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COURSE CORRECTOR

If NASA or amateur astronomers spot a space rock headed for Earth and this object is large enough to wipe out a city, what should we do? Adam Hadhazy spoke to managers of a proposed mission that could give us the answer.

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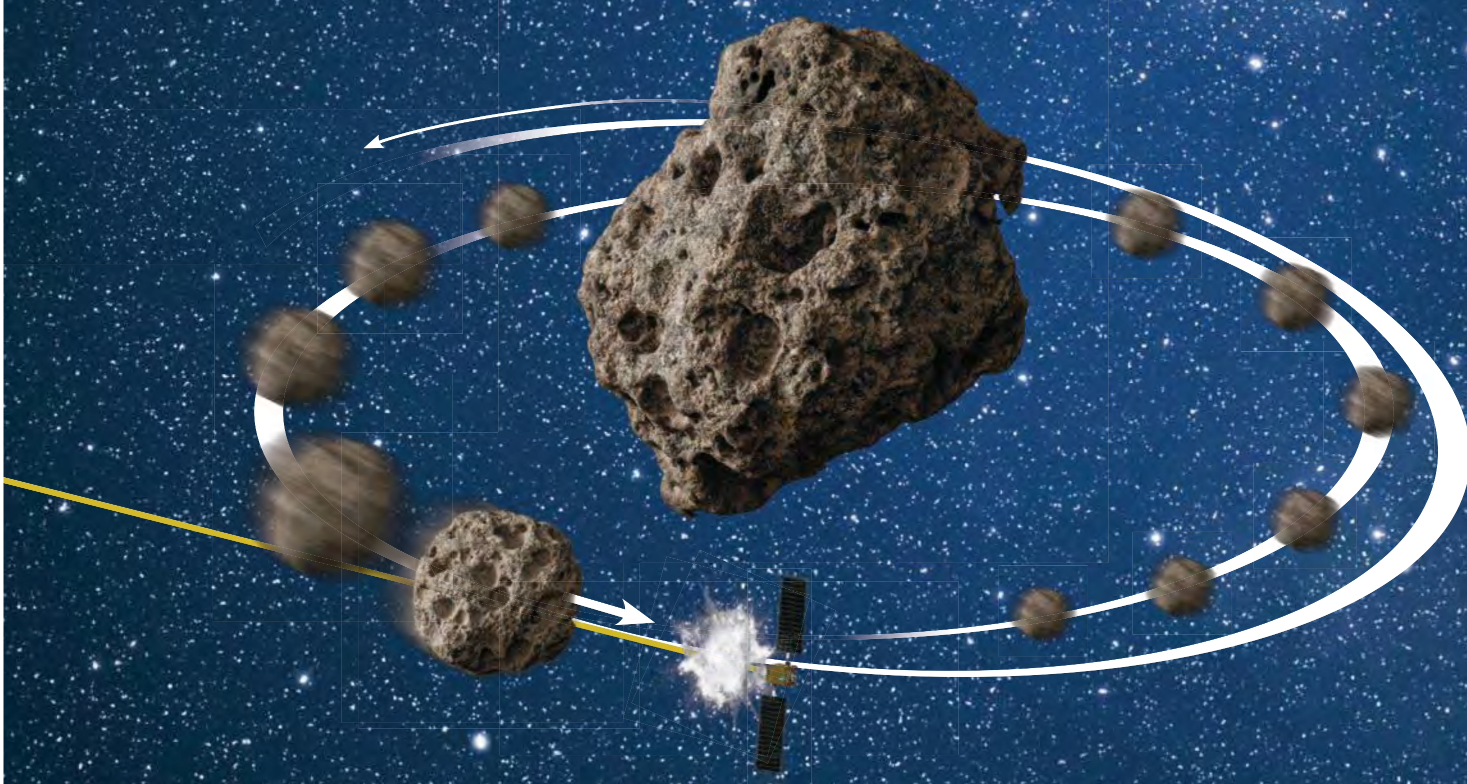


Not to scale.

On Oct. 12, 2017, a hefty asteroid will give our planet a shot across the bow. The house-sized space rock, designated 2012 TC4, will miss Earth by 50,000 kilometers — a mere fifth of the moon's remove.

Knowing about a threat is one thing; mitigating it is another. Planners of a proposed 2020 mission called AIDA (pronounced "eye-EE-duh"), the Asteroid Impact and Deflection Assessment, are proceeding on that planetary defense front. The mission would consist of two spacecraft, one to strike a small asteroid and hopefully nudge it onto a slightly new course, and the other to watch and characterize the collision up close.

NASA is preparing the kinetic impactor portion of the mission, a proposed spacecraft dubbed DART, the Double Asteroid Redirection Test. DART received the agency's go-ahead in June to enter a preliminary design phase. This spacecraft would cruise toward the asteroid Didymos, arriving in its vicinity in October 2022 when the object and its moonlet, nicknamed Didymoon, make a near but harmless sweep past Earth. The rendezvous would be short-lived, though, for DART's goal is to intentionally plow right into Didymoon. The punch of the sacrificial spacecraft should alter the moonlet's orbit around its host asteroid by a tiny, yet measurable amount. Didymoon is no threat to Earth, but this kind of slight momentum transfer might well save us from catastrophe from other objects. Over a span of millions of kilometers, the cumulative trajectory change would turn a collision with a genuinely Earth-bound asteroid or comet into a safe, albeit nerve-wracking, close shave.

There is no shortage of enthusiasm in some quarters to get this mission done. DART would be "the first demonstration of a kinetic impactor and we want to know that it works if we ever have a realistic threat," says Cheryl Reed, the DART project manager at the Johns Hopkins University Applied Physics Laboratory in Maryland. For Lindley Johnson, NASA's planetary defense officer and a DART leader, the "mission is deeply exciting" because it would demonstrate autonomous navigation software for a guided-missile-like strike, show off a next-generation thruster powered by sunlight and electricity, not to mention how NASA might someday "'save the world,' so to speak," as Johnson puts it.

Didymoon's name might be amusing, but an asteroid of its size, 160 meters across, could do enormous damage, although short of endangering the entire world. For a sense of scale, the asteroid that blazed into the atmosphere as a meteor over Chelyabinsk, Russia, in 2013 measured only about 20 meters across, NASA estimates. The 1908 asteroid or comet that leveled a forest near the Podkamennaya Tunguska River in Siberia was probably just twice Chelyabinsk's size. The behemoth that wiped out the dinosaurs and 75 percent of Earth's species measured an estimated 10 km across.

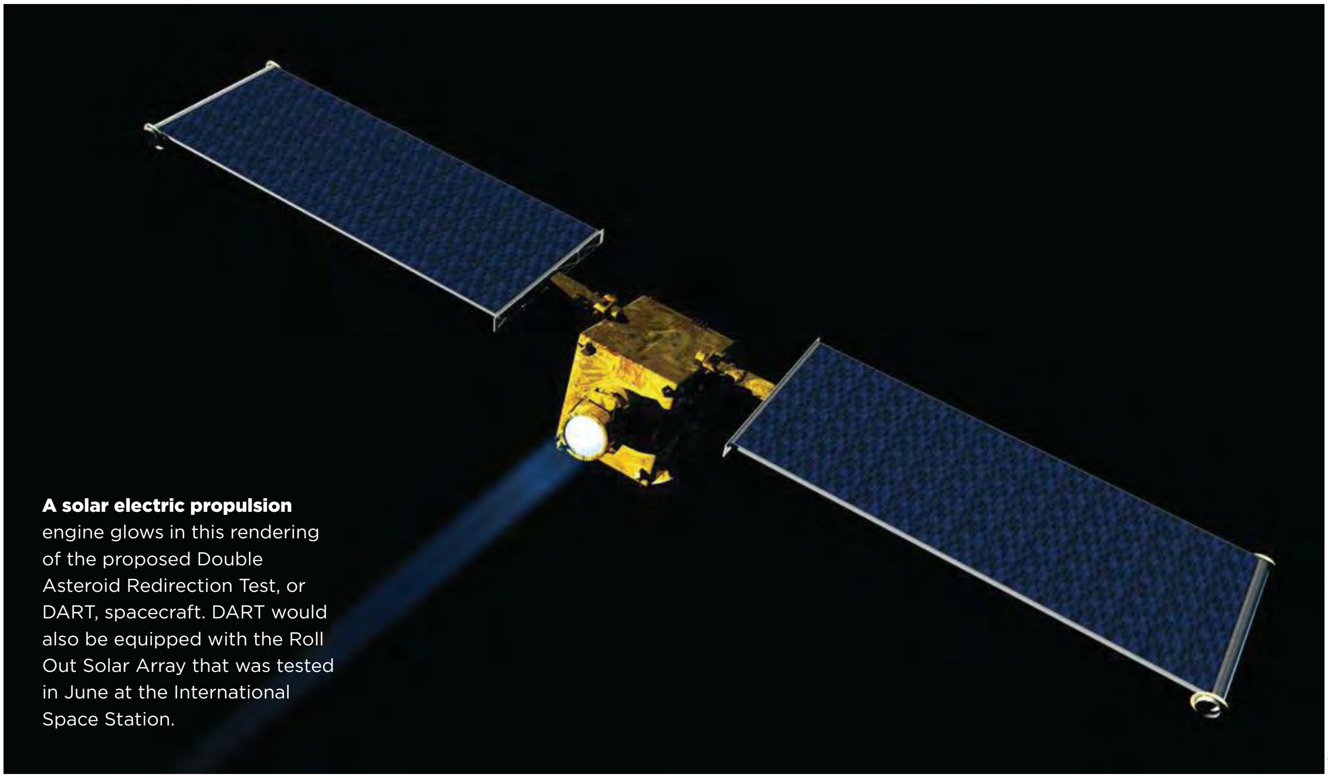
If DART makes it off the drawing board and works as planned, NASA will have demonstrated a technique for protecting us from what is the most likely risk from space: a collision with a Didymoon-size asteroid that could gouge out a crater at least a kilometer wide and hurl searing heat and debris for tens of kilometers. In short, a city killer.

The DART technique could in theory be applied on smaller objects, but the trick would be to spot those far enough away and get enough lead time, something that can't reliably be done now because of the dimness of these objects at considerable distances. Designers have ideas about how to scale up the concept for kilometer-class objects too, should that ever be necessary.

Hammers of the gods

Protecting the planet is a task that Congress has increasingly asked of NASA. The agency's Planetary Defense Coordination Office, established in 2016 and led by Johnson, has brought together efforts dating back to the 1990s to make early detections of potentially hazardous space rocks. These include asteroids whose orbital paths take them near Earth, as well as their icier cousins, comets, which swing out to vast distances from the sun and can come at our planet at great speed from unexpected angles. "It's an area people think a space agency needs to be involved in," says Johnson.

So far, sky surveys conducted by ground telescopes have pinned down the paths of around 94 percent of the monster objects a kilometer or more in size expected to cross Earth's path. None in that size range are anticipated to pose a threat for at least a century. The odds of humanity imminently facing such a calamitous collision are low in the grand scheme, though, with impacts on that magnitude occurring approximately once every million years. As for that behemoth space rock that doomed so many species 65 million years ago, we can breathe a further sigh of relief,



A solar electric propulsion engine glows in this rendering of the proposed Double Asteroid Redirection Test, or DART, spacecraft. DART would also be equipped with the Roll Out Solar Array that was tested in June at the International Space Station.

NASA

for they coldcock our planet only every 100 million years or so and likely would be spotted with many years of warning.

A far likelier scenario is an asteroid bearing down on us that is about the size of Didymoon, says Johnson. Space rocks in this 150-meter ballpark strike not in abstract geological intervals, but in spans applicative to human history, every few thousand years on average. And unlike the Chelyabinsk asteroid, these objects are substantial enough to survive passage through the atmosphere and reach the ground. Their impacts would devastate a sizable population area. Scientists estimate 25,000 city-killers lurk in our solar system, though to date, surveys have turned up about 8,000. "We've only found around a third of this population," says Johnson. "They are a large enough hazard that we should be seriously concerned about them and how to divert them."

Researchers have given serious thought to numerous asteroid mitigation techniques. They range from detonating nuclear weapons to deploying "gravity tractor" spacecraft, whose subtly insistent gravitational attraction could escort space rocks off collision courses. Of the bandied-about ideas, many like the kinetic impactor the best. "The kinetic impactor is at the top of our list largely because the technology for doing it is the most mature," says Johnson. As he points out, space agencies have already performed the feat, for instance with NASA's Deep Impact mission that plowed an impactor into a comet's nucleus in 2005, though with no expectation of changing its speed and course.

"Essentially, we are just positioning ourselves in [Didymoon's] way."

– Cheryl Reed, Johns Hopkins University Applied Physics Lab

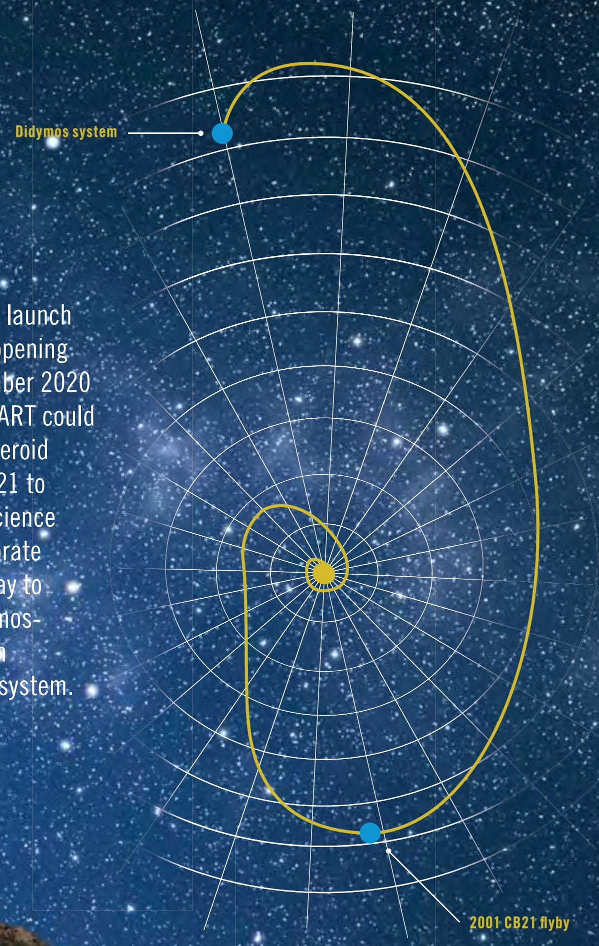
Gliding on ions

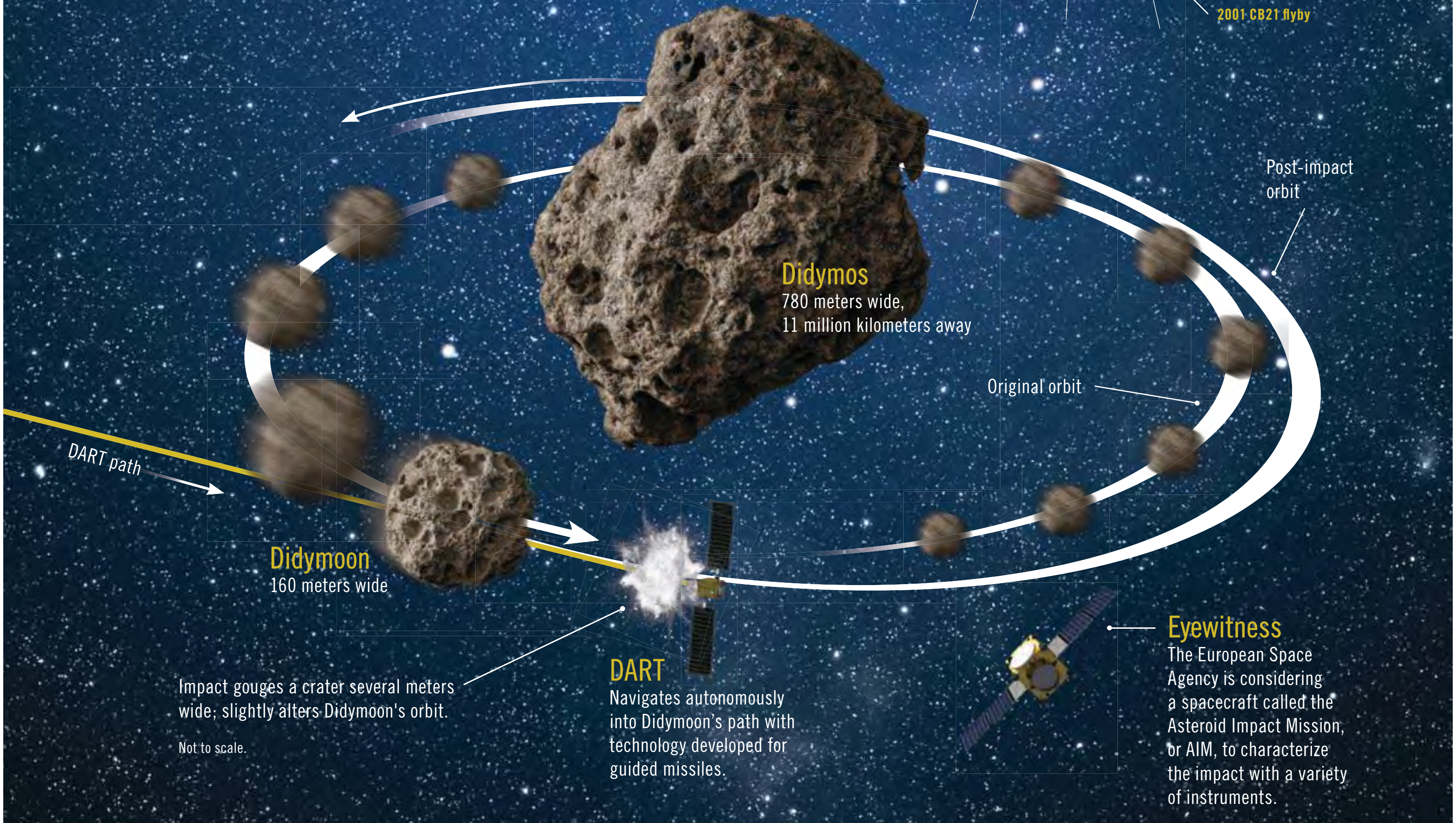
Despite its unconventional suicide mission, DART would look like a typical interplanetary craft. At around 1.3 meters in height and width — about the size of a squat refrigerator — it will be constructed of conventional aluminum honeycomb panels, weighing in circa 500 kilograms. DART's solar panels would be of a new roll-out variety, first tested by NASA at the International Space Station in June 2017. Rather than rigid panels, a Roll Out Solar Array consists of flexible thin-film photovoltaics that unfurl from a compact, cylinder shape, reducing mass and

Nudging an asteroid

Orchestrating a collision between a dangerous space rock and a spacecraft might only change the velocity of the rock by mere millimeters, but over vast distances that change in trajectory should make the rock miss Earth. NASA hopes to test this kinetic impactor concept next decade with the Double Asteroid Redirection Test or DART spacecraft.

A flexible launch window opening in December 2020 means DART could fly by asteroid 2001 CB21 to gather science and calibrate on the way to the Didymos-Didymoon asteroid system.





Sources: NASA and the Johns Hopkins University Applied Physics Laboratory volume for launch. [See related story, Page 34.] The spacecraft's maneuvering capabilities would come courtesy of standard, hydrazine-fueled thrusters.

Elsewhere on the propulsion front, DART will forge ahead as the first slated flight of the NASA Evolutionary Xenon Thruster–Commercial (NEXT-C) ion drive. A next-generation solar electric propulsion system, it pumps energy reaped by the solar arrays into a chamber full of xenon gas, creating a plasma like that found in a neon sign. Charged grids at the back of the engine shoot the ionized gas into space, generating thrust. The thrust is minuscule, on the order of a few hundred millinewtons, equivalent to the pressure felt on your palm when holding a handful of coins. But over significant time and interplanetary distances, ion drives can attain greater speeds than their conventional chemical brethren, reaching up to 324,000 kilometers per hour, more than five times faster than the speedy Voyager 1 probe.

"The difference between electrical and chemical is like the tortoise and the hare," says Michael Patterson, who was principal investigator for the NEXT technology development program at NASA's Glenn Research Center in Ohio. The electrical tortoise in his analogy starts out slow, but steadily accelerates, eventually overtaking the chemical-burning hare that started fast, ran out of fuel and then could only coast along. Just as importantly for deep space missions, NEXT-C is efficient, using just a tenth of the propellant of a chemical rocket for equivalent momentum, slashing fuel needs at launch.

Speed and fuel efficiency are not the purposes for integrating NEXT-C into DART as a tech demonstration, however, given the relatively short voyage to Didymos. Instead, the benefit is launch window flexibility. DART's designers plan for it to rideshare on a commercial rocket, meaning it could be carried to space as an additional payload on any number of regularly scheduled launches. The electric propulsion system can spiral DART out from Earth, biding time before then setting off for Didymos, versus having to depend on a specific launch date. The upshot, says Reed: "NASA does not have to buy us a rocket." That translates to significant cost savings and keeps DART inexpensive for a planetary mission at around $250 million, Reed says.

Throwing a DART

To bring its journey to a close, DART must accurately hit Didymoon near the space rock's center, maximizing the transfer of momentum. The mission drew inspiration for its name from this bull's-eye-like goal. "DART is a good analogy of throwing a dart at a dart board and trying to get very close to the point you're trying to hit," says Reed. A key nuance is that Didymos and Didymoon will be moving faster than DART. The asteroid pair will overtake the spacecraft to cause the collision, sort of like if the dart board flew through the air to meet a slower projectile. "Essentially, we are just positioning ourselves in [Didymoon's] way," says Reed. "Our thrusting is neither accelerating nor braking; think of it as steering, aligning ourselves to the body to be in the right spot at the right time."

To pull this off, she and her colleagues have turned to the Johns Hopkins Applied Physics Laboratory's history of developing guided missiles for the U.S. Navy. For DART, this has culminated in the Small-body Maneuvering Autonomous Real-Time Navigation — acronym SmartNav — algorithm, which will zero in on Didymoon through image processing and guidance, navigation and control. At a distance of about 38,000 kilometers, or about an hour and a half before impact, SmartNav will begin processing target uncertainties and making precision adjustments via the thrusters to tweak the spacecraft's position.

Ahead of their crash, DART and Didymoon will be hurtling toward each other at a rate of 6 kilometers per second — about 10 times faster than a bullet shot from an AK-47. What the smash-up will look like depends on the moonlet's composition, thought to be primarily iron and nickel, as well as compaction. Most likely, DART will blow out a crater several meters wide and eject a plume of material into space. To large ground telescopes conducting scientific observations of the impact's aftermath, Reed says the ejecta will probably appear as a comet's tail-like cone of lighter, diffuse material. Even relatively modest telescopes with 1- to 2-meter-wide mirrors should be able to detect this plume, mean-

DART and Didymoon will be hurtling toward each other at a rate of 6 kilometers per second — about 10 times faster than a bullet shot from an AK-47.

NASA

ing members of the general public could monitor the crash's aftermath in real time at participating science centers.

Besides compelling visuals, the plume should further alter Didymoon's orbit on top of the kinetic impactor's prod. "It's not just the force of the spacecraft hitting the object," says Johnson. "The material ejected away from the surface, away from impact crater — that acts like an additional rocket force that enhances the momentum transfer from the impact."

As a binary asteroid, the Didymos system — Greek for "twin" — should provide a uniquely ideal way to measure the effectiveness of this deflection approach. From our planetary vantage point, Didymoon passes behind its host, the 800-meter-wide Didymos, over the course of an 11.9-hour orbit. Slight perturbations to the timing of that orbit would be readily quantifiable to ground telescopes using optical light observations and radar. Overall, DART is expected to alter the speed of Didymoon's orbit by about half a millimeter per second, resulting in an orbital period change of perhaps 10 minutes. Officials want to understand the degree of this alteration to inform future planetary defense. For example, they might want to dial up the mass of a kinetic impactor, based on a threatening asteroid's properties, or alternatively throw many impactors at it to render enough of a deflection.

▲ **NASA's Deep Impact** probe collided with Tempel 1 on July 4, 2005. A camera on the mission's flyby craft recorded a bright, small flash. Researchers found Tempel 1 has a fluffy structure of fine dust. They also detected carbon-containing materials in the comet's ejection plume.

Keeping watch

NASA is expected to make an ultimate decision regarding DART in March 2018, after the preliminary design is submitted. Meanwhile, the second spacecraft element of the AIDA mission remains in jeopardy. As originally conceived, AIDA called for a sister vessel, named the Asteroid Impact Mission, or AIM, to arrive at Didymos ahead of DART. AIM would characterize the rocky Didymos duo up close and offer a front-row seat to DART's demise and its deflection assessment. The European Space Agency developed this partner craft for several years, but at a governing body meeting in December 2016, AIM's budget was not further approved. Researchers are now working on a slimmed-down version of AIM, which will not include a planned Didymoon lander or an optical communications tech demonstration.

If eventually greenlit, AIM could visit Didymos after DART and still gather valuable data, says Patrick Michel, the European lead on AIDA and the director of research at France's National Center for Scientific Research at the Observatoire de la Côte d'Azur. Or, the DART team could wait to go to Didymos until its next closest pass, in 2024, and the two spacecraft might sync up then.

Michel has his fingers crossed that AIM does fly and helps advance humanity's ability to shield itself against cosmic slings and arrows. "The risk of an asteroid impact is the least probable natural risk, compared to earthquakes, tsunamis and hurricanes," Michel says. "But it is the only one that we can predict and prevent by feasible means that just need to be tested."

For the kinetic impactor as well as other countermeasures to reliably succeed, early detection many months or even years ahead of a menacing asteroid's or comet's planetfall will be critical. Despite what movies like 1998's "Armageddon" depict, when a Texas-sized asteroid appears out of nowhere, en route to smashing Earth 18 days hence, emergency responses such as nuclear Hail Marys have little chance of averting disaster.

No matter how thorough the vigilance, though, some smaller, potentially deadly asteroids will still blindside the Earth — especially if, like Chelyabinsk's, they come from the direction of the sun, where telescopes cannot discern them. Over the longer term, modern humanity's luck could suddenly run out. Just ask the dinosaurs.

"Finding these asteroids before they find us is the best way," says University of Arizona planetary scientist Vishnu Reddy, who is leading the detection and tracking efforts of the space rock careening past in October 2017 and is not involved in AIDA. "The best defense we have is time." ★