DOCUMENT

Asteroid Investigation Mission (AIM) Mission Objectives

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1 PURPOSE OF DOCUMENT

The purpose of this document is to describe the high-level mission objectives for the Asteroid Impact Mission (AIM) spacecraft and its payload in the context of the AIM Phase A and the AIM payload assessment activities. It contains information on all scientific and technological objectives (including objectives linked to asteroid hazard mitigation) influencing the assessment of the S/C during that phase.

2 REFERENCES

Reference Documents (RD) are applicable to this document only when specifically stated in the text and called up with references to specific parts of the document that are to be applicable. Otherwise the documents below are listed for information and as an aid for understanding.

[AD2] AIM Payload Interface Document (PID)

[AD3] Didymos Reference Model

[RD1] AIM-3P CDF-149(A) Report

[RD22] Deep Space Instrument Design for Thermal Infrared Imaging with MERTIS, Infrared Remote Sensing and Instrumentation XIX, 2011, I. Walter et al.

[RD23] FANTINA Part II: Payload design and development, Marco Polo Proposal, 2012, A. Herique et al.

[RD24] ExoMars WISDOM a GPR designed for shallow and high resolution sounding of the Martian subsurface, Proceedings of the IEEE, Manuscript ID: 0023-SIP-2010-PIEEE. D

[RD25] Optical Deep Space Link for AIM System Architecture, Link Analysis and Preliminary Design Concept, ESA DOCUMAS study CCN, 2014

[RD26] OPTEL-μ: A Compact System for Optical Downlinks from LEO Satellites, Dreischer et al

[RD27] ISIS ISIPOD 2U CubeSat Deployer Product Overview

3 ACRONYMS

AIM	Asteroid Impact Mission
CDF	Concurrent Design Facility
COPINS	Cubesat Opportunity Payload Independent Nano-Sensors
DART	Double Asteroid Redirection Test
DLR	Deutsches Zentrum fuer Luft- und Raumfahrt
FOV	Field Of View
GNC	Guidance Navigation & Control

HFR	High Frequency Radar
JAXA	Japanese Space Exploration Agency
LFR	Low Frequency Radar
LT	Laser Terminal
PID	Payload Interface Document
RSE	Radio Science Experiment
S/C	Spacecraft
SoW	Statement of Work
TBC	To Be Confirmed
TBD	To Be Defined
TIRI	Thermal InfraRed Imager
VIS	Visual Imaging System
YORP	Yarkovsky–O'Keefe–Radzievskii–Paddack effect

4 DEFINITION OF TERMS

In the context of this document, ¨Asteroid Research Objectives¨ shall be interpreted as the goals driven by either scientific research of the asteroids, or by operational purposes, in particular asteroid impact risk assessment and mitigation.

5 INTRODUCTION

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. When the AIM mission is combined with the Double Asteroid Redirection Test (DART) (Cheng, 2012) both missions complement one another in a joint asteroid impact test and observation campaign called Asteroid Impact & Deflection Assessment (AIDA).

AIDA is in essence a “mitigation precursor” that would validate the kinetic impact approach to deflect threatening asteroids with sizes up to a few hundred meters in diameter. The physical and dynamical characterisation of the mission target, the Didymos binary asteroid system, is of maximum importance in this joint mission and the main purpose of the AIM spacecraft.

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 characterised 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 the following:

1) Rotational evolution. Asteroids rotate in various ways, for example with simple rotation, precession or tumbling, and their rotation evolves along different pathways due to a variety of torques and mechanisms that can alter their spin properties. The story of asteroid rotation is complex and still unfolding. Moreover, the spin rates of small Solar System bodies give an important clue about the composition and strength of those bodies. Indeed, this is one of the fastest-changing areas of planetary research.

We can discern the rotation state (and shape) of an individual asteroid through a number of techniques. Space missions such as AIM are rare, but they can characterize the spin of a mission target with extreme precision. For a few hundred asteroids, radar echoes allow detailed rotation models to be developed and can often reveal complex rotation states. The most common technique of all is the photometric light curve from high-density photometric measurements taken over a number of nights. But the most promising, and soon to be the most prolific, source of rotation information are the all-sky surveys, which can provide hundreds of occasional photometric measurements of a single object over a ten year survey. These so-called sparse light curves will likely be the primary source of spin and shape information within the next decade.

While we accumulate ever more information on the rotation states of asteroids, we understand that rotational evolution is driven by an array of mechanisms. Virtually no asteroids larger than a few hundred meters in size are spinning faster than the ~2-hr period of the “spin limit” beyond which centrifugal accelerations cause material to escape the body, which was used to infer that these larger bodies are not monolithic. However, it was then shown that he presence of tensile and cohesive strength for a large body (>10 km) makes no difference in the permissible spin. Therefore, the observed spin limit for large bodies cannot be used to infer zero-strength (cohesive/tensile) rubble-pile bodies. These bodies may well be rubble piles, based on different arguments, but they do not need to be based on their spin limit. On the other side of that coin, it was found that the strength that allows the higher spins of the smaller and fast-spinning km-sized bodies is only on the order of 10–100 kPa, a very small value compared to small terrestrial rocks. So these bodies need not be very strong, they could be essentially rubble-piles that have accumulated slight bonding between constituent particles. This shows the richness of information that can be extracted regarding asteroid physical properties, based on their spin properties. The YORP effect, i.e., the torque due to photon pressure on an irregular body, has a great influence of asteroid spin properties. It can spin bodies up or down depending on the shape.

Those that spin up too fast can lose material and, under certain conditions, form binary systems, either episodically or catastrophically. Numerical models predict that this can only happen if the progenitor was a gravitational aggregate. However, different scenarios lead to different constraints regarding the secondary’s internal properties that can only be tested by a space mission.

The study of the Didymos binary system and its dynamic characterisation, plus the characterisation of the thermal emission of the asteroids´ surfaces by AIM can provide ¨ground-truth¨ for ground-based observations and for modelling activities, concerning for instance the formation mechanisms of binary systems and the geophysics of asteroids. The unique feature of this mission is the close approach of Didymos to the Earth at only 0.11 AU in 2022 during its opposition, which would enable simultaneous observations from the AIM spacecraft and from ground-based optical and radar instruments. possibly even with combined space and ground observation e.g. bistatic radar measurements and calibration.

2) Collisional Evolution. The solar system originated in a gas and dust cloud in which relatively gentle collisions between sticky particles quickly resulted in the planets, asteroids and comets we know today. Eventually, accretion gave way to more energetic collisions that were more likely to result in catastrophic disruptions. This collisional evolution of the Solar System continues today and is most evident in the asteroid belt that is slowly being turned back into the dust from which it came.

Theorists study the collisional evolution of asteroids by developing detailed models of the asteroids collisional environment. In these models asteroids either disrupt or create craters on bigger asteroids, thus generating more small asteroids to disrupt other big ones in a `collision cascade’. Meanwhile, experimentalists conduct high-speed projectile tests to study the effects of an impact, allowing us to understand the role of fracturing and disruption in the structural make up of asteroids. However, 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 adimensional 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. 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. Nevertheless, such relationships are necessarily idealized, as they assume a uniformity of the process as well as a structural continuity. Consequently, they cannot predict with a high degree of reliability large-scale impact outcomes. Numerical simulations are also intensively used to study the collisional process. It is now possible to simulate an impact with a certain degree of sophistication and reasonable accuracy thanks to dedicated numerical codes that have been developed in the past decades, 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. However, until an experiment at the real scale of an asteroid collision will performed, the validity of these simulations at these scale will remain highly uncertain, so performing a large scale experiment is even more crucial.

Craters on asteroids visited by spacecraft, such as Lutetia, Vesta, and Ceres, provide essential constraints on the population of small impactors in the main belt and their effects on larger bodies. An exciting and very recent development in just the past few years is that asteroid surveys have become powerful enough to detect the aftermath of collisions between asteroids in the main belt. Detailed morphological studies of the collision products allow direct comparison to hydrodynamic code models that describe the process, although too many observational constraints are missing to derive a robust scenario from these models.

The AIDA scenario will provide a unique opportunity to observe a collision event directly, and simultaneously from space and ground-based optical and radar facilities. For the first time, an impact experiment at asteroid scale will be performed with the knowledge of both the precise impact conditions and the impact outcome, as well as information on the physical properties of the target. This will be the first fully documented asteroid scale impact experiment that can then be used to validate at appropriate scale impact codes. The impact velocity being compatible with impact velocities in the asteroid belt, it will in addition provide key input parameters to perform even more accurate impact simulations of main belt collision events, such as those at the origin of asteroid families or those detected by current surveys.

3) Evolutional Coupling. The collisional, orbital and rotational evolutions are each individually complex and rich in detail, and yet they are each coupled with one another in ways that make the complete evolutionary picture of asteroids truly fascinating. This coupling takes a number of forms:

• Rotational evolution plays a major effect in orbital evolution through the subtle effect of thermal emissions that can alter the spin state of a body (YORP effect) or slowly drive the orbit into resonances (Yarkovsky effect), which can cause the body to rapidly evolve out of the main belt. Similarly, the Yarkovsky effect depends on the spin state, which is continually changing due to collisions and the YORP effect.

• Collisions are a key driver in the rotation state of asteroids in an obvious and important way, but also through more subtle mechanisms. The YORP-induced rotational evolution depends critically on an asteroid's shape, including small scale topography, even as collisions episodically alter the shape and spin state of asteroids. Conversely, the rotation state of a given asteroid can have a significant effect on the outcome of a collision, which is so far badly understood.

• The orbital evolution of asteroids is decisively driven by collisions. Over long timescales (Gy), the collisional grinding in the asteroid belt tends to flatten orbits and causes the belt to cool dynamically. On shorter timescales (10-100 My), collisions create smaller fragments that can be driven more easily into resonances by the Yarkovsky effect and then rapidly evolve out of the main asteroid belt. This transport mechanism is the major source of Near-Earth Asteroids.

Binary (and higher) asteroid systems add still more complexity, where the formation of companion bodies can follow abruptly from catastrophic collisions or more gradually from the YORP effect. And the evolution and separation of these multi-body systems and their components is again subject to the complicated dynamical environment that defines the asteroid belt.

We now have numerous theoretical models and predictions that describe the rich dynamical environment of the main asteroid belt, and these theories are now on the verge of being regularly tested with new discoveries by the surveys and detailed follow-up observations. For example, we have recent discoveries of “activated asteroids” that appear to be shedding mass, either through rotational fission or small collisions. Modern surveys are now identifying asteroids small enough and frequently enough to identify these events early and allow real time follow-up of their morphological behavior to test formation theories. The same techniques, applied to Didymos close flyby and DART impact event in October 2022, with direct confirmation by the AIM spacecraft, can represent a quantum leap in the accuracy of modelling and the interpretation of observations, and hence of our understanding of the issues that govern the dynamical evolution of these Solar System bodies.

These processes are therefore not a second-order problem in the understanding of the past, present and future history of our Solar System; in fact, they are at the heart of its formation and evolution. It is now increasingly clear that -either directly or indirectly- such processes might have had a crucial role in the development of life on our planet. On one side, through massive collisions and mass extinctions; on the other, by a ¨mass input´ on the building blocks of life, possibly including Earth´s water. Researches on asteroid impacts are therefore key to understand our past and perhaps also our future.

5.1 AIM payload

The AIM spacecraft will carry a Visual Imaging System (VIS) as part of the AIM spacecraft guidance and navigation system. The payload would also feature ¨dual-use¨ science and technology payloads that can gather data and provide navigation or positioning information, increase data handling and telecom flexibility or enhance the mission performance in other ways. The payload includes a Thermal Imager (TIRI), an Optical Terminal doubling as altimeter (Optel-D), two radar systems, an asteroid microlander and a certain number of CubeSat-based payloads hosted on two CubeSat dispenser. A short description of these payloads is given in [AD2].

6 AIM HIGH-LEVEL OBJECTIVES

6.1 Mission statement

AIM shall characterize the secondary component of the binary near-Earth asteroid (65803) Didymos (1996 GT) from a dynamical and geophysical point of view while demonstrating spacecraft technologies and operations to advance future small and medium missions.

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

6.1.1 AIM Scientific Research Objectives

si. To determine geophysical properties of (68528) 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 analyse the asteroid dynamical state.

sii. 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.

siii. To characterise Didymoon's deep interior structure.

siv. 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.

6.1.2 AIM Technology Research Objectives

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

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

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

To achieve these objectives, an asteroid research payload suite and a technology research payload suite are embarked with the following objectives (in order of priority, P):

Asteroid Research Payload Objectives			
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 Didymos moonlet (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 • Thermal InfraRed Imager (TIRI) for surface roughness • Hi-frequency radar for shallow subsurface structure
4	*S#4* Deep internal structure of the moonlet	Interior can affect absorption of impact energy, "data point" to validate asteroid mitigation models. Key to distinguish between scenarios of binary origin	• Low-frequency radar • Drift-bys to estimate gravity field (not a must)

Table 1

*The VIS is also the GNC camera.

7 AIM DETAILED PAYLOAD OBJECTIVES

In this section, the S#1-S#4 payload objectives defined in the precious section are expanded and -where needed- completed for each of the AIM payload elements. The detailed objectives are presented in order of priority, also in agreement with S#1-4 AIM high-level payload objectives. They are also separated into primary and secondary payloas objectives.

It should also be noted that some of the S#1-4 objectives will be addressed by the combined operation of several AIM payload instruments, either simultaneously or in sequence.

The nomenclature of the detailed payload objectives is the following:

S.INS.x.n

Where:

- *S* stands for Science, and in this context, asteroid research, thus including both mitigation assessment and pure scientific objectives;
- *INS* is a 3-letter label, specific to each of the payload instruments e.g. VIS for Visual Imaging System, OPD for Optel-D, COP for COPINS etc;
- x can be p (primary) or s (secondary) to describe whether the objective has to be considered as a must or as a desirable goal;
- *n* is a sequential number and expresses level of priority in line with S#1-4.

7.1 Visual imager (VIS)

The Visual Imaging System on AIM will be used both for GNC and to perform scientific measurements. In its scientific role it will be imaging the target asteroid system from multiple fixed positions and from various distances during the course of the AIM asteroid observation phases. The purpose of the measurements is to provide information on the binary asteroid dynamics and (especially for the smaller "Didymoon", DART´s target), its physical characteristics.

The primary asteroid research objectives of the instrument are the following:

S.VIS.p.1: to determine Didymoon´s mass, volume and size with an accuracy of at least 10% (goal 1%)
S.VIS.p.2: to determine the binary system orbital period and Didymoon´s rotational period with an accuracy of 10%
S.VIS.p.3: to characterise Didymoon´s the shape, topography and the granularity of its surface material.

The secondary goals of the VIS include the following:

S.VIS.s.1: to determine Didymos dynamics and Didymoon physical parameters again after DART´s impact.
S.VIS.s.2: to perform impact ejecta real-time observations.
S.VIS.s.3: to determine and compare the crater density and geomorphology of both the primary and the secondary component.
S.VIS.s.4: to study Didymos primary physical characteristics.
S.VIS.s.5: to support the study of chemical and mineralogical properties of the surface material.

A full coverage of the secondary asteroid body shall be achieved in the course of the AIM asteroid observation phases. As required for navigation and collision risk mitigation purposes, during the observation phases the VIS shall keep the primary and secondary components within its FOV. In addition to this the VIS limiting magnitude shall be compatible with the expected heliocentric orbit uncertainty (due to both ground navigation and Didymos position uncertainties). Spacecraft might need to provide a range of solar phase angles for phase function analysis.

7.2 Thermal Imager (TIRI)

The AIM thermal imager (TIRI) primary goal is to investigate the thermal properties of the asteroid surface that are relevant to the characterisation of the soil structure and cohesion, and that contribute to thermal effects (Yarkovsky/YORP).

The instrument aims to address such goal by: (1) characterizing the thermal cycles for the different parts of the surface (minimum, maximum and average temperature), and the rate of temperature variations with time; (2) determining the bulk thermal properties of the surface; (3) constraining the solar absorption, thermal emission, and heat conduction on the surface. In particular, the main goal is to derive the thermal inertia with a precision better than 10%, so an accuracy of 5K (goal 1K) and a spatial resolution of a few meters are needed.

Thermal inertia provides also information on the nature of the regolith, its thickness and its degree of maturity. A surface covered by a coarse (cm- to dm-sized) regolith or no regolith (like asteroid Itokawa) has a much higher thermal inertia (750 J m-2 s-0.5 K-1 at 1 AU from the Sun) than a surface with a thick mature regolith (e.g. the Moon which has an average thermal inertia of 50 J m-2 s-0.5 K-1 at 1 AU from the Sun).
A spatial resolution of a few meters can be used also to identify locally colder and hotter regions. These are interesting because they reveal inhomogeneities, areas with different thermal environments than the average of the asteroid, which can be linked to the regolith structure and dynamics. Information on the degree of roughness of the surface can also be derived. All of this is relevant to the efficiency of momentum transferred by an impact, and in the design of devices aimed at interacting with a small body's surface.

The scale that is relevant to the AIM mission is given by the likely size of a crater generated by a DART-like impact. Numerical simulations of the DART impact indicate that a resolution of at least 20 m will be required.

Therefore, the primary AIM TIRI asteroid research objectives are:

S.TIR.p.1: to map the regolith properties such as its grain size by measuring the thermal inertia of the (sub)surface layer.
S.TIR.p.2: to characterize the surface temperature to an accuracy of 5K (goal 1K)

In the AIDA scenario where AIM arrives to the asteroid before DART impacts on the secondary asteroid, TIRI would be able to study the ejected dust plume from DART impact. Images can be used to determine the dust temperature and its rate of change. This will allow deducing the grain size and the thermal inertia of the dust. The amount of fine dust produced by an impact remains a poorly understood problem because of the limited resolution of impact simulations that cannot access the properties fragments down to dust sizes.

If the thermal IR spectroscopy can be done, it will possible to study the degree of crystallinity of the dust and then constrain its mineralogical composition.

Therefore secondary AIM TIRI objectives include the following:

S.TIR.s.1: to obtain a map of the surface composition
S.TIR.s.2; to study the plume of dust ejected by DART´s impact on Didymoon
S.TIR.s.3: to compare the thermal properties of the asteroid and its satellite

For TIRI certain constraints imposed by AIM operational needs apply. In particular, the TIRI shall be able to view the entire binary system simultaneously to the VIS camera and could be used for navigation. in addition to perform scientific measurements.

7.3 Monostatic High Frequency Radar (HFR)

The AIM High-Frequency Radar (HFR) main objective is to obtain information on the structure of the asteroid´s outermost surface and sub-surface layers, up to a depth of 10 m.

The primary asteroid research objectives of AIM HFR are:

S.HFR.p.1: to determine the structure and layering of the secondary asteroid shallow sub-surface down to a few meters with a vertical resolution of approximately 1 m (goal 0.01 m) and 1 m (goal 0.02 m) in horizontal position (TBC depending on the spacecraft speed relative to the asteroid surface).
S.HFR.p.2: to study the 2-D distribution of geomorphological elements (rocks, boulders, etc) that are embedded in the subsurface with the same resolution.
S.HFR.p.3: to obtain the average electrical characteristics of the sub-surface material, mainly its electrical permittivity, and its horizontal and vertical variations by analysing the signature from individual reflectors and/or by analysing the surface echo amplitude.

As secondary asteroid research goals the HFR shall address:

S.HFR.s.1: to support asteroid mass determination with range measurements.
S.HFR.s.2: to support ground-based bistatic radar measurements.
S.HFR.s.3: to observe the impact ejecta generated by the collision of the DART spacecraft in the vicinity of the secondary asteroid, to estimate size distribution, speed, total mass.

S.HFR.s.4: to determine of the same structure and layering aspects, building block distribution and electrical characteristics of the primary asteroid shallow sub-surface down to a few meters.

A priori, the HFR operation preparation requires a shape, motion and orbitography model. The accuracy should be 10 m for the shape and 100 m for the orbit of the secondary asteroid. The HFR may require operating within a short range of the asteroid surface (<10 km). The instrument could be used for navigation (i.e. ranging/altimetry mode) in addition to perform scientific measurements.

7.4 Bistatic Low Frequency Radar (LFR)

The AIM bistatic Low-Frequency Radar (LFR) main goal is to obtain data on the asteroid internal structure.

The primary asteroid research objectives of AIM LFR are:

S.LFR.p.1: to determine the homogeneity of Didymoon. This includes monolithic structure vs. building blocks and size and homogeneity of the building blocks.
S.LFR.p.2: to determine Didymoon subsurface dielectric properties.

The secondary goals of the LFR shall address:

S.LFR.s.1: to investigate the same internal structure aspects and electrical characteristics of the primary asteroid sub-surface.

A priori, the LFR operation preparation requires a shape, motion and orbitography model. The accuracy should be 10 m for the shape and 100 m for the orbit of the secondary asteroid. The LFR may require dedicated trajectories (especially in case of investigations of the primary are attempted i.e. collinear situation with respect to Didymos primary and secondary components).

7.5 MASCOT-2

The MASCOT-2 lander, apart from accommodating the component of the bistatic LFR, could include other instruments such as e.g. a camera or an accelerometer (TBD).

The primary asteroid research objectives of AIM MASCOT-2 are:

S.MAS.p.1: to provide data on surface mechanical properties and thermal inertia in at least one location (goal: three locations)
S.MAS.p.2: to support the investigation of the secondary asteroid internal structure by enabling the operation of the Low Frequency Radar
S.MAS.p.3: to provide ground-truth on AIM-borne and ground-based visual albedo and thermal emission of the surface in at least one surface site (goal: three sites)

The secondary asteroid research objectives of MASCOT-2 are

S.MAS.s.1: to provide data on surface topology and structure at scales from about 10 m to 0.01 m.
S.MAS.s.2: to support the investigation of the primary asteroid internal structure by enabling the operation of the Low Frequency Radar
S.MAS.s.3: to study Didymoon´s surface chemical and mineralogical properties.

MASCOT-2 will be deployed on the secondary component of the asteroid system, on a landing area providing safe landing and operation conditions e.g. vertical speed well below escape velocity right after touchdown, and illumination conditions that alternate sun and shadows at regular intervals. Its operative lifetime once deployed on the surface will be at least 3 months.

7.6 Optical Laser terminal (OPTEL-D)

The Optel-D optical downlink system will be an In-Orbit-Demonstration of its capability to transmit data from large distances in deep space, but will also be used as a scientific instrument.

The primary asteroid research and scientific objectives of AIM Optel-D would be:

S.OPD.p.1; to provide the accurate three-dimensional shape of the asteroid, in combination with imaging data from VIS. *Explanation:* This will allow an accurate description of surface structures, slopes, local gravity and, together with a mass determination, density.
S.OPD.p.2; to contribute to determining the 3-dimensional position of the spacecraft with an error of +/-50 m (TBD). *Explanation:* numerical modelling should determine what is the level of accuracy required to determine Didymoon mass through flybys, maybe requiring close approach of the spacecraft i.e. within 2 km in periods of at least 1 day.
S.OPD.p.3; to determine Didymoon surface topography i.e. highlands, lowlands, ponds.
S.OPD.p.4; to determine Didymoon fine-scale altimetry i.e. regolith, bedrock, boulders. This provides constraints on surface mechanical strengths, structures and evolution.
S.OPD.p.5; to determine the thickness of the layer of regolith on Didymoon, if present.

The secondary asteroid research objectives of AIM Optel-D would be:

S.OPD.s.1; to determine Didymoon shape and support mass determination after DART´s impact.
S.OPD.s.2; to determine Didymos primary component shape model, together with VIS measurements.
S.OPD.s.3; to determine Didymos primary component surface topography i.e. highlands, lowlands, ponds.
S.OPD.s.4; to determine Didymos primary component fine-scale altimetry i.e. regolith, bedrock, boulders.

S.OPD.s.5; to determine the thickness of the layer of regolith on Didymos primary, if present.
S.OPD.s.6: to support the of study surface chemical and mineralogical properties.

7.7 CubeSat opportunity payloads (COPINS)

Two cubesat deployment systems will be mounted on the AIM spacecraft. These will carry and deploy the Cubesat Opportunity Payload Independent Nano-Sensors (COPINS) that will operate during the AIM mission.

Once in the asteroid vicinity, the AIM spacecraft will deploy at least two and up to six payloads, based on either 1-U, 2-U or 3-U cubesat configurations.

The primary asteroid research and scientific objectives of AIM COPINS shall be determined through an open AO and will be specified as a result of the selection of experiment concepts. Primary objectives shall be relevant to AIM high-level mission goals stated above (e.g. surface remote or in-situ sensing, impact plume imaging, orbiting dust imaging etc)

8 MEASUREMENT PHASE SUMMARY

Table 8-1 presents a summary on the basic measurement phases that have been defined to meet the asteroid observation goals. A ¨measurement set¨ corresponds to the absolute minimum data set that is required to obtain meaningful information needed to achieve the goal. In most cases they correspond to the observation of the Didymos system over a full orbital period (i.e. approx. 12h), assuming an inertial observation point fixed with respect to the barycentre of the system.

Observation phase	Measurements
Early Characterisation Phase	1 measurement set of VIS
Detailed Characterisation Phase Period 1.	1 measurement set of VIS + 1 measurement sets from TIR + HFR
Detailed Characterisation Phase Period 2.	2 measurement sets of VIS + 2 measurement sets from TIR
Detailed Characterisation Phase Period 3.	2 measurement sets of VIS + 3 measurement sets from TIR
TBD	Minimum data volume (MASCOT-2 inc. LF) + COPINS

Table 8-1 AIM basic measurement phases