Fermi paradox

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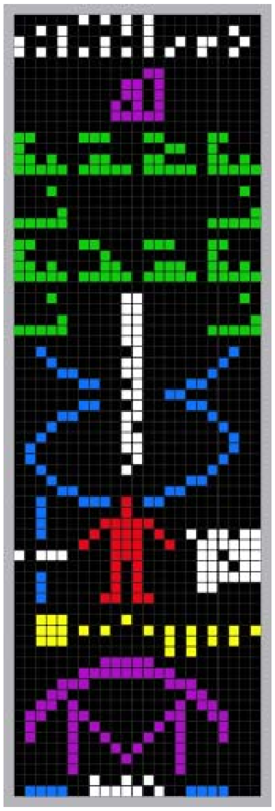
This article is about the absence of evidence for extraterrestrial intelligence. For the type of estimation problem, see Fermi problem. For the music album, see Fermi Paradox (album). For the short story, see The Fermi Paradox Is Our Business Model.



A graphical representation of the Arecibo message – Humanity's first attempt to use radio waves to actively communicate its existence to alien civilizations

The **Fermi paradox** (or **Fermi's paradox**) is the apparent contradiction between high estimates of the probability of the existence of extraterrestrial civilization and humanity's lack of contact with, or evidence for, such civilizations.[1] The basic points of the argument, made by physicists Enrico Fermi and Michael H. Hart, are:

- The Sun is a young star. There are billions of stars in the galaxy that are billions of years older;
- Some of these stars likely have Earth-like planets[2] which, if the Earth is typical, may develop intelligent life;
- Presumably some of these civilizations will develop interstellar travel, as Earth seems likely to do;
- At any practical pace of interstellar travel, the galaxy can be completely colonized in just a few tens of millions of years.

According to this line of thinking, the Earth should have already been colonized, or at least visited. But no convincing evidence of this exists. Furthermore, no confirmed signs of intelligence elsewhere have been spotted, either in our galaxy or the more than 80 billion other galaxies of the observable universe. Hence Fermi's question "Where is everybody?"

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Overview

The age of the universe and its vast number of stars suggest that unless the Earth is very atypical, extraterrestrial life should be common.[3] In an informal discussion in 1950, the physicist Enrico Fermi questioned why, if a multitude of advanced extraterrestrial civilizations exists in the Milky Way galaxy, evidence such as spacecraft or probes is not seen. A more detailed examination of the implications of the topic began with a paper by Michael H. Hart in 1975, and it is sometimes referred to as the **Fermi–Hart paradox**.[4] Other common names for the same phenomenon are *Fermi's question* ("Where are they?"), the *Fermi Problem*, the *Great Silence*,[5][6][7][8][9] and *silentium universi*[9][10] (Latin for "silence of the universe").

There have been attempts to resolve the Fermi paradox by locating evidence of extraterrestrial civilizations, along with proposals that such life could exist without human knowledge. Counterarguments suggest that intelligent extraterrestrial life does not exist or occurs so rarely or briefly that humans will never make contact with it.

Starting with Hart, a great deal of effort has gone into developing scientific theories about, and possible models of, extraterrestrial life, and the Fermi paradox has become a theoretical reference point in much of this work. The problem has spawned numerous scholarly works addressing it directly, while questions that relate to it have been addressed in fields as diverse as astronomy, biology, ecology, and philosophy. The emerging field of astrobiology has brought an interdisciplinary approach to the Fermi paradox and the question of extraterrestrial life.

Basis

The Fermi paradox is a conflict between an argument of scale and probability and a lack of evidence. A more complete definition could be stated thus:

The apparent size and age of the universe suggest that many technologically advanced extraterrestrial civilizations ought to exist.
However, this hypothesis seems inconsistent with the lack of observational evidence to support it.

The first aspect of the paradox, "the argument by scale", is a function of the raw numbers involved: there are an estimated 200–400 billion[11] ($2–4 \times 10^{11}$) stars in the Milky Way and 70 sextillion (7×10^{22}) in the visible universe.[12] Even if intelligent life occurs on only a minuscule percentage of planets around these stars, there might still be a great number of civilizations extant in the Milky Way galaxy alone. This argument also assumes the mediocrity principle, which states that Earth is not special, but merely a typical planet, subject to the same laws, effects, and likely outcomes as any other world.

The second cornerstone of the Fermi paradox is a rejoinder to the argument by scale: given intelligent life's ability to overcome scarcity, and its tendency to colonize new habitats, it seems likely that at least some civilizations would be technologically advanced, seek out new resources in space and then colonize first their own star system and subsequently the surrounding star systems. Since there is no conclusive or certifiable evidence on Earth or elsewhere in the known universe of other intelligent life after 13.7 billion years of the universe's history, we have the conflict requiring a resolution. Some examples of possible resolutions are that intelligent life is rarer than we think, or that our assumptions about the general behavior of intelligent species are flawed.

The Fermi paradox can be asked in two ways. The first is, "Why are no aliens or their artifacts physically here?" If interstellar travel is possible, even the "slow" kind nearly within the reach of Earth technology, then it would only take from 5 million to 50 million years to colonize the galaxy.[13] This is a relatively small amount of time on a geological scale, let alone a cosmological one. Since there are many stars older than the Sun, or since intelligent life might have evolved earlier elsewhere, the question then becomes why the galaxy has not been colonized already. Even if colonization is impractical or undesirable to all alien civilizations, large-scale *exploration* of the galaxy is still possible; the means of exploration and theoretical probes involved are discussed extensively below. However, no signs of either colonization or exploration have been generally acknowledged.

The argument above may not hold for the universe as a whole, since travel times may well explain the lack of physical presence on Earth of alien inhabitants of far away galaxies. However, the question then becomes "Why do we see no signs of intelligent life?" since a sufficiently advanced civilization[Note 1] could potentially be observable over a significant fraction of the size of the observable universe.[14] Even if such civilizations are rare, the scale argument indicates they should exist somewhere at some point during the history of the universe, and since they could be detected from far away over a considerable period of time, many more potential sites for their origin are within range of our observation. However, no incontrovertible signs of such civilizations have been detected.

It is unclear which version of the paradox is stronger.[Note 2]

Name

In 1950, while working at Los Alamos National Laboratory, Fermi had a casual conversation while walking to lunch with colleagues Emil Konopinski, Edward Teller and Herbert York. The men discussed a recent spate of UFO reports and an Alan Dunn cartoon[15] facetiously blaming the disappearance of municipal trashcans on marauding aliens. They then had a more serious discussion regarding the chances of humans observing faster-than-light travel by some material object within the next ten years, which Teller put at one in a million, but Fermi put closer to one in ten. The conversation shifted to other subjects, until during lunch Fermi suddenly exclaimed, "Where are they?" (alternatively, *"Where is everybody?"*).[16] One participant recollects that Fermi then made a series of rapid calculations using estimated figures. (Fermi was known for his ability to make good estimates from first principles and minimal data, see Fermi problem.) According to this account, he then concluded that Earth should have been visited long ago and many times over.[16][17]

Drake equation

Main article: Drake equation

While numerous theories and principles are related to the Fermi paradox, the most closely related is the Drake equation.

The equation was formulated by Dr. Frank Drake in 1961, a decade after the objections raised by Enrico Fermi, in an attempt to find a systematic means to evaluate the numerous probabilities involved in alien life. The speculative equation factors in: the rate of star formation in the galaxy; the fraction of stars with planets and the number per star that are habitable; the fraction of those planets which develop life, the fraction of intelligent life, and the further fraction of detectable technological intelligent life; and finally the length of time such civilizations are detectable. The fundamental problem is that the last four terms (fraction of planets with life, odds life becomes intelligent, odds intelligent life becomes detectable, and detectable lifetime of civilizations) are completely unknown. We have only one example, rendering statistical estimates impossible, and even the example we have is subject to a strong anthropic bias.

A deeper objection is that the very form of the Drake equation assumes that civilizations arise and then die out within their original star systems. If interstellar colonization is possible, then this assumption is invalid, and the equations of population dynamics would apply instead.[18]

The Drake equation has been used by both optimists and pessimists with wildly differing results. Dr. Carl Sagan, using optimistic numbers, suggested as many as one million communicating civilizations in the Milky Way in 1966, though he later suggested that the actual number could be far smaller. Frank Tipler and John D Barrow used pessimistic numbers and concluded that the average number of civilizations in a galaxy is much less than one.[19][Note 3] Frank Drake himself has commented that the Drake equation is unlikely to settle the Fermi paradox; instead it is just a way of "organizing our ignorance" on the subject.[20]

Empirical resolution attempts

One obvious way to resolve the Fermi paradox would be to find conclusive evidence of extraterrestrial intelligence. Efforts to find such evidence have been made since 1960, and several are ongoing as of 2012.[21] As human beings do not possess interstellar travel capability, such searches are being remotely carried out at great distances and rely on analysis of very subtle evidence. This limits possible discoveries to civilizations which alter their environment in a detectable way, or produce effects that are observable at a distance, such as radio emissions. It is very unlikely that non-technological civilizations will be detectable from Earth in the near future.

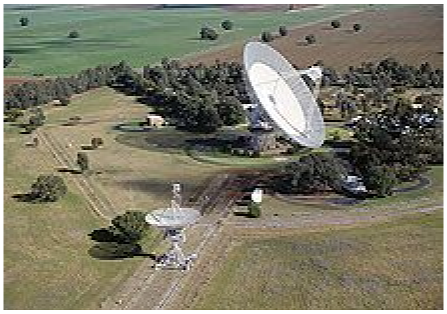
One difficulty in searching is avoiding an overly anthropocentric viewpoint. Conjecture on the type of evidence likely to be found often focuses on the types of activities that humans have performed, or likely would perform given more advanced technology. Intelligent aliens might avoid these "expected" activities, or perform activities totally novel to humans.

Mainstream astronomy and SETI

There are two ways that astronomy might find evidence of an extraterrestrial civilization. One is that conventional astronomers, studying stars, planets, and galaxies, might serendipitously observe some phenomenon that cannot be explained without positing an intelligent civilization as the source. This has been suspected several times. Pulsars, when first discovered, were called LGMs (Little Green Men), because of the precise repetition of their pulses (they rival the best atomic clocks). Likewise Seyfert galaxies were suspected to be *industrial accidents*[22] because their enormous and directed energy output had no initial explanation. Eventually, natural explanations not involving intelligent life have been found for all such observations to date,[23] but the possibility of discovery remains.[24] Proposed examples include asteroid mining that would change the appearance of debris disks around stars[25] or large-scale use of solar power changing the light curve of planets measured near eclipse.[26]

The other way astronomy might settle the Fermi paradox is through a search specifically dedicated to finding evidence of life.

Radio emissions



Further information: SETI, Project Ozma, Project Cyclops, Project Phoenix (SETI), SERENDIP, and Allen Telescope Array

Radio telescopes are often used by SETI projects

Radio technology and the ability to construct a radio telescope are presumed to be a natural advance for technological species,[27] theoretically creating effects that might be detected over interstellar distances. Sensitive observers of the Solar System, for example, would note unusually intense radio waves for a G2 star due to Earth's television and telecommunication broadcasts. In the absence of an apparent natural cause, alien observers might infer the existence of terrestrial civilization. It should be noted however that even much more sensitive radio telescopes than those currently available on Earth would not be able to detect non-directional radio signals even at a fraction of a light year, so it's questionable whether any such signals could be detected by an extraterrestrial civilization.[28]

Therefore, the careful searching of radio emissions from space for non-natural signals may lead to the detection of alien civilizations. Such signals could be either "accidental" by-products of a civilization, or deliberate attempts to communicate, such as the Communication with Extraterrestrial Intelligence's Arecibo message. A number of astronomers and observatories have attempted and are attempting to detect such evidence, mostly through the SETI organization, although other approaches, such as optical SETI, also exist.

Several decades of SETI analysis have not revealed any main sequence stars with unusually bright or meaningfully repetitive radio emissions, although there have been several candidate signals. On August 15, 1977 the "Wow! signal" was picked up by The Big Ear radio telescope. However, the Big Ear only looks at each point on the sky for 72 seconds, and re-examinations of the same spot have found nothing. In 2003, Radio source SHGb02+14a was isolated by SETI@home analysis, although it has largely been discounted by further study. There are numerous technical assumptions underlying SETI that may cause human beings to miss radio emissions with present search techniques; these are discussed below.

Direct planetary observation

A composite picture of Earth at night, created with data from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). Large-scale artificial lighting as produced by the human civilization is detectable from space.[29]

Detection and classification of exoplanets has come out of recent refinements in mainstream astronomical instruments and analysis. While this is a new field in astronomy—the first published paper claiming to have discovered an exoplanet was released in 1989—it is possible that planets which are likely able to support life will be found in the near future.

Direct evidence for the existence of life may eventually be observable, such as the detection of biotic signature gases (such as methane and oxygen)—or even the industrial air pollution of a technologically advanced civilization—in an exoplanet's atmosphere by means of spectrographic analysis.[30] With improvements in our observational capabilities, it may eventually even be possible to detect direct evidence such as that which humanity produces (see right).

However, exoplanets are rarely directly observed (the first claim to have done so was made in 2004[31]); rather, their existence is usually inferred from the effects they have on the star(s) they orbit. This means that usually only the mass and orbit of an exoplanet can be deduced. This information, along with the stellar classification of its sun, and educated guesses as to its composition (usually based on the mass of the planet, and its distance from its sun), allows only for rough approximations of the planetary environment.

Prior to 2009, methods for exoplanet detection were not likely to detect life-bearing Earth-like worlds. Methods such as gravitational microlensing can detect the presence of "small" worlds, potentially even smaller than the Earth, but can only detect such worlds for very brief moments of time, and no follow-up is possible. Other methods such as radial velocity, astrometry, and the transit method allow prolonged observations of exoplanet effects, but only work with worlds that are many times the mass of Earth, at least when performed while looking through the atmosphere. These seem unlikely candidates to harbor Earth-like life. However, exoplanet detection and classification is a very active sub-discipline in astronomy, with 424 such planets being detected between 1988 and 2010,[32] and the first possibly terrestrial planet discovered within a star's habitable zone being found in 2007.[33] New refinements in exoplanet detection methods, and use of existing methods from space, (such as the Kepler Mission, launched in 2009) are expected to detect and characterize terrestrial-size planets, and determine if they are within the habitable zones of their stars. Such observational refinements may allow us to better gauge how common potentially habitable worlds are. Using methods like the Drake equation with this data would therefore allow a much better idea of how common life in the universe might be; this would have a profound influence over the expectations behind the Fermi paradox itself.

Alien constructs

Probes, colonies, and other artifacts

Further information: Von Neumann probe and Bracewell probe

As noted, given the size and age of the universe, and the relative rapidity at which dispersion of intelligent life can in principle occur, evidence of alien colonization attempts might plausibly be discovered. Evidence of exploration not containing extraterrestrial life, such as probes and information gathering devices, may also await discovery.

Some theoretical exploration techniques such as the Von Neumann probe (a self-replicating device) could exhaustively explore a galaxy the size of the Milky Way in as little as half a million years, with comparatively little investment in materials and energy relative to the results. If even a single civilization in the Milky Way attempted this, such probes could spread throughout the entire galaxy. Evidence of such probes might be found in the Solar System—perhaps in the asteroid belt where raw materials would be plentiful and easily accessed.[34]

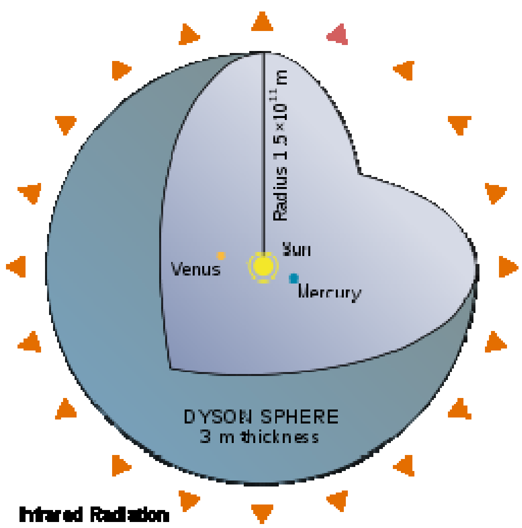
Another possibility for contact with an alien probe—one that would be trying to find human beings—is an alien Bracewell probe. Such a device would be an autonomous space probe whose purpose is to seek out and communicate with alien civilizations (as opposed to Von Neumann probes, which are usually described as purely exploratory). These were proposed as an alternative to carrying a slow speed-of-light dialogue between vastly distant neighbours. Rather than contending with the long delays a radio dialogue would suffer, a probe housing an artificial intelligence would seek out an alien civilization to carry on a close range communication with the discovered civilization. The findings of such a probe would still have to be transmitted to the home civilization at light speed, but an information-gathering dialogue could be conducted in real time.[35]

Since the 1950s, direct exploration has been carried out on a small fraction of the Solar System and no evidence that it has ever been visited by alien colonists, or probes, has been uncovered. Detailed exploration of areas of the Solar System where resources would be plentiful—such as the asteroids, the Kuiper belt, the Oort cloud and the planetary ring systems—may yet produce evidence of alien exploration, though these regions are vast and difficult to investigate. There have been preliminary efforts in this direction in the form of the SETA and SETV projects to search for extraterrestrial artifacts or other evidence of extraterrestrial visitation within the Solar System.[36] There have also been attempts to signal, attract, or activate Bracewell probes in Earth's local vicinity, including by scientists Robert Freitas and Francisco Valdes.[37] Many of the projects that fall under this umbrella are considered "fringe" science by astronomers and none of the projects has located any artifacts.

Should alien artifacts be discovered, even here on Earth, they may not be recognizable as such. The products of an alien mind and an advanced alien technology might not be perceptible or recognizable as artificial constructs. Exploratory devices in the form of bio-engineered life forms created through synthetic biology would presumably disintegrate after a point, leaving no evidence; an alien information gathering system based on molecular nanotechnology could be all around us at this very moment, completely undetected. The same might be true of civilizations that actively hide their investigations from us, for possible reasons described further in this article. Also, Clarke's third law suggests that an alien civilization well in advance of humanity's might have means of investigation that are not yet conceivable to human beings.

Advanced stellar-scale artifacts

Further information: Dyson sphere, Kardashev scale, Alderson disk, Matrioshka brain, Stellar engine



A variant of the speculative Dyson sphere. Such large scale artifacts would drastically alter the spectrum of a star.

In 1959, Freeman Dyson observed that every developing human civilization constantly increases its energy consumption, and theoretically, a civilization of sufficient age would require *all* the energy produced by its star. The Dyson Sphere was the thought experiment that he derived as a solution: a shell or cloud of objects enclosing a star to harness as much radiant energy as possible. Such a feat of astroengineering would drastically alter the observed spectrum of the star involved, changing it at least partly from the normal emission lines of a natural stellar atmosphere, to that of a black body radiation, probably with a peak in the infrared. Dyson himself speculated that advanced alien civilizations might be detected by examining the spectra of stars, searching for such an altered spectrum.[38]

Since then, several other theoretical stellar-scale megastructures have been proposed, but the central idea remains that a highly advanced civilization—Type II or greater on the Kardashev scale—could alter its environment enough as to be detectable from interstellar distances.

However, such constructs may be more difficult to detect than originally thought. Dyson spheres might have different emission spectra depending on the desired internal environment; life based on high-temperature reactions may require a high temperature environment, with resulting "waste radiation" in the visible spectrum, not the infrared.[39] Additionally, a variant of the Dyson sphere has been proposed which would be difficult to observe from any great distance; a Matrioshka brain is a series of concentric spheres, each radiating less energy per area than its inner neighbour. The outermost sphere of such a structure could be close to the temperature of the interstellar background radiation, and thus be all but invisible.

There have been some preliminary attempts to find evidence of the existence of Dyson spheres or other large Type-II or Type-III Kardashev scale artifacts that would alter the spectra of their core stars.[40][41] These surveys have not located anything yet, though they are still incomplete. Similarly, direct observation of thousands of galaxies has shown no explicit evidence of artificial construction or modifications.

Explaining the paradox theoretically

Certain theoreticians accept that the apparent absence of evidence implies the absence of extraterrestrials and attempt to explain why. Others offer possible frameworks in which the silence may be explained without ruling out the possibility of such life, including assumptions about extraterrestrial behaviour and technology. Each of these hypothesized explanations is essentially an argument for decreasing the value of one or more of the terms in the Drake equation. The arguments are not, in general, mutually exclusive. For example, it could be both that life is rare, and technical civilizations are short lived, or many other combinations of the explanations below.[42]

Few, if any, other civilizations currently exist

One explanation is that the human civilization *is* alone (or very nearly so) in the galaxy. Several theories along these lines have been proposed, explaining why intelligent life might be either very rare, or very short lived. Implications of these hypotheses are examined as the Great Filter.[7]

No other civilizations have arisen

See also: Rare Earth hypothesis

Those who believe that extraterrestrial intelligent life does not exist argue that the conditions needed for life—or at least complex life—to evolve are rare or even unique to Earth. This is known as the *Rare Earth* hypothesis, which attempts to resolve the Fermi paradox by rejecting the mediocrity principle, and asserting that Earth is not typical, but unusual or even unique. While a unique Earth has historically been assumed on philosophical or religious grounds, the Rare Earth Hypothesis uses quantifiable and statistical arguments to argue that multicellular life is exceedingly rare in the universe because Earth-like planets are themselves exceedingly rare and/or many improbable coincidences have converged to make complex life on Earth possible.[43] It is possible that complex life may evolve through other mechanisms than those found specifically here on Earth,[43] but the fact that in the history of life on the Earth only one species has developed a civilization to the point of being capable of space flight and radio technology lends more credence to the idea of technologically advanced civilizations being rare in the universe.

For example, the emergence of intelligence may have been an evolutionary accident. Geoffrey Miller proposes that human intelligence is the result of runaway sexual selection, which takes unpredictable directions. Steven Pinker, in his book *How the Mind Works*, cautions that the idea that evolution of life (once it has reached a certain minimum complexity) is bound to produce intelligent beings, relies on the fallacy of the "ladder of evolution": As evolution does not strive for a goal but just happens, it uses the adaptation most useful for a given ecological niche, and the fact that, on Earth, this led to technological intelligence only once so far may suggest that this outcome of natural selection is rare and hence by no means a certain development of the evolution of a tree of life.

Another theory along these lines is that even if the conditions needed for life might be common in the universe, that the formation of life itself, a complex array of molecules that are capable simultaneously of reproduction, of extraction of base components from the environment, and of obtaining energy in a form that life can use to maintain the reaction (or the initial abiogenesis on a potential life-bearing planet), might ultimately be very rare.

Additionally, in the nondirectional meandering from initial life to humans, other low-probability happenings may have been the transition from prokaryotic cells to eukaryotic cells (with separate nucleus, organelles, specialization, and a cytoskeleton allowing the cell to take on different shapes) and the transition from single-cellular life to multicellular life, which was recorded in the Cambrian Explosion of 530 mya when significant numbers of organisms had evolved hard body parts, although multicellular life perhaps first started to evolve a couple of hundred million years before that. Single celled life emerged c. 3.5 billion years ago, and for most of Earth's history and for reasons not fully understood there have only been single-celled creatures.

And there are many other potential branching points. For example, perhaps the transition from ocean creatures to land-dwelling creatures crucially depends on an unusually large moon and significant tides. Many astronomers refer to our Earth Moon pairing as a double planet. This ratio between parent and satellite is rare in our planetary system. There is no observational data on the numbers of 'double planets' in other planetary systems. And even fundamental conditions such as the chemical composition of the nursery nebula from which a planetary system forms could have unusual or detrimental consequences for the emergence and survival of life.

It is also possible that intelligence is common, but industrial civilization is not. For example, the rise of industrialism on Earth was driven by the presence of convenient energy sources such as fossil fuels. If such energy sources are rare or nonexistent elsewhere, then it may be far more difficult for an intelligent alien race to advance technologically to the point where humans could communicate with them. There may also be other unique factors on which our civilization is dependent. Or, on a water world, where the intelligent creatures are something like dolphins, it may be difficult to build fire and forge metals.

Another possibility is that Earth is the first planet in the Milky Way on which industrial civilization has arisen.[44] However, critics note that according to current understanding, many Earth-like planets were created many billions of years prior to Earth, so this explanation requires repudiation of the mediocrity principle.[45]

Insofar as the Rare Earth Hypothesis privileges life on Earth and its process of formation, it is a variant of the anthropic principle. The variant of the anthropic principle states the universe seems uniquely suited towards developing human intelligence. This philosophical stance opposes not only the mediocrity principle, but also the wider Copernican principle,[*citation needed*] which suggests there is no privileged location in the universe.

Opponents dismiss both Rare Earth and the anthropic principle as tautological—if a condition must exist in the universe for human life to arise, then the universe must already meet that condition, as human life exists—and as an argument from incredulity or lack of imagination. According to this analysis, the Rare Earth hypothesis confuses a description of how life on Earth arose with a uniform conclusion of how life *must* arise.[46] While the probability of the specific conditions on Earth being widely replicated is low, we do not know what complex life may require in order to evolve.[47][48]

It is the nature of intelligent life to destroy itself

See also: Doomsday argument

This is the argument that technological civilizations may usually or invariably destroy themselves before or shortly after developing radio or space flight technology. Possible means of annihilation include nuclear war, biological warfare or accidental contamination, climate change, nanotechnological catastrophe, ill-advised physics experiments,[Note 4] a badly programmed super-intelligence, or a Malthusian catastrophe after the deterioration of a planet's ecosphere. This general theme is explored both in fiction and in mainstream scientific theorizing.[49] Indeed, there are probabilistic arguments which suggest that human extinction may occur sooner rather than later. In 1966 Sagan and Shklovskii suggested that technological civilizations will either tend to destroy themselves within a century of developing interstellar communicative capability or master their self-destructive tendencies and survive for billion-year timescales.[50] Self-annihilation may also be viewed in terms of thermodynamics: insofar as life is an ordered system that can sustain itself against the tendency to disorder, the "external transmission" or interstellar communicative phase may be the point at which the system becomes unstable and self-destructs.[51]

From a Darwinian perspective, self-destruction would be an ironic outcome of evolutionary success. The evolutionary psychology that developed during the competition for scarce resources over the course of human evolution has left the species subject to aggressive, instinctual drives. These compel humanity to consume resources, extend longevity, and to reproduce—in part, the very motives that led to the development of technological society. It seems likely that intelligent extraterrestrial life would evolve in a similar fashion and thus face the same possibility of self-destruction. And yet, to provide a good answer to Fermi's Question, self-destruction by technological species would have to be a near universal occurrence.

This argument does not require the civilization to entirely self-destruct, only to become once again non-technological. In other ways it could persist and even thrive according to evolutionary standards, which postulate producing offspring as the sole goal of life—not "progress", be it in terms of technology or even intelligence.

It is the nature of intelligent life to destroy others

See also: technological singularity and Von Neumann probe

Another possibility is that an intelligent species beyond a certain point of technological capability will destroy other intelligence as it appears, as is exemplified by the theorised extermination of Neanderthals by early man. The idea that something, or someone, is destroying intelligent life in the universe has been well explored in science fiction[Note 5] and scientific literature.[5] A species might undertake such extermination out of expansionist motives, paranoia, or simple aggression. In 1981, cosmologist Edward Harrison argued that such behavior would be an act of prudence: an intelligent species that has overcome its own self-destructive tendencies might view any other species bent on galactic expansion as a kind of virus.[52] It has also been suggested that a successful alien species would be a superpredator, as is *Homo sapiens*.[53]

This hypothesis requires at least one civilization to have arisen in the past, and the first civilization would not have faced this problem.[54] However, it could still be that Earth is alone now. Like exploration, the extermination of other civilizations might be carried out with self-replicating spacecraft. Under such a scenario,[Note 5] even if a civilization that created such machines were to disappear, the probes could outlive their creators, destroying civilizations far into the future.

If true, this argument reduces the number of visible civilizations in two ways—by destroying some civilizations, and forcing others to remain quiet, under fear of discovery (see They choose not to interact with us) so we would see no signs of them. This may also make it impossible for life to evolve in regions of the universe close to a developed civilization, assuring that any new civilizations will start off far away from preexisting ones.

Life is periodically destroyed by naturally occurring events

On Earth, there have been numerous major extinction events that destroyed the majority of complex species alive at the time. The extinction of the dinosaurs is the best known example. These are believed to be caused by events such as impact from a large meteorite, massive volcanic eruptions, or astronomical events such as gamma ray bursts.[55] It may be the case that such extinction events are common throughout the universe and periodically destroy intelligent life (or at least destroy their civilizations) before the species is able to develop the technology to communicate with other species.[56]

Human beings were created alone

Religious and philosophical speculation about extraterrestrial intelligent life long predates modern scientific inquiry into the subject. Greek philosophers Leucippus, Democritus, and Epicurus (5th and 4th century BC) suggested that there may be other inhabited worlds. Some religious thinkers, including the Jewish philosopher Rabbi Hasdai Crescas (c. 1340–1410/1411) and the Christian philosopher Nicholas of Cusa (1401–1464), also put forward their views of the possibility of such extraterrestrial intelligence.

On the other hand, philosophers such as Aristotle and religious thinkers such as Thomas Aquinas claim that human beings are unique in the divine plan and counsel against belief in intelligent life on other worlds.[57] Aristotle believed the element of the heavens was Fire, as opposed to Earth, and so the heavens could not support life.[58] Thomas Aquinas additionally believed the uniqueness of God implied the uniqueness of Earth, and also notes the Bible refers to the world in the singular.[59]

Religious reasons for doubting the existence of extraterrestrial intelligent life resemble some forms of the Rare Earth Hypothesis. The argument here would be a teleological form of the strong anthropic principle: the universe was designed for the express purpose of creating human (and only human) intelligence.[60] This argument presupposes that a prior advanced intelligence existed in order to create human life, which might pose the question whether that intelligence was the only one to exist before it created us, but the perspective is a philosophical and abstract one.

Inflation theory and the Youngness Argument

Cosmologist Alan Guth proposed a multi-verse solution to the Fermi Paradox. In this theory, using the synchronous gauge probability distribution, young universes exceedingly outnumber older ones (by a factor of $e^{10^{37}}$ for every second of age). Therefore, averaged over all universes, universes with civilizations will almost always have just one, the first to develop. However, Guth notes "Perhaps this argument explains why SETI has not found any signals from alien civilizations, but I find it more plausible that it is merely a symptom that the synchronous gauge probability distribution is not the right one."[61]

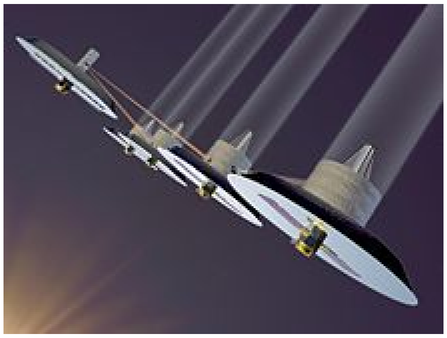
They do exist, but we see no evidence

It may be that technological extraterrestrial civilizations exist, but that human beings cannot communicate with them because of constraints: problems of scale or of technology; because they do not wish to communicate or their nature is simply too alien for meaningful communication, or perhaps even be recognized as technology.

Communication is improbable due to problems of scale

See also: Relativity of simultaneity

Intelligent civilizations are too far apart in space or time



NASA's conception of the Terrestrial Planet Finder

It may be that non-colonizing technologically capable alien civilizations exist, but that they are simply too far apart for meaningful two-way communication.[62] If two civilizations are separated by several thousand light years, it is very possible that one or both cultures may become extinct before meaningful dialogue can be established. Human searches may be able to detect their existence, but communication will remain impossible because of distance. This problem might be ameliorated somewhat if contact/communication is made through a Bracewell probe. In this case at least one partner in the exchange may obtain meaningful information. Alternatively, a civilization may simply broadcast its knowledge, and leave it to the receiver to make what they may of it. This is similar to the transmission of information from ancient civilizations to the present,[63] and humanity has undertaken similar activities like the Arecibo message, which could transfer information about Earth's intelligent species, even if it never yields a response (or does not yield a response in time for humanity to receive it). It is also possible that archaeological evidence of past civilizations may be detected through deep space observations—especially if they left behind large artifacts such as Dyson spheres.

The problem of distance is compounded by the fact that timescales affording a "window of opportunity" for detection or contact might be quite small. Advanced civilizations may periodically arise and fall throughout our galaxy, but this may be such a rare event, relatively speaking, that the odds of two or more such civilizations existing at the same time are low. There may have been intelligent civilizations in the galaxy before the emergence of intelligence on Earth, and there may be intelligent civilizations after its extinction, but it is possible that human beings are the only intelligent civilization in existence *now*. The term "now" is somewhat complicated by the finite speed of light and the nature of spacetime under relativity. Assuming that an extraterrestrial intelligence is not able to travel to our vicinity at faster-than-light speeds, in order to detect an intelligence 1,000 light-years distant, that intelligence will need to have been active 1,000 years ago. Strictly speaking, only the portions of the universe lying within the past light cone of Earth need be considered, since any civilizations outside it could not be detected. Another issue is the possibly very small length of time (even in historical timescales) that a civilization might be 'loudly' broadcasting material that could be reasonably detected (see below).

A related argument holds that other civilizations exist, and are transmitting and exploring, but their signals and probes simply have not arrived yet.[64] However, critics have noted that this is unlikely, since it requires that humanity's advancement has occurred at a very special point in time, while the Milky Way is in transition from empty to full. This is a tiny fraction of the life of a galaxy under ordinary assumptions and calculations resulting from them, so the likelihood that we're in the midst of this transition is considered low in the paradox.[65] Work on the theory of Neocatastrophism, wherein galactic and even super-galactic dynamics are seen as possibly frequently injurious to extant biospheres in a way that is roughly analogous to the way geological and climatological catastrophes have occasionally set back biological developments on Earth, might be given as a partial, if not full, resolution to the paradox, as advanced species might well be fragile to major events at a pace that would argue against a short transition.

It is too expensive to spread physically throughout the galaxy

See also: Project Daedalus, Project Orion (nuclear propulsion), and Project Longshot

Many assumptions about the ability of an alien culture to colonize other stars are based on the idea that interstellar travel is technologically feasible. While the current understanding of physics rules out the possibility of faster than light travel, it appears that there are no major theoretical barriers to the construction of "slow" interstellar ships. This idea underlies the concept of the Von Neumann probe and the Bracewell probe as evidence of extraterrestrial intelligence.

It is possible, however, that present scientific knowledge cannot properly gauge the feasibility and costs of such interstellar colonization. Theoretical barriers may not yet be understood and the cost of materials and energy for such ventures may be so high as to make it unlikely that any civilization could afford to attempt it. Even if interstellar travel and colonization are possible, they may be difficult, leading to a colonization model based on percolation theory.[66] Colonization efforts may not occur as an unstoppable rush, but rather as an uneven tendency to "percolate" outwards, within an eventual slowing and termination of the effort given the enormous costs involved and the fact that colonies will inevitably develop a culture and civilization of their own. Colonization may thus occur in "clusters," with large areas remaining uncolonized at any one time.

A similar argument holds that interstellar physical travel may be possible, but is much more expensive than interstellar communication. Furthermore, to an advanced civilization, travel itself may be replaced by communication, through mind uploading and similar technologies.[67] Therefore the first civilization may have physically explored or colonized the galaxy, but subsequent civilizations find it cheaper, faster, and easier to travel and get information through contacting existing civilizations rather than physically exploring or traveling themselves. In this scenario, since there is little or no physical travel, and directed communications are hard to see except to the intended receiver, there could be many technical and interacting civilizations with few signs visible across interstellar distances.

Human beings have not been searching long enough

Humanity's ability to detect and comprehend intelligent extraterrestrial life has existed for only a very brief period—from 1937 onwards, if the invention of the radio telescope is taken as the dividing line—and *Homo sapiens* is a geologically recent species. The whole period of modern human existence to date (about 200,000 years) is a very brief period on a cosmological scale, while radio transmissions have only been propagated since 1895. Thus it remains possible that human beings have neither been searching long enough to find other intelligences, nor been in existence long enough to be found.

One million years ago there would have been no humans for any extraterrestrial emissaries to meet. For each further step back in time, there would have been increasingly fewer indications to such emissaries that intelligent life would develop on Earth. In a large and already ancient universe, a space-faring alien species may well have had many other more promising worlds to visit and revisit. Even if alien emissaries visited in more recent times, they may have been interpreted by early human cultures as supernatural entities.

This hypothesis is more plausible if alien civilizations tend to stagnate or die out, rather than expand. In addition, "the probability of a site never being visited, even [with an] infinite time limit, is a non-zero value."[68] Thus, even if intelligent life expands elsewhere, it remains statistically possible that such extraterrestrial life might never discover Earth.

Communication is improbable for technical reasons

Humans are not listening properly

There are some assumptions that underlie the SETI search programs that may cause searchers to miss signals that are present. For example, the radio searches to date would completely miss highly compressed data streams (which would be almost indistinguishable from "white noise" to anyone who did not understand the compression algorithm). Extraterrestrials might also use frequencies that scientists have decided are unlikely to carry signals, or do not penetrate our atmosphere (e.g., gamma rays), or use modulation strategies that are not being looked for. The signals might be at a data rate that is too fast for our electronics to handle, or too slow to be recognised as attempts at communication. "Simple" broadcast techniques might be employed, but sent from non-main sequence stars which are searched with lower priority; current programs assume that most alien life will be orbiting Sun-like stars.[69]

The greatest problem is the sheer size of the radio search needed to look for signals (effectively spanning the entire visible universe), the limited amount of resources committed to SETI, and the sensitivity of modern instruments. SETI estimates, for instance, that with a radio telescope as sensitive as the Arecibo Observatory, Earth's television and radio broadcasts would only be detectable at distances up to 0.3 light years.[70] Clearly detecting an Earth type civilization at great distances is difficult. A signal is much easier to detect if the signal energy is limited to either a narrow range of frequencies (Narrowband transmissions), and/or directed at a specific part of the sky. Such signals can be detected at ranges of hundreds to tens of thousands of light-years distance.[71] However this means that detectors must be listening to an appropriate range of frequencies, and be in that region of space to which the beam is being sent. Many SETI searches, starting with the venerable Project Cyclops, go so far as to assume that extraterrestrial civilizations will be broadcasting a deliberate signal (like the Arecibo message), in order to be found.

Thus to detect alien civilizations through their radio emissions, Earth observers either need more sensitive instruments or must hope for fortunate circumstances: that the broadband radio emissions of alien radio technology are much stronger than our own (e.g., gamma-ray bursts); that one of SETI's programs is listening to the correct frequencies from the right regions of space; or that aliens are sending focused transmissions such as the Arecibo message in our general direction.

Civilizations broadcast detectable radio signals only for a brief period of time

It may be that alien civilizations are detectable through their radio emissions for only a short time, reducing the likelihood of spotting them. There are two possibilities in this regard: civilizations outgrow radio through technological advance or, conversely, resource depletion cuts short the time in which a species broadcasts.

The first idea, that civilizations advance beyond radio, is based in part on the "fiber optic objection": the use of high power radio with low-to-medium gain (i.e., non-directional) antennas for long-distance transmission is wasteful of spectrum, yet this "waste" is precisely what makes these systems conspicuous at interstellar distances. Humans are moving to directional or guided transmission channels such as electrical cables, optical fibers, narrow-beam microwave and lasers, and conventional radio with non-directional antennas is increasingly reserved for low-power, short-range applications such as cell phones and Wi-Fi networks. These signals are far less detectable from space. Analog television, developed in the mid-twentieth century, contains strong carriers to aid reception and demodulation. Carriers are spectral lines that are very easily detected yet do not convey any information beyond their highly artificial nature. Nearly every SETI project is looking for carriers for just this reason, and UHF TV carriers are the most conspicuous and artificial signals from Earth that could be detected at interstellar distances. But advances in technology are replacing analog TV with digital television which uses spectrum more efficiently by eliminating or reducing components such as carriers that make them so conspicuous. Using our own experience as an example, we could set the date of radio-visibility for Earth as December 12, 1901, when Guglielmo Marconi sent radio signals from Cornwall, England, to Newfoundland, Canada.[72] Visibility is now ending, or at least becoming orders of magnitude more difficult, as analog TV is being phased out. And so, if our experience is typical, a civilization remains radio-visible for approximately a hundred years. So a civilization may have been very visible from 1325 to 1483, but we were just not listening at that time. This is essentially the solution, "Everyone is listening, no one is sending."

More hypothetically, advanced alien civilizations evolve beyond broadcasting at all in the electromagnetic spectrum and communicate by principles of physics we don't yet understand. Some scientists have hypothesized that advanced civilizations may send neutrino signals.[73] If such signals exist they could be detectable by neutrino detectors that are now under construction.[74] If stable wormholes could be created and used for communications then interstellar broadcasts would become largely redundant. Thus it may be that other civilizations would only be detectable for a relatively short period of time between the discovery of radio and the switch to more efficient technologies.

One counter to this argument is that although broadcast communication may become difficult to detect, other uses for radio such as radar and power transmission cannot be replaced by low power technologies or fiber optics. These will potentially remain visible even after broadcast emission are replaced by less observable technology.[75]

A different argument is that resource depletion will soon result in a decline in technological capability. Human civilization has been capable of interstellar radio communication for only a few decades and is already rapidly depleting fossil fuels and confronting possible problems such as peak oil. It may only be a few more decades before energy becomes too expensive, and the necessary electronics and computers too difficult to manufacture, for us to continue the search. If the same conditions regarding energy supplies hold true for other civilizations, then radio technology may be a short-lived phenomenon. Unless two civilizations happen to be near each other and develop the ability to communicate at the same time it would be virtually impossible for any one civilization to "talk" to another.

Critics of the resource depletion argument point out that alternate energy sources exist, such as solar power, which are renewable and have enormous potential relative to technical barriers.[76] For depletion of fossil fuels to end the "technological phase" of a civilization, some form of technological regression would have to invariably occur, preventing the exploitation of renewable energy sources.

They tend to experience a technological singularity

See also: Sentience Quotient and Matrioshka brain

Another possibility is that technological civilizations invariably experience a technological singularity and attain a posthuman (or more properly, post-biological) character. Theoretical civilizations of this sort may have advanced drastically enough to render communication impossible. The intelligences of a post-singularity civilization might require more information exchange than is possible through interstellar communication, for example. Or perhaps any information humanity might provide would appear elementary, and thus they do not try to communicate, any more than human beings attempt to talk to ants—even though we do ascribe a form of intelligence to them. For example, a superintelligent civilization might consist of an advanced megastructure such as a Matrioshka brain or a black hole and communicate using neutrinos or by gamma-ray bursts at bandwidths that exceed our receiving capabilities.

Even more extreme forms of post-singularity have been suggested, particularly in fiction: beings that divest themselves of physical form, create massive artificial virtual environments, transfer themselves into these environments through mind uploading, and exist totally within virtual worlds, ignoring the external physical universe. Surprisingly early treatments, such as Lewis Padgett's short story *Mimsy were the Borogoves* (1943), suggest a migration of advanced beings out of the presently known physical universe into a different and presumably more agreeable alternative one.

A further argument, suggested by Charles Stross in *Accelerando*, is that although advanced virtual civilizations - possibly en route developmentally to a Matrioshka Brain - could engage in travel to other star systems, they choose not to. This is not due to a lack of curiosity, but more through a set of energy-information economic choices, whereby in an information market predicated on available stellar energy and planetary matter for building more computing capacity, the most successful virtual intelligences have to remain central to the star. Energy and proximity (and therefore wireless communication bandwidth and speed) are much greater closer to the matter and energy sources of the star, and larger planets, and so to be successful requires focus on their home planetary system. In this scenario, economic incentives to travel out of a star system are inhibited.

One version of this perspective, which makes predictions for future SETI findings of transcension "fossils" and includes a variation of the Zoo hypothesis below, has been proposed by singularity scholar John Smart.[77]

They are too busy online

It may be that intelligent alien life forms cause their own "increasing disinterest" with the outside world.[78] Perhaps any sufficiently advanced society will develop highly engaging media and entertainment well before the capacity for advanced space travel, and that the rate of appeal of these social contrivances is destined, because of their inherent reduced complexity, to overtake any desire for complex, expensive endeavors such as space exploration and communication. Once any sufficiently advanced civilization becomes able to master its environment, and most of its physical needs are met through technology, various "social and entertainment technologies", including virtual reality, are postulated to become the primary drivers and motivations of that civilization.

They are too alien

Another possibility is that human theoreticians have underestimated how much alien life might differ from that on Earth. Aliens may be psychologically unwilling to attempt to communicate with human beings. Perhaps human mathematics is parochial to Earth and not shared by other life,[79] though others argue this can only apply to abstract math since the math associated with physics must be similar (in results, if not in methods.)[80]

Physiology might also cause a communication barrier. In *Contact*, Carl Sagan briefly speculated that an alien species might have a thought process orders of magnitude slower (or faster) than humans. Such a species could conceivably speak so slowly that it requires years to say even a simple phrase like "Hello". A message broadcast by that species might well seem like random background noise to humans, and therefore go undetected.

They are non-technological

It may be that at least some civilizations of intelligent beings are not technological, perhaps because it is difficult in their environment, or because they choose not to, or for other reasons yet unknown. Such civilizations would be very hard for humans to detect.[81] While there are remote sensing techniques which could perhaps detect life-bearing planets without relying on the signs of technology,[82][83] none of them has any ability to tell if any detected life is intelligent. Not even any theoretical methods for doing so have been proposed, short of an actual physical visit by an astronaut or probe. This is sometimes referred to as the "algae vs. alumnae" problem.[81]

The evidence is being suppressed

It is theoretically possible that SETI groups are not reporting positive detections, or governments have been blocking extraterrestrial signals or suppressing publication of detections, perhaps in response to National Security and Trade Interests from the potential use of advanced extraterrestrial technology or weapons. It has been suggested that the detection of an extraterrestrial radio signal or technology could well be the most highly classified military information that exists.[84] Claims that this has already happened are common in the popular press,[85][86] but the scientists involved report the opposite experience – the press becomes informed and interested in a potential detection even before a signal can be confirmed.[87] Another issue is the diverse number of organisations and governments involved in science activities that might chance upon detections, of which SETI forms only a small part. Numerous conspiracy theories have been proposed, including the possibility of extraterrestrial life at Area 51.

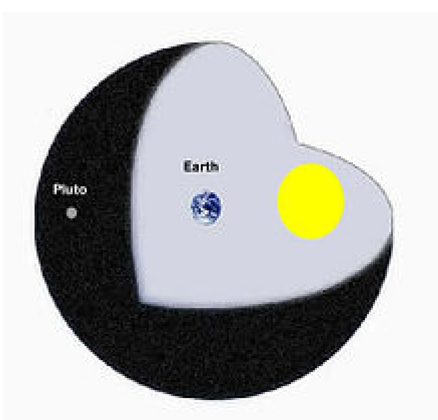
They choose not to interact with us

In these scenarios, alien civilizations exist that are technically capable of contacting Earth, but explicitly choose not to do so. This is the official position of the Earth today; we listen (SETI), but except for a few small efforts, do not explicitly transmit. Of course if all, or even most, civilizations act the same way, the galaxy could be full of civilizations eager for contact, but everyone is listening and no-one is transmitting. This is the so-called *SETI Paradox*.[88]

They don't agree among themselves

Official policy within SETI community [89] is that "[no] response to a signal or other evidence of extraterrestrial intelligence should be sent until appropriate international consultations have taken place.". However, given the possible impact of any reply[90] it may be very difficult to obtain any consensus on "Who speaks for Earth?" and "What should we say?". Other civilizations might suffer from this same lack of consensus, and therefore send no messages at all.

Earth is purposely not contacted (The zoo hypothesis)



Schematic representation of a planetarium simulating the universe to humans. The "real" universe is outside the black sphere, the simulated one projected on/filtered through it.

Main article: Zoo hypothesis

The zoo hypothesis states that superintelligent extraterrestrial life exists and does not contact life on Earth to allow for its natural evolution and development.[91]

These ideas are perhaps most plausible if there is a relatively universal cultural or legal policy among a plurality of extraterrestrial civilizations necessitating isolation with respect to alien life. In a Universe without a hegemonic power, random civilizations with independent principles would, in all likelihood, make contact. This makes a crowded Universe with clearly defined rules seem more plausible.

This theory may break down under the uniformity of motive flaw: all it takes is a single culture or civilization to decide to act contrary to the imperative within our range of detection for it to be abrogated, and the probability of such a violation increases with the number of civilizations.[13] However, perhaps a sufficiently technologically and socially advanced civilization would be capable of enforcing rules.

T. W. Hair [92] has done Monte Carlo analysis of the inter-arrival times between civilizations in the galaxy based on common astrobiological assumptions that suggest that since the initial civilization would have such a commanding lead over the later arrivals, it may have established what we call ZH as a galactic/universal norm and the resultant "paradox" by a cultural founder effect with or without the continued activity of the founder.

Compare with the Prime Directive from *Star Trek*.

Earth is purposely isolated (planetarium hypothesis)

Main article: Planetarium hypothesis

A related idea is that, beyond a certain distance, the perceived universe is a simulated reality. The planetarium hypothesis[93] holds that beings may have created this simulation so that the universe appears to be empty of other life.

It is dangerous to communicate

An alien civilization might feel it is too dangerous to communicate, either for us or for them. After all, when very different civilizations have met on Earth, the results have often been disastrous for one side or the other, and the same may well apply to interstellar contact.[94] Even contact at a safe distance could lead to infection by computer code[95] or even ideas themselves[96] (see meme). Perhaps prudent civilizations actively hide not only from us but from everyone, out of fear of other civilizations.

The Fermi paradox itself is what prevents communication

Perhaps the Fermi paradox itself—or the alien equivalent of it—is the ultimate reason for any civilization to avoid contact with other civilizations, even if no other obstacles existed. From any one civilization's point of view, it would be unlikely for them to be the first ones to make first contact. Therefore it is likely that previous civilizations faced fatal problems with first contact. So perhaps every civilization keeps quiet because of the possibility that there is a real reason for others to do so.[5]

They are here unobserved

It may be that intelligent alien life forms not only exist, but are already present here on Earth. They are not detected because they do not wish it, human beings are technically unable to, or because societies refuse to admit to the evidence.[97] Several variations of this idea have been proposed:

Carl Sagan and Iosif Shklovsky[98] argued for serious consideration of "paleocontact" with extraterrestrials in the early historical era, and for examination of myths and religious lore for evidence of such contact. Sagan and Shklovsky noted that many or most religions were founded by men who claimed contact with supernatural entities who bestowed wisdom, guidance and technology, citing the fish-god Oannes as a particularly salient example.

It is possible that a life form technologically advanced enough to travel to Earth might also be sufficiently advanced to exist here undetected. In this view, the aliens have arrived on Earth, or in our solar system, and are observing the planet, while concealing their presence. Observation could conceivably be conducted in a number of ways that would be very difficult to detect. For example, a complex system of microscopic monitoring devices constructed via molecular nanotechnology could be deployed on Earth and remain undetected, or sophisticated instruments could conduct passive monitoring from elsewhere while concealing themselves with stealth technologies that need not be much more advanced than current terrestrial ones.

UFO researchers note that the Fermi Paradox arose within the context of a wave of UFO reports, yet Fermi, Teller, York and Konopinski apparently dismissed the possibility that flying saucers might be extraterrestrial – despite contemporary US Air Force investigations that judged a small portion of UFO reports as inexplicable by contemporary technology. (Mainstream scientific publications have occasionally addressed the possibility of extraterrestrial contact,[99] but the scientific community in general has given little serious attention to claims of unidentified flying objects.) Given that UFO investigators argue compelling evidence supports the reality of UFOs as anomalies, but that extant UFO evidence does not support an extraterrestrial origin, it is suggested that closer examination of UFO data may confirm or falsify the Fermi paradox and/or the extraterrestrial hypothesis of UFO origins: "Any refusal of interest [by mainstream scientists] in investigating the UFO phenomenon, using an ETI [extraterrestrial intelligence] concept as one working hypothesis, should surely be astonishing."[100]

This extraterrestrial hypothesis was jokingly suggested in response to Fermi's paradox by his fellow physicist, Leó Szilárd, who suggested to Fermi that extraterrestrials "are already among us—but they call themselves Hungarians",[101][102] a humorous reference to the peculiar Hungarian language, unrelated to most other languages spoken in Europe.[101][Note 6]

See also

- Anthropic principle
- Fermi problem
- Interstellar travel
- Rare Earth Hypothesis
- The Drake Equation
- Zoo hypothesis