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# Asteroid Impact and Deflection Assessment mission ☆

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ABSTRACT

The Asteroid Impact and Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor to deflect an asteroid. AIDA is an international cooperation entering Phase A study at NASA and ESA, consisting of two mission elements: the NASA Double Asteroid Redirection Test (DART) mission and the ESA Asteroid Impact Mission (AIM) rendezvous mission. The primary goals of AIDA are (i) to test our ability to perform a spacecraft impact on a potentially hazardous near-Earth asteroid and (ii) to measure and characterize the deflection caused by the impact. The AIDA target will be the binary asteroid (65803) Didymos, with the deflection experiment to occur in October, 2022. The DART impact on the secondary member of the binary at ~6 km/s will alter the binary orbit period, which can be measured by Earth-based observatories. The AIM spacecraft will characterize the asteroid target and monitor results of the impact in situ at Didymos. AIDA will return fundamental new information on the mechanical response and impact cratering process at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defense, human spaceflight, and near-Earth object science and resource utilization. AIDA will return unique information on an asteroid's strength, surface physical properties and internal structure. Supporting Earth-based optical and radar observations, numerical simulation studies and laboratory experiments will be an integral part of AIDA.

## 1. Introduction

On Feb. 15, 2013, an exceptionally close approach to Earth by the small asteroid 2012 DA14 was eagerly awaited by astronomers around the world, but a different small asteroid unexpectedly impacted Earth over Chelyabinsk, Russia the same day without warning. The Chelyabinsk meteor released several hundred kilotons TNT of energy and injured over 1500 people. This dramatic reminder of the asteroid impact hazard re-emphasized the importance of discovering hazardous asteroids and learning how to mitigate the hazards. The Asteroid Impact and Deflection Assessment (AIDA) mission will be the first demonstration of a mitigation technique to protect the Earth from a potential asteroid impact, by performing a spacecraft kinetic impact on an asteroid to deflect it from its trajectory.

AIDA is an international collaboration between NASA and ESA, 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 NASA Double Asteroid Redirection

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Test (DART) and the ESA Asteroid Impact Mission (AIM). The AIDA target will be the binary asteroid (65803) Didymos, with the deflection experiment to occur in October, 2022. The DART impact on the secondary member of the binary at ~6 km/s will alter the binary orbit period, which can be measured by Earth-based observatories. The AIM spacecraft will rendezvous with Didymos in advance of the DART impact to characterize the asteroid target, and AIM will monitor results of the DART impact in situ, to measure precisely the deflection resulting from the kinetic impact experiment.

AIDA will return fundamental new information on the mechanical response and impact cratering process at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defense, human spaceflight, and near-Earth object science and resource utilization. AIDA will return unique information on an asteroid's strength, surface physical properties and internal structure. Supporting Earth-based optical and radar observations, numerical simulation studies and laboratory experiments will be an integral part of the AIDA mission.

## 2. Motivation

Roughly 50–100 tons of extraterrestrial material falls into the atmosphere of the Earth every year, with infalls of meter-sized bodies a daily event [1]. 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 or less. Impacts of 1 km objects, which would result in civilization-threatening effects, are thought to occur on roughly million-year timescales. The population of NEOs 50 m or larger is modeled to number in the hundreds of thousands. While impacts by 50-m asteroids may devastate “only” a region (like the Tunguska Event of 1908), they also occur much more frequently, occurring on century-to-millennium timescales.

Uniquely for natural disasters, destructive impacts can be not only predicted but also potentially avoided by human action. The United States Congress directed NASA to find and characterize at least 90% of potentially hazardous asteroids (PHAs) 140 m and larger, following up on an earlier charge to find at least 90% of all km-scale NEOs. Surveys to meet this Congressional mandate are underway via ground-based and a space-based telescopes, and programs are in place to characterize the sizes, shapes, rotation periods, compositions, and other properties of NEOs. Moreover, in 2013, the General Assembly of the Committee of Peaceful Use of Outer Space (COPUOS) of the United Nations (UN) welcomed with satisfaction the recommendations made by its Near-Earth Object Working Group for an international response to the near-Earth object impact threat, which was endorsed by the COPUOS Scientific and Technical Subcommittee at its fiftieth session and by the Committee at its fifty-sixth session. This led to the establishment of an International Asteroid Warning Network (IAWN) by the UN.

However, there are still a great many unknowns with respect to how an incoming NEO might best be deflected [2,3]. Some elegant techniques like the “gravity tractor” or changing a target's albedo and allowing the Yarkovsky force [4] to change the target's orbit require decades or more for a deflection to be achieved, whereas the so-called “impulsive” techniques achieve immediate effect. The use of nuclear weapons for asteroid deflection is an impulsive technique (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.

## 3. Objectives and requirements

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. The resulting period change can be measured to within 10% 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 October, 2022.
- Demonstrate asteroid deflection by kinetic impact and measure the period change of the binary orbit resulting from the impact.
- Determine the impact location on the target asteroid, the local surface topography and the geologic context.

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 [5,6]. The impact of the >300 kg DART spacecraft at 6.25 km/s will produce a velocity change on the order of 0.4 mm/s, which 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. This is 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.

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 [7] 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 AIM mission objectives are addressing three main pillars: asteroid deflection, asteroid science and technology demonstration. In this frame, the main objectives of the AIM rendezvous spacecraft are to:

- Characterize the Didymos secondary component by analyzing its dynamical state, mass, geophysical properties, surface and subsurface structure.
- Demonstrate deep-space optical communication technology and perform inter-satellite communication network with CubeSats and lander.
- Deploy the MASCOT-2 lander on Didymos secondary asteroid and sound its interior structure.

When AIM is operated together with DART, the mission covers supplementary objectives:

- Determine the momentum transfer resulting from DART's impact by measuring the dynamical state of Didymos after the impact and imaging the resulting crater.
- Study the shallow subsurface and deep-interior structure of the secondary after the impact to characterize any change.

This will enable to derive the impact response of the object as a function of its physical properties. Additionally, AIM would be in an ideal position to image the ejecta plume providing valuable data to validate impact models.

## 4. DART mission design

The DART spacecraft, the interceptor, can be launched on a small class launch vehicle for the baseline mission in December 2021 to impact Didymos in Oct 2022, targeted to the secondary member of the binary system. There are multiple intercept opportunities for both the 2022 and 2024 close approaches providing program flexibility. For all AIDA mission options, the interceptor is on a low-energy trajectory and the impact occurs close to Earth. The baseline mission design is shown in Fig. 1 and Table 1. The interceptor spacecraft trajectory was designed to minimize launch energy and offer favorable arrival conditions. The interceptor's arrival relative velocity should lie mostly in the Didymos system's orbital plane to maximize the orbital period change, and the solar phase angle at arrival should be minimized for optimum illumination of the target. 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.

The DART trajectory remains near 1 AU from the Sun and has a maximum Earth distance $<0.11$ AU. The impact velocity on Didymos is 6.25 km/s. A mono-propellant propulsion system provides $\sim 100$ m/s for trajectory corrections, terminal guidance, and attitude control.

The DART time of flight is less than two years to arrive at the asteroid in October, 2022. Activities are minimal during the cruise phase of the mission, and the mission duration is less than two years.

## 5. Target asteroid

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 [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 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 h, 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 $1.7 \pm 0.4$ g/cm$^3$.

## 6. Deflection effects

The key objective of the AIDA mission is to detect any change in the velocity ($\Delta v$) of Didymos' moon as a result of kinetic impact by the DART spacecraft into its surface. 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. We estimate below the magnitude of the mutual orbit changes from impact of the 300 kg DART spacecraft at 6.25 km/s.

Current theories of asteroid satellite formation predict satellites should have similar or smaller densities than the primaries. From the system mass $5.27 \times 10^{11}$ kg and the diameter ratio [6], the calculated mass of the secondary is $5 \times 10^9$ 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 $\Delta v$ of the moon would be $\sim 0.4$ mm/s and the period change would be easily

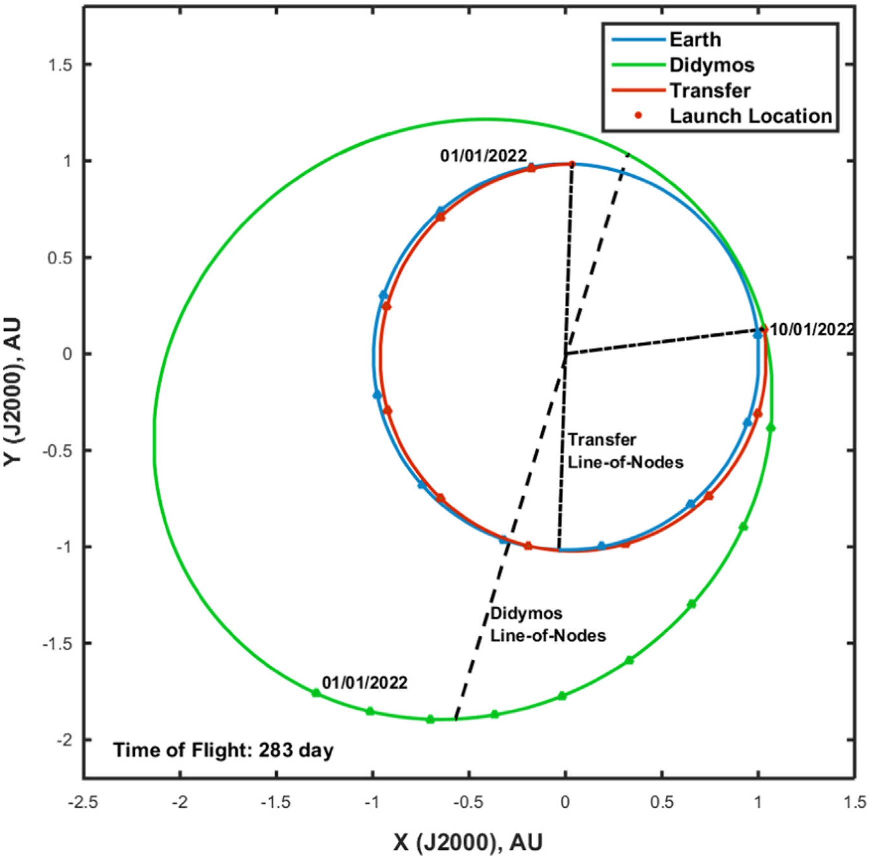

**Fig. 1.** DART launches Dec 20, 2021 and intercepts Didymos on Oct 1, 2022.

detectable by 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 [2,3], 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 [8–11]. Impact angle [12–14] 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 $\Delta v$.

The momentum transfer has been estimated using either well-known scaling relationships or numerical simulations [15,16]. We outline a simple method following [8] to estimate the momentum transfer efficiency using the so-called point source scaling law relationships [9] for a variety of target conditions. These scaling relations give reasonable estimates of cratering efficiency under a wide range of impact conditions, when the projectile size and the initial coupling time are small such that the impact can be regarded as a point source of energy and momentum [13].

**Table 1**
Baseline DART Trajectory.

| Launch date | Dec 20, 2021 |
|---|---|
| Launch C3 | 3.74 $\mathrm{km}^2/\mathrm{s}^2$ |
| Arrival relative velocity | 6.27 km/s |
| Time of flight | 283 days |
| Maximum earth distance | 0.13 AU |
| Earth distance at impact | 0.07 AU |
| Incoming solar phase angle | 59.8° |
| Impact angle, relative to orbit plane | 25.7° |

We consider a spherical impactor of mass $M_i$ and velocity $v_i$ incident on a much larger target of mass $M$ and radius $R$, with the impact occurring along the centerline. The impulse transferred to the target $p$ exceeds $M_i\ v_i$ because of momentum $p_{ej}$ carried away by impact ejecta, and the momentum transfer efficiency $\beta$ is defined by

$$p = \beta M_i v_i = p_{ej} + M_i v_i \tag{1}$$

where $\beta > 1$ unless there are ejecta released in the forward direction (a possible effect, not included here). We use the crater scaling relations and ballistic trajectories to find the momentum carried off to infinity by ejecta.

The total ejecta mass is written $M_{ej}$ and is given by point source scaling relations [13] as

$$\pi_V = M_{ej}/M_i = K\left(\pi_2\left(\frac{\delta}{\rho}\right)^{1/3} + \pi_3{}^{(2+\mu)/2}\right)^{-3\mu/(2+\mu)} \tag{2}$$

Here $\pi_2 = ga/v_i{}^2$ and $\pi_3 = Y/\rho v_i{}^2$ where $\pi_2$ is the gravity scaled size, with $g$ the target surface gravity and $a$ the projectile radius; and $\pi_3$ is the strength parameter with target impact strength $Y$ and target density $\rho$. The coupling parameter $\mu$ depends on target properties and takes a value in the range $1/3 < \mu < 2/3$. Empirical values for these parameters, based on fitting to terrestrial experiments [13], are shown in Table 2 for several target types.

The ejecta velocity distribution takes the power law form $M(>v) = M_{ej}(v/v_{min})^{-n}$ above a minimum velocity $v_{min}$, where point source scaling gives the index $n = 3\,\mu$. The minimum ejecta velocity $v_{min}$ is written $v_{min} = \max\left(0.5\sqrt{gR_c},\ 0.24\sqrt{Y/\rho}\right)$ with $R_c$ the crater radius (i.e., the former applies in gravity-controlled cratering, and the latter applies in strength-controlled cratering).

The ejecta momentum becomes $p_{ej} = -\int_{v_{min}}^{\infty} dv\, n\, M_{ej}(v/v_{min})^{-n}(v_{inf}/v)\cos\theta$ with $\theta$ the angle between the asymptotic velocity and the incidence direction and with $v_{inf}$ the ejecta speed at infinity. If the ejecta are launched below the escape velocity, $v_{esc} = \sqrt{2GM/R}$, then we put $v_{inf} = 0$.With the dimensionless parameter $u = v/v_{esc}$ the ejecta momentum is [16]

$$p_{ej} = fM_{ej}v_{esc}(v_{esc}/v_{min})^{-n}$$

$$f = -n\int_{u_{min}}^{\infty} du\, u^{-n-1}\sqrt{u^2-1}\,\cos\theta$$

Here $u_{min} = \max(v_{min}, v_{esc})/v_{esc}$ and $\cos\theta$ is expressed in terms of $u$ assuming ejection at 45° to the incidence direction onto ballistic trajectories, by

$$\cos\theta = \sin\varphi\sin\alpha - \cos\varphi\cos\alpha$$

$$\cos\varphi = (u^2-1)\left(1+2u^2(u^2-1)\right)^{-1/2}$$

$$\cos\alpha = \left(1+2u^2(u^2-1)\right)^{-1/2}$$

The integral over $u$ is evaluated by numerical quadrature.

The momentum transfer efficiency is then given by

$$\beta - 1 = \frac{p_{ej}}{M_i v_i} = \frac{fM(>v_{esc})v_{esc}}{M_i v_i} \tag{3}$$

Hence $\beta - 1$ is the ratio of (momentum from the escaping mass, at escape velocity) divided by incident momentum, times the numerical coefficient $f$ from crater ejecta dynamics. This model accounts for the ejecta velocity distribution, the need to escape from the target, and the ballistic slowing and bending of ejecta. It does not account for the target's being in a binary system.

Examples of the momentum transfer efficiency and crater radii from this model are given in Table 2 for a 1.4 m diameter spacecraft of 300 kg, impacting a 170 m moon at 6.25 km/s, using four sets of target material cases from [13]. Didymos is not wet, but the “wet soil” case is representative of relatively non-porous, moderate strength target material. The dry soil case, on the other hand, is a more porous, lower strength target.

Table 2 shows $\beta$ values in the range 1.53–2.52. Since $f$ does not depend on incident velocity, the quantity $\beta - 1$ in the strength limit obeys the power law $\beta - 1 \propto v_i{}^{3\mu-1}$ agreeing with [19]. For highly porous targets where $\mu$ can be $\sim$0.4, $\beta - 1$ increases very slowly with $v_i$. However, for non-porous targets with μ near its upper limit 2/3, then $\beta - 1$ increases almost linearly with $v_i$. In lab experiments with very strong, non-porous targets, $\beta > 4$ is reported [19].

Numerical simulations of asteroid fragmentation resulting from the impact of a kinetic impactor yielded similar $\beta$ estimates of 1.1–2.3 for a variety of low strength, high strength, low cohesion and high cohesion target materials, at impact speeds of 1–15 km/s [15]. These estimates also bound the $\Delta v$ from the DART impact to be on the order of $\sim$mm/s.

Table 3 shows the changes in Kepler orbit parameters of the Didymos binary system caused by the DART impact, assuming the velocity change is along the incident momentum. The changes in the Kepler elements depend on the true anomaly at the impact, and the maximum values are shown in the table.

**Table 2**
Momentum transfer efficiency and crater radius from DART impact into various target materials.

| Case | $\mu$ | $K$ | $Y$ [M Pa] | $\rho$ [g cm$^{-3}$] | $\beta$ | $R_c$ [m] |
|---|---|---|---|---|---|---|
| Dry soil | 0.41 | 0.132 | 0.18 | 1.7 | 1.53 | 5.04 |
| Wet soil | 0.55 | 0.095 | 1.14 | 2.1 | 2.52 | 6.74 |
| Soft rock | 0.55 | 0.105 | 7 | 2.65 | 1.93 | 4.23 |
| Hard rock | 0.55 | 0.12 | 18 | 2.65 | 1.78 | 3.41 |

**Table 3**
Changes in Kepler orbit parameters of Didymos binary from DART impact.

| Imparted $\Delta v$ [mm/s] | 0.3 | 0.4 | 0.5 | 1.52 |
|---|---|---|---|---|
| Δ semi-major axis [m] | 3.65 | 4.87 | 6.10 | 18.8 |
| Δ period [sec] | 199 | 266 | 333 | 1029 |
| Δ period [%] | 0.46% | 0.62% | 0.78% | 2.4% |
| Δ eccentricity | 0.0031 | 0.0041 | 0.0051 | 0.016 |
| Δ inclination [deg] | 0.046 | 0.061 | 0.077 | 0.235 |

## 7. Asteroid impact mission

ESA's Asteroid Impact Mission (AIM) is a small mission of opportunity (Figs. 2 and 3) to explore and demonstrate new technologies for future science and exploration missions while addressing planetary defense and performing asteroid scientific investigations. Thus, AIM main objectives are to: determine Didymos secondary asteroid orbital and rotation state, size, mass and shape and analyze geology and surface properties. In the AIDA mission together with the DART kinetic impact, AIM will observe the impact crater and derive collision and impact

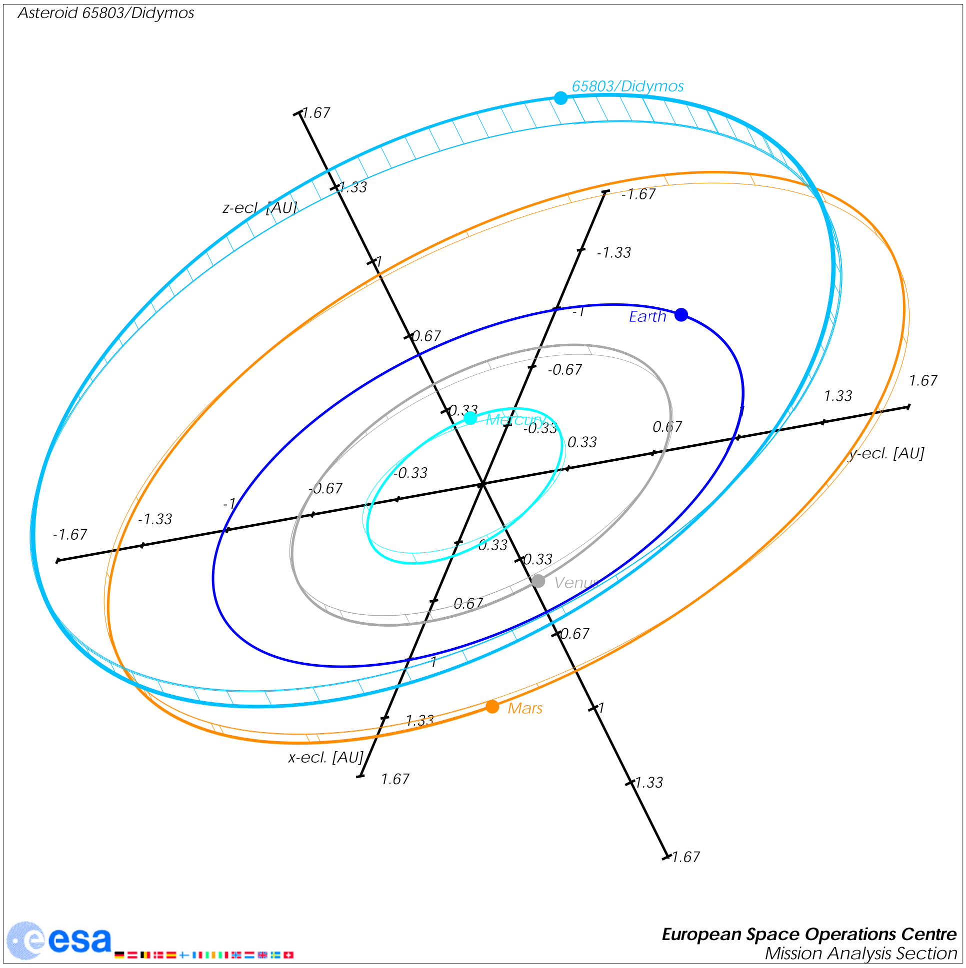

**Fig. 2.** AIM interplanetary trajectory.

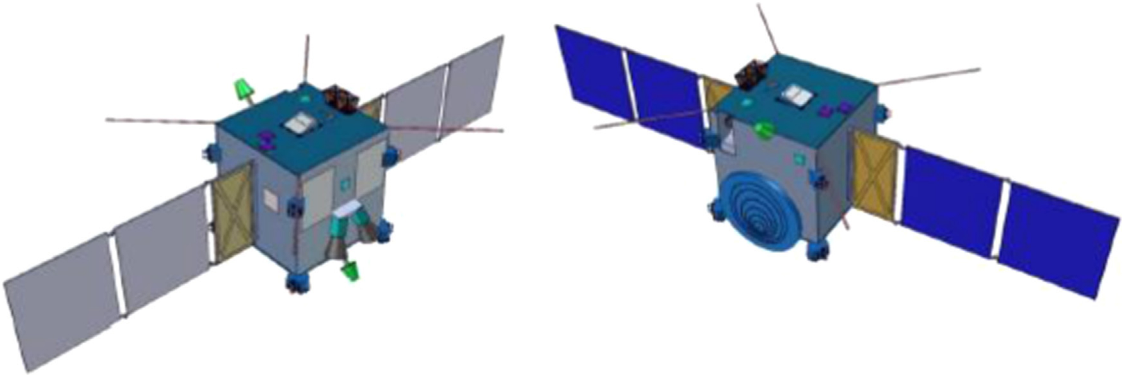

**Fig. 3.** AIM spacecraft in deployed configuration.

properties. AIM will be a small spacecraft mission demonstrating a number of technologies including deep-space optical communication and inter-satellite network in deep-space with a number of CubeSats deployed in the vicinity of the Didymos system and lander on the surface of the secondary.

In addition to the Visual Imaging System (VIS) that is part of the guidance, navigation and control system of the spacecraft, the strawman payload for the characterization of the asteroid consists of a Thermal IR Imager (TIRI), a monostatic High-Frequency Radar (HFR), a bistatic Low-Frequency Radar (LFR), the Optel-D optical communication terminal, the MASCOT-2 lander, and CubeSats opportunity payloads (COPINS). The masses for this instrument suite are shown in Table 4.

The AIM rendezvous mission design is driven by the relative geometry of Earth and asteroid (65803) Didymos and the resulting mission design of the DART high velocity impact mission in October 2022. AIM is required to arrive at its first observation station (a location about 35 km distant from the asteroid) in May, 2022 to allow for a timely asteroid characterization before DART arrival. The rendezvous mission design is summarized in Table 5.

The AIM launch shall not take place earlier than late 2020 to allow a realistic time span for all project phases leading up to the launch. Based on these constraints, an opportunity is identified in late 2020 with a transfer duration of around 19 months (i.e. arriving in mid-2022) that leads to a theoretical Earth departure velocity of approximately 5 km/s and an arrival velocity of about 1 km/s. Such a trajectory is based on a launch with a Soyuz 2.1b/Fregat MT from Kourou allowing a 21-day launch window and will lead the spacecraft to a maximum Sun distance of up to 2.2 AU and a maximum Earth range of 3.2 AU. A superior conjunction in Oct/Nov 2021 will interrupt communications but does not interfere with critical operations.

**Table 4**
Payload mass budget for AIM spacecraft component of AIDA.

| Payload | Mass [kg] | Margin [%] | Mass incl. margin |
|---|---|---|---|
| VIS | 2.2 | 10 | 2.4 |
| TIRI | 3.3 | 10 | 3.6 |
| HFR | 1.4 | 20 | 1.7 |
| LFR | 1.1 | 10 | 1.2 |
| OPTEL-D | 32.7 | 20 | 39.3 |
| MASCOT-2 | 11.7 | 10 | 13.0 |
| COPINS | 11.8 | 10 | 13.2 |
| TOTAL | 64.5 | | 74.4 |

**Table 5**
AIM rendezvous trajectory characteristics.

| Launch date | 27/10/2020 |
|---|---|
| Escape velocity [km/s] | 4.994 |
| Escape declination [deg] | 25.9 |
| Deep-space maneuver date | 20/12/2020 |
| Deep-space maneuver size [m/s] | 118 |
| Asteroid arrival date | 22/04/2022 |
| Transfer duration [d] | 544 |
| Rendezvous maneuver | 1132 |
| Total $\Delta V$ | 1250 |

Observation of the Didymos system begins from a formation-flying quasi-orbit at a distance of around 35 km from the primary allowing for a safe distance, out of the sphere of influence of both Didymos components. This station point will be within the plane of the asteroid around the sun but offset by around 45° from the direction towards the sun. Thus, the spacecraft would be positioned above the illuminated side of the asteroid at a favorable phase angle for optical observing of surface morphology.

The spacecraft position is controlled within deadbands of ± 1.5 km in the radial, normal and transverse directions. The orbit maintenance, numerically simulated taking into account gravitational and solar radiation pressure perturbations, leads to a $\Delta \nu$ budget of about 0.3 m/s per month. In order to enable more detailed characterization of the asteroid and to allow radar observations, a second observation station point at 10 km distance is considered. Finally, in the AIDA scenario, the impact of the DART spacecraft will be observed from a third characterization point of about 100 km distance to Didymos in order to avoid any damage by impacting debris.

Ideally, both AIM and DART will move forward to target Didymos for a joint mission. AIM will arrive at Didymos before the DART impact, in order to observe the collision as well as the resulting ejecta and crater. Then the mission objectives are addressed in full, to obtain Didymos characterization, monitor the kinetic impact, and perform momentum transfer assessment. The rendezvous spacecraft AIM, which will characterize the binary asteroid, would be under responsibility of ESA.

The combined concept has the additional feature, even if AIM arrives after the DART impact, that AIM can characterize the post-impact scenario, similar to Stardust-NExT [17] at the Deep Impact mission impact site on comet Tempel 1. AIM's characterization of the binary system, and its studies of the DART impact site, target surface and subsurface structures, would still be useful to constrain models of the impact and the momentum transfer even if AIM arrives after the DART impact. However, the baseline plan is for AIM to arrive before the DART impact, so that AIM will characterize the Didymos binary and the target asteroid surface and subsurface structures both before and after the DART impact.

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. Linked with the DART mission, the AIM mission (in addition to the science return AIM has by itself) will provide the size and shape 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 target 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 be measured directly without AIM.

## 8. Dust and ejecta dynamics

The AIDA mission will provide a unique opportunity to study a spacecraft kinetic impact on an asteroid, like the Deep Impact mission [18] except that the kinetic energy of the DART impactor is somewhat smaller, and AIDA impact effects are monitored by the rendezvous spacecraft AIM. In addition, the AIDA target is expected to be rocky rather than cometary, and it is much smaller (170 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 ground-based radar or a light curve effect but this requires further investigation. If the AIM spacecraft arrives at the binary after the impact, it may be possible, via comparison with DART images of the surface prior to impact, to study the ejecta emplacement. However, the highest science return would be achieved by direct observation of the impact ejecta 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 ejecta size distribution. An infrared spectrometer on AIM would measure the plume temperatures of the impact directly. These data would yield valuable information to constrain the energy partitioning during a large-scale impact.

With the AIM spacecraft at the secondary, the precise size and shape of the crater can be determined after the DART impact. Again these observations would allow us to constrain 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, this information, with in-situ measurements characterizing the Didymos binary system before and after the DART impact, allows us to understand better how binary asteroids form in the near-Earth population and how they evolve.

## 9. Conclusions

The AIDA mission will combine US and European space experience and expertise to address an international concern, the asteroid impact hazard. AIDA will target the binary Near-Earth asteroid Didymos with two independently launched spacecraft, with the deflection experiment to occur in October, 2022. 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. AIDA will furthermore return fundamental new science data on impact cratering, surface properties and interior structure.

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