The Double Asteroid Redirection Test (DART): Overview and Update.

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Overview: The Double Asteroid Redirection Test (DART) will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor [1]. DART is currently in Preliminary Design Phase ("Phase B"), and is part of the Asteroid Impact and Deflection Assessment (AIDA), a joint ESA-NASA cooperative project. The AIDA target is the near-Earth binary asteroid 65803 Didymos, an S-class system that will make a close approach to Earth in fall 2022. The DART spacecraft is designed to impact the secondary of the Didymos system (Didymos B) at 6 km/s and demonstrate the ability to modify its trajectory through momentum transfer. The primary goals of AIDA (Table 1) are: (1) perform a full-scale demonstration of the spacecraft kinetic impact technique for deflection of an asteroid; (2) measure the resulting asteroid deflection, by targeting the secondary member of a binary NEO and measuring the resulting changes of the binary orbit; and (3) study hypervelocity collision effects on an asteroid, validating models for momentum transfer in asteroid impacts.

Table 1: DART Investigation Goals

Goals	Measurements
Demonstrate kinetic impactor deflection of an asteroid by impacting Didymos B	Period change of the Didymos binary system induced by DART impact, with Earth-based observations
Characterize the amount of deflection	
Improve modelling and assess momentum transfer efficiency of hypervelocity asteroid impact	Location of the impact site and local surface geology
	Sizes and shapes of Didymos A and B

The DART impact on the Didymos secondary will change the orbital period of the binary by several minutes, which can be measured by Earth-based optical and radar observations. The baseline DART mission launch window is open from late 2020 to spring 2021 for an impact into Didymos B in October 2022 near the time of its close pass of Earth, which enables an array of ground- and space-based observatories to participate in gathering data. The AIDA project will provide the first measurements of momentum transfer efficiency from hyper-velocity kinetic impact at full scale on an asteroid, where the impact conditions of the projectile are known, and physical properties and internal structures of the target asteroid are also characterized. The DART kinetic impact is predicted to make a crater of 6 to 17 meters diameter, depending on target physical properties, 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.

Need for DART: The planetary defense community has found that three technologies are sufficiently mature to warrant consideration an asteroid impact threat arose [2]: impulsive deflection by stand-off nuclear explosion, gradual orbit change via a nearby mass (the "gravity tractor" concept), and impulsive deflection via a sudden addition of momentum (the "kinetic impactor" concept). *DART is designed to be the first meaningful demonstration of a kinetic impactor for planetary defense.*

DART is needed because there are key unanswered questions about the kinetic impactor technique. Studies considering asteroid mitigation suggest kinetic impactors are useful in situations where ΔV of mm/s to cm/s are appropriate. Such studies envision the use of kinetic impactors on would-be hazardous asteroids a decade or more before their Earth impact date. This amount of time is enough to allow deflection, but the ΔV imparted is a very small fraction of a typical Near Earth Object's (NEO) heliocentric speed, which is typically several tens of km/s. Thus, measuring this small fractional change in velocity can be a challenge. In addition, there is great uncertainty in the efficiency of momentum transfer from an impactor to the target, with current models and computer simulations extrapolated many orders of magnitude from experiments. The innovation used by DART to overcome the difficulty of measuring small fractional velocity changes is to use the secondary of a binary asteroid system as the target of the kinetic impactor, which will also allow an experiment to be conducted at the appropriate scale. Near-Earth asteroid satellites typically have orbital speeds of order cm/s to a few m/s around their primaries with orbit periods of order tens of hours, and a change of orbital speed by mm/s quickly results in offsets in orbital phase compared to the pre-impact state that can be easily measured either by an accompanying observer platform or by ground-based assets.

DART is designed to be an end-to-end demonstration of a deflection mission, delivering a ΔV of the correct order of magnitude to a real geological target of an appropriate size using well-understood technology. Upon completion, we will measure the efficiency of momentum transfer from kinetic impactor to target, and understand this process on a scale that allows hypervelocity impact codes to be extended to other targets.

Table 2: Didymos Apparitions

Opposition Date	Peak V Mag*	Minimum Earth Distance (AU)
10 Apr 2015	20.58	1.24
28 Mar 2017	20.25	1.14
13 Mar 2019	19.79	0.97
20 Feb 2021	18.91	0.70
19 Aug 2022	14.45	0.07
10 Jan 2023	16.48**	0.30**

*The peak V magnitude does not always occur on the opposition date. **Over 2022—2023 Didymos steadily retreats from Earth and has two distinct opposition times. The V magnitude and Earth distance for 2023 are listed for the opposition date.

The Didymos System: The asteroid system (65803) Didymos fulfills the needs of a kinetic impactor demonstration as described above. It is a binary system with a satellite of a size that allows an appropriate change of ΔV to be made and measured. The Didymos system was observed as a radar target in 2003 and makes several optical apparitions prior to 2022 (Table 2), allowing its baseline state to be well characterized. Didymos has been spectrally classified as an S-type asteroid [3], and its modeled composition is like the very common ordinary chondrite meteorites [4]. The ubiquity of ordinary chondrites suggests that Didymos' properties are shared by a large fraction of objects classified as Potentially Hazardous Asteroids (PHA).

DART Measurements: DART carries one instrument, a LORRI-derived imager called DRACO. About 1 hour before DART's impact, Didymos B becomes a resolved object. Resolvable images with more than 25 pixels across Didymos B are available within roughly 5 min before impact. Shape models of the components of the Didymos system will be produced from the images collected by using stereophotoclinometry (SPC) with limb constraints [5]. Modeling of DRACO images is being done to estimate the expected uncertainties on volume measurements.

Besides being used for modeling the shapes of Didymos A and B, the images acquired in the proximity phase of the DART mission provide inferences on the broad geological properties of the Didymos system (even though only hemispherical coverage will be obtained), with ~m/pixel coverage of Didymos A which is commensurate to the ground-sample distance of most images acquired by Hayabusa. Such data allow assessment of the size, shape, location, and frequencies of blocks on both objects in the Didymos system that can — as for Itokawa [6] — help confirm the rubble-pile nature of these objects. The final suite of images obtained during this phase of the mission will be of Didymos B and the target site where DART will impact. The images will view the target site with a ground-sample distance ranging from 20 cm/pixel 13s before impact to 3 cm/pixels 2s before impact (Figure 1).

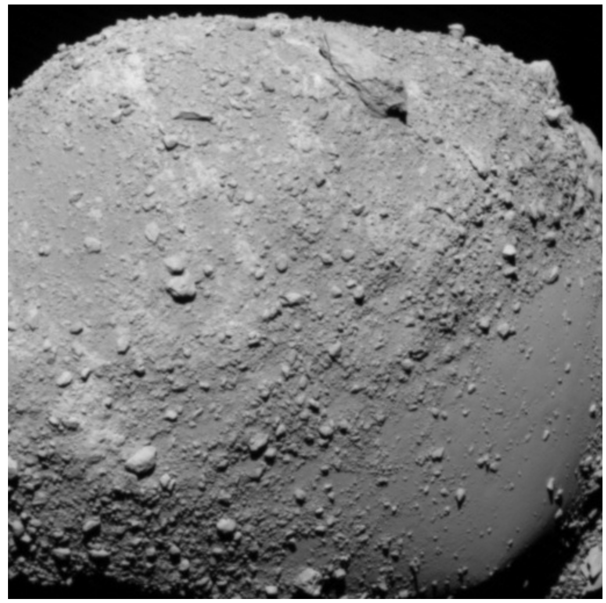

Figure 1: Hayabusa image of Itokawa at 50-cm pixel scale. Planned DRACO imaging will achieve the required 50-cm pixel scale ~17 s prior to impact, and higher resolution images will continue to be acquired and downlinked during the final seconds of the mission.

References: [1] A. F. Cheng et al. (2016) Planetary snd Space Science 121, p. 27-35. [2] National Research Council (2010), https://doi.org/10.17226/12842. [3] J. de León et al. (2006) Advances in Space Research 37, 178-183. [4] T. L. Dunn et al. (2013) Icarus 222, 273-282. [5] R. W. Gaskell et al. (2008) Met. Plan. Sci. 43, 1049-1061. [6] A. Fujiwara et al. (2006) Science 312, 1330-1334.