THE DOUBLE ASTEROID REDIRECTION TEST (DART): NEW DEVELOPMENTS. A. F. Cheng[1], A. S. Rivkin[1], N. L. Chabot[1], [1]JHU/APL, MD USA (andrew.cheng@jhuapl.edu)

Introduction: The NASA Double Asteroid Redirection Test (DART) mission will be the first space experiment to demonstrate asteroid deflection by a kinetic impactor. DART will impact the secondary member of the [65803] Didymos binary asteroid system in late September, 2022 in order to demonstrate the ability to modify the trajectory of the moon through momentum transfer. DART is part of the Asteroid Impact & Deflection Assessment (AIDA) international cooperation along with the ESA Hera mission study. 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. DART will provide validation of the kinetic impactor technique and improve models of kinetic impactor effects to enable applicability to different targets. The DART mission was confirmed in August, 2018.

The impact of the 650 kg DART spacecraft at 6.65 km/s on the 160-m Didymos moon will change the binary orbital period by ~10 minutes (more than a 1% change) assuming momentum transfer efficiency $\beta = 1$. This change will be measured by supporting Earth-based optical and radar observations, since Didymos in October, 2022 will be only 0.0748 AU from Earth. Ground-based optical observations of the Didymos light curve will measure the period change via the timing of mutual events, while radar will observe the orbital motions. These measurements determine the orbital velocity change from the DART impact.

The momentum transfer efficiency βdepends on impact conditions such as local slope, on target physical properties such as strength and porosity, and on internal 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 models which predict the effects on impact outcomes 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 the terminal approach.

The DART impact will release a large volume of particulate ejecta that may be directly observable from Earth or possibly resolvable as a coma by ground-based telescopes [1]. The impact ejecta will also be observed by the LICIA Cube 6U CubeSat which is provided by the Italian Space Agency to be carried by DART to Didymos. LICIA Cube would be released ~2 days prior to the impact, so as to perform a separate flyby of Didymos with closest approach several minutes after the DART impact. It will obtain images of the impact ejecta and their evolution, the DART impact site and impact crater if the ejecta plume is sufficiently transparent, and the non-impact hemisphere of the target asteroid.

AIDA with both DART and AIM will be the first fully documented impact experiment at asteroid scale, including characterization of the target's properties and the outcome of the impact to test and refine our understanding and models at an actual asteroid scale. AIDA will check whether current extrapolations of material strength from laboratory scale to asteroid scale are valid. AIDA will validate the kinetic impactor technique to deflect a small body and reduce risks for future asteroid hazard mitigation.

DART: The momentum transfer efficiency β of a kinetic impactor is the ratio of the momentum transferred to the target over the incident momentum. Because there is momentum carried away by impact ejecta released back towards the incident direction, this β generally exceeds unity [6,3,4]. There are many unknowns that affect β, which is critical to predicting the amount of deflection to be achieved by a kinetic impact.

Table 1. DART Mission Design with NEXT ion propulsion

Launch Date	22 July 2021
Arrival Date	27 September 2022
Arrival Relative Speed	6.65 km/s
Maximum Earth Distance	0.1316 AU
Earth Distance at Impact	0.0748 AU
Solar Distance	0.934 AU – 1.05 AU
Arrival Solar Phase Angle	53.3°
Impact Angle to Orbit Plane	24.4°
Flyby of 1994 AW1	09 July 2022
Flyby Speed	14.26 km/s
Flyby Solar Phase Angle	80.6°

DART Mission and Payload: The DART baseline mission has changed from that given in [1] and again from that described in [3]. DART will launch as a primary payload and be injected directly into an interplanetary transfer orbit. DART use the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system for the transfer to Didymos (see Table 1). DART will be the first mission to fly the NEXT propulsion system.

The DART payload consists of a high-resolution visible imager to support the primary mission objective of impacting the target body through its center. The DART imager is required for optical navigation and for autonomous targeting to hit the 160-m Didymos moon. The DART imager DRACO is derived from New Horizons LORRI [5]. DRACO will use a 20.8 cm aperture, f/12.6 telescope to obtain images at 0.5 arc second per pixel. DART will determine its impact location within 1 m and will characterize pre-impact surface morphology and geology to <20 cm/px.

DART Observable Outcomes: The DART impact on the Didymos moon will occur on Sept. 27, 2022, a few weeks earlier than in [3]. With a larger ~650 kg spacecraft incident at 6.65 km/s, the impact momentum is significantly increased from that in [3], leading to a larger target deflection and a larger crater. Fig. 1 shows the expected changes in the Didymos orbit after the DART impact, assuming unit momentum transfer efficiency and Keplerian motion, with a Didymos system mass 5.28×10^{11} kg and a secondary mass of 4.8×10^{9} kg as in [1]. The binary orbit before the DART impact is assumed to be circular, since zero eccentricity is consistent with light curve observations [7]. Only the impulse component along the orbit velocity causes an orbital period change. DART will target true anomaly of 270°, where the impact will decrease the orbit period by ~10 min and change the eccentricity and inclination. DART will target the moon's center-of-figure, but will induce both free and forced librations [4].

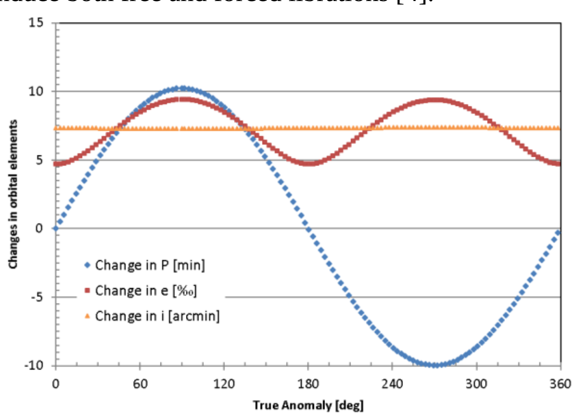

Figure 1. Changes in Didymos binary orbit period, eccentricity, and inclination after DART impact. DART will target true anomaly of 270°and reduce the orbit period.

The ground-based telescopic measurements of the orbital period change after the DART impact will directly determine the efficiency of the impact kinetic energy transfer to circular orbit energy (a 1% period change corresponds to 0.667% energy change). However, the period change measurement determines only the velocity change component along the circular motion, constraining one component of the vector momentum transfer. DART observations will constrain the other components as well with high resolution images of the impact site [3] and with impact impact simulations [3] accounting for effects of local slopes, topography and structures (of the spacecraft and of the target, such as boulders). The impact simulations are further needed to understand effects of target strength, porosity and other physical properties [8].

The ESA Hera mission [2,4], currently in Phase B1 study, plans a rendezvous with Didymos in 2026. Hera will directly measure the mass of the DART target to determine the tangential momentum transfer, combined with the DART measurement of tangential velocity change. Hera will also measure the DART impact crater diameter and depth, to strongly constrain target physical properties, and it will make precise measurements of the Didymos orbital and spin states. These measurements, especially libration, further constrain vector momentum transfer from the DART impact.

The LICIA Cube cubesat, to be provided by the Italian Space Agency, will be carried by DART to Didymos. LICIA Cube is a 6U+ cubesat based on the ArgoMoon cubesat which will fly to the Moon on the NASA EM-1 mission. Like ArgoMoon, it has 3-axis stabilization and 56 m/s propulsion capability. After release 2 days prior to the DART impact, LICIA Cube will perform a separation maneuver, autonomously acquire Didymos with its imagers, and then perform a flyby of Didymos with closest approach several minutes after the DART impact. Afterwards it will return data directly to Earth via an X-band link.

LICIA Cube will observe the ejecta plume from the DART impact and will obtain high resolution images of the surfaces of both bodies. The LICIA Cube imager uses a 7.56 cm aperture, f/ 5.2 telescope with IFOV of 2.9 arc sec per pixel. The images will study ejecta evolution, particularly of the slower velocity fraction (at <5 m/s) which is important for momentum transfer.

DART will return fundamental new information on hypervelocity impact responses of an asteroid, and it will improve and validate models and simulations of kinetic impact to reduce uncertainty of momentum transfer in future kinetic impactor missions.

References: [1] Cheng A. F. et al. (2016) Planet. Space Sci., 121, 27–35. [2] Michel P. et al. (2016) Adv. Space Res., *57*, 2529-2547. [3] Cheng A. F. et al. (2018) Planet. Space Sci., 157, 104-115. [4] Michel, P et al. (2018) Adv. Space Res., 62, 2261-72. [5] Cheng A.F. et al. (2008) Spa. Sci. Revs. 140, 189. [6] Holsapple K. and Housen K. (2012) Icarus, 221, 875. [7] Scheirich P. and Pravec P. (2009) Icarus, 200, 531. [8] Stickle, A.M. et al (2015) Procedia Eng. 103, 577-584.