FIRST TRIP TO THE STARS

A wild plan is taking shape to visit the nearest planet outside our Solar System. Here's how we could get to Proxima b.

BY GABRIEL POPKIN

Anybody who longs to see an alien world up close got an exciting gift last year. In August, researchers reported the discovery of a potentially habitable, Earth-sized planet orbiting the Sun's closest stellar neighbour — Proxima Centauri, a mere 1.3 parsecs, or 4.22 light years, away.

It's a tempting — some might say irresistible — destination. Sending a spacecraft to the planet, dubbed Proxima b, would give humans their first view of a world outside the Solar System. "Clearly it would be a huge step forward for humanity if we could reach out to the nearest star system," says Bruce Betts, director of science and technology for the Planetary Society in Pasadena, California. The data beamed back could reveal whether the alien world offers the right conditions for life — and maybe even whether anything inhabits it.

The idea of reaching Proxima b is not just science fiction. In fact, a few months before the discovery of the exoplanet, a group of business leaders and scientists took the first steps towards visiting the Alpha Centauri star system, thought to be home to Proxima. They announced Breakthrough Starshot, an effort backed by US$100 million from Russian investor Yuri Milner to vastly accelerate research and development of a space probe that could make the trip. When Proxima b was found (G. Anglada-Escudé et al. *Nature* **536,** 437–440; 2016), the project gained an even more tantalizing target.

Getting there won't be easy. Despite Proxima b's name, it is still nearly 2,000 times farther from Earth than any human-made object has ever travelled. To reach it within a scientist's working lifetime, a probe would have to reach around one-fifth the speed of light and navigate a treacherous path through unseen debris in our own Solar System and interstellar space. Then it would need to collect useful data during a 60,000-kilometre-per-second fly-by of the Proxima system, and beam the information back across the 4 light years to Earth. It all amounts to a monstrous engineering challenge, but project researchers say it is possible and are now moving towards that goal.

Other groups are also aiming for nearby stars, but none has the momentum — or money — of Breakthrough Starshot. And even astrophysicists who are not involved with Starshot agree that it has the most realistic chance at an interstellar mission in the next few decades, thanks in part to scientists who have published many concept papers on interstellar travel. "Starshot takes the best bits out of all of that, and puts them together into something new," says Caleb Scharf, an astrophysicist at Columbia University in New York City who is not on the Starshot team.

Leaders of the mission plan to start funding technology-development projects within months, with the aim of launching a fleet of tiny, laser-propelled probes in the next 20 years. The effort would ultimately cost about $10 billion, leaders hope, and take another 20 years to reach Alpha Centauri.

THE LAUNCH

The first truly challenging step in any mission such as Breakthrough Starshot is to accelerate the spacecraft to interstellar velocities. Conventional rockets are out of the question because they can't store enough chemical energy in the form of fuel, says Philip Lubin, an astrophysicist at the University of California, Santa Barbara, who is on the project's advisory and management committee. "Chemistry will get you to Mars," he says, "but it won't get you to the stars."

So Starshot is focusing on harnessing light. Since the turn of the twentieth century, scientists have known that light carries momentum and can give objects a push. Researchers at the Japan Aerospace Exploration Agency (JAXA) and the Planetary Society have demonstrated this in space by launching large sails propelled by sunlight. But the Sun's light isn't powerful enough to accelerate a ship to Alpha Centauri; that would require an enormous, unwieldy sail, says Betts, who led a team that in 2015 deployed a 32-square-metre solar sail.

Starshot evaluated more than 20 ideas for propulsion beyond the Solar System, but "virtually all" seemed out of reach, says Pete Worden, the project's executive director. They settled on one that Lubin had proposed, involving lasers. In 2015, Lubin produced a conceptual road map for getting a spacecraft to Alpha Centauri in 20 years (P. Lubin *J. Br. Interplanet. Soc.* **69,** 40–72; 2016). He suggested using an array of lasers on Earth to generate a beam powerful enough to propel a small light sail.

The Starshot team plans to use conventional rockets to send its probes into orbit. Then a 100-gigawatt laser array on Earth would fire continuously at the sail for several minutes, long enough to accelerate it to 60,000 kilometres per second (see 'Are we there yet?').

Starshot leaders acknowledge that they are counting on breakthroughs from the laser industry. One hundred gigawatts will be a million times more powerful than today's biggest continuous lasers, which put out hundreds of kilowatts. One way around that gap would be to combine light from hundreds of millions of less powerful laser beams across an array that is at least a kilometre wide. But the beams would all need to be brought into phase with each other so that their light waves add rather than cancel each other out — making the lasers one of the mission technologies that requires the most development work.

THE CRAFT

The Starshot craft will look like nothing ever launched into space. Imagine a small collection of electronics, sensors, thrusters, cameras and a battery on a roughly one-centimetre-wide chip in the centre of a circular or square sail, roughly 4 metres wide — all weighing just a gram. The lighter the craft, the faster a given force can accelerate it.

To maximize speed and minimize damage from the lasers, the sail needs to reflect almost all the incoming light, although it could let some pass through. Suitable materials already exist in the form of thin layers of electrical insulators that can reflect up to 99.999% of incoming light, close to the threshold needed. But researchers will need to increase production of the exotic materials, and lower their cost. And they need to study how the materials will respond to the intense light levels required, which could produce unpredicted optical effects.

In the acceleration phase, the sail will need to stay extremely flat and actively sense and compensate for imperfections in the laser beam, so that the craft will stay on course; even a slight deviation early on could send it on a wildly different trajectory. One option for doing this is to set the sail spinning, creating a centrifugal force that would pull it taut and allowing beam irregularities to average out over the sail area. JAXA has already demonstrated a spinning solar sail, and the concept "looks extremely promising" for Starshot, says Worden.

Whatever the design, the sail must be strong. A 100-gigawatt laser beam will hit it hard, generating tens of thousands of times the acceleration that an object feels on Earth owing to gravity. Artillery shells have survived such forces in military tests, Worden notes, but for less than a second — not the several minutes for which the laser will pound the device.

Starshot's plan would build strength in numbers. The spacecraft would be small and relatively low-cost, so the project could launch one or more every day, and even afford to lose some of them.

Development of the probes will proceed in stages, says Worden. The first step is to build a prototype system that would accelerate to perhaps 1,000 kilometres per second — less than 2% of the speed planned for Starshot — for a total cost between $500 million and $1 billion.

THE JOURNEY

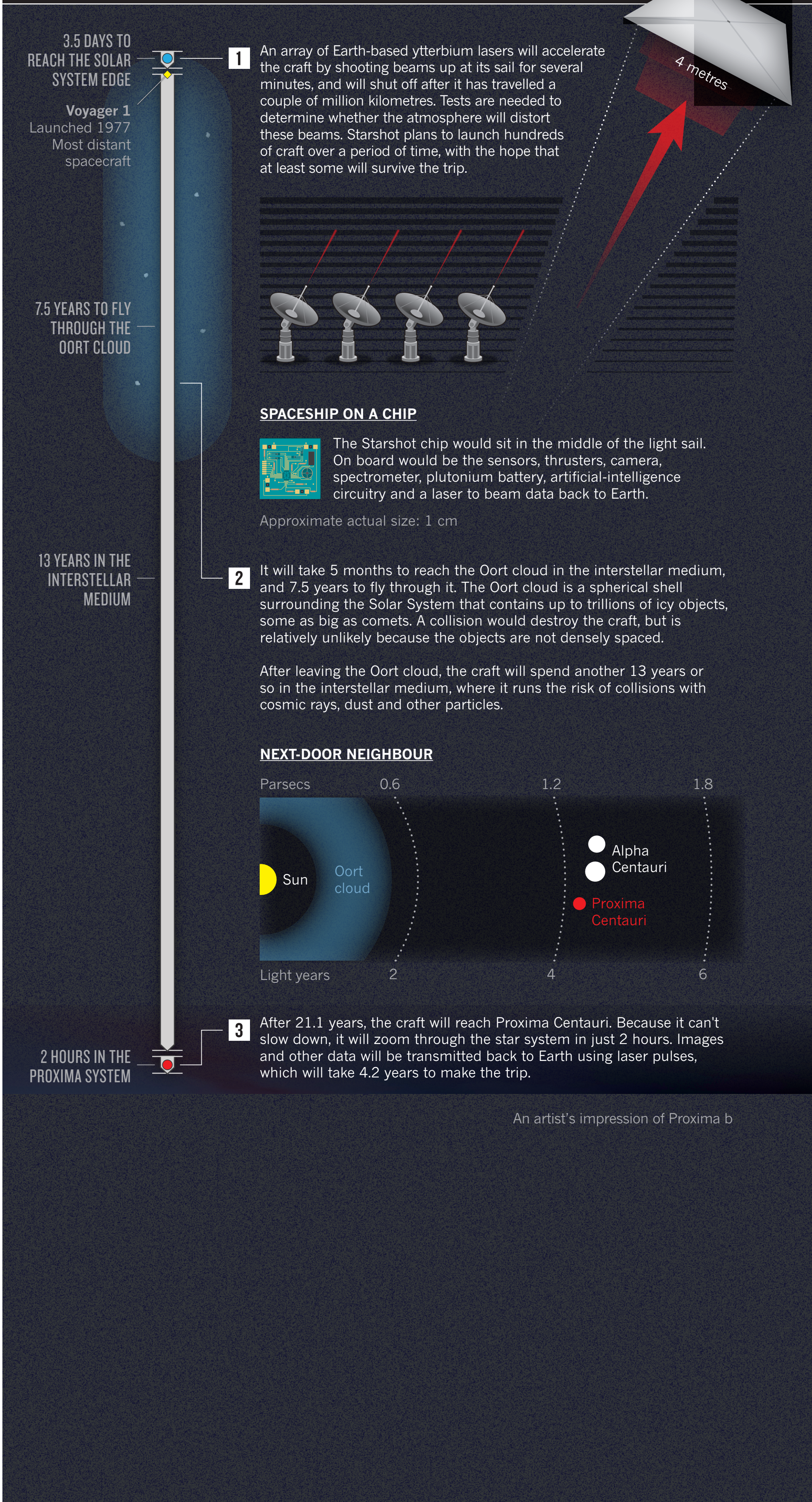
The lasers will shut down after several minutes, once the probe has reached one-fifth of the speed of light and travelled a couple of million kilometres — about five times the distance from Earth to the Moon. The next 20 years will, ideally, be boring.

The biggest risk at this stage is serious damage from collisions with dust specks, hydrogen atoms and other particles in the interstellar medium. Added danger comes in the form of cosmic rays — atomic nuclei that zip through space at close to the speed of light and could degrade crucial electronics. No one knows exactly how many particles fill interstellar space, or how big they are, but Starshot plans to protect its craft from potential collisions by covering the leading edge with at least a millimetre-thick coating of a material such as beryllium copper.

Even if it doesn't destroy the craft, a strike could send the probe hurtling off-course. The probe will therefore need its own navigation and steering systems, powered by a lightweight generator that uses a radioactive isotope such as plutonium-238 — essentially a nuclear battery. These systems will need to include rudimentary artificial intelligence that monitors the position of stars and adjusts course by firing photon thrusters. "The way I put it to

ARE WE THERE YET?

Even at one-fifth of the speed of light, Breakthrough Starshot's spacecraft will take more than 20 years to get to the planet Proxima b — if it can survive dangers along the way.



An artist's impression of Proxima b

ARTIST'S IMPRESSION: ESO/M. KORNMESSER

LUCAS JACKSON/REUTERS

Breakthrough Starshot founder Yuri Milner holds a chip similar to one that could fly to Proxima b.

people is, you really want Neil Armstrong or Chuck Yeager on a chip, to make all of those critical decisions in real time," says Scharf.

Mission designers will not be able to eliminate all risks, especially from as-yet unknown objects in the interstellar medium. That's why they are considering launching exploratory probes as soon as a prototype propulsion system is built. Those early craft could sample the interstellar medium and report back, to fill in gaps in astronomers' understanding of this environment.

THE FLY-BY

Some time around 2060, if all goes as planned, the Starshot craft's onboard computer will wake up, ping Earth for a periodic status check, detect that it is approaching Proxima Centauri and get ready for its fly-by.

The highest priority, experts agree, will be to take a photo. Lubin estimates that the craft should be able to get within one astronomical unit — the distance from Earth to the Sun — of Proxima b. Even from that distance, a photo could reveal whether the planet is watery and green like ours, or barren like Mars. It could also capture large-scale features such as mountains and craters.

An on-board spectrometer could probe the make-up of the planet's atmosphere, if it has one. Researchers will be on the lookout for molecules such as oxygen, methane and more complex hydrocarbons, which are possible signatures of life. Instruments might also attempt to measure the planet's magnetic field or other variables that could reveal whether Proxima b has a life-nurturing environment or a much harsher one.

When the craft gets to Proxima Centauri, there will be no way to slow it down, so it will whip through the star system in about two hours. This will create challenges for the design of its measuring instruments. No photo has ever been taken by a camera moving at one-fifth the speed of light. The craft's cameras will have to swivel to keep the planet in view, and Earth-based computers will have to correct images for distortions caused by the effects of relativity and the camera's changing angle and distance from the planet.

Then will come one of Starshot's toughest challenges, one that leaders admit they have not yet solved: how to transmit data from Proxima back home to eager astronomers using a roughly 1-watt laser beam while still making the signal strong enough to be detectable on Earth after the 4.22-year journey. Lubin envisions building a kilometre-wide array of detectors on Earth, possibly occupying the same area as the acceleration lasers, to capture the craft's faint transmission.

The onboard nuclear battery will power capacitors that will make the beam as bright as possible, similar to a camera flash. And it may be possible to use the sail as an antenna to boost the signal. But the light beam will still be a tenuous wisp amid the vast darkness of space.

An alternative approach could be to launch a succession of craft to serve as relays, so that each chip's signal would only have to travel perhaps one-tenth of a parsec (0.2 light years), instead of the full distance. But such a scheme would create further complications, Lubin and others note.

A NEW CAPABILITY

Experts not involved with the project express a mix of tempered optimism and scepticism. "I think there are tremendous challenges" in scaling up laser power and other needed technologies, says Gregory Quarles, chief scientist at the Optical Society in Washington DC. But he adds that with the right level of private and public funding for research into optics and materials, "there will be returns on that investment".

Some say that Starshot's minimalist approach sets the mission apart from previous, less plausible proposals. "There's nothing I can see that's obviously totally impossible," says Scharf. "They're not talking about a large ship to another star."

Others, however, worry that the multiple technological hurdles may prove overwhelming. "I'm cautious about the near-term future of this," says Betts. "Any one piece seems surmountable, until you realize you have to cram it into a little, tiny, low-mass object."

Even if Starshot gets to Proxima b, Andreas Tziolas, president of the space-exploration organization Icarus Interstellar, thinks it is unlikely to provide useful data. "It has an extremely slim to non-existent chance of succeeding in sending an image back from Alpha Centauri," he says. "You can't have that small a spacecraft carry enough power to transmit back a signal." Although his organization also studies laser propulsion, he is focusing on a nuclear-fusion-powered mission that could send a much larger spacecraft to Alpha Centauri in a century — something he says would be powerful enough to beam back useful data and maybe even transport robotic rovers.

Before any craft gets off the ground, astronomers could learn a lot about Proxima b without sending anything beyond our immediate neighbourhood. The James Webb Space Telescope is scheduled to launch in late 2018, and several giant Earth-based telescopes are likely to come online in the next decade. Using these, astronomers might be able to determine whether the exoplanet's atmosphere contains signatures of life.

But as any explorer would say, there is no substitute for going to a new place. The 2015 fly-by of Pluto, for instance, revealed ice mountains and nitrogen glaciers that Earth's most powerful telescopes were blind to. Similarly, Proxima b — and every other nearby exoplanet — may hold surprises that will be visible only in a close encounter.

There will also be broader pay-offs, say mission proponents. "I see Starshot as about the development of capability," says Kelvin Long, director of the London-based Initiative for Interstellar Studies and a member of the project's advisory committee. "It's like going to the Moon." A laser array with the power to push spacecraft to Proxima Centauri could send probes anywhere in the Solar System in a few days, or to the interstellar medium within a week or two, he says.

That kind of capability could make Solar System exploration routine. "How would you like to deliver next-day Amazon to Mars?" says Lubin. "This is a radical transformation of how we might be able to explore." ■

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