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SCIENCE NEWS BY AGU

VOL. 104 | NO. 3
MARCH 2023

Converging Science and Grand Challenges

DART's Smashing Success

EEAGER Beavers

CHRONICLING CLIMATE IN Rings and Rocks

Scientists find fresh approaches to familiar data.

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harvested. (A barrel is equivalent to about 146.5 liters.)

"Historical reconstructions of unrecognized climatic processes can be extremely important for understanding the role of the nonhuman world in human affairs," said Andy Bruno, an environmental historian and professor at Northern Illinois University. But he warned that we should be wary of "claims that reduce any complicated historical event to a sole climate trigger."

The eruption of Huaynaputina and shifts in glacial dynamics in the Arctic played a role in the Great Famine in Russia, Bruno said, but were far from the only factors. The extended crop failures exacerbated an ongoing political and social conflict known as the Time of Troubles, which lasted until the establishment of the Romanov dynasty in 1613.

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For Jersy Mariño, research that explores the connection between the Huaynaputina eruption and historical events around the world is essential for recognizing the "cultural and geological value" of this volcano and the importance of studying it. Mariño is a geologist from the Peruvian Geological, Mining, and Metallurgical Institute who has conducted extensive research on the geological history and risk posed by this and other volcanoes in southern Peru.

During a recent expedition to Huaynaputina, Mariño and his team found evidence of six towns and several terraces used for agriculture in the 17th century that were completely buried during the 1600 eruption. (The volcano has not erupted since then.)

The scientists recommended that the Peruvian government start archaeological expeditions as soon as possible.

By **Santiago Flórez** (@rflorezsantiago), Science Writer

NASA's Double Asteroid Redirection Test Is a Smashing Success

Rocks from space have walloped Earth for eons, and it's only a matter of time until our planet lands yet again in the crosshairs of a very large asteroid. But unlike other forms of life—here's looking at you, dinosaurs—humans have a fighting chance of altering our cosmic destiny. At AGU's Fall Meeting 2022, researchers presented a slate of new results from NASA's Double Asteroid Redirection Test (DART) mission, the first demonstration of asteroid deflection.

Peering at an Orbit

DART's target, the Didymos-Dimorphos asteroid system, was first discovered in the mid-1990s. Astronomers back then spotted only its larger member, Didymos, which is roughly 800 meters (half a mile) in diameter. It wasn't until 2003 that scientists realized that a much smaller body, dubbed Dimorphos, was also present. Dimorphos is about one fifth the size of Didymos, and its orbit takes it in front of and behind Didymos as seen from Earth. That's serendipitous, because by monitoring how the brightness of the Didymos-Dimorphos asteroid system varies over time, scientists were able to determine precisely how long it took Dimorphos to complete an orbit: 11 hours and 55 minutes.

"We needed to understand the Didymos-Dimorphos system before we changed it," said Cristina Thomas, a planetary scientist at Northern Arizona University in Flagstaff, at AGU's Fall Meeting 2022.

The primary goals of the DART mission were simple, at least in concept: to hit Dimorphos with the roughly 570-kilogram (half-ton) DART spacecraft to significantly alter the orbital period of Dimorphos around Didymos, to measure that change, and to characterize the physics of the impact. If successful, it would be the first demonstration of deflecting an asteroid using so-called kinetic impactor technology. (In 2005, another NASA mission, Deep Impact, tested kinetic impactor technology with a comet.)

On 23 November 2021, a Falcon 9 rocket lifted off from California's Vandenberg Space Force Base. By then, the SpaceX-designed rocket had notched more than 100 successful launches, but for members of the DART mission, the event was anything but ordinary: Nestled within the rocket's nose cone was the spacecraft they'd spent well over a decade designing, building, and testing.

The launch went smoothly, and DART soon entered orbit around the Sun. For roughly 10 months, the spacecraft largely tracked the orbit of Earth, essentially waiting to catch up to the Didymos-Dimorphos asteroid system, which orbits the Sun between Earth and Mars. "We stayed close to Earth the entire time and just caught up with the Didymos system at its closest approach to Earth," said Elena Adams, DART mission systems engineer at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Md.

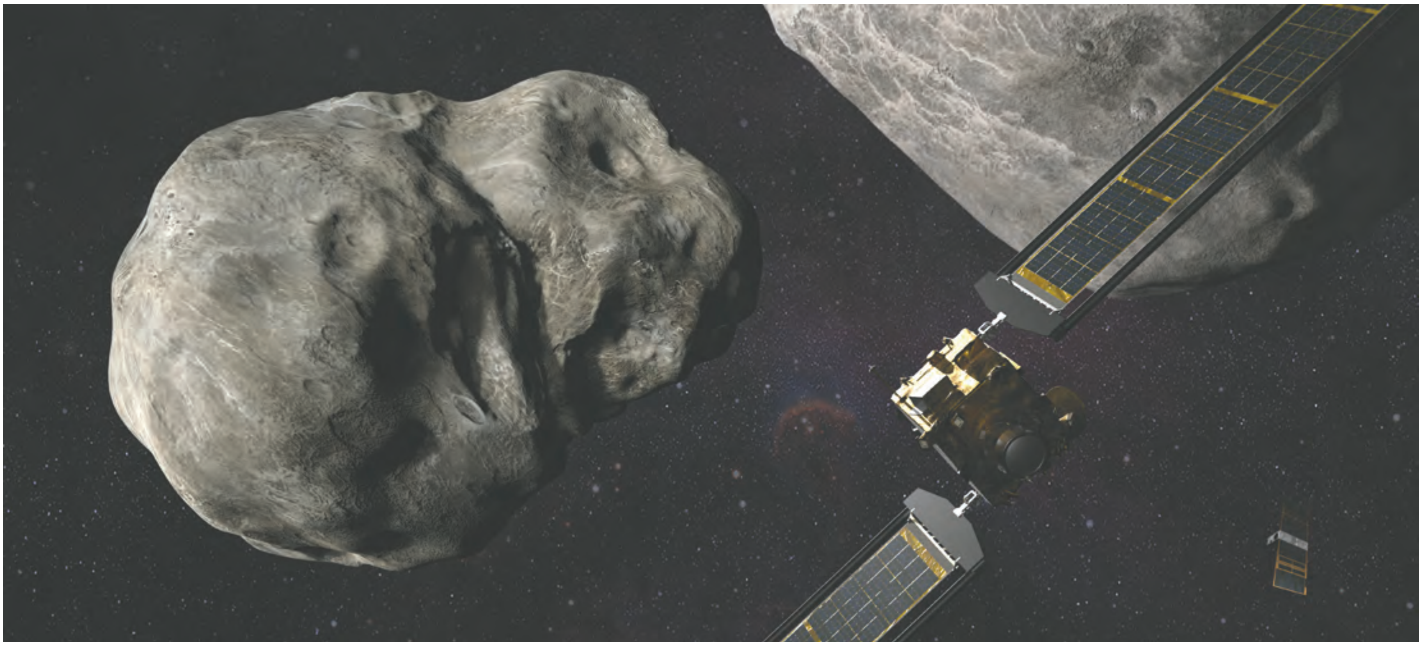
Approaching the Unknown

It was only around July 2022 that DART's onboard camera—the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO)—caught its first glimpse of Didymos. But Dimorphos wouldn't come into view until much, much later: Just 1 hour before impact, at a distance of roughly 25,000 kilometers, the tiny moonlet was still a mere 2 pixels across in DRACO images.

"We didn't see Dimorphos until late in the game," said Adams. To prepare for the uncertainties of striking a body they knew virtually nothing about, DART team members ran thousands of Monte Carlo simulations beforehand, in which they varied the moonlet's size, shape, albedo, and a slew of other parameters.

"We needed to understand the Didymos-Dimorphos system before we changed it."

The DART spacecraft successfully hit Dimorphos on 26 September 2022. The event was recorded by a cadre of Earth-based telescopes and also the Light Italian Cubesat for Imaging of Asteroids (LICIACube), a briefcase-sized spacecraft carrying two cameras that launched with DART and was released from the spacecraft 15 days prior to impact.



This illustration of NASA's Double Asteroid Redirection Test (DART) spacecraft (foreground) and the Italian Space Agency's LICIACube depicts them just prior to impact at the Didymos-Dimorphos binary system on 26 September 2022. Credit: NASA/Johns Hopkins APL/Steve Gribben

A Serendipitous Boost

Researchers had calculated that the impact, which occurred roughly head-on, would shorten Dimorphos's orbital period by just under 10 minutes. That was assuming the simplest scenario, in which no ejecta is produced, said Andy Cheng, DART investigation team lead at APL, at a press conference.

"The amount of momentum that you put in the target is exactly equal to the momentum that the spacecraft came in with." But if ejecta flies off the asteroid after impact, physics dictates that the asteroid can get an extra boost, said Cheng. "You end up with a bigger deflection."

That's good news when it comes to pushing a potentially harmful space rock out of the way, said Cheng. "If you're trying to save the Earth, that makes a big difference."

And ejecta there was, in spades—on the basis of detailed follow-up observations of the Didymos-Dimorphos system, scientists discovered that Dimorphos is now traveling around Didymos once every 11 hours and 22 minutes. That's a full 33 minutes shorter than its original orbital period, a finding that implies that a substantial amount of ejecta was produced. Imagery from ground- and space-based telescopes has borne that out: A plume of debris tens of thousands of kilometers long currently stretches out from Dimorphos. Researchers estimated that at least a million kilograms (1,100 U.S. tons) of material were blasted off the asteroid by the impact. That's enough debris to fill several rail cars, said Andy Rivkin, DART investigation team lead at APL, at a press conference at the Fall Meeting (bit.ly/AGU22-DART).

Follow the Debris

Of particular interest, the ejecta shed by Dimorphos has remained in distinctly more plumelike configurations than the debris shed by comet 9P/Tempel 1 when NASA's Deep Impact spacecraft intentionally crashed into it in 2005. "The Dimorphos ejecta has a lot of morphological features," said Jian-Yang Li, a planetary scientist at the Planetary Science Institute in Fairfax County, Virginia, and a member of the DART team, at the Fall Meeting.

The reason is probably the different compositions and surface features of the two bodies, he said. Tempel 1 is rich in volatiles and fine-grained dust; Dimorphos's surface, on the other hand, is littered with boulders. Scientists plan to continue to monitor Dimorphos's debris plume through at least this month.

The DART mission also has enabled scientists to investigate a fundamental question about the Didymos-Dimorphos asteroid system: Do the two asteroids have the same composition? It's a common assumption when it comes to binary asteroids, but it's never been confirmed. Thomas, leader of the DART Observations Working Group, presented new results on the subject at the press conference at the Fall Meeting. She shared near-infrared spectra of the binary asteroid system that astronomers had collected both before and after impact using a NASA telescope in Hawaii.

Observations obtained prior to impact (when the overwhelming majority of the sunlight reflected off the asteroid system came from Didymos) and after impact (when the debris shed by Dimorphos was responsible for more than two thirds of the reflected light) revealed very similar spectra, with characteristic dips at wavelengths of 1 and 2 micrometers in both cases. That's strong evidence that the two asteroids have similar compositions, said Thomas.

Scientists aren't yet finished with Didymos and Dimorphos: In 2024, researchers involved in the European Space Agency's Hera mission plan to launch a spacecraft to the system to further characterize the asteroids—including accurately measuring the mass of Dimorphos—and to study the crater created by the DART impact.

By **Katherine Kornei** (@KatherineKornei), Science Writer