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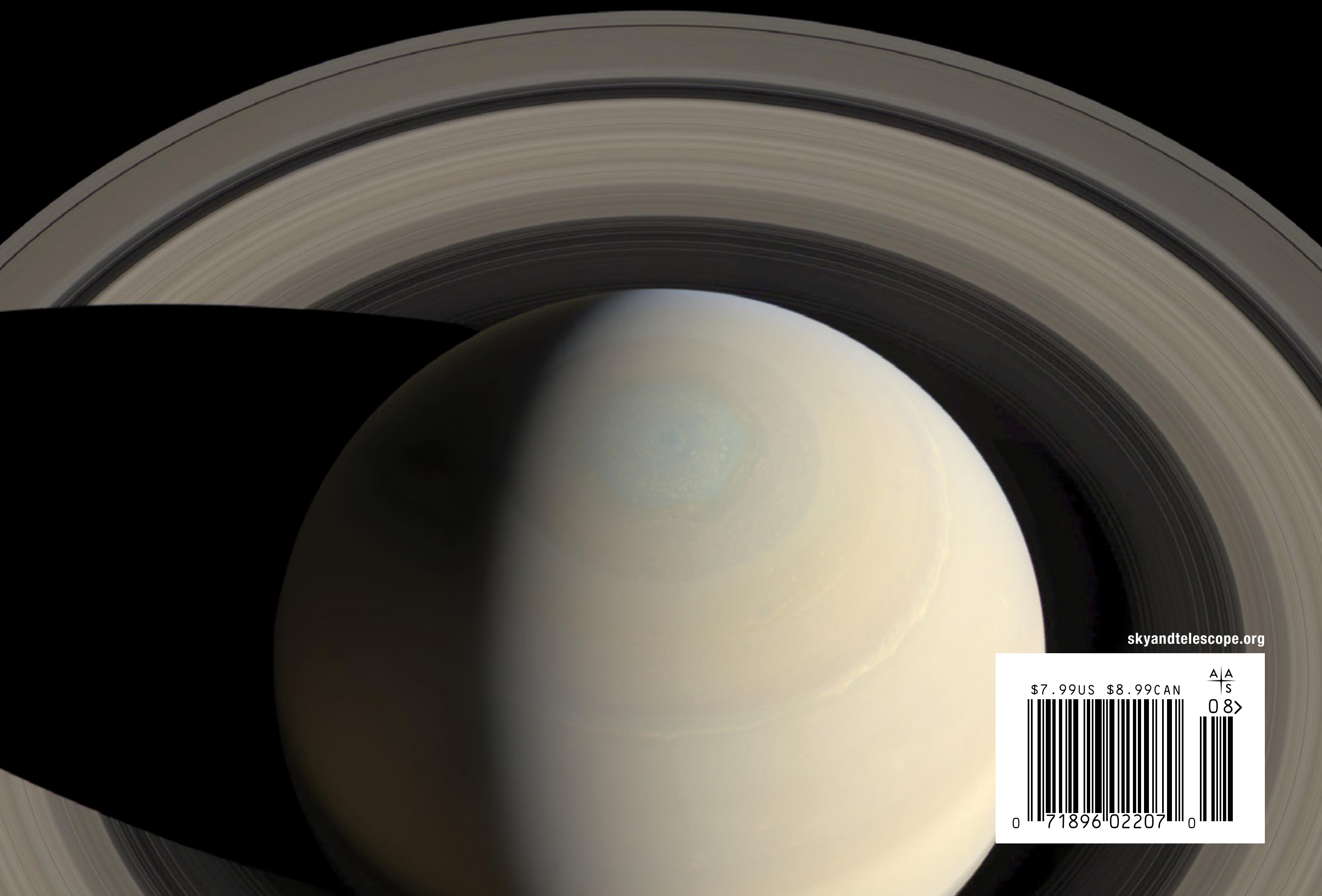

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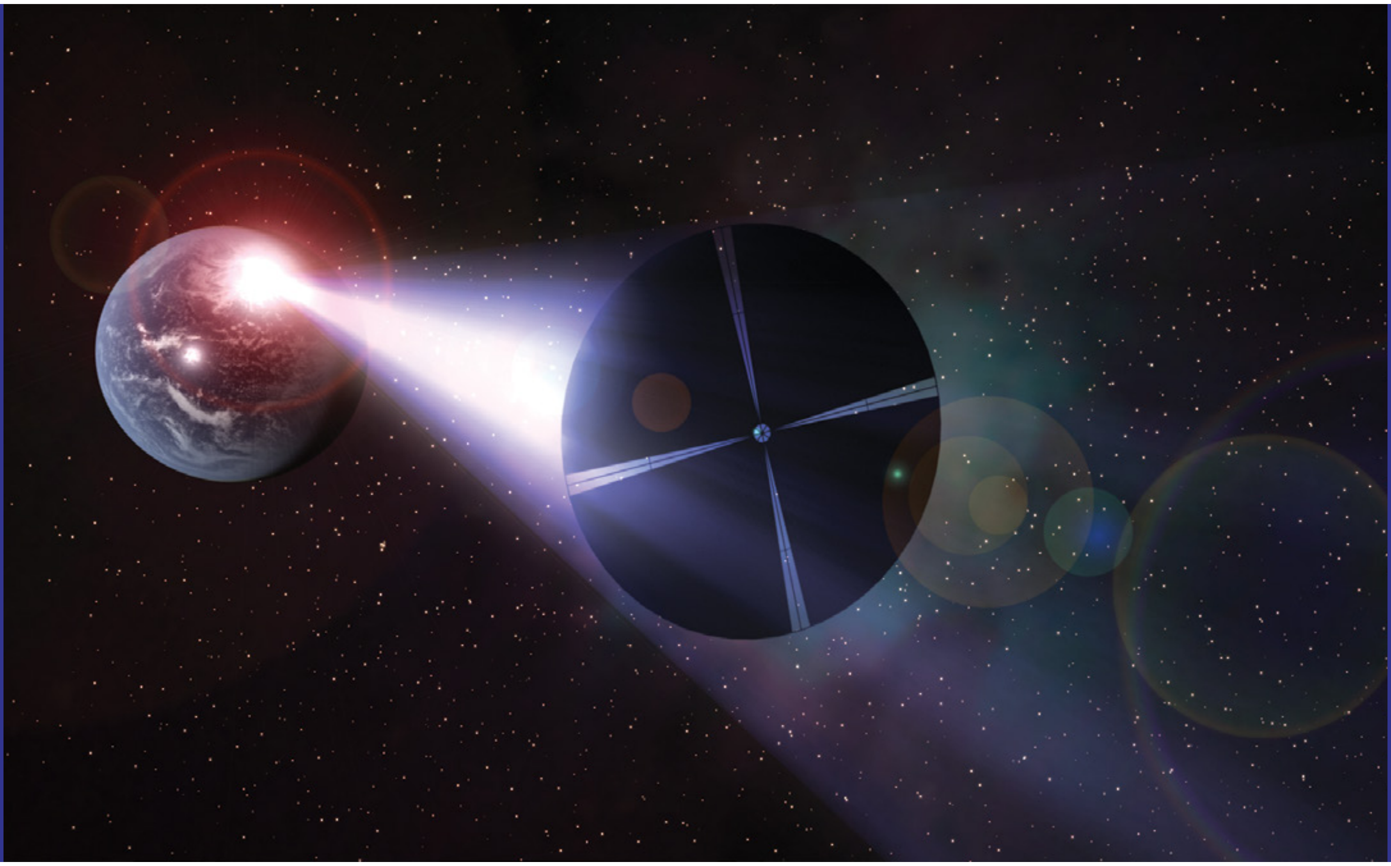


SETI'S BIG BOOST

New instruments and data-analysis tools are opening more sky to the search for extraterrestrial intelligence.

The Kepler Space Telescope's haul of more than 100 potentially habitable planets has revolutionized our search for life in the universe. In the next decade, astronomers will pursue a step-by-step program to find and explore Earth-like exoplanets, which apparently not only exist but are plentiful. "The next thing we don't know is how many planets are able to support life," says Ian Crossfield (University of Kansas), a member of the decadal survey's panel on exoplanets, astrobiology, and the solar system.

One goal is to look for *biosignatures*, chemical fingerprints in a planet's atmosphere that indicate lifeforms (*S&T:* May 2021, p. 34). But beyond that, astronomers are also looking for *technosignatures*, signs of sophisticated technology that advanced civilizations might use, which we could detect light-years away. In other words: E.T.

The search for extraterrestrial intelligence, or SETI, began by seeking deliberate communications from other civilizations. Now, researchers are expanding their quest to include signals that intelligent life might send unintentionally, from sudden bursts of light from spacecraft-propelling lasers to anomalous spectra that might reveal a shell built around a star to capture its energy.

"The search for technosignatures — signs of advanced life — is very much complementary to the search for biosignatures of the basic forms of life," says Andrew Siemion

▲ **LASER LIGHT SAIL** One day, laser banks on Earth might power mini-spacecraft on a journey to Alpha Centauri, as imagined here in an artist's concept. Perhaps also one day, humans might detect errant light from an alien civilization using the same technology.

(University of California, Berkeley), director of the Berkeley SETI Research Center. Simple life appeared within Earth's first billion years, but uncovering definitive evidence of life from that time period has been difficult, even though we live here. Finding biosignatures on distant exoplanets will be even harder, he says.

We already know of one potentially habitable planet within 10 light-years and several more within 20. Even with the coming generation of 30-meter telescopes on the ground and 6-meter ones in space, we only expect to find a couple dozen potentially habitable planets close enough to detect biosignatures. In contrast, we could see a laser beam shot directly at us from a distance of up to thousands of light-years, and we might be able to register a powerful radar beam aimed at Earth from across the galaxy.

Thanks to recent exoplanet discoveries as well as fresh sources of funding, astronomers are doubling down on SETI. Thirteen white papers submitted to the astronomy decadal survey featured SETI work, says Siemion, a sharp rise from just two a decade ago. There are a growing number who wonder if gathering vast amounts of data from the galaxy could yield an unexpected signal so unnatural that only intelligent beings could have produced it.

A Long-term Quest

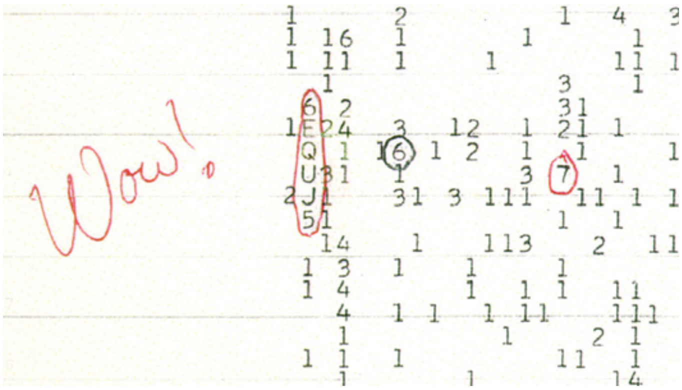
The term technosignature is new, but the basic idea remains what it has been for decades: a signal that, to our knowledge, nature cannot generate. Generally, such signals are either narrow in frequency or short in time. A laser beam, for example, would create a single-color signal spanning an unnaturally narrow range of wavelengths. A bright signal that lasts for only a nanosecond would also arouse suspicion. The shortest natural pulses we know come from pulsars and last 100,000 times longer: An outburst lasts at least as long as it takes light to travel across the source, which is 0.1 millisecond for a 30-kilometer object. Light can travel only 30 centimeters in a nanosecond, and no natural object that small could produce enough energy to be seen light-years away. Such a short signal might come from intelligent life.

Frank Drake began the first SETI experiment in the spring of 1960, when he turned the new 85-foot radio telescope at the National Radio Astronomy Observatory's site in West Virginia toward two nearby, Sun-like stars. Since then, SETI researchers have picked up some promising signals but no convincing evidence of extraterrestrials. Perhaps the most famous is the "Wow!" signal, a bright, narrowband radio burst that lasted 72 seconds, recorded in 1977 by the Big Ear radio telescope at Ohio State University. Its origin remains a mystery, and it has never repeated (*S&T:* May 2021, p. 84).

Over the years, the SETI quest has expanded to explore two regions of the electromagnetic spectrum in which cosmic noise is low and atmospheric transmission is high: radio frequencies from 1 to 10 gigahertz and visible/near-infrared wavelengths from 400 to 2300 nanometers. The biggest changes over the past decade have been in funding and

▼ **POTENTIALLY HABITABLE** An artist imagines the appearance of known Earth-size planets in their star's *habitable zone*, where water could conceivably remain liquid on a rocky surface. For comparison, on this scale Proxima Cen b is about the size of Earth. The planets are ordered by their distance from Earth, given in light-years (ly).

POTENTIALLY HABITABLE PLANETS: PLANETARY HABITABILITY LABORATORY / UNIVERSITY OF PUERTO RICO, ARECIBO; WATER TEXTURE: POLYGRAPHUS / SHUTTERSTOCK.COM



▲ **“WOW!”** The Big Ear Radio Observatory recorded incoming signals’ brightness first using numbers and then, if the signal was bright enough, in letters. The letter “U” indicates a signal 30 times the background noise level; the signal as a whole lasted 72 seconds.

equipment, says Seth Shostak (SETI Institute). Shostak wrote this magazine’s last report on SETI (*S&T:* Nov. 2010, p. 22). Back then, the premier SETI instrument was the Allen Telescope Array (ATA), a collection of 42 six-meter radio antennas that covers several square degrees of sky. Within that large field of view, back-end processing enabled SETI researchers to focus on one or two nearby star systems per pointing.

Built with more than $30 million from Microsoft cofounder Paul Allen in Hat Creek, California, and owned by the SETI Institute, the ATA was the world’s first instrument dedicated to SETI when it began operation in 2007.

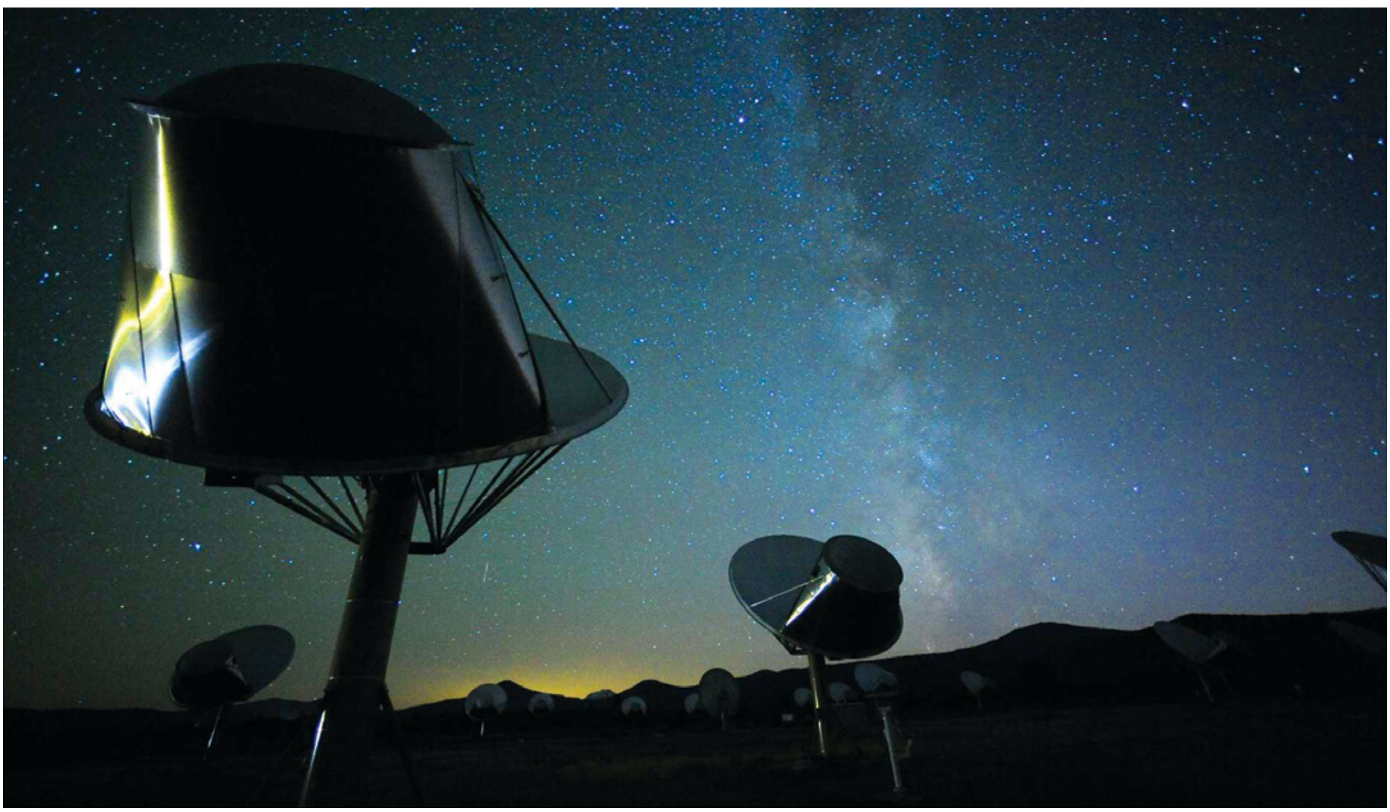
Meanwhile, the Kepler mission launched in 2009. While astronomers had already discovered 417 exoplanets, SETI astronomers were eagerly awaiting Kepler’s haul — particularly the Earth-size worlds around Sun-like stars that the mission aimed to find.

However, funding issues plagued the array. Resources weren’t available to realize the initial plans, which had called for a total of 350 dishes. Then the array shut down for several months in 2011, before the Berkeley Radio Astronomy Laboratory turned operations over to the nonprofit research institute SRI International. SRI used about a third of the array’s time for projects such as tracking space junk, with the rest of the time available for the SETI Institute.

In 2020, the SETI Institute took over management from SRI, having already begun a major upgrade funded by Franklin Antonio, cofounder of Qualcomm. The improvements, to be completed this year, will enable the ATA to point at 16 star systems at any given time, speeding searches at frequencies from 1–15 gigahertz by a factor of 35. Upgrades will also improve the array’s reliability and usefulness in collaborative searches. “It doesn’t guarantee we’re going to find E.T.,” Shostak cautions, “but it will both speed up and increase the sensitivity of the search.”

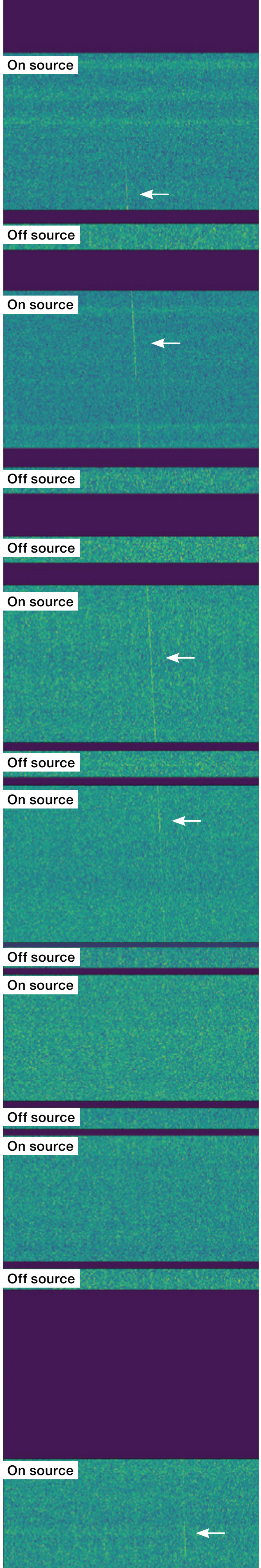
A Monetary Breakthrough

ATA is far from the only SETI enterprise, though, thanks to a recent increase in funding. In the early 2010s, Shostak received an email from Russian-Israeli billionaire Yuri Milner,



▲ **DEDICATED DISHES** The Allen Telescope Array surveys the sky above Hat Creek, California, for alien intelligence.

“WOW” SIGNAL: BIG EAR RADIO OBSERVATORY / NORTH AMERICAN ASTROPHYSICAL OBSERVATORY; ALLEN TELESCOPE ARRAY: SETI INSTITUTE



◀ **CANDIDATE 1** This plot shows what Breakthrough Listen found when pointed at Proxima Centauri ("on source"), a faint signal around 982 MHz that drifted in frequency (*x*-axis) over time (*y*-axis). The resulting faint yellow diagonal line is not visible in off-source pointings. Dark purple panels indicate time periods with no data, primarily telescope slews.

S. Z. SHEIKH ET AL. / *NATURE ASTRONOMY* 2021

a physicist by training who had turned his attention to business. Milner was initially interested in setting up a prize related to SETI research, but Kepler's trove of potentially habitable planets motivated him to instead launch the Breakthrough Initiatives, a set of programs to study the fundamental questions of life in the universe: "Are we alone? Are there habitable worlds in our galactic neighborhood? Can we make the great leap to the stars? And can we think and act together — as one world in the cosmos?"

The biggest of these efforts is Breakthrough Listen, which Milner and Stephen Hawking launched in 2015. It's providing $10 million annually for 10 years for radio and visible-light surveys of the 1 million closest stars, the galactic plane, and the 100 nearest galaxies. That big boost in funding is being spread around. Some goes to new equipment for the SETI Institute, and some goes to the Berkeley SETI Research Center headed by Siemion. Other money goes to acquire time for SETI research on major radio telescopes: the 100-meter Robert C. Byrd Green Bank Telescope in West Virginia, the 64-meter Parkes telescope in Australia, and the MeerKAT array in South Africa, as well as visible-light searches on the 2.4-meter Automated Planet Finder at Lick Observatory. All Breakthrough Listen data are stored in a public archive.

Parkes found the most interesting signal so far, dubbed Breakthrough Listen Candidate 1, a narrowband radio signal that appeared to emanate from Proxima Centauri over a period of five hours. It had "all the hallmarks of a technosignature," says Siemion. However, an exhaustive analysis published in November in *Nature Astronomy* found the cause was what he calls "pathological radio-frequency interference," the combination of multiple human-generated signals from near or inside the observatory.

Techno Leaks

A surge in backing has enabled SETI to expand its focus from detecting purposeful communications from advanced civilizations to unintentional technosignatures.

For example, physicists have envisioned that advanced civilizations might build vast megastructures around star systems. In 1960 at the Institute for Advanced Study in Princeton, Freeman Dyson suggested that aliens might surround their star with a shell to capture most of its energy. The star itself would thus be dark, only visible from the outside by the shell's heat emission.

Other evidence might arrive on our interplanetary doorstep. Some have suggested that the thin interstellar object 1I/'Oumuamua might be a derelict alien spaceship, much as Arthur C. Clarke described in his 1973 novel *Rendezvous with Rama*. That idea was part of the impetus behind the Galileo Project, an endeavor led by Abraham Loeb (Harvard) to build a dedicated array of instruments to search the skies not for electromagnetic signals from far-off systems, but for physical objects that might have originated in such systems and made their way here.

Advanced civilizations using laser propulsion on scales vaster than anything yet demonstrated by humans could lead to another class of technosignatures. "If you want to travel around the galaxy at a significant fraction of the speed of light, you have to use antimatter or a laser-powered light sail," says Eliot Gillum (SETI Institute).

Even humans are trying out the latter: The $100 million Breakthrough Starshot project plans to use high-power lasers to accelerate a fleet of stamp-size probes flying meter-scale light sails to the Alpha Centauri system. The trajectory would include a flyby of the potentially habitable planet Proxima Centauri b (*S&T:* Dec. 2016, p. 10).

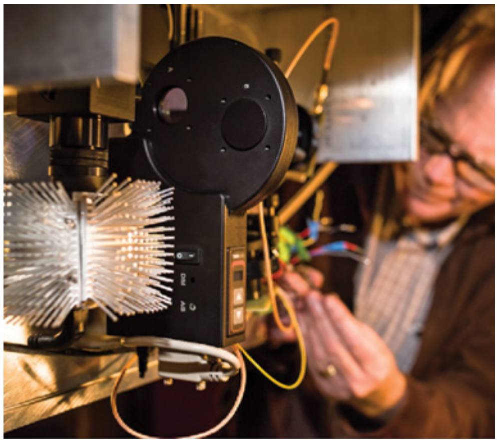
Physicist James Benford (Microwave Sciences) suggested that astronomers could recognize glints of laser light reflected from or escaping around the edges of far-away light sails as coherent light. This idea also has a science-fiction connection: One of Benford's collaborators is his identical twin brother, Gregory, a well-known science fiction writer as well as retired professor of astrophysics from the University of California, Irvine.

LaserSETI

Detecting laser light, whether stray or intentional, will require searching vast swaths of both sky and time. While searches for visible flashes from other civilizations go back decades, those largely relied on focusing light onto a photomultiplier tube — the equivalent of a single-pixel camera. Last year, Gillum instead began installing a low-cost camera-based system named LaserSETI for what he calls the first "all-sky-all-the-time" search. He designed the instruments to seek short pulses of coherent light like those that James Benford envisioned. With it, he could capture the light from a propulsion beam as it sweeps across the sky, as both the beam and Earth move.

To detect such technosignatures, Gillum points two pairs of wide-angle cameras at the same area of sky from widely separated spots. Each camera has a 75° field of view — nearly twice the height of Ursa Major — and is set at right angles to its partner. The initial observations have had one pair looking west from California and the other looking east from Hawai'i. The system, which uses transmission gratings to obtain spectra, looks for sources displaying only a narrow range of wavelengths, as you'd expect from a laser. A burst of laser-like light would leave a telltale signal in the data collected by the camera pair.

"Breakthrough Starshot is our ideal scenario," Gillum says, adding that a civilization using laser-powered satellites could be visible from far away. "Those lasers are extremely bright,



◀ **NIROSETI** The near-infrared/optical instrument mounted on the Nickel 1-meter telescope at Lick Observatory didn't find nanosecond-long pulses expected from far-off lasers, but its field of view was small.

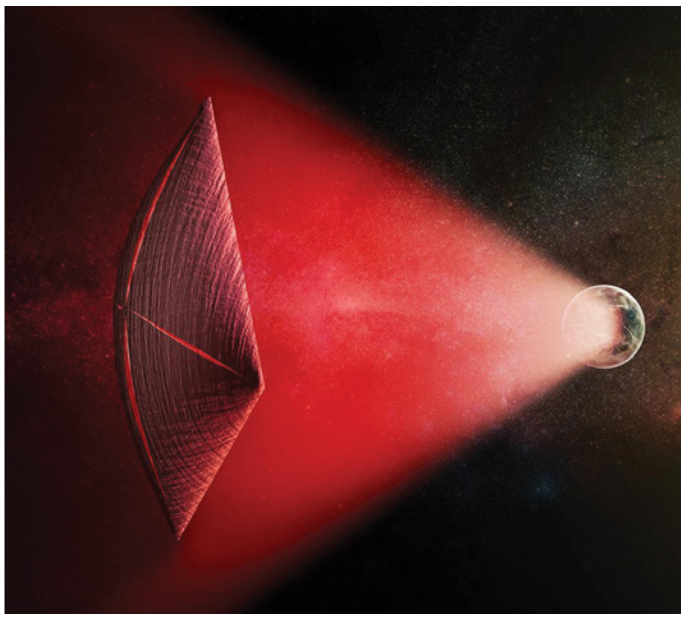
and [detection] does not require anyone trying to communicate."

With two pairs of cameras monitoring the same region of sky simultaneously, combining data from the two can filter out errant detections. Observing from two locations also provides the source's parallax; Gillum says astronomers should be able to measure distances up to 25 times the distance of the Moon, so the system will not mistake a terrestrial spacecraft for E.T. In the long term, Gillum hopes to monitor the sky from about 70 sites.

Expanding the View

Another new thrust in search efforts is the doubling of the spectral range under study. SETI has long relied on silicon CCD detectors, which can record infrared light out to about 1,000 nanometers. Longer infrared wavelengths pass more successfully through interstellar dust than shorter wavelengths do; however, detecting them requires camera chips made from more exotic semiconductors, which have historically been beyond limited SETI budgets. More recently, though, mass production of indium-gallium-arsenide

▲ **MEGASTRUCTURE** The late futurist Freeman Dyson imagined that alien civilizations might need to utilize more energy from their host stars than we do. Such energy usage could ultimately come in the form of a "Dyson sphere," shown here in an artist's concept. Such a structure would block some or all of the visible light from the central star, but it would heat up and re-radiate that energy at infrared wavelengths.



▲ **STARSHOT** Lasers on Earth shining on light sails could power small spacecraft on interstellar journeys, as imagined here for the project Breakthrough Starshot. Alien civilizations might have thought of similar technology, from which we could detect laser "leaks." It's even possible that extraterrestrials might power such laser beacons as a means to communicate intentionally.

(InGaAs) detectors — sensitive at 900 to 1700 nanometers — has made them affordable.

Shelley Wright (University of California, San Diego) and others used InGaAs sensors to construct the Near-Infrared and Optical (NIRO) SETI instrument, now on the 1-meter Anna L. Nickel Telescope at Lick Observatory. Wright's team designed the system to spot nanosecond-long flashes, 100 million times shorter than the time it takes to blink an eye. So far, they haven't found any repeating pulses from 1,280 objects, each observed for at least 300 seconds.

Because the small field of view reduces the odds of looking at the right place at the right time, Wright is now working on a more ambitious project: Panoramic SETI. Called PanoSETI for short, the project will ultimately comprise a pair of observatories, each filled with half-meter telescopes searching the whole sky for flashes less than a second long.

To test the concept, the team installed two prototype telescopes at Lick, in the dome that houses the historic Carnegie Double Astrograph, and tested another two at a temporary site near Palomar Observatory. Installation at Lick finished in February 2020, but COVID-19 stalled first light; the group began testing in March 2021. Wright and her colleagues are now seeking additional funding and testing observing conditions at their preferred site on Palomar Mountain in southern California, the site of the 200-inch Hale Telescope.

In the full-scale installation at Palomar, the two domes, separated by 1 kilometer, would both contain 45 identical telescopes, each fixed in place with a 10° × 10° field of view. As Earth turns, the telescopes will scan 10,000 square degrees — the whole observable sky. The separation between the two domes will help rule out false alarms.

Piggybacking

Besides building its own equipment, the SETI Institute has long borrowed time on other instruments. "Sometimes we add new instruments, sometimes new sensors, sometimes a new detector, and sometimes new algorithms," says Siemion. With radio telescopes, he adds, "the main thing we need to do is to bring large computers to [analyze] the data to look for narrowband radio signals."

Two technological revolutions occurring in parallel are proving to be boons for SETI: the development of powerful radio arrays able to collect vast amounts of data, and the development of powerful computers able to process that data. The gigabytes and even terabytes collected daily by big arrays — including Australia's Murchison Widefield Array, the 27-dish Very Large Array (VLA) in the U.S., and MeerKAT, a 64-antenna South African precursor to the Square Kilometer Array — would have overwhelmed earlier generations of computers. But newer processors are capable of not only handling the data but piggybacking on other astronomical research to create additional search opportunities. After all, processing power comes cheaper than brand-new telescopes.

For example, a project called the Commensal Open-Source Multimode Interferometer Cluster (COSMIC) SETI aims to copy over signals gathered by the VLA for conventional radio astronomers. A splitter takes the feed from each radio dish and digitally copies the signals that astronomers are recording for other purposes. The data then go to SETI's processors, which can use them to examine other parts of the sky. "Even though the principal VLA observer might be studying galaxies or galactic nebulae," Shostak says, "the SETI scientists can be studying several nearby star systems as if they had a couple of large, single-dish antennas at their disposal."

Looking Forward

The odds against finding alien intelligence may be long, but that doesn't phase Shostak, Siemion, Wright, and others involved in SETI projects. They have an enormous universe to

Coming Up Empty

Ultimately, what SETI seeks is signals. So, what happens if we don't find any? Do we give up? Stop funding SETI?

Similar questions have arisen around other topics, such as dark matter. Ample indirect evidence suggests dark matter's presence in galaxies and clusters, yet the lack of direct detections troubles many. Nevertheless, progress continues as scientists conduct increasingly sensitive searches — and in that respect, SETI is no different.

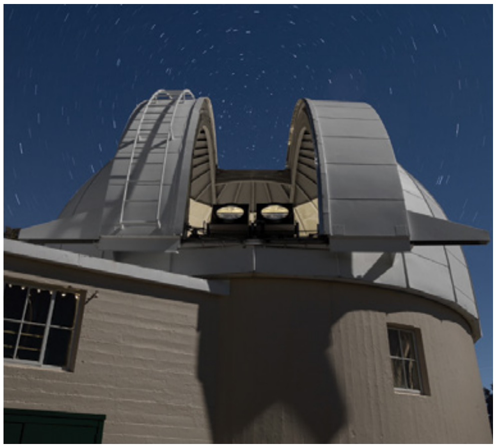
In fact, the lack of a signal can be informative in and of itself, ruling out certain stellar systems or types of technosignatures. As just one example, the Breakthrough Listen team has searched 1,327 nearby stars for the type of radio signals our own civilization can make — and found nothing. The survey eliminates the possibility of both an Earth-directed radio beacon as well as radio noise from a human-equivalent civilization. The upper limit that Danny Price (University of California, Berkeley) and colleagues derived from this non-detection? Less than 0.1% of the stellar systems within 160 light-years possess such transmitters.

Such experiments will guide future searches by setting ever more meaningful upper limits to what's out there. And maybe someday, they'll narrow the search enough to help snag a signal from E.T.

— MONICA YOUNG

search and a wealth of technology to bring to bear.

Breakthrough Listen plans to examine 1 million star systems in the next decade, up from the few thousand it has already covered. The SETI Institute aims to study red dwarf systems and other promising targets with the upgraded Allen Telescope Array. And LaserSETI, PanoSETI, and other programs will scan the whole night sky at visible and near-infrared wavelengths, looking for monochromatic sources.



◀ **PANOSETI PROTOTYPES** These two telescopes, in the same dome that houses the historic Carnegie Double Astrograph, served as a testbed for PanoSETI technology. Ultimately, plans call for 90 telescopes, housed in two domes separated by 1 km.

Complementary searches for technosignatures in astronomical data will occur via piggybacking programs such as COSMIC SETI. As of early April, the COSMIC team has installed amplifiers and splitters on all 27 VLA antennas, giving SETI scientists a full copy of the data streams. Siemion expects the most exciting results from these information troves as they're fed into powerful computers for analysis. By 2023, radio searches "will transition from a relatively small boutique endeavor to an integral part of the quest to understand the nature and distribution of life in the universe," says Siemion. "This isn't a hope — it is a fact.

"In my wildest dreams, we would detect convincing evidence of the existence of extraterrestrial intelligence," he adds. Less speculatively, though, he expects "clear and definitive constraints" on the distribution of technologically capable life in our part of the galaxy.

"In the next decade," he says, "I predict that we will, for the first time, have a robust ability to detect a modern-era, human-like technosphere, if it exists, among a handful of nearby extrasolar planets."

Shostak, for his part, thinks that by 2030 astronomers will either have found an intelligent signal or have discovered an unambiguous alien artifact, such as a Dyson sphere. But his wildest hopes are even grander than that: "We will have found more than one!"

He may seem overly optimistic, but then again, who a few decades ago would have expected to find the universe so full of planets?

■ **JEFF HECHT** writes about science and technology from the Boston suburbs. He has enjoyed reading *Sky & Telescope* since his teens, when he thought he would have needed a spaceship to see exoplanets.

▲ **SPLITTING THE FEED** The Very Large Array is a collection of 27 radio antennas in Socorro, New Mexico. Each antenna in the array measures 25 meters (82 feet) in diameter and weighs about 230 tons. In the COSMIC SETI initiative, feed splitters will copy the data that the VLA collects, enabling special correlators to analyze astronomical data for extraterrestrial intelligence.

PANOSETI: © LAURIE HATCH; VERY LARGE ARRAY: NRAO / AUI / NSF