DART IMPACT EJECTA PLUME OBSERVATIONS.

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Introduction: The NASA Double Asteroid Redirection Test (DART) mission [1,2] will be the first space experiment to demonstrate asteroid deflection by a kinetic impactor. DART will impact Dimorphos, the secondary member of the (65803) Didymos system, on September 26, 2022 in order to change the binary orbit period. DART will carry to Didymos a 6U cubesat called LICIACube, contributed by the Italian Space Agency, to document the DART impact and to observe the impact ejecta. DART is the first hypervelocity impact experiment on an asteroid at a realistic scale relevant to planetary defense, where the impact conditions and the projectile properties are fully known. The experiment results will validate the effectiveness of the kinetic impactor technique and improve models of momentum transfer to reduce risks and uncertainties of possible future applications to asteroid deflection.

LICIACube will observe the structure and evolution of the DART impact ejecta plume and image the non-impact hemisphere of Dimorphos. We will present new modeling results of DART impact ejecta plume observations by LICIACube and discuss how these will contribute to the DART determinations of the momentum transfer efficiency [5].

Planetary defense science: The DART impact will change Dimorphos's orbital period around Didymos. Because the Didymos system is an eclipsing binary [6], this period change is observable through light curve measurements of mutual events and radar measurements to quantify the amount of asteroid deflection from the kinetic impactor experiment [1, 7, 8]. Didymos in October, 2022 will be only 0.072 AU from Earth. The impact of the ~590 kg DART spacecraft at 6.15 km/s on the 163 m moon Dimorphos will change the binary orbital period [1,2] by ~10 minutes (~ 1% change) assuming momentum transfer efficiency $\beta = 1$. Values of $\beta > 1$ are expected for the impact because ejecta carries momentum largely opposite to the direction of the DART approach.

The determination of momentum transfer efficiency β for kinetic impact on an asteroid is an important planetary defense objective. The momentum transfer efficiency β depends on impact conditions such as local slope, on target physical properties such as strength and porosity, and on surface and sub-surface structures such as boulders. To understand the effectiveness of the kinetic impact deflection, DART will determine or constrain these impact conditions and target material properties in order to compare with simulations of the hypervelocity impact [9, 10, 11] and the momentum transfer efficiency. Data from the DRACO instrument will allow determination of the DART impact location and the local surface slope and topography through high-resolution images (ground sampling distance of 50 cm per pixel or better) from terminal approach.

The primary DART measurements of asteroid deflection are the ground-based telescopic measurements of the orbital period change [1, 8]. These measurements allow us to determine the transverse velocity change, which is the component of the velocity change along the circular orbit motion. The other two components of velocity change are not measured by DART. The transverse component of the momentum transfer is determined from the transverse velocity change, using a mass M for the target body Dimorphos determined from approach imaging combined with density estimates. DART will determine M from approach imaging by finding the size and the shape, and hence the volume, assuming that the Didymos primary bulk density 2170 kg m^{-3} [4,8] applies also to the secondary.

The ESA Hera mission [3,4] will rendezvous with the Didymos system in late 2026, about 4 years after the DART impact. Hera will directly measure the mass of Dimorphos to determine β. Hera will also study the DART impact crater, the binary system dynamics, and the internal structure of Dimorphos.

LICIACube also contributes to the mass determination by imaging Dimorphos after closest approach, viewing the non-impact hemisphere (which is the side of Dimorphos not seen by DART). LICIACube images will significantly improve the volume determination for Dimorphos and hence also the mass estimate.

Finally, an important contribution to determination of β comes from LICIACube imaging of the DART impact ejecta plume to determine its structure and temporal evolution so as to infer both direction and magnitude of ejecta momentum. The LICIACube flyby trajectory, with a closest approach distance of about 55 km and 165 s time delay of closest approach, is designed to enable study of plume evolution [8].

Models of the ejecta plume evolution as imaged by LICIACube [5] show how LICIACube images can discriminate between different target physical properties (mainly strength and porosity), thereby allowing inferences of the magnitude of the ejecta momentum. This is because the ejecta plume structure, as it evolves over time, is determined by the amount of ejecta that has reached a given altitude at a given time. The LICIACube plume images enable characterization of the ejecta mass versus velocity distribution, which is strongly dependent on target properties like strength and porosity, and which is therefore a powerful diagnostic of the DART impact. LICIACube ejecta plume images provide information on the direction of the ejecta momentum and the spatial distribution of mass in the plume at a given time [5], which is important for determination of the vector momentum transfer from the DART impact.

This work develops a model of the DART impact ejecta plume opacity as observed by LICIACube from its flyby trajectory, extending the previous plume model [5] that studied observable differences in ejecta plume structure and evolution that result from different target physical properties, distinguishing between strength-controlled and gravity-controlled impacts. This model calculated the optical depth profiles along a specific image line, namely, the line connecting the impact site with the intersection of the LICIACube trajectory and the image plane-of-sky at Dimorphos. The direction along this line in the image plane-of-sky is the x direction, and distance along this line is denoted b. Distance orthogonal to this line in the image plane-of-sky is denoted z, and the present work extends the model [5] to calculate profiles of optical depth versus distance b along image lines at arbitrary z, covering the full two-dimensional plume images.

The LICIACube plume optical depth profiles can distinguish between gravity-controlled and strength-controlled impact cases with target properties ranging from strong and nonporous to weak and porous [5, 12], using specific observables from the plume images, which include the time at which clearing of ejecta becomes evident over the impact site. An example of the differences between gravity-controlled and strength-controlled impact cases is shown in Fig. 1, at a time of 135.15 s after the DART impact with LICIACube at a range of 200 km from Dimorphos. The point source scaling laws [12] are used to model the ejecta plume as in [5], with sand-fly ash as the strength-controlled case and sand as the gravity-controlled case (with an assumed strength of 1 Pa). Clearing of opacity, or reductions of the optical depth, are seen over the impact site in the strength-dominated case but not in the gravity-dominated case, reflecting differences in the ejecta mass versus velocity distributions. In the gravity-controlled case, a much larger proportion of ejecta is at very low velocity.

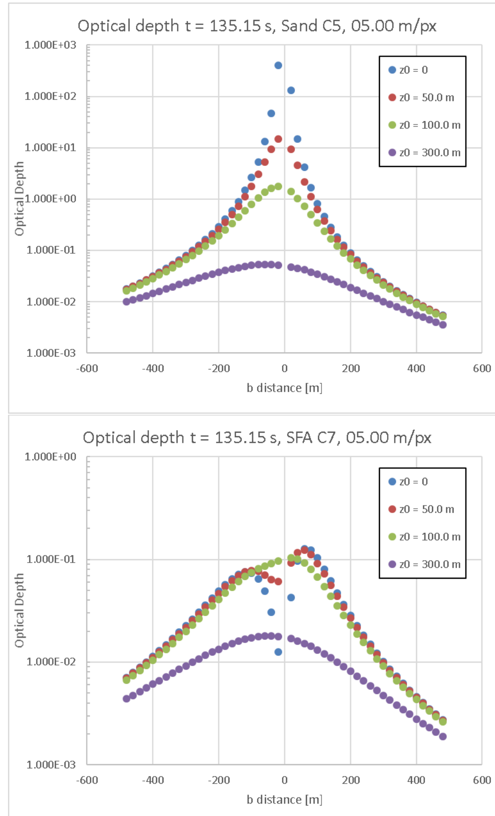

Figure 1. (upper panel) plume model optical depth profiles, for image 135.15 s after DART impact, from range 200 km. Gravity-controlled impact case, assumed target strength 1 Pa. (lower panel) plume model optical depth profile, for image 135.15 s after DART impact, from range 200 km. Strength-controlled impact case, assumed target strength 4 kPa. Clearing of opacity has started over impact site.

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Acknowledgments: AFC, AS, and EF thank NASA for support of the DART mission. ED and VDC thank the Italian Space Agency for support of LICIACube. SR thanks ESA for support of Hera and thanks the EU Horizon 2020 program for support of NEO-MAPP.