Serb. Astron. J. № 167 (2003), 1 - 10

UDC 52–37
Invited review

ON THE DETECTABILITY OF INTELLIGENT CIVILIZATIONS IN THE GALAXY

N. Duric[1] and L. Field[2]

[1] *Institute for Astrophysics, Department of Physics and Astronomy*
University of New Mexico, 800 Yale Blvd., N.E., Albuquerque, NM 87131

[2] *Department of Anthropology*
University of New Mexico, 800 Yale Blvd., N.E., Albuquerque, NM 87131

(Received: October 1, 2003; Accepted: October 1, 2003)

SUMMARY: In this paper we argue for the possibility that even in the event of a Galaxy teeming with extraterrestrial intelligence (ETI) the probability of receiving recognizable signals from the ETIs may be very low. There are two majors factors that may limit our ability to detect other civilizations.

(i) Evolutionary mismatches may cause difficulties analogous to humans attempting to communicate with lower primates.

(ii) Independent evolutionary paths resulting from differing planetary/stellar environments may result in life whose cognitive processes and consequent perceptions of the universe are very different from ours. Interpreting signals from such civilizations may prove a very difficult or even futile task. Even on Earth, an example of a cognitive mismatch is that between humans and dolphins, where evolution in very different environments has led to difficulty in establishing communication between these two species.

The main effect of the second factor is to limit communication while the effect of the first is to constrain what communication is possible to a "window of opportunity", a finite period of time, τ_ω, when communication may be possible before diverging evolution makes it impossible. For example, if the number of ETIs in the Galaxy is one million and if $\tau_\omega < 10^6$ years, the average separation of "contactable" civilizations, $\langle r \rangle > 5 \times 10^3$ light years so that one star in 10^{10} harbors such a civilization.

If the above arguments are correct we reach the following conclusions.

- **The absence of detected signals does not translate into an absence of ETI's.**
- **Targeting individual stars in the search for ETI has a low probability of success.**
- **The use of radio signals is of limited value because with such large separations between "contactable" civilizations interstellar scintillation strongly limits the propagation of radio signals. Similarly, optical communication would be hindered by interstellar extinction.**
- **Possible alternatives to current searches for narrow band signals include listening for modulated broadband signals, searching for narrow-band signals in the microwave/FIR spectrum and searching for evidence of artificially processed environments. All such searches would need to be "all sky" to have a reasonable chance of success.**

Key words. Astrobiology – Extraterrestrial intelligence – Radio lines: general – Galaxy: stellar content

1. INTRODUCTION

The search for extraterrestrial intelligence (SETI) has now spanned four decades. As in other areas of science, this discipline has both a theoretical and an experimental basis. Although the experimental side has proceeded sporadically, the theory has developed more or less continuously over this period of time and has led to controversial debates on the prevalence of extraterrestrial intelligence (ETI) in our Galaxy. The state of the field can be summarized with the following observations.

The theory which, in principle, drives the observations makes two distinct predictions. (i) The Galaxy is filled with ETIs and communication with them is likely to succeed. SETI should, therefore, be encouraged. (ii) There are very few ETIs (perhaps none) in the Galaxy and SETI is therefore a waste of time and resources.

The great proliferation of life on Earth, the discovery of extrasolar planets and the common physics shared by all stars suggest that platforms for the development of life, analogous to ours, are very common and that other civilizations in the Galaxy should, therefore, exist. Adding to this argument the possibility that life evolves according to other paradigms (life as we don't know it - as might hypothetically exist in the oceans of Europa and Titan) we are tempted to conclude that the Galaxy should be teeming with life.

On the other hand, direct evidence suggests otherwise. After a number of unsuccessful searches SETI has failed to turn up even a hint of extraterrestrial life. If the Galaxy is indeed crowded with intelligent civilizations we shouldn't have to look very hard. Even if such societies are not directly communicating with us, we should be able to see "evidence" of their existence analogous to the EM pollution emitted by daily activity on Earth.

In this paper we investigate a scenario under which the Galaxy may well be full of life but at the same time it is invisible to our listening devices. We begin with a short review of the SETI literature and the Drake equation. We then describe the cognitive process as it might relate to extraterrestrial communication. In the final section we discuss the role played by cognition in limiting our ability to understand communications from civilizations that are significantly more advanced than we are.

2. OVERVIEW

2.1. The Drake Equation

Most estimates of the number of ETIs are based on some variant of "The Drake equation", commonly written as,

$$N_c = N_* f_p N_{hz} f_L f_i F_S, \qquad (1)$$

where N_c is the number of civilizations (or ETIs), N_* is the number of stars in the Galaxy, f_p is the fraction of stars that harbor planets, N_{hz} is the number of planets per star that lie in the habitation zone, as defined by terrestrial standards, f_L is the fraction of such planets that host the initiation of life and f_i is the fraction of life-initiating planets on which life evolves to intelligence, as defined by human standards. The final parameter, F_S, represents the fraction of the star's life over which the civilization survives. The probabilities are normally assumed to be independent of each other but this view has been recently challenged by Livio (1999, see below).

2.2. The Case Against Numerous Civilizations

Pessimistic scenarios (e.g. Barrow and Tipler 1986) correctly point out that investigations of ETIs ignore the possibility that our existence is the product of a low-probability event. In fact, our existence is independent of probabilities; we ask questions because we exist, regardless of how we came to be, and our existence does not, in any way, imply that life is a universal phenomenon (this is the so called weak anthropic principle). Proponents of the pessimistic scenario also use the colonization argument. If there are many civilizations in the Galaxy, they are most likely characterized by a distribution of evolutionary stages such that we are at the low-end tail of the distribution. At the high-end tail there must exist the most advanced civilization in the Galaxy and it might have as much as a 10^{10} year evolutionary jump over us. Such a civilization should be capable of colonizing the entire Galaxy. Since we see no evidence of such colonization, ETIs must be sufficiently sparsely distributed so that the high-end of the distribution is unpopulated. The ETIs must therefore be low in number, or nonexistent. A third argument, that derives from the Cold War, is that F_S is very low ($F_S \approx 10^{-8}$) because civilizations destroy themselves through war or pollution as soon as they develop advanced technology. Finally, an argument made by Carter (1983) is based on the similarity between the biological evolutionary time scale here on Earth and the Sun's evolutionary time scale. In this view it takes longer to evolve life than to evolve stars, thus ETIs are rare. This argument holds so long as the two time scales are independent. The counterargument is provided by Livio (1999).

2.3. The Case for Numerous Civilizations

Recent developments in extrasolar planet research have worked in favor of the optimistic scenarios. There are three major new pieces of evidence that support a large value of N_c. We now describe briefly the rash of recent discoveries of extrasolar planets, the discovery of short-period planets and the work of Livio (1999) on ozone evolution time scales and the impact these have had on our interpretation of the Drake equation.

2.3.1. Discovery of Extrasolar Planets

As of the writing of this paper there are over 100 planets reported in the literature (e.g. see the extrasolar planets catalog at www.obspm.fr/encycl/catalog.html). Most of these planets have been discovered via the radial velocity method. Since the amplitude of the radial velocity signal depends on the proximity of the planet to the star (in addition to the dependence on the apparent planet mass) there is a selection that favors the discovery of massive, short period planets. Consequently, the actual distribution of planets may be quite different and it is plausible that the discoveries are just sampling the "tip of the iceberg" in terms of the actual population of planets. It is therefore quite possible that most stars may have planets. Certainly we are evolving away from the position that planets are relatively rare objects in the Galaxy. We therefore adopt $f_p = 1$.

2.3.2. The Number of Planets in the Habitable Zones of Stars

The traditional argument against a large number of planets in the habitable zones of stars is based on two observations. For early type stars, the zones are broad but the stars are too few to provide sufficient planets (the stars also evolve too quickly – see the next subsection). In the case of the late type stars, the zones are too narrow and too close to the stars to be relevant to planets. Since the late stars are the most numerous, the argument goes, there are relatively few stars to chose from.

The recent discoveries of short-period extrasolar planets go a long way in countering the above argument. If such planets exist around late type stars, they are within the habitation zones of stars later than G. The relatively high frequency with which short period planets are found suggests that they are common. It is therefore possible that all the later spectral types may contain significant populations of planets in their habitable zones. Although there is not enough data to place a hard number on N_{hz} the discovery of short period planets and the relatively high frequency of late type stars support the optimistic scenarios that favor high values of N_{hz}. We therefore optimistically set $N_{hz} = 1$.

2.3.3. Time Scale for the Evolution of Life

Perhaps the greatest uncertainty in the Drake equation is the parameter f_L. The pessimistic view (e.g. Carter 1983) is based on the only example we know, that of life on Earth. The essential argument is based on the following assumption and observation.

Assumption: The time scale for the development of intelligent civilizations, τ_c, is independent of the time scale for the evolution of the parent star, τ_*.

Observation: The first observation of τ_c is that on Earth. Since that is the first such observation and since $\tau_c \approx \tau_*$ for the Earth (to within a factor of 2) it must be true that $\tau_c \gg \tau_*$, in general.

This simple but powerful argument remained unchallenged until very recently when Livio (1999) proposed a counterargument. Livio challenges the argument that τ_c is independent of τ_*. Instead, Livio argues, $\tau_c = \tau_c(\tau_*)$. The argument is based on the observation that the development of the ozone layer (the key ingredient to the formation of advanced life here on Earth) is a strong function of the amount of UV flux incident on the planet. Since the UV flux is greater for earlier spectral types, the time scale for the development of ozone, τ_{uv}, is much shorter for early type stars and increases strongly toward the later spectral types.

If one assumes that $\tau_c \propto \tau_{uv}$, then according to Livio's calculation the most likely result is that $\tau_c \approx \tau_*$. In other words, it is not at all surprising that we see $\tau_c \approx \tau_\odot$ on Earth because the equivalence of the two time scales is the most likely outcome for any place in the Galaxy. This line of reasoning strongly argues against the pessimistic scenarios.

The above argument suggests that it is not unreasonable to hypothesize that $f_i \approx 1$. Shklovskii et al (1966) suggest that $f_L \approx 0.1$, a number that is consistent with assuming $f_i \approx 1$. We therefore adopt $f_i = 1$ and $f_L = 0.1$.

2.3.4. Civilization Lifetimes

The last term, F_s, is normally taken to represent the lifetime of a technologically advanced society as a fraction of the host star's lifetime. Thus, for example, if our society were to continue until the Sun evolves off the main sequence, the fraction would be ≈ 0.5. Under a pessimistic scenario in which the society destroys itself through weapons of mass destruction (say after 100 years of technological development) the fraction becomes vanishingly small, $\approx 10^{-9}$. In this paper we shall assume an optimistic scenario, namely that such societies evolve away from unstable equilibria as we have done in recent years, on the basis that survival is an evolutionary trait even at a societal level. Certainly, the establishment of single superpower leads to a type of stability where the one power will ensure that its survival is guaranteed. Shklovskii et al (1966) suggest a typical civilization lifetime of 10^7 years. This lifetime represents a time scale that is 10^{-3} that of the Sun. We therefore adopt $F_s = 10^{-3}$.

2.3.5. Optimistic Estimates of N_c

Using the numbers we have adopted above, we estimate that $N_c \approx 10^6$. This estimate is similar to that quoted in Shklovskii et al (1966). Recent developments in extrasolar planet research (as discussed above) support this optimistic number. Nothing in those results argues for numbers lower than 10^6. We therefore adopt this number for all subsequent discussions.

2.4. Current SETI Investigations

The general strategy of current SETI efforts is based on two major assumptions.

(i) Most signal-emitting ETI's are more evolved than we are and are, therefore, capable of emitting signals of much greater strength than those emanating from Earth-based commercial transmitters. Sensitivity of the listening device is therefore not of paramount importance but since we don't know where the signals are coming from, sky coverage is important. This assumption is a reasonable one in light of the fact that our civilization has just entered the era of electromagnetic communication.

(ii) The signals we should search for are probably quite distinct from those produced naturally in the Galaxy. They are probably narrow band signals (frequency spread < 1 Hz; something that is not commonly observed in nature) and they are probably emitted at radio frequencies, since the Galaxy is relatively opaque at other wavelengths. The logical radio frequency is the neutral hydrogen 21cm line transition (and integer multiples thereof) since it is a universally observable line and can act as a natural reference. Such narrow-band emissions make useful beacons because it is easy to measure small changes in frequency arising from the rotation of the emitting planet (thereby confirming that the signal is arriving from a planet, which by itself cannot produce detectable radio signals).

We now describe ongoing projects that are based on the above assumptions.

2.4.1. Project Phoenix

Phoenix is a multi-phased project that targets primarily solar type G dwarfs. It's first phase was completed in 1995, after a 16-week observing run at the Parkes radio telescope in Australia. It has the capability to explore a large frequency band of $\approx 10^6$ Hz and has a limiting sensitivity given by:

$$S = 1.6 \text{ GW}d^2 \text{ (pc)},$$

where GW means gigawatts (10^9 Watts), and the distance is expressed in parsecs. By comparison, commercial transmitters on the Earth are capable of no more than 0.01 GW of power. Even in the case of the nearest stars ($d \approx 1$pc), the project Phoenix sensitivity does not allow detection of commercial type transmissions analogous to those currently polluting the near- Earth environment. However, in light of assumption (i), above, this is probably not a major constraint. To date project Phoenix has targeted 200 stars with no convincing (repeated) detections made.

In a future phase, project Phoenix will utilize the Arecibo 300m radio telescope to perform a much more sensitive search for ETI transmissions.

2.4.2. META

The META project consists of two phases, the first of which has already been completed (Horowitz and Sagan 1993). Its approach differs somewhat from project Phoenix. It searches less of the spectral window but covers most of the sky and therefore most of the volume of the Milky Way. Thus, the presence of even just one ETI in the entire Galaxy could be detected if its transmitter is powerful enough. META uses the Harvard/Smithsonian 26 meter dish located at Agasizz Station. The sensitivity of the META search is given by,

$$S = 17 \text{ GW}d^2 \text{ (pc)}.$$

Project META has detected 37 narrow-band signals of a kind that has never before been seen in nature. Unfortunately, none of the detections were sustained, i.e. they were absent in re-observations minutes later.

2.4.3. SERENDIP

This project, run by the Lawrence Livermore Laboratory in California, is similar to project META. It has greater sensitivity, given by:

$$S = 0.2 \text{ GW}d^2 \text{ (pc)}.$$

but has not covered as much sky as the META. It also has detected a number of narrow-band signals but none have been re-observed.

2.4.4. OSETI

There are several projects that rely on optical beacons, hence the term optical SETI or OSETI. There are groups at Harvard/Smithsonian (http://mc.harvard.edu/oseti), Princeton (pugg.princeton.edu/˜ oseti), Berkeley (sag-www.ssl.berkeley.edu/opticalseti) and at the Columbus Optical SETI Observatory in Columbus, Ohio (www.coseti.org). This search assumes that other civilizations will utilize optical pulses for their messages. This method is not subject to interstellar scintillation. All these searches are targeted, i.e. they look for these pulses one star at a time.

3. WHERE ARE THEY?

If the Galaxy is filled with ETIs why have we not detected them? Surely, at least one of them should have evolved to a sufficiently advanced stage to build a beacon that can be detected from anywhere in the Galaxy. There are, by way of explaining these phenomena, two major possibilities. Either, there are no ETIs, which we, along with other researchers view as very unlikely, or there is an unforeseen problem that prevents communication across the Galaxy.

Recently, Cordes et al. (1997) came up with one such problem that is based on physical considerations. Any radio signal that travels through the Galaxy is subject to the same problem that starlight is subject to when it passes through the Earth's atmosphere. In the latter case, the star appears to twinkle. In the former case, the radio signal twinkles also, but more dramatically. Thus, a possible way out of the "where are they" dilemma is that we are, in fact, detecting ETI signals, though only the scintillation peaks. In other words, one sees the signal once and then it's gone, unless one is prepared to search for a much fainter after-signal. Cordes et al. (1997) propose a statistical analysis that takes scintillation into account and might be able to address the question of how many ETIs there are without actually indicating their location.

Despite the technical "safety net" provided by Cordes et al, there remains the question of why there is no one ETI that can emit sufficiently strong signals to overcome this technical difficulty. For example, if we take the most advanced ETI in the Galaxy (if randomly placed in the Galaxy, it is about 10 kpc away from us, assuming $N_c = 10^6$), it would have to transmit 10^8 GW of power in order to be detected by the current search techniques. Although this power requirement is 10 orders of magnitude greater than that of commercial transmitters on Earth, it represents less than a thousandth of the Sun's power falling on the Earth. A sufficiently advanced civilization should be able to harness this kind of energy.

This problem relates to the greater issue of how ETIs communicate with each other. Assumption (ii), above, inherently assumes that most ETIs communicate according to a paradigm that we have developed here on Earth, This assumption operates despite the fact that we are probably among the least developed communicating civilizations in the Galaxy (having just developed the ability ourselves). Although one can make the argument that common physics drives common technologies, we have no way of predicting what our own future holds in store and what future approaches to communication will look like.

In this paper we wish to examine the possibility that assumption (ii) is not, in fact, correct. The following section details an argument that communication with ETIs may be much more limited than is currently believed.

4. COGNITIVE DEVELOPMENT AND THE WINDOW OF OPPORTUNITY

Our understanding of the universe is ultimately based on a model that is constructed from sensory inputs feeding the cognitive processes of our brains. Our ability to communicate is similarly determined. The cognitive model of the world changes with time as does our manner of communication. On Earth, all species share the same initial conditions (the advent of life on Earth) so differences in communication are the result of differing evolutionary paths and the passage of time. On other planets such cognitive diversity may be greatly enhanced by the diversifying effect of initial conditions that vary globally from planet to planet (i.e., life as we don't know it).

On the experimental side, SETI has so far turned up nothing. Admittedly, SETI has not been active over a long enough period to make a strong statement but given the predictions of the optimistic scenario, it is somewhat surprising that no hint of ETIs has been discerned. In response to this outcome we have re-examined the Drake equation by considering the concept of cognitive interfaces. That is, the ability for two species to communicate, given their totally independent evolutionary paths, must also be evaluated. We pose the question of whether a strong mismatch of cognitive processes may lead to an absence of meaningful communication (particularly radio communication) even in the presence of teeming Galactic ETIs. The argument is made that, even with similar evolutionary paths, the stage of development is a critical factor in the communication process. An example would be the attempt of a modern human to communicate meaningfully with an ape. An ETI that is too far ahead of us (we are the apes) or one that is too far behind (they are the apes) cannot easily communicate with us. The time scale over which the two ETIs can communicate meaningfully is therefore limited because an ETI that has evolved by a factor equal to our evolutionary advantage over apes is unlikely to make its message understandable to us because we don't have the cognitive skills to recognize their messages. Or, it may simply be a matter of the more advanced society abandoning arcane communication methods in favor of more efficient methods that would be unrecognizable by us. If the time scale of the evolutionary overlap is short enough then even a Galaxy teeming with ETIs will be invisible to us.

Since we don't know how cognition evolves in extraterrestrial environments we have to consider three possibilities.

(i) Most ETIs have similar enough cognitive models of the universe so that communication between them is always possible at any time of their development. In this scenario there is little or no divergence of cognitive evolution between civilizations.

(ii) Most ETIs have similar but evolving cognitive models such that communication between them is possible but only when their stages of evolution coincide to within some finite time scale. Such a window of opportunity is determined by the relative timing of cognitive evolution time scales of any two civilizations.

(iii) ETIs evolve from such different initial conditions that their cognitive models rarely overlap and communication between them is not possible. In this "worst case" scenario the evolutionary paths are radically different, rendering communication and even contact impossible.

The essential issue is whether we can presume that the sensory systems of ETIs and our own overlap? Even if we did share "cognitive structures" (a term that gets tweaked below), it is more than possible that what we hear and they hear, we see and they see, we sense in other ways and they sense in other ways, may be vastly unlike. On Earth, communication between cultures, though we take it for granted now, was not always possible and, where possible, was not always sought. Since we have no data on how evolution might proceed under alien conditions, arguments for or against scenarios (ii) and (iii) must be based on observations borrowed from life and history here on Earth.

4.1. Lessons from Earth

Consider the cetaceans, about whose intelligence so much is made nowadays. The range of hearing they experience is very different from ours, thus the way our two kinds communicate through sound waves does not overlap easily (Pryor and Norris 1991). So even if in the unlikely event that we and they shared "cognitive models" we and they exist on fundamentally different perceptual planes which has so far severely limited complex communication. Another apt comparison could be between "normal" humans and those humans whose brain chemistry is different from "normal", such as autistic persons, schizophrenics, or individuals under the influence of hallucinogenic drugs. The latter types of individuals share the same evolutionary history and fundamental physiology with the rest of their species, yet subtle changes in brain chemistry make for extremely divergent perceptions among the "abnormals," thus rendering communication between "normals" and "abnormals" extremely precarious (Sacks 1990, 1995). Assuming a perceptual overlap between humans and ETIs is thus somewhat presumptuous.

Second, what do we mean by "cognitive models"? An anthropologist would read this term as a synonym for "culture." In this light, we must take stock of several presumptions that are at best arrogant, and are, moreover, arrogant in Euro-centric terms. Since the Paleolithic times, different human groups have invented vastly different technologies, adaptive to the various conditions different societies have encountered. Thus the plow was developed in European, Middle Eastern, and Asian societies whose agriculture had adapted to very thick and fertile topsoils. When Europeans arrived on the east coast of North America they were simply unable to perceive that what native peoples were doing was also a form of agricultural cultivation. Their horticulture was very different from Euro-agriculture but well adapted to very thin and sandy topsoils. Europeans refused to see or understand these practices as forms of agriculture (Cronon 1983). In the case of Californian native peoples, the Spanish were utterly mystified by ways of life based upon foraging in ultra-rich biological habitats which yielded sufficient food for a sedentary, materially wealthy way of life (Bean and Blackburn 1976). Again, that which Europeans could not understand simply escaped their cognition – and this occurred between cultures based on the same biology and brain chemistry.

Third, even when humans develop nearly identical technologies, they don't do the same things with them. The Chinese had gunpowder centuries before the Europeans did and made fireworks, not firearms, with them. Similarly, they possessed advanced navigation technology before the Europeans but did not utilize it in the same ways as Europeans appear to have been compelled to do (Wolf 1982). Technologies are mostly quite neutral. Even if the ETIs know about radio waves – does that mean they want to do the same things with them that we do? Consider nuclear power. In the total scheme of history, the US and France are very similar sorts of nations; yet the French public and technocratic elite feels quite safe with nuclear power, while in the US, the public has felt so utterly insecure about nuclear power that the technocratic elite was obliged to reverse the trajectory they had initially planned for this technology (Goldschmidt 1982, Falk 1982). Ultimately, "we" (i.e. Euro-American scientists) have absolutely no way to predict how ETIs will use technologies, even if (and that is an if) the ETIs develop the same technologies we do within the time frame window scenario (ii) describes.

Finally, the biggest presumption in scenario (ii) is "the imperial presumption." In the extraordinary circumstance of ETIs who exist in the same perceptual plane as we do, have the same or similar technologies as we do, and who develop in a time period that opens the window of opportunity for contact, why should we assume that they would feel the desire or compulsion to communicate with other intelligent species? There are so many examples of xenophobic human cultures in relatively recent historical times, that it may not be wise to automatically assume that ETIs want to "make contact." The Chinese of, say, 500 AD to 1500 AD didn't set out to militarily dominate or culturally assimilate Southeast Asia, or the area that is now Indonesia, even though they apparently could have, because they didn't want to. The Japanese of the 15th through early 19th centuries closed the door to outsiders, and did not open that door until they were ready. We may be naive to believe, having turned our technological sights up to the skies, that everyone "out there" is waiting on the edge of their seats to hear from us and to have us hear from them. "To boldly go where no man has gone before" is really a European adventure story, based upon narratives of both exploration of "the unknown" and the hope for conquest or at least material gain when we get "there." It may be difficult to argue that a species with more advanced technologies than ours would necessarily be motivated by such imperialistic or resource-driven interests; and in the absence of a truly "disinterested curiosity" in our own species, it is probably fruitless to speculate on its presence in others. There is yet another objectionable assumption too, that we have also intimated: that we already know enough about what there is to know about wave phenomena and inter-stellar communication to be able to assert that ETIs would use radio waves to communicate with other civilizations.

Based on these considerations we hold that scenario number two is the most likely. Scenario (iii) would be an extreme variant of this view. On the basis of this premise we calculate how narrow this cognitive window would have to be in order to yield a less than even chance of meaningful communication even under a variety of scenarios. We will show that even with a window of the order of 10^8 years, ETIs are difficult to detect, given the current search philosophies, even if the Galaxy contains a million ETIs.

5. DISCUSSION

5.1. The Number of Contactable Civilizations

Our goal in this paper is to separate the question of the number of civilizations in the Galaxy from the one of how many can actually be contacted, or otherwise known about. The latter is more relevant to SETI because it influences the probability of the search being successful. We begin by re-visiting the Drake equation, and adding a term to the equation.

Under the optimistic scenario, there may be as many as 10^6 technologically advanced civilizations in the Galaxy. However, these societies are at various stages of development. The probability that two extraterrestrial societies are at the same stage of evolution, to say within a million years, is very small. Using the Earth as an example, it has taken 5×10^9 years to evolve an intelligent species which then has the potential to survive another 5×10^9 years. Taking the latter time frame and applying it to all other civilizations and assuming continued evolution over that period of time, the probability of any two civilizations achieving the same evolutionary stage (to within a million years) at any given time is $\approx 2 \times 10^{-4}$. If we take a time scale, of τ_w years, as a communications window then we see that $f_w \approx 2 \times 10^{-10}\tau_w$, the fraction of all civilizations that are emitting signals that we are capable of detecting. Application of this new parameter to the Drake equation yields $N_d = N_c f_w \approx 2\tau_w$ detectable civilizations, where τ_ω is in years.

The galactic volume occupied by all stars is $V_G \approx 4 \times 10^{11}$ pc^3. Therefore the average number density of detectable civilizations is

$$n_d \approx N_d/V_G = \frac{N_c f_w}{V_G} = \frac{N_c \tau_w}{\tau_*} \tag{2}$$

$$= 0.25 \times 10^{-22} N_c \, \frac{\tau_w}{\text{yrs}} \ \text{pc}^{-3} \tag{3}$$

or

$$n_d \approx 0.025 \times 10^{-3} \, \frac{N_c}{10^6} \, \frac{\tau_w}{10^6\text{yrs}} \ \ \text{kpc}^{-3}. \tag{4}$$

5.2. The Challenge to SETI

The average separation of such civilization follows from the above,

$$\langle r\rangle \approx \frac{1}{n_d^{1/3}} = 1.6 \left(\frac{N_c}{10^6}\right)^{-1/3} \left(\frac{\tau_w}{10^6\text{yrs}}\right)^{-1/3} \text{kpc}. \tag{5}$$

Note that $\langle r\rangle$ is not a strong function of τ_w. For a relatively narrow window of 10^6 years and $N_c = 10^6$, the average separation of detectable civilizations is $\approx 5,000$ light years.

These figures present a number of difficulties with regard to SETI.

The number of stars, N, contained in a sphere of radius $\langle r\rangle$

$$N = \frac{4}{3}\pi\langle r\rangle^3 = \left[\frac{10^{10}}{\frac{N_c}{10^6}\,\frac{\tau_w}{10^6\text{yrs}}}\right]. \tag{6}$$

For $\tau_\omega = 10^6$ years, $N = 10^{10}$ stars. This is a daunting number of stars to survey in a targeted search. In fact, if $\tau_w < 10^5$ years then all stars in the Milky way must be surveyed.

It is clear that if the cognitive window is narrower than 10^6 years, targeted searches are not practical. Even with a window of 10^8 years a total of 10^8 stars need to be surveyed. Limiting the search to G stars still means targeting a million stars. Only if the cognitive window approaches the stellar evolutionary time scale does the number become more practical (about 10,000 G stars).

We conclude that all sky-survey-type searches are more likely to be effective if the cognitive window is narrower than $\approx 10^8$ years. However, even with an all sky survey there are two major difficulties.

5.3. Minimum Detectable Beacon Power

If the window of opportunity for communication is important, ($\tau_w \ll \tau_*$) the separation between detectable ETIs (those that would build radio beacons) is much larger than the separation of all ETIs. For example, if $\tau_w \approx 10^6$ years, $\langle r\rangle \approx 1.6$ kpc. Based on the search sensitivities used by current SETI programs, any emitting beacon would require a power output,

$$P_{\text{beacon}} \approx 1\text{GW}(\frac{d}{\text{pc}})^2 = 10^{15} \text{ W}.$$

By comparison, the amount of solar radiation falling on the Earth is 10^{19}W. Thus, the nearest detectable civilization would need to construct a beacon utilizing a tangible fraction of the stellar radiation falling on its planet's surface. Although large, this amount of power may be manageable by a sophisticated society. However, for detectable ETIs located further away the required power approaches what might be available locally to the planet that harbors the ETI. Thus, even an all sky survey would benefit from greater sensitivity.

At these distances, the ETI must broadcast with a power of 10^8 GW, 10 orders of magnitude greater power than that of our most powerful commercial broadcasts, in order to be detected by the current searches. Alternatively, if the goal is to detect "leakage" radiation, our systems must be ten orders of magnitude more sensitive than they are currently. As noted above, the leakage of radiation might be deliberately minimized by a more advanced culture.

5.4. Interstellar Scintillation

Even if powerful beacons do exist in the Galaxy, interstellar scintillation severely limits our ability to interpret the signals we intercept. In their landmark study, Cordes et al. (1997) show that repeatable detections of signals may not be possible for beacons located more than 300 pc away.

This distance sets a natural criterion for the proximity required to detect radio beacons. In our analysis, the cognitive window of opportunity sets the average separation between detectable (beacon-constructing) civilizations. It is interesting therefore to examine the situation when the two scales are the same. Using equation (5) and setting $\langle r \rangle \approx 300$ pc, we obtain a window of opportunity of 10^8 years.

Thus, even with a liberally wide τ_w, our ability to detect uncorrupted signals is limited. If the average separation of "contactable" civilizations is, in fact, greater than the scintillation distance, we are forced to conclude that narrow band radio signals are impractical for communicating across the Galaxy. Presumably an emitting ETI would also be aware of this and would choose some other means of communication.

6. HOW DO WE SEARCH?

The challenge to SETI, as conventionally practiced, is great. Narrowband radio signals are subject to distortion and there are too many stars to search. What are the alternatives? It is not the purpose of this paper to develop new ideas for communication but we briefly note some obvious alternatives.

Optical SETI is appearing on the scene. It does not suffer from scintillation type effects, but if the separation of "contactable" civilizations is of the order of kpc or more, then extinction becomes the relevant issue. The fundamental problem remains. The proposed optical searches are of the targeting kind, and that is not feasible if our argument is correct.

An alternative would be a search for broad band radio signals using an all-sky survey. Broadband signals are less affected by scintillation and greater sensitivities may be possible. The difficulties would include the burden placed on the beacon-constructing ETI and our ability to sort out the broadband signal from the Galactic background.

Another possibility would be to search for narrow band signals at microwave or far infrared frequencies. Scintillation is not a factor at these frequencies. However, the Galactic background is very high and it may be difficult to pick out such signals readily.

A possible alternative to EM contact would be a search for evidence of artificially processed environments. Presumably, as a civilization matures its energy requirements increase and the ability to shape environments also increases. Evidence of large scale "projects" may not be difficult to find. It may take the form of Dyson spheres or other artificial looking structures. The jets and lobes associated with active galactic nuclei are examples of very efficient engines and one may speculate fancifully that such engines could be the work of energy starved super-civilizations.

On the surface, searching for such processed environments would appear to present significant advantages over attempts to communicate, given the cultural biases associated with direct communication. However, more careful consideration of the role of culture warrants a note of caution. Even over the short period of time representing the industrial age on Earth, we have witnessed a marked change in our attitudes toward the environment. Pollution of the air, ground and water are no longer accepted as unavoidable consequences of technological development, and attempts are being made to reverse these effects. In other words, the evidence of our industrial capacity may actually be diminishing to an outside observer. The counter argument is that we now boast much greater levels of electromagnetic pollution in the form of visible light and radio-frequency waves. However, in the latter case some reversals are taking place. Tucson, AZ in the USA is now emitting less visible light into space than before as a result of a strict lighting ordinance. The essential point here is that culture plays a role in determining how we shape and affect our environment. It may well be that more advanced civilizations choose not to pollute and thereby avoid exhibiting their activities.

7. CONCLUSIONS

In this paper we have argued for the possible existence of a cognitive window, a limited time scale over which any two civilizations are matched for communication. If such a window is sufficiently narrow, $< 10^8$ years, the separation between detectable civilizations is too great to allow for either a high chance of detection or meaningful communications. This is true even if the Galaxy is teeming with intelligent civilizations. In order to detect other civilizations with relative ease, it is necessary for the cognitive window to be much wider than 10^8 years. If the window is narrower than 10^8 years then the following conclusions hold.

(i) The absence of detected signals does not translate into an absence of ETI's.

(ii) Targeting individual stars in SETI has a low probability of success.

(iii) The use of radio signals is of limited value because with such large separations between "contactable" civilizations, interstellar scintillation strongly limits the propagation of radio signals.

(iv) Similarly, optical communication would be hindered by interstellar extinction.

(v) Possible alternatives to current searches for narrow band signals include: listening for modulated broadband signals; searching for narrow-band signals in the microwave/FIR spectrum; and searching for evidence of artificially processed environments.

REFERENCES

Barrow, J. and Tipler, F.: 1986, "The Anthropic Cosmological Principle", Oxford: Oxford University Press.

Bean, L. and Blackburn, T. (eds): 1976, "Native Californians: A Theoretical Retrospective", Ballena Press: Monlo Park, CA.

Carter, B.: 1983, *Philos. Trans. R. Soc. London*, **A 310**, 347.

Cordes, J., Lazio, J. M., Joseph, W. and Sagan, C.: 1997, "Scintillation-induced Intermittency in SETI", *Astrophys. J.*, **487**, 782.

Cronon, W.: 1983, "Changes in the Land: Indians, Colonists and the Ecology of New England", Hill and Wang: NY.

Falk, J.: 1982, "Global Fission: The Battle over Nuclear Power", Oxford University Press: Oxford, UK 1982.

Goldschmidt, B.: 1982, "The Atomic Complex: A Worldwide Political History of Nuclear Energy", American Nuclear Society: La Grange, Il.

Horowitz, and Sagan, C.: 1993, "Five years of Project META - an all-sky narrow-band radio search for extraterrestrial signals", *Astrophys. J.*, **415**, 218.

Livio, M.: 1999, "How Rare are Extraterrestrial Civilizations and When Did they Emerge?", *Astrophys. J.*, **511**, 429.

Pryor, K. and Norris, K.S.: 1991, "Dolphin Societies: Discoveries and Puzzles", UC Press Berkeley.

Sacks, O.: 1990, "The Man Who Mistook his Wife for a Hat and Other Clinical Tales", Harper Perennial: New York.

Sacks, O.: 1995, "An Anthropologist on Mars: Seven Paradoxical Tales", New York: Knopf.

Shklovskii, I.S., Samuilovic, J. and Sagan, C.: 1966, "Intelligent Life in the Universe", San Francisco: Holden-Day.

Wolf, E.: 1982, "Europe and the People Without History", Berkeley: University of California Press.

О МОГУЋНОСТИ ДЕТЕКЦИЈЕ ИНТЕЛИГЕНТНИХ ЦИВИЛИЗАЦИЈА У ГАЛАКСИЈИ

Н. Ђурић[1] **и Л. Филд**[2]

[1] *Institute for Astrophysics, Department of Physics and Astronomy*
University of New Mexico, 800 Yale Blvd., N.E., Albuquerque, NM 87131

[2] *Department of Anthropology*
University of New Mexico, 800 Yale Blvd., N.E., Albuquerque, NM 87131

UDK 52–37
Прегледни рад по позиву

У овом раду се износе аргументи у прилог могућности да је, чак и у случају да наша Галаксија врви од ванземаљских интелигенција (ВЗИ), вероватноћа пријема препознатљивих сигнала вештачког порекла веома ниска. Постоје два главна фактора која ограничавају нашу способност да детектујемо друге цивилизације.

(i) Еволутивне разлике могу узроковати тешкоће аналогне онима које постоје у људским покушајима комуникације са нижим приматима.

(ii) Независни еволутивни путеви који произлазе из различитих планетарних/звезданих окружења могу произвести ВЗИ чији су когнитивни процеси и произлазећа перцепција универзума веома различити од наших. Интерпретирање сигнала таквих цивилизација може се показати веома тешким, ако не и немогућим задатком. Чак и на Земљи, пример таквих когнитивних разлика постоји између људи и делфина, где еволуција у веома различитим окружењима доводи до тешкоћа у успостављању комуникације између две врсте. Главни ефекат другог фактора јесте суштинско ограничење комуникације, док је ефекат првог ограничење оне комуникације која је могућа на ”прозор”, тј. коначан период времена τ_ω у коме комуникација може бити могућа пре него што је дивергентна еволуција учини немогућом. На пример, ако је број ВЗИ у нашој Галаксији један милион и ако $\tau_\omega < 10^6$ година, просечно растојање цивилизација које би могле да комуницирају је $\langle r \rangle > 5 \times 10^3$ светлосних година, тако да тек једна звезда у 10^{10} представља станиште такве цивилизације. Ако су горњи аргументи коректни, долазимо до следећих закључака:

- Одсуство детектованих сигнала не значи и одсуство ВЗИ.
- Посматрање појединачних звезда у СЕТИ пројектима има веома малу вероватноћу успеха.
- Коришћење радио сигнала је од ограничене вредности, зато што на тако великим растојањима између цивилизација које могу да комуницирају међузвездана сцинтилација снажно ограничава ширење радио сигнала. Слично, оптичка комуникација је ометена међузвезданом екстинкцијом.
- Могуће алтернативе садашњим потрагама за сигналима уског опсега укључују ослушкивање модулисаних сигнала великог опсега, потрага за сигналим уског опсега у микроталасном/ФИР делу спектра и потрага за траговима вештачки процесираних астрофизичких окружења. Све такве потраге требало би да се врше преко читавог неба да би имале разумне изгледе на успех.