HUBBLE SPACE TELESCOPE OBSERVATIONS OF THE EVOLUTION OF DIMORPHOS'S EJECTA CREATED BY THE DART IMPACT

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NASA's DART spacecraft successfully impacted asteroid Dimorphos on September 26, 2022 [1]. We studied the evolution of the impact ejecta using the Hubble Space Telescope (HST) from impact (T) +20 min to T+18.5 days at a resolution of ~2.1 km/pixel. These images revealed the detailed evolutionary process of the ejecta under the influence of the gravity of Didymos and solar radiation pressure (SRP), ultimately forming a long, narrow dust tail that was visible from the ground for months. From the evolution of the ejecta, we determined the basic properties of the ejecta dust. The ejecta properties help us better understand the impact cratering process, which is important for assessing the momentum transfer efficiency for asteroid deflection utilizing a kinetic impact.

The HST-observed impact ejecta contained dust particles from µm to cm in size ejected at speeds from below the escape speed of the binary system (0.17 m/s) up to ~300 m/s. The particle size and ejection speed and direction are the determining factors for the fate of the ejecta. The fastest ejecta, with projected speeds in the images > 10s m/s, is diffuse with an overall fan-shaped morphology (Fig. 1a). After the fast, diffuse ejecta dissipated, many morphological features appeared, including linear structures, blobs, and arcs. These features appeared to escape the binary system radially at speeds >2 m/s without being appreciably affected by the gravity of Didymos (Fig. 1b). Slower ejecta features with speeds a few times the escape speed, on the other hand, formed two spirals by the gravity of Didymos that have distinct morphological characteristics (Fig. 1c). Such differences are attributed to the dust dominated by different ejection directions in the two spirals, one towards Didymos and the other away from Didymos, with their trajectories affected by the gravity of Didymos differently. Additionally, the dust in both spirals and the linear features in between was accelerated by SRP towards the anti-solar direction. As a result, these morphological features stretch along the sun-antisun direction because smaller particles are accelerated faster than larger particles. Some linear features overlapped with the extended northern spiral and formed a complex pattern (Fig. 1d).

The dynamics of the slowest dust particles ejected at comparable or slower speeds than the escape speed are dominated by SRP, forming a long, narrow tail (Fig. 2). A short-lived secondary tail is noticed between T+8.8 days and T+14.9 days (Fig. 2e), and the driving mechanism is still under investigation. From the particle size sorting along the tail under the influence of SRP, we determined a broken power law differential size frequency distribution for the ejecta dust particles with slopes of -2.6 and -3.7, transitioning at a dust radius of ~3 mm. Our HST observations revealed the detailed evolution of asteroid impact ejecta and the subsequent formation of a dust tail for the first time.

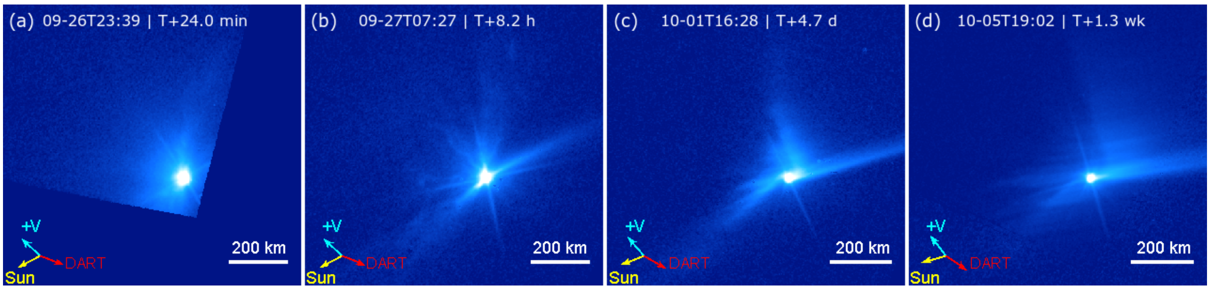

Figure 1. Dimorphos's ejecta evolution from HST images. All images are displayed north up and east to the left with the same logarithmic brightness stretch. The red arrows are the projected incoming direction of the DART spacecraft at impact.

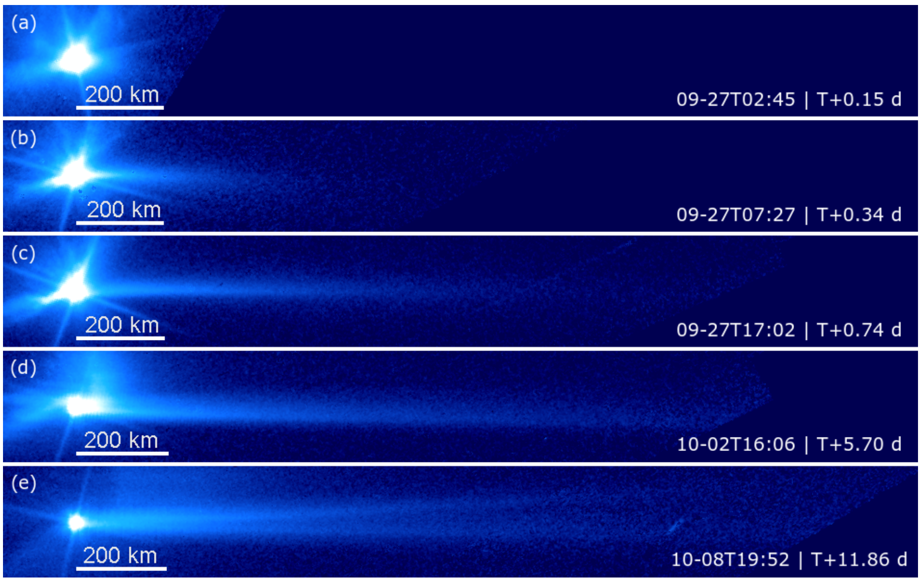

Figure 2. Dust tail formation sequence (a – e) from Dimorphos's ejecta in HST images. All frames are rotated such that the expected direction of the tail based on a dust dynamic model is in the horizontal direction extending towards the right. (a) The first

post-impact image that shows the initial formation of a tail at T+0.15 day. (b) The tail grows to >500 km by T+0.34 days. (c) The tail at T+0.74 days (17.8 hours) shows a slight curvature near its base. (d) The tail shows a relatively sharp southern edge and a diffuse northern edge, potentially due to the northward initial velocity of ejecta. (e) A secondary tail pointing to about 4º north of the original tail appears.

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References: [1] Daly, R.T., et al. DART: An Autonomous kinetic impact into a near-Earth asteroid for planetary defense. Nature, in revision.