ASTEROID IMPACT AND DEFLECTION ASSESSMENT (AIDA) MISSION: THE DOUBLE ASTEROID REDIRECTION TEST (DART). A. F. Cheng[1], P. Michel[2] , O. Barnouin[1], A. Campo-Bagatin[3], P. Miller[4], P. Pravec[5], D. C. Richardson[6], A.S. Rivkin[1], S. R. Schwartz[2], A. Stickle[1], K. Tsiganis[7], S. Ulamec[8], [1]JHU/APL, MD USA (andrew.cheng@jhuapl.edu), [2]Lagrange Lab., Univ. Côte d'Azur, Obs. Côte d'Azur, CNRS, Nice, France, [3]Univ. Alicante, Spain, [4]LLNL, USA, [5]Ondrejov Obs, Czech Rep., [6]Univ. MD, USA, [7]Univ. Thessaloniki, Greece, [8]DLR, Germany

Introduction: The Asteroid Impact & Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor. AIDA is a joint ESA-NASA cooperative project [1,2], that includes the ESA Asteroid Impact Mission (AIM) rendezvous spacecraft and the NASA Double Asteroid Redirection Test (DART) mission. The AIDA target is the near-Earth binary asteroid 65803 Didymos, which will make an unusually close approach to Earth in October, 2022. The ~300-kg DART spacecraft is designed to impact the Didymos secondary at 7 km/s and demonstrate the ability to modify its trajectory through momentum transfer. DART and AIM are currently Phase A studies supported by NASA and ESA respectively.

The primary goals of AIDA are (1) perform a full-scale demonstration of the spacecraft kinetic impact technique for deflection of an asteroid, by targeting an object larger than ~100 m and large enough to qualify as a Potentially Hazardous Asteroid; (2) measure the resulting asteroid deflection, by targeting the secondary member of a binary NEO and measuring the period change of the binary orbit; (3) understand the hypervelocity collision effects on an asteroid, including the long-term dynamics of impact ejecta; and validate models for momentum transfer in asteroid impacts, based on measured physical properties of the asteroid surface and sub-surface. The primary DART objectives are to demonstrate a hypervelocity impact on the Didymos moon and to determine the resulting deflection from ground-based observatories. The DART impact on the Didymos secondary will cause a measurable change in the orbital period of the binary.

The AIM spacecraft will be launched in Dec. 2020 and arrive at Didymos in spring, 2022, several months before the DART impact. AIM will characterize the Didymos binary system by means of remote sensing and in-situ instruments both before and after the DART impact. The asteroid deflection will be measured to higher accuracy, and additional results of the DART impact, like the impact crater, will be studied in great detail by the AIM mission.

AIDA DART: When a kinetic impactor of mass m strikes a target at speed U, the impulse p transferred to the target exceeds mU because of momentum p_{ej} carried away by impact ejecta released back towards the incident direction, and the momentum transfer efficiency β is defined by

$$p = \beta mU = p_{ej} + mU$$

where $\beta > 1$ unless there are ejecta released in the forward direction. There are many unknowns that affect the deflection of an incoming asteroid by a kinetic impact, such as its size, mass and physical properties. If energy and momentum are applied impulsively to the asteroid through a kinetic impact, how much deflection will result, in what direction, and what additional consequences may there be (e.g., fragmentation, changes in rotation state)? How will these outcomes depend on the physical properties of the asteroid and the projectile [1,3,4]?

The combined mission AIDA will make the first measurement of momentum transfer efficiency β from hypervelocity kinetic impact at full scale on an asteroid, where impact conditions of the projectile are known, and physical properties and internal structures of the target asteroid are also characterized. The supporting Earth-based optical and radar observations and numerical simulation studies are an integral part of the DART mission. The two mission components of AIDA, namely DART and AIM, are each independently valuable, but together provide a greatly increased knowledge return.

Mission and Payload: The baseline DART mission launches in December, 2020 to impact the Didymos secondary in September, 2022. There are multiple launch opportunities for DART leading to impact around the 2022 Didymos close approach to Earth. The December 20, 2021 launch for DART shown by Cheng et al. [1] is the back-up launch opportunity.

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 to support optical navigation on approach and autonomous navigation in the terminal phase. The imager is derived from the New Horizons LORRI instrument (Cheng et al. 2008), which used a 20 cm aperture Ritchey-Chretien telescope to obtain images at 1 arc second per pixel. The DART imager will determine the impact point within 1% of the target diameter, and it will characterize the pre-impact surface morphology and geology of the target secondary asteroid to <20 cm/px.

DART Observable Outcomes: Figure 1 shows predicted Didymos binary orbit changes from the >300 kg DART spacecraft impact at ~7 km/s [2]. From the system mass 5.28×10^{11} kg and the diameter ratio [6], the calculated mass of the secondary is 4.8×10^{9} kg. For an assumed $\beta = 1$, the target Δv ~0.4 mm/s.

If the binary orbit before the kinetic impact is assumed to be circular, since zero eccentricity is consistent with current orbit observations [7], then only the component of Δv along the orbit velocity component causes an orbital period change. The changes in the period, eccentricity, and inclination of the binary orbit depend on the orbit phase at which the impact occurs (Figure 1). The period change vanishes if the impact occurs at either of two orbit phases where the incident momentum is orthogonal to the orbital velocity; one of which is chosen as the zero of true anomaly in Figure 1. DART will target a true anomaly near 90°, where the period change and the eccentricity change are both maximized at ~4.4 minutes and 0.004, respectively. This period change, in an 11.92 hour orbit period, is expected to be observable within a few days.

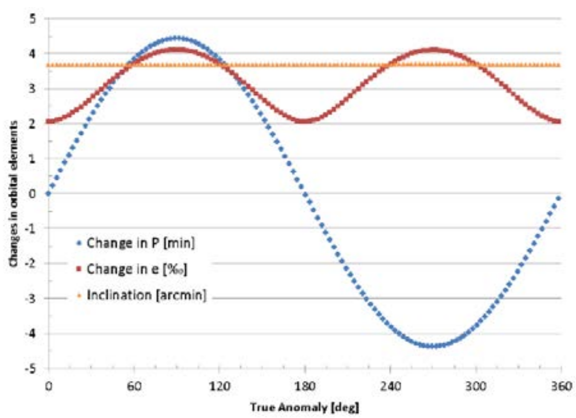

Figure 1. Changes in binary orbit period, eccentricity, and inclination after DART impact at 27.5° out of the orbit plane, assuming a total speed change of 0.4 mm/s and an initial circular orbit.

The crater size and momentum transfer efficiency β can be predicted [2] using crater scaling relations and assuming ballistic trajectories to find the momentum carried off to infinity by ejecta. Crater scaling relations are from Housen and Holsapple [8], who used laboratory measurements of impact crater ejecta mass and velocity distributions. Their four strength-dominated target cases are used (basalt, weakly-cemented basalt WCB, perlite-sand PS, and sand-fly ash SFA).

The β predictions in Table 1 for DART, modeled as a 300 kg sphere at 7.03 km/s, are similar to previous results [1,3,9], where the basalt case yields much higher values than the other cases. The predicted β from the DART impact is uncertain and could span at least the range of values shown in Table 1. Also shown is the mass fraction of ejecta released into temporary binary orbits, which will be accreted by the primary, re-accreted by the secondary, or lost from the system. AIM will make direct observations of these ejecta.

Table 1 DART Kinetic Impact Results

	Basalt	WCB	PS	SFA
Transfer efficiency β	3.324	1.096	1.229	1.30
Crater radius [m]	4.89	3.06	8.47	5.70
Temporary orbiting mass	<1%	<1%	32%	<1%

The DART kinetic impact will not only make a crater of ~6 to ~17 meters diameter (Table 1) but will also release a large volume of particulate ejecta that may be directly observable from Earth or even resolvable as a coma or an ejecta tail by ground-based telescopes. The DART ejecta cloud will increase the amount of reflected sunlight in proportion to the cross sectional area of ejecta compared to that of Didymos, assuming ejecta to have the same albedo. The ejecta area is estimated assuming a size distribution adopted from the size distribution measured for Itokawa regolith (gravel, cobbles and blocks) by Hayabusa [10]. Table 2 shows the predicted ejecta coma brightness.

Table 2 Brightness of Coma from DART Ejecta

	Basalt	WCB	PS	SFA
brightening (mag)	-0.08	-0.02	-0.38	-0.12
Integrated V mag	17.3	18.8	15.5	16.8

DART will return fundamental new information on hypervelocity impact responses of an asteroid as a function of its strength, surface physical properties, and internal structure, and it will improve and validate models and simulations of kinetic impact to reduce uncertainty of momentum transfer in future kinetic impactor missions.

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