14].

The porosity of the Didymos secondary is difficult to determine with good precision, although estimates can be made. Other material properties remain highly unknown. Nevertheless, based on a range of assumptions of their values, we can use these results to help form some basis for numerical simulations of the fate of the material ejected during the DART impact.

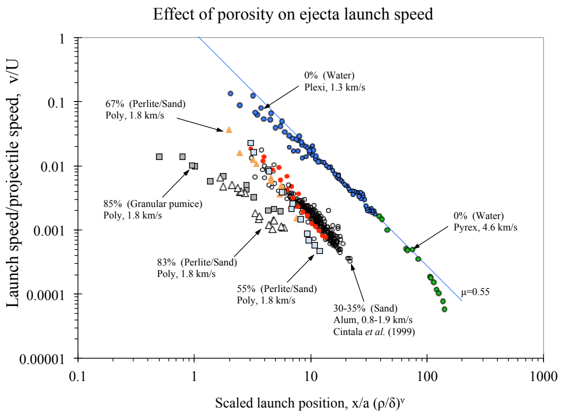

Fig. 1: Measurements of the crater ejecta velocity distribution from lab experiments. Each data set is labeled by the target porosity, material type, impactor material, and impact speed. Data are from experiments conducted by K. R. Housen in the Boeing Shock Physics Lab, save for the dataset for sand [15]. Notation: v—launch speed, *U*—impactor speed, *x*—launch distance from impact point, *a*—impactor radius, *ρ*—target density, *δ*—impactor density, *ν*—point-source scaling exponent = 0.4.

Given the impact speed of DART (7 km/s) and the escape speed from the Didymos secondary (~6 cm/s), a great challenge will be determining a range of appropriate distributions of low-speed ejecta (material at least two orders of magnitude below the lowest ordinate in Fig. 1). Very low-speed material extremely relevant to the safety of the AIM spacecraft may loft from the crater at late stages of the impact process, or from locations on the surface far from the impact site.

Lofting of loose surface regolith: Cratering on asteroids can have effects far beyond the final crater radius, resulting from re-impacting ejecta, and also from seismic propagation in very low gravity. The seismic efficiency and quality factor as a function of porosity is being investigated by applying numerical models to impact experiments equipped with seismic sensors and pressure gauges [16]. Seismic effects in microgravity can be expressed as the low-speed lofting of material not initially lying within the nominal crater radius, as well as structural changes (fissures, slumps) occurring regionally or globally, as well as crater erasure [17–20]. The manner in which cohesion manifests in asteroid regolith is extremely speculative at present, as is the nature of the seismic propagation that determines the amount and manner of energy propagating through or along the surface at some distance from the impact point. One science objective of AIDA is therefore to compare the detailed before-and-after asteroid geomorphology, down to the precise (~10 cm) locations and orientations of major boulders and the precise (~1 m) global shape. These displacements can be translated into models for ground motion and cohesion. These models will complement the in-situ seismology of the AIM lander by providing global- and regional-scale context, and will compensate the likelihood that the seismic array itself will be displaced by DART.

DART-induced dust tail: Several asteroid disruptions have been observed recently (P/2010 A2 [21–22] and 596 Scheila [23]). In these cases dust clouds similar to a comet tail were created and remained visible from ground based observatories for weeks to months afterward. Numerical simulations of these tails can be used to date the event, but also to study the complex dynamics of the ejecta, including post-impact fragmentation of large chunks of ejected material [21].

We are now performing such simulations to predict the size, shape, and magnitude of the tail to be generated by DART. We are particularly interested in looking for signatures of the binary system in the tail morphology. For instance tidal forces may periodically accelerate the dust, leading to overdense regions in the tail.

Full-scale models of the ejecta fate: We currently have multiple groups working on ejecta cloud evolution models resulting from the DART impact, e.g., [24]. These groups have been working largely independently of each other, each developing their own strategies of addressing the problem. These strategies include the uses of different *N*-Body codes and semi-analytical tools using wide ranges of plausible initial conditions. Ongoing results will be presented.

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