Next-Gen SETI:

Pioneering the Search for ET

SETI INSTITUTE

01

RADIO SETI

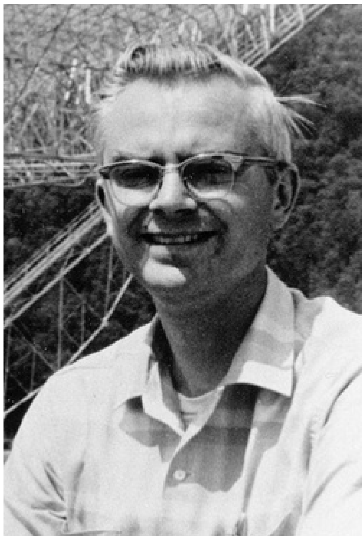
The Very Large Array (VLA) is a collection of 27 radio antennas located at the NRAO site in Socorro, New Mexico. Each antenna in the array measures 25 meters (82 feet) in diameter and weighs about 230 tons. Credit: Alex Savello/NRAO.

THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

SETI, or the search for extraterrestrial intelligence, is a relatively new scientific field that has grown during the last sixty years. Humans have always believed that other planets and creatures existed beyond Earth, and thanks to the tireless work of many scientists, some believe that it's only a matter of time before we find life outside our planet

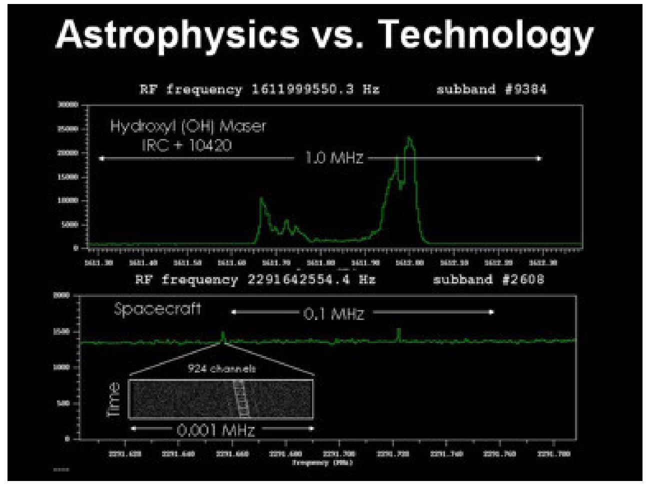
NOT YOUR GRANDPA'S RADIO ASTRONOMY

Dr. Frank Drake is known as the father of SETI because he pioneered the modern search for intelligent life beyond Earth. He attempted to detect radio transmissions from other civilizations. When Drake conducted the first ever SETI experiment at the Green Bank Observatory in Green Bank, West Virginia, most Earth-based communication technologies relied on radio, so Drake reasoned that other civilizations might also use this technology.



While all astronomical objects give off some radio waves, intentional radio transmissions generally make- signals at a narrow bandwidth not typical of most naturally occurring objects.

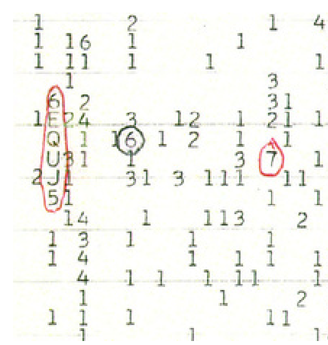
To this day, radio astronomy is the primary method used when looking for intelligence beyond Earth. Dr. Drake paved the way, and the next generation of scientists is making huge strides in continuing this work.



ALLEN TELESCOPE ARRAY

The Allen Telescope Array (ATA) is the only radio telescope built from the ground up to conduct the search for the technologically-capable extraterrestrial life. Recent upgrades to the system, as of mid of 2024, allow for the concurrent digitization and processing of 28 antennas, at a data bandwidth of 150 GB per second, a rate equivalent to 50 HD movies every single second.

The SETI programs at the ATA encompass a variety of initiatives. One key effort involves a systematic search for narrowband signals from nearby stars. Additionally, some surveys aim to detect leakage radiation from potential interplanetary communications by observing exoplanetary systems when their planets align with Earth. Another significant focus is on identifying periodic signals that are unlikely to be naturally occurring.



The science portfolio of the ATA extends beyond SETI. It includes studying the afterglow of supernova explosions, which marks the end of a massive star's life. Additionally, the ATA investigates enigmatic Fast Radio Bursts—millisecond-wide bursts of radio emissions from deep in the cosmos. The ATA also explores various other phenomena and objects, such as supermassive black holes and pulsating neutron stars, known as pulsars.

BREAKTHROUGH LISTEN

Breakthrough Listen is undertaking one of the most comprehensive and profound surveys for technosignatures in human history. Utilizing nearly two dozen radio telescopes worldwide, this ambitious project spans a vast portion of the electromagnetic spectrum.

With the recent inauguration of its headquarters at the University of Oxford, UK, Breakthrough Listen is expanding its technosignature searches internationally and has established a rigorous academic platform to encourage participation in this field. Additionally, the initiative has set an ambitious goal: conducting a feasibility study for establishing 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 listen in on systems that include potentially habitable exoplanets.

Breakthrough Listen image credit: https://seti.berkeley.edu/lunarseti/
Breakthrough Listen image credit: 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 this 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 began in 2016, FAST has conducted a series of targeted SETI campaigns. FAST telescope is equipped with 19-beams which means it can simultaneously look at 19 different parts of the sky. A key focus of technosignature research has been the use of this multibeam coincidence matching, allowing detection of extremely weak signals that could emanate from advanced extraterrestrial technologies.

Another notable achievement includes the development of a new technique of using polarization to enhance technosignature searches. This innovative approach improves the ability to distinguish between natural and artificial signals, thereby refining the search for extraterrestrial intelligence.

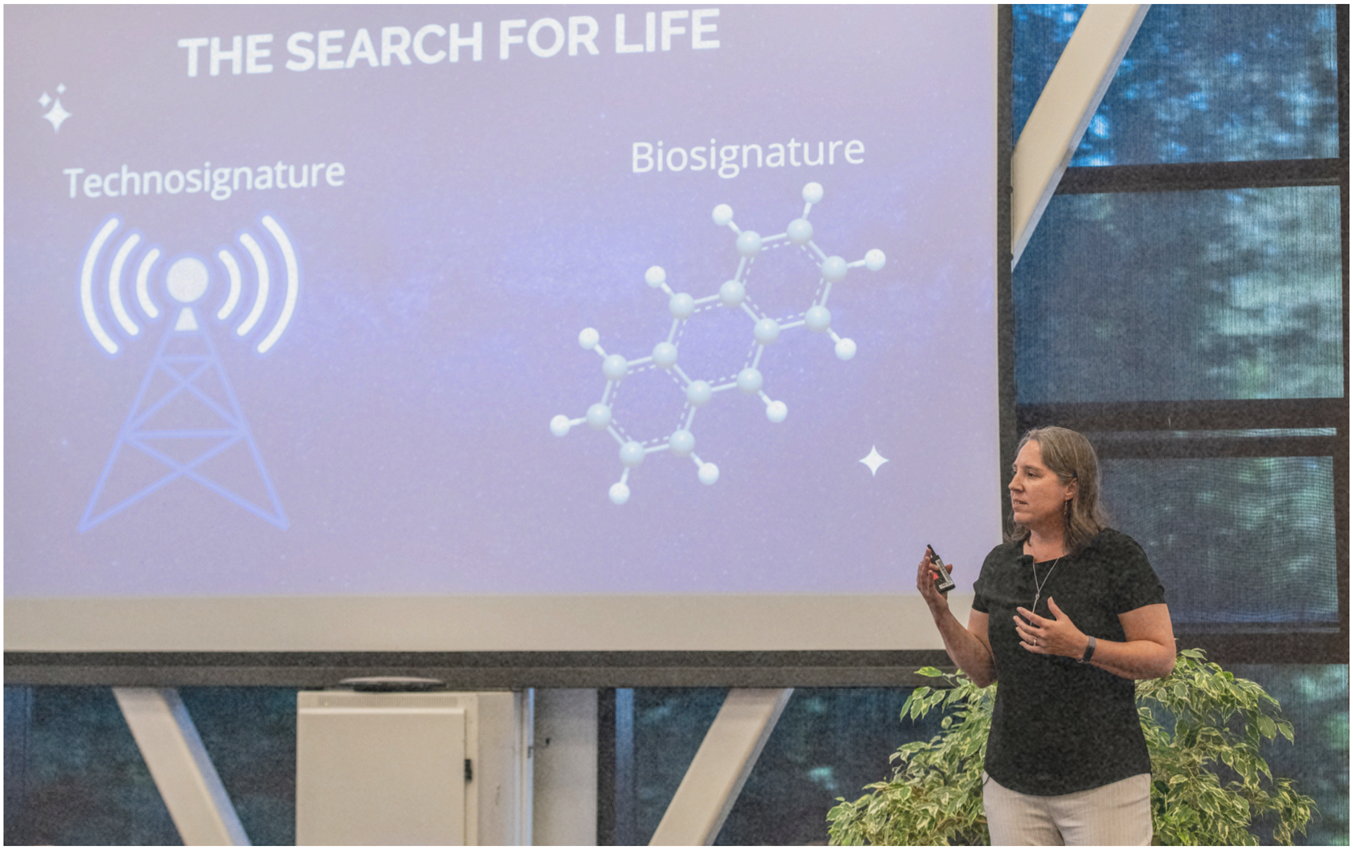
SIMULTANEOUS DUAL-SITE SETI

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

However, if a signal is detected at multiple, widely-separated sites simultaneously, 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 targets simultaneously. This technique enabled them to confidently rule out signals from human-made sources, ensuring that any detected signals were more likely to be genuine technosignatures.

FAST image credit: Ou Dongqu/Xinhua/ZUMA.

PROJECT COSMIC



The Commensal Open-Source Multi-mode Interferometric Cluster (COSMIC) is a new commensal Ethernet-based digital signal processing backend and computer cluster on the Karl G. Jansky Very Large Array (VLA) in New Mexico, which is operated through the National Radio Astronomy Observatory (NRAO).

In addition to serving as a test bed and training instrument for future upgrades and developments, COSMIC conducts cutting-edge research in astronomy and planetary science. In conjunction with all observations, the high spectral resolution mode is being used to conduct the deepest and widest survey of radio technosignatures (spectral-temporal features that may be indicative of extraterrestrial technology) in history.

With modern telescopes like the VLA, we can be relatively agnostic to the specific purpose of the transmitter, allowing us to detect both intentional and unintentional (leakage) emissions from communication, ranging, directed energy, or other pathological (to radio astronomy) technologies. Thus there exists a compelling case for continuous monitoring of the nearest stars and planets. A cost-effective and efficient way forward is through simultaneous observations with telescopes, such as COSMIC and its software pipeline.

A significant advantage of the COSMIC on the VLA is that it records and processes data during the observatory-led all-sky survey, which covers 80% of the observable sky at wavelengths of 7.5 to 15 cm, providing the opportunity to conduct the largest search for technological signatures ever conducted. We are covering over 2000 sources per hour during this survey, accumulating data on hundreds of thousands of stars every six months.

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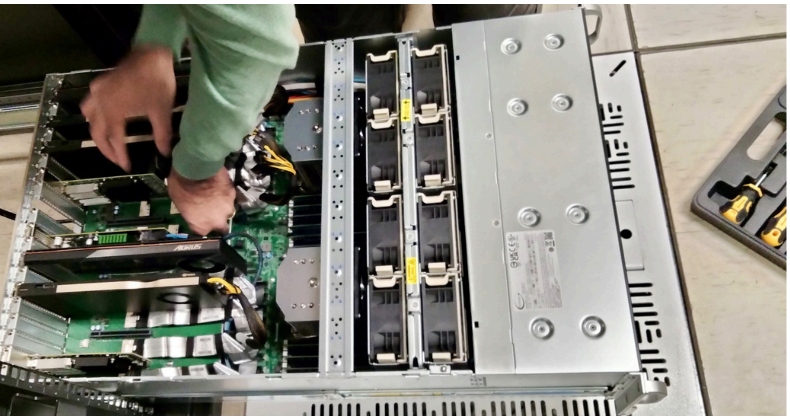

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02
OPTICAL SETI

L I G H T S ,   C A M E R A ,   L A S E R S !

While radio astronomy may make up most SETI efforts, some new projects focus on searching other parts of the electromagnetic spectrum. Two major initiatives center on signals at visible or infrared wavelengths.

L A S E R   S E T I

Laser flashes could transmit data faster than radio advanced civilizations might rely on these wavelengths for communication. And technologically savvy aliens could even use lasers to propel spacecraft.

Breakthrough Listen image credit: Breakthrough Listen / Danielle Futselaar.
TESS image credit: NASA's Goddard Space Flight Center.
FAST image credit: Ou Dongqu/Xinhua/ZUMA.

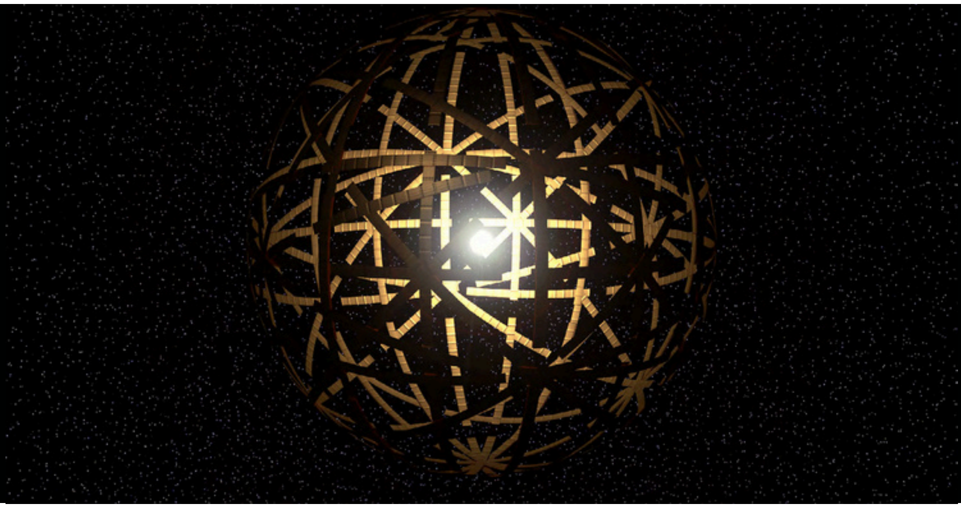
Because of this, the SETI Institute developed LaserSETI, the first optical SETI survey with aims to monitor all the sky, all the time for extrasolar laser pulses. To scan the entire sky, multiple observatories must be in place around the globe. Although the current installations in California and Hawaii observe 20% of the sky combined, that coverage is soon to increase — two new LaserSETI stations will be installed this summer in Arizona. With nine more observatories currently under construction and slated to be placed outside the United States, soon, LaserSETI will be able to capture evidence of 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 could have originated from sources beyond our solar system. It uses an impressive instrument located at the Lick Observatory in California. It includes two cameras that simultaneously observe the sky to identify coincidental near- infrared flashes (aka laser flashes detected by both cameras simultaneously). Dr. 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

03
ALIEN ARTIFACTS



Signals are just one of the ways another intelligent society could make itself known. They could build artifacts like spaceships, large structures around their stars, or other constructions we can detect from Earth. An alien artifact is anything from beyond Earth that looks artificial.

DETECTING DYSON SPHERES

As technology proliferates throughout society, energy demands on Earth skyrocket. Humanity needs far more energy now with cell phones, computers, and airplanes than it did hundreds of years ago when we relied on handcrafted goods. To solve this problem of ever-increasing energy needs, an advanced society may look to its home star for energy. After all, what is a star but a giant nuclear reactor?

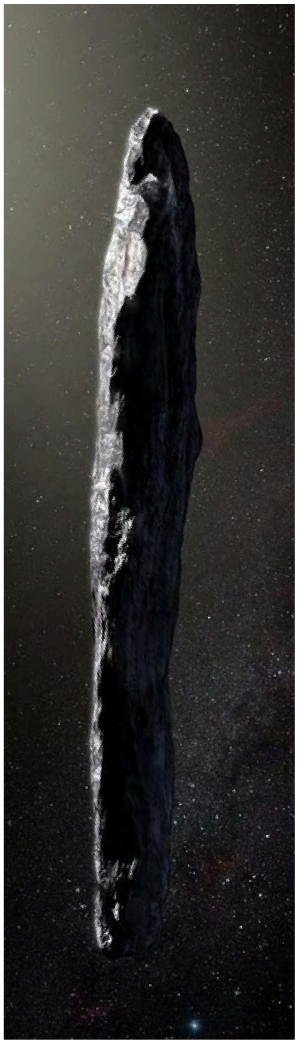
A Dyson swarm is a hypothetical structure around a star for harvesting energy, and we might be able to detect them. These individual megastructures will block some of the light emitted by the star, and if we can observe a changing light pattern, we can potentially identify another advanced civilization. In addition, the swarm's outer surface will emit in the infrared, and this excess infrared light could be detected.

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

SETI Institute astronomer Ann Marie Cody is on the case. She and her team use NASA's TESS telescope data to identify brightness variations in 60 million nearby stars. If they find an intriguing drop in brightness that can't be explained, they'll take a closer look at that star to see what might be behind the change. It might just be another civilization.

After running their anomaly detection procedures in the past two years, they're down to a few thousand objects of interest that are most likely astrophysical in origin (e.g., eclipsing star systems). Cody and her team are now engaged in vetting those objects to see if any are particularly unusual, but so far, none stick out as such.

Vetting is a multi-stage process. First, Cody's team checks multiple data pipelines to see if a "weird" light curve's behavior is reproduced with 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," 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 transpired for an advanced civilization to emerge. It also stands to reason that extremely advanced technology like spacefaring ships, floating habitats, and other objects (including alien trash) might be out there.

These items are nearly impossible to detect unless they're in our backyard, but one might zoom through the solar system. We had an interstellar visit as recently as 2017. This space rock, called 'Oumuamua, had many intriguing features: it was shaped like a cigar and underwent unusual changes in speed as it left the vicinity of the Sun. Could this indicate that, rather than being an asteroid, this object is an interstellar vehicle?

'Oumuamua's visit also sparked a conversation in the science community about becoming better prepared to detect and analyze interstellar visitors.

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

04

ANOTHER EARTH

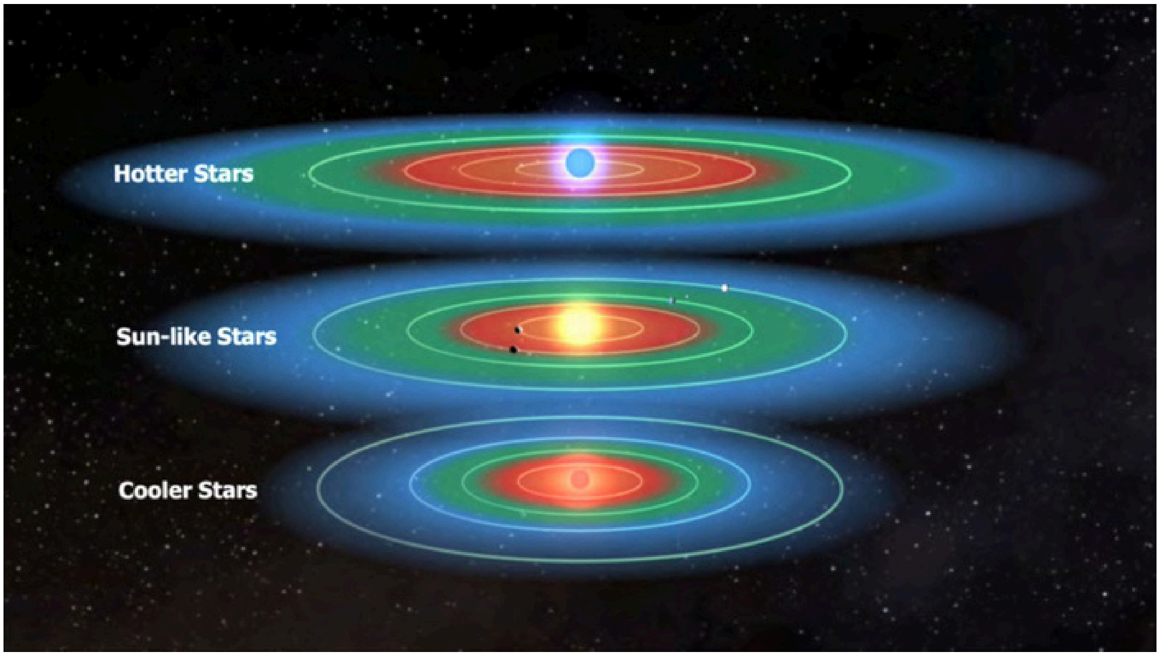
ANOTHER EARTH?

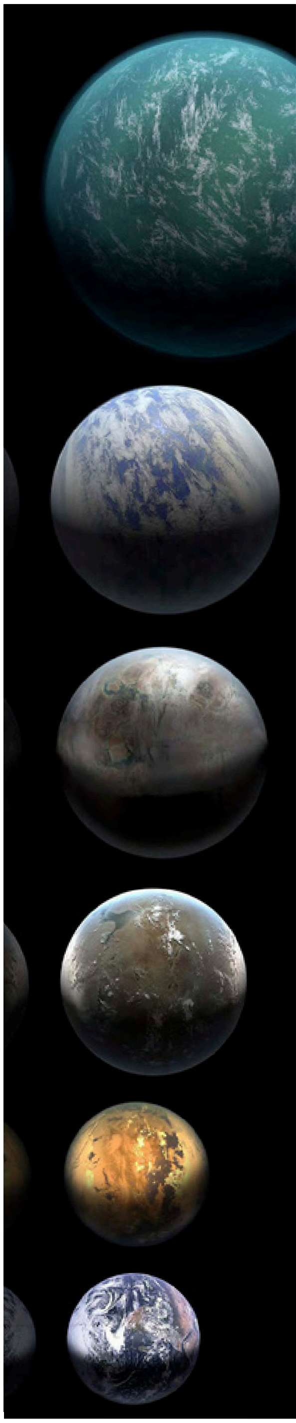
There are hundreds of billions of planets outside of our solar system (commonly called exoplanets) in the Milky Way galaxy, so how do scientists decide which ones might host life? We could write a whole eBook on this topic alone, so we'll keep to the topline facts here.

The key is to look for water—liquid water specifically. Life as we know it (which is life on Earth) needs water to survive, so that it would follow that life beyond Earth would also need this molecule to thrive, or at least a liquid of some kind.

Earth has so much liquid water because it's the perfect distance from the Sun. It's not too close like Mercury and Venus and not too far like Jupiter. The range of distances from a star at which liquid water could be present on the surface of a planet is called the habitable zone. Since stars vary 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. Dyson Sphere structure illustration credit: Danielle Futselaar.





The star also needs to be relatively stable, as too much activity, like solar flares, can harm 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.

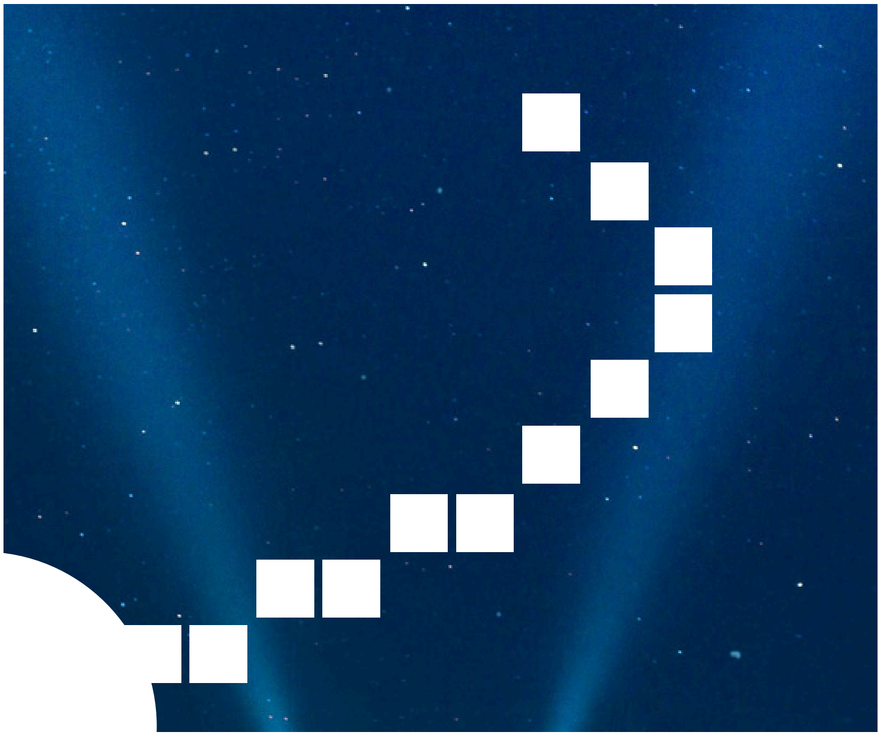
If scientists find another planet that appears to be habitable, we could look for life in several ways. The first would be to direct any radio telescopes at the planet to listen for technology.

Researchers would also take measurements of the atmosphere to understand its composition. A handful of gases, such as oxygen or methane, can be used as “biosignatures” because they can be (but not necessarily are) byproducts of living organisms. Suppose we find a particularly promising candidate, such as oxygen. We could also study the planet and its host star for several years to look for changes in the star's brightness or atmospheric composition that could indicate life is thriving on the surface.

Figure 1 credit: NASA Earth-like planets image credit: NASA/Ames/JPL-Caltech

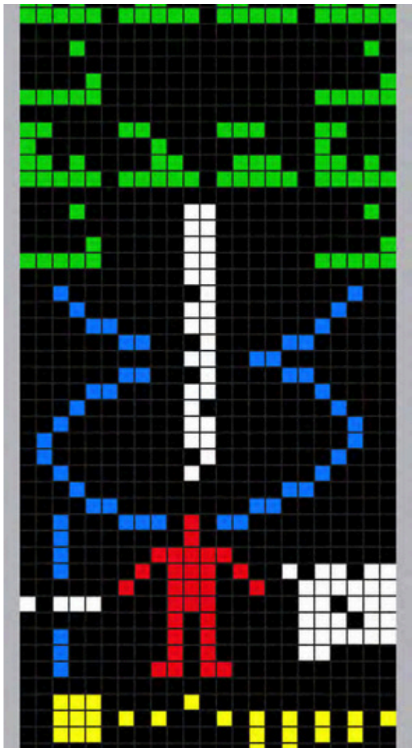
05
METI

A NOTE ON METI



We've talked about listening for signals or studying a star's light for signs of a massive structure, but why don't we blast a message into space and see if anyone responds? This idea is called METI, which stands for Messaging Extraterrestrial Intelligence, however many in the SETI community are critical of this initiative.

The first problem is: what to say? We don't know how another civilization would communicate, and thus, writing a message that would get a response will be challenging. The second, arguably bigger problem is: what if we don't like what we hear back?

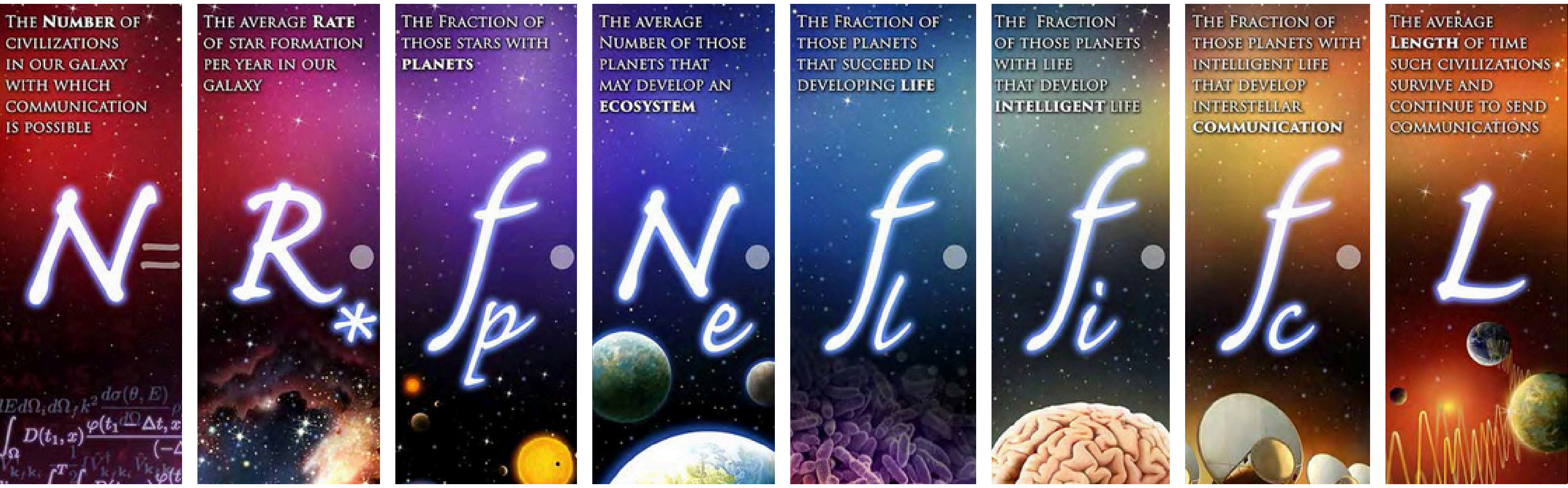


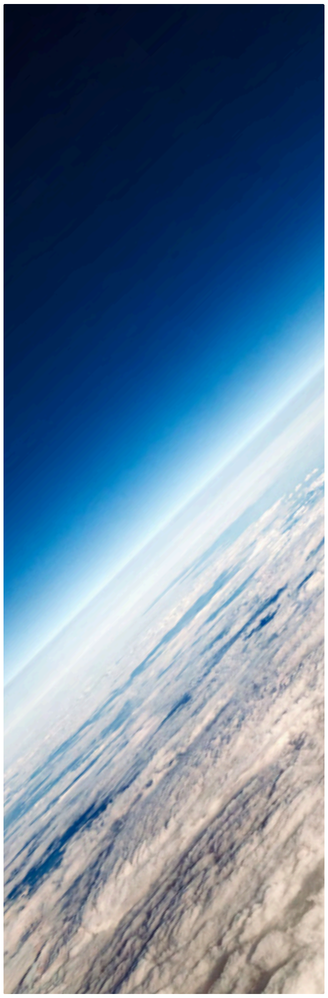
We're young, cosmically speaking and can't get along with each other. We don't want to invite anyone to our doorstep without getting to know them a little first. Some scientists have sent messages, though. In one of the early SETI experiments Frank Drake beamed a message to the M13 cluster more than 25,000 lightyears away in 1974, known as the Arecibo Message.

Another factor to consider is that our technology is already beaming signals into space. TV broadcasts and radio programs shoot past our atmosphere to hurtle through the cosmos at the speed of light. So, if some aliens in our galactic neighborhood turned their receivers in Earth's direction, they'd already find plenty of noise indicating that we're here.

06

HELPFUL CONCEPTS





There are a few equations and concepts that are important when thinking about SETI science.

THE DRAKE EQUATION

Frank Drake created the Drake Equation to jumpstart a scientific discussion about the existence of other advanced civilizations. The equation has become the backbone of 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 is the basis of the Fermi Paradox.

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

THE GREAT FILTER

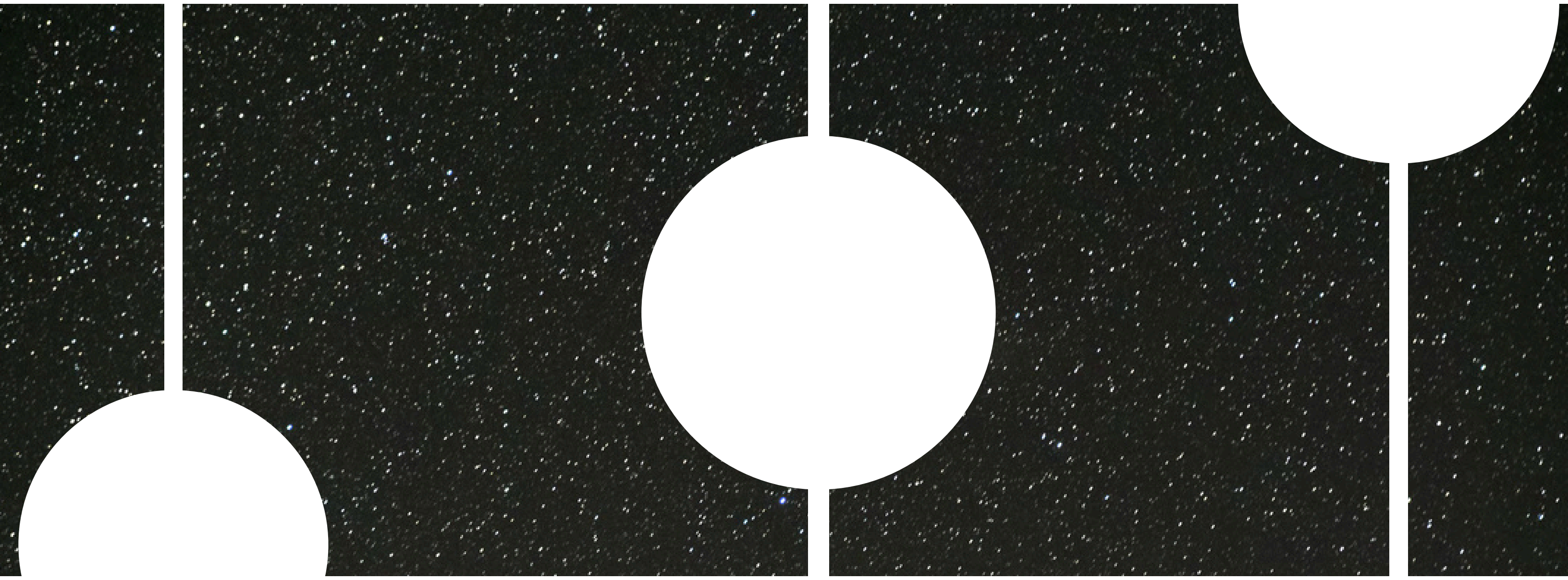
In 1994, Robin Hanson introduced the idea of the great filter to address the Fermi Paradox. The idea is that there is a step in the process between life emerging from insensate matter and the dawn of technology that is very unlikely to occur. This might be a bottleneck for the emergence of the type of advanced civilizations we can detect.

Many scientists believe the filter lies in the emergence of multicellular life, while others think it's the evolution of tool-using intelligence. Another group thinks advanced civilizations are likely short-lived because they self-destruct and become extinct before making contact.

It may also boil down to the fact that we haven't been looking for very long, and our technology is still primitive compared to what others have been able to create.

07

WHAT IF WE FIND SOMEONE OUT THERE?



Imagine the scene: a young scientist is sipping coffee while they look over data from a radio telescope -- their jaw drops. The coffee cup falls to the floor. A signal!

What happens now?

Thankfully, the International Academy of Astronautics has outlined protocols for what to do if we discover extraterrestrials, and we can condense the major points of the protocol into three areas:

1. **The detection of alien life should be carefully verified by repeated observations.**
2. **The discovery should be publicized.**
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 a while 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 interference or a naturally occurring phenomenon.

And, of course, any discovery would quickly become public knowledge partly because those who discovered it would also want their science colleagues to study the signal's origin. The entire science community would be keen to understand the signal, where it came from, and what it all means.

The third factor here is interesting. If we found a signal and figured out what it was, we'd need to figure out if we wanted to announce ourselves to the source. There would undoubtedly be a lot of international discussions. And if we did send a signal back, it would be the start of a conversation that could last generations.

Think about it: we'd have to figure out what to say, beam it to the source, and cross our fingers 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.

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

"SETI is a mirror, a mirror that can show ourselves from an extraordinary perspective and can help to trivialize the differences among us."

-JILL TARTER

The search for life—and even intelligence—beyond Earth is one of the most exciting and rewarding missions humanity has ever undertaken.

Many believe that it's only a matter of time before we definitely know we aren't alone in the universe.

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Message us at info@seti.org

SETI Institute
339 Bernardo Ave, Suite 200
Mountain View, CA 94043
www.seti.org