

The Asteroid Impact and Deflection Assessment (AIDA) mission: Science Proximity Operations. O.S. Barnouin¹, J. Biele², I. Carnelli³, V. Ciarletti⁴, A. Cheng¹, A. Galvez⁴, S.F. Green⁵, B. Grieger⁶, A. Herique⁷, M. Kueppers⁵, K. Mellab⁸, P. Michel⁹, A.S. Rivkin¹, S. Ulamec², and J.-B. Vincent⁹, ¹The JHU Applied Physics Laboratory, Johns Hopkins Road, Laurel, MD, USA; ²DLR, Germany; ³ESA-HQ, France; ⁴U. Versailles Saint-Quentin en Yvelines, LATMOS, France; ⁵Open Univ., UK; ⁶SRE-OOR, ESA/ESAC, Spain; ⁷IPAG, France; ⁸ESA/ESTEC, Noordwijk, Netherlands; ⁹Lagrange Laboratory, U. Nice Sophia-Antipolis, CNRS, Côte d'Azur Observatory, Nice, France.

Introduction: The moon of the near-Earth binary asteroid 65803 Didymos is the target of the Asteroid Impact and Deflection Assessment (AIDA) mission. This mission is a joint concept between NASA and ESA to investigate the effectiveness of a kinetic impactor in deflecting an asteroid. The mission is composed of two components: the NASA-led Double Asteroid Redirect Test (DART) that will impact the Didymos moon (henceforth Didymoon), and the ESA-led Asteroid Impact Mission (AIM) that will survey the Didymos system. Using much of ESA's Rosetta experience, the AIM mission will undertake all the proximity operations both before and after the impact produced by DART. The physical and dynamical characterization of both Didymain (primary) and Didymoon is of maximum importance in the joint AIDA mission and the main purpose of the AIM spacecraft. The characterization includes measuring before and after the DART impact, the internal properties of the primary and secondary, the mass of Didymoon, the surface geology and regolith properties of both objects, and the dynamical state of Didymoon [1].

In this abstract, we summarize the proximity operations needed to achieve the scientific objectives of the AIM spacecraft using the broad suite of experiments it will carry to satisfy its mission objectives.

AIM's Technological and Scientific payload: The AIM spacecraft will carry an Optical Terminal (Optel-D), a Thermal Infrared Imager (TIRI), two radar systems, an asteroid micro-lander and from two to six CubeSat-based payloads hosted on two CubeSat dispensers. A Visual Imaging System (VIS) is also included as part of the AIM spacecraft system.

Visual Imaging System (VIS): AIM's VIS will be used both for GNC and to perform scientific measurements. It will be part of the spacecraft system. In its scientific role it will be imaging the target asteroid system from multiple locations at various distances during the course of the AIM asteroid observation phases. Its objective will be to provide information on the binary asteroid dynamics and (especially for the smaller secondary component) asteroid volume, shape, and surface morphology. Techniques employed to determine the shape of both objects in the Didymos system will include traditional geometric stereo and stereophotoclinometry.

Thermal InfraRed Imager (TIRI): TIRI's primary goal is to investigate the thermal properties of the asteroid surface that are relevant to the characterisation of the soil structure and cohesion. Such measurements are critical for assessing the evolution of the binary, and constraining the origin and physical characteristics of Didymoon.

Monostatic High-Frequency Radar (HFR): HFR's main objective is to obtain information on the structure of the asteroid's outermost surface and sub-surface layers, up to 10 m depth. The radar is a Step-Frequency (SF) radar operating from 300 MHz to 2.5 GHz that can identify layering and the distribution of geological elements (rocks, boulders etc.).

Bistatic Low-Frequency Radar (LFR): The primary goal of this radar is to obtain data on the asteroid internal structure. The baseline design heritage comes from Rosetta's CONSERT transmission radar experiment. The instrument consists of two subsystems, one on the main spacecraft and one on the lander. The radar operates within a 20 MHz bandwidth at a centre frequency of 60 MHz and requires a shape, motion and orbitography model to process the data.

MASCOT-2: This lander is an evolution of its predecessor, MASCOT, developed by DLR for JAXA's Hayabusa-2 mission. It would accommodate the second component of the bistatic LFR, plus possibly and if feasible other payloads, such as a radiometer, a camera and an accelerometer. It will be deployed on Didymoon. Its operative lifetime once deployed on the surface will be at least 3 months.

Optel-D optical downlink system: This system will perform an In-Orbit-Demonstration of its capability to transmit data from large distances in deep space. It operates in the 1550 nm C-band and will enable the transmission of AIM payload data to ESA's Optical Ground Station while the spacecraft is operating close to the asteroid. Other optical ground stations would also be used for larger distances if they became available. If confirmed by the design activities, the instrument will in addition feature lidar, ranging and NIR narrow-field imaging capabilities. The lidar capability will be used to facilitate shape modelling of the primary and secondary, and allow determination of the displacement of the primary w.r.t. the centre of mass of

the binary. Use of Optel-D NIR camera option will improve results.

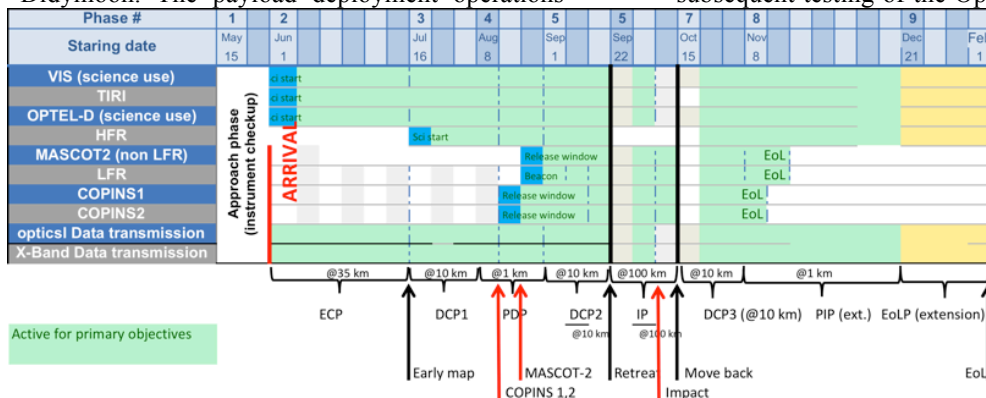
CubeSats: The AIM spacecraft will possess a 3U cubesat deployment system based on existing developments with flight heritage. This system will allow deployment of Cubesat Opportunity Payload Independent Nano-Sensors (COPINS): at least two and up to six additional payloads, based on either 1-U, 2-U or 3-U cubesat configurations. These nano-satellites, once in the asteroid vicinity, will carry out complementary measurements (e.g. surface remote or in-situ sensing or impact plume imaging). After deployment, the spacecraft will only support COPINS operations for 3 months.

Summary of proximity operations: The basic operations schedule for AIM is given in Figure 1. There are 8 main phases of the mission:

1. **Early Characterization Phase (ECP).** This ~6 week phase is dominated by an imaging phase where the objectives include measuring the size of the objects, estimating the mass of Didymoon from the "wobble" around the system's barycentre, estimating the density from the combination of the two measurement, and characterising the orbital and rotation periods. This phase occurs at ~35 km distance.
2. **Detailed Characterization Phase 1 (DCP1).** This is a ~3 week phase where, from ~10 km distance, it is possible to obtain medium-resolution imaging and operate the HFR. The TIRI would nominally obtain most of its data at this distance.
3. **Payload Deployment Phase (PDP).** This is a 3 week phase where the AIM spacecraft would be put in a trajectory close to both Didymain and Didymoon, guaranteeing a prolonged gravitational interaction for unperturbed periods of time within ~2 km. Prior to payload deployment, complementary mass estimates of the primary and possibly secondary will be undertaken with Radio Science measurement, and very high-resolution imaging (~10cm/pixel) obtained of both Didymain and Didymoon. The payload deployment operations

follow with the release of COPINS, which will allow to further refine the gravity field. Then MASCOT-2 is released close to Didymoon (~50m), before returning to a stable proximal altitude where AIM supports MASCOT localization and relocation operations. Once MASCOT-2 has successfully reached its operating station, the AIM spacecraft returns to the DCP station.

4. **Detailed Characterisation Phase 2 (DCP2).** This 3-week phase is equivalent to DCP1 but also involves operations of MASCOT-2, LFR and COPINS.
5. **Impact Phase (IP).** This 3-week phase occurs in late September-early October 2022. The AIM spacecraft is likely to relocate to a safe distance of ~100km and will either observe the impact directly or through COPINS.
6. **Detailed Characterisation Phase 3 (DCP3).** This ~3 week phase will explore the consequences of DART's impact. This phase might include an initial ECP-like stepped approach first at 35 km to assess the debris environment closer to the asteroid's gravity sphere of influence before moving to the 10 km station point for full payload operations including MASCOT-2 and COPINS.
7. **Post-Impact close Phase (PIP).** This optional 6-week extension would include PDP-like close-range phases to precisely assess mass variations and image the location of the lander after the impact (with MASCOT-2 and LFR operations also in extended mission). If the crater is in the same region, then very high resolution imaging of the DART crater will be undertaken. Any additional secondary mission goals can be addressed in this phase as well.
8. **End of Life Phase (ELP).** This last 5-week phase might involve a higher-risk autonomy demonstration experiment close to the surface, possibly close to MASCOT-2 or the crater location (or both), and might culminate in AIM landing on the surface. Alternatively, AIM may go into hibernation with subsequent testing of the Optel-D optical communication system at long ranges (3 AU or more).



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References: [1] Michel et al., Submitted to *Adv. Space. Res.*, 2016.

Figure 1. Overview of AIM's proximity operations.