

contrast, the Milky Way's radius is thousands of parsecs. "There's a debate over whether reionization was due to many smaller galaxies or fewer big ones," says Witstok. "This points toward smaller galaxies, which could exist earlier on."

The observation also raises the question of how the galaxy generated such an intense Lyman- α emission in the first place. "It doesn't line up with our standard models of stars," says Witstok. Even without encountering a neutral IGM, he points out, between 90% and 95% of the Lyman- α light was likely absorbed on its trip toward Earth. "So it must have started out incredibly luminous. Something in that galaxy is very powerful—maybe hot massive stars, or maybe a black hole that's accreting."

The earliest stars and galaxies must have been different from the ones that formed more recently because they formed from different material. Stars such as our Sun were forged from the leftovers of previous generations of stars, and they contained a mix of chemical elements from the start. But the universe's first generation of stars, known to astronomers as Population III, formed directly out of the primordial material

that emerged from the Big Bang: mostly hydrogen, a little helium, and a trace of lithium. And their formation process would have been qualitatively different.

Perhaps counterintuitively, the first step toward star formation is cooling: For a mass of material to coalesce to the density needed to trigger nuclear fusion, it needs to shed its excess energy. That happens through collision and radiation: Atoms collide, promote one another into excited states, and relax back to the ground state by hurtling photons out into space. The process is much easier with some heavier elements, such as carbon and oxygen, in the mix because of their rich spectra of low-energy excited states. To radiatively cool a gas of just hydrogen, the collisions would have to pack enough of a punch to excite the Lyman- α transition—a tall order.

Population III star formation has never been observed directly. All that researchers have are computer models of how the process would have played out and what the resulting stars would have looked like. The models suggest that Population III stars would have been much hotter and more massive than the Sun, and they would have shone brightly

at the Lyman- α wavelength. Although the resemblance to the $z = 13$ object is tantalizing, it's far too tenuous a case for the researchers to conclude that that's what they've observed.

Whatever the Lyman- α was inside the $z = 13$ galaxy, it had an influence on the universe far beyond its galactic home: The researchers estimate that the ionized region around the galaxy must have had a radius of at least 200 000 parsecs. The connection across scales—from the hot, dense environment of stars and black holes to the enormous desolation of intergalactic space and ultimately the universe as a whole—is what Witstok finds inspiring about reionization. "It's a very important transition that the universe goes through, and it's controlled by the physics of how stars form inside galaxies," he says. "It's important to understand how these processes connect from one scale to another."

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References

1. J. Witstok et al., *Nature* **639**, 897 (2025).
2. See, for example, B. Robertson et al., *Astrophys. J.* **970**, 31 (2024).

UPDATES

Putting holes in a sail to reach the stars

Sails made of photonic crystal membranes may one day propel spacecraft to Alpha Centauri.

The Planetary Society, a nonprofit space organization, in 2019 launched a solar-sail-powered spacecraft that orbited Earth. Its reflective mylar sail used only the energy of solar photons to push it through space. The society demonstrated that solar-powered light sails can work locally, but more energy is needed for them to quickly travel greater distances. A high-powered laser fired for less than an hour from Earth's surface could provide enough momentum to accelerate a sail to a fifth of light speed and reach Alpha Centauri within 20 years (see figure 1). All that's re-

quired is a sail that is optimized to reflect as much light as possible and is lightweight enough to make use of the resulting energy. A research team working as part of the Breakthrough Starshot initiative has designed a new photonic crystal reflector that the team believes does just that.

Photons reflect off the sail, which is then propelled because of conservation of momentum. But as the sail picks up speed, the laser light becomes Doppler shifted. To reflect for as long as possible—and accelerate as much as possible—before getting out of range of the laser, a sail needs to reflect across a range of wavelengths. When designing the latest sail, Richard Norte (Delft University of Technology in the Netherlands) and his group targeted a range of 1.55–1.86 μm , where atmospheric ab-

sorption is low. That wavelength window provides a wider range than other theoretical designs so as to account for the Doppler-shifted wavelength of the proposed laser. Thus, the sail has lower reflectivity over a wider waveband compared with designs that have high reflectivity within a narrower waveband.

To reach relativistic speeds, the payload and the sail need to have masses of no more than 1 g each. The ultimate goal is a microchip payload carried by a 10 m^2 sail, so the material needs to be lightweight yet strong. Previous lightsail designs have been multilayered to increase the broadband reflectivity at the expense of mass. Norte set his sights on a single-layer silicon nitride photonic crystal with subwavelength holes in the membrane that would determine what wavelengths are re-

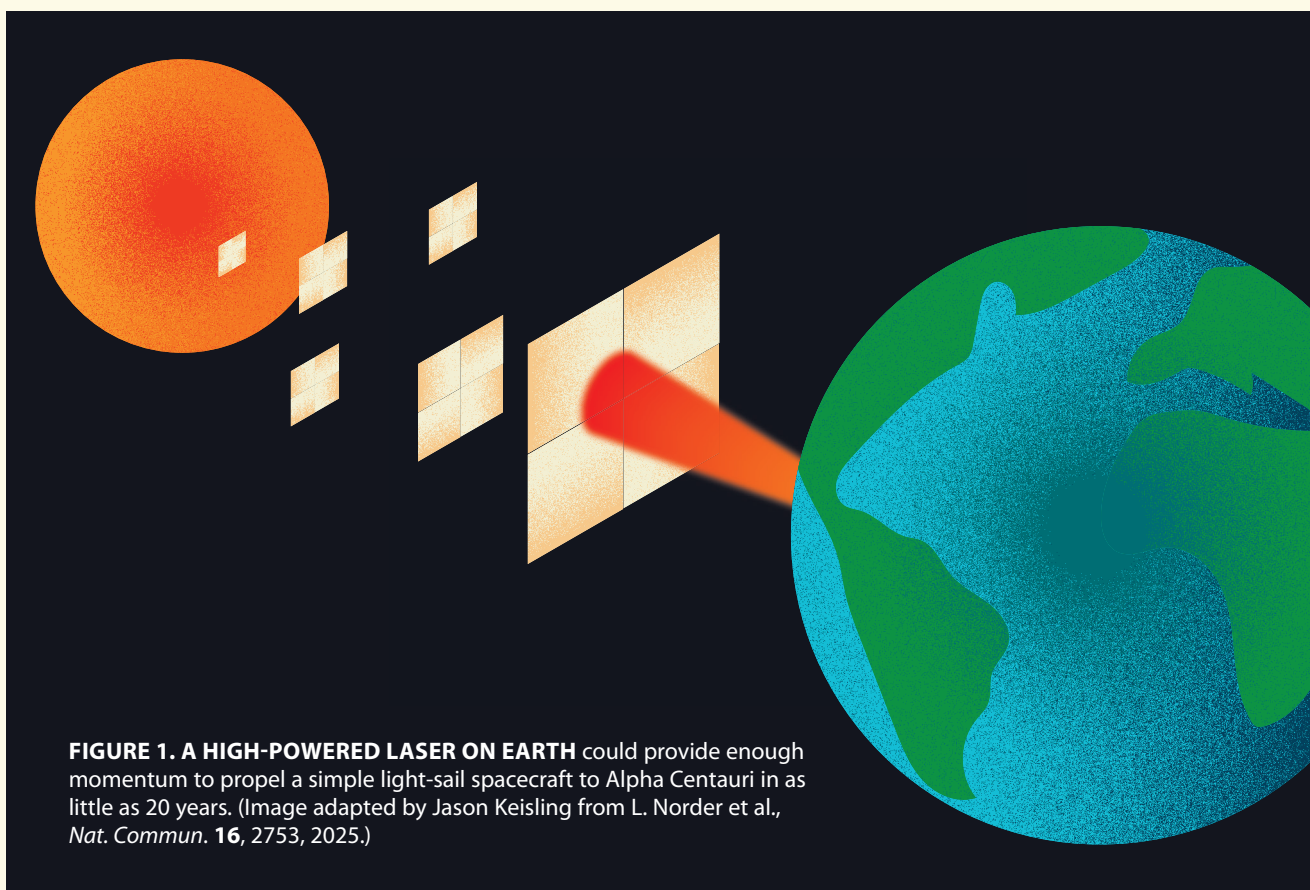


FIGURE 1. A HIGH-POWERED LASER ON EARTH could provide enough momentum to propel a simple light-sail spacecraft to Alpha Centauri in as little as 20 years. (Image adapted by Jason Keisling from L. Norder et al., *Nat. Commun.* **16**, 2753, 2025.)

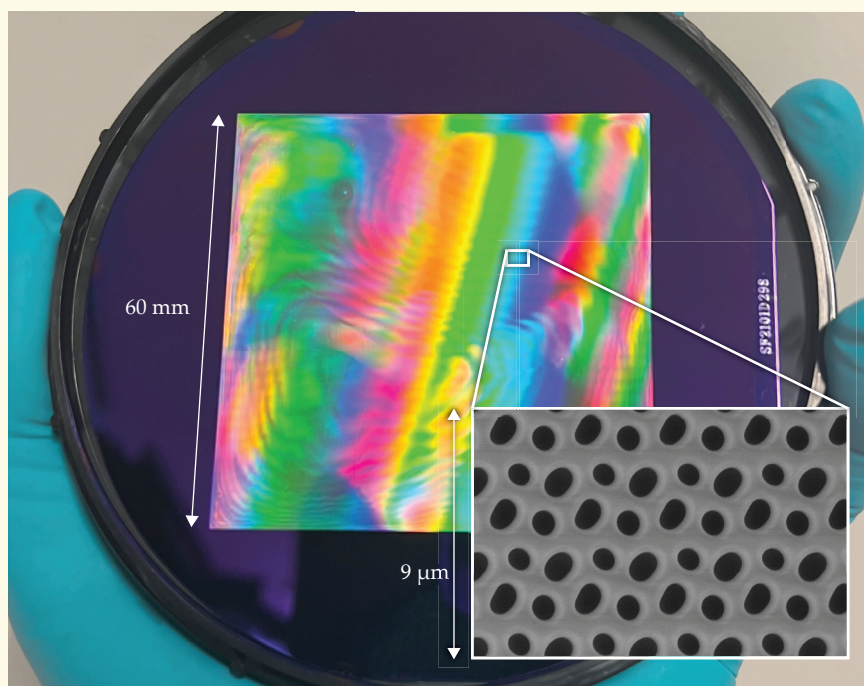


FIGURE 2. THIS 60 × 60 MM SAIL MEMBRANE has a repeating pattern of potato-shaped holes, as seen in the inset, imaged by a scanning electron microscope. Different hole sizes reflect different wavelengths of light, which allow the sail to continue reflecting laser light even when it is Doppler shifted. (Image adapted from L. Norder et al., *Nat. Commun.* **16**, 2753, 2025.)

flected. To design the pattern of holes, Miguel Bessa (Brown University in Rhode Island) used neural topology optimization to balance ideal hole sizes and arrangement for precise reflection against real-world manufacturing constraints. The result was a configuration featuring potato-shaped holes with slightly varied forms and sizes (see the inset in figure 2), each with a different wavelength at which maximum reflectance is achieved.

The pentagonal lattice pattern of holes lends strength to the membrane because its homogeneity creates a stable, crack-free suspension when unfurled. The repetitive pattern mask used to create the holes also reduces the manufacturing time of their 60 × 60 mm sail when compared to hole-by-hole fabrication. Although many technological advances are still needed before the meter-scale sail can be created, the thin sail material is projected to require a drastically reduced manufacturing time and be a promising final design for future light sails. (L. Norder et al., *Nat. Commun.* **16**, 2753, 2025.)

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