ESA's Asteroid Impact Mission
concept, currently under study,
would be humanity's first mission
to a binary asteroid

→ AIMING FOR ASTEROIDS

A mission for testing deep-space technologies

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Europe's proposed Asteroid Impact Mission is set to become humanity's first mission to a binary asteroid system, and ESA's first mission to a small body since Rosetta put down its lander on Comet 67P/Churyumov-Gerasimenko.

ESA's Asteroid Impact Mission (AIM) will have a ringside seat for the collision of a separate NASA spacecraft with the asteroid's tiny moon, gathering data that could help save Earth from impacts in the future. In addition, with its own microlander plus accompanying CubeSats, AIM will serve as a deep-space technology demonstrator gathering cutting-edge science data.

AIM is a mission in a hurry. It must be built and ready to fly for a firm October/November 2020 launch window in order to reach the Didymos binary asteroid system by June 2022. April saw the formal start of the AIM's design Phase-A/B1. Benefiting from a wealth of studies started in 2002 addressing the potential role of space missions to mitigate asteroid hazards, up to the latest Marco-Polo-R and Phobos sample return mission assessments and technology developments, AIM has taken full benefit of these results to run on a fast-track focused design effort.

As a result, the current AIM mission scenario is in fact the simplest and most cost-effective solution. It will enable the spacecraft to gather all the data necessary to validate the asteroid deflection technique known as 'kinetic impact' and its underlying physical models, demonstrate technologies for future exploration missions and retrieve scientific information that will finally constrain models describing the formation and evolution of our Solar System as well as planetary rings.

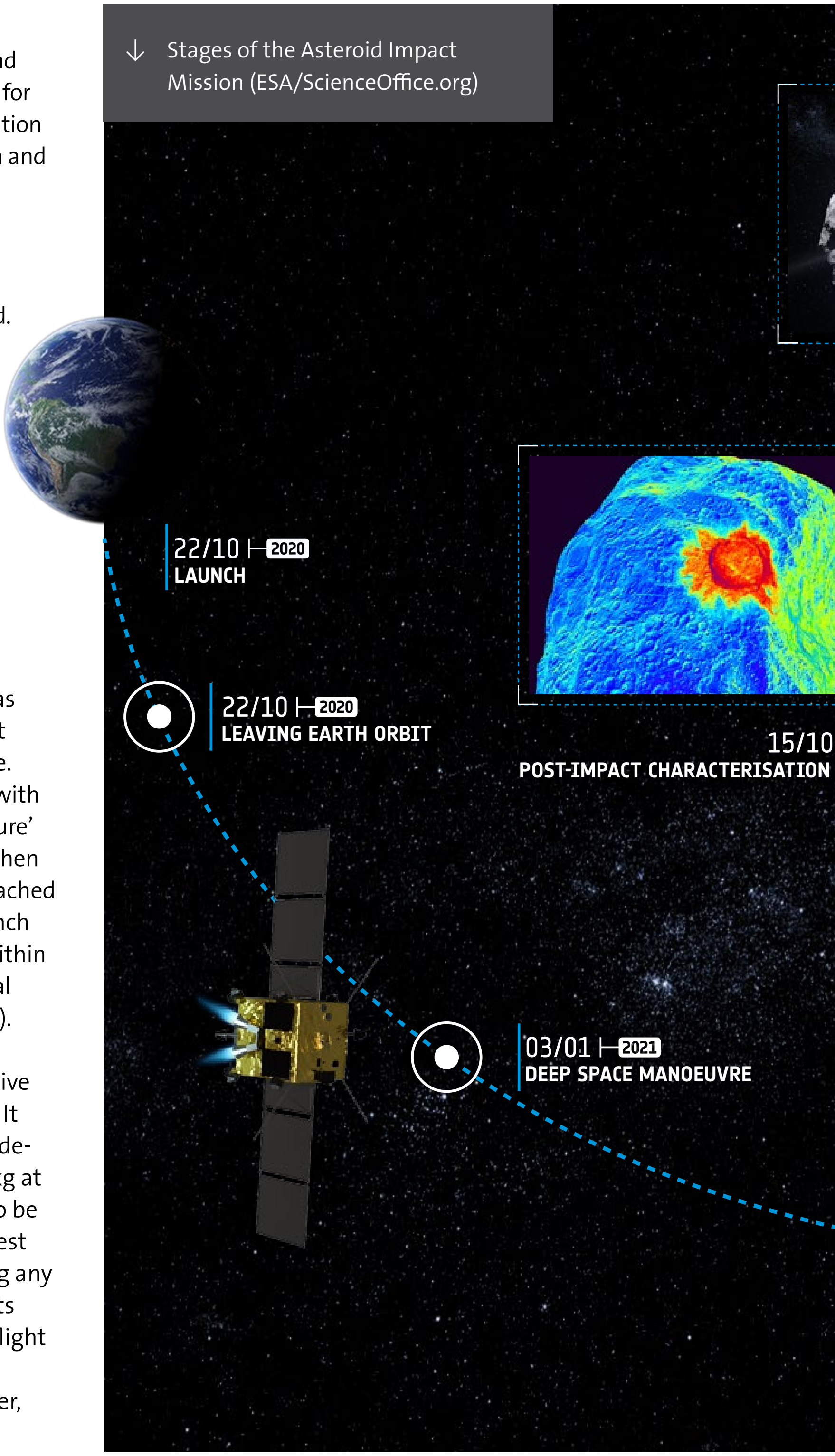
Two separate industrial consortia began working on design concepts for the mission's satellite platform, payload accommodation and operations in proximity to the asteroid. Running dual industrial contracts in parallel is a tried and tested way of encouraging as much innovation as possible, where a decision will be made between the two sets of results in summer 2016 following the intermediate system requirements review. The finalised design will enable ESA Member States to take a decision for the full mission implementation. After that, things should get really busy.

Low in cost, high in innovation

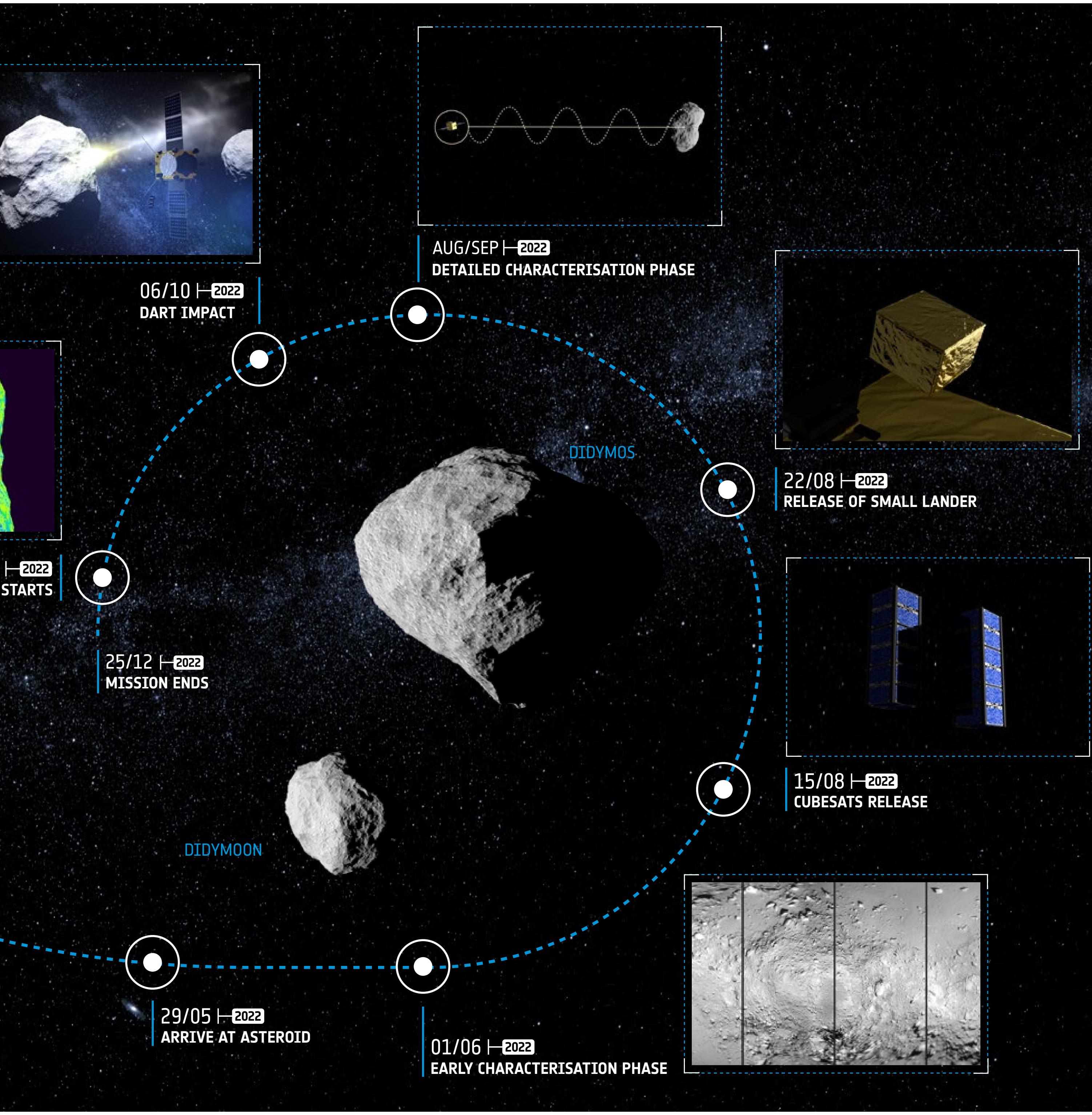
The objective of AIM is to be a new type of deep-space mission – low in cost, high in innovation and developed as fast as possible while accepting a higher level of risk. Past missions beyond Earth orbit proceeded at a statelier pace. Rosetta, by way of example, took a decade to construct, with key technologies such as its 'low intensity, low temperature' solar cells in development for much longer still. Rosetta then needed another ten years of planetary flybys before it reached its goal. AIM has to come together more rapidly – its launch window will allow it to reach its binary asteroid target within merely a year and a half thanks to a one of a kind celestial encounter with binary asteroid 65803 Didymos (1996 GT).

To stay affordable, AIM is first of all applying an aggressive development strategy, including testing and validation. It will also be a much shorter-lived mission than the decade-spanning Rosetta. AIM, with a maximum mass of 800 kg at launch and about the size of a large office desk, will also be much more compact than the lorry-sized Rosetta. The rest of the savings are coming from a simple design avoiding any costly mechanisms, exploiting technology developments from other ESA programmes – where AIM will provide flight validation – and reusing as much proven technology as possible. As a result, AIM will be a cheaper, though riskier, mission compared to the past.

AIM's target system comprises an 775 m diameter main asteroid orbited in turn by a 163 m moon, informally known as 'Didymoon'. In mid 2022, the path of these two asteroids will take them a relatively close 15 million km to Earth (less than 0.1 AU), enabling a battery of ground-based telescope and radar observations to complement the measurements performed from space. The smaller moon will be AIM's main focus, although data will also be gathered from the larger asteroid on an opportunistic basis.



↓ Stages of the Asteroid Impact Mission (ESA/ScienceOffice.org)



aim
ASTEROID IMPACT MISSION

+

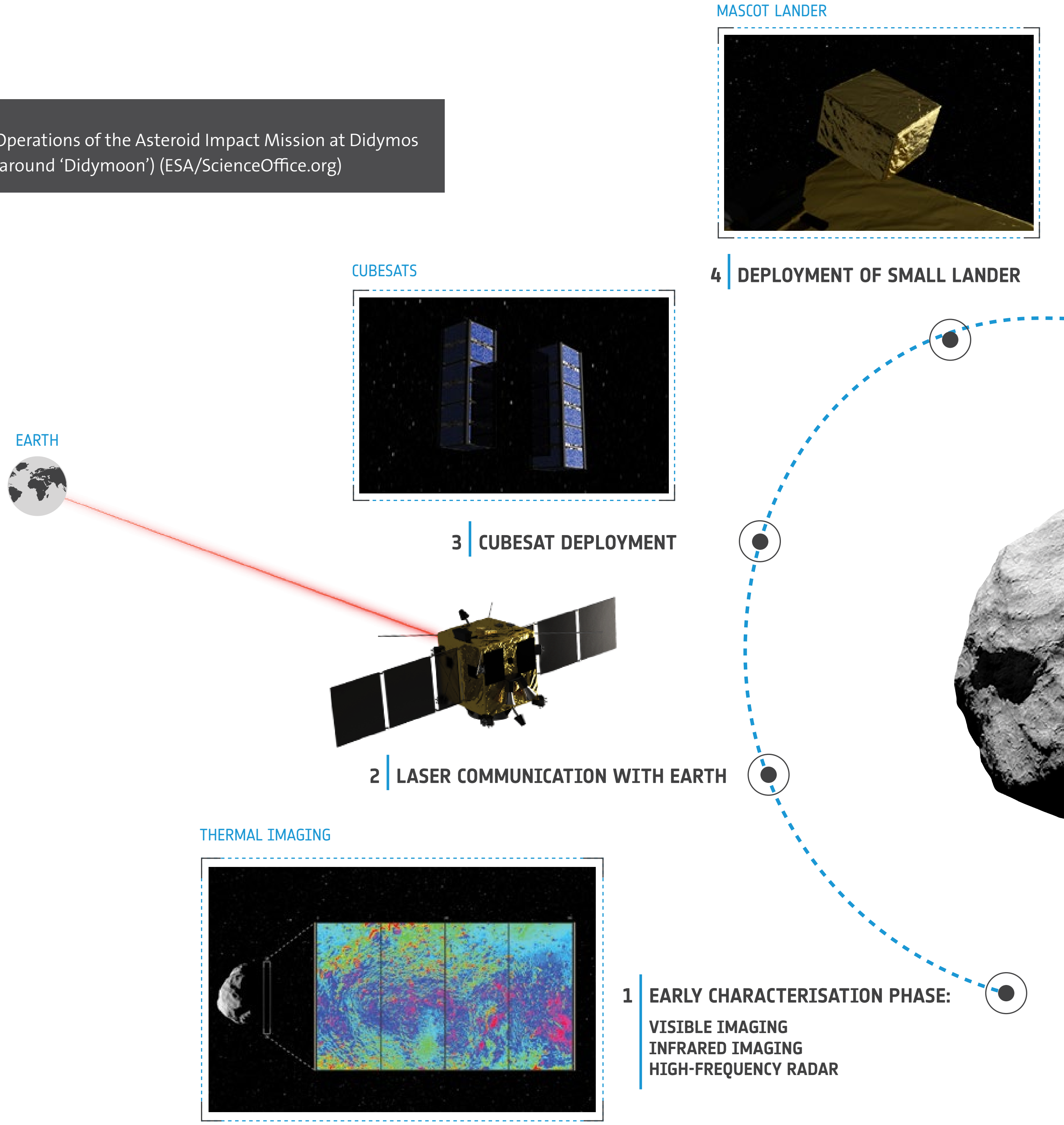
dart
DOUBLE ASTEROID REDIRECTION TEST

=

aida
ASTEROID IMPACT & DEFLECTION ASSESSMENT

AIDA is the combination of ESA's Asteroid Impact Mission with two triple-unit CubeSats to observe the impact of the NASA-led Demonstration of Autonomous Rendezvous Technology (DART) probe with the secondary Didymos asteroid, planned for late 2022

↓ Operations of the Asteroid Impact Mission at Didymos (around ‘Didymoon’) (ESA/ScienceOffice.org)



Making history

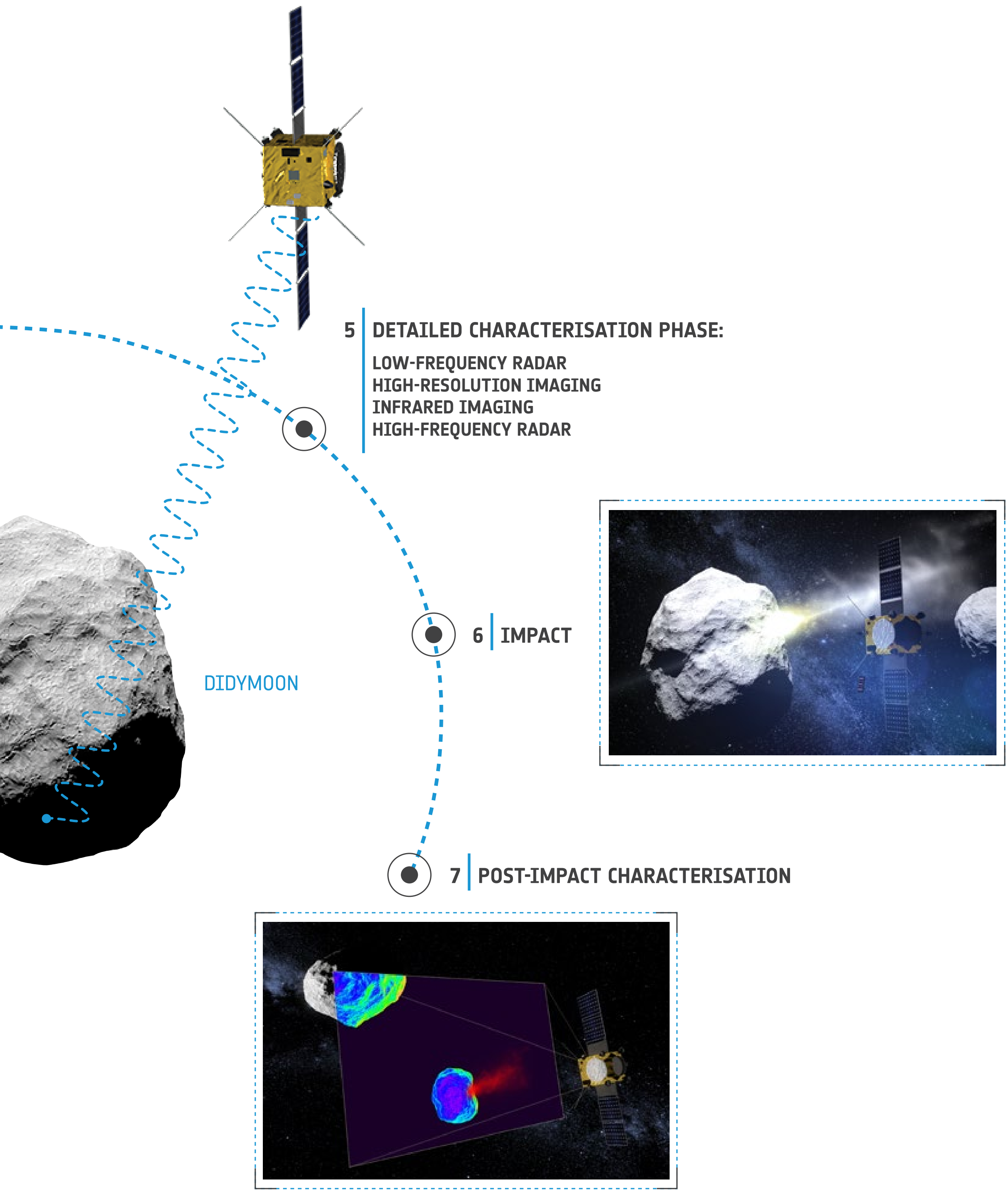
After about four months of detailed observations at Didymos, the next stage of the mission will be reached, when AIM is joined briefly by a terrestrial companion. Another spacecraft, the NASA-led Double Asteroid Redirection Test (DART) probe will home in on Didymoon, then crash into it at about 6 km/s.

DART, developed by the Johns Hopkins University’s Applied Physics Laboratory, intends to test the feasibility of diverting the path of an asteroid. This historic first attempt to shift the orbit of a Solar System body in a measurable way represents a ground-breaking test of planetary defence methods.

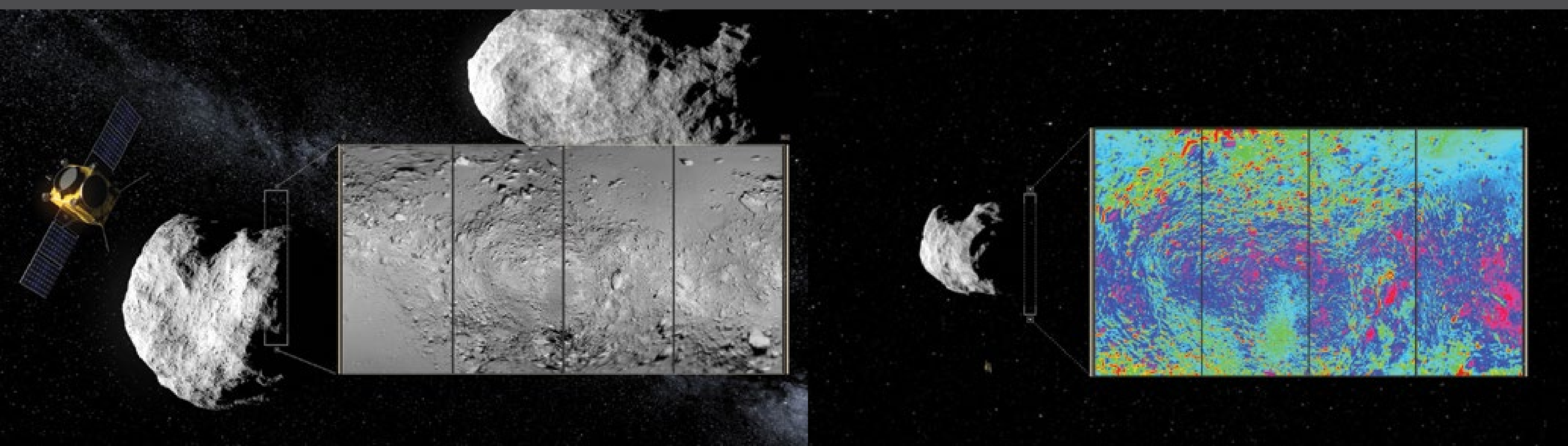
Meanwhile, AIM itself will be on hand to carry out detailed before-and-after observations of the asteroid’s deep-interior structure as well as its orbit, fully documenting the consequences of DART’s kinetic impact.

The closest precedent to this collision would be the 2005 impact of NASA’s Deep Impact probe with Comet Tempel 1, but that comet was a mountain-size 6 km across, whereas Didymoon is only the size of the Great Pyramid of Giza.

There was no prospect of deflecting Tempel 1’s orbit – the mission was actually tasked with revealing the cometary subsurface. Deep Impact’s accompanying observer spacecraft



↓ A combination of visual (left) and thermal (right) imagers will be trained on the asteroid’s surface



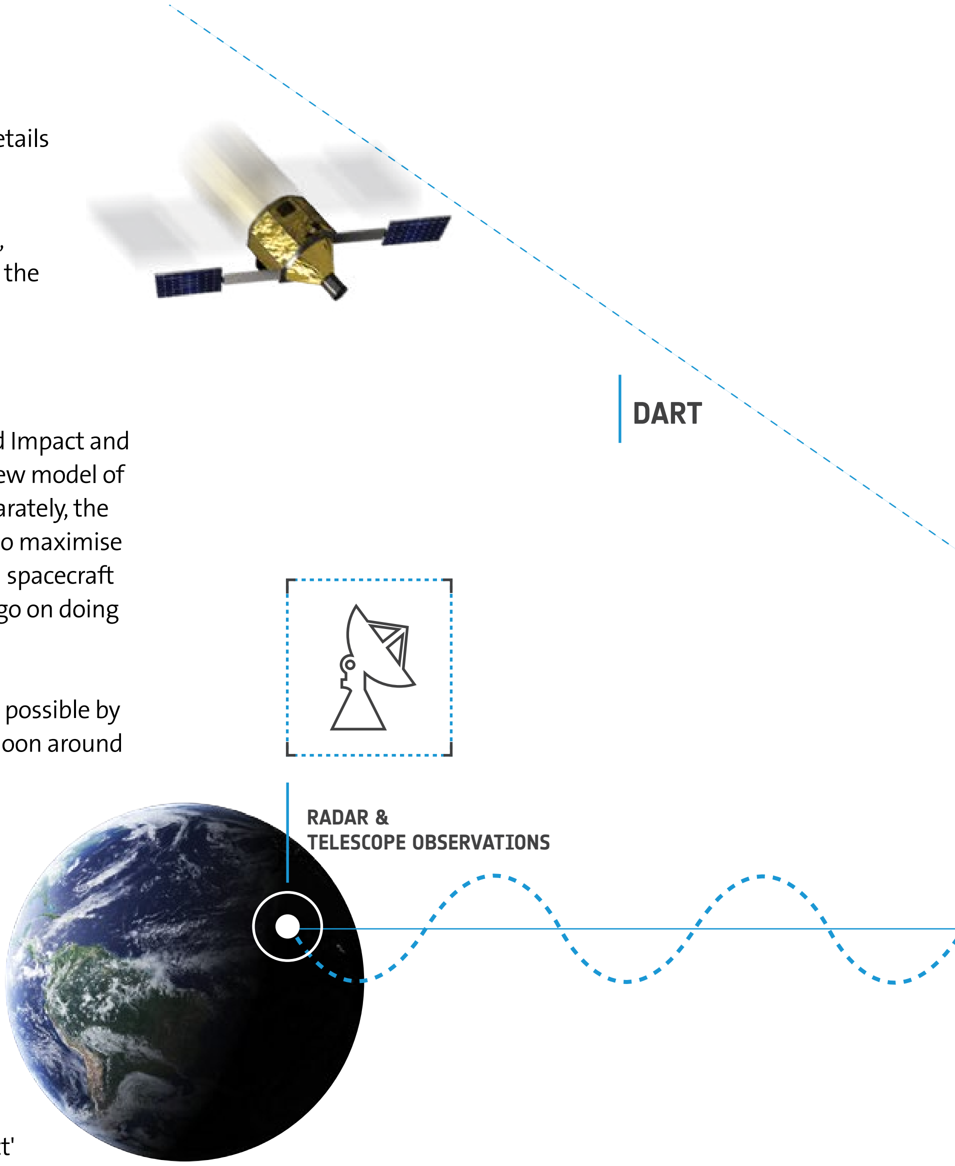
was on a fast-moving flyby trajectory, and many details of the cratering event and its aftermath were not captured. This time the watching AIM will remain in a safe but close distance to the Didymos system, imaging in high resolution the cratering event and the ejecta plume dynamics.

A new model of cooperation

The two missions combined are called the Asteroid Impact and Deflection Assessment (AIDA) mission. AIDA is a new model of international cooperation: while built and run separately, the two spacecraft are being planned in coordination to maximise their overall mission return. At the same time both spacecraft can pursue their own independent goals, and can go on doing so even if one of the two never reaches Didymos.

The fundamental measurement that will be made possible by AIDA is the variation of the orbital period of Didymoon around its parent 'Didymain' after the impact. AIM's own post-impact observations will be supplemented by monitoring from the ground. Cooperating astronomers will apply the light curve technique to estimate the shifted asteroid's rotation – measuring shifts in its light intensity over time. Ground-based radars will complement such measurements providing a second independent set of data.

In the aftermath, once the collision's effects have been fully documented and studied, 'kinetic impact' will become a proven technique that could feasibly be applied to other targets, should the need ever arise to protect our home planet. In this context, AIM will also enable the ground-truthing of a number of parameters for future asteroid observations relevant to the Near Earth Object segment of ESA's Space Situational Awareness programme.



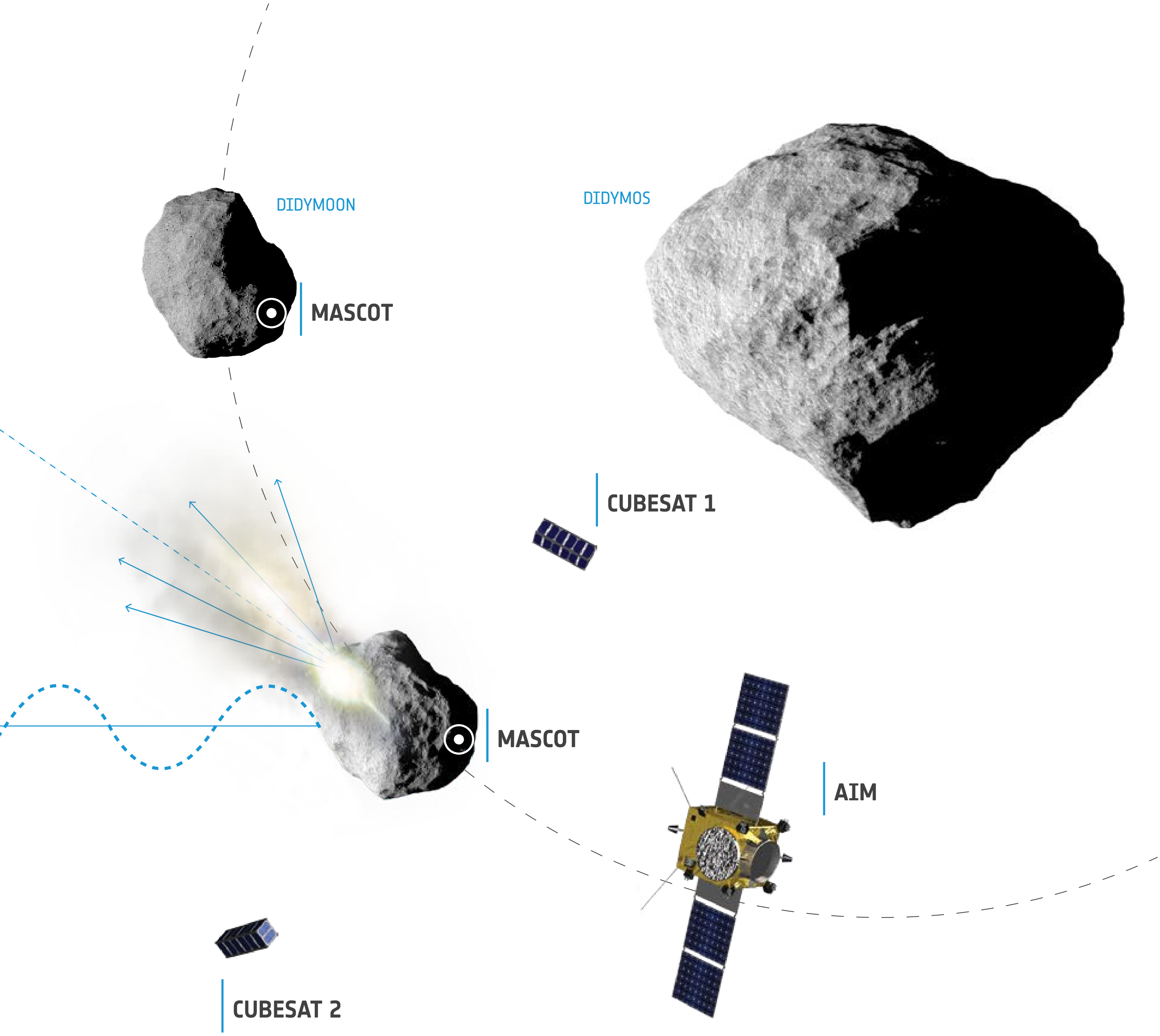
↑ The Asteroid Impact and Deflection Assessment (AIDA) mission (ESA/ScienceOffice.org)

Intended to be launched on an Ariane 6.2 rocket from Europe's Spaceport in French Guiana, the spacecraft design will be a simple one. Measuring 1.8 x 2.0 x 2.1 m^3 (with solar arrays stowed), it will have a simple integration-optimised structure, a fixed high-gain antenna and a bipropellant thruster system with 24 10-Newton thrusters.

Among its other purposes, AIM will serve as an important technology demonstration mission. It will prepare the way for future interplanetary missions to come by using deep-space optical communication techniques, intersatellite communication with its CubeSats and microlander, and novel autonomous proximity operations in low gravity. In addition, AIM will perform science – indeed, meaningful scientific results are seen as the best possible proof of its various technologies – but to do this within the available budget, mass and time envelope requires an extremely tight focus in terms of mission design.

AIM is therefore undergoing streamlined design work, with many trade-off options already closed through numerous past ESA studies of asteroid missions. For instance, during its 18 month-long cruise phase – the bulk of AIM's time in space – the spacecraft will remain largely inactive. However, once at Didymos, there will be six months of extremely busy days. With a payload suite selected early on, teams are devising detailed plans to operate every instrument in an optimal way while coping with a simple, resource-limited platform.

AIM's hardware, therefore, will operate in an interdisciplinary, multi-tasking fashion. Take the visual imaging system used to perform guidance and navigation on the way to Didymos: this will also work to achieve the main mission objectives, measuring the Didymos orbital period change and mapping the asteroid surface in high resolution. The laser, too, which

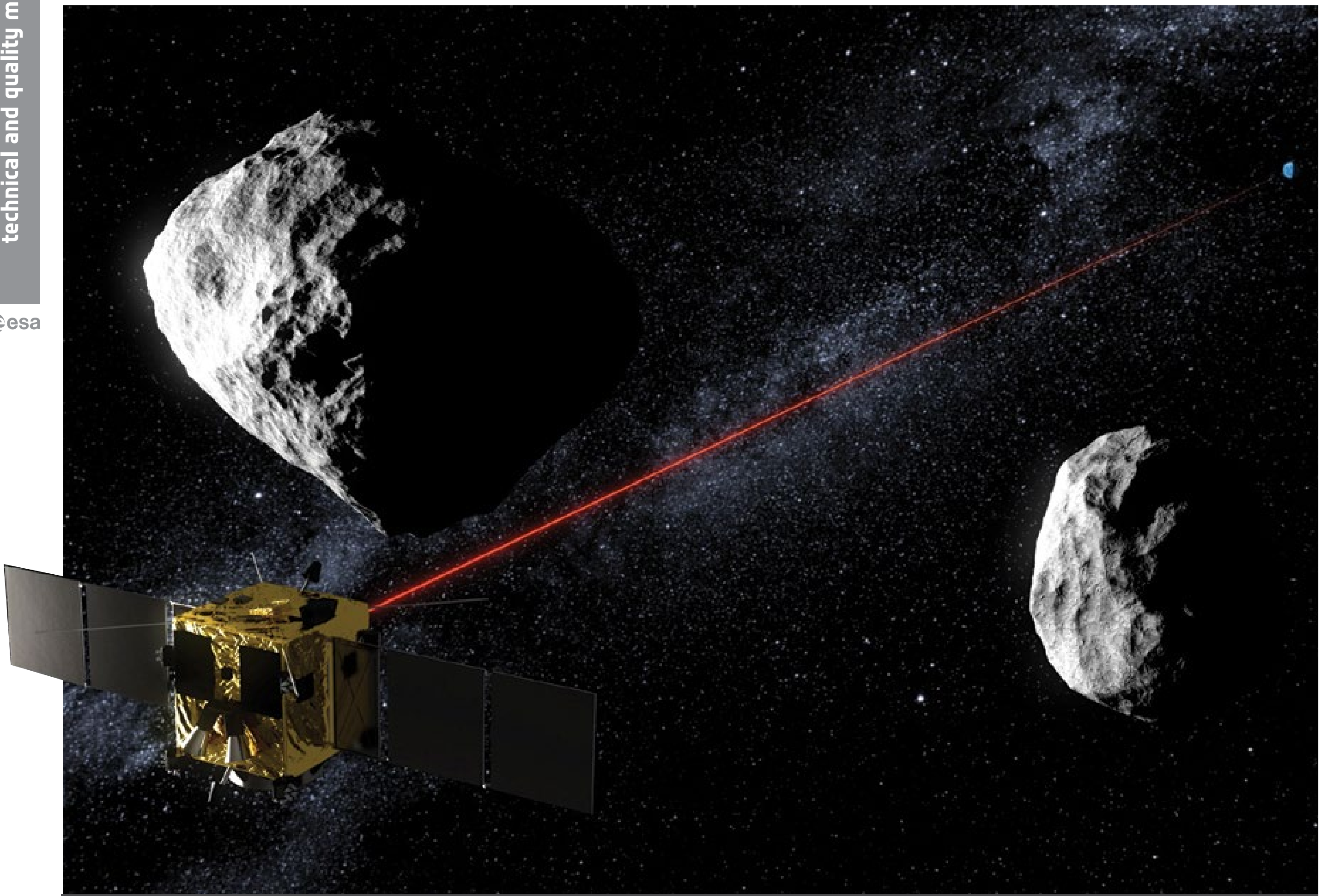


will be demonstrating potentially high-bandwidth return of science data high-bandwidth return of science data to Earth, will also perform laser ranging with the asteroid for both close proximity operations in closed loop with AIM's guidance system and altimetry measurements.

A combination of visual and thermal imagers will be trained on the asteroid's surface. The thermal imager – also being considered to do double duty as the potential receiving end of the optical communications terminal – will work to discriminate between the various properties of the Didymoon surface, from solid rock to loose stones to layers of dust. Such thermal measurements will help characterise the structure and cohesion of the soil, as well as other effects believed to influence asteroid motion (photon pressure on an irregular asteroid body can induce force and torque – known as the 'Yarkovsky/YORP effect').

These imagers will be complemented by high-frequency radar (HFR) to sound the outermost surface and sub-surface layers, down to a depth of a few metres. A unique bistatic low-frequency radar will also characterise, for the first time in history, the deep interior structure of the asteroid, shedding light over decades of debate on the formation processes of these tiny celestial bodies.

The HFR is a stepped frequency radar which, with very modest power consumption, can operate over a wide bandwidth to provide a free-space resolution distance between spacecraft and asteroid of less than 10 cm. As the AIM spacecraft passes relatively slowly across the surface, HFR will build up a detailed 3D surface map. Pulses at the lower end of the spectrum will penetrate down to 6–10 m depth.



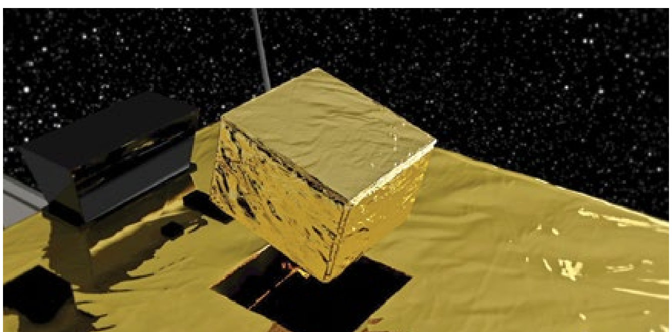
AIM would send science results back to Earth via a high-bandwidth laser link

Getting the data back

The large amounts of data generated by the AIM payload will be returned to Earth via a novel holographic high-gain antenna plus its laser communication system, maintaining a high-bandwidth link back to ESA's Optical Ground Station in Tenerife. To keep mission costs down, AIM's laser terminal is not optimised to be the main communication system. Instead, an existing terminal designed for low-Earth orbiting satellites is being adapted for deep space and demonstrate key new features (such as using Earth's own infrared emission as a beacon for coarse pointing). Optical communication in general is not yet a well-established technology for space and ESA's European Data Relay System (EDRS) will be the first commercial application.

EDRS satellites in high orbits will use laser links to return environmental data from Europe's low-orbiting Sentinel satellites on a real-time basis, a technique previously demonstrated using ESA's Alphasat and Artemis telecoms missions. Such technology in the future will be key to enabling deep-space human exploration missions where high bandwidth will be required.

In principle, optical communication works something like Morse code, with encoded rapid flashes on and off. The much higher frequency of laser light delivers higher directivity and as a result increased bandwidth.
The scale of optical communications continues to increase: in 2013 ESA's Optical Ground Station in Tenerife participated in a two-way contact with NASA's LADEE lunar orbiter, across 400 000 km. However, AIM will need to operate over much



AIM's MASCOT-2 lander deployment

→ Choosing CubeSats

Five CubeSat concepts to potentially accompany AIM into deep space are being studied following a call for mission proposals. Other options may be addressed in the near future following ESA Member States' capabilities and advancing technologies.

The ideas currently being looked at include taking a close-up look at the composition of the asteroid surface, measuring the gravity field, assessing the dust and ejecta plumes created during a collision and landing a CubeSat for seismic monitoring.

The proposals selected for further study are:

- AGEX (Royal Observatory of Belgium, ISAE-SUPAERO, Antwerp Space, EMXYS, Asteroid Initiatives Ltd). A CubeSat touches down to assess the surface material, surface gravity, subsurface structure and DART impact effects. Another CubeSat in orbit deploys smaller 'chipsats' dispersed over the asteroid.

- ASPECT (VTT Technical Research Centre of Finland, University of Helsinki, Aalto University Foundation). A CubeSat equipped with a near-infrared spectrometer to assess the asteroid composition and effects of space weathering and metamorphic shock, as well as post-impact plume observations.

- DustCube (University of Vigo, Micos Engineering GmbH, University of Bologna). A CubeSat to measure the size, shape and concentration of fine dust ejected in the aftermath of the collision and its evolution over time.

- CUBATA (GMV, Sapienza University of Rome, INTA). Two CubeSats measure the asteroid system's gravity field before and after impact through Doppler tracking of CubeSats, as well as performing close-range imaging of the impact event.

- PALS (Swedish Institute of Space Physics, Institute for Space Sciences IEEC, Royal Institute of Technology KTH, AAC Microtec, DLR). Two CubeSats characterise the magnetisation, bulk chemical composition of, and presence of volatiles in, the impact ejecta, as well as performing very high resolution imaging of the ejecta components.

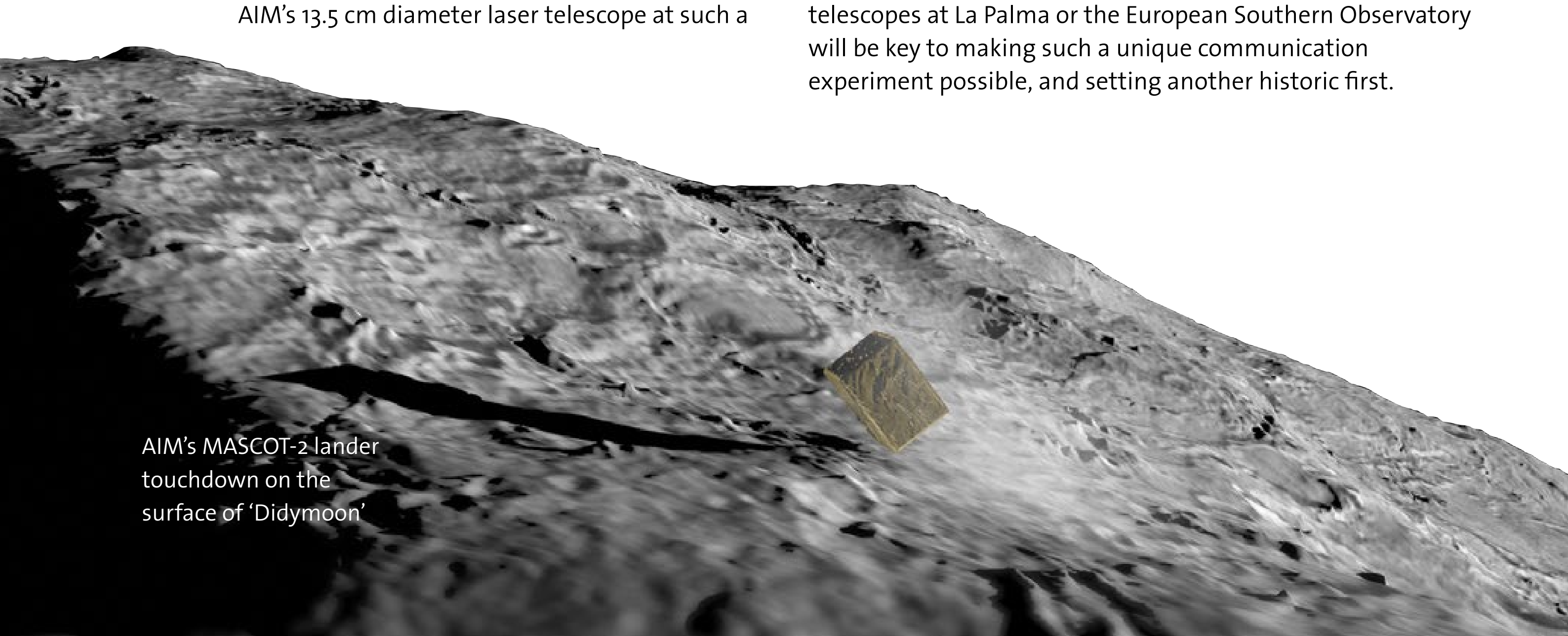
With these opportunity payloads, ESA is applying current European technology miniaturisation efforts to explore our wider Solar System in unprecedented ways, lowering the cost and risk of interplanetary missions. The selected proposals will complete their detailed study phase in June 2016, helping the AIM team define all necessary interfaces, ahead of a final selection to fill the two berths.

→ A pair of triple-unit CubeSats. ESA's Asteroid Impact Mission spacecraft will have room to carry six CubeSat units – potentially single-unit miniature spacecraft but more probably a pair of larger CubeSats

farther distances: the team is benchmarking a maximum span of 75 million km, or half the distance between Earth and the Sun. That might sound like a lot, but operating around Mars one day will involve much greater distances still.

That is why the industrial team is working hard to devise a low-power mode to demonstrate the terminal's operability when the transfer orbit will take AIM at distances very close to the ones of Mars. A laser beam shone back from AIM's 13.5 cm diameter laser telescope at such a distance would have a ground footprint of about 1100 km – farther than from London to Berlin. That may seem large, but an equivalent radio beam radiating out across space would end up wider than our whole planet. Even so, many photons will get lost on the way, so the 1 m diameter scale receiver telescope will need sophisticated photon-counting methods to detect the signal reliably.

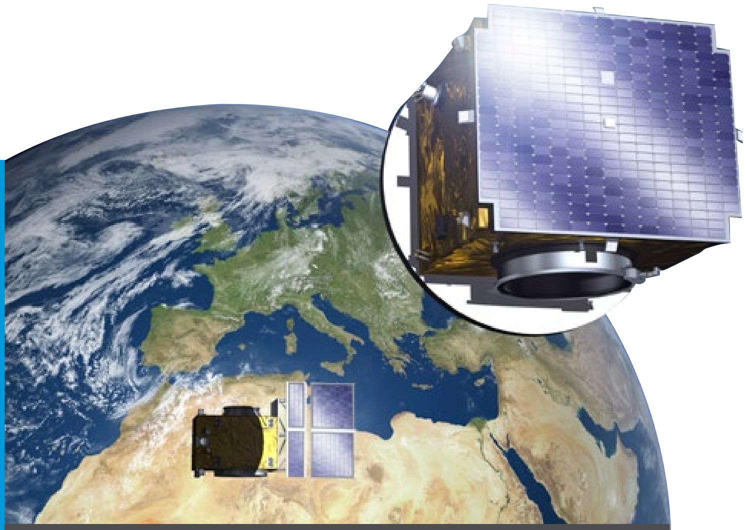
When AIM is furthest away, the support of larger ground telescopes at La Palma or the European Southern Observatory will be key to making such a unique communication experiment possible, and setting another historic first.



AIM's MASCOT-2 lander touchdown on the surface of 'Didymoon'

→ Technology testers

ESA has a noble history of technology demonstration missions, which go on to double as innovative science missions. Demanding science payloads serve as the best possible demonstration of experimental technologies. If the results are good enough, then the scientific end users will come – challenging Europe's space engineers to do their very best to make it happen.



↑ Proba-3

The Project for On-Board Autonomy (Proba) family of mini-satellites exemplifies this approach. Proba-1, launched in 2001 and still going strong, was an experimental hyperspectral satellite turned operational Earth observation mission. Onboard innovations included what were then novel gallium arsenide solar cells, one of the first lithium-ion batteries – now the longest operating such item in low-Earth orbit – and attitude and orbit determination using only star trackers and GPS sensors, doing without the then-standard Earth or Sun sensors or gyros (GPS timing being used to synchronise operations).

Navigation and attitude control software was generated through 'autocoding' to cut costs – essentially applying code to write code – with Proba-1's onboard computer running on one of the first ERC32 microprocessors.

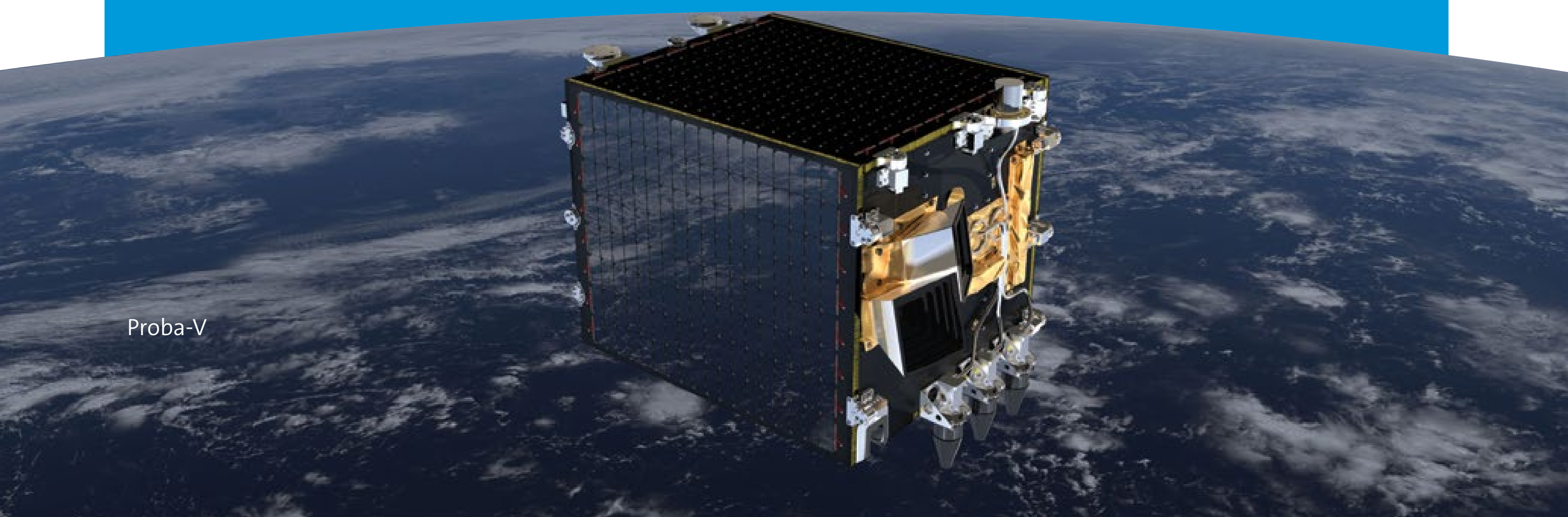
Next, ESA's SMART-1 took technology testing beyond Earth orbit, demonstrating an innovative electric engine on a slow flight to the Moon following its launch on 27 September 2003. It went on to survey the lunar surface and investigate the prospect of ice at the lunar poles, finally ending its mission in September 2006 with a planned impact on the lunar surface.

Proba-2, launched in 2009, focused on solar observations and space weather monitoring. The satellite's main computer ran on the first LEON2-FT microprocessor operated in space, while the mission also hosted 16 other new technologies including a new type of lithium-ion battery, an advanced data and power management system, combined carbon-fibre and aluminium structural panels, the first Active Pixel Sensor startracker (subsequently used on BepiColombo) and new models of reaction wheels.

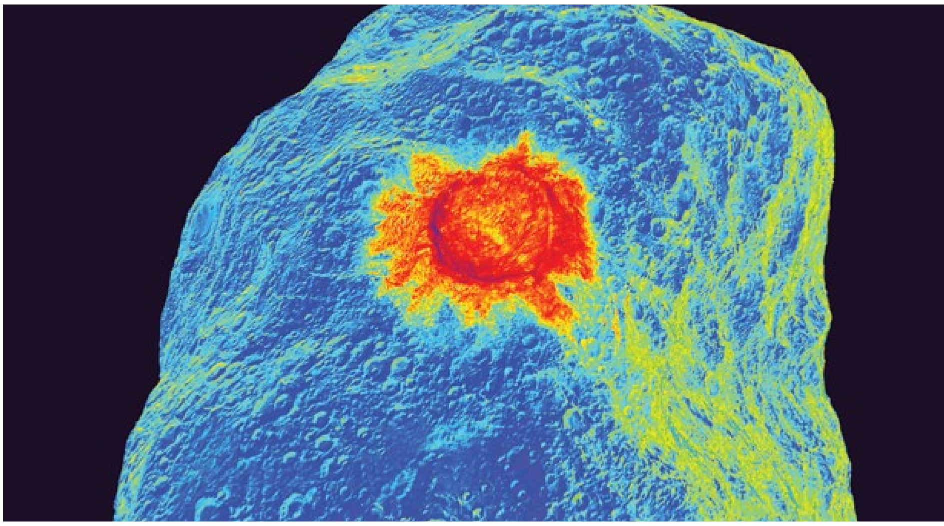
Proba-V, launched in 2013, was tasked with a full-scale operational mission, previously handled by the Vegetation instrument on France's full-sized Spot satellites: to map land cover and vegetation growth across the entire planet every two days. Key technology developments underpinning its improved, miniaturised version of the instrument included a novel short-wave infrared detector and a compact three-mirror-anastigmat telescope. Proba-V also performed the first detection of aircraft ADS-B signals from orbit and demonstrated the first transmitter based on gallium nitride.

Proba-3, planned for launch in 2018, will be ESA's – and the world's – first precision formation-flying mission. A pair of satellites will fly together, maintaining a fixed configuration as a 'large rigid structure' in space, to prove formation-flying technologies down to millimetre precision. The mission will demonstrate formation flying in the context of a large-scale science experiment. The paired satellites will form a 150 m long solar coronagraph to study the Sun's faint corona closer to the solar rim than has ever before been achieved.

A follow-on Proba NEXT mission is currently under study, involving either stratospheric limb sounding or microwave-based Earth observation.



Proba-V



← AIM's thermal imaging of the crater left by the NASA-led DART probe impacting the Didymoon asteroid in 2022 (ESA/ScienceOffice.org)

Four spacecraft in one

AIM's onboard payload will be supplemented by more mobile elements, effectively rendering the AIM mission four spacecraft in one. The main 'mothership' will be the carrier of the Mobile Asteroid Surface Scout-2 (MASCOT-2) microlander, supplied by the German Aerospace Centre DLR – a direct descendant of the MASCOT-1 lander currently in transit aboard JAXA's Hayabusa-2 mission, heading to near-Earth asteroid 1999 JU3 for a planned 2018 landing.

MASCOT-2 will have two main differences compared to its predecessor: it will carry low-frequency radar systems to perform soundings right through the body of the asteroid, and a solar panel to allow it to go on working for several weeks on the surface of Didymoon.

This shoebox-sized lander will carry the surface transmitter of the low-frequency radar measuring the propagation of waves between MASCOT-2 and the AIM orbiter. This allows the deep internal dielectric properties of Didymos to be sounded, while benefiting from the heritage of Rosetta's CONSERT instrument, which leads to an instrument architecture with separated orbiter and lander parts.

In addition, its sophisticated payload suite consists of a compact wide-angle CMOS camera (CAM) designed to cover a large part of the surface in front of MASCOT, an accelerometer (DACC) assessing the unknown surface mechanical properties (the effective soil-lander E-module, the strength of regolith material, the friction coefficients between soil and lander), and a radiometer (MARA) measuring the surface temperature brightness temperature for a full day/night cycle at least one location completes the highly sophisticated yet compact payload suite. Rosetta's Philae lander bounced right back off the surface of Comet 67P during its first attempt at landing; MASCOT-2 will be a chance to gain extra experience of operating in low-gravity environments for future sample-return missions (for example, to Phobos).

Devising a safe collision-free strategy for MASCOT-2's landing with a high probability of success is no easy task. This will be the most critical phase for AIM – as the spacecraft will come to just 140 m from the asteroid. Onboard autonomy can be used but careful analysis is also being performed with the support of laboratory analysis.

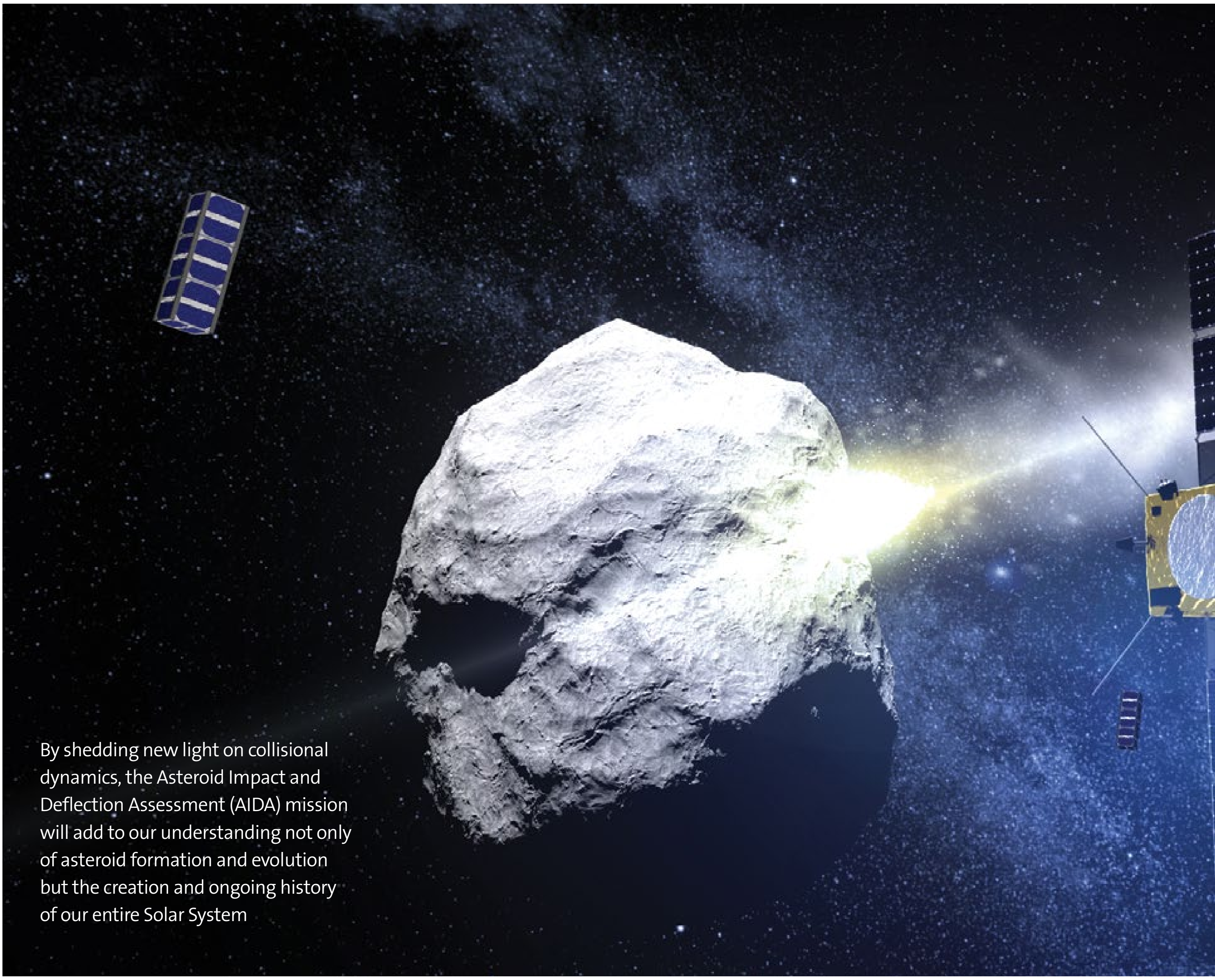
AIM will also be carrying two CubeSats. This early demonstration of standardised nanosatellites in deep space will enable valuable intersatellite communication and data relay experiments between spacecraft, opening up the prospect of such miniaturised satellites accomplishing exploratory tasks that might be judged too risky for a standard full-sized model. Achieving the maintenance of communications and rendezvous operations between separate spacecraft will be essential in accomplishing future sample-return missions to Mars or other targets.

The mission team put out an announcement of opportunity for what are referred to as CubeSat Opportunity Payloads Intersatellite Network Systems (COPINS), seeking innovative hosted sensors to complement and boost AIM's own scientific return. AIM's two three-unit CubeSats currently under study will possess the necessary capability to produce meaningful scientific results fully complementing AIM's main objectives.

The stuff of science fiction

AIM as a whole is likely to revolutionise asteroid science. Each new close encounter with an asteroid body has led to a fresh transformation of our understanding, but there is still much to learn. Spacecraft flybys combined with ground-based observations, meteorite analysis and software modelling have highlighted the striking variety of asteroids in terms of size, shape, surface characteristics and constituent materials.

Similarly, asteroids rotate in various ways, from simple rotation to slow precession or rapid tumbling. It is possible



By shedding new light on collisional dynamics, the Asteroid Impact and Deflection Assessment (AIDA) mission will add to our understanding not only of asteroid formation and evolution but the creation and ongoing history of our entire Solar System

that asteroid rotation is constrained by fundamental 'spin limits', beyond which centrifugal acceleration would cause material to escape from the surface of rubble-pile bodies. Indeed, such escaping might explain the origins of many binary asteroid systems, which are estimated to make up 15% of the known total.

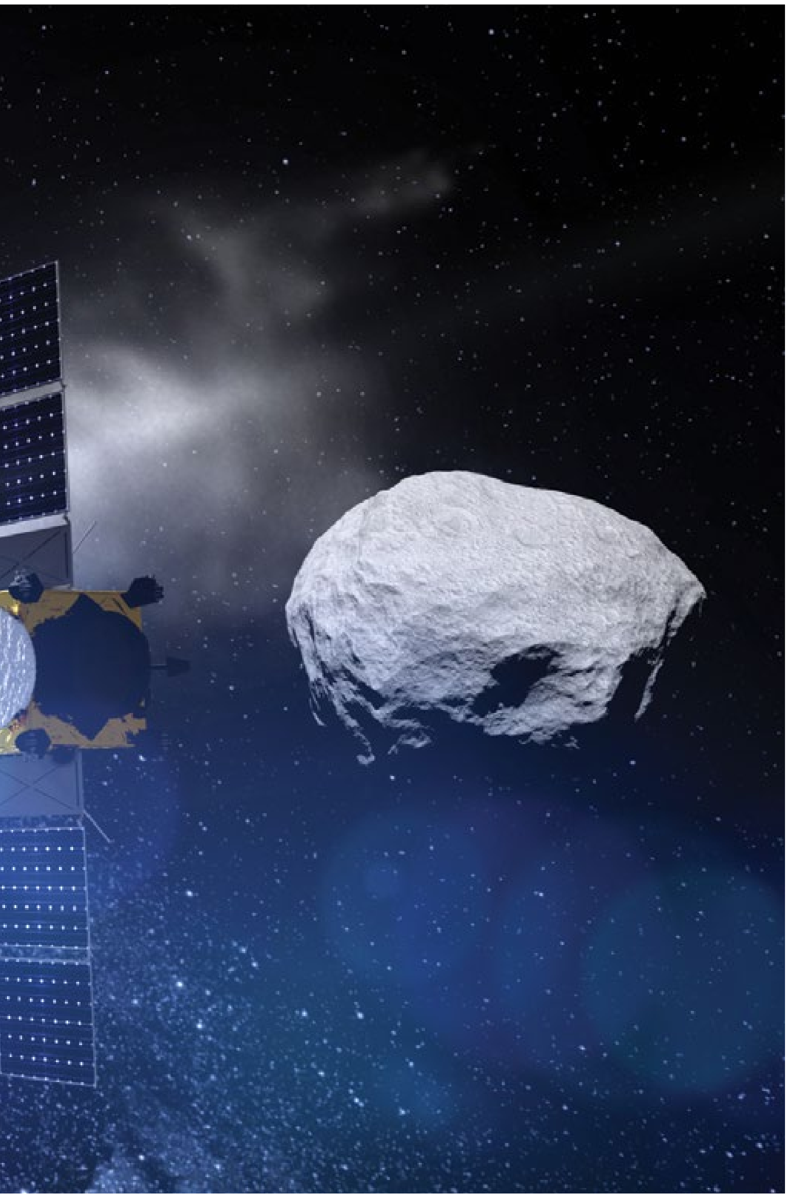
The internal structure of asteroids remains a blank spot in scientific understanding. Are there large voids within the deep interior of asteroids, or are they composed of loose dust or rubble, or conglomerates of monolithic rock? In particular, there is no way of knowing how an actual asteroid would respond to the specific external stimulus of an impact – short of trying it for real.

The sheer scale of the DART impact dwarfs anything that could be replicated in terrestrial laboratories, and software models rely on assumptions and extrapolations that cannot be verified – yet.

By shedding new light on collisional dynamics, the AIDA mission will add to our understanding not only of asteroid formation and evolution but the creation and ongoing history of our entire Solar System, and even the arising of preconditions for life on Earth.

Down at a smaller scale, AIM's surface observations will reveal the range of physical phenomena apart from gravity that govern the surface character of asteroids, influence their material properties and keep them bound together. What are the relative roles of electrostatic and Van der Waals forces, for example?

One suggestion is that some fine-grained asteroids might resemble 'fairy castles', crumbling to the touch. Such findings would be relevant to asteroid mining as well as planetary defence, while also offering insight into the very earliest microscopic-scale processes of accretion, right back at the dawn of this and other planetary systems.



AIDA, if it goes ahead as envisaged, will represent humanity's very first attempt to address an extremely important question: what could humanity do if an asteroid were on a collision course with Earth? A mission that would previously have been the stuff of science fiction movies, is likely to prove a massive hit with the global public. ■

Sean Blair is an EJR-Quartz writer for ESA

→ Intersatellite links

AIM's release of nanosatellites and a small lander across the Didymos system presents a problem: how to keep them linked with Earth? They are simply too small to house the amount of electrical power and host an antenna of the necessary scale. Instead they will employ radio-based intersatellite links to their AIM mothership, already equipped for direct communication with our planet.

However, all these smaller spacecraft will end up in constant motion relative to AIM, so that maintaining high-speed transmission of data will have to cope with ongoing changes in distance, visibility or available power. The optimal solution would be an auto-adjusting network that seeks to maintain transmission speed at the maximum achievable at that moment – rather than pre-programmed to operate on a worst-case basis. This technique will be demonstrated for the first time in deep space by AIM.

Another important goal will be to determine the distance between transmitters and receivers within this intersatellite link system on a continual basis. This will become vital to understanding the position of the CubeSats in relation to the asteroid and eventually that of the lander. Such knowledge would provide a big boost to the quality of science data as well as assisting mission planning. AIM's intersatellite link system will build up to a complete three-dimensional localisation of each element, and this autonomous positioning determination system would be another AIM first.

Enabling such an intersatellite link system for all elements of the AIM mission will have to be achieved within an extremely tight design space, taking account of the extremely tight mass and volume constraints on such tiny spacecraft. Nevertheless, the rewards would be significant: opening up the prospect of future missions that are more and more based on multiple satellites cooperating in common goals, both in Earth orbit and deeper into space.

→ AIM's two CubeSats will demonstrate the use standardised nanosatellites in deep-space intersatellite communication