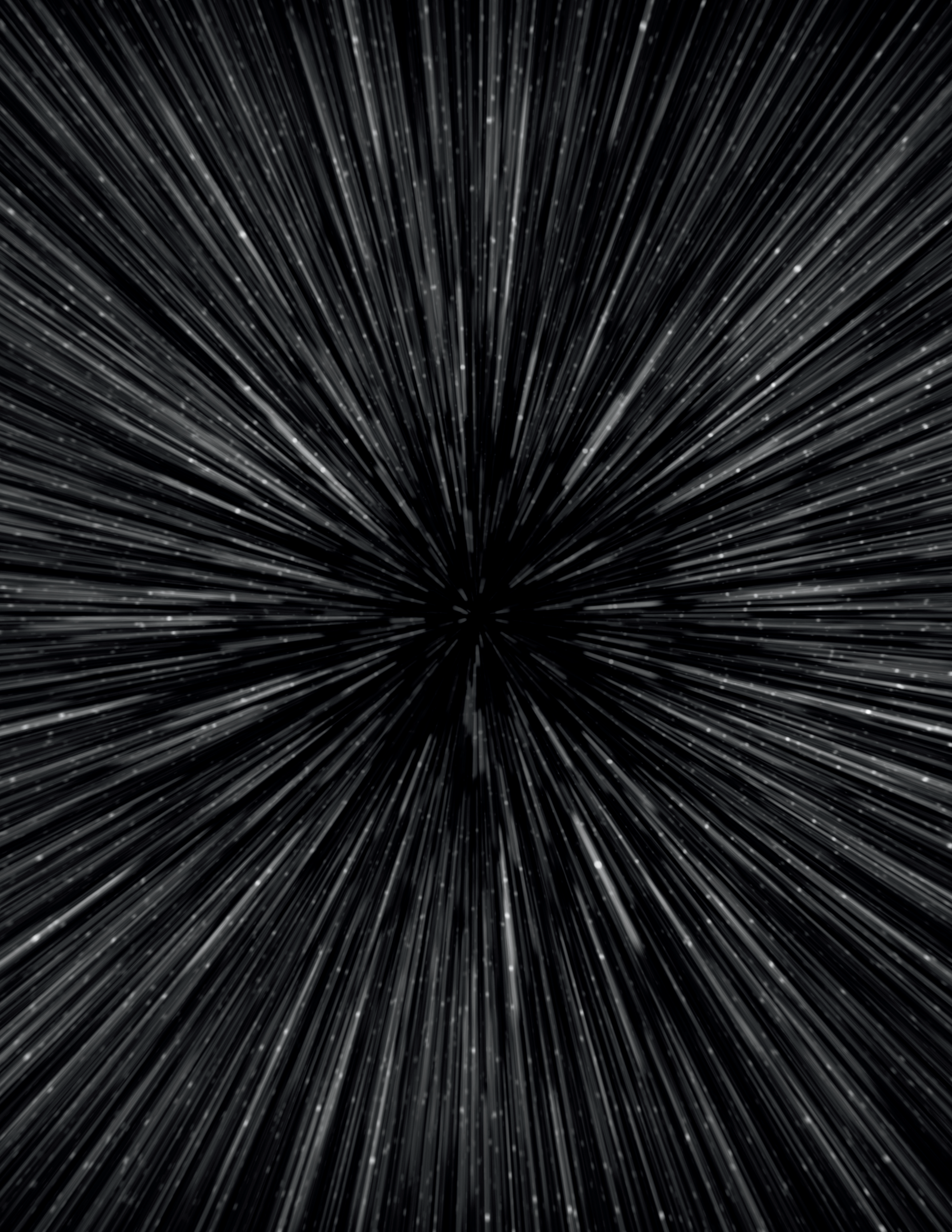
Next-Gen SETI:
Pioneering the Search for ET

SETI INSTITUTE



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Pioneering the Search for ET

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Cover image credit: Simon Steel/SETI Institute.

1

RADIO SETI

The Very Large Array (VLA) is a collection of 27 radio antennas located at the NRAO site in Socorro, New Mexico.

THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

SETI, or the search for extraterrestrial intelligence, is a relatively new scientific field that began six decades ago. Humans have long believed that biology exists beyond Earth, and many think that it's only a matter of time before we discover life elsewhere.

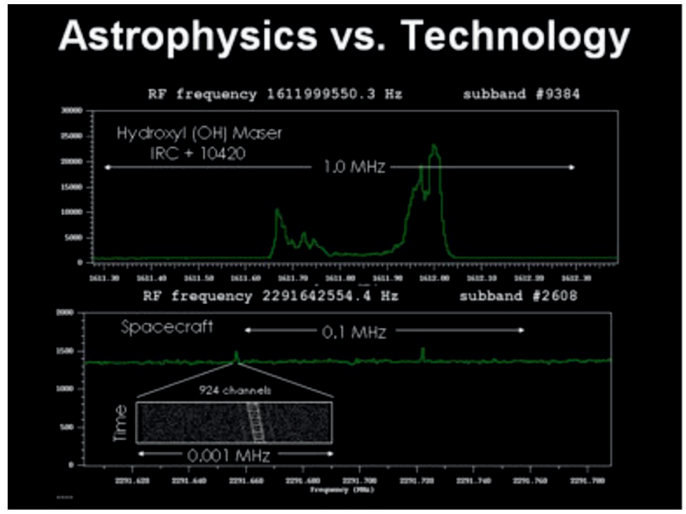
NOT YOUR GRANDFATHER'S RADIO ASTRONOMY

Frank Drake is considered the father of SETI because he undertook the first modern search for intelligent life elsewhere in the cosmos. In 1960, Drake conducted his pioneering SETI experiment at the Green Bank Observatory in West Virginia. He searched for radio signals from other worlds, choosing radio because it can easily penetrate the gas and dust hanging between the stars. It is an obvious technology for interstellar messaging.

VLA image credit: Alex Savello/NRAO.
Frank Drake image credit: NRAO.

While all astronomical objects emit some radio, emissions from transmitters generally produce signals having narrow bandwidths, a characteristic unlike that of most naturally occurring radio emitters.

A search for radio signals is still the primary method used to hunt for intelligence beyond Earth.



ALLEN TELESCOPE ARRAY

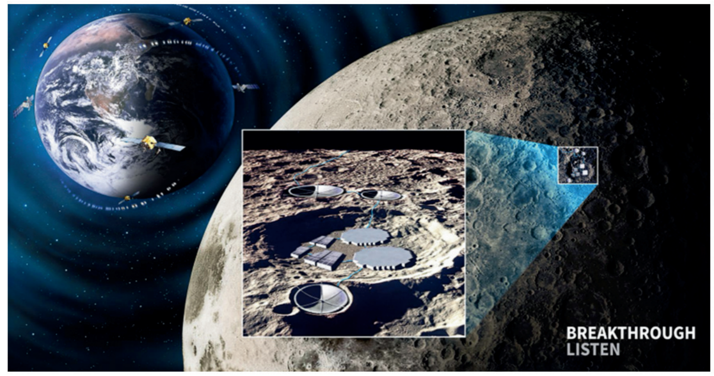
The Allen Telescope Array (ATA), located in northern California, is the only radio telescope built from the ground up to conduct the search for technologically advanced extraterrestrial life. Recent upgrades to the system, as of mid 2024, allow for the digitization and processing of input from 28 antennas, operating at a data rate of 150 GB per second. This is equivalent to the information content of 50 HD movies.

The SETI programs at the ATA use a variety of schemes, one optimizes a search for narrowband signals from nearby star systems by observing exoplanetary systems when their planets align with Earth. Another looks for periodic signals that are unlikely to be naturally produced.

ATA / Hat Creek Radio Observatory images credit: Simon Steel/SETI Institute.

The science portfolio of the ATA comprises more than SETI. It includes studying the afterglow of supernova explosions, which mark the end of a massive star's life. Additionally, the ATA investigates enigmatic Fast Radio Bursts—millisecond-long bursts of radio emission from deep in the cosmos. The ATA is also used to study other phenomena, such as supermassive black holes and pulsating neutron stars, known as pulsars.

BREAKTHROUGH LISTEN



The Breakthrough Listen project is one of the most comprehensive surveys for technosignatures ever undertaken. Using nearly two dozen radio telescopes worldwide, this project searches a vast swath of the electromagnetic spectrum.

With the recent inauguration of its headquarters at the University of Oxford, Breakthrough Listen is expanding its technosignature searches internationally. It has established an academic platform to encourage participation in this effort. Additionally, the initiative has set an ambitious goal of conducting a feasibility study for a radio antenna on the far side of the moon.

In an exciting move, the Breakthrough Listen team also works with the Transiting Exoplanet Survey Satellite (TESS) team to examine stellar systems that include potentially habitable exoplanets.

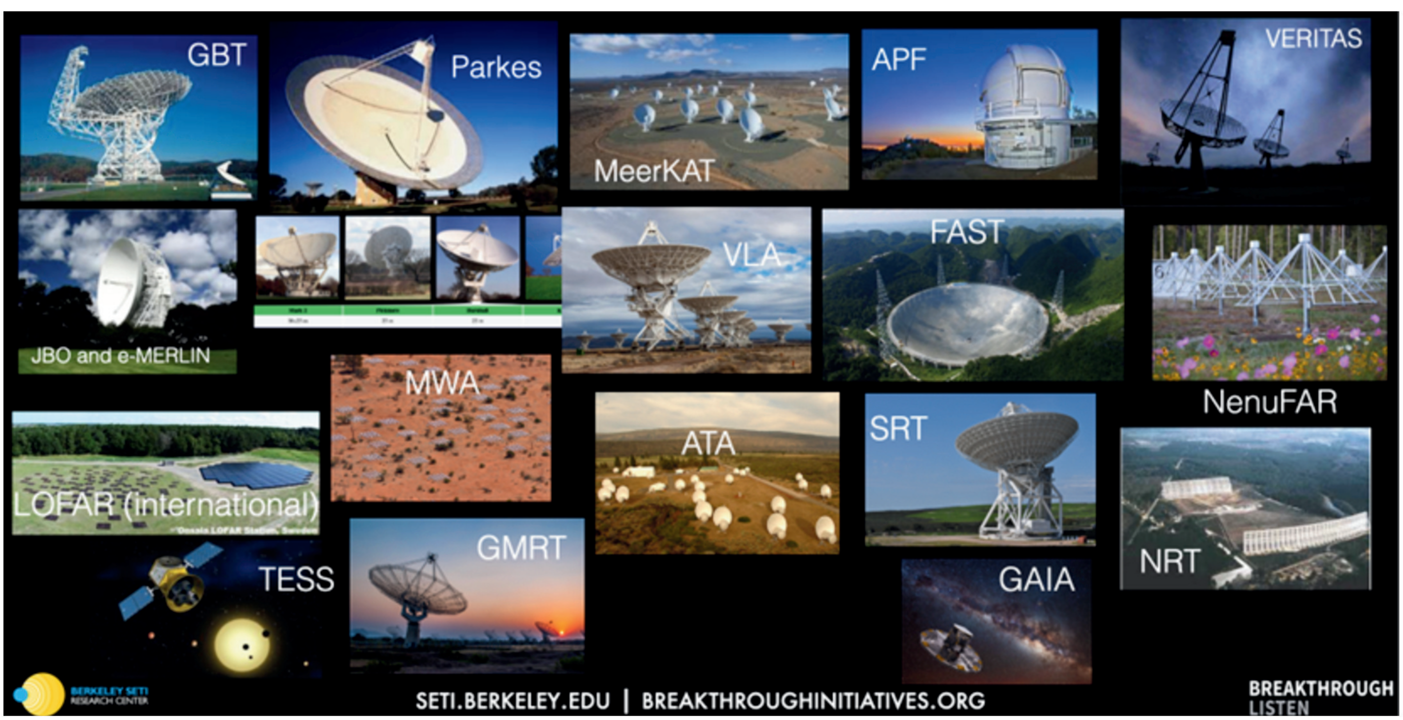
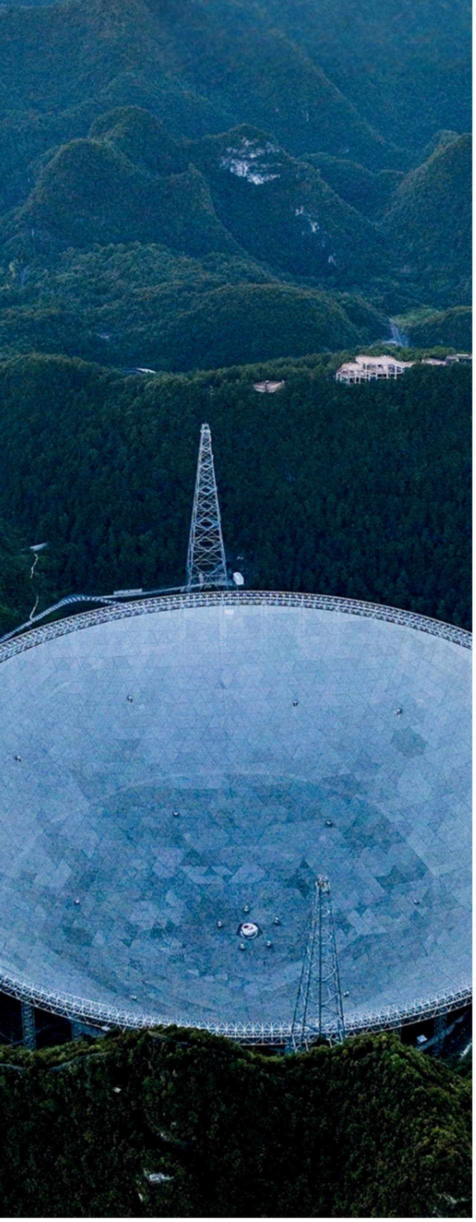


Figure 1 image credit: Breakthrough Listen, https://seti.berkeley.edu/lunarseti/.
Figure 2 image credit: Breakthrough Listen/Vishal Gajjar.



FIVE HUNDRED-METER APERTURE SPHERICAL TELESCOPE

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) in China, the largest single-aperture radio telescope in the world, plays a pivotal role in the global SETI endeavor. FAST's unmatched sensitivity allows it to perform deep searches for radio emissions that may indicate the presence of extraterrestrial intelligence.

Since its collaboration with the Breakthrough Listen initiative begun in 2016, FAST has conducted a series of targeted SETI campaigns. The FAST telescope sports 19-beams, which means it can simultaneously look at 19 different patches of the sky. A key focus of technosignature research has been the use of this multibeam instrument in a coincidence matching scheme, allowing detection of extremely weak signals that could indicate advanced extraterrestrial technology.

Another notable initative includes the development of a new technique of using polarization to enhance our searches. This innovative approach improves the ability to distinguish between natural and artificial signals on the basis of their polarization, thereby refining the search.

SIMULTANEOUS DUAL-SITE SETI

A significant challenge in the field of SETI is distinguishing potential extraterrestrial signals from human-made interference. One approach to overcome this difficulty is simultaneous SETI observations using multiple observation sites. This method has a key advantage: It allows researchers to reject signals that originate on Earth. If a signal is detected at only one site, it is likely from a terrestrial source.

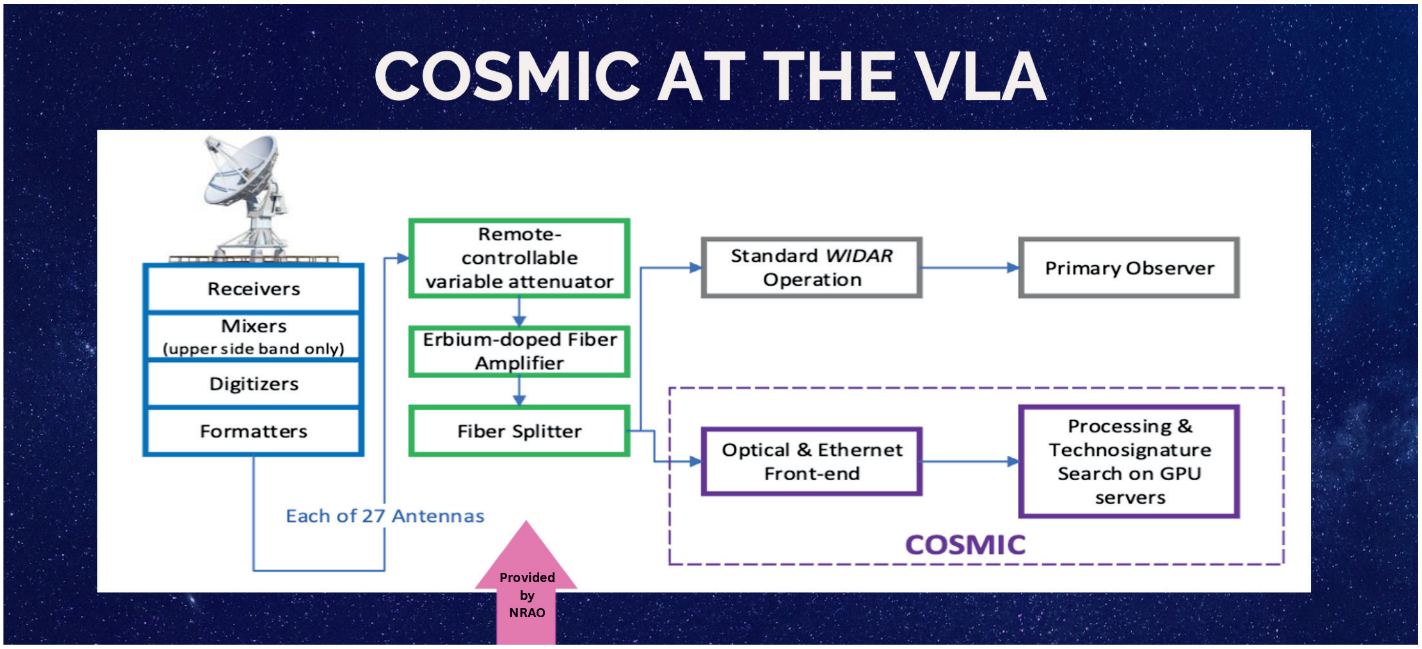
However, if a signal is simultaneously detected at multiple, widely-separated sites, it is more likely to be of extraterrestrial origin. For example, in a recent survey, researchers used two international LOFAR stations in Europe to observe the same, known targets simultaneously. This technique enabled them to confidently rule out signals from human-made sources, thus demonstrating the utility of this approach.

FAST image credit: Xinhua.

COSMIC

The **C**ommensal **O**pen-**S**ource **M**ulti-mode **I**nterferometric **C**luster (COSMIC) is a new Ethernet-based digital signal processing backend and computer cluster on the Karl G. Jansky Very Large Array (VLA) in New Mexico. This system piggybacks on other VLA observing programs.

In addition to serving as a test bed and training instrument for future upgrades to the observatory, COSMIC conducts cutting-edge research in astronomy and planetary science. Its high spectral resolution is advantageous in a search for radio technosignatures that may indicate extraterrestrial technology.



COSMIC at the VLA, credit: Dr. Chenoa Tremblay/SETI Institute/Breakthrough Listen.
Image of Dr. Tremblay and image of the VLA Credit: Dr. Chenoa Tremblay.

With modern telescopes like the VLA, we can be relatively agnostic to the specific purpose of the transmitting society, allowing the detection of both intentional and unintentional (leakage) emissions, such as ranging, directed energy, or other efforts. There is obviously a compelling case for any search to continuously monitor the nearest star systems. A cost-effective and efficient way to do this is with simultaneous observations with telescopes such as COSMIC and its associated software pipeline.

A significant advantage of the COSMIC experiment on the VLA is that it records and processes data during the observatory-led all-sky survey, a project that covers 80% of the observable sky at wavelengths of 7.5 to 15 cm. COSMIC is the largest search for technological signatures ever conducted. It examines over 2000 sources per hour, collecting data on hundreds of thousands of stars every six months.

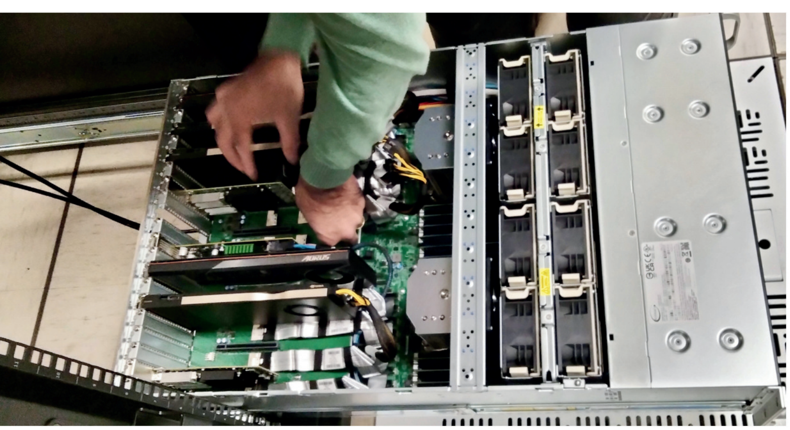


Image of installation credit: Dr. Chenoa Tremblay.
Image of Dr. Savin Varghese and Dr. Chenoa Tremblay, in front of one of the 82-foot diameter dishes that makes up the Very Large Array. Credit: Dr. Chenoa Tremblay.

2

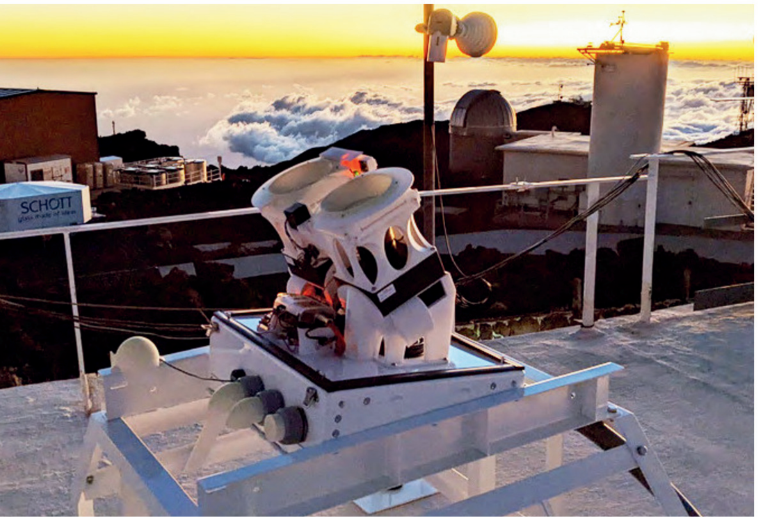
OPTICAL SETI

LIGHTS, CAMERA, LASERS!

While looking for radio transmissions is the strategy used in most SETI efforts, some new projects focus on examining other parts of the electromagnetic spectrum. Two major initiatives look for signals at visible or infrared wavelengths.

LASER SETI

Laser flashes could transmit data at a significantly higher rate than radio, so advanced civilizations might use these wavelengths for communication. In addition, technologically savvy aliens might even use lasers to propel spacecraft.



LaserSETI illustration credit: LaserSETI/SETI Institute.
LaserSETI station at Haleakalā Observatory, image credit: Eliot Gillum/LaserSETI.
LaserSETI station at Robert Ferguson Obsevatory, image credit: Eliot Gillum/LaserSETI.

Because of such possibilities, the SETI Institute developed LaserSETI, the first optical SETI survey with the aim to monitor all the sky, all the time for extraterrestrial laser pulses.

To scan the entire sky multiple observatories must be used. Although the current installations in California and Hawaii only observe 20% of the sky combined, that coverage is soon to increase — two LaserSETI stations were installed in the summer of 2023 in Arizona. With nine more observatories currently under construction situated outside the United States, LaserSETI will be able to detect laser pulses from any part of the sky.

NEAR-INFRARED OPTICAL SETI (NIROSETI)

Near-Infrared Optical SETI (NIROSETI) is an experiment designed to identify laser flashes that originate from sources beyond our solar system. It uses an instrument at the Lick Observatory in California that comprises two cameras that simultaneously observe the sky. They search for coincidental near- infrared flashes (aka laser flashes detected by both cameras simultaneously). Shelley Wright, who received the SETI Institute's 2022 Drake Award, was one of the scientists behind this project.

Portrait of Dr. Shelley Wright and Image of Lick Observatory credit: Laurie Hatch Photography.

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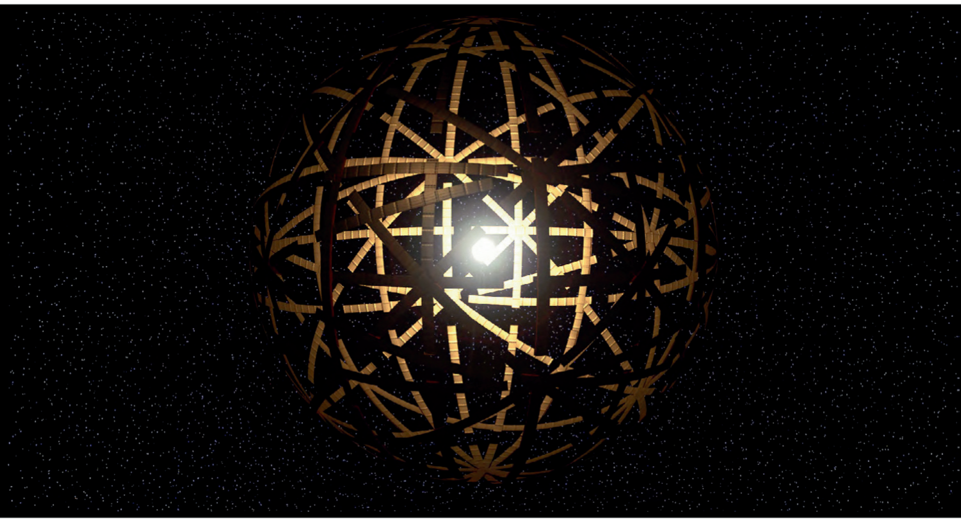
ALIEN ARTIFACTS



Signals are just one way an intelligent society could make itself known. Advanced socicties might construct detectable artifacts such as spaceships, large structures around their stars, or other constructions visable from Earth.

DETECTING DYSON SPHERES

Recognizing that energy demands on Earth are relentlessly increasing, physicist Freeman Dyson suggested that an advanced society may look to its home star for energy. A star, after all, is a giant nuclear reactor.

He envisioned a so-called Dyson swarm, a collection of satellites orbiting a star that we might be able to detect. The satellites would inevitably warm and emit infrared radiation. In addition, large artifacts might intermittently block some of the light from their home star.

Dyson Sphere 3D rendering header image credit: Kevin Gill.
Dyson Sphere structure illustration credit: Danielle Futselaar.

A direct search for large alien constructions is being pursued by SETI Institute astronomer Dr. Ann Marie Cody. She and her team are using data from NASA's TESS telescope to search for brightness variations in 60 million nearby stars. If they find an intriguing drop in brightness that can't be otherwise explained, they'll take a closer look at that star to see what might be causing the change. It might be another civilization.

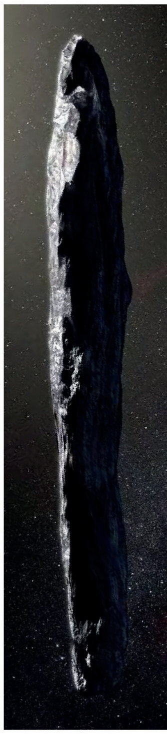
Using their anomaly detection setup during the past two years, they have compiled a list of a few thousand objects of interest. Dr. Cody and her team are now vetting these, but so far none has proven to be of unnatural origin.

The vetting of these objects is a multi-stage process. First, Dr. Cody's team checks several data pipelines to see if a "weird" light curve is shown by all of them. If the answer is no, they move on. If yes, they check whether the event is consistent with the shape expected from an eclipsing star system.

“We have a model representing two luminous spheres of different sizes,” Dr. Cody explains, “and we find the best-fitting parameters of that model with respect to the light curve shape. If it is a good fit, we're confident we're observing two stars, not one star orbited by an anomalous megastructure.”

ONE PERSON'S TRASH

The universe is more than 13 billion years old, so more than enough time has elapsed for other advanced civilizations to emerge. It also stands to reason that advanced technology, such as large ships, space habitats, and other objects (including alien trash) might be out there.



These items are nearly impossible to detect unless they're very nearby. But it's conceivable that one might accidentally traverse our solar system.

There was an interstellar visitor as recently as 2017, a space rock called 'Oumuamua. It was shaped like a cigar and underwent perplexing changes in speed as it left the vicinity of the Sun. Could this indicate that, rather than being an asteroid, this object was an interstellar vehicle? Most scientists are skeptical of this idea.

'Oumuamua's visit also sparked a discussion in the science community about being better prepared to detect and analyze interstellar objects that enter the solar system.

Dr. Ann Marie Cody portrait credit: Dr. Ann Marie Cody.
'Oumuamua image credit: European Southern Observatory / M. Kornmesser.

4

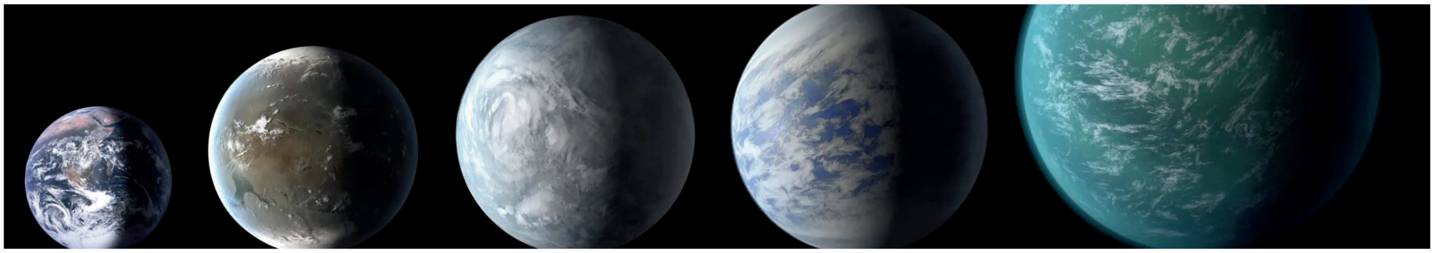
ANOTHER EARTH

ANOTHER EARTH?

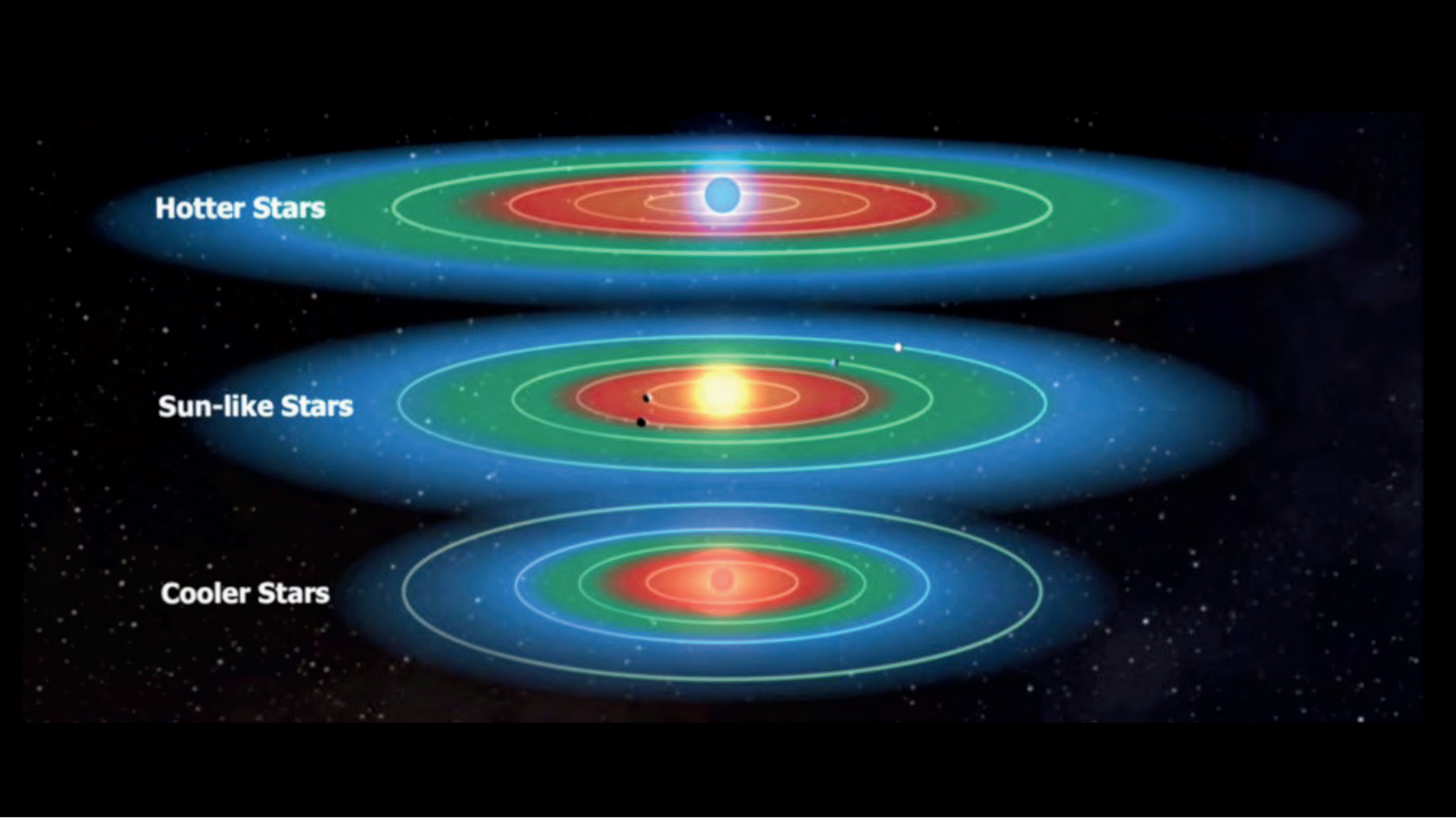
There are hundreds of billions of planets (known as exoplanets) in the Milky Way galaxy, so how do scientists decide which ones might host life? We could write a whole eBook on this topic alone, so we'll keep to the most important facts here:

The most promising approach is to look for liquid water. Life as we know it depends on water to foster the chemistry of life. We assume that life beyond Earth would also need this molecule to arise and subsist, or at least a liquid of some kind.

Earth has so much liquid water because it's at the right distance from the Sun. It's neither too close like Mercury and Venus, nor too far, like Jupiter. The range of distances from a star at which liquid water could be present on a planet's surface is called the habitable zone. Since stars differ in luminosity, the habitable zone varies depending on which star you're considering.



Kepler-452b and Earth comparison image credit: NASA/JPL-Caltech/T. Pyle.
Earth-like planets image credit: NASA/Ames/JPL-Caltech.



The star also needs to be relatively stable, as too much activity, such as solar flares, can be fatal to any emerging life on an orbiting planet.

Atmospheres, the mixture of gasses surrounding a planet, are also critical to the development of life. These cushions keep climates temperate by trapping heat from the nearby star and preventing extreme temperature changes between night and day.

If scientists find another planet that appears to be habitable, we could look for life in several ways. The first would be to direct any radio telescopes at the planet to listen for deliberately produced emissions.

Researchers would also study its atmosphere to determine its composition. A handful of gases, such as oxygen or methane, can be considered “biosignatures” because they can be (but not necessarily are) byproducts of living organisms. Suppose we find a particularly promising atmospheric component, such as oxygen. That might be a compelling indication of life. We could also study the planet and its host star for several years to look for changes in the planet’s brightness or atmospheric composition that could indicate the presence of biology.

Figure 1 credit: NASA.

5

METI

A NOTE ON METI

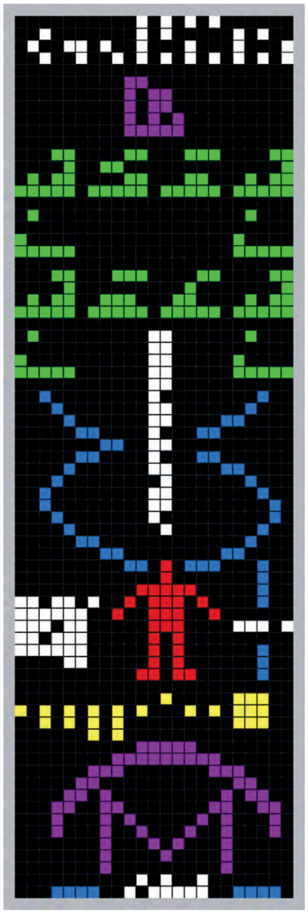
We've talked about listening for signals or studying a star's light for signs of an orbiting, massive structure, but why don't we simply transmit a message into space and see if anyone responds? This idea is called METI, Messaging Extraterrestrial Intelligence.

However, many in the SETI community do not favor this idea.

One obvious problem with broadcasting is: what to say? We don't know the language of another civilization, and thus composing a message that would elicit a response would be challenging. The second, arguably bigger problem is: could there be danger in betraying our presence?

We don't want to invite anyone to our doorstep without first getting to know them. Nonetheless, there have been some transmitting efforts. In 1974 Frank Drake beamed a signal to the M13 star cluster more than 25,000 light-years away, known as the Arecibo Message. Any response won't reach us until deep in the future.

It's also worth noting that our society is already beaming signals into space. TV broadcasts and radio transmissions hurtle through the cosmos at the speed of light. If some aliens in our galactic neighborhood turned their receivers in Earth's direction, they'd already find plenty of emissions indicating that we're here.

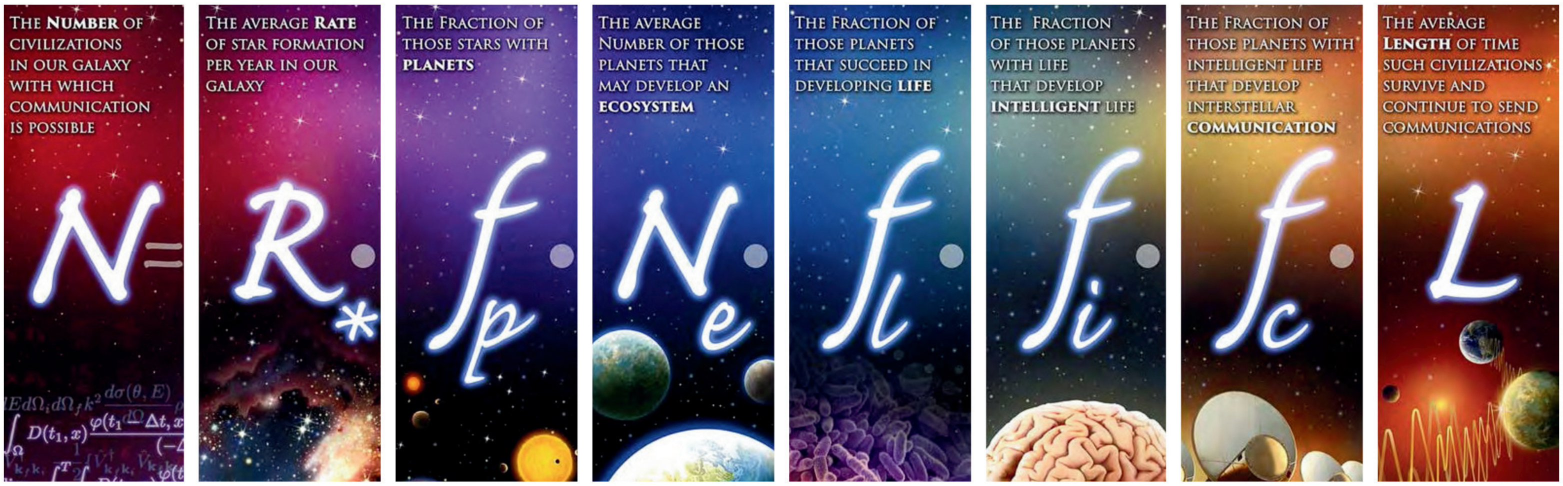


Arecibo Message image credit: Arecibo Observatory.

Image credit: metamorworks/Getty Images.

6

RELEVANT CONCEPTS



These are a few additional concepts relevant to thinking about SETI.

THE DRAKE EQUATION

In 1961, astronomer Frank Drake came up with what's known as the Drake Equation to provoke a scientific discussion about the possible existence of other advanced civilizations. This equation has become a framework for how scientists think about SETI.

FERMI PARADOX

If it's likely that advanced civilizations exist and humans are young compared to the rest of the cosmos, why haven't we found anyone yet? This contradiction between expectation and reality is known as the Fermi Paradox.

There have been several attempts to reconcile this paradox, but it has yet to be convincingly explained.

Drake equation illustration image credit: Danielle Futselaar.

THE GREAT FILTER

In 1994, Robin Hanson introduced the idea of the great filter as an explanation for the Fermi Paradox. The idea is that there is a step in the process between life arising from insensate matter and the dawn of technology that might be a bottleneck for the emergence of the type of advanced civilizations we could detect.

Some scientists believe the bottleneck is the evolution of multicellular life, while others think it's the rise of tool-using intelligence. Others suggest that advanced civilizations are likely to be short-lived because they will self-destruct.

It may also come down to the fact that we haven't been looking for very long, and our technology is still incapable of finding other societies.

Image credit: ktsimage/Getty Images.

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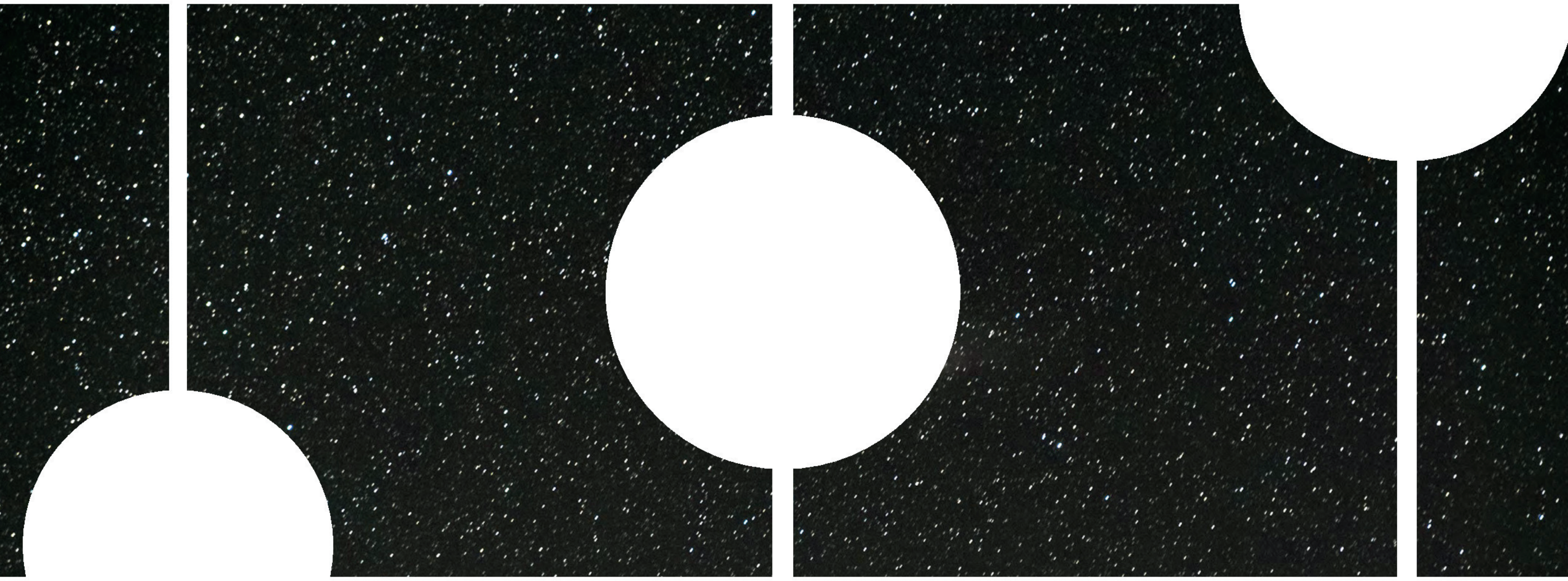
WHAT IF WE FIND SOMEONE OUT THERE?



Imagine the scene: a young scientist is sipping coffee while looking over data from a radio telescope -- his jaw drops. The coffee cup falls to the floor.

A signal!

What happens now?

The International Academy of Astronautics has developed protocols for what to do if we discover extraterrestrials. These protocols consist of three steps:

1. **The detection should be carefully verified by others.**
2. **The discovery should be made public.**
3. **No response should be sent without international consultation.**

The big thing to note here is that if an alien signal is detected, it will take time to verify. First, the organization that discovered the signal would double-check their findings and ensure—as best they can—that the signal wasn't the result of terrestrial interference or a naturally occurring phenomenon.

Of course, any discovery would quickly become public knowledge. This is true because those who discovered it would also want other scientists to study the signal. The science community would be keen to determine where the signal comes from, and attempt to ascertain its meaning.

If we were to find a signal, we'd need to decide whether to reply. This would would undoubtedly lead to considerable international discussion. If we did reply, that might begin a conversation that could last for generations.

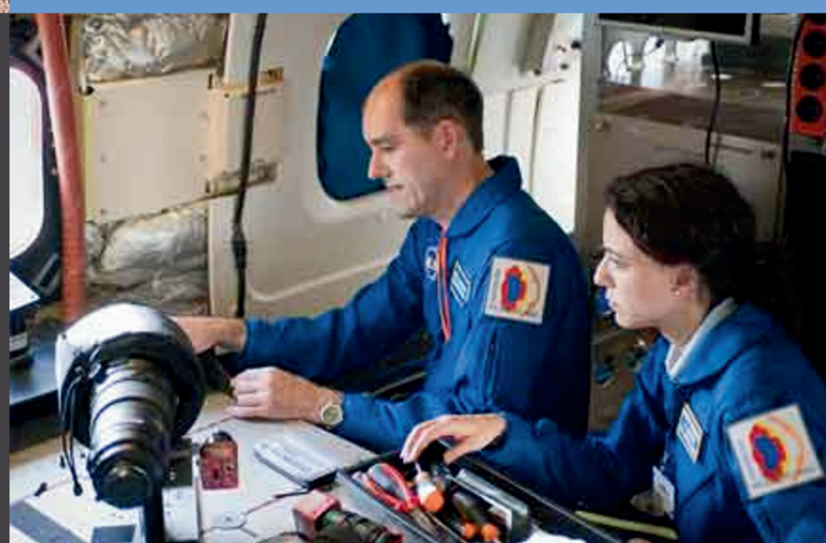
At the very least, we'd have to decide what to say, beam it to the source of the signal, and hope that they get it. Once whoever is on the other end gets our message, they'd have to decode it and figure out what to say back, if anything.

It would be the most exciting discovery in history, but because of the time delays caused by the finite speed of light, it would likely be a tedious series of events.

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

Our mission is to lead humanity's quest to understand the origins and prevalence of life and intelligence in the universe and share that knowledge with the world.

We are a nonprofit research organization. From microbes to alien intelligence, the SETI Institute is America's only organization wholly dedicated to searching for life in the universe.



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