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SPACEFLIGHT

NEAR-LIGHT-SPEED MISSION TO ALPHA CENTAURI

A billionaire-funded plan aims to send a probe to another star. But can it be done?

By Ann Finkbeiner

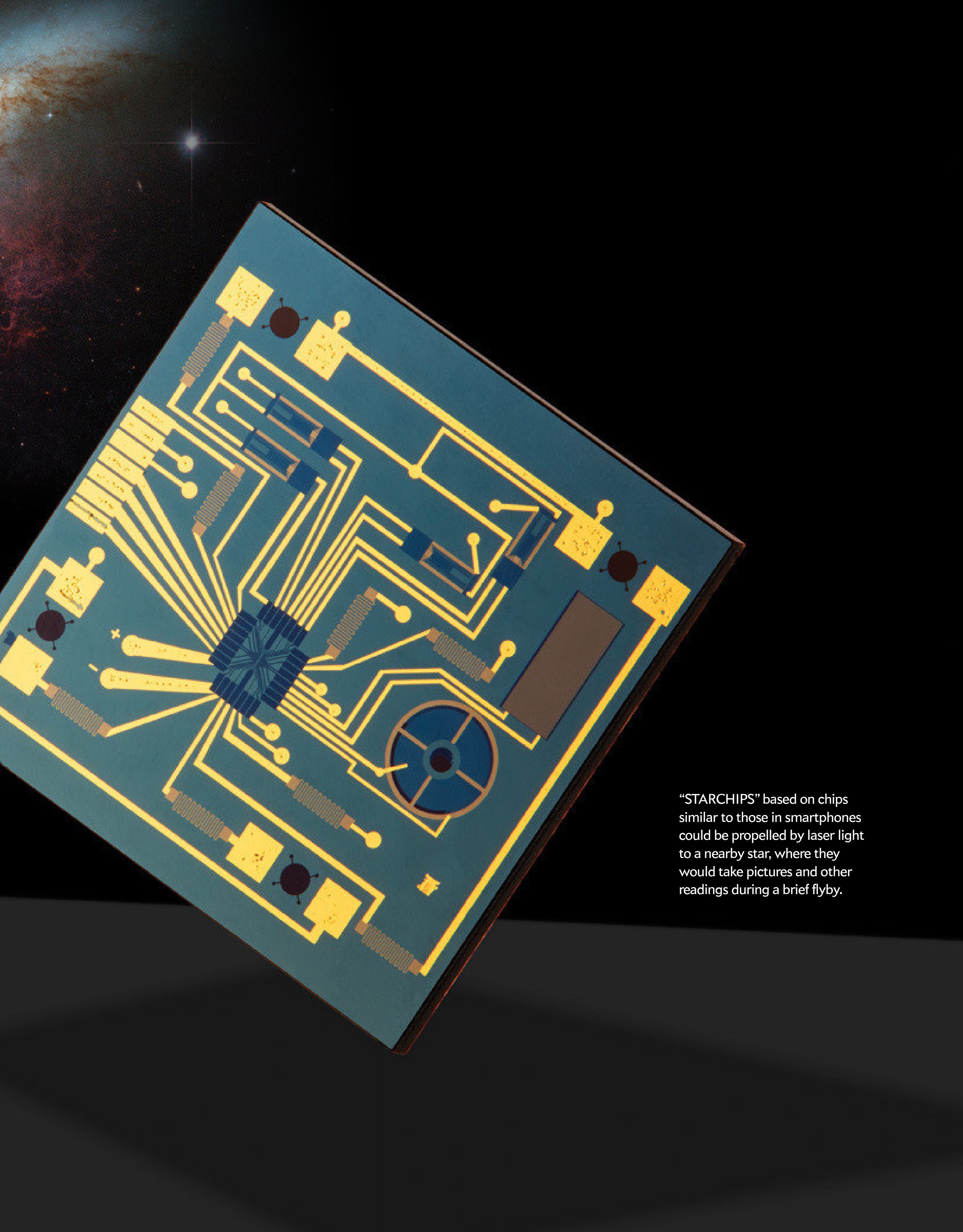
IN BRIEF

A Silicon Valley billionaire is funding an audacious plan to send a spacecraft to one of the sun's closest stellar neighbors.

The mission, called Breakthrough Starshot, would use lasers to propel "light sails" attached to small, smartphonelike chips that could take pictures, make measurements and beam their findings back to Earth.

Experts say the plan is risky and expensive and may not work—but is nonetheless exciting, offering a chance to send the first man-made object to another star.

Photographs by Stan Musilek



“STARCHIPS” based on chips similar to those in smartphones could be propelled by laser light to a nearby star, where they would take pictures and other readings during a brief flyby.

Ann Finkbeiner is a science writer based in Baltimore. She specializes in writing about astronomy, cosmology, and the intersection of science and national security and loves unlikely technologies. Her most recent book is *A Grand and Bold Thing* (Free Press, 2010) about the Sloan Digital Sky Survey project to map the entire night sky.

In the spring of 2016 I was at a reception with Freeman Dyson, the brilliant physicist and mathematician, then 92 and emeritus at the Institute for Advanced Study in Princeton, N.J. He never says what you expect him to, so I asked him, "What's new?" He smiled his ambiguous smile and answered, "Apparently we're going to Alpha Centauri." This star is one of our sun's nearest neighbors, and a Silicon Valley billionaire had recently announced that he was funding a project called Breakthrough Starshot to send some kind of spaceship there. "Is that a good idea?" I asked. Dyson's smile got wider:

"No, it's silly." Then he added, "But the spacecraft is interesting."

The spacecraft is indeed interesting. Instead of the usual rocket, powered by chemical reactions and big enough to carry humans or heavy instruments, Starshot is a cloud of tiny, multifunction chips called StarChips, each attached to a so-called light sail. The sail would be so insubstantial that when hit by a laser beam, called a light beamer, it would accelerate to 20 percent of the speed of light. At 4.37 light-years away, Alpha Centauri would take the fastest rocket 30,000 years to reach; a StarChip could get there in 20. On arrival, the chips would not stop but rather tear past the star and any of its planets in a few minutes, transmitting pictures that will need 4.37 years to return home.

The "silly" part is that the point of the Starshot mission is not obviously science. The kinds of things astronomers want to know about stars are not the kinds of things that can be learned from a quick flyby—and no one knows whether Alpha Centauri even has a planet, so Starshot could not even promise close-ups of other worlds. "We haven't given nearly as much thought to the science," says astrophysicist Ed Turner of Princeton University, who is on the Starshot Advisory Committee. "We've almost taken for granted that the science will be interesting." But in August 2016 the Starshot team got lucky: a completely unrelated consortium of European astronomers discovered a planet around the next star over, Proxima Centauri, a tenth of a light-year closer to us than Alpha Centauri. Suddenly, Starshot became the only semifeasible way in the foreseeable future to visit a planet orbiting another star. Even so, Starshot sounds a little like the dreams of those fans of science fiction and interstellar travel who talk seriously and endlessly about sending humans beyond the solar system with technologies that would surely work, given enough technological miracles and money.

Starshot, however, does not need miracles. Its technology, though currently nonexistent, is based on established engineering and violates no laws of physics. And the project has money behind it. Yuri Milner, the entrepreneur who also funds other research projects called Breakthrough Initiatives as well as yearly science awards called Breakthrough Prizes, is kick-starting Starshot's initial development with $100 million. Furthermore, Milner has enlisted an advisory committee impressive enough to convince a skeptic that Starshot might work, including world experts in lasers, sails, chips, exoplanets, aeronautics and managing large projects, plus two Nobel Prize winners, the U.K.'s Astronomer Royal, eminent academic astrophysicists, a cadre of smart, experienced engineers—and Dyson, who, despite thinking Starshot's mission is silly, also says the laser-driven sail concept makes sense and is worth pursuing. On the whole, few would make a long-range bet against an operation with this much money and good advice and so many smart engineers.

Whatever its prospects, the project is wholly unlike any space mission that has come before. "Everything about Starshot is unusual," says Joan Johnson-Freese, a space policy expert at the U.S. Naval War College. Its goals, funding mode and management structure diverge from all the other players in space travel. Commercial space companies focus on making a profit and on manned missions that stay inside the solar system. NASA, which also has no plans for interstellar travel, is too risk-averse for something this uncertain; its bureaucratic procedures are often cumbersome and redundant; and its missions are at the mercy of inconsistent congressional approval and funding. "NASA has to take time; billionaires can just do it," says Leroy Chiao, a former astronaut and commander of the International Space Station. "You put this team together, and off you go."

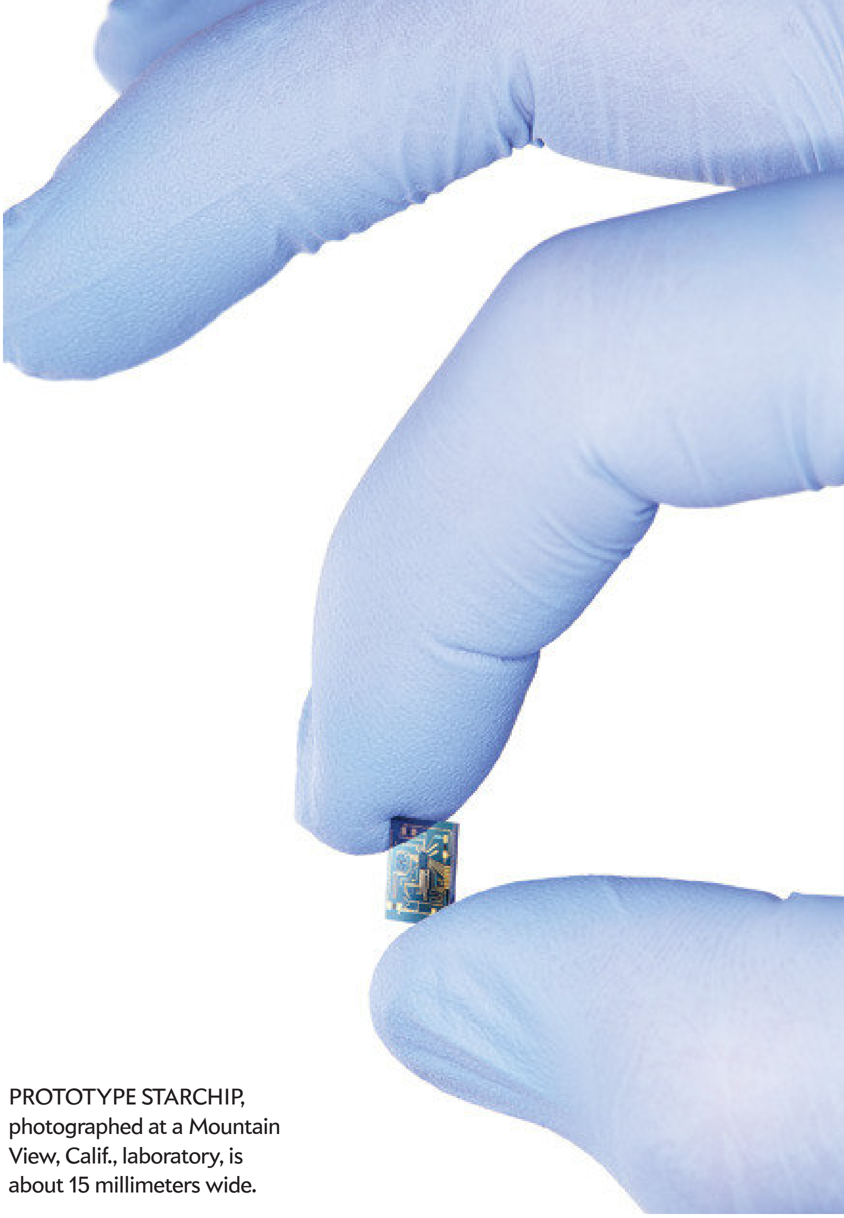
THE GAME PLAN

THE MAN DRIVING the Starshot project has always been inspired by the far reaches. Yuri Milner was born in Moscow in 1961, the same year Yuri Gagarin became the first human to go into space. "My parents sent me a message when they called me Yuri," he says—that is, he was supposed to go somewhere that no one had ever been. So he went into physics—"it was my first love," he says. Milner spent 10 years getting educated, then worked on quantum chromodynamics. "Unfortunately, I did not do very well," he says. Next he went into business, became

PAGE 30: COURTESY OF NASA, ESA, A. GOOBAR *Stockholm University* AND HUBBLE HERITAGE TEAM (STScI/AURA) *(galaxy)* an early investor in Facebook and Twitter, and amassed a fortune reported to be nearly $3 billion. "So maybe four years ago," Milner says, "I started to think again about my first love."

In 2013 he set up the Breakthrough Prizes, one each for the life sciences, mathematics and physics. And in 2015 he started what he calls his hobby, the Breakthrough Initiatives, a kind of outreach to the universe: a $1-million prize for the best message to an extraterrestrial civilization; $100 million for a wider, more sensitive search for extraterrestrial intelligence; and now $100 million to Starshot.

In early 2015 Milner recruited a central management team for Starshot from people he had met at various Breakthrough gatherings. Starshot's Advisory Committee chair and executive director, respectively, are Avi Loeb, chair of Harvard University's astronomy department, and Pete Worden, who directed the NASA Ames Research Center and was involved in a DARPA/NASA plan for a starship to be launched in 100 years. Worden recruited Pete Klupar, an engineer who had been in and out of the aerospace industry and had worked for him at Ames, as Starshot's director of engineering. They in turn pulled together the impressive committee, which includes specialists in the relevant technologies who are apparently willing to participate for some or no money, as well as big names such as Facebook's Mark Zuckerberg and cosmologist Stephen Hawking. Starshot's management policy seems to be a balance between NASA's hierarchical decision-tree rigor and the Silicon Valley culture of putting a bunch of smart people in a room, giving them a long-term goal and standing back. One committee member, James Benford, president of Microwave Sciences, says the charge is to "give us next week and five years from now, and we'll figure out how to connect the two."



PROTOTYPE STARCHIP, photographed at a Mountain View, Calif., laboratory, is about 15 millimeters wide.

The assembled team members began by agreeing that they could rule out sending humans to Alpha Centauri as too far-fetched and planned to focus on an unmanned mission, which they estimated they could launch in roughly 20 years. They then agreed that the big problem was spacecraft propulsion. So in mid-2015 Loeb's postdocs and graduate students began sorting the options into the impossible, the improbable and the feasible. In December of that year they received a paper by Philip Lubin, a physicist at the University of California, Santa Barbara, called "A Roadmap to Interstellar Flight." Lubin's option for propulsion was a laser phased array—that is, a large number of small lasers ganged together so that their light would combine coherently into a single beam. The laser beam would push a sail-carried chip that would need to move at a good fraction of light speed to reach another star within a couple of decades. (A similar idea had been published 30 years earlier by a physicist and science-fiction writer named Robert Forward; he called it a Starwisp.) Although the technology was still more science fiction than fact, "I basically handed Starshot the road map," Lubin says, and he joined the project.

In January 2016 Milner, Worden, Klupar, Loeb and Lubin met at Milner's house in Silicon Valley and put together a strategy. "Yuri comes in, holding a paper with sticky notes on it," Lubin says, "and starts asking the right science and economic questions." The beauty of the project's unusual approach was that, rather than going through a drawn-out process of soliciting and reviewing proposals as NASA would or being concerned about the potential for profit like a commercial company, the Starshot team was free to hash out a basic plan based purely on what sounded best to it.

Starshot's only really expensive element was the laser; the sails and chips would be low cost and expendable. The latter would be bundled into a launcher, sent above the atmosphere and released like flying fish, one after another—hundreds or thousands of them—so many that like the reptilian reproduction strategy, losing a few would not matter. Each one would get hit by the laser and accelerated to 20 percent the speed of light in a few minutes. Next the laser would cut off, and the chip and sail would just fly. When they got to the star, the chips would call back home. "Ten years ago we couldn't have had a serious conversation about this," Milner says. But now, what with lasers and chips improving exponentially and scientists designing and building new materials, "it's not centuries away, it's dozens of years away."

Starshot management sent the idea out for review, asking sci-

How to Visit a Star

Breakthrough Starshot is an ambitious plan to send tiny spacecraft to one of our neighboring stars to snap pictures and make measurements during a quick flyby. The mission would be the first interstellar voyage humanity has launched. Funded by the Breakthrough Initiatives, the plan calls for the pressure of laser light, beamed from the surface of Earth, to propel ultrafine sheets called light sails attached to tiny spacecraft called StarChips (together called nanocraft), which would then beam their messages back home to us.

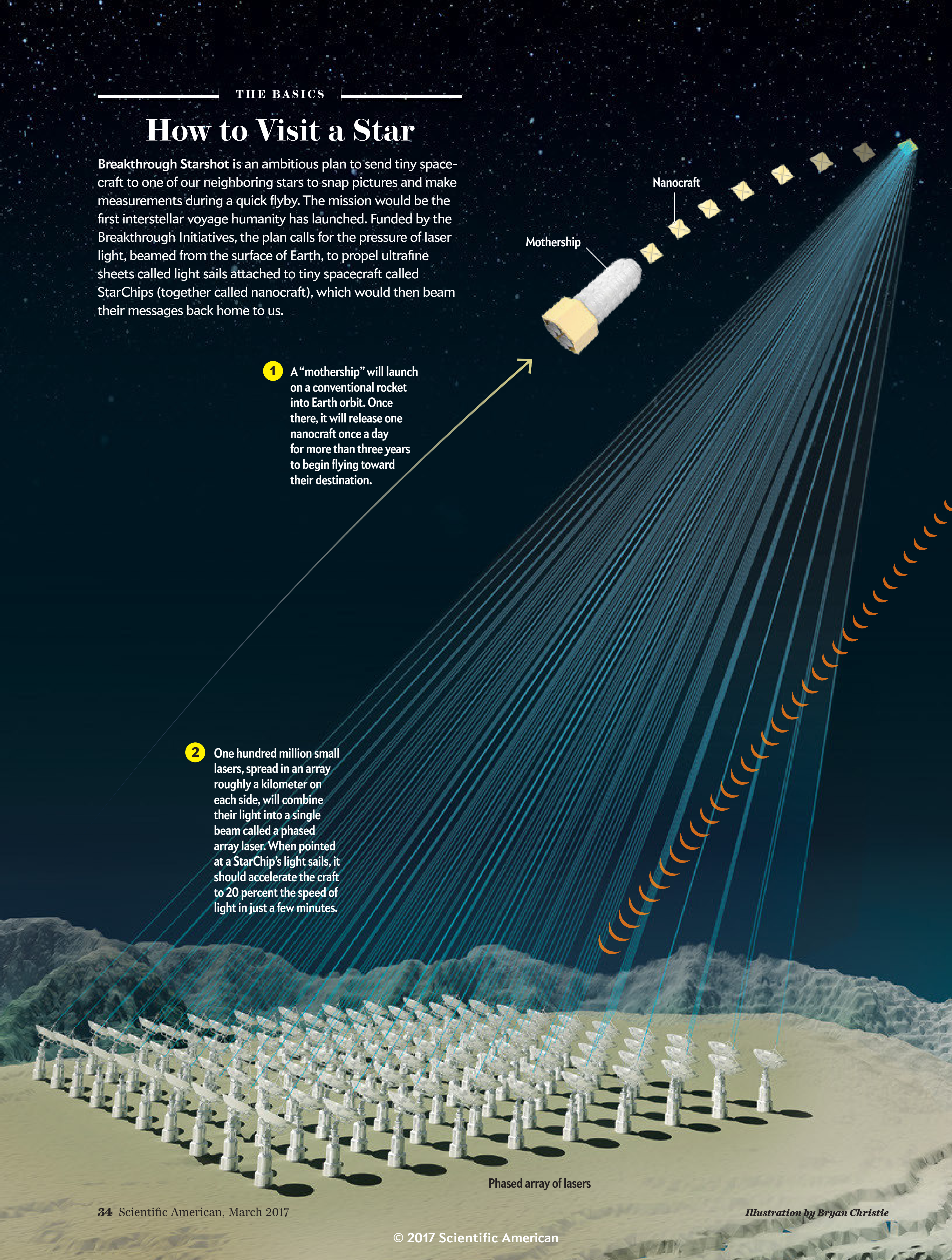
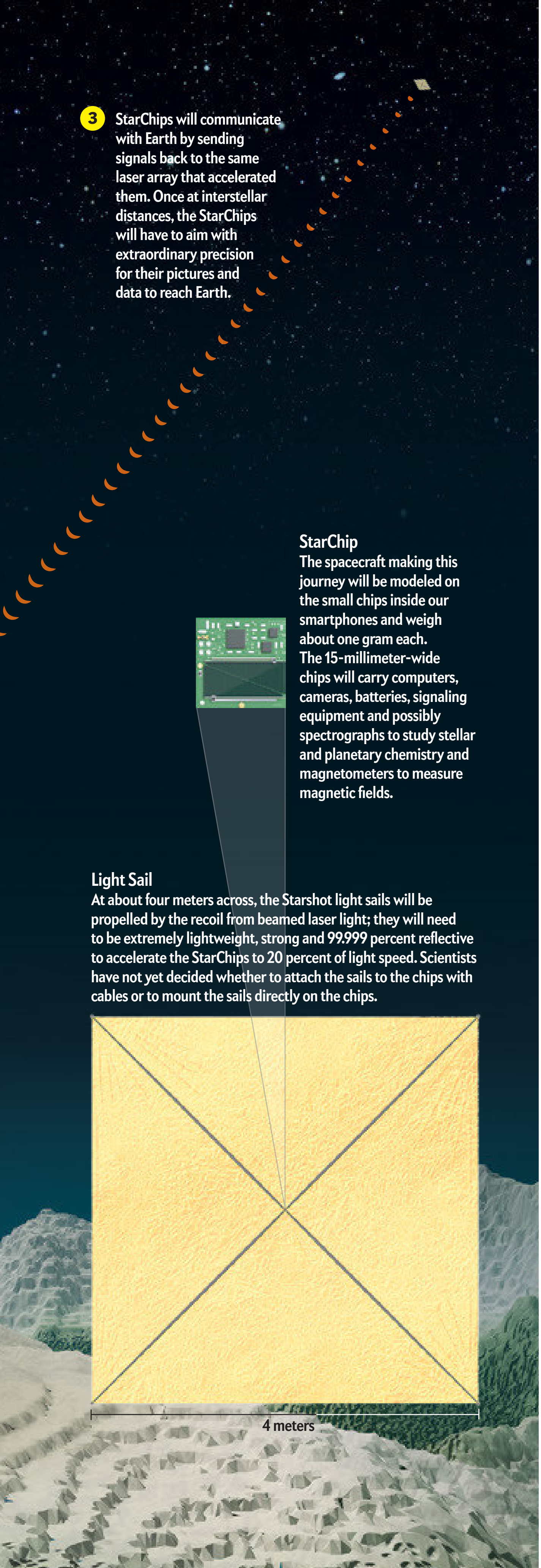


Illustration by Bryan Christie



entists to look for deal breakers. None found any. "I can tell you why it's hard and why it's expensive," Lubin says, "but I can't tell you why it can't be done." By April 2016 the team had agreed on the system, and on April 12 Milner arranged a press conference atop the new Freedom Tower in New York City, featuring videos, animations and several members of the advisory committee. He announced an "interstellar sailboat" driven by a wind of light. The researchers spent the following summer outlining what had to happen next.

STARCHIPS AND LIGHT SAILS

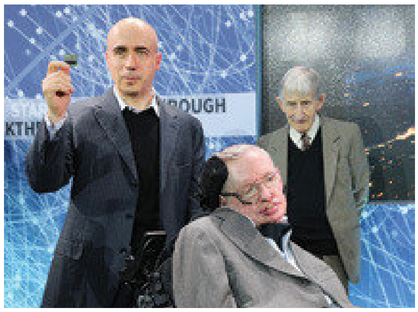
THE TEAM SOON FOUND that, though technically feasible, the plan would be an uphill climb. Even the easiest of the technologies, the StarChip, poses a lot of problems. It needs to be tiny—roughly gram-scale—yet able to collect and send back data, carry its own power supply and survive the long journey. Several years ago engineer Mason Peck's group at Cornell University built what they call Sprites, smartphonelike chips that carry a light sensor, solar panels and a radio and weigh four grams each. The Starshot chips would be modeled on the Sprites but would weigh even less, around a gram, and carry four cameras apiece. Instead of heavy lenses for focusing, one option is to place a tiny diffraction grating called a planar Fourier capture array over the light sensor to break the incoming light into wavelengths that can be reconstructed later by a computer to any focal depth. Other equipment suggested for the chip include a spectrograph to identify the chemistry of a planet's atmosphere and a magnetometer to measure a star's magnetic field.

The chips would also need to send their pictures back over interstellar distances. Satellites currently use single-watt diode lasers to send information but over shorter distances: So far, Peck says, the longest distance has been from the moon, more than 100 million times closer than Alpha Centauri. To target Earth from the star, the laser's aim would need to be extraordinarily precise. Yet during the four-year trip the signal will spread out and dilute until, when it reaches us, it will come in as just a few hundred photons. A possible solution would be to send the pictures back by relay, from one StarChip to a series of them flying at regular distances behind. Getting the information back to Earth, says Starshot Advisory Committee member Zac Manchester of Harvard, "is still a really hard problem."

The chips also need batteries to run the cameras and onboard computers to transmit data back during the 20-year voyage. Given the distance to Alpha or Proxima Centauri and the few watts achievable on a small chip, the signal would arrive on Earth weak but "with just enough photons for Starshot's receiver to pick it up," Peck says. To date, no power source simultaneously works in the dark and the cold, weighs less than a gram and has enough power. "Power is the hardest problem on the chip," Peck says. One possible solution, he offers, is to adapt the tiny nuclear batteries used in medical implants. Another is to tap the energy the sail gains as it travels through the gas- and dust-filled interstellar medium and heats up via friction.

The same interstellar medium could also pose hazards for the Starshot chips. The medium is like highly rarefied cigarette smoke, says Bruce Draine, an astronomer at Princeton University who is also a committee member. No one knows exactly how dense the medium is or what size the dust grains are, so its potential for devastation is hard to estimate. Collisions near the speed of light between the StarChips and grains of any size could create damage that would range from minor craters to complete destruction. If the StarChips are a square centimeter, Draine says, "you'll collide with many, many of these things" along the way. One protectant against smaller particles might be a coating of a couple of millimeters of beryllium copper, although dust grains could still cause catastrophic damage. "The chip will either survive, or it won't," Peck says, but with luck, out of the hundreds or thousands sent off in the chip swarm, some will make it.

The next-hardest technology is the sail. The StarChips would be propelled by the recoil from light reflected off their sails, the way the recoil from a tennis ball pushes a racket. The more light gets reflected, the harder the push and the faster the sail; to get to 20 percent of light speed, the Starshot light sail has to be 99.999 percent reflective. "Any light that isn't reflected ends up heating the sail," says Geoffrey Landis, a scientist at the NASA Glenn Research Center and a member of the advisory committee—and given the extraordinary temperatures of the light beamer, "even a small fraction of the laser power heating the sail would be disastrous." Compared with today's solar sails, which have used light from the sun to propel a few experimental spacecraft around the solar system, it also has to be much lighter, of a thickness measured in atoms or about "the thickness of a soap bubble," Landis says. In 2000, in the closest approximation yet, Benford used a microwave beam to accelerate a sail made of a carbon sheet. His test achieved about 13 *g*s (13 times the acceleration felt on Earth caused by gravity), whereas Starshot's sail would need to withstand an acceleration up to 60,000 *g*s. The sail, like the StarChip, would also have to stand up to dust in the interstellar medium punching holes in it. So far no material exists that is light, strong, reflective and heat-resistant and that does not cost many millions of dollars. "One of the several miracles we'll have to invent is the sail material," Klupar says.



BILLIONAIRE ENTREPRENEUR Yuri Milner, who is funding Breakthrough Starshot, holds up a prototype of the StarChip during an April 12, 2016, press conference in New York City announcing the mission. Scientists Stephen Hawking and Freeman Dyson, who are advising the project, also spoke.

Other sail-related decisions remain. The sail could attach to the chip with cables, or the chip could be mounted on the sail. The sail might spin, allowing it to stay centered on the light beamer. After the initial acceleration, the sail could fold up like an umbrella, making it less vulnerable during the journey. And once it got to Alpha Centauri, it could unfold and adjust its curvature to act like a telescope mirror or an antenna to send the chip's messages back to Earth. "It sounds like a lot of work," Landis says, "but we've solved hard problems before."

Yet all these challenges are still easier than those of the light beamer that will push the sail. The only way Starshot could reach a good fraction of light speed is with an unusually powerful 100-gigawatt laser. The Department of Defense has produced lasers more powerful, says Robert Peterkin, chief scientist at the Directed Energy Directorate at the U.S. Air Force Research Laboratory, but they shine for only billionths or trillionths of a second. The Starshot light beamer would have to stay on each sail for minutes. To reach this kind of power for that long, small fiber lasers can be grouped into an array and phased together so that all their light combines into one coherent beam. The Defense Department has also built phased array lasers, but theirs include 21 lasers in an array no more than 30 centimeters across, Peterkin says, which achieves a few tens of kilowatts. The Starshot light beamer would have to include 100 million such kilowatt-scale lasers, and the array would spread a kilometer on each side. "How beyond the state of the art is that?" Peterkin says.

"And it all gets worse and worse," he adds. The 100 million little lasers would be deflected by the normal turbulence of the atmosphere, each one in its own way. In the end, the light beamer would need to bring them all to a single focus 60,000 kilometers up on a four-square-meter sail. "At the moment," says Robert Fugate, a retired scientist at the Directed Energy Directorate who is on the committee, drily, "phasing 100 million lasers through atmospheric turbulence on a meter-class target 60 megameters away has my attention." The light could miss the sail completely or more likely hit it unevenly so parts of the sail would be pushed harder, causing it to tumble, spin or slip off the beam.

Again, the Starshot team has a potential solution but one that comes with its own set of problems. A technology called adaptive optics, already used by large telescopes, cancels out the distortion created by the atmosphere's turbulence with a flexible mirror that creates an equal and opposite distortion. But this technology would need major adaptations to work for Starshot. In the case of the beamer, instead of an adjustable mirror scientists would have to minutely adjust each laser fiber to make the atmospheric correction. Current adaptive optics on telescopes can resolve at best a point 30 milliarcseconds across (a measure of an object's angular size on the sky). Starshot would need to focus the beamer within 0.3 milliarcsecond across—something that has never been done before.

And even if all these disparate and challenging technologies could be built, they must still work together as a single system, which for the Starshot managers is like creating a puzzle with pieces whose shapes evolve or do not yet exist. Worden calls the process "the art of a long-term hard-research program." The system has "no single design yet," says Kevin Parkin of Parkin Research, a systems engineer who is on the committee. The plan, for the first five years, Klupar says, is to "harvest the technologies"—that is, with the guidance of the relevant experts on the committee, the team members will carry out small-scale experiments and make mathematical models. They began in the winter of 2015–2016 by scoping out existing technologies and requesting proposals for not yet developed technologies; in spring 2017 they intend to award small contracts of several hundred thousand to $1.5 million each. Prototypes would come next, and, assuming their success, construction of the laser and sail could begin in the early 2030s, with launch in the mid-2040s. By that

JEMAL COUNTESS *Getty Images*

time Starshot will likely have cost billions of dollars and, with any luck, have collected collaborators in governments, labs and space agencies in the U.S., Europe and Asia. "I will make the case, and I hope more people will join," Milner says. "It has to be global," he adds, citing the reasonable national security concerns of an enormous laser installation. "If you start something like this in secrecy, there will be many more question marks. It's important to announce intentions openly."

STARWARD, HO!

GIVEN ALL THESE HURDLES, what are the odds of success? Technologically savvy people not connected to Starshot estimate they are small; several people told me flatly, "They're not going to Alpha Centauri." David Charbonneau of the Harvard-Smithsonian Center for Astrophysics says the project will ultimately be so expensive that "it may amount to convincing the U.S. population to put 5 percent of the national budget—the same fraction as the Apollo program—into it."

Those connected with Starshot think the odds are better but are pragmatic. "We can certainly use lasers to send craft to Alpha Centauri," says Greg Matloff of the New York City College of Technology, a member of the committee. "Whether we can get them there over the next 20 years, I don't know." Harvard's Manchester says, "Within 50 years the odds are pretty good; in a century, 100 percent." Worden thinks their approach is purposefully measured, "and maybe in five years we'll find we can't do it." Milner sees his job on Starshot, besides funding it, as keeping it practical and grounded. "If it takes more than a generation," he says, "we shouldn't work on that project."

Until late last August I thought Dyson was right; the Starshot technology was intriguing, but Alpha Centauri was silly. The star is a binary system (Alpha Centauri A and B), and both stars are sunlike, neither one unusual. Astronomers' understanding of such stars, Charbonneau says, "is pretty good," and although comparing their flares and magnetic fields with our sun's might be useful, "what we'd learn about stellar physics by going there isn't worth the investment."

Now that astronomers know Alpha Centauri's neighbor has a planet, the science case is more promising. The star, Proxima Centauri, is a tad nearer to Earth and is a red dwarf, the most common kind of star. The planet, Proxima Centauri b, is at a distance from its star that could make it habitable. When the discovery was announced, the Starshot team celebrated over dinner. Would members consider changing the project's target? "Sure," Milner says. "We have plenty of time to decide." The laser array should have enough flexibility in pointing that it could "accommodate the difference, about two degrees," Fugate says.

Ultimately the Breakthrough Initiatives' general goal is to find all the planets in the solar neighborhood, Klupar says, and Proxima Centauri b might be just the first. "I feel like an entomologist who picks up one rock, finds a bug, then thinks every rock after that will have a bug under it, too," he says. "It's not true, but it's encouraging somehow."

Of course, even the presence of Proxima Centauri b still does not make Starshot slam-dunk science. The chip could take images, maybe look at the planet's magnetic field, perhaps sample the atmosphere—but it would do this all on the fly in minutes. Given the time to launch and the eventual price, says Princeton astrophysicist David Spergel, "we could build a 12- to 15-meter optical telescope in space, look at the planet for months and get much more information than a rapid flyby could."

But billionaires are free to invest in whatever they wish, and kindred souls are free to join them in that wish. Furthermore, even those who question Starshot's scientific value often support it anyway because in developing the technology, its engineers will almost certainly come up with something interesting. "They won't solve all the problems, but they'll solve one or two," Spergel says. And an inventive solution to just one difficult problem "would be a great success." Plus, even if Starshot does not succeed, missions capitalizing on the technologies it develops could reach some important destinations both within and beyond our solar system.

Milner's own fondness for the project stems from his hope that it can unite the world's humans in a sense of being one planet and one species. "In the past six years I've spent 50 percent of my time on the road, a lot of time in Asia and Europe," he says. "I realized that global consensus is difficult but not impossible." That theme fits with the other Breakthrough Initiatives, which chiefly want to find aliens to talk to, and with Milner's considerable investments in the Internet and social media, which have changed the nature of conversation and community. But in the end, even he acknowledges that wanting to go to a star is inexplicable. "If you keep asking me why, eventually I'll say I don't know. I just think it's important."

Almost everyone I asked said the same: they cannot explain it to someone who does not already understand—they just want to go. James Gunn, emeritus professor in Princeton's department of astrophysical sciences, who thinks Starshot's chances of success are slim and who dismissed the scientific motivations, still says, "I'm rational about most things, but I'm not particularly rational about the far reach of humanity. I dreamed of going to the stars since I was a kid." Many of the advisory committee said the same thing. "It is just *so* cool," Landis says, echoing the exact words of other members.

The contradictions inherent in such dreams are perhaps best expressed by Freeman Dyson. Starshot's laser-driven sail with its chip makes sense, he says, and those behind the project are smart and "quite sensible." But he thinks they should stop trying to go to Alpha or Proxima Centauri and focus on exploring the solar system, where StarChips could be driven by more feasible, less powerful lasers and travel at lower speeds. "Exploring is something humans are designed for," he says. "It's something we're very good at." He thinks "automatic machines" should explore the universe—that there is no scientific justification for sending people. And then, being Dyson and unpredictable, he adds, "On the other hand, I still would love to go." SA

MORE TO EXPLORE

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