4th IAA Planetary Defense Conference – PDC 2015
13-17 April 2015, Frascati, Roma, Italy

IAA-PDC-15-04-02
ASTEROID IMPACT AND DEFLECTION ASSESSMENT MISSION: Double Asteroid Redirection Test (DART)

Andy Cheng[(1)], **A. Stickle**[(1)], **J. Atchison**[(1)], **O. Barnouin**[(1)], **A. Rivkin**[(1)], **Patrick Michel**[(2)], **Stephan Ulamec**[(3)], **and the AIDA Team**

[(1)]*JHU/APL, 11100 Johns Hopkins Road, Laurel, Maryland 20723, USA*
email: andy.cheng@jhuapl.edu
[(2)]*Lagrange Laboratory, University of Nice-Sophia Antipolis, CNRS, Côte d'Azur Observatory, CS 34229, 06304 Nice Cedex 4, France, tel.: +33 4 92 00 30 55*
[(3)]*DLR RB-MC, Linder Höhe 1, 51147 Cologne, Germany*

Keywords: *Asteroid Deflection, Binary Asteroid, Asteroid Characterization, Kinetic Impactor, Impact Simulations*

Extended Abstract—

The Asteroid Impact & Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate an asteroid impact hazard mitigation technique by using a kinetic impactor to deflect an asteroid. AIDA is an international collaboration between NASA and ESA, composed of two mutually supportive mission elements, ESA's Asteroid Impact Mission (AIM) and NASA's Double Asteroid Redirect Test (DART). AIM is in ESA Phase A/B1 study, and DART is planned to enter NASA Phase A in 2015. The AIDA target is the near-Earth binary asteroid 65803 Didymos, which will make an unusually close approach to Earth in 2022. The ~300-kg DART spacecraft is designed to impact the moon at 6.25 km/s and demonstrate the ability to modify the trajectory of an asteroid through momentum transfer. The Didymos system is an ideal target for the kinetic impactor experiment in October, 2022 because it is easily observable from Earth, and because it is accessible for a low cost rendezvous mission. Thus, the deflection of the moon following the DART impact will be measured by Earth-based observations of the change in the orbital period of the moon. In addition, AIM will rendezvous with the Didymos system in advance of the DART impact, and it will characterize the moon and make detailed studies of the impact effects including crater formation and orbital deflection. While each of these missions has its value independently, the return is greatly increased when they fly jointly.

The primary goals of DART are (i) to demonstrate a hypervelocity spacecraft impact on a small near-Earth asteroid (NEA) and (ii) to measure and understand the deflection caused by the impact. The DART mission includes ground-based optical and radar observing campaigns of Didymos both before and after the kinetic impact experiment, as well as modeling and simulation programs. DART has the further objective to learn how to mitigate an asteroid threat by kinetic impact and to develop and validate models for momentum transfer in asteroid impacts.

The AIDA target is the binary NEA (65803) Didymos, with the deflection experiment to occur in October 2022. The DART impact on the secondary member of the binary at ~6.5 km/s will alter the binary orbit period, which will be monitored by Earth-based observatories. The DART and AIM spacecraft are launched in December and October 2020, respectively, where AIM arrives first at Didymos in May, 2022 to begin the characterization of the binary system. AIM further makes detailed measurements of the DART impact and its outcome.

Baseline payloads for AIM include the following remote sensing and in-situ instruments: a Visual Imaging System, a lander (based on DLR MASCOT heritage), a thermal infrared imager, a high frequency (decimeter-wave) radar, and a low frequency (60 MHz) radar, to measure Didymos surface and sub-surface physical properties and to study internal structures. AIM also includes an optical communication demonstration and CubeSat payloads.

DART Mission and Payload

The target of the AIDA mission will be a binary asteroid, in which DART will target the secondary, smaller member in order to alter its orbit around the primary. DART will measure the resulting period change to measure the deflection by Earth-based observations. 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 will return vital data to determine the momentum transfer efficiency of the kinetic impact and key physical properties of the target asteroid. The two mission components of AIDA, DART and AIM, are each independently valuable, but when combined they provide a greatly increased knowledge return.

The main objectives of the DART mission, which includes the spacecraft kinetic impact and Earth-based observing, are to:

- Impact the secondary member of the Didymos binary system during its close approach to Earth in September-October, 2022
- Demonstrate asteroid deflection by kinetic impact and measure the period change of the binary orbit resulting from the impact, by ground-based observations
- Determine the impact location on the target asteroid, the local surface topography and the geologic context
- Develop and validate models for momentum transfer efficiency I kinetic impacts on an asteroid

DART is targeted to impact the smaller secondary component of the binary system [65803] Didymos, which is already well characterized by radar and optical instruments [1,2]. The impact of the ~300 kg DART spacecraft at 6.5 km/s will produce a velocity change on the order of 0.4 mm/s, if the momentum is simply transferred to the target. This leads to a significant change in the mutual orbit of these two objects, but only a minimal change in the heliocentric orbit of the system, because the target's velocity change from the impact is significant compared to its orbital speed ~17 cm/s, although it is quite small compared to the heliocentric orbit speed ~23 km/s. Thus the change in the binary orbit is relatively easy to measure compared with the change in the heliocentric orbit. Production of crater ejecta, back towards the incident direction, results in an increased transfer of momentum to the target.

The DART mission will use ground-based observations to make the required measurements of the orbital deflection, by measuring the orbital period change of the binary asteroid. The DART impact is expected to change the period by ~0.5%, and this change can be determined to 10% accuracy within months of observations. The DART target is specifically chosen because it is an eclipsing binary, which enables accurate determination of small period changes by ground-based optical light curve measurements. In an eclipsing binary, the two objects pass in front of each other (occultations), or one object creates solar eclipses seen by the other, so there are sharp features in the lightcurves which can be timed accurately.

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 [3] which used a 20 cm aperture Ritchey-Chretien telescope to obtain images at 1 arc sec resolution. 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 asteroid and the primary to <20 cm/px.

The target asteroid for DART is the smaller member of the binary Near-Earth asteroid (65803) Didymos. Didymos is an already well-observed radar and optical binary system [1, 2]. Binary systems are of particular interest since they comprise roughly 15% of the NEO population, and in addition to the planetary defense applications, AIDA will be the first mission targeting a binary NEO. Ground-based reflectance spectroscopy of Didymos shows it to be a member of the "S complex" of asteroids, the most common compositional group of NEOs. This group includes the spacecraft targets (433) Eros and (25143) Itokawa and is associated with the common ordinary chondrite meteorites. The choice of an S-complex asteroid ensures that the mitigation demonstration will be applicable to a large fraction of the likeliest potential Earth impactors.

The satellite of Didymos orbits the primary with a period of 11.9 hours, a best-fit semi-major axis of 1.1 km, and a nearly circular orbit. The primary has a diameter of 800 m, the secondary 170 m. The presence of a satellite has allowed the density of the primary to be calculated as 1.7 +/- 0.4 g/cm^3. From the system mass 5.27×10^{11} kg and the diameter ratio [2], the calculated mass of the secondary is 5×10^9 kg.

The momentum transfer efficiency of the spacecraft impact is characterized by the factor β, defined as the ratio of momentum transferred to the target to the incident momentum. The momentum transfer has been calculated using either well-known point source scaling relationships or numerical simulations [4,5,6,7]. Laboratory experiments have also measured the momentum transfer efficiency versus incident velocity in various target materials [8]. These studies predict β typically in the range 1.1 to 2.5 for a variety of target material properties, with lower β for low strength, porous targets, but higher values, even β>4, are predicted for very strong, non-porous targets.

The DART and AIM missions, comprising AIDA, will return fundamental new information on the mechanical response of an asteroid, on the impact cratering process at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defense, human spaceflight, and Solar System science.

Acknowledgments

We are happy to acknowledge the support of NASA for the DART studies and the support of ESA for the AIM studies.

References

[1] Pravec, P., L. A. M. Benner, M. C. Nolan, P. Kusnirak, D. Pray, J. D. Giorgini, R. F. Jurgens, S. J. Ostro, J-L.

Margot, C. Magri, A. Grauer, and S. Larson (2003), (65803) 1996 GT, IAU Circular 8244.

[2] Scheirich, P., and P. Pravec, 2009, Modeling of lightcurves of binary asteroids, Icarus, 200:531-547.

[3] Cheng A. F. et al., (2008), Long-Range Reconnaissance Imager on New Horizons, Space Science Reviews, 140, 189, doi:10.1007/s11214-007-9271-6.

[4] Holsapple, K. A., and K. R. Housen (2012), Momentum transfer in asteroid impacts. I. Theory and scaling, Icarus, 221(2), 875–887.

[5] Holsapple, K. A. (1993), The scaling of impact processes in planetary sciences, Annual Review of Earth and Planetary Sciences, 21, 333–373.

[6] Jutzi, M., and P. Michel (2014), Hypervelocity impacts on asteroids and momentum transfer. I. Numerical simulations using porous targets. Icarus 229, 247-253.

[7] Cheng, A. F. (2013) AIDA: Test of Asteroid Deflection by Spacecraft Impact. 44th LPSC 2013, paper 2985

[8] Housen, K. R. and K. Holsapple (2012) Deflecting asteroids by impacts: what is beta? 43rd LPSC 2012, paper 2539