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AIDA: ASTEROID IMPACT & DEFLECTION ASSESSMENT

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The abstract knowledge that small body impacts on Earth continue to occur to this day became concrete reality for the residents of Chelyabinsk, Russia on Feb. 15, 2013 with the unexpected explosion of a small asteroid over the city, releasing several hundred kilotons of energy. ESA and NASA are studying techniques to protect the Earth from a potential asteroid impact, including deflection of the asteroid by a spacecraft impact. The AIDA mission will perform the first test of this technique for asteroid deflection. It is an innovative, low cost, international collaboration, consisting of two independent but mutually supporting missions, one of which is the asteroid kinetic impactor and the other is the characterization spacecraft. These two missions are, respectively, the US Double Asteroid Redirection Mission (DART) and the European Space Agency's Asteroid Impact Monitoring (AIM) mission. DART will deflect the trajectory of an asteroid and measure the deflection to within 10%. This will be done using a binary asteroid target with accurate determinations of orbital period by ground-based observations. AIDA will return vital data to determine the momentum transfer efficiency of the kinetic impact and key physical properties of the target asteroid.

AIDA follows the previous Don Quijote mission study performed by ESA in 2005-2007, with the objective of demonstrating the ability to modify the trajectory of an asteroid and measure the trajectory change. Don Quijote involved an orbiter and an impactor spacecraft, with the orbiter arriving first and measuring the deflection, and with the orbiter making additional characterization measurements. Unlike Don Quijote, DART envisions an impactor spacecraft to intercept the secondary member of a binary near-Earth asteroid, using ground-based observations to measure the deflection. In the joint AIDA mission, DART combines with the ESA AIM mission which will rendezvous with the asteroid. Each of these missions has independent value, with greatly increased return when combined. AIDA will be a valuable precursor to human spaceflight to an asteroid, as it would return unique information on an asteroid's strength and internal structure and would be particularly relevant to a human mission for asteroid mitigation. AIDA will furthermore return fundamental new science data on impact cratering and collisional evolution of asteroids. AIDA will target the binary Near-Earth asteroid Didymos with two small launches, with the deflection experiment to occur in October, 2022.

I. MISSION MOTIVATION

Roughly 54 tons of material falls on the Earth every year, with impacts of meter-sized bodies a nearly-annual event. However, much larger objects lurk nearby, astronomically speaking: nearly 1000 objects 1 km or larger are classified as near-Earth objects (NEOs), with perihelia of 1.3 astronomical units (AU) or less. Impacts with objects of that size, which would result in civilization-threatening effects, are thought to recur on roughly million-year timescales. The population of NEOs 50 m or larger is modelled to number in the hundreds of thousands. While impacts by 50-m asteroids may "only" devastate a region (like the Tunguska Event of 1908), they also occur much more frequently; we can expect those impacts on century-to-millenium timescales.

Uniquely for natural disasters, destructive impacts can not only be predicted but also potentially avoided via human action. The United States Congress directed the National Aeronautics and Space Administration (NASA) to find and characterize 90% of potentially hazardous asteroids (PHAs) 140 m and larger, following up on an earlier charge to find 90% of all km-scale NEOs. Surveys to meet this Congressional mandate are underway via ground-based and space-based telescopes, and programs are in place to characterize the sizes, shapes, rotation periods, compositions, and other properties of NEOs.

However, there are still a great many unknowns with respect to how an incoming NEO might best be deflected [1, 2]. Some elegant techniques like the "gravity tractor" or changing a target's albedo and allowing the Yarkovsky Force to change the target's orbit require decades or more for a deflection to be achieved, leading many to support so-called "impulsive" techniques with immediate effect. The use of nuclear weapons for asteroid deflection is a possibility (and perhaps the possibility most ingrained in popular culture), but brings a host of political and other complications. As a result, the non-nuclear "kinetic impactor" technique of impacting an incoming object to alter its trajectory has gained favor in the NEO science community.

While we may be technically capable of carrying out a kinetic impactor mission on a threatening asteroid, we are far from understanding its effectiveness or optimizing such a mission for success. This serves as impetus for flying a practice mission or missions to understand how asteroids and asteroidal material behave in a kinetic impact. The Don Quijote mission study, performed by ESA in 2005-2007 [3], had the objective of demonstrating the ability to modify the trajectory of an asteroid using a kinetic impactor and to measure the trajectory change. The Don Quijote mission was judged to be unaffordable, but a demonstration of asteroid deflection by spacecraft impact remains of interest, as the magnitude of the deflection resulting from a spacecraft impact is highly uncertain, owing to the poorly understood contribution of recoil momentum from impact ejecta.

The Asteroid Impact and Deflection Assessment (AIDA) mission concept follows Don Quijote as a cheaper, more flexible alternative. AIDA consists of two independent but mutually supporting mission concepts, one of which is the asteroid kinetic impactor and the other is the characterization spacecraft. These two missions are, respectively, the Double Asteroid Redirection Test (DART) study undertaken by the Johns Hopkins Applied Physics Laboratory with support from members of NASA centers including Goddard Space Flight Center, Johnson Space Center, and the Jet Propulsion Laboratory, and the European Space Agency's Asteroid Impact Monitoring (AIM) mission study.

DART will be the first ever space mission to demonstrate asteroid deflection. This will be done using a binary asteroid target. AIM is a rendezvous mission which focuses on the monitoring aspects i.e., the capability to determine in-situ the key physical properties of a binary asteroid playing a role in the system's dynamic behavior.

II. AIDA OVERVIEW

The AIDA mission comprises two small spacecraft, launched separately, that will target the Near-Earth asteroid 65803 Didymos which will make unusually close approaches to Earth in 2022 and 2024. The Didymos close approaches are exceptionally favorable for a first demonstration of asteroid deflection and an impact experiment on an asteroid, as the impact occurs close to Earth and is observable at many wavelengths including radar. The deflection from the 6.25 km/s impact of a 300 kg intercept spacecraft is measurable to <10% from Earth *without a second spacecraft*, although the rendezvous spacecraft will make a superior measurement of the deflection as well as important additional measurements of the asteroid surface and interior. There are multiple intercept opportunities for both the 2022 and 2024 close approaches, as well as rendezvous opportunities for both (see Figure 1), mitigating the risks of two launches and providing program flexibility.

The DART spacecraft, the interceptor, will be launched on a Minotaur V for the baseline mission in July-Aug 2021 and impact Didymos in Oct 2022, targeted to the secondary member of the binary system. It will have an optical telescope to support terminal guidance and to obtain high-resolution images of the illuminated hemisphere and impact site. This information will determine the precise impact location and pre-impact surface morphology independently of the rendezvous spacecraft. After the impact, the rendezvous spacecraft will study the newly formed crater and impact ejecta dynamics.

For all AIDA mission options, the interceptor is on a low-energy trajectory and the impact occurs close to Earth. ***AIDA is a low-cost, low-risk, and high heritage mission***.

In 2005, the Deep Impact mission flew an impactor spacecraft into Comet Tempel 1 and observed the impact with a flyby spacecraft. Deep Impact made no measurable deflection of the comet. AIDA on the other hand will make a measurable deflection of its asteroid target, because the AIDA target is much smaller and it is in a binary system, greatly enhancing observability of the deflection. Moreover, the AIDA target Didymos is not in an Earth-crossing orbit, and there is no possibility that the deflection experiment would create an impact hazard on Earth.

III. DART DEFLECTION DEMONSTRATION

Target Asteroid: The Double Asteroid Redirection Test (DART) mission will use a single spacecraft to impact the smaller member of the binary Near-Earth asteroid (65803) Didymos in October, 2022. Didymos is an already well-observed radar and optical binary system [4, 5]. Binary systems are of particular interest since they comprise roughly 15% of the NEO population [6, 7], 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 use of an S-complex asteroid will help in planning for impact and constraining outcomes, and also ensure that the mitigation demonstration will be applicable to a large fraction of the likeliest 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 150 m. The presence of a satellite has allowed the density of the primary to be calculated as 1.7 +/- 0.4 g/cm^3.

Deflection Effects: The key objective of the AIDA mission is to detect any change in the velocity (Δv) of Didymos' moon as a result of kinetic impact by the DART spacecraft into its surface. We demonstrate below that for the 300 kg DART spacecraft at 6.25 km/s, the resulting kinetic impact will cause a sufficient change of momentum to the moon that alter the mutual orbit of these two objects. By targeting the smaller member of a binary system, the DART mission produces an orbital deflection which is larger and easier to measure than would be the case if DART targeted a typical, single near-Earth asteroid so as to change its heliocentric orbit.

Current theories of asteroid satellite formation predict satellites should have similar or smaller densities than the primaries. If we assume the secondary is a sphere of 150 m diameter and a density of 1.7 g/cm^3, the calculated mass is 3×10^9 kg. For the least efficient impact possibility, where all of the impact momentum goes into changing the momentum of the satellite, simple calculations show that Δv of the moon would equal ~0.3 mm/s and its period would change by roughly 10 minutes, easily detectable even from Earth-based observations. It is expected that the formation of the DART crater will provide more than just the momentum transferred by the DART spacecraft itself as shown below..

For the most dramatic results, the impact should happen close to the moon's perihelion [1, 2], though the circular orbit of Didymos' secondary makes this point moot. The magnitude of the change in velocity depends primarily on the production and integrated velocity of the excavated ejecta produced by the impactor that is not retained by the moon's gravity field [8]. Impact experiments and numerical efforts clearly demonstrate that the efficiency and velocity of ejecta production depend on the target properties and local gravity [9, 10, 11,12]. Impact angle [13, 14, 15] and location relative to the center of the mass may also be important in evaluating how well an asteroid can be displaced via kinetic impact.

Here we have investigated some nominal target conditions and impact geometries when evaluating the momentum transfer efficiency expected by the impact of the DART spacecraft on Didymos' moon. The impactor autonomously targets the asteroid centroid, to maximize the impact momentum transfer and deflection Δv.

The momentum transfer is estimated from well-known scaling relationships developed for the study of laboratory impact craters [15]. These relationships have been found to give reasonable estimate of the efficiency of cratering for a variety of target conditions and impactors. Following the approach taken by *Holsapple and Housen* [8] where we account for ejecta that is retained by the target asteroid, we compute the momentum transfer and Δv for four target types: a strong rock, a weakly cemented rock, a highly porous weak rock, and a cohesionless sand-like surface. The momentum generated is parameterized by β, the total momentum multiplication factor resulting from adding the spacecraft momentum to the momentum of the ejecta excavated by the crater generated during impact. The calculations assume a 2m diameter spacecraft of 300 kg, impacting a 150 m moon at 6.25 km/s. The resulting β ranged from 1.28 to 4.1, so the Δv imparted by the spacecraft ranged from 0.5-1.52 mm/s.

Numerical integrations [16] of the momentum carried away by impact ejecta, accounting for gravitational bending of ejecta trajectories, yielded similar β estimates of 1.28 to 2.52 for a variety of low strength, high strength, low cohesion and high cohesion target materials. These estimates also bound the Δv from the DART impact to be on the order of ~mm/s.

Payload: The DART mission returns vital data needed to determine the momentum transfer efficiency from the DART impact. DART will carry a high resolution visible imager, based on New Horizons LORRI [17], to study the target object as well as its binary companion. DART will autonomously guide itself to impact using this imager. The high resolution images returned to Earth shortly before impact will enable determination of the precise impact point as well as fundamental assessments of the target body geology and surface physical properties. This information will answer questions such as, is the target object a rubble pile asteroid (a gravitationally re-accumulated assembly of fragments from a catastrophic collision)? Is there a mobile regolith surface? This information greatly enhances physical interpretation of the momentum transfer efficiency using the measured binary orbital change, and will be the first step to gaining understanding of, and eventually becoming able to predict, the results of hypervelocity kinetic impacts for asteroid deflection.

The DART payload based on New Horizons LORRI uses a 20-cm aperture, CCD camera. Payload objectives are: to support autonomous guiding to impact the target body through its center, to determine the impact point within 1% of the target diameter, and to characterize the pre-impact surface morphology and geology of the target asteroid and the primary to <20 cm/px (goal).

The DART mission uses a simple, high-technology-readiness, and low-cost spacecraft to intercept Didymos.. The spacecraft is single string, and most of the components are either rebuilds of previous APL designs or commercial off-the-shelf equipment. Terminal guidance to the target asteroid is accomplished using the LORRI telescope for optical navigation and using autonomous guidance algorithms based on APL experience in development of the Standard Missile. A mono-propellant propulsion system is used for all delta-V burns. Three-axis attitude control is performed using thrusters as on New Horizons.

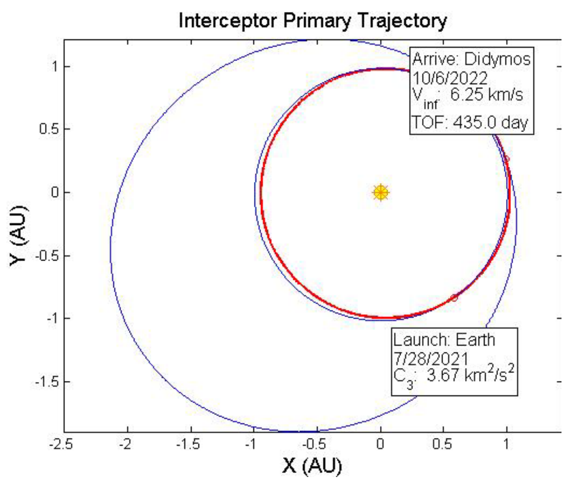

Figure 1 DART mission impacts Didymos in 2022 under excellent Earth-based viewing conditions

Mission Design: The baseline mission design is shown in Figure 1 and Table 1. The interceptor spacecraft trajectory was designed to minimize launch energy and maximize arrival velocity. Additionally intercept must occur on the sunlit hemisphere and with relative velocity mostly in the orbital plane, maximizing orbital period change. Science return is maximized if the AIM rendezvous spacecraft is present before, during and after impact, but the science goals can be met even if the rendezvous occurs after the impact. This allows a resilient mission design with two launches and substantial cost savings over a single medium-class EELV launch.

The DART trajectory remains near 1 AU from the Sun and has a maximum Earth distance <0.11 AU. The DART launch will use a Minotaur V launch vehicle. The impact velocity on Didymos is 6.25 km/s. A mono-propellant propulsion system is used for Δv burns and for attitude control.

The DART spacecraft needs to carry ~100 m/s of ΔV in all cases. Time of flight is less than two years to arrive at the asteroid. Activities are minimal during the cruise phase of the mission, so operations expenses can be minimal. The mission duration is less than two years for the interceptor.

	Baseline
Launch Date	7/28/2021
Impact Date	10/6/2022
Launch C3 (km²/s²)	3.67
Arrival Relative Velocity (km/s)	6.25
Time of Flight (days)	435
Maximum Earth Distance (AU)	0.11
Earth Distance at Impact (AU)	0.07
Incoming Solar Phase Angle (deg)	66
Impact Angle to Orbit Plane (deg)	14

Table 1: In the baseline mission for 2022 impact (Figure 2) DART launches in July 2021, with a two-week launch window. Backup intercept opportunities exist for the 2022 and the 2024 encounters

Interceptor Concept: The interceptor is a simple, high-TRL, and low-cost spacecraft to intercept Didymos. The spacecraft is single string, and most of the components are either rebuilds of previous APL designs or COTS equipment. Figure 2 shows the spacecraft block diagram.

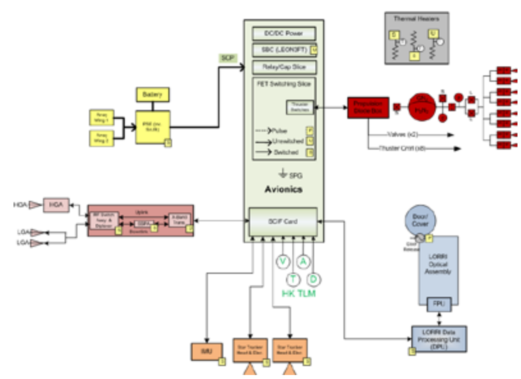

Figure 2 Interceptor block diagram – a simple spacecraft

The key technical driver for the mission is terminal guidance to the target asteroid, which is accomplished using the LORRI instrument from New Horizons for optical navigation. The spacecraft dry mass is estimated to be 167 kg. A ΔV of 100 m/s is required, resulting in an additional 19 kg of wet mass. This results in a total mass of 235 kg (with 30% margin). Power is estimated at 202 W.

The spacecraft wet mass is estimated to be 235 kg with 30% dry mass margin and with delta-V capability of 100 m/s. Ballast mass would be added to reach the launch capability of 330 kg. Power is estimated at 202 W. The spacecraft has a fixed 1-meter high gain antenna with X-band telemetry. The mechanical layout of the spacecraft is optimized for the terminal navigation phase, with fixed geometries for the imager, high gain antenna, and solar arrays. The spacecraft has no gimbals or deployables.

Mechanical Subsystem: The mechanical layout of the spacecraft has been optimized for the final terminal navigation phase. The HGA, LORRI instrument and solar arrays are fixed, with angles between them optimized for the terminal guidance geometry. Prior to terminal guidance, the spacecraft will be sun tracking, with slews to downlink data and capture images. The spacecraft has no gimbals or deployables.

Spacecraft structure is made from aluminum honeycomb with aluminum facesheets. A mono-propellant propulsion system is used for all ΔV burns as well as attitude control. Thermal control is a passive system, with thermostats and survival heaters used to maintain temperatures. Three-axis attitude control is performed using thrusters as on New Horizons which currently uses LORRI. A low-cost IMU and star tracker provide pointing knowledge.

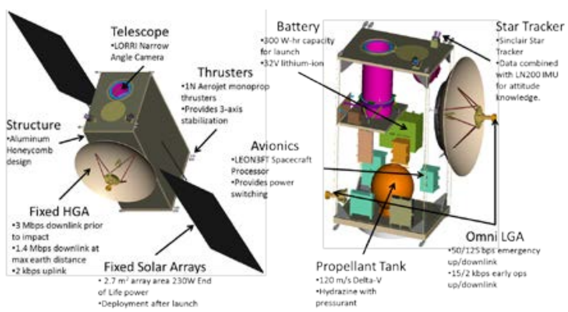

Figure 3: Mechanical Layout

Power and Avionics: DART has a data handling system based upon the low-cost and low-power LEON3FT. Heritage of the CDH system is from the MBD design. Additionally, power system electronics are used to condition 230W of power from the solar arrays, augmented by a 300 W-hr battery. Processing of the image data will be done in Instrument electronics, so the avionics are only responsible for handling telemetry and guidance algorithms.

Communications: The spacecraft has a fixed 1 meter HGA antenna, with an X-band, 3 Mbps data link to DSN. Data rates are driven by the need to return high resolution images to determine the spacecraft impact location on the target asteroid. Additionally, there are two LGAs used for telemetry data and provide spherical coverage. The radio is heritage from the APL Frontier radio developed for RBSP.

Long Range Reconnaissance Imager (LORRI): The optical navigation instrument selected is a rebuild of LORRI, with heritage from New Horizons [17]. LORRI is based on a Ritchey–Chrétien telescope with a 20 cm aperture and ~1 arcsecond resolution. LORRI is a capable imager, allowing for early discrimination between the primary and secondary of Didymos, allowing the terminal guidance more capability.

Image centroiding for terminal guidance can be completed in LORRI's Data Processing Unit (DPU), allowing for minimal image processing on the spacecraft processor. LORRI's DPU is centered around an FPGA, which also provides data compression.

Guidance and Navigation: Guidance to Didymos consists of three different stages: Coast, Primary-Targeting and Terminal Guidance. During coast, DART uses traditional deep-space navigation with ground-computed states and maneuvers. Once the primary of Didymos because visible through LORRI, the navigation uses images of the primary to do course correction and reduce uncertainty.

Several TCMs are planned to reduce navigation errors prior to starting autonomous terminal navigation, reducing the ΔV needed for terminal guidance. The final four hours of approach use autonomous guidance algorithms based on APL experience in development of the Standard Missile.

Ground based navigation aims DART for an intercept with the Didymos primary. At the hand-off, the terminal guidance software initializes and diverts to the target using proportional navigation. The autonomy shuts down in the final 2 minutes to allow for a science imaging campaign.

In simulation, DART is initialized for terminal guidance with a 20 km error in its targeting, and given highly degraded sensor characteristics. Even in these conditions, the autonomy converges on the target and impacts successfully, using less than 10 m/s ΔV. The nominal case has an accuracy of less than 5m.

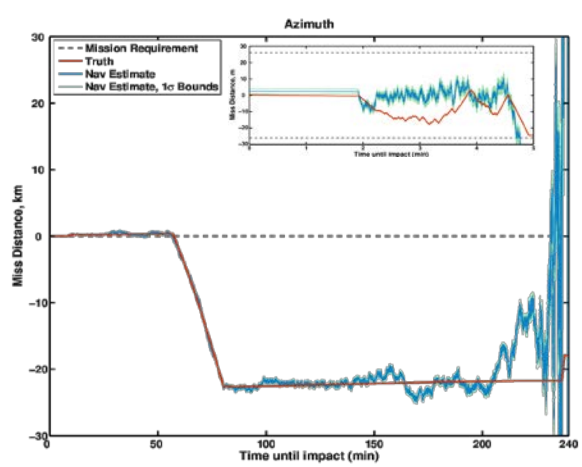

Figure 4: Terminal Guidance Simulation Accuracy

IV. ASTEROID IMPACT MONITORING

The main objectives of ESA's Asteroid Impact Monotoring (AIM) mission are to: determine binary asteroid orbital and rotation state; analyze size, mass and shape of both binary components; analyze geology and surface properties; observe the impact crater and derive collision and impact properties (requires the DART mission). AIM will be a small spacecraft mission.

The strawman payload for the characterization of the asteroid, which satisfies the minimum requirements, consists of a Narrow Angle Camera, a Micro laser Altimeter, a Thermal IR Imager and a NIR spectrometer. Some specs for this instrument suite are shown in Table 2. However, as the mission moves forward it is possible that further payload elements, including a landing package, could be added.

Instrument	Mass (kg)	Power (W)	Data Rate (kbps)	FOV (°)
NAC	1.5	0.75	1	4
µ-LIDAR	2.5	4.0	0.5	0.003
TIR Imager	1.5	1.0	0.1	4
NIR Spec	1.5	7.0	10	4

Table 2: Strawman payload for AIM component of AIDA

The AIM rendezvous mission is designed to be compatible with the VEGA launch vehicle, which would require an additional "kick motor" (e.g., STAR-48) to perform the Earth escape burn. The baseline trajectory (Figure 5) begins with a launch in the summer of 2019, with an Earth swing-by in fall 2020. The baseline assumes a SNECMA PPS-1350 Hall-effect thruster, as demonstrated by ESA's SMART-1 lunar mission.

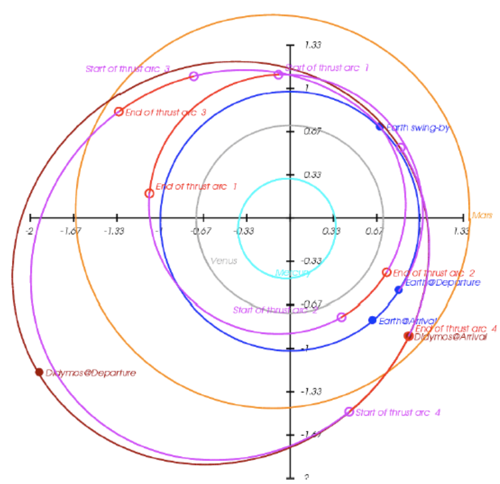

Figure 5. AIM electric propulsion trajectories.

On arrival, the spacecraft would perform continuous observations from a serious of "station points" fixed point relative to the asteroid inertial frame and at a safe distance, out of the sphere of influence of both Didymos components. In order to be able to image the two bodies for precise measurements of the orbital state, distances of 13.5 to 17 km were considered for the 1st characterization point. The AIM study required an arrival at Didymos two months prior to impact, although that requirement may be relaxed in the future. If the AIM spacecraft arrives at the target before the DART spacecraft, the impact of the DART spacecraft will be observed from a 2nd characterization point of 100 km to avoid any damage by impact debris.

V. AIM PLUS DART

Ideally, both AIM and DART will move forward to target Didymos (or another suitable asteroid) for a joint mission. If so, the mission objectives can be addressed in full - object characterization, impact test, and momentum transfer assessment. The rendezvous spacecraft (AIM), which will characterise the binary asteroid, would be under responsibility of ESA.

The combined concept key feature is AIM's capability to characterise the post-impact scenario (in a similar way that Stardust attempted to do for Deep Impact's Temple 1 impact crater) including asteroid spectral type determination, material properties investigation and crater observation, which should help constrain models and the momentum transfer in a way that would be more difficult with either of the two spacecraft missions alone. If ESA's spacecraft (AIM) could arrive before the APL/JHU impactor spacecraft (DART) it may also be possible to observe the impact as well as the resulting ejecta and crater.

The DART mission will allow performing an impact experiment and momentum transfer measurement at the real scale of an asteroid for the first time, with the knowledge of both the impact conditions and the estimate of the mass and density of the target. This would thus be the first data point at relevant scales that can be used to test our ability to model such an impact event with numerical codes and consequently our understanding of the impact process.

Linked with the DART mission, the AIM mission (in addition to the science return AIM has by itself) will give us the size of the crater. There is great benefit to obtain the size of the crater in addition to the momentum transfer measurement. Indeed, it is well known that effects of porosity and strength of the targets are hardly separable unless both the crater size AND the momentum transfer efficiency are characterized. Using data of both missions will thus allow us to probe the internal structure of the target, and determine its influence on the impact process.

While the change in orbit period caused by the impact will be easily detectable from Earth, any change in orbit inclination or eccentricity will very likely be too small to directly measure without AIM on station.

Dust and ejecta dynamics: The AIM/DART mission will provide a unique opportunity, similar to Deep Impact. The kinetic energy of the impactor is somewhat smaller. However, the target object is expected to be of rocky nature rather than cometary and it is much smaller (150 m diameter versus 3 km). It can be expected that a cloud of ejecta will result from the DART impact and that, subsequently, a prominent crater will be visible. It may be possible to observe the ejecta by radar or a light curve effect but this requires further investigation. If the AIM spacecraft is to arrive at the binary after the impact it may be possible, via comparison with DART images of the surface prior to impact, to observe the ejecta emplacement. However, the highest science return would be achieved by observing the impact directly while it is taking place using the AIM spacecraft. From optical observations the ejecta sizes and velocities versus angular distribution after a high velocity impact can be determined. The size distribution can also give direct information on the target material properties. For instance, a rubble pile with a preferred rubble size distribution should be reflected in the eject size distribution. If an infrared spectrometer were available, the plume temperatures of the impact could be directly measured. These data would yield valuable information to constrain the energy partitioning during a large-scale impact.

If the observer spacecraft can be maneuvered close enough to the impact site, in-situ dust sensors like piezo-sensors could be used to determine the time-of-flight of the ejecta particles. An instrument using large-surface piezo electric foils could be used for this. With the observer spacecraft orbiting the secondary, the precise size and shape of the crater can be determined after the impact. Again this observation would allow to constrain both scaling laws and numerical models of the cratering process; this information is important both for better understanding the cratering process of planetary surfaces and for assessing the impact threat on Earth. Additionally, in-situ measurements of the dust produced during the impact may provide important results for the many fields of study mentioned in the list above.

VI. SUPPORTING OBSERVATIONS

To help ensure mission success, a campaign of Didymos observations will be undertaken to provide a baseline prior to impact, collect data during the impact, and study the effects of the impact. The main observing strategy for the AIDA support is to use lightcurve observations, which can be made from a wide variety of telescopes around the world with the CCD cameras typically found at observatories.

The orbital period of well-observed eclipsing NEAs can generally be determined to an accuracy of about 0.1% from light curve observations [e.g., 5]. A change of the period by that order caused by an impact can be detected by ground-based follow-up observations. The orientation of the orbit plane of the system is provided by the geometry of the events, if observed over several apparitions. The spin period of the primary component of the binary can be determined even more accurately, to the order of 0.01 % or even better. We again note that we can anticipate a much larger change in the rotation period of Didymos. The orientation of the spin axis can be constrained if the asteroid was observed from various geometries. Didymos' spin pole is not yet pinned down, but there are several opportunities to do so prior to the launch(es) of AIDA.

DART targets the asteroid Didymos in October, 2022, during a close approach to Earth. The DART impact will be observable by ground-based radar and optical telescopes around the world, providing exciting opportunities for international participation in this first asteroid deflection experiment. 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. As noted above, an initial estimate suggests the DART impact could change the period by 0.5% – 1%, a change that would accumulate fast enough that roughly a month after the impact the satellite would be on the opposite side of the primary compared to its unperturbed ephemeris. 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.

Dates	**V Range**	**P1 events?**	**P2 events?**
Jan-Jun 2015	21-22	No	Yes
Jan-Jun 2017	21-22	No	Yes
Dec 2020-May 2021	19-22	No	Yes

Table 3: Observing opportunities for Didymos from 2013 through 2021 (i.e., when Didymos is bright enough and far enough from the Sun in the sky) when mutual events for the system will allow the two best-fit pole positions to be distinguished from one another. Also included in the table is the apparent V magnitude range. Pole 1 is $(\lambda,\beta) = (157^\circ,19^\circ)$; Pole 2 is $(329^\circ,-70^\circ)$.

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