The search for extra-terrestrial intelligence

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Modern history of the search for extra-terrestrial intelligence is reviewed. The history of radio searches is discussed, as well as the major advances that have occurred in radio searches and prospects for new instruments and search strategies. Recent recognition that searches for optical and infrared signals make sense, and the reasons for this are described, as well as the equipment and special detection methods used in optical searches. The long-range future of the search for extra-terrestrial intelligence (SETI) is discussed in the context of the history of rapid change, on the cosmic and even the human time scale, of the paradigms guiding SETI searches. This suggests that SETI searches be conducted with a very open mind.

Keywords: search for extra-terrestrial intelligence; radio search for extra-terrestrial intelligence; optical search for extra-terrestrial intelligence; search for extra-terrestrial intelligence history; observing strategies

1. Introduction

This will be a review of the modern history of the search for extra-terrestrial intelligence, where we stand today, and prospects for the future. Since the 1950s, many astrobiologists have endorsed the idea that there are many intelligent civilizations in space, although, through lack of solid information, we cannot arrive at a good estimate of their numbers. Indeed, elsewhere in this volume are several papers that challenge these ideas. However, the search for extra-terrestrial intelligence (SETI) scientists have approached the subject from an Occam’s Razor viewpoint, and have assumed that the history of our Solar System and the development of a technology-using civilization is a common occurrence in the history of stars, and that indeed, life is abundant in the Universe and intelligent civilizations are fairly abundant. They assume that some of them are using technology, which we can already detect.

The searchers have questions that must be asked before we begin our searches. The first one is ‘where should we look?’, and, after answering the first, ‘how should we go about looking for it?’. Turning to that first question, 50 years ago, the few astrobiologists of that time believed that the place to search was towards single stars in space, like our Sun. It was believed that binary and multiple stars would not have planetary systems, and we knew of only the Sun as an *fdrake@seti.org

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appropriate abode for life. This was a very parochial view, of course. But, as always in SETI, scientists had to assume that which we know. The example of our own existence and history is a prime, yet obviously limited, source of guidance. Although limiting, it encourages scientists to at least think about what other possibilities there might be, and to search for phenomena that broaden our view.

2. Discussion

What new thinking has occurred in the 50 years since this discussion started? First, we have greatly broadened our understanding of habitable planets. We have discovered that planetary systems are commonplace in the Milky Way. Indeed, the M stars, the most numerous type of stars, have planets. As another example of progress, until recently it was thought that M star planets close enough to their star to have temperatures suitable for life would be in synchronous rotation, keeping one face to the star, at all times. The opposite face would be in perpetual darkness and cold. This would lead to a freezing out of the atmosphere, preventing the emergence of life. Now we know that even that conjecture is probably not so, since models have shown that there could well be sufficient circulation of air from the bright to dark sides to maintain a temperature above that of atmospheric freezing on the dark side. Furthermore, if the orbits of these stars are sufficiently elliptical, they will not be in synchronous rotation, and they could well be suitable for life. Our own planet Mercury provided us with an example of this escape from the synchronous rotation problem. These results have enormous importance because they have made the 80 per cent of the stars that are M stars potential abodes for life after all. They are now attractive targets for searches. Furthermore, the recent planetary discoveries have shown that multiple stars do have planetary systems, contrary to old beliefs, and so they have joined the large population of places we should look.

There are still other places SETI scientists might search that we had not imagined 50 years ago. Our models of the formation of planetary systems and studies of the actual arrangements of planets in newly discovered systems have shown that it is very probable that, in the process of planetary-system formation, some of the planets are actually ejected from systems to become what we call ‘rogue’ planets, or ‘wanderers’, or ‘nomads’. These roam through the Milky Way isolated from any star. It might seem that these would not be suitable abodes for life. But studies have shown that if these planets have a sufficiently massive atmosphere, perhaps like the one on Venus atmosphere, temperatures on the surfaces of stars can be maintained at habitable temperatures for periods of thousands of millions of years. There might be as many habitable rogue planets as there are stars in the Milky Way! In most scientists’ opinion, it is implausible that intelligent technology using life would arise there, but we cannot rule it out.

Thus, the original paradigm guiding SETI searches has greatly changed in 50 years. It will soon change even more as the Kepler project starts producing results within the next 2 years. These results should show clearly how many Earth-like planets there are in our Galaxy. So what are the upshots of our new understandings? We should search for signals from stars of type F and later—these all have long enough lifetimes to evolve an intelligent, technology-using species. Searchers should give equal emphasis to M stars; they may be just as
suitable as locations of habitable planets as stars like our Sun. To expedite the search, searchers should mount a search that examines the maximum number of stars at any time. This suggests that searches in the vicinity of the galactic plane are ideal. The probable existence of habitable rogue planets calls for a major expansion of the search if resources permit. Their possible existence argues that even observations of ‘empty’ space should be made, because apparently empty space may not be empty after all.

Now to the second question, ‘where should SETI searchers look?’ Here, scientists have depended on our own civilization and its use of technology to give guidance. Obviously, this is naive and limiting, but we are loath to speculate about the detectability of very exotic technologies, especially any that disobey the laws of physics. Should we look for the lights of cities at night? These are clear evidence of a technology using civilization, and there is no ambiguity about it. If our civilization is a good example, they certainly look bright. But, always, in SETI, one has to quantitatively analyse the realistic detectability of various technologies. If that is done with contemporary city lights, and calculations are made of how large an optical telescope is needed to detect these lights, using our present detectors, it turns out that one would require an optical telescope several square kilometres in collecting area. We are building very large telescopes indeed, but not that large. So, it is currently foolish to search for the lights of cities at night. Perhaps 50 years from now it will be possible.

What might work? Fifty years ago, and still today, the strongest sign of our existence is our radio transmissions, in particular television and the radiation of military radars. Thus, we continue to think the most promising way to search for extra-terrestrial life is to search for radio signals. Figure 1 is a picture of the telescope that was used in the first project of this nature. The search was carried out at the National Radio Astronomy Observatory in the United States, at Green Bank, West Virginia in April 1960. Therefore, this year is not only the anniversary of the Royal Society, but also the 50th anniversary of this first search. The people you see here are the group of people who made this happen 50 years ago, and this 25 m telescope, which is still in operation. It was instrumented with detectors at the radio frequency of the hyperfine transition of the nucleus of the hydrogen atom, at 1420 MHz, and it was used for a total of about 200 h over a period of two months to search for signals from the two nearest stars like the Sun that are single in the sky. Those are the stars Tau Ceti and Epsilon Eridani. No signals were detected.

Now you might think, ‘wasn’t it rather foolish to search only two stars—it’s very improbable that you would succeed’. Actually, back then, for all we knew, every star in the sky had a planet that was transmitting radio signals. It could have been that the observers would have succeeded the very first day! They did not succeed, and the experiment did show that radio-transmitting civilizations are not ubiquitous in our galaxy. Figure 2 is a picture of the equipment that was used then. It is all based on vacuum tubes; this was a time before the transistor was available. There is no computer in sight here because suitable ones did not exist. The receiver monitored only one channel with a bandwidth of 100 Hz. There is a tape recorder visible on the right-hand side of the figure.

Despite the lack of success, which was not a surprise, this search motivated other people in subsequent years to conduct searches. Indeed, since that time over 100 searches have been conducted with varying degrees of sensitivity, bandwidth
Figure 1. The 26 m radio telescope used in the first modern search for extra-terrestrial intelligent radio signals, with the team who carried out the project. It is at the National Radio Astronomy Observatory of the US in Green Bank, West Virginia.

Figure 2. The receiving apparatus used in the 1960 search for extra-terrestrial intelligent signals.

coverage, number of channels, etc. Among the most powerful ones are those conducted by the SETI institute. These used telescopes all over the world with very sensitive multi-channel radio systems and automatic search and analysis hardware and software to search for signals. No signals have been found.
Our civilization as a whole has moved on to much larger instruments, the largest and most sensitive of which is the 300 m Arecibo Radio Telescope, which has been used extensively for searching for signals by ourselves and others, and is used regularly to capture the data that is delivered to the ‘SETI at home’ project in which more than three million people participate. Now, along with much larger telescopes, we have much better receivers today. Altogether, over the 50 years, the sensitivity of our telescopes has increased by about 1000 times. Furthermore, searchers have gone from monitoring one channel at any moment to hundreds of millions of channels. Putting it all together, the capabilities of our telescopes and systems of today are about $10^{14}$ times more powerful than the best systems of 50 years ago. Instrument capability has been growing exponentially over those 50 years, and is continuing to improve at the same pace. No end is in sight, except as limited by the availability of funding for these projects.

Over the 50 years, thousands of stars have been looked at without success. Unfortunately, this had led to the notion of an ‘eerie silence’ as expressed by Paul Davies [1]. In fact, there has been a silence, yes, but not eerie. If you take plausible estimates and guesses for the factors in the Drake equation, as suggested by many SETI workers informally, and crudely estimate the number of detectible civilizations in our Galaxy, you arrive at a number of the order of 10 000. That is a big number. Ten thousand detectible civilizations, and by the way, that value depends on civilizations on average being detectable for 10 000 years or so, which is little more than a guess. Ten thousand—that is very exciting, although we are well aware that the actual number could be much smaller or larger. It does suggest that there is something out there to be found. Nevertheless, this working number suggests that within our Galaxy, with its 200 or so thousand million stars, only about 1 in 10 million stars has a detectable civilization. It says that SETI may not succeed until SETI workers have searched some 10 million stars. Of course, an added problem is that we do not know what frequency to search. We do have an idea of a promising range of frequencies to search. We know that the microwave region of the spectrum is where the Universe is darkest and quietest, so is perhaps promising. Nevertheless, we have so far searched well only a few thousands of stars. Compared with the numbers above, that is just a trivial start. We should have detected nothing. So there is a silence, but it is not eerie, it is predictable!

It is interesting to note that the Arecibo telescope produces the most powerful sign of our existence, and provides a benchmark as to the possible capabilities of other civilizations at our stage of development. The Arecibo telescope has a radar transmitter with a power of one million watts. When this power is concentrated into a narrow ‘beam’, it has an effective power of about 20 million watts. This is strong enough to be detected by similar instruments far across our Galaxy. However, note that this will only be possible if the beam of the transmitter is pointed towards the searching civilization.

Recently, major advances in the power of optical and infrared lasers created a rationale to search for optical signals. Fifty years ago, this seemed nonsensical because the power of our most potent lasers then was so little that there was no hope at all of collecting and detecting a laser signal from even the nearest stars. That has changed in recent years as a result of developments made in conjunction with efforts to achieve clean nuclear fusion as a source of electrical power. One such experiment, a very major one, is the ‘National Ignition Facility’
at the Lawrence Livermore National Laboratory in California. There the approach is to take a small bead about 5 mm in diameter, a glass bead, containing isotopes of hydrogen, deuterium and tritium, and then raise the temperature and pressure in those gases to the values necessary for nuclear fusion to occur, which are of the order of 100 million degree Celsius and a thousand million times normal atmospheric pressure.

Now as you can guess, there is a practical problem there, which is how to get the gases that hot and dense before the inevitable explosion causes the gas to disperse before fusion can occur. The solution is to heat the gas so quickly that there is confinement by the inertia of the gas itself. To achieve that, one must invent a very powerful pulsed laser. This has led to the development of a laser that creates pulses of light whose peak power is $10^{15}$ W, a petawatt! That is more power than the power output from all the electrical plants of the Earth combined. Of course, it cannot last very long. The pulse lasts less than a billionth of a second. But that is long enough. It turn out, though, that one such pulse is not enough. About 166 simultaneously pulses are needed to achieve fusion. So at Lawrence Livermore, there is a building the size of a soccer field, within which there are 166 of these lasers all carefully focused by sophisticated optics onto the tiny bead. First tests of the system are underway. Well, that is all interesting, but the especially interesting thing to SETI is that it says that lasers can exist which emit brief pulses with a power of at least a petawatt. One can speculate that extra-terrestrials might use these as a transmitter, focusing those pulses into a narrow beam with, say, a 10 m class optical telescope, as exists on Mauna Kea and in Chile. The resulting flash of light will be concentrated in a very narrow beam, to a very small area in the sky. The flash of light in that small area would be, incredibly, actually brighter than all the starlight combined on all wavelengths. For perhaps a few billionths of a second, the star would become perhaps thousands of times brighter. What a fantastic event! If our eyes could sense such a brief flash, we could just detect these transmissions by going outside on a summer night and watching the sky. Of course, our eyes are not capable of seeing such brief pulses, but we have a great variety of photodetectors that can. In this approach to interstellar signalling, the observer does not even need to know the wavelength of the laser light—you can accept all the starlight captured by the telescope and the laser pulses will still exceed in brightness all the captured starlight during the brief magic moment that the pulses from the laser are on. The pulses are readily detected by optical photomultiplier detector tubes (PMTs) that are very sensitive, relatively inexpensive and have nanosecond time resolution.

An optical SETI instrument must be capable not only of detecting bright nanosecond pulses, but also to identify as ‘false positives’ apparent bursts of pulses detected by the PMTs that are created by instrumental artefacts such as radioactive decays in the tubes themselves, corona discharges from the high voltages required by the tubes, and cosmic ray hits, for example.

Instrumentation to do all this is very inexpensive. There are several projects in the world that are carrying out searches for brief laser pulses. Figure 3 shows a detector system that the SETI Institute has used in partnership with the Lick Observatory of the University of California. In comparison to the many millions of pounds required for radio systems, the cost of optical SETI systems is only a few thousand pounds. The construction is simple, and, indeed, a college student constructed this instrument.

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This instrument uses a clever design concept to reduce false positives. In figure 3, the light from the telescope enters the system through a hole in the casing at the right top and is sent down a short length of black tubing to a beam splitter, which sends one-third of the light to the left, to a PMT. The remaining two-thirds of the light goes down the vertical black tube to a second beam splitter, which divides the light into two equal beams, which are sent to two more PMTs. Thus, the captured light is divided equally between three PMTs, and will travel along equal path lengths to the three PMTs. If there is a burst of laser-produced photons, all three PMTs will detect the burst simultaneously. This synchronized arrival will be detected by a coincidence detector, which is triggered by the simultaneous arrival of three or more pulses. The timing of the random arrival of photons from the starlight is governed by Poisson statistics. For the rate of arrival of photons in the telescope, Poisson statistics show that such a simultaneous arrival should only occur by accident about once per year. The experience has been that about one triple coincidence per year is actually detected, as predicted. Of course, a triple coincidence is not conclusive proof of a laser detection, and is the cause for continued observation of the observed star. So far, no triple coincidence has been repeated with any stars. It is interesting that, in this approach, the detection of a laser pulse is not caused by photon-stream intensity, but by a deviation from Poisson statistics.
in the photon stream, a new and novel approach to detect occasional bursts of photons within a stream of events. Daniel Wertheimer of the Space Sciences Laboratory of the University of California, Berkeley, invented this powerful technique [2]. Taking into account the quantum efficiencies of PMTs, the capture of 10 optical photons arriving simultaneously would be sufficient to reveal the existence of a technology using civilization. The total energy in the photons would be about $3 \times 10^{-19}$ J. It is striking that the capture of such a small amount of energy could lead to one of the most important discoveries to be made by science.

The program at the Lick Observatory used a 1m telescope, and a detector system as just described [3]. In the course of 10 years, about 6000 stars were searched for signals for a time of 10 minutes each. Although several triple coincidences were detected, none was repeated, and so it is felt that no discovery was made [4]. There is now a new system at Harvard University using a dedicated transit telescopes with a 1.8m spherical mirror, and detectors that can record pulses in 1024 individual pixels in PMTs. So far, no convincing photon bursts have been detected.

Returning to the subject of radio SETI, the most important development is the Alan Telescope Array (ATA), which is being built by a partnership between the SETI Institute and the University of California at Berkeley. It is planned to use 350 6m telescopes. This approach exploits the fact that a very large aperture telescope can be built at low cost by using an array of many small dishes and connecting them together through computer technology to simulate the behaviour and sensitivity of a very large telescope. The completed array will have the collecting area of a 112m diameter single large reflector. Figure 4 shows a small part of the array. The dishes are Gregorian systems, providing a
clear aperture, which minimizes the collection of interference signals from our own technology and thermal radio noise from the Earth. At present, there are 42 dishes completed and in place, and the system is in operation and working very well.

The device at the focus of the antenna, the ‘feed’, has several important innovations. It has a refrigerator actually built within it to cool the first amplifying stages of the receiver and thus reduce receiver noise. It uses a ‘log-periodic’ antenna system, very long, very large, to cover the wide bandwidth from radio frequencies of 0.5 GHz to about 11 GHz. A suitable small refrigerator was found to be available from the companies that build mobile-telephone towers. The dishes can be connected together using computer-based ‘beam-formers’, which construct beams as with a traditional telescope. As many as four individually pointed beams can be constructed at one time within the reception beams of the individual dishes, at chosen radio frequencies within the feed-frequency coverage. They can also be connected to computers so as to produce radio ‘images’ of the sky using correlators in the style of traditional aperture synthesis. One clever and novel capability of the system is the possibility of constructing a ‘null’ beam at a chosen place in the sky to eliminate, for example, the unwanted signal from a satellite such as those that send television to homes.

Figure 5 is an artist’s conception of the completed ATA. Its unusual, apparently random, distribution of the dish locations is not an accident, but is intentional to allow the sharpest and cleanest radio images to be produced when the ATA is used to image the radio sky.

There are other telescopes now in use for SETI. Of course, there is Arecibo itself, which has been upgraded recently, so that it has seven feeds, and a very wide frequency coverage. It is being used regularly to collect data for the SETI at home project.

A new telescope under construction is the ‘FAST’, the 500 m Astronomical Spherical Telescope, being constructed by China in southwest China. It will have a reflector like the Arecibo telescope, 500 m in diameter rather than the 300 m

Figure 5. Artist’s conception of the completed Allen Telescope Array, with 350 6 m antennas. (Online version in colour.)
diameter of Arecibo. The feed will be supported from six towers by movable cables, which will accurately move the feed around to produce beams pointed in desired directions in space. A real challenge will be the Chinese plan to have devices that move the panels of the dish so as to make the dish into a parabolic reflector form, making it possible to use very simple feeds with the antenna. Of course, all of this will have to operate continuously as the telescope tracks an object in the sky, which will require ingenious and careful engineering.

Now a brief retrospective. For 50 years, we have used ourselves as a model for what intelligent life and technology might be present in space. We have realized that the Earth has been very easily detected for a long time—50 years or so. This has been encouraging to us. However, that model is now warning us that our optimism may be too great. We observe ourselves becoming fainter, less easy to detect. This is a result not of a failure, but success in improvements in our technology. Weaker transmitters than required in the past can successfully carry out our communication and radar needs. One of the long-term signs of our existence, the early warning radars that were prime instruments in the cold war, have become much harder to detect. Fifty years ago, they emitted a single very powerful frequency on one channel. Today, the transmitters are weaker, but, more importantly, the transmitted signal, for military reasons, is spread over a wide range of frequencies. The signal at any given frequency is much weaker than it was, even a few years ago. Nevertheless, in our searches we still search, usually, for a solitary strong signal. We are still searching with detection algorithms that are optimized for the radio technology of a few decades ago.

Fifty years ago, the other strong sign of our existence was broadcast television. Our style was to transmit millions of watts into space, much of it at narrow bandwidths, facilitating detection by other searching civilizations. Now, the United States has adopted digital television, and Europe and the rest of the world is proceeding to do the same soon. Digital signals can be weaker, and do not contain any strong narrow-band signals. They resemble noise, and thus are difficult to detect. More worrisome, at least to those of us pursuing SETI, is the great success in using synchronous satellites in space to transmit television to people’s homes. Instead of transmitting a million watts or so, as do the traditional ground stations, the satellites that provide television to people’s homes have outputs of 20 or 75 W, very much less than the traditional stations. What is worse, from a SETI standpoint, is that the radio beams from these satellites are cleverly engineered so that almost all the radio power is carefully aimed at the Earth, so almost none of that radiation goes into space. The power released into space from these systems is literally a hundred thousand or more times fainter than the power from the traditional television stations. Also, much of television is delivered by cable systems, which release no power into space. These technologies are clearly the wave of the future, and undoubtedly we will be, very soon, much less undetectable.

Mobile phones are a similar case of advancing technology making us less detectable. With them, the great challenge is to share radio frequencies successfully so that the limited electromagnetic spectrum can be shared at the same time by enormous numbers of users. To share frequencies, the power levels must be very low so that many mobile phone towers can operate simultaneously. All of these consequences of expanded utilization of the radio spectrum and
advanced technology cause us to expect that our planet will become much less easy to detect. If this is so, and we are the model for extra-terrestrial technology, the search will be much more difficult than we imagined 50 years ago.

Of course, there may be new technologies and enterprises that will reverse our trend towards invisibility. If, for example, we and others build the already proposed electrical power stations in space that transmit electric power to Earth using microwaves, these will create a very powerful sign of our existence, since some of the transmitted microwaves will inevitably be reflected from the Earth into space. Perhaps civilizations often colonize their planetary system, and interplanetary communication will occur using a detectable technology. Nevertheless, in the end, we have to fall back on a search for the lights of cities at night—a daunting task requiring optical telescopes several kilometres in diameter. Perhaps our best, and very optimistic, hope is that altruism is common in civilizations, and technologically advanced civilizations sense a duty to transmit powerful information-rich signals to less advanced civilizations. Could there possibly be a network of intercommunicating civilizations, a real version of a mythical galactic Internet?

3. Conclusion

Very much has changed over the last 50 years in our ideas of where and how to search for extra-terrestrial intelligent life. This is an alarm reminding us that our present views may be naive and will be replaced. What may the next 50 years bring?

References