DART IMPACT-DRIVEN SKEWED EJECTA PLUME. M. Hirabayashi[1], T. L. Farnham[2], J. D. P. Deshapriya[3], J.-Y. Li[4], E. Dotto[3], P. H. Hasselmann[3], A. Rossi[5], S. L. Ivanovski[6], O. S. Barnouin[7], R. T. Daly[7], I. Gai[8], H. Nair[7], E. E. Palmer[4], A. Zinzi[9], H. F. Agrusa[2,10], B. W. Barbee[11], N. L. Chabot[7], A. F. Cheng[7], E. G. Fahnestock[12], A. J. Meyer[13], A. S. Rivkin[7], M. E. DeCoster[7], V. Della Corte[9], C. M. Ernst[7], K. M. Kumamoto[14], A. Lucchetti[15], E. Mazzotta Epifani[3], M. Pajola[15], S. D. Raducan[16], D. C. Richardson[2], T. S. Statler[17], A. M. Stickle[7], the DART Investigation Team, and the LICIACube Team. [1]Aubern Univ., AL, USA (thirabayashi@auburn.edu), [2]UMD, MD, USA, [3]INAF-Osservatorio Astronomico di Roma, Rome, Italy, [4]PSI, AZ, USA, [5]IFAC-CNR, Sesto Fiorentino (FI), Italy, [6]INAF-Osservatorio Astronomico di Trieste, Trieste, Italy, [7]JHU/APL, Laurel, MD, USA, [8]Università di Bologna, Bologna, Italy, [9]Agenzia Spaziale Italiana, Roma, Italy, [10]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Nice, France, [11]NASA GSFC, Greenbelt, MD, USA, [12]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [13]Univ. of Colorado, Boulder, CO, USA. [14]Lawrence Livermore National Laboratory, CA, USA, [15]INAF-Astronomical Observatory of Padova, Padova, Italy, [16]Univ. of Bern, Bern, Switzerland, [17]NASA Headquarters, Washington DC, USA.

Introduction: NASA's Double Asteroid Redirection Test (DART) successfully impacted Dimorphos, the satellite of the binary system (65803) Didymos [1]. After the DART impact at 23:14:24.183±0.004 UTC on September 26, 2022, the resulting ejecta plume immediately grew, and was captured in detail by ground- and space-based telescopes and LICIACube, the Italian CubeSat released from DART before the impact. The impact reduced Dimorphos's orbital velocity, leading to an orbital period change of 33.0±1.0 (3σ) minutes [2] and thus a momentum enhancement (β) factor of 2.2-4.9, depending on its unknown mass [3]. This β (>1) factor indicates the critical role of the DART impact-driven ejecta in kinetic deflection.

Here, we apply image processing and statistical estimation techniques to show that the ejecta cone has a skewed geometry, stretched along Dimorphos's short axis. Given both Hubble Space Telescope (HST) and LICIACube LUKE images taken at an early stage of the ejecta formation, our preliminary solution prefers a cone opening angle of ~145 deg along the short axis and that of ~95 deg along the equatorial plane.

Methodology: Images taken by HST and LICIACube LUKE were used to constrain the ejecta geometry. For LICIACube, nine LUKE images were selected for its close approach to Dimorphos 83 - 243 s after the DART impact with the closest approach at 167 s. The images' exposure times were ~0.3 ms so that we could capture clear morphological contrasts. However, we also confirmed that this process lost some dimmer morphological features captured in images with longer exposure times. For HST, we selected six images taken 0.24-8.50 h after the impact [4]. The exposure times were longer than 25 s. The reason for choosing different time intervals for each observer was to capture the ejecta cone geometry created by similar particle speeds (~2 m to ~10 m/s). In this speed range, the particles are negligibly affected by gravitational and non-gravitational accelerations that change the cone geometry [4].

We used these measurements and a Monte-Carlo-based estimation approach to determine the cone geometry. A cone geometry was numerically generated to reproduce the cone edge directions. Each numerical case calculated a score to see how the geometry was similar to the observed one at a given time. In this, the cone's axis direction and shape were free parameters. We assumed a skewed cone (a cone having an ellipse when sliced normally to the cone axis) as the reference cone shape. The algorithm was made to search a set of parameters describing the cone geometry and orientation. After obtaining a solution, we manually compared simulated cone geometries for that result with the observations to ensure that our results were consistent.

Results: The best solution derived contains the cone axis at a Right Ascension (RA) of 136 deg and a Declination (DEC) of 16 deg in the J2000 Ecliptic frame and the cone geometry consisting of cone opening angles of 145 deg along the short axis of Dimorphos and 95 deg along the equatorial plane. The cone axis solution is consistent with earlier work using different approaches [3-5]. While LICIACube images provided some insights into this skewed cone geometry, the major contribution to it in the present approach is a misalignment seen between HST and LICIACube images, causing difficulties in a suitable overlapping of solutions from both observers, if a perfect cone is given as a reference cone geometry, regardless of higher uncertainties in the cone edge directions. Figure 1 shows the comparison between the cone geometries captured by LICIACube and HST images and those reconstructed by our model.

Interpretations: Below, we summarize our initial interpretations of how this skewed cone evolved. The ejecta formation strongly depends on complex geological and impact conditions [6-9]. There exist many meter-sized boulders on Dimorphos [10,11], though the shape looks like a smooth ellipsoid [12] with some crater candidates [10]. The shape extents are 177 m x 174 m x 116 m [1], indicating a highly oblate shape [1,13]. The impact site hosted two large boulders with sizes of 6.1 m and 6.5 m, and DART's solar panels impacted these boulders; at the time of impact, the spacecraft's solar panels were roughly aligned in the north-south direction of Dimorphos [14].

Based on these observations, there are a few possible explanations. First, the wider cone opening angle may result from variations in the curvatures (defined as 1/R, where R is the radius) along the short axis and the equatorial plane [1]. The curvature along the short axis is about twice that along the equatorial plane. The higher curvature caused particles to depart in a way that the opening angle became wider. Another explanation may be that the spacecraft's orientation and the target conditions such as boulders local to the impact site might change the crater excavation mechanisms, contributing to the observed skewed cone geometry [7]. Finally, the plume morphology was observed to be highly complex. Some features highly deviated from the defined ideal cone shape were observed in both HST and LICIACube images [4,15]. Nevertheless, the skewed feature is likely part of the ejecta plume's critical morphologies.

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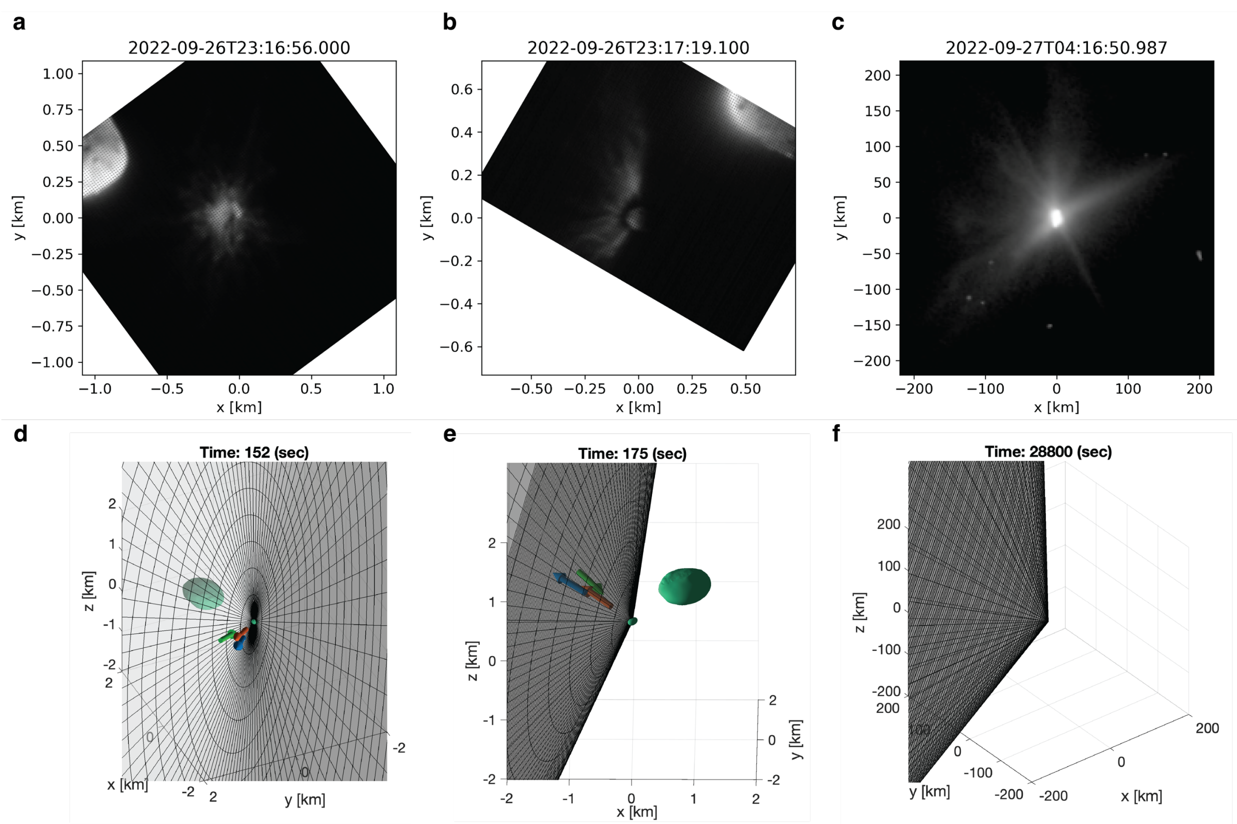

Figure 1. Ejecta cone geometry seen by Hubble Space Telescope and LICIACube LUKE described in the J2000 Ecliptic frame. Panels **a** through **c** are edited image data (**a** and **b** are from LICIACube and Panel **c** from Hubble Space Telescope. Panels **e** through **f** are simulated cone geometries seen by provided observers. The arrows in these panels show the surface normal (blue), the cone axis (red), and the DART impact direction (green). The bright feature departing from the center (Didymos) on the left seen by HST (Panel **c**) is a tail affected by solar radiation pressure, while our reconstruction by numerical analysis (Panel **f**) only generated the impact-driven ejecta cone at an early stage, which spread in the North-East direction.