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ASTEROID IMPACT AND DEFLECTION ASSESSMENT (AIDA) MISSION: SCIENCE RETURN AND MITIGATION RELEVANCE

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Extended Abstract—

The Asteroid Impact & Deflection Assessment (AIDA) mission is a joint ESA-NASA cooperative project, which includes the ESA Asteroid Impact Mission (AIM) rendezvous spacecraft and the NASA Double Asteroid Redirection Test (DART) mission. Both AIM and DART have been approved for a Phase A/B1 study, starting in early 2015 for 15 months. The primary goals of AIDA are (i) to test our ability to impact a small near-Earth asteroid (NEA) by a hypervelocity projectile and (ii) to measure and characterize the deflection caused by the impact. AIDA will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor to deflect an asteroid.

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 km/s will alter the binary orbit period, which can then be measured by Earth-based observatories. The AIM spacecraft, launched in 2020, will characterize in 2022 the Didymos binary system by means of remote sensing and in-situ instruments and monitor the impact of DART and its outcome.

Baseline payloads for AIM include a Visual Imaging System, a lander (based on DLR MASCOT heritage), a thermal infrared imager, a mono-static high frequency radar as well as a bi-static low frequency radar (using both the lander and spacecraft to transmit and receive the signals, respectively). The mission is also testing technologies for the lander deployment, the operations of a laser space-to-ground communications system and offers an Opportunity for CubeSat Payloads and Inter-satellite Networking Sensors Payloads, an opportunity for science and a test of inter-satellite links based on CubeSat standards.

AIDA addresses issues that interest a large variety of communities, such as scientists and engineers working on impact physics, planetary defense, geophysics (surface and internal properties), dynamics, spectral and physical properties of small bodies, low-gravity environments and human exploration. In the following, we briefly discuss examples of science topics that AIDA will be able to address.

Asteroid physical properties

The target of AIM is the secondary of the binary NEA Didymos. The characterization of this small asteroid satellite by AIM will allow us to improve drastically our knowledge on the physical and thermal properties of a component of a binary system. In particular, for the first time, we will have direct information on the sub-surface properties and internal structure of an asteroid.

Physical and compositional properties of small bodies provide crucial information on the dynamical and collisional history of our Solar System. In addition, the formation mechanism of small binaries is still a matter of debate, although several scenarios have been theoretically analyzed and proposed to explain their existence. In particular, rotational disruption of an NEA, assumed to be an aggregate, as a result of spin-up above the fission threshold due to the YORP effect (a thermal effect which can slowly increase or decrease the rotation rate of irregular objects) has been shown to be a mechanism that can form binary asteroids with properties that are consistent with those observed by radar. These properties include the usually oblate spheroidal shape of the primary, the size ratio of the primary to the secondary and the circular equatorial secondary orbit. Different fission scenarios have been proposed to form these systems, which imply different physical properties of the binary and its progenitor (Walsh et al. 2008, 2012, Jacobson and Scheeres 2011). Binary formation scenarios therefore place constraints on, and implications for the internal structure of these objects. Internal structure measurements by AIM will allow us to discriminate between these scenarios.

Small asteroids undergo various processes (e.g., impacts, thermal effects) that can alter their physical properties and in turns these properties drive their response to those processes. However, the geophysics and mechanics of these processes are still very poorly understood. This is at least partly due to a lack of scientific data, both on the mechanical properties of small asteroids in their very unique micro-gravity environment and on their sub-surface and global geophysics. In effect, neither ground-based observations nor remote observations from a spacecraft allow accessing this information. A direct interaction, such as the impact by DART and the landing of Mascot 2, is the only way to access the detailed mechanical properties of a surface and to measure how it responds to an external solicitation. Accessing this information will allow us to perform a giant step in our understanding of asteroids and of impact processes that will have profound implications in various studies of Solar System small bodies.

AIDA, trough the observations by AIM, will thus allow us to address fundamental questions, such as: what are the subsurface and internal structures of asteroid's satellites and how does an asteroid's surface relate to its subsurface? What are the geophysical processes that drive binary asteroid formation? What are the strength and thermal properties of a small asteroid's surface? What is the cohesion within an aggregate in micro-gravity? What are the physical properties of the regolith covering asteroid surfaces and how does it react dynamically to external solicitations, such as the deployment of a surface package or an impact?

The collisional process

Collisional events are of great relevance in the formation and evolution of planetary systems, including our own Solar System. In the first stages of planetary formation, low-velocity collisions between planetesimals drive planetary growth by collisional accretion. In the particular case of our Solar System, some energetic events also started to take place quite early. The Moon of our Earth is understood as the product of ejected debris re-accumulation resulting from the impact of a planetesimal with our proto-Earth (e.g. Canup et al. 2013). In further stages, once the planets were formed, relative velocities between small bodies increased as a result of planetary perturbations. Consequently, our Solar System entered in a new regime of high impact energy, in which it continues to evolve currently. In this regime, collisions do not lead to accretion phenomena anymore but rather to disruptive events. Asteroid families in the asteroid main belt between Mars and Jupiter are the traces of disruptive events of large parent bodies (e.g. Michel et al. 2001). Meteorites collected on Earth are another indication of the collisional activity as they are the remnants of collisions that take place in the main belt. In this sense, collisions can be seen as representing an important threat against human efforts in space, which can even lead to the destruction of our biosphere. The collisional process is therefore not a second- order problem in the understanding of the past, present and future history of our Solar System; it is actually at the heart of its formation and evolution.

The scales of the phenomena that are involved in planetary and small body impacts are by far much larger than those reached in laboratory impact experiments. Extrapolations by 15 orders of magnitude in mass are necessary to achieve ranges that are relevant to asteroids and planetesimals. Theoretical models of catastrophic collisions try to fill this gap by establishing non-dimensional relationships between the projectile's size, the impact velocity, the target's strength, its density etc. that are supposed to be valid at all scales, and which are regrouped in the so-called scaling laws (see e.g. Holsapple 1993). These scaling laws are quite successful to relate the projectile's size to crater's size in the cratering regime, as long as the analogy with an explosion holds, but they do not allow studying the dynamics of the process. Fortunately, it is now possible to fully simulate an impact with a certain degree of sophistication and reasonable accuracy thanks to dedicated numerical codes that have been developed recently (see, e.g., Jutzi et al. 2015 for a review) accompanied with the improvement of computer performances. Impact experiments in laboratory are crucial to validate those numerical models at small scales before they are applied to large-scale events. Simulations and theoretical study have been performed to estimate the momentum transfer efficiency of a kinetic impactor (see, e.g., Holsapple and Housen 2012, Jutzi and Michel 2014). However, until an experiment at the real scale of an asteroid collision will be performed, the validity of these simulations at these scales will remain uncertain.

AIM will contribute to access the initial conditions of the impact, e.g. the impact angle, and will relate the position of the impact point on the target measured by DART to the detailed properties of the whole object. This knowledge is crucial for our correct interpretation of the momentum transfer efficiency measurement. Moreover, although ground-based observations will observe the deflection, AIM will allow measuring it with greater accuracy and provide additional information on the binary system behavior after the impact.

AIDA will thus provide unique knowledge on the impact process in the very conditions of an asteroid environment at a scale that is unreachable in the laboratory (where one is limited to centimeter or meter-scale targets). For the first time, AIDA will allow testing hypervelocity impact modeling and scaling laws at an appropriate scale, and provide direct data regarding the outcome, in terms of crater's size, morphology, as well as ejecta production and properties. Such information is essential to confirm the validity of numerical codes or to refine them so that they can be applied with a higher confidence to design other similar concepts in the future.

This knowledge will also have a wide range of implications in planetary science, as the understanding of the impact response of a small body as a function of impact conditions and physical properties is crucial to estimate its collisional lifetime, the collisional evolution of asteroid populations (when this knowledge is extrapolated to other bodies), and the role of collisions in the different phases during the history of our Solar System.

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. AIDA will return unique information on an asteroid's strength, surface and sub-surface physical properties and internal structure.

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AIDA community web site:
http://www.oca.eu/michel/AIDA/