HUBBLE SPACE TELESCOPE OBSERVATIONS OF THE EVOLUTION OF DIMORPHOS'S EJECTA CREATED BY THE DART IMPACT. Jian-Yang Li[1], M. Hirabayashi[2], T.L. Farnham[3], J.M. Sunshine[3], M.M. Knight[4], G. Tancredi[5], F. Moreno[6], B. Murphy[7], C. Opitom[7], S. Chesley[8], H.A. Weaver[9], D.J. Scheeres[10], C.A. Thomas[11], E.G. Fahnestock[8], A.F. Cheng[9], A.S. Rivkin[9], F. Ferrari[12], A. Rossi[13], J.M. Trigo-Rodríguez[14], and the DART Investigation Team, [1]Planetary Science Institute, USA, jyli@psi.edu, [2]Auburn University, USA, [3]Department of Astronomy, University of Maryland at College Park, USA, [4]United States Naval Academy, USA, [5]Departamento de Astronomía, Facultad de Ciencias, Udelar, Uruguay, [6]Instituto de Astrofísica de Andalucía, CSIC, Spain, [7]University of Edinburgh, Royal Observatory, UK, [8]Jet Propulsion Laboratory, California Institute of Technology, USA, [9]Johns Hopkins University Applied Physics Laboratory, USA, [10]University of Colorado, USA, [11]Northern Arizona University, USA, [12]Department of Aerospace Science and Technology, Politecnico di Milano, Italy, [13]IFAC-CNR, Italy. [14]Institute of Space Sciences (CSIC-IEEC), Spain.

Introduction: On September 26, 2022, NASA's first planetary defense experiment, the Double Asteroid Redirection Test (DART) mission, successfully performed an impact experiment on Dimorphos, the secondary asteroid, of the Didymos binary asteroid system [1]. With a spacecraft mass of 579 kg impacting the 151 m equivalent diameter asteroid at a speed of 6.14 km/s, this impact is comparable to the natural impacts occurring on asteroids, providing us with a unique opportunity to study the asteroidal impact process and the fate of the ejecta. As part of the worldwide observing campaign to monitor the impact, we imaged the ejecta with the Hubble Space Telescope (HST) starting one hour before the DART impact with observations continuing for the next 18.5 days at pixel scales of ~2.1 km at the asteroid. The data revealed a complex and unique dynamic evolution of the ejected dust under the gravitational interaction with the binary system and solar radiation pressure (SRP), ultimately forming a dust tail similar to the tails observed to evolve from active asteroids thought to be triggered by natural impacts (e.g., [2]).

Data: HST observed the impact in 19 orbits with WFC3/UVIS through filter F350LP. The observations started with the first orbit immediately before the impact and six consecutive orbits from ~15 min after the impact. Then the intervals of observations increased to ~0.5 days for three days, ~1 day for the next three days, and ~3.5 days for the next two weeks until October 15, 2022. Three levels of exposure were used in order to image both the asteroid and the faint ejecta. All images were calibrated with the standard calibration pipeline at STScI. All images were registered and stacked. Short exposures that did not saturate the asteroid and long exposures were stacked separately for each orbit to enhance the signal and remove cosmic rays and background objects.

Ejecta evolution: The data were roughly divided into three partially overlapping phases in time, determined by the different ejecta speeds.

In the first phase within ~10 hours after impact, fast-moving dust with escape speeds >~1 m/s and up to ~300 m/s as projected in the sky, dominate the ejecta (Fig. 1a). Faster ejecta would have left the HST field of view when the post-impact observations started. These ejecta directly leave the binary system without being appreciably affected by the gravity of the binary system and SRP. The morphology of the ejecta in this phase has an overall cone-like shape viewed from the side. Modeling suggests that the cone axis of the ejecta is in the sky plane with uncertainties of 16º (3σ). The morphologies of the cone and the discrete features in the ejecta during this phase should represent the original morphology of the ejecta as excavated from Dimorphos, and can be directly related to the LICIACube high-resolution ejecta observations within 3 min after impact for 100s km around the Didymos system [3].

The second phase is characterized by two curved ejecta streams that start to appear in the HST images about 18 hours after impact and extend outward in directions that are offset from the radial directions to the asteroid, as well as some smaller, curvilinear features inside the cone (Fig. 1b, 1c). These features are composed of dust escaping at speeds <~1 m/s. Their trajectories are appreciably curved by the gravity of Didymos (the gravitational potential of Dimorphos at the impact site is only 13% of that of Didymos). Because the orbital plane of Dimorphos around Didymos is inclined by about 51º as seen from HST at the time of impact, the northern stream is dominated by dust ejected towards Didymos, whereas the southern stream is dominated by dust ejected away from Didymos. The dust in the two streams thus have different trajectories due to the different directions relative to Didymos, resulting in the different shapes of the two features. This phase of ejecta evolution is unique to impacts in a binary system.

The third phase starts about 3 to 4 days after the impact when observable effects due to SRP start to appear (Fig. 1c, 1d). The northern stream, roughly perpendicular to the direction of the Sun, is widened by SRP towards the antisolar direction due to particle size sorting, forming a wing-like feature north of Didymos. The particles in the southern stream, which roughly extends towards the Sun, are decelerated by SRP and eventually turned back towards the antisolar direction. The dust particles in those smaller curvilinear features north of Didymos are stretched by SRP towards the

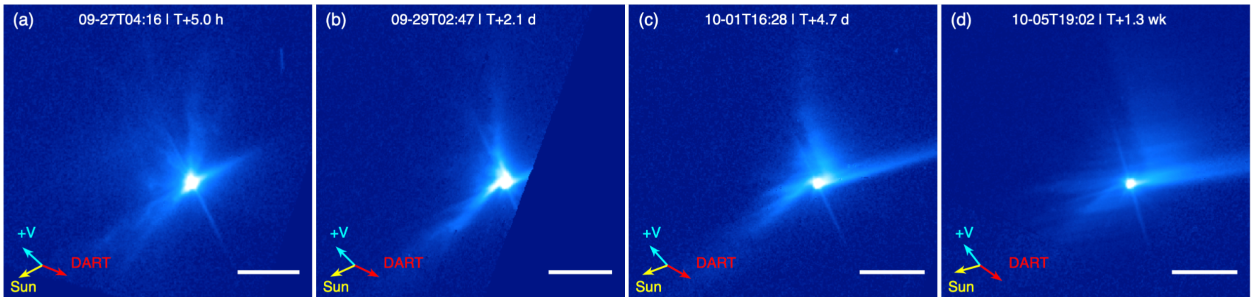

Figure 1. Dimorphos's ejecta evolution from HST images. All images are displayed north up and east to the left with the same logarithmic brightness stretch. The scale bars are 200 km at the distance of Didymos.

wing-like feature, with the small particles catching up with the large particles in the wing-like features, forming complex overlapping patterns.

During the ejecta evolution, a dust tail starts to appear ~3 hours after impact, growing in length with time and visible in all subsequent images (Fig. 2). The orientation of the tail is consistent with being driven by SRP based on a dust dynamic model [4]. The width of the tail is consistent with an initial velocity dispersion of 0.15 m/s for the dust in the tail, comparable to the orbital velocity of Dimorphos, which is inherited by the ejecta dust. Therefore, the tail is composed of the slowest ejecta particles driven by SRP, which sorts out particle size along the tail. Based on the tail brightness profile, assuming a power low dust size frequency distribution (SFD) and a grain density of 3.5 g/cm^3 consistent with LL chondrites as the composition of Dimorphos [5, 6], we derive a differential SFD slope of -2.7±0.2 for µm to mm particles, and -3.7±0.2 for mm to cm particles. This SFD suggests that large (>mm radius) particles could account for more than half of the ejecta mass.

Discussion: The DART impact provides us with the first opportunity to study the detailed evolution of asteroid impact ejecta from excavation to the formation of a tail with precisely known impact conditions. Compared to the ejecta from the only previous planetary scale impact experiment with comparable projectile momentum and energy, the Deep Impact impact on Comet 9P/Tempel 1 [7], the Dimorphos ejecta shows a distinctly different morphology. As also observed by HST, the 9P ejecta was diffuse, fan-shaped, and expands at speeds of 100 – 300 m/s [8]. The difference is likely due to the volatile-rich composition and a more homogeneous interior of 9P that is rich in fine-grained particles [9], in contrast to the volatile-free composition [6], boulder-rich surface, and rubble pile interior of Dimorphos [1].

Previous observations of active asteroids suggested that some are likely triggered by impact [e.g., 2]. The formation of Dimorphos's tail is the first time that the formational process of a tail from impact is directly observed. The DART impact directly confirmed the formation of active asteroid tails from impact or other impulsive dust emission events [e.g., 10]. The DART observation thus provides insights into the interpretation of active asteroid observations.

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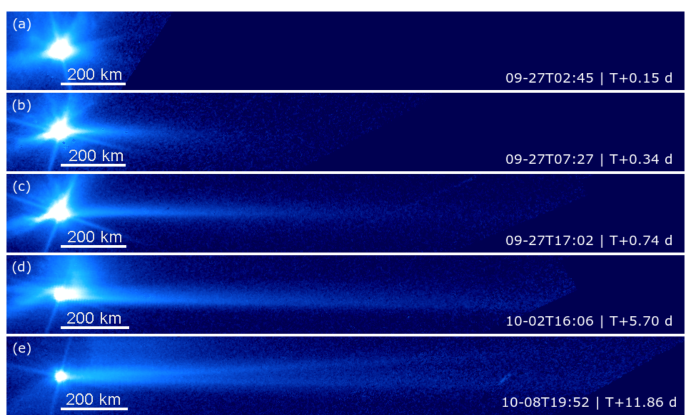

Figure 2. Dust tail formation sequence from Dimorphos's ejecta in HST images. All frames are rotated such that the expected direction of the tail based on a dust dynamic model [4] is in the horizontal direction extending towards the right.