The Search for Life and Aliens

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Abstract

This article is a comprehensive survey describing our search for life and aliens beyond earth. The search for life inside our Solar System continues by digging into the Martian soil and exploring the underground oceans of Jupiter's moon Europa. As we peer into the Milky Way, exoplanets are the target. Improved sky-survey telescopes identify exoplanets. Then, subsequent analysis using spectrographs obtained via exoplanet transits or direct imaging hope to identify biosignatures.

Detection of intelligent life is either circumstantial or definitive. Technosignatures offer circumstantial evidence of alien civilizations. Definitive or positive detection can be physical, for example, discovering interstellar objects (spaceship/UFOs) or as in the movie Contact, an alien message. Future giant optical/infrared telescopes, sophisticated radio telescopes, and a proposed space telescope, HWO, will dramatically enhance detection.

Significant technical advances in earth-based and space telescopes, documented in four key figures, dramatically improve the probability of discovery over the next ten years. Thus, we may soon have an answer to the question, are we alone?

Introduction.

What is the current status of our search to discover life and aliens?

No definitive record of life outside of earth in our Solar System.
No definitive biosignatures on earth-like exoplanets.
No technosignatures found (exoplanets or galaxies).
No messages (electromagnetic communication) from aliens ever received.
No UFOs confirmed.

Sounds dire, after sixty-five years of searching for signs of life (Frank Drake's first radio search in 1960), both in the Solar System and deep space, with nothing to show for it! Is the search a lost cause?

This article, by presenting the positive actions supporting the future search, argues that the probability of success is significantly higher over the next ten years. The activities are primarily technical (advanced telescopes) but also political, motivational, and psychological - the world wants to know, **are we alone**?

If microbes (bacteria, archaea, protists, fungi) were found in another world, it would be one of the greatest scientific discoveries ever. If alien intelligence were found, it would be even more monumental. Thus, our question: is the current status fatal to the search or will existing and future programs revive the search in the five areas mentioned above are: Solar System, biosignatures, technosignatures, messages or communications, and UFOs.

A. Solar System

"Today, our reconnaissance of the Solar System has ruled out widespread microbes on the surface of the moon and Mars. The search for life inside our Solar System will continue, but in remote places, by digging into the Martian soil and exploring the underground oceans of Jupiter's moon Europa." (Winn, J., *A Little Book of Exoplanets*, 2023, page 252*)*

NASA's Viking missions in 1976 searched for signs of microbes on Mars, finding none. Forty-five years later (2021), the most recent NASA rover, Perseverance, returned to Mars with the goal of collecting samples by drilling rock cores and packaging them for a trip to earth.

Future activity, the pick-up spacecraft is scheduled to arrive at Mars in 2028 with the return to earth in the 2030s (date depends on funding). Hopefully a definitive answer to life on Mars follows from direct sampling.

Beyond Mars, the search for microbes in our Solar System will concentrate on Titan, a moon of Saturn, and three moons of Jupiter - speculation is that the Jupiter moons may have liquid oceans below their ice crusts, if so, hydrothermal vents, resulting from planet internal heat, might provide the energy source required for life.

A future NASA project, Dragonfly, scheduled for launch in 2027, will deliver a drone to Saturn's moon Titan in 2034. This rotorcraft-lander will land on Titan's surface and use its suite of instruments to assess its potential for habitability and search for signs of life, including microbes. Titan is the only Solar System moon with an extensive atmosphere and standing bodies of liquid on its surface. Despite being a distant moon, it often ranks as one of the most Earth-like worlds in the Solar System. Dragonfly carries a mass spectrometer, allowing it to analyze in detail the materials it encounters across Titan's surface and determine their chemical makeup.

Also, there are other Solar System missions in progress - two moon probes have been launched, one by ESA and the other by NASA to explore possible underground oceans beneath icy moons.

ESA's Jupiter Icy moons Explorer (JUICE) will probe three moons: Europa, Ganymede, and Callisto. Launched April 2023, JUICE will investigate these moons' potential habitability and their subsurface oceans. The spacecraft is expected to arrive at Jupiter in 2031.

The Europa Clipper is a NASA mission designed to explore Europa, one of Jupiter's largest moons, known for its potential subsurface ocean beneath an icy crust. This mission aims to determine the moon's habitability and explore its potential for life. Equipped with nine scientific instruments, including spectrometers, cameras, ice-penetrating radar, and a magnetometer, it launched in October 2024 and will arrive at Europa in April 2031.

In summary, in less than ten years these efforts will prove life exists or does not exist in our Solar System. However, the news, when it arrives, would be old news if intelligent life were already discovered by efforts addressed next.

B. Exoplanet Biosignatures

Planets orbiting remote stars, exoplanets, were only speculative until the 1990s. The first exoplanet, named PSR 1257+12, was discovered around a Pulsar 2,300 light years away in June 1992 by the Arecibo Observatory, a 300-meter radio telescope (since collapsed in December 2020). The discovery in 1995 of Bellerophon, a gas giant, was the first confirmed exoplanet orbiting a sun-like star, 51 Pegasi, 50 light years away.

Nineteen years later (2014) the first earth-sized exoplanet (the vast majority of exoplanets discovered are larger than earth) named Kepler186f was detected by the Kepler space telescope, a notable discovery since it was in the habitable zone (where liquid water could potentially exist on its surface) of its star, Kepler-186, a M-type main-sequence red dwarf star 582 light years away.

Habitable zones are not necessarily a reproduction of the earth's location in our Solar System but can result from a complex combination of multiple factors**.** For example, consider characteristics that determine if liquid water exists on a planet: the planet's mass, radius, density, gravity, specific elements, magnetic fields, temperature (from radiation, collisions, radioactivity), atmosphere (greenhouse effect), distance from its star(s), moons, accompanying other planets in the solar system, orbit (tidally locked or not), and the type of star(s) it is orbiting. These factors lead to a surprising number of bizarre and extreme worlds, some with liquid water.

The study of exoplanet biosignatures involves two steps, finding exoplanets and then analyzing the light from their atmosphere or surface. Notable unprecedented exoplanet findings were listed above. Historically, astronomers have not identified many earth-like exoplanets because they are difficult to find; large gas planets like Jupiter are more easily identified.

The positive progress, a recent wide-field sky survey, Transiting Exoplanet Survey Satellite (TESS) from 2018 to 2024, identified thousands of exoplanet candidates and of these 4-6% are earth-like orbiting in the habitual zone, 200-300 total. The low percentage is partly due to bias in the search, primarily the transit technique, which favors finding larger planets like Jupiter closer to their stars. But since there are trillions of planets in our Milky Way alone, there are, conservatively, millions of targets for analysis.

The soon-to-be completed Nancy Grace Roman space telescope (2027) will confirm thousands more prime candidates (Reference Figure 1).

Now turning to the next step, analysis. Biosignatures, elements and molecules associated with living things (oxygen, carbon, methane, and water), are detected in the atmospheres of exoplanets via spectrograph when planets transverse their stars or by direct imaging of the exoplanet. The spectrographs can analyze exoplanet atmospheres from thousands of light years away via transit or direct imaging. From just trickles of light, these magical instruments recognize elements and molecules from the surface or atmosphere of exoplanets. The Hubble Space Telescope and the James Webb Space Telescope (JWST), although not verifying biosignatures, have identified elements/molecules from planet transits, a predecessor observation of more extensive transit and ultimately direct imaging (Reference Figure 1).

For perspective, consider a quote from J. Winn's book (page 259), *A Little Book of Exoplanets*, "Surely, given the unfathomable number … of planets in the universe, and the billions of years that have elapsed, every possible chemical reaction has been repeated many times in many places, including those that spawn life. The only question is how far we need to look."

The preferred technique for obtaining biosignatures is direct imaging. However, because exoplanets are separated from their stars by small observing distances (range 0.2 to 4 arcseconds) and stars are so much brighter than the exoplanets (as much as a billion times) advanced technology, such as coronagraphs (sun shields that block out light from the star to make nearby exoplanets visible), high resolution, large apertures, AI data analysis, and adaptive optics (for ground-based telescopes), are prerequisites.

The first exoplanet directly imaged was 2M1207b, an exoplanet 4-5 times the mass of Jupiter orbiting a brown dwarf at 240 light-years from earth. It was discovered in 2004 using the Very Large Telescope (VLT) in Chile. More recently in January 2024, JWST imaged the exoplanet AF Leporis b, a gas giant 88 light-years away with a mass estimated between two to five times that of Jupiter, orbiting its host star at a distance comparable to Saturn's orbit. The image revealed active atmospheric convection currents and unexpected levels of carbon monoxide, possible biosignatures.

Three future activities enhance the search for biosignatures. First, existing large earth-based optical/infrared telescopes (Keck I/II, Very Large Telescope, and Gemini), and the orbiting JWST will focus detection on the most habitable exoplanets found by sky surveys. These telescopes all have coronagraphs for direct imaging. Second, three giant aperture telescopes (GMT, ELT, and TMT) are under construction and will be operational in the next few years (Reference Figure 2). These three giant telescopes all have advanced spectrographs, coronagraphs, and high resolution for direct imaging. Of course, telescope observation time for exoplanets competes with other priorities like black holes, universe expansion rate, early galaxy structure, etc., but a focused list of exoplanets increases the priority of exoplanet analysis for telescope observing time. Third, although farther in the future, the Habitable Worlds Observatory (HWO), a large space telescope customized for studying exoplanets, is planned for 2035 (Reference Figure 1).

It is anticipated that biosignature detections will be reported periodically. Discovering life via a statistically significant number of exoplanets biosignatures could turn out to be easier than detecting it in the crevices of our Solar System.

C. Exoplanet Technosignatures

Technosignatures provide circumstantial evidence, possibly strong evidence, of alien life. They may represent artificial processes or structures. Examples are a) byproducts of energy consumption - chemical pollutants or industrial gases; b) artificial lighting; c) waste heat from excessive energy consumption; and d) orbital megastructures, for example, hypothetical Dyson spheres (large energy collectors used by advanced alien society to harness more energy from their sun). However, distinguishing between natural and artificial technosignatures remains a key hurdle.

In this article, alien messages are considered a subset of technosignatures because they are definitive; it absolutely requires intelligence to send a message. Thus, messages are discussed separately in the next section.

Recently, an ambitious study based on the Wide-field Infrared Survey Explorer's (WISE) survey of 100,000 galaxies was reported on April 15, 2015. The hypothesis assumed that a Kardashev supercivilization would emit high mid-infrared luminosity based on the civilization's technology spanning an entire galaxy. The negative results headline was "Alien supercivilization absent from 100,000 nearby galaxies", which implies a major strike against finding aliens. However, the headline is misleading because the assumption of a type three Kardashev supercivilization, a civilization capable of harnessing enormous amounts of energy on a cosmic scale, is highly speculative, for example, civilizations might self-limit their energy consumption or galactic dominance may not align with their motivations, societal structures, or environmental constraints. Thus, a proper perspective diminishes the implication of the headline. So, what lies ahead for exoplanet technosignatures?

In a few years, as with biosignatures, exoplanet atmospheric searches for technosignatures will be significantly enhanced by the three-giant optical/infrared ground telescopes (GMT, ELT, and TMT). Second, advanced large radio telescopes are under construction LOFAR 2.0, SKA-low/mid, and ngVLA (Reference Figure 4). These future arrays have unprecedented sensitivity and resolution to detect faint or dispersed signals, making it easier for AI analysis of data to isolate unusual phenomena indicative of large-scale astro engineering. Their sensitivity and global collaboration networks make them key players in the search for technosignatures. And equally good news, as with biosignatures, the Habitable World Observatory (HWO), will be customized for studying potential exoplanet technosignatures (Reference Figure 1).

In summary, technosignature searches focus on habitable exoplanets, stars, and entire galaxies. However, discoveries will be more difficult than biosignatures. Now turning to definitive options.

D. Messages

In the movie Contact (1997), a radio message received by the VLA radio telescope in New Mexico, was discovered by Dr. Ellie Arroway (Jody Foster) who was working for the Search for Extraterrestrial Intelligence (SETI) program. The message provided coded instructions for building a machine which subsequently transported Dr, Arroway, virtually instantaneously, to the star Vega. An advanced civilization had constructed corridors (possibly wormholes) for interstellar travel. As it turned out, no one believed her story of alien contact although her recorder had 18 minutes of static confirming the duration of the trip and contradicting the few seconds elapsed on earth – a great story.

The modern Search for Extraterrestrial Intelligence (SETI) began in 1960 with Project Ozma, led by American astronomer Frank Drake. He used the National Radio Astronomy Observatory in Green Bank GBA), to scan two nearby Sun-like stars, Epsilon Eridani and Tau Ceti, for radio signals that might indicate intelligent life. Nothing was found.

Eventually, SETI formed in 1984 as a not-for-profit research organization committed to search for intelligent life via alien communication/messages. They have conducted multiple Breakthrough Listen projects employing rather extensive searches over the past forty years.

One recent optimistic project was on October 16, 2024, when scientists at the SETI Institute used the Allen Telescope Array (ATA) to search for signs of alien communication among the seven exoplanets in the TRAPPIST-1 star system, which includes exoplanets in the habitable zone. If intelligent aliens inhabited multiple planets, they might communicate with each other.

Also, any inhabited planet might, intentionally or unintentionally, send out electromagnetic transmissions. In the 28 hours of monitoring, the result was negative.

But the search has just begun, and future endeavors are promising. First, existing sensitive radio telescopes will continue their search for communication/messages: Parks, VLA, GBT, ATA, ALMA, FAST, and MeerKAT (Reference Figure 3). Second, as with technosignatures, advanced large radio telescopes under construction (LOFAR 2.0, SKA-low/mid, and ngVLA) will significantly enhance search sensitivity (Reference Figure 4). And third, two optical laser telescopes used in the Breakthrough Listen initiative will continue operation: a) Automated Planet Finder (APF), with four light year sensitivity, located at Lick Observatory in California (identical telescopes are planned for other locations), and b) Very Energetic Radiation Imaging Telescope Array System (VERITAS). This array based in Arizona consists of four 12-meter telescopes. It traditionally studies high-energy gamma-ray sources but has been adapted to detect very short optical pulses which could be indicative of intentional laser signals from advanced extraterrestrial civilizations.

Receiving an interstellar message is positive proof of aliens. With focused future searches and new sophisticated telescopes, the odds of detection significantly improve.

E. UFOs

A UFO, with living or robotic subjects, is undeniable proof of alien intelligence. However, in our search, it is the most improbable because of the time required traveling from distant star systems. It is more likely that electronic communications, traveling at the speed of light, would be intercepted hundreds or thousands of years prior to a physical ship. This assumes communication is emanating from exoplanets hundreds or thousands of light years away from earth.

More interesting than unfounded UFO sightings is the interstellar traveler Oumuamua, a small object estimated to be between 300 and 3,000 feet long, with its width and thickness both estimated to be between 115 and 548 feet. In 2017 it was spotted by the 1.8-meter PanSTARRS1 telescope in Maui. Astrophysicist Avi Loeb's book, *Extraterrestrial*, defends his belief that it was a relic of alien technology. His logic reflects Oumuamua's strange trajectory, shape, luminosity, and reflectivity. Unfortunately, Oumuamua was detected too late, based on its small size, trajectory, and high speed, for detailed analysis and subsequently "flew" out of telescope range. However, most astronomers disagree with Loeb's hypothesis and believe Oumuamua was a comet.

So, what is the future? Advanced wide-field sky surveys will identify similar interstellar objects in adequate time for rigorous investigation. The Vera C. Rubin telescope scheduled for 2025

(Reference Figure 2) would have spotted Oumuamua three months earlier. Thus, the next interstellar visitor will not get away!

F. Assumptions for the Search

There are several assumptions implied in this article which have not been explained or defended. A few major assumptions, both those related to discovering microbes and those related to discovering alien intelligence, are listed below. Some are philosophical, for example, aliens wanting to communicate. Others are speculative, for example, the life span of alien civilizations, and some may require a lengthy discussion about opposing assumptions, for example the uniqueness of advanced technology (communication, energy consumption, megastructures, etc.). However, debating these issues is beyond the article's objective, which is providing a comprehensive overview of the future search for life and intelligence.

<u>Microbe life assumptions</u>
Requirements for life (energy source, carbon based organic material, and liquid water) exist on a large number of exoplanets orbiting in the habitable zone; processes leading to life are governed by universal physical and chemical laws, suggesting that life could arise under similar conditions in different locations; and, many exoplanets are billions of years older than earth (the most common M type stars, red dwarfs, shine for 100 billion to a trillion years). Thus, there is a significant likelihood of life evolving.

<u>Intelligent life assumptions</u>

Intelligence is inherent in the universe's evolution, for example on earth, intelligence developed at least three times (humans, whales, and dolphins); aliens on exoplanets orbiting long-living stars (M, red dwarfs) have extended time, billions of years, to develop advanced technology; aliens use the same communication, electromagnetic waves, as we do rather than neutrinos or gravitational waves or dark matter or other means; some civilization will exist for thousands or millions of years and want to communicate; some alien civilizations will broadcast for extended periods of time; our telescopes have adequate sensitivity to detect alien signals, beacon or targeted, over thousands of lightyears away; aliens might evolve into robotic, non-organic entities which still produce observable technosignatures; and energy consumption increases with a civilization's progression.

Summary

From the Solar System to the Milky Way to deep space, the search for life continues. Within the Solar System, space probes, specifically JUICE and Clipper, are key detection tools. They are armed with technical instruments to analyze the atmosphere contents and moon sub-surfaces from their orbits. Dragonfly, a landing rover on its way to Titan, is another detection tool. Currently, the Perseverance rover is drilling and storing soil core samples on Mars for a space flight back to earth. Thus, results confirming that microbes exist in the Solar System are 5-6 years away.

As we peer into the Milky Way, exoplanets are the target. Improved sky-survey telescopes enhance this search by identifying exoplanets for subsequent analysis. Both existing and future telescopes have sophisticated technology, for example, adaptive optics, coronagraphs, giant apertures, advanced spectrometers, AI for data analysis, and integration of multiple telescope observations. If biosignatures reflecting organic life are present and the exoplanet is habitable, microbes are probable.

Detection of intelligent life is either circumstantial or definitive. Technosignatures offer circumstantial evidence of alien civilizations. Definitive or positive detection can be physical, for example, discovering interstellar objects (spaceship/UFOs) or as in the movie Contact, an alien message. Future giant optical/infrared telescopes, sophisticated radio telescopes, and a proposed space telescope, HWO, will dramatically enhance detection.

This article documented future technology and projects that enhance our search for life/intelligence. And, as stated in the introduction, the world wants to know, are we alone? Many countries, Europe, China, Chile, Japan, Australia, South Africa, Canada, and others collaborate in the search.

Quoting J, Winn again (page 252), "If we find intelligent life forms, we will have an intense desire to communicate. What might their civilization teach ours about the workings of the universe, about how to overcome the challenges of long-term existence, about the meaning of it all? There would be implications for science, technology, politics, religion, and, well, everything."

The motto for every search (Solar System, biosignatures, technosignatures, messages, and UFOs), must be: **"If life is out there, we will find it. It might be next week or next year or in ten years, but it is only a matter of time."**

Space Telescopes	Year	Mirror size	Freq	Cor	Res	Purpose
Hubble, NASA	1990 1995	2.4 m	UV, O, NIR	No	0.05	Deep field images, first to detect elements in exoplanet atmosphere
James Webb (JWST), NASA	2021	6.5 m	NIR, MIR, O	Y	0.1	Multiple objectives including direct imaging of exoplanets and chemical composition of atmosphere
Nancy Grace Roman (formerly WFIRST), NASA	2027	2.4 m	IR	Y	0.1	Wide-field view to find exoplanets with Roman Coronagraph Instrument (CGI), a technology innovation for direct imaging
Atmospheric Remote-sensing Infrared Exoplanet Large-survey (Ariel), ESA	2029	1.1 m	IR	No	N/A	Ingredients of atmospheres and planet weather for 1,000 planets, a Breakthrough Initiative
Habitable Worlds Observatory (HWO), NASA	2035-2041	8-15 m	MIR, FIR	Y	Low	Combined HabEX and LUVOIR plans, specifically for exoplanets direct imaging and technosignatures

Figure 1. Space Telescopes, current and future

Notes: Freq = Frequency: UV = ultraviolet; O = optical; IR = infrared; NIR = near-infrared; MIR = mid-infrared. Cor is coronagraph which blocks out light from host star allowing exoplanet imaging; Res is resolution limit of a telescope in arcseconds. This is not an all-inclusive list.

Location	Telescopes, Optical/Infrared/Ultraviolet	Year	Mirror size	Freq.	AO	Cor.	Res.	Purpose
Mauna Kea 13,287 ft Chile 8,900 ft	Gemini, North and South	2000	8.1 m	O, IR	Y	Y	0.04	Multiple objectives including direct imaging and biosignatures
Mauna Kea 13,287 ft	Keck telescopes	1993	2 x 10 m	O	Y	Y	0.04	Multiple objectives including biosignatures and direct imaging, for example, HR 8799 (over 7 years)
Chile 8,645 ft	Very Large Telescope (VLT), ESA	1998	Four 8.2 m plus four 1.8 m	O, IR	Y	Y	0.05	Resolution with all four mirrors, first direct image of an exoplanet, named 2M1207b in 2005. biosignature capable
Chile 8,900 ft	Vera C. Rubin Observatory, NASA	2025	8.4 m, wide field of view	IR	No	No	0.2	Focus on wide field sky-surveys, will identify interstellar objects
Chile 8,248 ft	Giant Magellan Telescope (GMT), NASA	2026/ 2030s	24.5 m	O, NIR	Y	Y	0.01	Multiple objectives including direct imaging and technosignatures, full capabilities in 2030
Chile 9,993 ft	Extremely Large telescope (ELT), ESA	2028	39 m	O, IR	Y	Y	0.01	Multiple objectives including direct imaging and technosignatures
Mauna Kea 13,287 ft	Thirty meter telescope (TMT)	2030?	30 m	O, NIR MIR, UV	Y	Y	0.01	Multiple objectives including direct imaging and technosignatures

Figure 2. Optical/Infrared/Ultraviolet Telescopes

Notes: Frequency: O = optical; IR = infrared; NIR = near-infrared; MIR = mid-infrared; UV = ultraviolet. AO is adoptive optics which correct for atmospheric disturbances; Cor is coronagraph which blocks out light from host star allowing exoplanet imaging; Res is resolution limit of a telescope in arcseconds. This is not an all-inclusive list.

Location	Existing Radio Telescopes	Year	Size	Frequency	Purpose
Australia	Parks Observatory (Murri Yang)	1961	one 64 m dish	700 MHz to 4 GHz	Breakthrough Listen Southern Hemisphere participant along with GBT and VLA
New Mexico	Very Large Aperture (VLA/LaVLA)	1981	27 dishes each 25 m	1 GHz to 50 GHz	One objective is looking for communication/messages
West Virginia	Green Bank Telescope (GBT)	2002	one 100 m dish	0.29 GHz to 115 GHz	Major role in Breakthrough Listen initiative looking for communication/messages
Northern California	Allen Telescope Array (ATA)	2007	42 dishes each 6 m	0.5 GHZ to 11.2 GHz	Designed specifically for SETI, searches for interstellar communication
Chile	Atacama Large Millimeter/submillimeter Array (ALMA)	2013	66 dishes each 12 m	84 GHz to 950 GHz	Can detect molecules like water vapor, carbon dioxide, and organic molecules.
China	Five Hundred Meter Telescope (FAST)	2016	one 500 m dish	70 MHz to 3 GHz	Detecting interstellar communication signals is part of mission
South Africa	Karoo Array Telescope Meer (MeerKAT)	2016	64 dishes each 13.5 m	0.58 GHz to 14.5 GHz	Breakthrouh Listen initiative, search for communication/messages, will merge with SKA-mid

Figure 3. Exiting Radio Telescopes

Note. This is not an all-inclusive list.

Location	Future Radio Telescopes	Year	Size	Frequency	Purpose
Europe	Low Frequency Array 2.0 (LOFAR)	2025	100s diploe two types low/high band	10 - 90 MHz 110 - 240 MHz	Largest low frequency radio telescope, search for communication/messages, and technosignatures
Australia	Square Kilometer Array (SKA-low)	2027	10,000s of Diploe antenna	50 MHz to 350 MHz	Provides better resolution and sensitivity than current instruments, search for communication/messages, and technosignatures
South Africa	Square Kilometer Array (SKA-mid)	2027	197 dishes each 15 m	350 MHz to 14 GHz	Merged with MeerKAT, similar design to Allen (ATA), but significantly more sensitive, search for communication/messages
New Mexico	New Generation VLA (ngVLA)	2031 to 2037	244 antenna each 18 m	1.2 - 50.5 GHz 70 - 116 GHz	Designed to increase sensitivity ten times and angular resolution 5-10 times over existing VLA and ALMA, search for communication/messages, and technosignatures

Figure 4, Future Radio Telescopes

Note. This is not an all-inclusive list.