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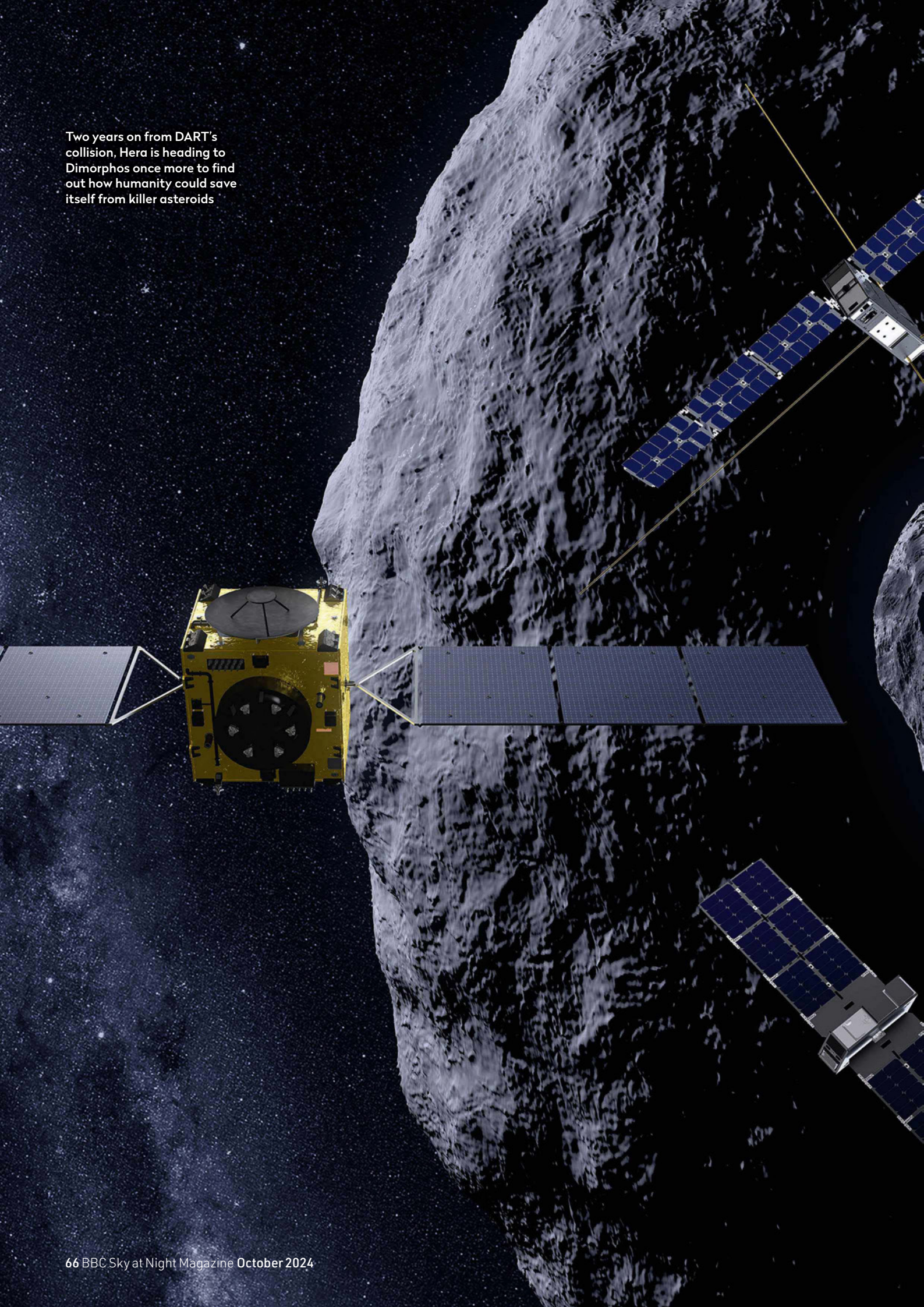


Two years on from DART's collision, Hera is heading to Dimorphos once more to find out how humanity could save itself from killer asteroids

CRASH SCENE investigator

With the launch of ESA's Hera mission scheduled for October, **Jenny Winder** examines how the spacecraft will turn asteroid impact and deflection from a one-off into a repeatable plan

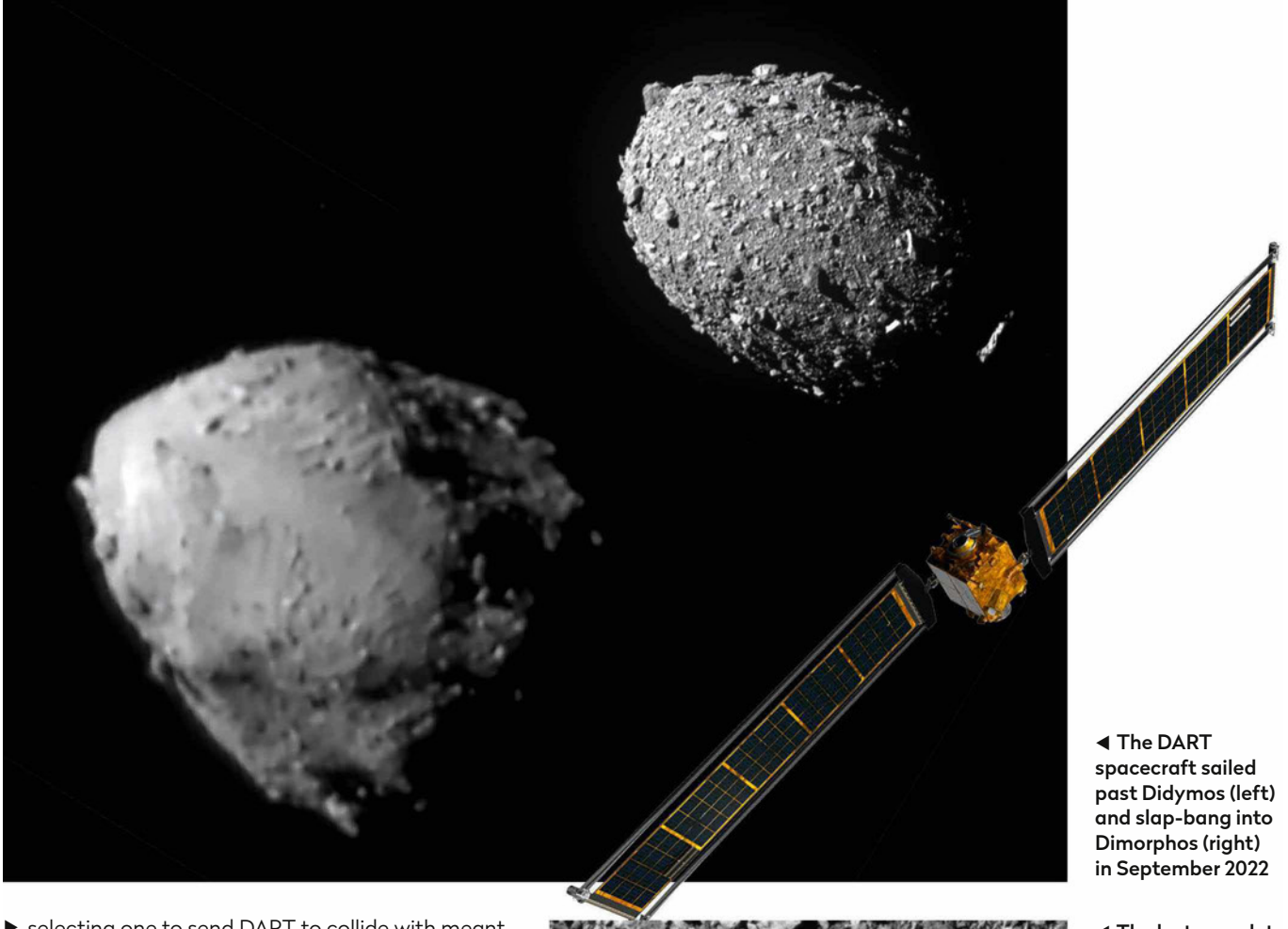
On 26 September 2022, 11 million kilometres (7 million miles) from Earth, a spacecraft weighing 610kg (1,345lb) hurtled through space at 6.1km per second (13,645mph) and crashed headlong into an asteroid called Dimorphos. The plume of debris it sent up was like something from a science-fiction disaster movie, but it was far from that.

This was the culmination of NASA's Double Asteroid Redirection Test (DART), a mission designed to test Earth's ability to deflect an asteroid using a kinetic impactor. The collision shortened the orbit of Dimorphos, demonstrating for the first time that humanity can alter the orbit of a body in space and defend our planet from incoming asteroids.

This month, the European Space Agency (ESA) plans to launch a follow-up mission to study the impact of this collision. Named Hera, after the Greek goddess of marriage, it will undertake a detailed and thorough investigation of the double asteroid system that Dimorphos is part of, its data forming an essential element of the plan to turn the successful DART experiment into a repeatable planetary defence strategy.

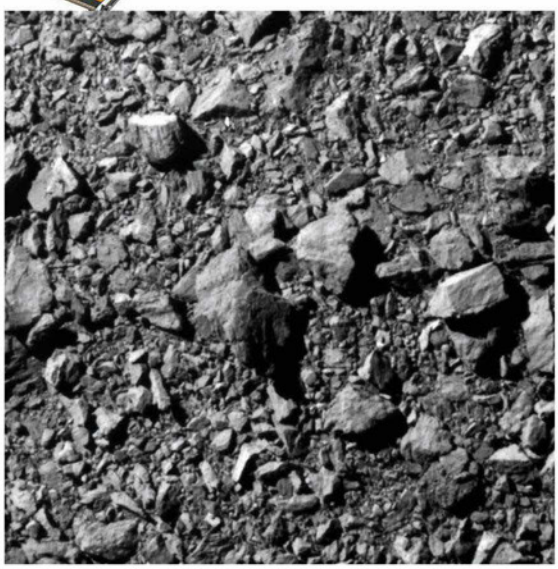
Hera will be the first mission to make a study of a binary asteroid. The larger body of the pair, Didymos, is about 780 metres (half a mile) in diameter and spins once every 2.26 hours, putting it at the very limits of structural stability. The smaller 'moonlet', Dimorphos, is just 160 metres (525 feet) across. About 15 per cent of all small asteroids are binary; ▶

ILLUSTRATION: ESA



◀ The DART spacecraft sailed past Didymos (left) and slap-bang into Dimorphos (right) in September 2022

▶ selecting one to send DART to collide with meant mission control could measure the effect the impact had on Dimorphos's orbit as it transited Didymos after the impact. It also helped that the Didymos system poses zero threat to Earth.



◀ The last complete image sent by DART two seconds before its destruction

What's the damage?

Scientists have already been able to paint a broad picture of how successful DART was, using ground observations and the Hubble Space Telescope. For instance, the impact changed the shape of the moonlet. Up until the mission, Dimorphos was a regular 'oblate spheroid', a squashed sphere wider around the equator and shorter pole to pole. Now it's thought to be a 'triaxial ellipsoid', a 3D shape with three axes of different lengths (think an oblong watermelon).

The impact also changed Dimorphos's orbit. Until 26 September 2022, it took 11 hours and 55 minutes to orbit Didymos; now it orbits in just 11 hours and 23 minutes. By hitting the moonlet in the opposite direction to its orbit, DART shortened the orbit by 33 minutes and 15 seconds – far surpassing the mission's objective of shaving 73 seconds off the orbit time. This success is partly thought to be due to the debris ejected from the explosion acting like a thruster.

The impact turned Dimorphos into an 'active asteroid', one that exhibits a coma or tail, more like a comet. In July 2023, Hubble imaged a swarm of 37 boulders drifting from the crash site. Ranging in size from 1 to 6.7 metres (3.2 to 22ft) across, their total mass is about 0.1 per cent the mass of Dimorphos. But ground observations carry a 10 per cent uncertainty, which Hera will remove when it arrives at the double asteroid, providing rock-solid observations.

It will be Hera's task to investigate the crash scene and submit a full report. Launching from Cape

▼ Four months on from the impact, Hubble showed boulders were still being flung off by Dimorphos

NASA/JOHNS HOPKINS APL/X4, NASA/ESA/DAVID JEWITT (UCLA), NASA/GODDARD/UNIVERSITY OF ARIZONA, NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

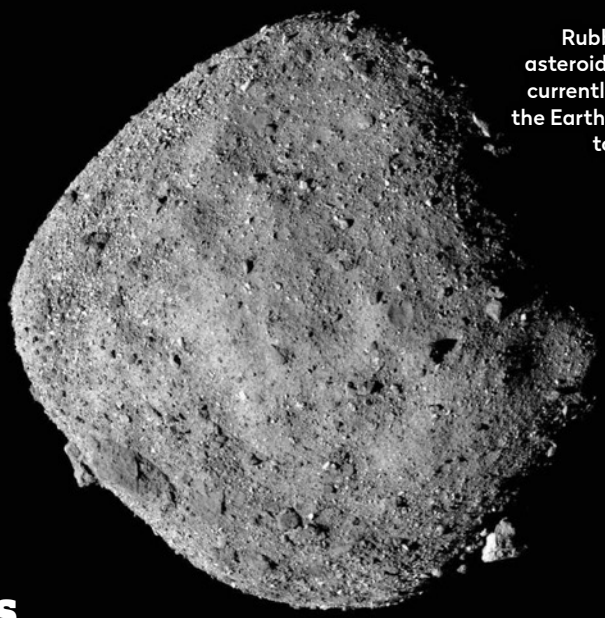
Dangerous space rocks

Assessing the threat level to Earth is tricky when the threat is constantly changing

A potentially hazardous asteroid (PHA) is defined as a space rock with a size larger than 140 metres (459ft), or a brightness of magnitude +22.0 or more, which also has a trajectory that brings it within 0.05 astronomical units (AU) from Earth, or 19.5 lunar distances.

An organisation known as the Minor Planet Center uses data from space and ground-based telescopes to work out asteroid and comet orbits, and make the call on whether an object is a PHA or not. This essential monitoring is complicated by the fact that asteroids' orbits can vary over time, as they are affected by the gravitational influence of other bodies or impacts with them.

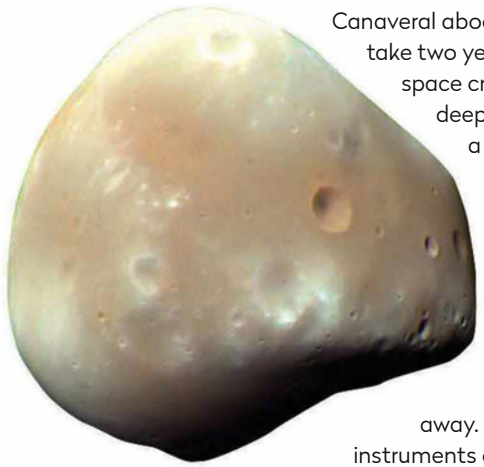
At the time of writing, NASA estimates that over 90 per cent of PHAs have been found; they have identified 35,376 near-Earth asteroids (NEAs) of all sizes, 863 of which are larger than 1km (0.6 miles) across, while 10,909 are 140 metres across or more. Asteroids over 140 metres across hit Earth about once every 25,000 years; those over 1km strike our planet every 500,000 years.



Rubble-pile asteroid Bennu currently takes the Earth-threat top spot

NASA's top 5 asteroid threats

	Name	Mass	Size	Probability of Earth impact	Year of potential impact
1	Bennu	74 million tonnes	0.49km	0.037 per cent	2182
2	29075	78 million tonnes	1.3km	0.0029 per cent	2880
3	2023 TL4	47 million tonnes	0.33km	0.00055 per cent	2119
4	2007 FT3	54 million tonnes	0.34km	0.0000087 per cent	2024
5	1979 XB	390 million tonnes	0.66km	0.000055 per cent	2113



▲ HERA will carry out a side mission to Mars's mini moon Deimos on its way

Canaveral aboard a Falcon 9 rocket, Hera will take two years to reach Didymos. This space cruise will include a sequence of deep-space manoeuvres, including a fly-by of Mars to gain extra velocity, passing just 6,000km (3,728 miles) from the Red Planet's surface. It will use the opportunity to train its science instruments on Deimos, the smaller, more distant of Mars's two moons, from 1,000km (621 miles) away. Here, Hera will calibrate its instruments on an object that astronomers think is an asteroid that Mars captured into its orbit, along with its larger moon, Phobos.

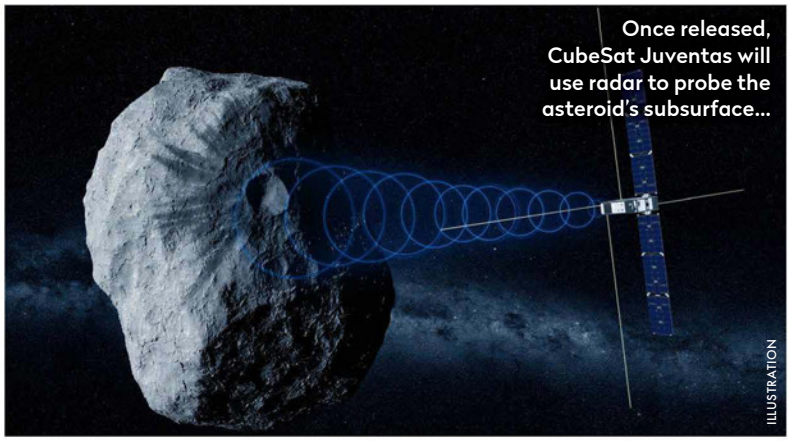
Hera is due to reach the Didymos double system on 28 December 2026 and will carry out a six-month investigation. It will measure the asteroid's mass to determine the efficiency with which DART's impact transferred its momentum. It will also study the crater left by the collision in detail, to verify whether it's the strength of the impact or gravity which is the most important for crater formation, furthering our understanding of the cratering process in low gravity. It will also investigate changes in the moonlet's orbit, spin and libration (wobble), as well as surveying the surface and interior composition of Dimorphos.

The Hera spacecraft itself will have two asteroid-facing cameras (AFC) on board, a thermal infrared instrument (TIRI) and a HyperScout H hyperspectral imager to identify the asteroid's mineral makeup beyond the limits of visible light. A laser range-finding instrument, the Planetary Altimeter (PALT), will be used for both navigation and science.

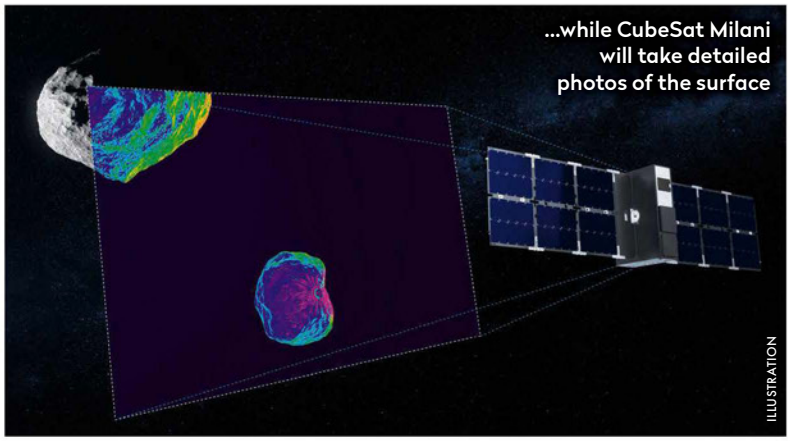
Fully loaded for science

The spacecraft won't be alone in its task. Hera will also carry two CubeSats, Juventas and Milani, each the size of a shoebox, weighing around 12kg (26lb). These will be released once Hera reaches the asteroids. Milani (named after Andrea Milani, the Italian mathematician and astronomer) will map Didymos and Dimorphos, and take images with its ASPECT spectrometer. This will mean scientists can identify both bodies' mineral composition, tell the characteristics of any dust left over from the impact and pick out individual surface boulders.

The two CubeSats and Hera will be linked by an inter-satellite system so that small changes in their positions relative to one another, due to the ▶



Once released, CubeSat Juventas will use radar to probe the asteroid's subsurface...



...while CubeSat Milani will take detailed photos of the surface

ESA X 2, ESA-SCIENCE OFFICE, ELEN11/ISTOCK/GETTY IMAGES, ASSOCIATED PRESS/ALAMY STOCK PHOTO

▶ gravitational interaction of the asteroids, will help to assess their masses and gravitational fields. The fleet of three craft will also pioneer autonomous navigation in deep space. Both CubeSats and Hera carry visible-light cameras, lidar and star trackers so that they can autonomously navigate in the asteroids' combined gravity field, which is 40,000 times weaker than on Earth. Once the core mission is complete, the new technology will be put through its paces, steering itself through the system like a self-driving car.

Meanwhile, CubeSat Juventas (the Roman name for Hera's daughter, Hebe) will carry the smallest radar ever flown in space, using it to carry out the first radar probe within an asteroid to determine whether Dimorphos is solid rock or a loose rubble pile. Understanding its composition will help determine how to deal with asteroids that threaten Earth in the future.

There are two basic methods of dealing with such threats to our planet: fragmentation and deflection. Many asteroids are loose rubble piles, so

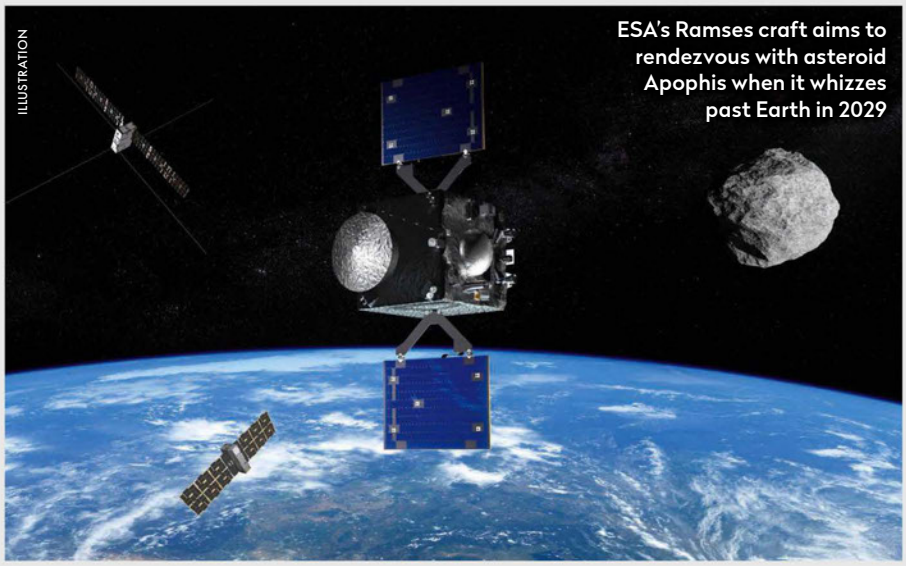
The planetary defence playbook

How will the lessons from DART and Hera be used to defend Earth from space impacts?

The DART mission proved that this method of deflecting an asteroid works. It's Hera's mission to turn the experiment into a controllable, repeatable planetary defence strategy.

The first step is to identify an asteroid threat. ESA is currently developing an early-warning system using up to four 'Flyeye' telescopes that will scan the sky each night, while NASA is planning to launch the NEO Surveyor mission in 2027. This infrared telescope is expected to discover up to 300,000 new near-Earth objects (NEOs), which include asteroids as well as comets and meteors.

In July 2024, ESA announced its Rapid Apophis Mission for Space Safety (Ramses). This will accompany asteroid Apophis during its close fly-by of Earth in 2029, to study how the tidal forces of Earth's gravity stretch and squeeze the asteroid. Apophis is about 375 metres (1,230ft) across and will pass within 32,000km (19,900 miles) of Earth on



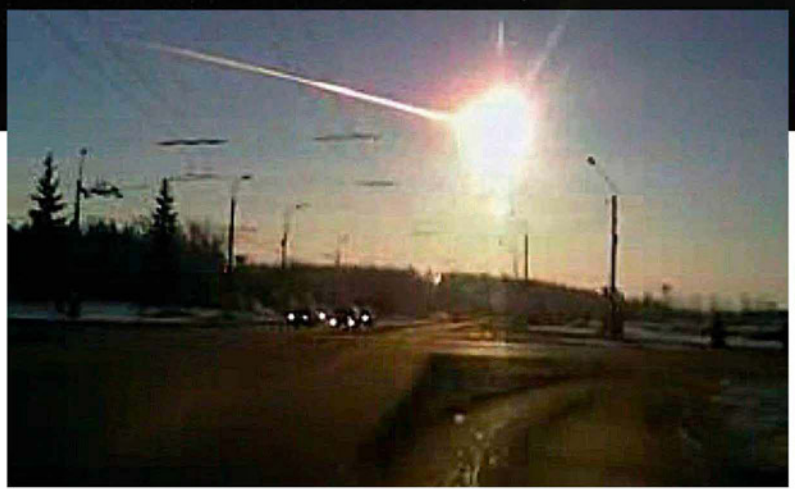
ESA's Ramses craft aims to rendezvous with asteroid Apophis when it whizzes past Earth in 2029

13 April 2029, when it will be visible to the naked eye.

China has also announced its plans to launch an asteroid-impact and deflection mission by 2030, sending two spacecraft to the asteroid NEO 2015 XF261. This asteroid is nearly 30 metres (98ft) across and passed within 50 million km (31 million miles) of our planet in early July this year. One spacecraft will impact the asteroid while the other will observe it for up to a year after the collision.

Dropping nucleur explosives onto an approaching asteroid is one (albeit dramatic) method being considered

ILLUSTRATION



▲ **Dashcams captured a 9,100-tonne asteroid streaking towards Chelyabinsk, Russia, on 15 February 2013**

fragmentation by exploding a nuclear device above, or on, the surface is a possibility. Drilling into an asteroid and planting a nuclear explosive to break up the asteroid and scatter the pieces was the solution depicted in the 1998 film *Armageddon*, but it's a risky one. Before any explosive is planted, you need a detailed knowledge of the asteroid's composition, as any fragments larger than 35 metres (115ft) across would still pose a threat to Earth.

Choose your weapons

Deflection by impact, using kinetic impactors like DART or nuclear explosives, can work quickly and at short notice against a solid asteroid. To be effective, they would need to delay or advance the approaching asteroid's orbit by about seven minutes, giving our planet time to move one Earth diameter along its orbit, out of the way. But direct methods may not work against a loose rubble-pile asteroid; indirect methods could be better. These include attaching rockets to the asteroid, thrusting it out of the way, or using a theoretical 'gravity tractor' that would deflect the asteroid with its own gravitational field.

It's estimated that about 90 tonnes of dust and rock from space hit our planet every day. An object doesn't have to be particularly large to cause substantial damage. In February 2013, the Chelyabinsk meteor exploded in the atmosphere above Chelyabinsk Oblast in western Russia. The 18-metre (59ft) asteroid weighed 9,100 tonnes, entering Earth's atmosphere at a shallow angle, travelling 69,000km/h (42,690mph). The explosion created a shockwave equivalent to up to 33 times the energy released from the atomic bomb at Hiroshima, seriously injuring 1,491 people and damaging 7,200 buildings in six cities across the region.

Two billion years ago, a 15km-diameter (9.3-mile) asteroid struck Earth at Vredefort near Johannesburg, South Africa, creating a 300km-diameter (185-mile) crater. Simple life forms may have existed then, but not so 66 million years ago, when an asteroid 10km (6 miles) across struck Chicxulub, off Mexico. This created a 200km-wide (125-mile) crater and caused the extinction of the dinosaurs.

When Hera ends its mission with a planned landing on Dimorphos, and its CubeSats come to rest on Didymos, it and DART will have paved the way for a planetary defence strategy that could save life on Earth from such an extinction event in the future.

Jenny Winder is a freelance science writer, astronomer and broadcaster