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An abandoned plan to visit another star highlights the perils of billionaire-funded science



N 2016 BILLIONAIRE YURI MILNER HOSTED a press conference at One World Observatory, the atrium topping the slick skyscraper at the center of the rebuilt World Trade Center complex. Milner had grown rich investing in tech start-ups, and now he wanted to spend some of that money on sending a spaceship to the stars.

> He called the plan Breakthrough Starshot: a project that would eventually take human technology to another solar system. The idea was that high-powered lasers would propel tiny probes to 20 percent of the speed of light, impelling them with enough inertia to launch them toward the nearest star system, Alpha Centauri, within 20 years. Milner and his Breakthrough Initiatives, a group of space science research projects related to life in the universe, were pledging \$100 million toward a proof of concept. At the event, Milner was joined by, among others, Mae Jemison, a former astronaut and head of 100 Year Starship, an interstellar research program funded by the Defense Advanced Research Projects Agency; Pete Worden, former director of NASA's Ames Research Center; and Stephen Hawking, world-famous physicist.

Zachary Manchester, currently an associate professor of robotics at Carnegie Mellon University, signed on for the project's early stages. He remembers it seeming incredible that he, then a wide-eyed 20-something, was at the top of a metropolis, hanging out with people he considered legends-people such as Freeman Dyson, a physicist best known for positing that advanced civilizations could eventually cloak their stars in megastructures that siphoned their power. Dyson was one of several scientific luminaries who were joining the project, including Nobel Prize winner Saul Perlmutter and Martin Rees, then the U.K.'s Astronomer Royal.

In short, the Starshot launch event was flashy. A video preview narrated by actor Seth MacFarlane was also flashy. The text that went along with the announcement? Flashy. "With current rocket propulsion technology, it would take tens or hundreds of millennia to reach our neighboring star system, Alpha Centauri," it read. "The stars, it seems, have set strict bounds on human destiny. Until now."

Milner's money wasn't quite an Apollo-project investment, but it was more than anyone had ever dedicated to interstellar travel, a field with a history of relatively little funding and a trail of projects that never reached the stars. In the 2010s DARPA and NASA founded the 100 Year Starship research program to figure out how to send humans light-years away in the next 100 years. Private research groups such as the Tau Zero Foundation and Project Icarus also launched initiatives. None of them have come to much. Maybe this time the goal was within reach. After all, besides the money itself, the big names attached to Breakthrough Starshot gave legitimacy to an endeavor that might otherwise have seemed fringe. The announcement made a splash in the press, including a cover story in this magazine.

But almost a decade later Breakthrough Starshot is conspicuously quiet. After the initial big bang the project seemed to whimper out. Now there are no more big announcements, no multi-institution meetings and no more funding. What remains is

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confusion among even scientists working on Breakthrough Starshot about the project's status. According to an e-mail from Worden, Starshot's executive director, who declined an interview for this article, "We have put the program on hold and are working to transition portions to others."

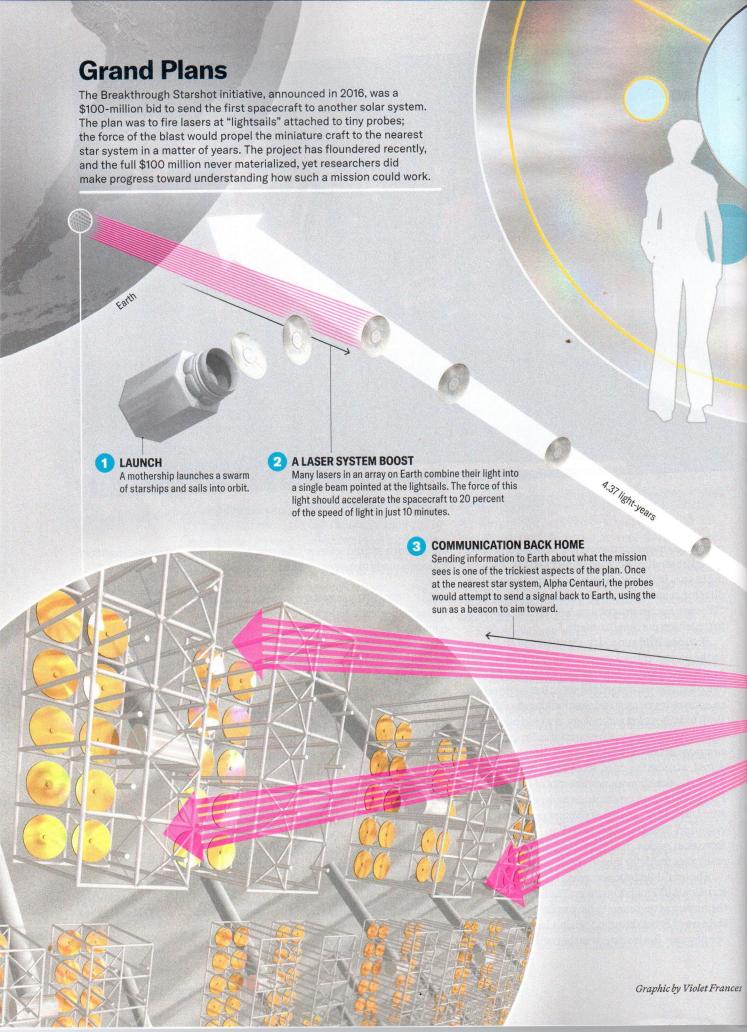
Between 2016 and today scientists and engineers on the project did make progress toward the starsor at least toward understanding what it would take to make progress toward the stars. But engineering an interstellar journey is almost ludicrously difficult. With today's rocket technology, it would take thousands of years to get to the nearest star. Processes and components need to be invented, iterated on and vetted, at great expense, most likely over decades. Sure, "\$100 million sounds like a lot of money," says Edwin Turner, an emeritus astrophysicist at Princeton University and one of the first people to be involved in Breakthrough Starshot. "It's certainly more than pocket change for most of us, but it's not really very much for huge technological programs."

The total doled out, according to one insider, was far below \$100 million anyway. The fact that most of the money never seems to have materialized means the case of Breakthrough Starshot isn't necessarily one of waste. But it's a study in the perils of relying on

the ultrarich to fund science: when the guy with the billions is ready to move on, the whole project is off.

BREAKTHROUGH STARSHOT is based on a simple but technologically audacious concept: build a powerful set of lasers on Earth, and use them to propel "lightsails" on tiny spacecraft weighing about as much as a paperclip. A traditional rocket would carry the craft to space; once it was some 37,000 miles from Earth, the lasers would light up, shooting 100 gigawatts of power at the lightsails. Their combined photons would slam into the sails, powering them forward like wind on a sailboat. Ten minutes later the spacecraft would be zooming at 20 percent of light speed and already halfway to Mars—a journey that takes months with current technology. At that rate it would hit Alpha Centauri-specifically, Proxima Centauri, the closest star in the system—in a couple of decades. During its flyby Starshot would glimpse both the star and the Earth-size exoplanet known to exist in the star system. The craft would send a signal back to Earth before sailing on toward the rest of the Milky Way.

The basic idea of using light for propulsion dates to the 1920s, when Russian scientists Friedrich Zander and Konstantin Tsiolkovsky, pioneers of The Breakthrough Starshot announcement event in April 2016 included, from left, documentary writer and producer Ann Druyan, Zachary Manchester, Yuri Milner, Stephen Hawking, Freeman Dyson, Mae Jemison, Pete Worden, Avi Loeb and Philip Lubin.





rocketry, proposed using the pressure of sunlight to push a vehicle through space. Some details of Breakthrough's specific plans, however, came from the work of a University of California, Santa Barbara, physicist named Philip Lubin. Back in 2009, seven years before Breakthrough Starshot began, Lubin attended a conference at the Naval Postgraduate School in Monterey, Calif. There researchers were discussing focused energy in the form of lasers, microwaves, particle beams, and more, known as directed energy, "mostly for purposes of taking down threats," Lubin says, meaning incoming missiles.

But as Lubin sat at the conference, he began to dream about other uses for the technology, especially if it were scaled up. Could it be used to protect Earth from asteroids rather than from intercontinental ballistic missiles? Or, he thought later, to propel a spacecraft far, far away? At home Lubin started crunching numbers. "I always want to figure out why it won't work, why you cannot do this," he says.

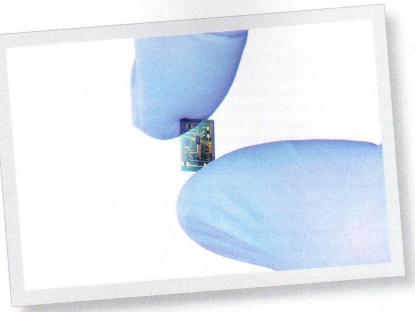
Despite his best efforts to defeat himself, it seemed the idea would work: You could direct energy at an incoming space rock, heat a portion of it up, vaporize that spot and shift the asteroid's orbit just enough to curve it away from Earth. And you could probably also send a spaceship on a significant journey. Lubin eventually applied for and received NASA funds to research both plans.

After the explosion of a meteor over the Russian city of Chelyabinsk in 2013, Lubin's planetary-protection work—under the project name DE-STAR—got more attention. Lubin, perhaps a future savior of the planet, was invited to give talks to other scientists, including one at the SETI (Search for Extraterrestrial Intelligence) Institute. There he mentioned that this same technology could also enable interstellar flight. A colleague told him he should talk to a guy named Pete Worden.

Lubin didn't, but he did keep working on his interstellar laser ideas with continued money from NASA. In 2015 he spoke at a conference hosted by the 100 Year Starship project. There he finally met Worden, who suggested Lubin send over a written version of his ideas. Lubin responded with a roadmap for interstellar flight, later published in the *Journal of the British Interplanetary Society*.

Worden wrote Lubin back quickly. "I have a friend," Lubin recalls him saying. "You mind if I send it to my friend?" Lubin told him sure, send it to whomever you want. The friend, of course, was Milner, and by January 2016 Lubin was meeting with Milner at his Bay Area mansion. In front of Milner was Lubin's interstellar roadmap, bedazzled with yellow Post-it notes. "Yuri says to me, 'You know, I've always dreamed, since I was a child, of





The Breakthrough Starshot spacecraft would probably be a small computer chip called a nanocraft. The prototype shown here is about 15 millimeters wide.

going to the stars," Lubin recalls. "'And now you've shown me the path."

Milner wanted to send the paper to experts who could evaluate its strengths and flaws. "If the reviews come back positive, then I'm willing to put in a fair amount of money," Lubin recalls Milner saying. He mentioned \$100 million. "Unfortunately that, by the way, never came true," Lubin says. "There was no \$100 million." The top two scientists affiliated with the project declined to be interviewed for this story.

BEFORE OFFICIALLY ANNOUNCING Starshot, Breakthrough officials had quietly recruited other thinkers in the field. In addition to Turner, who already knew Milner through a separate project called Breakthrough Listen, which searches for signals from alien civilizations, there was Mason Peck, an engineering professor at Cornell University and previously NA-SA's chief technologist. "That kind of opportunity does not come along every day, and I was all in from the very beginning," Peck says. Kelvin Long, a physicist and aerospace engineer who co-founded Project Icarus, also hopped onboard early. He sent Worden a design study, which he had written in three days while stuck in travel, for a hypothetical space probe that could move at 10 percent of the speed of light.

At Starshot's founding, the group identified around 30 problems to be solved before anyone could send an interstellar probe anywhere. Worden and James Schalkwyk of the Breakthrough Prize Foundation, working with three researchers from the Australian National University, wrote a chapter providing an overview of the project's initial phases for physicist and editor Claude Phipps's 2024 book Laser Propulsion in Space: Fundamentals, Technology, and Future Missions. Thirty-seven research groups, according to that summary, convened to understand

and reduce the technology risks in those major areas. "Then the whole project came down to trying to figure out how to spend \$100 million productively," Turner says.

Sometimes members of the crew got a bit of money to support their research, sometimes not. Starshot did bring people together, though—in person and virtually—to talk about their personal research on those problems. "Breakthrough is essentially a set of meetings," Lubin says. Other sources also cited meetings as a primary way scientists participated in the project.

Beginning in 2016, the Breakthrough Initiatives sponsored Breakthrough Discuss meetings "focused on life in the Universe and novel ideas for space exploration." The meetings, which were never specific to Starshot but did frequently cover topics related to the interstellar mission, have continued through 2025, with a gap in 2020 and a virtual meeting in 2021. Smaller satellite meetings also convened over the years to discuss specific technological and scientific aspects of the problem.

While they lasted, the meetings brought scientists and engineers together to investigate where the technology stood, what problems they didn't have solutions to, how feasible it was to overcome those problems and build something launchable, and what timelines and costs doing so would entail. There was palpable excitement in the early years—scientists felt they were part of a team embarking on an ambitious but tractable undertaking. They knew their biggest challenges were in certain areas: the design of the sail, the functionality of the laser system, the makeup of the spacecraft, and the construction of a communications apparatus that could signal back to Earth from light-years away. So, essentially, the whole system.

IT'S HARDLY WORTH SENDING a ship to another star if you won't be able to prove you've done it. Starshot would need to not just reach Proxima Centauri but also find a way to send back a signal strong enough to be detectable on Earth. It's a considerable challenge, however, to point a signal in the right direction from light-years away when both the probe and Earth are moving. Plus, both those feats must be accomplished with diminutive instruments on a spacecraft the mass of a pen cap or two.

According to Peck, Milner might have had unrealistic ideas—or at least ideas that conflicted with some of the scientists' suggestions—about what those signals should be like. "I do think Yuri Milner is very intelligent," Peck says. "I do think he has an adequate technical background" for the project. But he wanted things like video or 4K images from Alpha Centauri. And that, in Peck's view, was putting the cart before the horse, to make an ancient analogy for a 21st-century endeavor.

To Peck, getting just one computer bit of information from another solar system would be valuable. Perhaps the probe could send a yes-or-no answer to a single question—is there a certain percentage of oxygen in the planet's atmosphere, for instance, or does the radiation environment seem suitable for life? "It's only incrementally better to get a gigabit from Proxima Centauri," he says.

According to the 2024 book chapter, the team found several ways to make comms somewhat feasible. The scientists could build a huge array of smaller receivers on the Earth end to catch weak transmissions. They also could enlarge the spacecrafts' transmitting antenna and send communications in optical instead of radio wavelengths, which can transfer more data faster. The team decided to use the sun as a beacon to point the homebound transmission toward, helping the information reach the right part of the vast universe. Still, Long calls the communications problem the "elephant in the room" in that it didn't get as much attention in initial research as other topics did—an assessment Carnegie Mellon's Manchester agrees with.

ROPELLING THE PROBES far enough and fast enough that they have something to communicate requires solving another problem: the lasers. Or, as the Starshot team called them, "the photon engine."

The first issue, the team found, was that a single laser would need to be impractically powerful—incomparable to anything that exists today. The researchers could create an array of smaller lasers whose beams would combine into one with 100 gigawatts of power, but then they'd need to ensure the light waves lined up with one another, like sound waves that are in tune. "People made serious progress on that," Manchester says. "They were able to do it with tens of lasers in the lab, which is a breakthrough."

But not quite enough of a breakthrough for Breakthrough. The project would need even more lasers, and those lasers would have to work outside the lab to reach deep into space—which poses another problem. "How do you get that out of the atmosphere without getting messed up?" Manchester asks. Turbulence in the upper air will cause the beam to twinkle.

They would need to adjust for that twinkling in real time. One laser, called a guide star, could shoot through the atmosphere constantly, and the scientists could use data about how it got distorted to correct the other lasers. But that correction would require millions of adjustments every second. In the

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2024 book chapter, Worden and his co-authors pegged it as potentially the largest technical hurdle for the entire program.

The lasers pose a financial hurdle, too. To make Starshot feasible, the cost of powering them must come down from the current price of \$100 per watt to around \$0.01 to \$0.05 per watt, according to Long. Peck is optimistic because, theoretically, the cost of laser power should decrease over time, similar to how Moore's law predicted that transistors in computer chips should get steadily smaller as the years passed. Still, that discount isn't instantaneous. "We were likely looking at a launch date not in the next 20 years, as the sponsor had hoped, but perhaps in 30 or 40 years," Long says.

Regardless of how much the laser costs, what form it takes or when any of this finally happens, policy is an issue. A laser that blasts out the equivalent of four power stations' worth of energy is, as the conference that spurred Lubin's original research interest demonstrates, a weapon. The only solutions for that problem are international cooperation and trust, which aren't at all-time highs right now.

ONCE THE PHOTON ENGINE is up and working, that laser energy has to hit the lightsail of a given spacecraft and propel it forward with a power of about 100 gigawatts. The sail must hold up to the onslaught while withstanding acceleration at a g-force of 40,000—that is, 40,000 times the pull of gravity you would feel if you fell off a cliff.

Substances that can withstand both the rigors of warp speed and the shock of a laser-cannon blast and remain reflective tend to be heavy. Starshot envisioned a lightsail material that can stretch four meters wide but weigh only a gram. The initial Breakthrough phase aimed to identify potential materials and designs, a process led by Harry Atwater of the California Institute of Technology, who did not respond to a request for an interview. The leading candidate substance his team found, according to the 2024 summary, is silicon nitride. Atwater and his colleagues published that result in 2022. Engineers have been able to fabricate it at submicron thicknesses—less than one-tenth the thickness of Saran Wrap.

Ultrathin wafers of the material can be puzzlepieced together into a larger structure that is mostly reflective and doesn't absorb much light. Breakthrough engineers have done this assembly on the

When the project started, people thought interstellar travel was crazy.

millimeter scale but not the meter scale. Atwater and his team also coded a computer simulation that could figure out how various lightsail designs would perform during interstellar flight.

Another group, based at the University of Sydney, worked on ways to keep the hypothetical lightsail stable. The researchers joined meetings in 2021 and 2022 and shared their findings, but they never received any money from Breakthrough. "The whole thing always was outrageous," University of Sydney physicist Michael Wheatland says of the project's ambition. "I never believed it. But I think my perspective on things like this is that if you do fundamental research to try to solve a problem in the context of some outrageous scheme like that, then you can do really useful research."

And that's what the Sydney team did. They knew the sail would constantly be pushed around by the laser beam as it accelerated, so the team had to find some way to push it back to center. "But that then gives you oscillations," Wheatland says. Moving the laser could account for that, but like with the correction to untwinkle the lasers, the movement may be too much to ask of a bunch of lasers.

The sails are a separate problem from the spacecraft itself, which must be as small and lightweight as possible. Breakthrough calls the tiny spaceships "nanocraft." The leading candidate is the brainchild of Manchester, that wide-eyed graduate student when the program began. Manchester's early creations weren't meant for voyaging beyond the solar system—or even beyond Earth's orbit. As a graduate student at Cornell, working under Peck, he started designing postage-stamp-sized satellites around 2009. He called them, variously, Sprites and Chip-Sats. In 2011 he crowdfunded the project, and in 2014 he launched around 100 ChipSats to space. A glitch prevented them from deploying, though, and they burned up on the way back through the atmosphere.

After that disappointment, Manchester became involved with Breakthrough. His tiny satellites seemed like just what the team was looking for. "The notional idea was that some version of my ChipSat would end up being attached to that lightsail," he says. Manchester went on to do his postdoc at Harvard University, working officially on non-ChipSat projects. But with Breakthrough's help he was able to keep the ChipSat project on life support. "They were super nice to me during all of that," he says. "They would help me out, and they gave me little bits of funding."

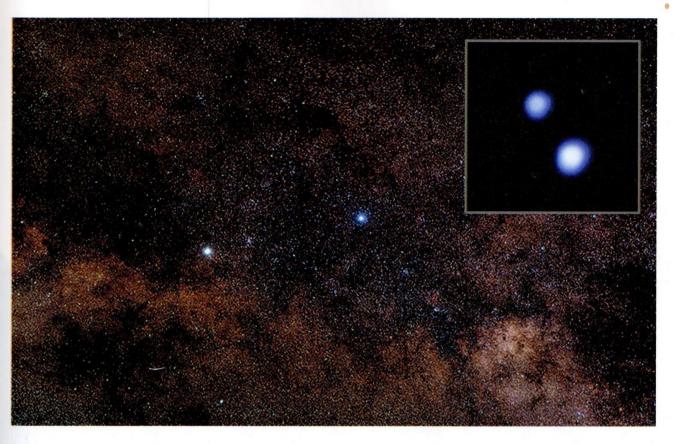
In 2019 Manchester was able to go for launch again, successfully deploying 105 ChipSats at once. He showed they could communicate with one another in space, acting as a swarm. The federal government let him fly them only once. "Then the [Federal Communications Commission] decided that we were going to destroy the world with space debris," he sayswhich wouldn't be a problem if they were headed way beyond low Earth orbit, to infinity and beyond.

REAKTHROUGH hasn't gone beyond anywhere, of course. Still, in all four problem areas, the teams found that nothing was technically wrong with the basic plan. They also did enough research to find out what they didn't know and what kinds of technical development (and money) would be required to make the concept reality.

Progress was almost certainly slowed by the fact that the \$100 million never materialized. Although the Starshot grants weren't made public, Lubin's experience might illustrate the scale of the spending. His group got two grants, one for \$116,000 and another for about \$80,000. Some of his colleagues in Australia also got \$80,000. "We got less than \$200,000 spread out over eight years," Lubin says. That was much less than NASA put toward Lubin's directed-energy interstellar work, although Breakthrough's press-centric approach meant its name was better associated with the project. "Breakthrough contributed less than 5 percent of the funding in our program in the end," Lubin says. "So it was always a little blip along the way. But in the public mind the entire program was a Breakthrough program, and that is simply not true at all."

Lubin calculates that overall, Breakthrough spent roughly \$4.5 million on about 30 contracts. In late January 2025, after I contacted Worden and Avi Loeb of Harvard, also a Breakthrough scientist, a spokesperson for the Breakthrough Prize Foundation reached out. Worden and Loeb had declined interviews, but the spokesperson said, "I have a potential way to move your story significantly forward." She later referred to a report on the project that would be finished around spring 2025 and made available to SCIENTIFIC AMERICAN, but that report had not appeared by the time this issue went to print.

At this stage the future of the program is murky. Starshot appears to be on indefinite hold, if not over, although there was no final announcement and no fanfare to match its beginnings. Peck is not sure where things stand. "As far as I can tell, they've put it on pause, at least," he says. "And I think it's probably not going to continue for the near future."



Physicist Martijn de Sterke, part of the Sydney group, and his colleague Boris Kuhlmey, a Sydney physicist who's helping with Starship-related research, heard only informally that Breakthrough Starshot was done. "It appears that this project has kind of disappeared," de Sterke says. "We have not heard from them for probably two years."

Some sources have interpreted the program's end as a realization that an actual starship, though technically possible, is still distant. "I think it's going to take 30 to 50 years of very hard work by a large number of very dedicated people, much like a Manhattan Project on steroids," Lubin says. Maybe that timeline wasn't appealing to Milner, some sources speculate, and neither was spending a Manhattan Project amount of money. Turner has a different perspective on how things turned out. To explain, he turns to the familiar example of medieval cathedrals, which took centuries to build—a length of time that humans rarely dedicate to any single project these days. "That [comparison] is often made as a kind of snide criticism of the short-sightedness of modern civilizations or people or profit motives," Turner says. "But I think it's actually a result of how fast technology is moving."

The innovations behind a cathedral's arches and finials didn't change much over the 200-year course of its construction. But the technology undergirding our world is unrecognizable compared with that

of just a couple of decades ago. "It's very hard trying to imagine a major technological thing we're working on now for which they could have done anything at all useful 200 years ago," Turner says. "Nothing they could have done would make the slightest difference to us." Maybe that's what Breakthrough leadership decided about Starshot: it's best left to the people of tomorrow.

Despite the project's nebulous end and uncertain future, many participants spoke about Breakthrough positively. Manchester, for instance, sees it as at least a psychological success. When the project started, people thought interstellar travel was crazy—or they didn't think about it at all. "Breakthrough changed society's conception of this kind of stuff as a legitimate area of scientific inquiry," he says.

Serious people worked on the project, did serious things, made serious progress—even if not directly on a path toward Alpha Centauri. "It's still a long way off, but it's a lot closer than it was five or six years ago," Manchester concludes. The program also inspired people such as de Sterke and Kuhlmey to work on fundamental physics and engineering problems that might not have gotten attention otherwise. And maybe, at the end of the day, that will be Starshot's legacy. "If there was a one-sentence summary of what Breakthrough was and did," Lubin says, "it was to bring attention to the dream."

The closest star system to the sun, Alpha Centauri, includes three stars. Two of them are a binary pair, seen in this close-up from NASA's Chandra X-ray Observatory (inset). A third star, Proxima Centauri, orbits the central two.

FROM OUR ARCHIVES

Near-Light-Speed Mission to Alpha Centauri. Ann Finkbeiner; March 2017. ScientificAmerican. com/archive