SPATIAL DISTRIBUTION OF THE BOULDERS IN THE DART IMPACT EJECTA: A 3-D ANALYSIS

T. L. Farnham[1], M. Hirabayashi[2], J. D. P. Deshapriya[3], O. S. Barnouin[4], M. Bruck-Syal[5], A. Cheng[4], V. Della Corte[6], E. Dotto[3], E. M. Epifani[3], E. G. Fahnestock[7], F. Ferrari[8], I. Gai[9], P. H. Hasselmann[3], S. Ivanovski[10], J.-Y. Li[11], F. Marzari[12], M. Pajola[13], J. M. Sunshine[1], K. T. Ramesh[4], S. Raducan[14], A. Rossi[6], A. Zinzi[15], the DART Investigation Team and the LICIACube Team, [1]University of Maryland, College Park, MD, USA, farnham@umd.edu, [2]Auburn University, Auburn, AL, USA, [3]INAF-Osservatorio Astronomico di Roma, Monte Porzio Catone, Roma, Italy, [4]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, [5]Lawrence Livermore National Laboratory, Livermore, CA, USA, [6]IFAC-CNR, Sesto Fiorentino, Firenze, Italy, [7]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [8]Politecnico di Milano - Bovisa Campus, Milano, Italy, [9]Argotec, Torino, Italy, [10]INAF-Osservatorio Astronomico di Trieste, Trieste, Italy, [11] Planetary Science Institute, Tucson, AZ, USA, [12]University of Padova Padova, Italy, [13]INAF-Astronomical Observatory of Padova, Padova, Italy, [14]Space Research and Planetary Sciences, Physikalisches Institut, University of Bern, Switzerland, [15]ASI-Space Science Data Center, Roma, Italy.

Introduction: NASA's Double Asteroid Redirection Test (DART) was designed to demonstrate the potential for using a kinetic impactor to deflect the trajectory of a potentially hazardous object, and to investigate the momentum enhancement, beyond that of the spacecraft itself, that is produced by the material ejected in the impact [1]. The DART spacecraft impacted asteroid Dimorphos, the secondary component of the binary asteroid system (65803) Didymos, on 26 September 2022, changing its orbital period by 33$\pm$1 (1σ) minutes [2,3]. The successful outcome of the experiment proved the feasibility of the kinetic impactor concept, but to fully understand how the momentum imparted by the ejecta contributed to the changes in Dimorphos' orbit, it is necessary to ascertain the net direction in which the material was expelled.

DART's companion spacecraft, LICIACube [4], observed the aftermath of the event during its post-impact flyby, imaging the complex structures formed by the ejected material, and we are using the parallax imparted by the spacecraft's changing viewpoint to map these structures in three dimensions. LICIACube also detected what appear to be clusters, consisting of dozens of boulders, that were launched in preferred directions. These boulders could represent a notable fraction of the ejecta mass, and determining the directions in which they were emitted could inform on the mechanisms that controlled the impact physics. As part of our ejecta mapping efforts, we will determine the relative positions and velocities of these boulders with respect to Dimorphos, and estimate their contributions to the total momentum yield from the DART impact.

Observations: The LICIACube spacecraft, which was carried by DART and released on 11 September, altered its trajectory to fly by the asteroid at a distance of 58 km 167 seconds after DART's impact. From this perspective, it was able to observe the impact and document the resulting ejecta cloud [5]. During the flyby, LICIACube's LUKE camera imaged from 83 to 243 seconds after impact, capturing pictures that show details of the ejecta morphology, including a well-defined cone surrounded by intricate filamentary structures (Figure 1). In addition to the general diffuse ejecta, the images also reveal dozens of point sources that can be tracked through a 12-sec sequence starting at 155 sec. These points are likely individual boulders, and preliminary photometry suggests that they range in

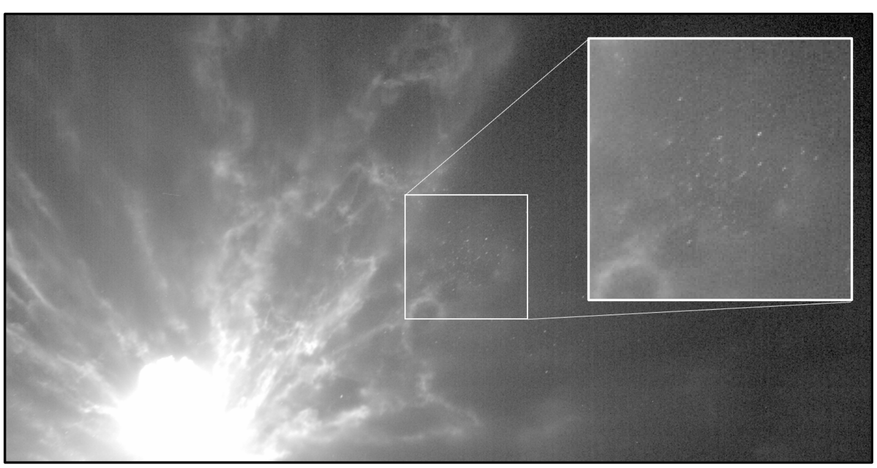

Figure 1. LICIACube image of ejecta around Dimorphos, showing the intricate filaments and structures produced by the DART impact. The inset enlarges a region containing a cluster of individual boulders seen in a sequence of images. Other regions (e.g., upper left) show no boulders of this type. This image (1664234224_00523) was obtained 160 s after impact. Both Didymos and Dimorphos are contained in the saturated region in the lower left.

size from sub-meter to as large as 5 meters in radius (assuming the photometric properties of Didymos). They are located at distances, projected onto the plane of the sky, up to ~10 km from Dimorphos, suggesting that they were ejected with speeds of 10s of meters per second (or significantly faster if they are highly projected).

Although the ejecta cone seems to be relatively symmetric around its central axis, the boulders are concentrated in a preferred direction. Relative to Dimorphos, they are restricted to a wedge ~45° wide as projected on the sky, with the majority clustered in two groups within a smaller ~25° wedge. Currently, no boulders have been detected outside of this zone, suggesting that there are processes governing the impact mechanisms that favor a specific direction for ejecting these large objects. By measuring the positions and velocities of the boulders, we can relate them to the DART trajectory and surface properties at the impact site. These relationships will then provide constraints on numerical impact models that may reveal important insights into the physics involved in the DART excavation.

Methods: The changing viewpoint over the course of these observations, produced by the spacecraft's motion during the flyby, reveals the three-dimensional nature of the ejecta, and provides a means of accurately deriving the positions and velocities of features recorded in the images. To investigate the positions of these features, we are using procedures developed for studies of the large particles detected in the coma of comet 103P/Hartley 2 [6]. With this technique we utilize the parallax imparted by the spacecraft's motion to derive the locations of boulders in inertial space. Pairs of images provide a measure of their positions in space, while sequences of multiple images can also reveal their velocities and, with sufficient data, allow us to investigate any potential acceleration.

One valuable aspect of our routines is that they are used interactively, deriving a position/velocity solution on the fly as features are identified in each individual picture. Thus, once a boulder has been measured from initial frames, it is possible to predict where it will appear in earlier or later images, improving our ability to track specific objects and minimizing misidentifications when multiple objects are available. The LICIACube sequence showing the boulders is currently cut off after 12 seconds because the asteroid temporarily leaves the image field of view near closest approach. Our ability to predict where the boulders should appear in later frames means that we may be able to recover them again when they come back into the field. This allows us to extend the temporal baseline and improve the solution for those objects.

Summary: We are analyzing the spatial distribution of individual boulders in the ejecta field produced by the DART impact. We will measure their positions and velocities using the parallax from LICIACube's flyby, and their sizes from their brightness in the images. Using these results, we can derive the momentum vector for each boulder, allowing us to evaluate what fraction of the DART momentum is contributed by individual objects. The derivation of the boulder's locations will also provide input for numerical modelling, to determine how the impact mechanism acts to eject these objects in preferred directions.

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