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

IAA-PDC-15-04-03
ASTEROID IMPACT MISSION: A UNIQUE OPPORTUNITY TO DEMONSTRATE PLANETARY DEFENSE

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Keywords: *Asteroid deflection, binary asteroid, asteroid characterization, technology demonstration*

I. ABSTRACT

The Asteroid Impact Mission (AIM) is a small mission of opportunity currently under implementation in ESA to explore and demonstrate technologies for future missions while addressing planetary defense and performing asteroid scientific investigations. It is part of an international cooperation both at NASA and ESA, consisting of two independent mission elements: the NASA Double Asteroid Redirection Test (DART) mission and the AIM rendezvous mission. The primary goals of AIDA are to test our ability to perform a spacecraft impact on a potentially hazardous near-Earth asteroid and 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 when Didymos will be on a close approach to the Earth. The DART impact on the secondary member of the binary asteroid will alter the binary orbit period, which will be measured by both AIM and Earth-based observatories.

The AIM spacecraft will be launched from Kourou in 2020 with the following main objectives: to determine Didymos secondary asteroid orbital and rotation state, size, its mass and shape and analyze the geology and surface properties. Also, by means of ground-penetrating radar, AIM will be able to characterize for the first time the internal structure of the asteroid. In the AIDA scenario, together with the DART kinetic impact, AIM will observe the impact crater and derive collision and impact properties. AIM will be a small spacecraft mission demonstrating for the first time a number of technologies including deep-space optical communication and inter-satellite network in deep-space with CubeSats deployed in the vicinity of the Didymos system and a lander on the surface of Didymos secondary. In addition to the Visual Imaging System (VIS) that is part of the guidance, navigation and control system of the spacecraft, the 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).

II. Asteroid Impact & Deflection Assessment

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 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 about 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. In fact, 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
- 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. 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, 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.

III. Asteroid Impact Mission

ESA´s Asteroid Impact Mission (AIM) is both a technology mission of opportunity, and a mission to characterise asteroids and contribute to the evaluation of impact mitigation strategies. In addition to using spacecraft for the scientific investigation of asteroids, like in the case of the Rosetta mission that flew by the asteroids Steins and Lutetia, ESA has been considering the use of space missions for asteroid hazard assessment for almost two decades. The asteroid impact risk is low but the potential consequences to our society can be very severe. Small bodies are continually colliding with the Earth, however the vast majority of these objects are very small and pose no threat to human activity. Larger impacts are more rare but, when they occur, can lead to a major natural catastrophe. For instance the energy released from the Tohoku earthquake in Japan (3rd March 2011) was estimated to be approximately 45 megatons; this natural disaster caused an estimated economic loss of over $200 billion according to the World Bank. The effects of an asteroid impact on Earth depends on many factors such as e.g., location, asteroid trajectory or physical properties, but a small 150 m object could release several times the amount of energy released in Tohoku. As opposed to what happens with earthquakes, the technology is available to mitigate such threat, but it has never been tested in realistic conditions.

Most of the techniques that have been proposed to avoid an Earth impact events are linked to altering the course of an asteroid in a collision course with the Earth. Among the proposals, the one that is considered more mature because it is based on existing and affordable spacecraft technology, is the kinetic impactor i.e. changing the orbit of an asteroid by a direct hit of a spacecraft at a very high relative speed (several km/s). Europe has conducted thorough studies on this approach, which would be suitable to address the statistically most common threats i.e. bodies of up to a few hundred meters in diameter. In the framework of such mitigation studies, a better understanding of the fragmentation process resulting from an impact is required to answer essential questions: how does impactor momentum transfer depend on the bulk density, porosity, surface layer or internal structure of the target NEO and the velocity vector of the impactor relative to the NEO? How much impactor kinetic energy may be going into fragmentation and restructuring? Can momentum enhancing ejecta production be characterized in terms of parameters that can for many objects only be available from ground-based observations e.g. taxonomic type?

In addition to risk-related asteroid research aspects, there are important science opportunities even for a simple demonstration mission such as AIM. The scientific rationale for AIM is based on fundamental asteroid research topics that can be advanced by the mission, on aspects such as rotational evolution, collisional evolution, evolutional coupling.

The AIM mission objectives are therefore defined as follows (in order of priority):

A. AIM Scientific Research Objectives

S1. To determine geophysical properties of Didymos secondary component, hereafter called Didymoon. This includes the shape, mass, surface and shallow subsurface structure as well as the mechanical and thermal properties of the asteroid surface. In addition is shall analyze the asteroid dynamical state.

S2. To determine the momentum transfer resulting from the impact of the DART spacecraft on Didymoon, by measuring the variation of the asteroid´s period and its rotation state, and imaging of the resulting impact crater.

S3. To characterize Didymoon's deep interior structure.

S4. To compare the surface and interior of the primary and the secondary to constrain the origin of the double asteroid, e.g. to discriminate between the different proposed scenarios of binary formation that make different predictions on the internal properties of binary components, and to provide ¨ground truth¨ for simultaneous ground-based observations.

B. AIM Technology Research Objectives

T1. To carry out a Telecommunication Engineering eXperiment (TEX) based on the OPTEL-D optical terminal.

T2. To perform the Moonlet Engineering eXperiment (MEX) based on the MASCOT-2 asteroid lander.

T3. To release the Cubesat Opportunity Payload Independent Nano-Sensors (COPINS).

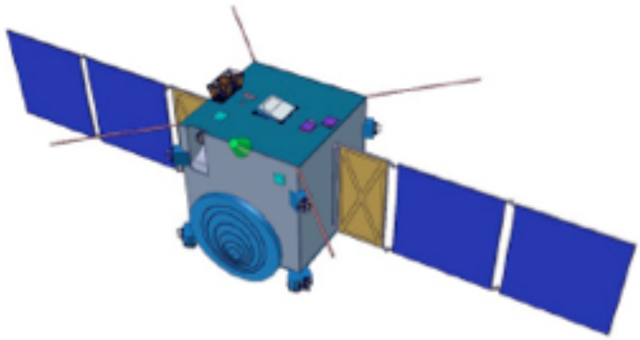
To achieve the above objectives, an asteroid research payload suite and a technology research payload suite are embarked. In addition to the Visual Imaging System (VIS) that is part of the guidance, navigation and control system of the spacecraft, the strawman payload for the characterization of the 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 hereafter:

Payload	Mass incl. margin
VIS	2.4
TIRI	3.6
HFR	1.7
LFR	1.2
OPTEL-D	39.3
MASCOT-2	13.0
COPINS	13.2
TOTAL	74.4

The objectives of these instruments are the following (in order of priority, P):

P#	Parameter	Relevance to goal	Supporting instrument(s)
1	S#1 Moonlet size, mass, shape, density	Mass key to momentum, size to shape, volume, gravity and density to internal structure, operations	Mass from binary orbit, spacecraft tracking (RSE, Optel-D) Shape model from Visual Imaging System (VIS)*, laser altimetry (Optel-D)
2	S#2 Dynamical state of Didymoon (period, orbital plane axis, spin rate and spin axis)	Key to determine momentum, indirect constraints on the internal structure	VIS
3	S#3 Geophysical surface properties, topology, shallow subsurface	Bulk composition, material mechanical properties, and surface thermal inertia, key to determine momentum as shallow subsurface drives the efficiency of the impact shock wave propagation, data point to validate kinetic impact simulations	VIS* for surface features. TIRI for surface roughness. HFR for shallow subsurface structure.
4	*S#4* Deep internal structure of Didymoon	Interior can affect absorption of impact energy, "data point" to validate asteroid mitigation models. Key to distinguish between scenarios of binary origin	LFR. Drift-bys to estimate gravity field (not a must)

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. 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.



IV. Conclusions

AIM will provide a unique opportunity to demonstrate planetary defense while performing fundamental asteroid science and demonstrate unique technologies for future missions. Linked with the DART mission, the AIM mission 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.