DART AND LICIACUBE: MOMENTUM TRANSFER FROM KINETIC IMPACT.

A. F. Cheng[1], N. L. Chabot[1], A. S. Rivkin[1], E. Dotto[2], V. Della Corte[3], A. Stickle[1], C. Thomas[4], D. C. Richardson[5], E. Fahnestock[6], O. Barnouin[1], P. Michel[7], M. Kueppers[8]. [1]JHU/APL, Laurel, MD, USA (andy.cheng@jhuapl.edu) [2]INAF-OA, Rome, Italy [3]INAF-IAPS, Rome, Italy [4]NAU, Flagstaff, AZ [5]U Maryland, College Park, MD [6]JPL, Pasadena, CA [7]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS France [8]ESA/ESAC, Madrid, Spain

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, in late September – early October, 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. The ESA Hera mission [3,4] will rendezvous with the Didymos system in late 2026, roughly four years after the DART impact. The Hera mission will perform a detailed characterization of the target asteroid, measuring the mass of Dimorphos and imaging the DART impact site. Members of the DART, LICIACube, and Hera teams contribute to the Asteroid Impact and Deflection Assessment (AIDA) collaboration. AIDA planetary defense objectives are to support international collaboration in planetary defense, to support the demonstration and validation of technologies needed to deflect a hazardous asteroid by means of a kinetic impactor, and to improve our understanding of the impact process and the momentum transfer to the target asteroid. 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 to 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 on Dimorphos will change its orbital period around Didymos. As the Didymos system is an eclipsing binary [6], this period change is observable through light curve measurements of mutual events and radar range and range rate measurements to quantify the amount of asteroid deflection from the kinetic impactor experiment [7, 8]. Didymos in October, 2022 will be only 0.072 AU from Earth. The impact of the 610 kg DART spacecraft at 6.58 km/s on the 163 m moon Dimorphos will change the binary orbital period [1,2] by ~10 minutes (more than a 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 planetary defense science objectives of the DART mission include the demonstration of asteroid deflection by kinetic impact, by hitting Dimorphos in Sept.–Oct. 2022, and measuring the deflection. The determination of momentum transfer efficiency β for kinetic impact on an asteroid is also an important planetary defense objective to improve modelling and simulation capabilities. The primary measurements of asteroid deflection made by the DART mission are the ground-based telescopic measurements of the orbital period change from the DART impact [1,8]. In addition, the DART spacecraft observations consist of approach imaging to measure Didymos light curves to determine rotation and orbital characteristics, further approach imaging to measure the sizes and shapes of Didymos and Dimorphos, and terminal approach imaging to determine the impact site location and local surface geology [7].

LICIACube is a 6U CubeSat carried by DART to the vicinity of Didymos and released 10 days prior to Didymos encounter [8]. The LICIACube flyby of Didymos will have closest approach distance of about 55 km and closest approach time delay of about 165 s after the DART impact. LICIACube will observe the structure and evolution of the DART impact ejecta plume and will obtain images of the surfaces of both bodies at peak ground sampling better than 2 m per pixel. LICIACube imaging importantly includes the non-impact hemisphere of the target asteroid, the side not imaged by DART.

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 characteristics in order to compare experimental results with hypervelocity impact simulations [9, 10, 11] of impact effects and momentum transfer efficiency. DART will determine the DART impact location and the local surface slope and topography by returning high-resolution images (ground sampling distance of 50 cm per pixel or better) from terminal approach.

As noted above, the primary DART measurements of asteroid deflection are the ground-based telescopic measurements of the orbital period change which determine the transverse velocity change. This 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. DART will determine M from approach imaging by finding the size and the shape, and hence the volume, and assuming that the Didymos primary bulk density 2170 kg m^{-3} [4,8] applies also to the secondary.

LICIACube makes an important contribution to this mass determination because it will provide images of the non-impact hemisphere of Dimorphos obtained after closest approach, viewing the side of Didymos not seen by DART. LICIACube images will significantly improve the volume determination for Dimorphos and hence also the mass estimate.

However, the more important contribution of LICIACube imaging to determination of β arises from the inference of ejecta momentum both in direction and magnitude. The LICIACube flyby trajectory, with its 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 in much the same way as measurements of the DART impact crater will be (crater measurements will be obtained by the ESA Hera mission).

LICIACube ejecta plume images further provide information on the direction of the ejecta momentum as well as the magnitude [5], important for accurate determination of the vector momentum transfer from the DART impact. The DART measurement of the orbital period change, as noted above, directly measures only the transverse component of velocity change.

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], using specific observables from the plume images, which include the time at which clearing of ejecta becomes evident over the impact site.

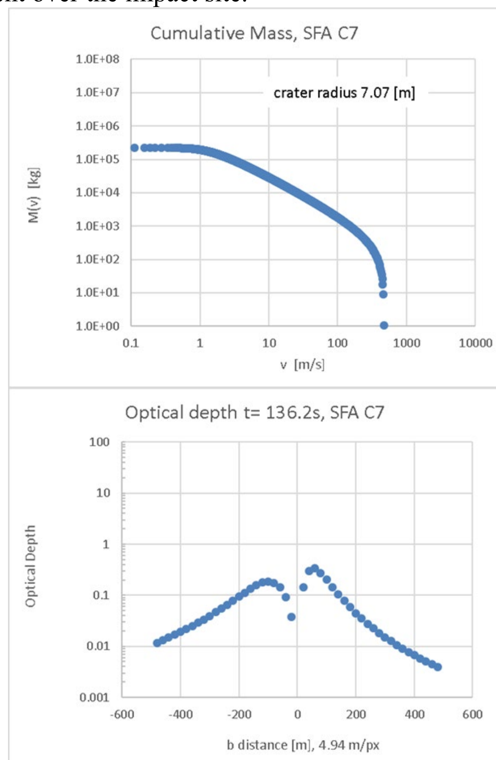

Figure 1. (upper panel) cumulative ejecta mass versus velocity distribution, weak target case from point source crater scaling [5,12]. (lower panel) plume model optical depth profile, for image 136.2 s after DART impact, from range 200 km. Clearing has started over impact site.

References: [1] Cheng A. F. et al. (2018) PSS, 157, 104–115. [2] Cheng A. F. et al. (2016) PSS, 121, 27–35. [3] Michel, P et al. (2018) ASR, 62, 2261–72. [4] Michel P. et al. (2016) ASR., 57, 2529–2547. [5] Cheng A. F. et al. (2020) Icarus, doi.org/10.1016/j.icarus.2020.113989 [6] Scheirich P. and Pravec P. (2009) Icarus, 200, 531–547. [7] Rivkin A. et al. 2021, PSJ, submitted. [8] Dotto E et al. (2021) PSS, in press. [9] Stickle, A.M. et al (2015) Procedia Eng., 103, 577–584. [10] Bruck Syal, M. al. (2016) Icarus, 269, 50–61. [11] Stickle, A. M. et al. (2020) Icarus, 338, doi: 10.1016/j.icarus.2019.113446. [12] Housen K., Holsapple K. (2011) Icarus 211, 856–875.

Acknowledgments: AFC, NLC, ASR, AS, CT, DCR, EF, and OB thank NASA for support of the DART mission. ED and VDC thank the Italian Space Agency for support of LICIACube. PM and MK thank ESA for support of Hera. P.M. thanks the EU Horizon 2020 program for support of NEO-MAPP.