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DO POTENTIAL SETI SIGNALS NEED TO BE DECONTAMINATED?

Richard A. Carrigan, Jr.
Fermi National Accelerator Laboratory
Box 500 MS221
Batavia, IL 60510 USA
carrigan@fnal.gov

ABSTRACT

Biological contamination from space samples is a remote but accepted possibility. Signals received by searches for extraterrestrial intelligence (SETI) could also contain harmful information in the spirit of a computer virus, the so-called "SETI Hacker" hypothesis. Over the last four decades extraterrestrial intelligence searches have given little consideration to this possibility. Some argue that information in an extraterrestrial signal could not attack a terrestrial computer because the computer logic and code is idiosyncratic and constitutes an impenetrable firewall. Suggestions are given on how to probe these arguments. Measures for decontaminating extraterrestrial intelligence signals (ETI) are discussed. Modifications to the current SETI detection protocol may be appropriate. Beyond that, the potential character of ETI message content requires much broader discussion.

INTRODUCTION

Since the dawn of SETI four decades ago[1] the potential for success has risen substantially. With the advent of powerful new facilities and sophisticated signal detection programs searches have taken on a new crescendo both for radio and optical frequencies[2]. Recent extraterrestrial planet searches have shown planets are more common than many anticipated. Year by year more is understood about the genesis of life[3]. Recent insights suggest the possibility that the pace and ease of evolution could be faster through endosymbiosis and the increasing temperature span suitable for life as exemplified by extremophiles. There are glimmerings on the horizon of artificial computer "life" so that we may be faced with this somber possibility in several decades. Even with electronic technology barely a century old earth civilizations have the capability to send signals to the stars. Earth no longer seems so rare[4]. This is no promise that there are intelligent signals in the cosmos that will soon be discovered. On the other hand, the possibility should be considered seriously and preparations made to cope with a signal if one is received.

ETI signals could come in a variety of forms. One type of potential SETI signal is a beacon containing little information. A second kind is a message. In what follows it is argued that particular care needs to be taken in the way messages are handled when they are received. A third possibility is that the galaxy may contain artifacts like TV or radar leakage signals[5]. These artifact "signals" are the equivalent of archaeological information from early civilizations on the earth. Few of the archaeological artifacts discovered on earth were intended to inform the future. At the outset of the SETI quest it was recognized that there was a dark side to the emanation of TV and radar artifacts from earth. A hundred year old sphere of high-tech signatures is radiating out from earth at the speed of light signaling mankind's presence and capabilities. A signal from the first radio activity on earth a century ago could have reached a star fifty light years away and a civilization there could have immediately responded and sent a signal back to earth. Such a signal could be useful or possibly very harmful to us. There are on the order of 400 stars within fifty light years of earth.

Interstellar signaling can also be broken into signals intended for two-way conversations and one-way signals. Two-way conversations are possible for stars that are close together. However even two bristlecone pines separated by ten light years could only get in a hundred or so exchanges in a lifetime, hardly the stuff of a good college education. At first glance a one-way message sounds like watching TV or stuffing a note in a bottle and tossing it in the ocean. On the other hand one only needs to remember the impact of Greek culture on the West to realize how significant one-way communication can be. (Interestingly, P. Morrison estimated that the total written contributions from ancient Greece amount to 10^9 bits of information[6].)

Finally, will a SETI signal be altruistic, benign, or malevolent? It would help to understand the motivation of a message before reading too much of it. Like Odysseus, we may have to stuff wax in the ears of our programmers and strap the chief astronomer to the receiving tower before she is allowed to listen to the song of the siren star.

The central premise of this article is that an ETI signal could be malevolent. The concept is that the signal might be able to take over the receiving computer or urge the construction of a translator with an unknown agenda. I call this hypothesis "SETI Hacker." This concept is not new. It is a theme in a large body of science fiction[7]. What is new here is an attempt to discuss the possibility in analytical terms and look for means to denature SETI signals. Some aspects of this have been discussed earlier in a paper prepared for Bioastronomy 2002[8].

The following sections of this paper discuss the possible nature of an interstellar signal, information transfer over interstellar distances by electromagnetic waves and matter carriers such as DNA, possibilities for denaturing or sterilizing a signal, and summarize the discussion.

THE NATURE OF AN ETI SIGNAL

The character and size of an ETI signal will shape the approach to treating the signal content. A beacon with a message of less than a hundred kilobytes repeating every 10 seconds or so could be handled without too many precautions. Based on current earth-based programs even a ten megabyte program or data set can be opaque. To appreciate the potential impact of a signal it is useful to review the character of ETI signals and the scale of information that might be transmitted.

Signaling or information transfer over interstellar distances might be either by electromagnetic waves such as a laser, radio or TV signal, or by a matter-based medium like an old-fashioned letter, panspermia[9] of DNA or silicon chips, or a spacecraft. This discussion focuses on electromagnetic signals. For an electromagnetic signal there will need to be a receiver and a decoder or demodulator. The signal will have to provide some attractive "advertisement" or lure to enlist the help of a host. Almost certainly actual messages will have gone through some sort of compression. The signal will have to carry the compression decoding algorithms embedded in the message. On a first level it is to the advantage of the sender to have the compression algorithm totally clear.

The actual message content could be quite different than we imagine. For example information about scent and odor might be much more important if the originator was an advanced dog. What information would be significant for an intelligent plant? Even for humans a large fraction of the intelligence base is grounded in pictorial images. Images are harder to characterize than text and numerically-based intelligence. Finally, the sender will probably have much more sophisticated technology available than we do today. For example we are just leaning how to read genomes and we do not yet have quantum computer engineering.

One anticipates that the message would be grounded in science and logic rather than magic incantations. Metaphors and analogies from non-scientific areas may be of little help in understanding ETI signals. My wife has recently completed a diptych that contrasts the view of an ant and an astrophysicist. The astrophysicist asks "Can I unweave the gauzy fabric of stars?" while the ant wonders "Can I untangle the matted carpet of earth?" We can be sure the sender of an ETI message will be looking out to the stars but its core perspectives may be more like the ant than the astronomer. A particular feature of a non-technical view of SETI is the temptation to try to apply moral arguments. Attempting to attribute human legal or ethical values to our explorer ant is a dangerous stretch. The one "ethical" framework we could have some confidence in is a Darwinian "survival of the fittest." This behavior standard is about as far from altruistic as one can get.

For message size one can consider examples based on human experience. A typical desktop computer operating system is now 1 Gbyte while Microsoft Word is about 0.01 Gbytes. (A Gbyte is 10^9 bytes.) Although the human genome consists of 3 billion DNA base pairs, the effective information content is on the order of 0.05 Gbytes. A typical education through graduate school could be subsumed in 1-10 Gbytes. A rough "memory" of a casual acquaintance including images might take 0.001-0.010 Gbytes so 1000 acquaintances could be summarized in 10 Gbytes. A lifetime of images stored once a minute might be 100 times larger. Crevier[10] has tried to determine the information needed to characterize a person's memory from several directions and gets numbers in the 2.5 Gbyte range. Taking $6*10^9$ people on earth and assuming 2.5 Gbytes/person gives 15 exabytes to send memory profiles of everyone on earth (1 exabyte is 10^{18} bytes). This is a very large amount of data. About 1997 Lesk[11] speculated that all the information in the world including pictorial information required 12 exabytes of storage. Adding profiles for all the world's inhabitants including their DNA information brings this number to about 25 exabytes. An even more ambitious transmission might include DNA profiles for all the creatures and plants on earth. Even an advanced civilization might have to draw the line somewhere on the scale of message transmission.

Exabyte data bases currently require transmission times of years over optical fibers with capacities of 10 Gbytes/s. (Note that the fifty light year SETI example below discusses a rate of 10^{-5} Gbytes/s.) Based on exabyte-scale databases we can anticipate the possibility of very long electromagnetic signals possibly interspersed with short, interesting messages to act as a lure.

Actual translators for signal decompression could be relatively simple. Even now these types of signals can be handled with PC-scale computers. SETI Hacker virus type software would likely be much more complicated.

INFORMATION TRANSFER OVER INTERSTELLAR DISTANCES

The fundamental challenge for SETI searches is to determine the most effective way to search. A useful tool to probe this is to ask what the "energy costs" are to transmit and receive an ETI signal. One needs to know how much energy is required to transmit a bit of information using different approaches. The sender will be driven to get the bit rate as high as possible and hold the cost per bit low. Folded into the transmission cost is a supposition about the level of technology at the receiving end as well as information about the degradation due to attenuation or damage to the message as it moves across the interstellar medium. Transmitting through the relatively dense galactic core is harder than transmitting in the outer halo. Transmitting further takes more energy. Transmitting to a small receiving antenna takes more energy than sending to a large antenna. Knowing the associated costs is a good tool to shape searches and direct the search to suitable SETI candidates.

Transmission by radio waves is well understood and can be easily quantified. The relative energy costs of radio and laser signals has been discussed elsewhere[8]. The ratio depends principally on assumptions made about how the laser signaling is handled. It should be noted that most so-called high power lasers are pulsed while it is integrated power that is important for message transmission. Lasers and laser detectors are still in a Moore's law development phase so that technology assumptions depend on the assumed framework for the calculation.

Information transfer across space breaks into three components: the launch or broadcast of the signal, propagation, and detection. Message costs can be factored into these three parts. The propagation part is dominated by the so-called gain or focusing power of the transmitting antenna. The gain of an antenna is:

$$G_e = \frac{4\pi}{\lambda^2} A_t \qquad (1)$$

where λ is the wavelength and A_t is the effective area of the transmitter. The gain increases as the square of the ratio of the effective diameter of the antenna divided by the wavelength. This is because the antenna cone narrows and the signal is more tightly focused. The antenna broadcast to a smaller and smaller region of the sky as the gain increases. This is generally satisfactory for a radio or TV signal since the star is much smaller on the sky than the radio beam area. Antennas employing interferometry can be an exception to this rule. The gain for a laser system is higher since λ is much smaller. As a result the cone of a laser beam can be smaller than a star's planetary system for nearby stars. The gain of an Arecibo-sized transmitter operating at 3 cm is 10^9.

For a noisy radio link, the Shannon limit for the channel capacity in bits/s is:

$$C \le \frac{B}{\ln 2} \ln\left(1 + \frac{P_r}{kT_N B}\right) \tag{2}$$

where B is the bandwidth, T_N is the receiver noise temperature, and k is Boltzmann's constant[12]. P_r is the power received by the earth antenna. Leigh showed that for a low signal to noise ratio the maximum channel capacity is:

$$C_m \approx \frac{P_r}{kT_N \ln 2}. \tag{3}$$

In this case the channel capacity depends on the power received but not the bandwidth. P_r is given by the Friis transmission formula:

$$P_r = P_t \frac{A_t A_r}{\lambda^2 R^2} \tag{4}$$

where P_t is the transmitter power, A_r is the effective area of the receiving antenna, and R is the distance between the transmitter and receiver. With a 10 GHz carrier (λ = 3 cm) a 1000 kW signal at 50 ly could transmit substantially more than 10 Kbytes/s assuming Arecibo-sized antennas with a receiver noise temperature of 10 degrees K and a 1% bit error rate. A 1 Gbyte program or computer encyclopedia would take less than a day to transmit and cost several thousand dollars assuming an energy cost of 10¢/kWH. This is only an order of magnitude more expensive than buying software on a CD. For some technology assumptions the energy cost for laser transmission could be substantially smaller. The dispersion of the interstellar medium limits the transmission bandwidth. Following Leigh the upper limit on the bandwidth for a 1000 ly path is 3.5 MHz, quite sufficient for a 10 Kbyte/s transmission rate at 50 ly.

These formulas can be used to determine δE_t, the transmitter energy per received bit:

$$\delta E_t = \frac{P_t}{C_m} = 4\pi \frac{R^2}{G_e} \frac{kT_N \ln(2)}{A_r} \tag{5}$$

and δE_r, the receiver energy per received bit:

$$\delta E_r = \frac{P_r}{C_m} = kT_N \ln(2). \tag{6}$$

The cost in the transmitted energy per bit increases as the square of the separation and decreases as the gain is increased. At the receiver a lower noise temperature and a larger receiving antenna decreases the energy/bit. For the example $\delta E_r = 10^{-22}$ Joules or .0006 eV and $\delta E_t = 3.6$ Joules. The energy per photon is $\delta E_\gamma = h\nu$ where h is Planck's constant and ν is the frequency. For the example the energy per photon is 6.63×10^{-24} Joules or .00004 eV. Detecting one bit in the example requires 14 photons at the receiver.

Interestingly, it can be shown that the energy costs per bit for electromagnetic processes and directed panspermia and spacecraft transmission via DNA are similar for matter velocities on the order of 10^{-4} of the speed of light. Part of this arises because DNA information storage is remarkably efficient. A 5 mm diameter sphere of DNA can store on the order of 25 exabytes of information. Of course matter transmission is much slower than electromagnetic transmission. Naturally different assumptions about radio, laser, and matter information transfer change the relative energy costs. The impact of future technologies could also change the relative relationships. In considering message delivery systems it would seem that none of them can be definitely ruled out at this point.

The most important point is that large amounts of information can be transferred inexpensively at the speed of light even with current technologies. In addition, the message size can easily be so large that the underlying intent of the message would not be apparent.

DENATURING A SIGNAL

As noted earlier, archaeological signatures and beacons appear to be comparatively safe for SETI. Characteristically a beacon would transmit little information. On the other hand it may be a short step from a beacon to a message. For example a beacon could point to a signal in a different wavelength band where a message was coming in. A message should be approached with great care. It may be extremely dangerous! Put simply the receiver needs virus protection and it had better have an electronic condom.

At least two scenarios need to be considered in protecting against a malevolent SETI Hacker signal. One is a computer virus in the message that takes over the computer at the receiver. The other is an open message that gives an impenetrable software code or instructions for a hardware translator to handle an opaque message. Both cases are dangerous. The damage may be done before the receiver appreciates that it is under attack. This is the current experience even with earth-based hacker attacks. There may not be an opportunity to pull the signal out of the computer or turn off the power before the intruding signal has taken over.

It is an open question whether an earth-based computer virus can penetrate a computer if it is not familiar with the operating system. The computer and computer security experts I have discussed this with don't think it is possible. The argument goes that viruses typically enter a computer by exploiting known features in the operating system. Further, experts argue, typical computer operating systems are quite idiosyncratic so that it can be difficult to analyze their structure from a logical point of view.

However, it seems worthwhile to approach the question with an open mind. For example, one could set up a thought or even a practical test with a primitive "toy" computer, perhaps modeled along the lines of the first Illiac and have programmers unfamiliar with the Illiac system try to hack the program. I believe it would also be useful to convene a workshop with diverse participants to discuss the subject in some detail. This might be coupled with broader discussions on the topic of denaturing ETI signals.

There are a number of approaches that might be taken to denaturing a SETI signal. Breaking the information into packets as is currently done for

SETI@home would seem to make it much harder for a large program to bootstrap itself back together. Isolating incoming message on a dedicated computer would keep the potentially dangerous signal in an isolated environment. There may be additional techniques such as the use of one-time only coding and constant program integrity checking. Again, a convocation of experts could identify approaches to handling this.

Ultimately what may be needed is a protocol similar to the one for biological contamination of a probe returning from space. The International Committee on Space Research (COSPAR) developed such a protocol through extensive international negotiations even involving the United Nations[13]. Concern about biological contamination grew out of many experiences with situations where new biological species were introduced to another ecology and then seriously impacted the environment. Note that the SETI field does have a protocol[14] to follow if a signal is discovered but its purpose is to avoid public relation problems if a signal is announced prematurely.

SUMMARY

The combination of energy cost and speed of transmission strongly favor the use of electromagnetic signals for propagation of information over interstellar distances. Present SETI efforts concentrate on electromagnetic searches. An electromagnetic signal is feasible even with current earth-based technologies and can carry enough information to be dangerous. However, for an ETI signal some sort of translator is required at the receiving end. As a result, the signal needs a lure to induce the receiver to untangle the message. Such a lure would probably be quite interesting and appear reasonable in intent. This implies care should be taken in working with SETI signals.

This situation deserves serious attention from the SETI community. The possibility of a malevolent SETI Hacker signal must be assessed and protective measures should be put in place prior to the receipt of any real signals.

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