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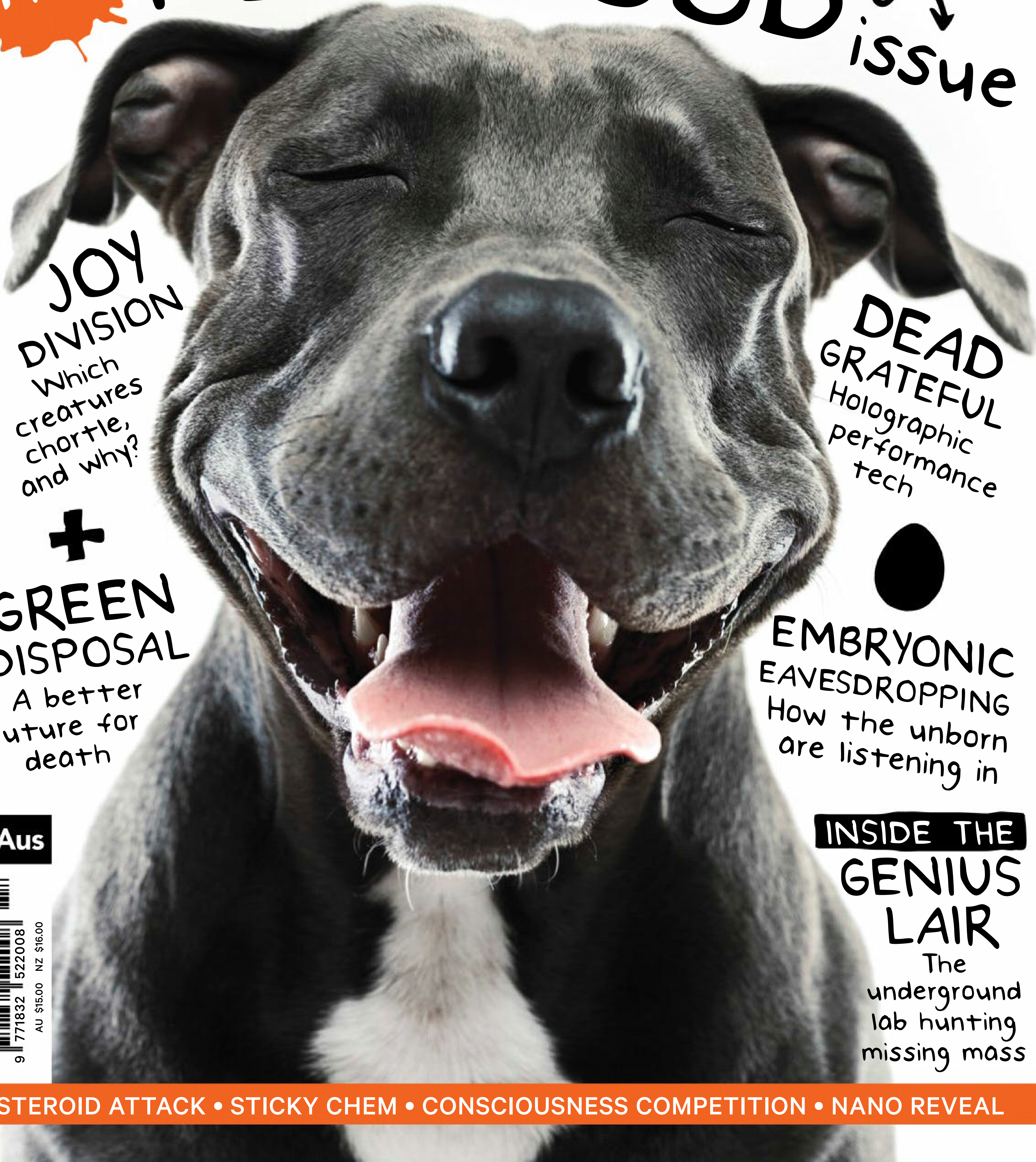
COSMOS

HOW THE SCIENCE OF EVERYTHING MAKES EVERYTHING BETTER Issue 94

The FEEL GOOD issue



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NASA's test of a system to defend Earth from an asteroid collision is underway. There's much at stake and much to learn, as **RICHARD A. LOVETT** explains.

DARTing towards Dimorphos

NASA / JOHNS HOPKINS / APL / STEVE GRIBBEN

In this artist's impression, NASA's Double Asteroid Redirection Test (DART) spacecraft is approaching the binary asteroid Dimorphos – which is scheduled to occur on 26 September this year. DART is designed to test whether it's possible to deflect an asteroid from its path by smashing a spacecraft into it – a potentially Earth-saving move.

In the 1998 science fiction movie *Armageddon*, Bruce Willis sacrifices his life to plant a nuclear device on an asteroid hurtling toward Earth, managing to blow it (and himself) to pieces moments before it's too late.

It's high drama, but not all that realistic – as astrophysicist Alan Duffy lamented in our last issue – because unless the nuke is big enough to vaporise the entire asteroid (not a good thing to be setting off that close to Earth, even if it was possible), all it would do would be to convert the incoming asteroid into a shotgun blast of smaller ones, all big enough to cause widespread damage.

Better, scientists say, to intercept such an asteroid far away – months, years, even decades before it has a chance to strike. "I would want to find an object at least 10 years before impact," Lindley Johnson, NASA's planetary defense officer, said a few years ago at a NASA briefing.

That way, all that's needed is to give the asteroid the tiniest of nudges to change its orbit from apocalyptic to nothing of concern. And how best to nudge it? The best option, many think, is to hit it with a "kinetic impactor" – not a bomb, but a small, fast-moving object with sufficient momentum to shift its orbit enough to do the trick, but not so hard that it splits the asteroid into multiple pieces.

"If you give too hard a push, instead of moving it out of the way, you might have five objects to keep track of instead of one," says Andy Rivkin, a planetary astronomer at Johns Hopkins University's Applied Physics Lab (APL), in Maryland, US.

If that, too, sounds like science fiction, think again. Rivkin leads a team on a NASA mission designed to test this approach with a 160-metre asteroid called Dimorphos. Named DART (Double Asteroid Redirection Test), the mission launched on 24 November 2021, and is expected to strike on 26 September 2022. Not that Dimorphos poses any risk to Earth. The goal is simply to test two things. First, can we actually hit such a small, distant object with a fast-moving spacecraft.

"It's the smallest natural object we've ever tried to land on," Rivkin says. Though "land" is a bit of a euphemism. DART will be coming in fast, and isn't exactly going to make a gentle landing. Crashing hard is the whole point, in fact. But it's still a daring navigational feat: hitting an object about the size of a soccer stadium 11 million kilometres away with a spacecraft moving at 6.6 kilometres per second (24,000km/h) at the time of impact.

The other goal is to see how Dimorphos responds to the impact, because hitting an asteroid with a spacecraft isn't like hitting a billiard ball with the cue ball. "When we have a high-speed impact on an asteroid, you create a crater," explained Andrew Cheng, another member of the DART team, at that NASA briefing. "You blow pieces back in the direction you came from."

The SpaceX Falcon 9 rocket (above and opposite top left) carrying the DART and LICIACube launched last November, but mission planning and testing has occupied years. DART's rollout solar array was tested (opposite right) on the International Space Station in 2017. It was shipped from the US east coast to its California launch site in a specialised shipping container (opposite bottom) the month before launch.

That, he says, means that even though the spacecraft will hit with the energy of about 2,000 tonnes of TNT, the backward-blowing debris will also help change the target's trajectory. "The amount can be quite large," he says. "More than a factor of two."

FRAMING THE TEST

The kinetic impactor idea isn't new. The problem always was that it was hard to test, because the desired nudge is in the order of millimetres or centimetres per second – somewhere between the pace of a caterpillar exploring a leaf and a three-toed sloth in high gear. Given the fact that asteroids are generally

ABOVE: NASA / JOHNS HOPKINS APL / ED WHITMAN

FROM TOP: BILL INGALLS, JACK FISCHER, ED WHITMAN / /NASA / JOHNS HOPKINS APL.

It's a daring feat: hitting an object the size of a soccer field 11 million kilometres away with a spacecraft moving at 24,000km/h at the time of impact.

orbiting the Sun at somewhere around 30km/s, that makes it very difficult to measure.

The genius of DART was the realisation that some asteroids are binary pairs, in which a small body circles a larger one. These orbital movements aren't fast – in the case of Dimorphos, in the order of 10-20cm/s. That means the effect of a kinetic impactor on the small one can be easily measured simply by looking for the change in its orbit around its larger companion.

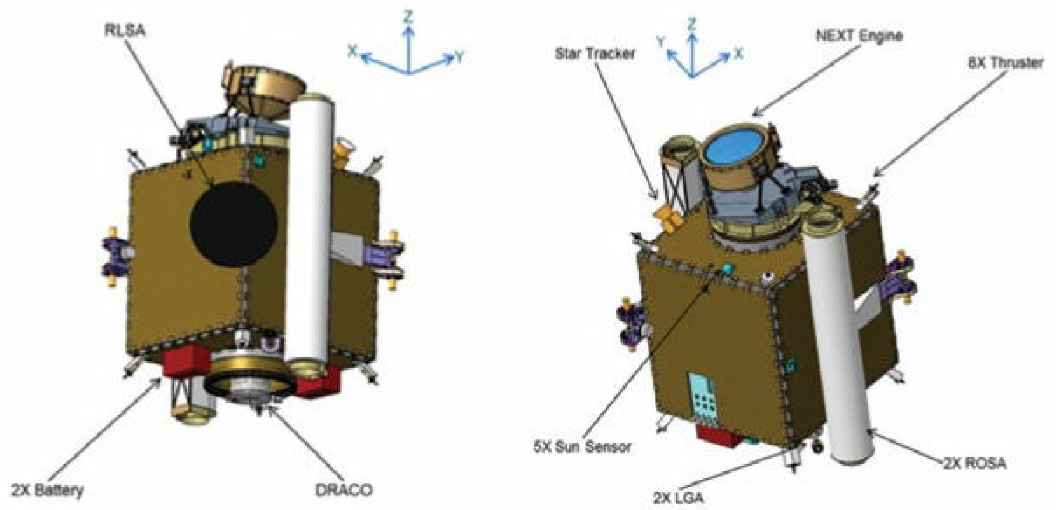
"Say, before the impact, [the orbit] takes 11 hours and 55 minutes," Rivkin says, "and now it's 11 hours and 47 minutes. You can say the change is due to what we did." As an added benefit, there's no chance the impact could knock it out of orbit, accidentally turning a non-threatening asteroid into one that might someday wind up on a collision course with Earth.

It is, of course, not quite that easy.

The only way to measure a change in the orbital speed of a moonlet like Dimorphos using telescopes on Earth is if it circles its primary in the same plane

WHAT'S IN THE BOX?

DART packs a lot of tech into its compact cube.



- **RLSA** Radial Line Slot Array antenna; the primary communication link with Earth; assisted by two low gain antennas (**LGA**).
- **DRACO** Didymos Reconnaissance and Asteroid Camera for Optical. "Traditional navigation techniques would only get DART somewhere within about 9 miles of the target asteroid," said APL's Zach Fletcher, DRACO lead engineer. "To achieve our mission objectives, we need to remove the rest of that error via on-board optical navigation." Assisted by **five sun sensors** and a **star tracker**.
- **ROSA** Two Roll Out Solar Arrays – 8.6m x 2.3m – produce 6.6 kilowatts of power, stored in **two batteries**.
- **NEXT Engine** NASA Evolutionary Xenon Thruster; a solar electric propulsion system, in which power from the ROSA array is harnessed to accelerate xenon propellant to speeds up to 145,000km/h (40km/s).
- **Thrusters** Eight thrusters (on each corner) help with course correction.

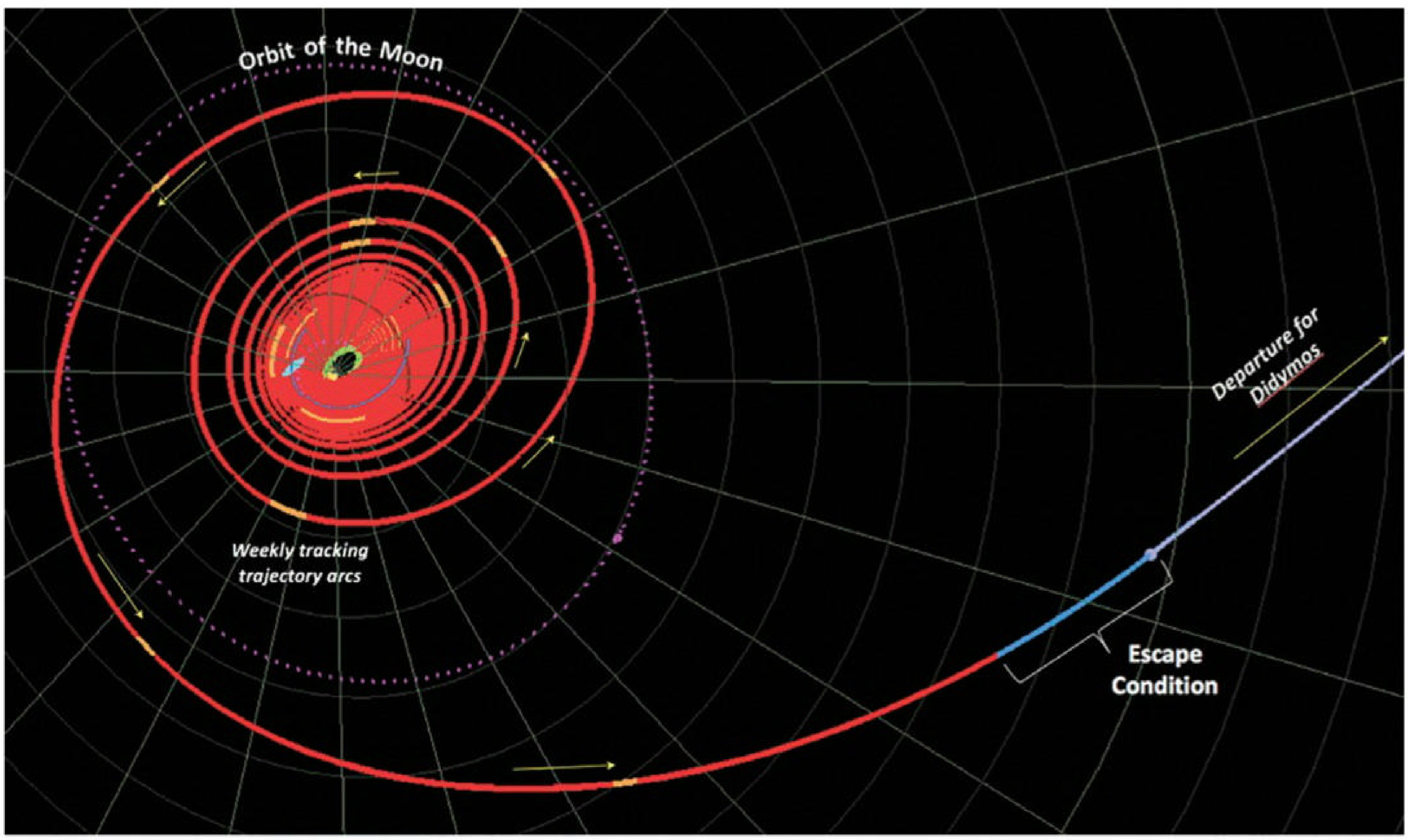
as the Earth. That makes it an "eclipsing binary" – meaning that every orbit it alternately passes in front of and behind its primary. That produces a "light curve" in which the combined brightness of the two objects periodically dips, as each obscures part or all of the other. Carefully timing these dips allows the change in the orbital period to be easily measured.

In addition to having its orbit perfectly aligned for it to be an eclipsing binary, the asteroid pair needs to be close enough to Earth for astronomers to easily see its light curve, and small enough for the impact to produce a measurable change in its orbit.

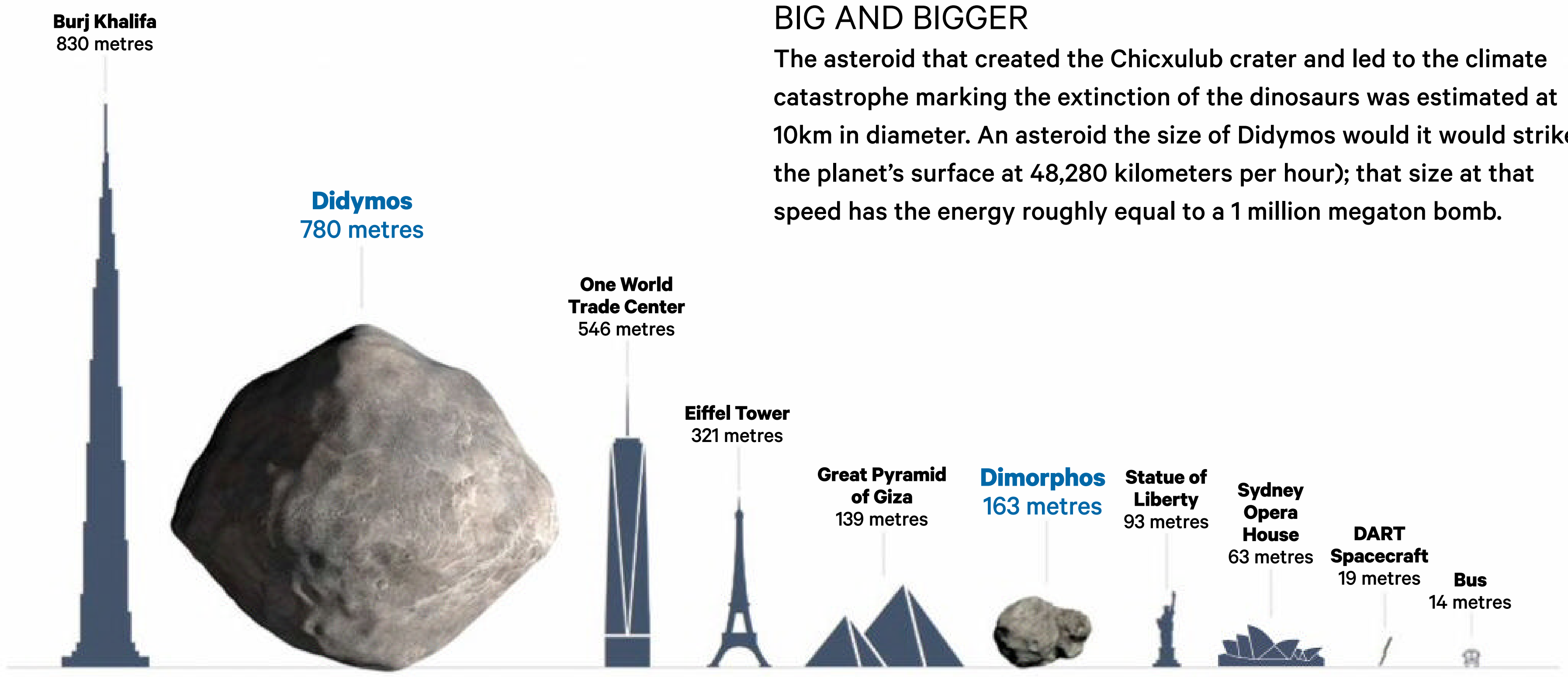
With all of those requirements, Rivkin says, the options become very limited, with Dimorphos not only being by far the best choice, "but the only choice if we wanted to do this in the next 20 to 25 years."

AFTER IMPACT, INVESTIGATION

Although DART's primary goal is to test a means of what NASA calls "planetary defense", it also has scientific objectives. Scientists now know that about 16% to 20% of all near-Earth asteroids are in binary pairs, but other than an incidental discovery by NASA's Galileo mission – when, en route to Jupiter in 1993, it passed 2,400km above Ida, a 56km-long potato-shaped asteroid, and spotted a previously unknown 1,400m moonlet – scientists have never had a chance to see an asteroid moon up close and personal. That said, DART won't give them very long to look at it. Dimorphos is so small that it will only be a single pixel in the spacecraft's camera until

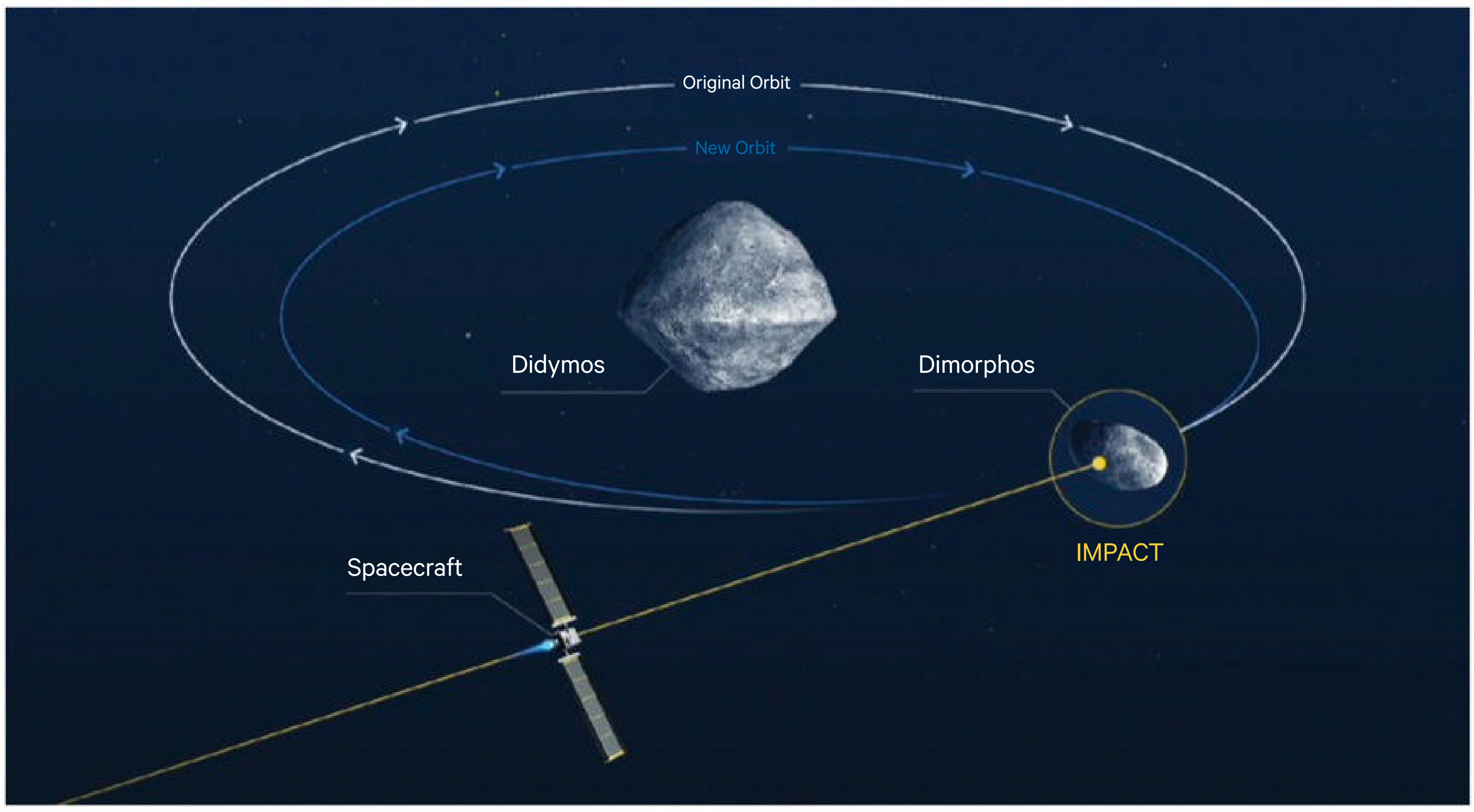


FROM TOP: NASA



BIG AND BIGGER

The asteroid that created the Chicxulub crater and led to the climate catastrophe marking the extinction of the dinosaurs was estimated at 10km in diameter. An asteroid the size of Didymos would it would strike the planet's surface at 48,280 kilometers per hour); that size at that speed has the energy roughly equal to a 1 million megaton bomb.



DART will use NASA's low-thrust NEXT-C ion propulsion system to escape Earth orbit (opposite) and reach Didymos. On final approach (above), DART's navigation will be a combination of instruction from Earth and onboard optical instruments to guide it to the impact point. LICIACube will separate 10 days from the destination, alter course and fly past Didymos at 55km distance just 165 seconds after impact.

BOTTOM: EUROPEAN SPACE AGENCY

the last hour or so before impact. Then, it will rapidly expand.

"Most of the good images that will let us look at its surface will be coming in the last two minutes," Rivkin says. "It's going to be a long ride, and a lot of payoff in the last bit."

The spacecraft's camera is descended from the one that sent back stunning images from Pluto during the New Horizons flyby in 2015. And because Dimorphos is a lot closer to Earth, the expectation is that DART will be able to return megapixel images, right up until the moment of impact, possibly as quickly as one frame per second.

One of the things this will reveal is what Dimorphos looks like. Is it a rubble pile, like many larger asteroids tend to be, or is it a single, solid block? That will tell a lot about how it may have been formed.

If it is a rubble pile, it may have formed from

THE GRAVITY TRACTOR

DART is based on the idea that the best way to shift an asteroid's course is to push it. But it's also possible to pull it using nature's own science-fiction-style tractor beam: gravity.

Gravity works both ways. If you are near an asteroid, its gravity tugs on you. But yours also tugs on it. Thus, if you want to change the course of an asteroid, all you need to do is to hover above it for an extended period of time, waiting while gravity tugs it your direction. If needed, the effect can be strengthened by first plucking a boulder from the surface of the asteroid, thereby adding its mass to that of the hovering spacecraft.

The effect is small, but it adds up, and a few years ago NASA had a mission in development called ARM (Asteroid Redirect Mission) that would actually have tested it out. (The mission was shelved by the Trump administration in 2017.)

The gravity tractor's main advantage is that it's gentle. There's no risk of breaking the asteroid into scattered pieces, any one of which might become a new hazard. Its disadvantage is that it is complex, slow, and needs a new type of rocket nozzle not yet created – one that wouldn't undo the process by blasting its exhaust right at the asteroid the spacecraft is trying to tow, thereby shoving it away rather than pulling it forward.

material flung off by Didymos, itself suspected to have once been a fairly rapidly spinning rubble mass early in its history. This material may then have coalesced into a new, smaller rubble pile…

But that's not the only possibility. It could be that Dimorphos will prove to be a single giant boulder flung out from Didymos as a shard from an ancient impact, says Maurizio Pajola, a planetary scientist at the National Institute for Astrophysics in Italy. On asteroid Ryugu, from which Japan's Hayabusa2 mission recently returned a sample, the researchers were startled to find a single, giant boulder, about 150m long, sitting atop the asteroid.

Ryugu isn't much bigger than Dimorphos' primary, Didymos. Could Dimorphos be a similar-sized rock that somehow escaped into orbit? Part of the answer will come from the final images returned by DART's camera, but more will come from a 14kg CubeSat hitching a ride with DART itself. Called LICIACube (Light Italian CubeSat for Imaging of Asteroids), it was built by the Italian Space Agency and will detach from DART 10 days before impact. It will then use tiny thrusters to slow down slightly and move itself off course, so that it will fly by Dimorphos 165 seconds after impact, at a distance of 55km.

But that's just the beginning. The European Space Agency is planning a mission called Hera, which will arrive at Didymos and Dimorphos in 2026, brake into orbit, and conduct a "crime scene investigation" of the DART impact. "Most of the science will come from the Hera mission," says an asteroid scientist who didn't have press clearance to speak officially about the project.

NUCLEAR OPTION

If gentler measures fail, nukes are still an option for warding off an incoming asteroid. But not in the blow-it-up manner depicted in the 1998 movie *Armageddon*. Instead, a bomb (or bombs) could be detonated close to the asteroid, and energy from the blast would superheat the near side of its surface, vaporising it and causing material to blow off into space. The effect would be to turn that side of the asteroid into a rocket nozzle powerful enough to divert its course.

This might be the best response if the Earth finds itself threatened by a fast-moving, incoming comet, like the one in the 2021 movie *Don't Look Up*, where there's not a lot of time to react. But for the type of near-Earth asteroid most likely to be dangerous, like the 800m object that passed by the Earth on 18 January (about the size of the Empire State Building), it's probably not necessary to resort to nukes – given that they'd be, at the least, highly controversial.

What it will find is, of course, an open question. But one interesting factor will be comparing LICIA-Cube's images of the crater formed by DART's crash to those seen by Hera, four years later. That's because the surface gravity on Dimorphos is probably no more than one-millionth that on Earth. This means that events on Dimorphos occur in super-slow motion – so slow that it could take several minutes for the crater formed by DART to assume its final shape.

Comparing the crater seen by LICIACube 165 seconds after impact to that seen by Hera long after things have had time to settle into their final shape could shed important light on cratering processes on low-gravity worlds throughout the Solar System. But there are, of course, other things to learn. Images from DART, LICIACube and Hera, for example, will let scientists tabulate statistics on the sizes of boulders on Dimorphos' surface. Doing this is really

DART (left and bottom) was mostly assembled by a mechanical engineering team from Johns Hopkins University Applied Physics Laboratory. The LICIAcube (below) was built by the Italian Space Agency. The end game is to have the knowledge and technical ability to avoid a catastrophic asteroid impact on Earth (illustration, opposite).

NASA / JOHNS HOPKINS APL / ED WHITMAN X3

ANDREUS / GETTY IMAGES

The biggest impact in recorded history was in 1908, when a 50–60m long asteroid exploded over Siberia, levelling trees over a 2,100 square kilometre region.

WHAT HAPPENS IF WE GET HIT?

The most spectacular asteroid impact in recent memory was in 2013, when a 20m space boulder exploded above Chelyabinsk, Russia, blowing out windows and injuring nearly 1,500 people, mostly with flying glass.

But the biggest in recorded history was in June 1908, when a 50-60m long asteroid exploded over the remote Podkamennaya Tunguska River region in central Siberia, more than 3,000km north-east of Moscow. Known as the Tunguska event, the blast levelled trees over a 2,100 square kilometre region and produced a shock wave heard as far away as London, England.

If anyone died there, nobody knows. It was too remote, and too long ago, for anyone to know. But if a similar blast occurred over a modern, major city? The death toll would be in the millions.

In 2019 at a Planetary Defense Conference in the US, the International Academy of Astronautics war-gamed just such a scenario. In it, the Earth was threatened by an asteroid about the size of Dimorphos: not a dino-killer, but big enough to do a lot of damage.

In the scenario (conducted while DART was still in its planning stages), efforts to divert it with a kinetic impactor struck it too hard and broke it into two pieces – one of which wound up still on course for Earth, eventually striking a major city with the force of a 15-megaton bomb.

It was, of course, a worst-case scenario. But there's no value in war-gaming one in which the asteroid either misses or is easily deflected, says Paul Chodas, of NASA's Centre for Near-Earth Object Studies. "We learn by studying these what-ifs," he says.

Not to mention by testing our defence technologies, as is being done with DART.

tedious, but it will be another important clue as to how double asteroids like Didymos and Dimorphos form.

Also important is looking for landslides that might indicate how tidal forces from Didymos are changing the landscape on Dimorphos. Along with that, scientists will be looking for cracks in Dimorphos' rocks, trying to see how solar heating and night-time cooling might be making them break down and split, much as temperature changes on Earth cause cliffs to break and drop rocks into valleys far below.

That said, DART's primary purpose is, and will remain, planetary defence, so we can learn more about how to avoid being clobbered by an asteroid in the near or distant future.

"This is a hazard that the dinosaurs succumbed to 65 million years ago," said John Holdren, science advisor to US President Barack Obama from 2009 to 2017. "We have to be smarter than the dinosaurs."

RICHARD A. LOVETT is a science and science fiction writer. His story about life as a principal investigator at NASA appeared last issue.