Please use Contact in Context:v2i2/third.pdf in any reference to this article

A Third, Complementary, Microwave Search Strategy for SETI

Richard Factor
Eventide, Inc.
http://www.eventide.com/

ABSTRACT

Microwave SETI (The Search for Extraterrestrial Intelligence) focuses on two primary strategies, the "Targeted Search" and the "All-Sky Survey." Although the goal of both strategies is the unequivocal discovery of a signal transmitted by intelligent species outside our solar system, they pursue the strategies in very different manners and have vastly different requirements. This paper introduces a third strategy, also with the goal of unequivocal discovery of an extraterrestrial signal, with equipment and data processing requirements that are substantially different from the commonly used strategies. This strategy is particularly suitable for use with smaller radiotelescopes and has budgetary requirements suitable for individual researchers.

Background

Since the first tentative SETI experiment in the 1960s, increasingly larger radiotelescopes and more powerful signal processing engines have been searching the sky for signals. Perforce these searches have been limited to looking largely for continuous or pulsed narrowband signals since these are the most likely to be detectable, and are most identifiable as being of unnatural origin. A number of "hits" have been recorded, beginning with the famous "Wow" signal and continuing to the present. After weeding out cases of equipment problems and man-made interference, a number of candidate signals remained, any of which might have been of intelligent origin. None of them could be proved to be so, largely because they were not verifiable. Revisiting the signal's supposed point of origin failed to provide a repetition of the event, leaving the original signal as a tantalizing but scientifically useless phenomenon.

In order for a detected signal to be accepted as of intelligent, extraterrestrial origin, it is generally agreed that it must meet two criteria[1]:

1: It must not be "natural." That is, no natural process could have created it. There have been false alarms, such as the initial apprehension that the regularity of pulsar signals signified intelligent design.

2: It must be verifiable. To rule out man-made causes it must be present long enough so that several observers in widely separated locations can verify its point of origin, and all must agree on the same, extrasolar point!

Of course, it would be desirable for the signal to have, somehow, a modulation that would impart information to the observer. An on-off modulation in some obvious pattern such as sequential prime numbers would comfortably fulfill this desirable but not-strictly-necessary characteristic.

With over two decades of sometimes fitful, sometimes diligent searching, the results can be summed up in two sentences: We know that the sky isn't teeming with strong signals. And we have searched such a small percentage of the phase space that it would be foolish to conclude there's nothing to be found.

Searches

The physics of detecting interstellar signals is challenging but not daunting. Calculations show that a relatively modest pair of radiotelescopes with easily achievable transmitter power could communicate between earth and the nearest stars. Two radiotelescopes the size of that at Arecibo, Puerto Rico, could, with 1-Megawatt transmitters, detect each other's presence a good fraction of the way across the galaxy. The Drake Equation is a construct that enables us to focus on and attempt to quantify the likelihood of other civilizations with which we might communicate. Although recent discoveries of planets circling nearby stars has reduced some of the uncertain terms in this heuristic, there remain sufficient imponderables to allow essentially any conclusion to be drawn. If one concludes that there are very large numbers of civilizations in the galaxy, it is reasonable to infer that several of them are quite "close" to us, perhaps within tens or hundreds parsecs. If one concludes that there are only a small number, then it is likely that they will be located at greater distances.

The location of the putative civilization defines the strategy for locating it. If it is nearby, our largest, most sensitive radiotelescopes would probably be able to detect signals emanating from it, even if those signals are not specifically being "beamed" toward us. Smaller radiotelescopes, and, in particular, very small ones, such as 3-5 meter backyard dishes, would not be able to detect "leakage" radiation from even the closest stars. On the other hand, if a very powerful signal were being beamed, either directly to us, or sent omnidirectionally into the galaxy as a beacon, even the largest radiotelescopes would likely fail to find it. Although they would be capable of detecting the signal, their beamwidth, which is inversely proportional to their size, would be so narrow

Copyright 2006 Contact in Context

that it would require either extremely large numbers of million-dollar instruments or extravagant luck to be pointing in the right direction to hear the signal.

Targeted Search

The bifurcation of microwave SETI into two search strategies accommodates these realities. Very large radiotelescopes, of which there are only a tiny number and whose observing time is precious, are used to probe the nearest stars. The SETI Institute's Project Phoenix is the main exemplar of this strategy. This targeted search has an excellent chance of detecting a radio-using civilization (such as ours) if it is on the planet of a star out to about 100 parsecs[2]. Such stars are well cataloged and can be selected on the basis of similarity to the sun. Extra emphasis can be given to stars that are known to have planets; waste can be obviated by foregoing binary stars or others presumed for various reasons to not support life.

One major advantage of the targeted search is that it doesn't presuppose deliberate attempts at communication. It systematically investigates nearby stars and, if one harbors a radio-using civilization, it will likely find it. The major disadvantage is its implicit assumption: civilizations are plentiful and hence nearby. Other, explicit assumptions which seem reasonable may simply be incorrect, e.g., non-sol-type stars are less likely to have associated civilizations.

All-Sky Survey

Almost a precise complement to the targeted search is the all-sky survey. Where the first assumes plentiful civilizations, the other makes no such assumption. Where the first assumes no deliberate attempt at communication, the other requires it. Where the first cherry-picks "appropriate" stars, the other makes no distinctions. In terms of instrumentation, at least as far as mechanical hardware is concerned, they are as far apart as can be. At least theoretically, one could argue that the all-sky survey could be accomplished by nothing more than a dipole antenna, while the targeted search will benefit by using the most enormous radiotelescope that can be built. As a practical matter, the size of the telescopes used in the all-sky survey must fall between limits imposed by sensitivity and interference rejection on one end and economics on the other.

Assume that one desires to cover the entire sky with as much sensitivity as possible. With appropriate location of the observatories, one could accomplish this with approximately 5000 "small" dishes on the order of 3-5 meters in diameter[3]. This is the essence of the SETI League's Project Argus, a "grass roots" endeavor. There are literally millions of these dishes in the hands of TV watchers, at least in the United States, and, due to the advent of DBS satellites, many of them are available for the price of carrying them away. Assuming the economic cost of recommissioning each dish is on the order of $1000, the antennas for the all-sky survey come in at only $5 million. This is a pittance compared to even the cost of a single research-grade radiotelescope[4]. However, the economics of scaling is very unfavorable. For instance, to only double the distance at which a given signal can be detected, one would need to double the diameter of the antenna, making it in the 6-10 meter range. Because these dishes are no longer littering the landscape, they must bear their actual economic cost, on the order of $10,000 each. Just as bad, doubling the diameter halves the beamwidth in two dimensions, raising the required number of dishes to 20,000. Thus, doubling the sensitivity increases the cost from $5 million to $200 million. Doubling the sensitivity yet again requires 80,000 12-20 meter dishes, at perhaps $50,000 per copy.

The economics of increasing the sensitivity of an all-sky survey are formidable. Given that the search is sensitivity limited, a reasonable but not conclusive assumption, an improvement in the strategy might be to concentrate a smaller number of larger dishes in the direction of the galactic plane. The galaxy is only a few hundred parsecs thick in this neighborhood and really strong signals are statistically more likely to come from a direction where there are more stars.

As with the targeted search, there is a major implicit assumption in the all-sky survey: Somewhere out there we (or the entire galaxy) are being sent a "beacon" signal. Unlike the leakage we as a civilization have been generating for almost a century, and which can be detected by a targeted search, to detect us at all-sky-survey distances, we would have to deliberately send a high-power signal to somebody who was looking for it. For a civilization at our level of development this is not economically and possibly not technically feasible; for one somewhat or substantially advanced, it may be possible or even routine. If the assumption that there is the equivalent of a "beacon" being sent is wrong, then the search will fail.

Common requirements

The two strategies were discussed without regard to the electronic instrumentation necessary. As divergent as the antenna requirements are, the receiver and signal detector requirements are very similar. For a research-grade radiotelescope, the cost of the mechanical system is so high that any reasonable electronic detection ensemble has a cost, you should forgive the expression, in the noise level. This is emphatically not the case in the all-sky-survey scenario, in which the electronic requirements of the receiver and data reduction hardware can equal or exceed the cost of the antenna, and yet come nowhere near the capability of the larger instrument's electronics.

Copyright 2006 Contact in Context

Fortunately, there is great cause for optimism! While the cost of constructing mechanical hardware increases slowly with time, the cost of constructing electronic hardware plummets with Moore's law. At the moment professional electronic hardware exceeds amateur capability by perhaps a few dB in sensitivity (disregarding antenna size), two orders of magnitude in stability, and three to four orders of magnitude in frequency coverage. Advances in DSP in particular, as well as improvements in semiconductors and other technology, are likely to bring today's professional capabilities within the reach of amateurs in only a few years.

Divergent requirements, both mechanically and culturally, do not obviate the desirability of conducting both types of searches. The fact is, nobody knows the prevalence or location of radio-using civilizations. Many or few, advanced or at our level of development, near or far, we simply have no idea. Proof of their existence is interesting and important and the cost of searching is insignificant.

A Third Strategy

The purpose of this extensive background discussion was to examine the implicit assumptions and requirements of both kinds of searches. Each has a distinctive vulnerability. If there are no nearby civilizations, the targeted search will fail. No matter how many civilizations there are, if nobody is transmitting a beacon the all-sky survey is unlikely to detect any of them. What if we happen to be in a deserted neighborhood? Too bad.

In the discussion above I stated that one of the requirements for a signal to be scientifically accepted as being of intelligent origin is that it be verifiable. This is not entirely true. Another way to prove extraterrestrial origin for a signal is for the content, i.e., modulation, to be both explicit and alien. Certainly a single frequency beacon wouldn't fulfill this criterion, nor would simple pulsed signals, the alien equivalent of telemetry signals, or anything else that could arguably have been produced on earth. What would be acceptable? A television signal depicting aliens or a signal whose decoded modulation revealed scientific knowledge beyond current competence would, although the first surely would be suspected of being a hoax. Signals with information between these extremes, upon detailed scrutiny, might be accepted, at least provisionally. Why, however consider these possibilities when it is commonly accepted that at best a single frequency beacon might be discovered.

The phenomenon of gravitational lensing, a consequence of general relativity, is scientifically accepted and has proved a valid astronomical and astrometrical tool. A gravitational lens occurs when electromagnetic radiation passes a massive astronomical object such as a star or even a galaxy. Because of the large area of signal "collected" by the lens and the potentially small area of its focus, enormous signal gain is possible. Claudio Maccone has written a treatise on the subject, stating that our own star would have a gravitational focus at about 550 AU[5], allowing a spacecraft at this distance to take advantage of this lens to provide signal gain greater by far than that of the Arecibo dish. One of the purposes of this spacecraft would be to look for signals of intelligent origin. Sadly, most of us do not have our own space program and therefore cannot rely on the sun to supplement our antenna. Is all lost? No!

For the sun, the closest point of focus is 550 AU. However, the focus of a gravitational lens is not a point, it is a line. This line is directed radially from the focusing mass, and signals at different radial distances from the mass focus at different points along the line. Any distance greater than 550 AU would therefore focus signals coming from a sufficiently great distance on the opposite side of the sun. At this focal point one could take advantage of the gain of the spacecraft antenna in addition to the gain of the gravitational lens, giving a great enough signal strength to detect even "leakage" signals from stars much farther away that those targeted in searches with our biggest telescopes.

Since the focus is a line, it follows that this effect can be employed at any distance beyond 550 AU. While we have no immediate prospect of going 550 AU from the sun, we are already more than 550 AU from every one of the billions of stars in our galaxy! Therefore, at any given time we could be in the line focus of some other star's gravitational lens, and could be receiving some other civilization's signals with relatively modest equipment. Perhaps we have already done so. One reasonable (but entirely conjectural) explanation of the SETI "hits" that we've received over the decades is that it was a transient gravitational lensing phenomenon.

Conceptually, then, we can see that it should be possible to take advantage of the gravitational lens to receive, without an enormous antenna, signals from a great distance. Unfortunately, doing so requires the fortuitous alignment of the transmitting source, a star (or other large mass), and an antenna, not to mention a receiving apparatus prepared to detect the signal. If we accept the notion that the lens is powerful enough to allow us to detect leakage radiation rather than a directed beacon, we're entitled to assume that any civilization such as ours would be detectable. Therefore, the number of detectable sources depends on the "solution" to the Drake Equation, compounded with two additional variables:

Copyright 2006 Contact in Context

Please use Contact in Context:v2i2/third.pdf in any reference to this article

1: What are the odds that, at any given instance, a star and potential transmitting source are so aligned that reception would be possible; and,

2: Is there an antenna/receiver combination available at the focus capable of capturing a signal if one were present.

In the spirit of the Equation I shall designate these variables as f_a for the fractional probability of an appropriate alignment, and f_r the probability that a signal, if present, will be detected. As with other terms of the Drake Equation, fa is determined by the universe. There will be just so many foci crossing ones antenna per time period. Like some, but not all, terms, this is susceptible to reasonable calculation, and values are available in the literature. Unlike Fa, Fr is under our control. If a SETI antenna capable of capturing a high-power, single-frequency beacon is also capable of capturing leakage signals with the aid of a fortuitous gravitational lens, then the all-sky survey model is also appropriate for this type of search, and the economic cost of the antennas necessary to bring Fr arbitrarily close to one is entirely reasonable. However, the electronic signal detection package useful for beacon detection is unsuitable for detecting and verifying gravitationally amplified signals.

Because of the relative motion of the notional transmitting source, the intervening lensing body, and the orbital and rotational motion of the earth, the focus of the signal is constantly shifting. Orbital and proper motions of bodies in this galaxy are on the order of tens to thousands of KM/Sec. With some lensing events these motions will fortuitously subtract and provide a relatively stationary focus, but probabilistically the large majority will add, giving a receiver a relatively short time in the focus. A reasonable estimate, derived from estimates of stellar brightening, gives periods of minutes to a few hours. A much longer period would be of little benefit since most antennas operate in drift-scan mode, and only look at a given area of the sky for 5 to 15 minutes.

Unfortunately for the initial verifiability model, it may be practically impossible to use multiple radiotelescopes to verify the presence of an intelligent signal. Not only will the signal be temporally transient and destined to never repeat, but the focus of the gravitational lens may encompass spatially only one of the antennas. Thus, one must look to the second verifiability model, one in which the signal(s) modulation characteristics are in themselves indicative or conclusive of alien origin. To accomplish this, as an absolute minimum, a recording of the signal is required.

The electronic package of a typical SETI system comprises, after the analog receiver components, a digitizing and analysis subsystem. An amateur system can be little more than a personal computer with a sound card. Such hardware can look for narrowband signals over a bandwidth of perhaps 40KHz. A professional system uses a number of dedicated processors to give several orders of magnitude more frequency range, on the order of tens or hundreds of MHz. In either case, however, the analysis system must make a decision: is there a narrowband signal present in the passband? If so, the immediate goal is to determine from whence the signal emanates. If it is coming from a point stellar source, it should show doppler shift characteristic of the earth's rotation, and should vanish if the radiotelescope is pointed momentarily in some other direction. If these conditions are fulfilled, then another telescope at another location is advised of the signal and asked to verify its presence. Missing from all this excitement is any analysis of the signal itself! A narrowband signal is characterized by a single number: its frequency. This, plus or minus a few hundred Hz due to Doppler shift, is all you need to know. There's no point in recording the signal itself

To see what to expect from a gravitational-lens-enhanced signal event, consider what would happen if one were to aim an antenna at the earth from space. As the earth swam into the focus of the dish, a panoply of signals would reveal themselves. Among the strongest would be television transmitters and pulsed radars. Weaker signals used for point-to-point communications and radio navigation, for example, would be evident if the receiver had enough sensitivity. These signals would be all along the frequency axis. Depending upon time of day or night, frequencies below approximately 5 MHz to 50 MHz would be filtered from the ensemble by ionospheric reflection and absorption. Anything from 50 MHz to many GHz would be fair game. For "internal" use by our civilization, there are no "magic" frequencies. In fact, the "waterhole" is the *least* likely to have strong signals, since it is reserved for receiving weak signals! Whether or not another planet has a radio-reflective ionosphere such as ours does isn't all that important, since for other reasons we will want to limit our search to a somewhat higher range of frequencies. Ideally, it would be desirable to search in the range of approximately 1 to 10 GHz, or even lower and/or higher if antenna size and/or precision permits.

Would we detect the earth with a receiver designed specifically for extremely narrow frequency bin detection? Maybe. Although there is little point in transmitting a totally modulation-free, extremely narrowband signal (except, perhaps, as a frequency standard or interstellar beacon), there is often enough energy transmitted at a "carrier" frequency used as a demodulation reference. It has been said that "a

Copyright 2006 Contact in Context

This article is available at http://www.contactincontext.org/cic/v2i2/third.pdf

sufficiently advanced form of modulation is indistinguishable from noise" and we have been approaching that "ideal" almost since the beginning of electromagnetic communication. For example, television transmission in the United States will, over the next decade, shift from a format with a strong carrier component to a "digital" format in which there will be no carrier at all. Another civilization's hope of detecting the next century's "I Love Lucy" will be greatly reduced. For the purpose of SETI it would be better to have a detector that could detect any artificial characteristic of a signal ensemble. Among the hallmarks of artificiality would be, in addition to frequency coherence, a broadened or otherwise interesting autocorrelation function, a non-Gaussian probability density function, a suddenly differing smoothed frequency spectrum, and amplitude modulated, at whatever rate, intensity. Another interesting detection method involves the Karhunen-Loeve transform[6], which promises to detect the presence of any non-random signal. The computational burden of these methods varies from minor (non-Gaussian PDF) to fearsome (KLT). While it would be desirable to employ all these methods, and it will be possible to do so with modest equipment in the near future, there is no reason not to use the simpler methods available right now.

Given an antenna and some method of detecting when a signal is present (using whatever methods we choose), we aren't quite there yet. If the detector alerts us to a possibly artificial signal (or group of signals) in the antenna beam, what good does it do us? With the gravitational lens scenario, we cannot count on a cooperative observatory to verify the location or existence of the signal(s) since their footprint may not include that observatory. Therefore, we must hope that the alternative criterion for acceptance, intelligibility of modulation, obtains. Moreover, we must record as much of the baseband signal as we possibly can since we will, in all likelihood, never have the opportunity again. This may not be as formidable an obstacle as it seems. For a traditional SETI search, little signal recording is necessary. Of primary interest is the existence of narrowband signals whose characteristics can be defined in a few bytes. To record the entire baseband in the hope of capturing the modulation of an intelligently generated signal would require an impressive recorder. Assuming a 10GHz bandwidth and an 8-bit dynamic range, the data generated would fill a standard VHS videotape roughly once per second. A more dramatic way of looking at this is that if you put the Statue of Liberty in the middle of a football field and covered the whole field with the data tapes, one year's worth of data would obscure the field, statue and all, up to the torch. I have no desire to bury the Statue of Liberty in worthless data, which is what most of it would be. A better way to handle this is to be more judicious in our data recording habits.

First, we would only want to run the recorder when there is a candidate signal present. Based on the gravitational lens statistics, or, alternatively, the number of "hits" received in SETI searches in the past, this would be comfortably under one per cent of the time. Of course, the time to initiate and terminate recording would be determined by a signal detector broadly described above. Next, recording the entire baseband, beyond the state of the art for a single recorder at present, isn't really necessary. Although it is conceivable that there would be a torrent of signals at all frequencies, it is more likely that they will appear in a more limited area. On earth we allocate frequency bands for different purposes. Some have a few strong signals (broadcasting), some have many weak signals (portable telephony). Even with the enormous gain of a gravitational lens it is unlike that we can receive signals unless they have many kilowatts behind them. By setting up a number of recorders capable of an instantaneous bandwidth of, say 50 MHz, and a suitable number of signal presence detectors, we should be able to deal whatever comes our way. Finally, we would need to decide on the recorder "dynamic range" which in turn is determined to a large extent by the number of signals expected to be received and the expected signal to noise ratio. This is normally specified in decibels (dB) wherein each bit of the sampled signal increases the range by a factor of two, or roughly 6dB per bit. As an example, a broadcast-quality television signal requires roughly ten bits of dynamic range, and a bandwidth of roughly 5 MHz. It is probably unrealistic to expect a "broadcast quality" anything at interstellar distances, but with a signal of any complexity and only one chance to capture it, it is better to err on the side of greater precision. A digitizer of at least 4 bits and preferably as many as 8 bits should handle a wide variety signals.

Given the above analysis, the absolute amount of data to be recorded reduces to a more manageable average rate of hundreds of kilobytes per second and a burst rate of, say, 25 megabytes per second. Even this rate would fill many tapes, but because of the "bursty" nature of the data, it should be possible to subject each burst to more comprehensive analysis during intervals when no candidate signals are being received. The data can be initially recorded in random access memory and only committed to tape or other storage medium when there is a reasonable probability of a signal being present. This is a more desirable method because "data acquisition" to memory is simpler and faster than recording directly to a magnetic or optical medium, and the RAM medium can be immediately and indefinitely reused if the candidate signal is found to be spurious.

An example small SETI "observatory" electronics package is shown in diagram x. A 'specially modified video obscenity delay line is used as a burst storage recorder. Electronically, it is arranged as an "endless loop" recorder, so that the last 20 seconds of data received are always in memory. A "signal detector," still to be optimized, works with a PC to determine the likelihood that there is a non-random signal in the 5MHz-wide pass band of the down-converted radiofrequency input. When such a determination is made, the computer, after a 10-second delay, tells the video recorder to stop recording, leaving 10 seconds of pre- and 10 seconds of post-"detection" signal in its memory. This memory, approximately 300 Mbytes worth, is then transferred to a computer for storage and subsequent detailed analysis.

It should be noted that the gravitational-lens scenario and the narrowband beacon scenario are by no means mutually exclusive, and the ability to perform both types of detection enhances the capability of both small- and large-antenna SETI observatories.

Summary

The advantages of looking for gravitationally-lensed intelligent signals include increasing the chance for detection at relatively small additional cost and at least the possibility of obviating the "we had a hit but couldn't confirm it" problem. It is a strategy that differs from the "targeted search" in that it has a chance of picking up "leakage signals" from solar systems that are otherwise completely out of range. It is a strategy that differs from the all-sky search in that it doesn't require a signal beamed to us directly by a civilization that knows where we are, or, transmitted omnidirectionally by a civilization that has incredible power at its disposal. It is a strategy that, given its modest antenna requirements, can be adopted by amateur and small observatories. And it is one that will benefit as the state-of-the art in signal processing improves inevitably, rather than one that requires ever bigger radiotelescopes.

References

1. Seth Shostak, An Alien Signal: Being Sure. SETI Institute, http://www.seti.org/site/apps/nl/content2.asp?c=ktJ2J9MMIsE&b=194993&ct=221038, checked July 14, 2006.
2. David Latham, David Soderblom, Todd Henrey, Targeted Star Search, http://www.seti.org/site/pp.asp?c=ktJ2J9MMIsE&b=179075, checked July 14, 2006.
3. H. Paul Shuch, One Hundred Up, 4900 to Go! A Project Argus Update, Contact in Context:v2i1/Argus.pdf, http://www.contactincontext.org/cic/v2i1/Argus.pdf, checked July 14, 2006
4. Finances: What Does It Cost? http://www.setileague.org/finances/cost.htm, checked July 14, 2006.
5. Claudio Maccone, Space Missions Enabling SETI Searches Farther and Farther Out, National Institute for Discovery Science, http://www.nidsci.org/essaycomp/cmaccone.html, checked July 14, 2006.
6. Michael A. Unser, Extension of the Karhunen-Loeve transform for wavelets and perfect reconstruction filter banks, *Proceedings of SPIE -- Volume 2034 Mathematical Imaging: Wavelet Applications in Signal and Image Processing,* Andrew F. Laine, Editor, November 1993, pp. 45-56.

Copyright 2006 Contact in Context