Chapter 15
The Search for Extraterrestrial Intelligent Life

The Search for Extraterrestrial Intelligence, or SETI, has traditionally been conducted and coordinated by the SETI Institute[1], based in Mountain View, California (USA). The SETI institute is a non-profit organization, which carries out not only research associated with possible extraterrestrial intelligent life, but also research related to planetary science, the origin of life, cultural evolution, and other topics. However, other initiatives are becoming increasingly visible, such as the Breakthrough Listen Project[2] and research associations in other countries including the United Kingdom SETI Research Network[3], the Forschungsnetzwerk Extraterrestrische Intelligenz in Germany[4], SETI.Austria[5], the SETI Australia Centre[6], and the Italian Radioastronomy Institute[7]. These organization are now conducting much of the research related to the search for extraterrestrial intelligent life.

15.1 Traditional SETI

The interest in extraterrestrial intelligent (ETI) life is probably as old as human civilization, but has been heightened in modern times by the discovery of radio waves from outside the Solar System. Cocconi and Morrison (1959) discussed the

[1]http://www.seti.org/)

[2]https://breakthroughinitiatives.org/initiative/1

[3]https://uksetiresearchnetwork.wordpress.com

[4]http://www.eti-research.net/personen.html#ds,

[5]http://www.setiaustria.at

[6]http://seti.uws.edu.au

[7]http://www.seti-italia.cnr.it

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suitability of radio waves for communication between stars, and suggested as an optimum frequency for monitoring radio signals emanating from extraterrestrial civilizations the 21-centimeter line of neutral hydrogen, corresponding to a frequency of 1420 MHz. Electromagnetic radiation at this frequency can pass through large clouds of interstellar dust (optical light cannot) and also pass easily through Earth's atmosphere with little interference. Shortly afterwards, Frank Drake started the first observational SETI program, searching for microwave radio signals from other solar systems at that particular frequency (Project Ozma). The search remained unsuccessful, but sparked interest and other observation projects in the former Soviet Union and the United States. With time the efficiency of the search increased by orders of magnitude and included some additional radio wave frequencies on which extraterrestrials might transmit (such as the tritium line at 1516 MHz).

In principle, it is unclear at which frequencies a technologically advanced civilization would transmit a signal if it chose to do so. Radio waves between 1 GHz to 10 GHz are one obvious choice, because much of the signal would be strongly absorbed by interstellar gas and dust at lower frequencies, and by Earth's atmosphere, as well as presumably the atmosphere of any other habitable planet, at higher frequencies. The so-called "Water Hole"—a frequency range between 1420 MHz and 1720 MHz—has received particular attention, because of the emission of hydrogen and hydroxyl molecules within this frequency range. A hydrogen atom plus a hydroxyl molecule combine to make water, which is, at least for life as we know it, essential; thus, the preference for frequencies within the "Water Hole." Whether an alien civilization would follow the same logic is certainly unclear. Whatever frequency might be used for long-range communication, an artificial signal would be expected to be a transmission at a very narrow frequency window to maximize the signal with the least amount of energy. In contrast to an artificial signal, nearly all natural sources have a rather broadband emission pattern.

After NASA discontinued the High Resolution Microwave Survey in 1993 due to termination of US government funding for that program, the SETI institute continued the search for ETI life in the Universe, and has been, together with the Breakthrough Listen Project, the main institution for this research ever since. Despite that termination, the SETI institute has received renewed funding from US government agencies such as NASA, the National Science Foundation, and the Department of Energy. A continuation of traditional SETI efforts has also included a targeted search by Project Phoenix that has screened the regions around 1000 nearby Sun-like stars. The search for clever life, as Seth Shostak (2015) terms it, is still on, and even expanded by including disciplines such as life and cognitive sciences, and incorporating advancements in communication theory, bioneural computing, machine learning, and big data analysis in the search for alien life (Cabrol 2016). However, no clear signs of an extraterrestrial communication from any of these efforts have been received thus far. This non-observation has also been referred to as the Great Silence, and its possible implications are discussed in Sect. 15.6.

Traditional SETI-efforts continue with Project SERENDIP conducted by the University of California, Berkeley, in the form of piggy-back searches operating alongside conventional radio astronomy observations. This is being done, for example, at the Arecibo telescope in Puerto Rico and also at the Parkes radio telescope in Australia. In connection with the SERENDIP Project, a screensaver program (SETI@home) for personal computers was developed by the University of California-Berkeley to assist with the data analysis and search for signs of an extraterrestrial civilization in the collected data. In addition, the Allen Telescope Array, built with the goal of conducting SETI-dedicated searches at centimeter wavelengths, has been in operation since 2007. This project's objective is to use an array of 350 small dishes to provide the equivalent resolution of a 100-meter radio telescope, and thus be able to detect not only an extraterrestrial signal targeted at Earth, but even leaking radio and television signals from another planet—similarly to Earth, where this has been occurring for many decades. However, due to budget issues and other problems, only 42 of the dishes have been built and are in operation at the time of this writing, thus limiting the goal as originally envisioned.

15.2 Optical SETI

The idea of using visible and infrared spectra rather than radio waves for the search of extraterrestrial intelligent life was suggested only a year after the maser was invented and Frank Drake started to use radio waves to explore the skies (Schwartz and Townes 1961). This strategy includes the search for both continuous and pulsed signals that might originate from an extraterrestrial beacon in the visible and infrared spectrum. However, since radio technology was more advanced in 1961, efforts were focused on the 21 cm neutral hydrogen line, rather than the use of optical methods. The strategy of optical SETI is based on the assumption that an extraterrestrial civilization would want to optimize the signal-to-noise ratio and that this could best be accomplished with a well-designed laser, which could be aimed accurately at a target enabling the best use of the transmitted energy (Darling and Schulze-Makuch 2016). Also, optical signals are not produced as noise from quasars, pulsars, or black holes, and thus are highly distinctive (something not known at the time when the first radio wave surveys were done). An extraterrestrial civilization may thus want to transmit a signal outside of the natural noise environment, although it would be difficult to speculate exactly at what frequency. Also, a transmission with a laser could easily be blocked, for example, by clouds of interstellar dust in the line of transmission.

Several optical SETI efforts are currently in progress. One effort is piggy-backed on Harvard's 155 centimeter optical telescope, which is otherwise used for more conventional star surveys. The SETI effort searches for laser signals coming from nearby Sun-like stars, but also any signals coming from globular clusters and sources outside our Galaxy. Also, optical searches are ongoing as part of the SERENDIP project and SETI@home, and at the Optical SETI Observatory at Boquete, in Panama. However, nothing has been detected to date that could be associated with an ETI civilization.

15.3 The Search for Extraterrestrial Artifacts (SETA)

The possibility of using interstellar messenger probes as artifacts in the search for extraterrestrial intelligence was first suggested by Bracewell (1960). Freitas (1980) advanced this argument by proposing that physical space probes would be superior to radio signals as a way of communicating between civilizations on different planets, as they would allow a true conversation between the extraterrestrial civilizations, including an almost instantaneous interchange and interweaving of cultures. Also, based on our own record of space exploration, probes may be sent out within other solar systems all the time, and even into interstellar space, such as the Voyager probes. Beyond the search for space probes, SETA also includes the search for possible remains and artifacts of ETI on other planets and moons, including possible constructions by an extraterrestrial civilization, or robotic probes left over from early exploratory efforts. One example of such a possible construction is a Dyson Sphere (Dyson 1960), which could potentially be detected by emanating infrared radiation (Brooks and Schulze-Makuch 2010). Another example is the search conducted by Valdes and Freitas (1983) for possible extraterrestrial interstellar probes in the vicinity of the Earth-Moon Lagrange points, where any such hypothetical probe would not have to expend any energy to maintain a stable position for a long period of time.

15.4 False Positives, or How Do We Know a Signal Is Coming from ETI?

False positives or false alarms are obviously a big problem for SETI initiatives. There have been quite a few in the past. One outstanding example was CTA-102 in 1963, which was claimed by Soviet astronomers to be evidence for a highly advanced extraterrestrial civilization (Kardashev 1964). It turned out to be a quasar. Another well-known false alarm was the recording of a regularly pulsating signal using a radio telescope in Cambridge, England, by Jocelyne Bell in 1967. Early interpretations included the suggestion that the pulses might come from an interstellar beacon, but it turned out that they could be explained naturally coming from a rotating neutron star (Hewish et al. 1968). At the beginning of the radio observations, it was still challenging to determine whether a specific signal had a terrestrial or extraterrestrial source. Technological advances and protocols that in the case of a positive detection also have other telescopes observing the same target area of sky have made this less of a problem. However, this still remains problematic for optical SETI searches to some degree, because in addition to the photons of the observed central star, other starlight, cosmic rays, muon showers, and radioactive decays can trigger the sensitive light detectors. The general approach for a remedy to this problem is the use of three instead of two light detectors for optical SETI experiments. This has reduced the number of false alarms from one per day to one per year.

Also, in 2005 the International Academy of Astronautics established the SETI Post-Detection Science and Technology Task Group, which is charged "to act as a Standing Committee to be available to be called on at any time to advise and consult on questions stemming from the discovery of a putative signal of extraterrestrial intelligent (ETI) origin."

It is interesting to note that the Wow! signal (see Sect. 15.5 below), probably the most promising of all recorded SETI signals as having an ETI source, is not recognized by SETI as being of extraterrestrial origin, because it could not be independently verified. Another example of the scrutiny with which SETI tries to analyze and verify any putative detection is the signal that was received at a frequency of 1420 MHz from the radio source SHGb02+14a in March 2003. It was a weak signal observed in a direction where no stars seem to be present, and the signal had a rapid drift corresponding to a rotation rate 40 times faster than Earth. Puzzlingly, for each detection the signal was at a frequency of 1420 MHz, at the original frequency before any drift and without the expected Doppler shift. Thus, the signal has been interpreted to be an artifact of cosmic noise, random chance, or a glitch in technology.

15.5 The Wow! Signal

A strong narrowband radio signal was detected at the Big Ear radio telescope located in Delaware, Ohio, on the 15th of August 1977. Jerry Ehman, who volunteered in the SETI program, discovered the radio signal a few days later, and wrote the comment "Wow!" next to it. The signal apparently originated from a location in the constellation Sagittarius, but many attempts by Ehman and others to receive the signal again were unsuccessful. The entire signal sequence lasted for 72 seconds and remains to date the most widely discussed possible signal deriving from a non-natural extraterrestrial source (Fig. 15.1).

The signal was received at a frequency of 1420.4556 MHz, within 10 kHz of the neutral hydrogen line. It appeared to be an unmodulated, continuous wave signal, with the sequence *6EQUJ5* simply representing the Gaussian distribution of signal intensity with respect to time. Several human- and Earth-based sources have been suggested (Ehman 2010; Gray 2012), but have not provided a satisfactory explanation. Thus, an extraterrestrial source from an ETI civilization cannot be excluded. However, why could it then not be detected anymore despite so many attempts? A possible explanation was provided by Bains (2015), who suggested that this signal may have represented a communication from one extraterrestrial civilization to another; or perhaps more likely, a signal from an extraterrestrial spacecraft back to its origin. Earth might have been simply in the way. Especially in the latter case the transmission target would be moving, so it would be very unlikely that the same signal would be picked up by an observer on Earth again. The same observation could apply to a hypothetical extraterrestrial observer with a sufficiently powerful detector who by chance intercepted the signals from Voyager 2 on 1 January 2015.

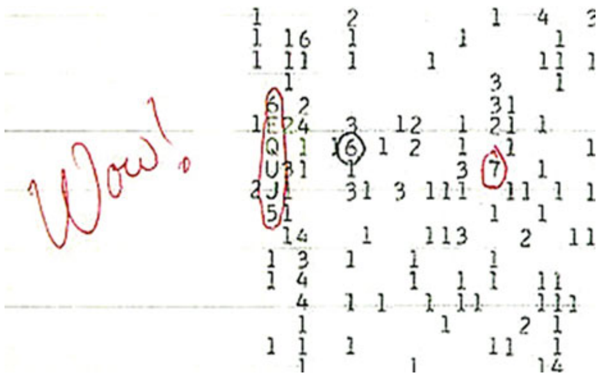

Fig. 15.1 The circled sequence *6EQUJ5* indicates the variation in intensity of the radio signal over time. It is measured as a unitless signal-to-noise ratio with the noise being averaged over the previous few minutes. Each character corresponds to the received signal, with a blank space denoting an intensity between 0 and 1; the numbers *1* to *9* denoting the correspondingly numbered intensities, and letters denoting an intensity of 10 and above, where *E,Q,U,J* correspond an intensity of 14–15, 26–27, 30–31, and 19–20, respectively

The observer might wrongfully conclude that humans live somewhere close to Eta Ophiuchi (Bains 2015). As Voyager is still moving, our hypothetical observer will never detect a signal from that region of the sky again, because both the Voyager spacecraft and its transmission target, the Earth, would have moved away. However, there is no evidence for this speculation nor that the received signal is from an extraterrestrial civilization.

Many signals received in the past have turned out to derive from natural phenomena of either terrestrial or extraterrestrial sources. One of the most recent examples is the detected signal apparently coming from the star HD 164595, which is a G-type star about 94 light years away with one known Neptune-size planet. It was detected by a RATAN-600 radio telescope in Russia in 2015, but couldn't be confirmed later on and might have been due to a Russian military satellite.

15.6 Messaging to Extraterrestrial Intelligence (METI)

Messaging to Extraterrestrial Intelligence (METI), also known as Active SETI, consists of sending signals into space with the expectation that they might be received by an ETI. Sending out interstellar messages continues to be highly controversial and several prominent scientists, including the late Stephen Hawking, have warned that we might just be inviting unfortunate consequences of an alien encounter.

Shuch and Almár (2007) described the divisions within the scientific establishment, particularly within the SETI Permanent Study Group of the International Academy of Astronautics, and summarized the most prevalent points they felt valid: "…no matter what positive motives we might ascribe to our cosmic companions, no matter how altruistic we may believe our neighbors to be, or no matter how unlikely we may consider it that we would encounter malevolent extraterrestrials, even the most ardent proponents of transmission from Earth, and other forms of Active SETI, must honestly concede that the probability of negative consequences from terrestrial transmission is non-zero.…" Musso (2012) agreed that METI is very unlikely to be dangerous for the human population on Earth, but, that at present, such a possibility cannot be completely excluded. Haqq-Misra et al. (2013) attempted to put forward a balanced view of both the benefits and harm of transmitting into space. In their advisory capacity to such policy-making bodies such as the United Nations Committee for the Peaceful Uses of Outer Space (COPUOS), the SETI Permanent Study Group struggled for a long time to find a consensus, with one subset of the group even urging a total moratorium on any transmissions. The discord has continued. Many members of that group signed a statement in 2015 that a worldwide scientific, political and humanitarian discussion must occur before any message is sent.

The opposing position was taken by Vakoch (2016), who argued that human nature tends to overrate fear and underrate the potential benefit of a contact. Altruistic aliens might, for example, be able to help guide humans on a path to environmental sustainability, and by reaching out to them, humanity may actually avoid its own annihilation. He also made the point that even a slightly advanced extraterrestrial civilization would already know of our existence through TV and other emissions that have been leaking into space for decades. If we would really have been in danger of an invasion, it would already be too late since they would know where we are. On the other hand, if we are just now being discovered, either by chance or due to our METI efforts, we can look to historical precedent on Earth for how such an encounter might play out. There is hardly any case in human history in which contact between a technologically more advanced and less advanced civilization has not ended badly for the latter.

Both sides seem to agree that there should be international protocols established for interstellar communication, including simple messages. But what should those protocols look like? There is some guidance available under the SETI charter in its "Declaration of Principles Concerning Sending Communications with Extraterrestrial Intelligence." However, this is an issue the United Nations needs to address. Meanwhile, messages continue to be sent into space, like the Arecibo Message in November 1974, which was sent towards the globular cluster M13, 25,000 light-years from Earth. More recently, in October 2016, an interstellar transmission was sent in the direction of the North Star (Polaris) by the nonprofit group "A Simple Response," using the European Space Agency's deep space antenna at the Cebreros ground station in Spain. Of greater concern because of the nearness of its target is a more scientifically informed transmission by METI sent from the Eiscat transmitter in Tromsø, Norway in October 2017 toward GJ 273, also known as Luyten's star, for a time period of 3 days. Luyten's star is a red dwarf (dM) about 12 light years from Earth with two confirmed planets, one of them a potentially habitable Super-Earth planet with about three times the mass of Earth.

15.7 The Fermi Paradox

In 1950, the physicist Enrico Fermi allegedly asked his co-workers over lunch: "Where are they?" meaning where are the intelligent extraterrestrials? If there are billions of stars and even more planets, chances should be good that ETIs have evolved on some of them. Traditionally the so-called Drake equation has been used to provide some kind of estimate of how many ETIs might be in our Galaxy (Eq. 15.1). If any of the factors in the Drake Equation are very low, the number of expected civilizations (N) in the Galaxy would be dramatically reduced

$$N = R^* \bullet f_p \bullet n_e \bullet f_l \bullet f_i \bullet f_c \bullet L \tag{15.1}$$

where R^* is the average rate of star formation in our galaxy,

- f_p is the fraction of formed stars that have planets,
- n_e is the average number of planets per star that can potentially support life,
- f_l is the fraction of those planets that actually develop life,
- f_i is the fraction of planets bearing life on which intelligent, civilized life has developed,
- f_c is the fraction of these civilizations that have developed communications, e.g., technologies that release detectable signals into space,
- L is the length of time over which such civilizations release detectable signals.

A more recent approach is the one by Irwin et al. (2014) who estimated that the number of planets with biological complexity could exceed 100 million in our Galaxy alone. If we assume that on 1% of those planets a species would evolve with a high enough level of advanced technology to transmit messages through space, then there could be a million radio-emitting planets in our Galaxy. So why have we not already been in contact with them? This problem has been known for decades, and is called the Fermi Paradox. According to Gray (2015), a better term would be "the Great Silence," since despite the vastness of the universe we still do not have any evidence of intelligent extraterrestrial life.

Historically, two camps emerged to explain the Great Silence. One group argued that the absence of any evidence for ETI means that there is no such life in the Galaxy. Hanson (1998) suggested that the number of ETI civilizations capable of deep space travel and communication might be drastically limited by a "Great Filter" located somewhere along the timeline between the origin of planets and the evolutionary culmination of a technological civilization. That filter could, in principle, be located at the origin of life, or could yet lie ahead of our current evolutionary stage, if technologically advanced civilizations have a tendency to self-destruct within a very short life time. If another ETI has never arisen, or has never survived long enough to search for other ETIs or advertise its own existence, SETI is a pointless exercise (Tipler 1981). The other group favored the likelihood of technologically advanced life elsewhere in the Galaxy, and came up with several explanations for why none has been detected so far. An extensive list of possible solutions to the so-called Fermi

Paradox can be found in Webb (2015). One of the most popular explanations is that Earth serves as something like a nature preserve for an alien ETI. Another is that some of the unexplained UFO observations are actually caused by extraterrestrial visitations, but that the aliens do not want to reveal themselves. Shostak (2015) argued that any intelligent biological life might rather quickly be replaced by machines, if the ETI is capable of fabricating them, and that therefore we should be prepared to communicate with machines instead of the life forms themselves. However, we don't know whether the presumably more advanced machines would be interested in communicating with us.

Perhaps the solution to the Fermi Paradox—or better, the Great Silence—is rather mundane. The distances between stars and their planetary systems are vast, so the challenge of finding an extraterrestrial civilization at or beyond our technological level is a matter of diminishing probability. We have previously argued that the likelihood of intelligible contact between another ETI and us is limited by three factors: (1) the remote distances between Earth and any planetary system that could harbor an ETI; (2) the small time window—only about a century—in which humans have had the ability to send radio signals into space and receive them from outer space; and (3) the questionable ability for us and a remote ETI to communicate in a way that we both would understand. For the detailed argument, see Irwin and Schulze-Makuch (2011). As Beck and Irwin (2016) noted, "…the problem is akin to detecting short flickers of light at great distances within the brief time span of a camera's open shutter, having to look in precisely the right direction, and being able to understand the significance of the signal."

15.8 Chapter Summary

The search for extraterrestrial intelligence has fascinated humans since ancient times, with serious efforts being ongoing since the second half of the twentieth century. Early efforts focused on detecting the 21 cm neutral hydrogen line in the microwave spectrum, but were later expanded to other frequencies, including optical wavelengths. In addition, searches for ETI artifacts have been conducted, but no firm evidence for the existence of any ETI civilization has been found to date. A number of possible explanations for this Great Silence—popularized commonly as the Fermi Paradox—have been offered. The absence of evidence for ETI may be surprising, given the large number of planetary systems known to exist, but even large numbers can be so diluted by the vastness of space and time, that the probability of contact within the infinitesimally small period that humans on Earth have been able to transmit and receive signals through space, is vanishingly small.