Searching for Extraterrestrial Civilizations

The search for extraterrestrial intelligence should begin by assuming that the galaxy has been colonized.

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A concerted national, and perhaps international, effort to find radio signals from extraterrestrial civilizations (ETC's) will probably be started within the next few years. It will be the outcome of nearly 20 years of smaller searches at various radio observatories (*1*) and about a decade of preliminary planning for a dedicated facility (*2*). One major study conducted by Stanford University and NASA Ames Research Center (*3*) resulted in a design for an array of up to 1000 antennas of 100-meter aperture. The search for extraterrestrial intelligence (SETI) has been identified in "Outlook for Space" (*4*) as one of the possible future tasks for the National Aeronautics and Space Administration (objective 125) and the large receiving array as one of the prerequisites (system 4010).

In planning for SETI, there are two possible approaches. One is to develop scenarios for the presence and behavior of ETC's based on our present understanding of the universe (and perhaps an anthropomorphic view of the nature of "civilizations"), and then to devise a strategy that appears to maximize the likelihood of contact. An advantage of this approach is that it makes it possible to demonstrate the feasibility of interstellar contact at our level of technological development. This is the approach that was used in Project Cyclops (*3*) and further pursued in the Science Workshop on Interstellar Communication. It has led to the concept of a very large antenna array for SETI. An alternate approach to SETI, which is being developed at the Jet Propulsion Laboratory (*5*), is to make no assumptions about extraterrestrial signals other than that they may exist, and to survey exhaustively in frequency over the whole sky for anomalous radio emission. This approach has also received the endorsement of the Science Workshop on Interstellar Communication (*6*). With this philosophy, one does not ask whether a particular receiving system is adequate, but rather whether the proposed program will extend our observational base to new frequencies, sky directions, or sensitivities. From this point of view, almost any SETI activity can make a valuable contribution.

The apparent premises used in scenario approaches to SETI planning can be reduced to the assumptions that (i) we are not unique as a technological civilization in our galaxy, (ii) interstellar travel for the purposes of "manned" exploration or colonization never reaches the level of feasibility or practicability, and (iii) interstellar beacons meant for contact between civilizations are likely enough to warrant intensive searches. A direct conclusion from these assumptions is that the likelihood of intercepting a beacon increases with increasing sensitivity of the detecting apparatus, and thus with increasing aperture size of the receiving antenna. Our purpose in this article is to examine critically these three interrelated assumptions in an attempt to outline a productive strategy for SETI. The scenario approach is pursued further to investigate the question of what sensitivity is required in the detecting apparatus in order to draw significant conclusions within the framework of our rather general scenario.

We follow the principle that, with complete lack of factual information on the existence or behavior of ETC's, the most meaningful way to proceed is to make a minimum number of assumptions and only assumptions that are consistent with (i) our understanding of natural physical processes, and (ii) the expectation that the behavior of extraterrestrial beings or civilizations may be extrapolated from the gross behavioral patterns of terrestrial animals and of human beings in particular. We consider this to be a proper application of Occam's razor, in that it puts the least number of unknown or unknowable parameters into a model for interstellar intercourse. Of course, if observations prove to be inconsistent with such a model, then it is proper to introduce additional or alternative hypotheses. By proceeding in this way, we hope to outline a maximum likelihood situation regarding the presence of other civilizations in the galaxy and their ability to contact ours. By referring to historical trends in human civilizations, we make the implicit but quite plausible assumption that all civilizations have, in principle, similar origins in the natural selection process and that the behavior of organisms is thus determined in large part by natural forces which are similar everywhere. By proposing a framework that is most consistent with available knowledge, we can suggest guidelines for a search for extraterrestrial intelligence that, whether successful or not, has meaningful consequences *at our level of understanding of the universe*.

Interstellar Travel Reexamined

It is often assumed that interstellar travel is, if not strictly impossible, highly impractical and therefore very improbable (*7*). The contention of this article is not that the practice of interstellar travel is an inevitability for all technologically advanced civilizations, but that the probability is high enough that, given a modest number of advanced civilizations, at least one of them will engage in interstellar travel and thus colonize the galaxy. Indeed, if various optimistic estimates for the rate of emergence of technological civilizations (*8*) are correct, then this probability would only have to exceed 10^{-8}.

The plausibility of interstellar travel has been argued previously (*9, 10*). The Project Cyclops report (*3*, p. 34), on the other hand, follows the analysis of Spencer and Jaffe (*9*), but comes to the entirely different conclusion that "interstellar flight is out of the question not only for the present, but for an indefinitely long time in the future." Spencer and Jaffe had shown that a multistage deuterium fusion rocket would require a mass ratio (fuel to payload) of 9 for a one-way trip (with

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deceleration) at one-tenth the speed of light ($0.1c$). The Project Cyclops report makes the unnecessary assumption that a return trip need also be made, which not only increases the mass ratio to 81, but also increases the travel time by a factor of 2. Without this assumption, it becomes possible to travel to about ten stars at $0.1c$ within one human lifetime (although we do not need to make the further assumption that the trip be limited to a single human lifetime). Even if a return voyage were intended, the spacecraft could be self-sufficient enough to replenish its fuel supply at the destination.

There are two potential objections to these arguments for the feasibility of interstellar travel. The first lies in the anticipation of nuclear fusion engineering capabilities. However, in keeping with the principle of minimum assumptions, no fundamentally new physics is being advocated, and since no known physical principle states that a deuterium fusion rocket is impossible or unfeasible (it appears to be primarily an engineering task), there is every reason to expect its realization within the next century or so. Indeed the feasibility of interstellar propulsion has been seriously investigated in Project Orion and Project Daedalus (*11*). Note also that, for the sake of a plausibility argument, we have confined ourselves to fusion energy propulsion, whereas other possible forms of propulsion can be envisioned.

The second possible objection is that the distances between suitable habitats might be prohibitively large; that is, the travel time is long compared to the lifetime of an individual. There are several answers to this. First, there is no reason to suppose that there are no intelligent beings having significantly longer lifetimes than ours. Second, a suitable habitat need not be narrowly defined: given presently foreseeable technological capabilities and the knowledge through preliminary unmanned exploration of what to expect, we suppose that a reasonably large fraction ($\gtrsim 0.01$) of planets could be rendered inhabitable. Third, given a somewhat more advanced technology, it may be possible to construct spaceships of sufficient sophistication to permit several generations to live in circumstances not significantly less comfortable than those encountered in crowded cities. Fourth, we cannot rule out the possibility that long voyages might be undertaken in a state of suspended animation. Finally, it is not clear that colonists need confine themselves to planets. With technology given a free reign, one can extrapolate O'Neill's (*12*) discussion of space colonies to consider orbiting habitable vessels about new stars (*13*).

This objection applies to any discussion of SETI. If habitats suitable for colonization are so rare as to preclude interstellar travel by *any* civilization, then one can argue that planets capable of engendering intelligent life are probably also rare, to the point that radio beacons are, at best, few and far between. The most urgent and the most technologically feasible development that will have a bearing on the presence of ETC's (aside from actually detecting their signals) is the measurement of the distributions of planets around a sizable number of stars.

Colonization of the Galaxy

Therefore, given advanced technological civilizations which are capable of transmitting powerful radio beacons which we could detect across interstellar distances, it is likely that a significant fraction of these civilizations will physically expand by colonizing their neighboring galactic environments (*14–16*). The argument may be advanced that, for economic or other reasons, ETC's may simply choose not to engage in colonization. This, however, would be counter to the trends evidenced by life-forms on our own planet, where every species extends itself as far as is physically possible. Given man's historically proved urge to explore, expand, and colonize, we make the minimal assumption that this trend will not be halted or reversed at our present stage of development. That is, the technological trend will continue, and manned visits to neighboring stars are likely to occur. This tendency is extrapolated to be the same for all technological civilizations.

Having argued that interstellar travel is a likelihood for technological societies that do not annihilate themselves, we now proceed to calculate how quickly a technological civilization might populate the galaxy. The minimal assumption here is that interstellar travel does not stop after the first jump from the home planet to the nearest stars, but rather continues to occur in steps as each colony becomes a new center of expansion after a suitable regeneration period. Hart (*16*) gives an estimate for the effective expansion velocity, but we estimate more conservatively that the regeneration period after each 10–light year step is 500 years (*17*). The effective expansion velocity becomes $0.016c$ for an actual travel velocity of $0.1c$, and is rather insensitive to the actual travel velocity assumed. At this effective expansion velocity, a technological civilization will populate the galaxy in a time $t_c \sim 5 \times 10^6$ years. Jones (*13*) has considered the expansion rate in some detail, and arrives at similar values for t_c. Viewing (*15*) arrives at much larger values of t_c by making extremely conservative assumptions about the regeneration period and the travel velocity, but as will be evident from the discussion below, our estimate can be revised upward by two orders of magnitude without affecting the conclusions.

The primary uncertainty in any discussion of SETI is the space density of technological civilizations in the galaxy. The relevant quantity, N, is the number of technological civilizations existing at any given time which are or have been able to maintain their technology long enough to begin the expansion process by establishing several nearby colonies. Once this occurs, self-annihilation of the home society would probably not affect the expansion process significantly, since the colonies are necessarily quite independent of the home planet (*18*). Estimates of N vary greatly [for example, see (*3*, p. 24) and references therein], so we will not make any assumptions about this number, but rather address ourselves concurrently to the full range of possibilities. If N is very small, then (i) the galaxy is probably not significantly populated or explored, and (ii) radio beacons from intelligent civilizations probably do not exist in sufficient quantity to justify a massive search. However, if N is not small, then the probability is near unity that the galaxy is completely colonized because $t_c << \Delta t$, where Δt is the dispersion in formation times of stars of any given type (population I). Indeed, $\Delta t \approx$ the age of the galaxy.

In summary, the above arguments yield two quite different possibilities: (i) technological civilizations that last long enough to begin the colonization process are rare, in which case the galaxy is essentially unpopulated and the number of radio contact beacons is negligible, and (ii) there are several such civilizations, in which case the galaxy is fully explored or colonized.

Case (ii) has several immediate implications, including the following.

1) A "galactic community" would exist, in which one or several different civilizations communicate with each other throughout the galaxy, and we are located within the "sphere of influence" of one or more of these civilizations.

2) The solar system would probably have been visited.

3) An advanced civilization would probably have representatives somewhere in the solar neighborhood. This encompasses Bracewell's (*19*) suggestion that an advanced civilization may already have sent an unmanned probe into our system to contact us when we reach some developmental threshold.

Implications for a SETI Strategy

The discussion above has definite implications for a radio search for beacons from extraterrestrial intelligent beings. In case (i), we see that the value of a radio search is problematic. Case (ii) is the one of interest. If the galaxy is thoroughly populated, as case (ii) implies, there is little reason to expect extraterrestrial beings to be transmitting radio beacons across galactic distances (either beamed or isotropic) which are meant explicitly for contact with new civilizations. The galactic community, in whole or in part, is probably aware of nascent civilizations, and if contact with a new civilization is desired, it can be made directly (physically) or through a radio signal from somewhere in their local neighborhood. Since, in case (ii), nearby extraterrestrial beings are probably aware of the existence of our civilization, we might address ourselves to the implications of the fact that obvious overt contact has not yet been made. This certainly does not rule out case (ii) because there are plausible arguments in favor of the possibility that extraterrestrial beings have chosen not to reveal themselves until, perhaps, we reach a certain developmental threshold. As this involves anticipating the motives of an advanced civilization, it is somewhat more speculative than the main body of this article, and thus we offer a few of many possibilities in appendix A.

In conclusion, we envision four possible situations regarding SETI.

1) There are no beacons, either because case (i) applies, or because extraterrestrial beings are concealing themselves or choose not to contact us at this time.

2) A radio beacon meant for contact is being beamed toward the earth from the solar neighborhood (within, say, ~10 light years), and therefore great sensitivity is not required to detect it. In this case, extraterrestrial beings are revealing themselves to our society at its present technological level, although in a minimally spectacular manner which least perturbs our civilization.

3) Beacons of a more sophisticated nature (beyond the capability of our technology to detect or interpret) are being sent to us from the solar neighborhood, so we must reach some relatively advanced technological level before we can establish contact.

4) Signals are being beamed toward the solar system, but they are not intended for our earthbound civilization. Rather, they form a communications link between local and distant extraterrestrial beings. If these signals are coded in radio waves, then, as we shall show, the ability of a modestly sensitive system (that is, presently operating systems) to detect such a signal will depend on how it is coded.

These four situations form the set of reasonable alternatives that one can arrive at with the arguments above. In none of these alternatives do we see any advantage in the construction and use of a very-large-aperture radio telescope for SETI over the use of large single-dish antennas of the type that already exist. The arguments above cannot rule out the occurrence of signals for which a large collecting area would be required, but suggest that they are relatively improbable and that a search for them is premature at present (*20*).

Considerations for an Initial SETI

We have identified two ways in which we might, by passive electromagnetic means, detect the presence of ETC's. Both involve searching for transmissions beamed at the solar system. We consider here what would constitute an adequate search for such signals. We use the range equation in the form

$$\frac{\eta_T \eta_R d_t^2 d_r^2 P_t}{\lambda^2 R^2} = 2 \times 10^3 k_D k_R T \left(\frac{B}{\tau}\right)^{1/2} \quad (1)$$

where η_T and η_R are the aperture efficiencies of the transmitting and receiving antennas, whose diameters are d_t and d_r (meters); λ is the wavelength (meters); P_t is the radiated transmitter power (megawatts); R is the range (light years); k_D, the detection factor, is the minimum detectable signal divided by the root-mean-square noise in the receiver; k_R is a receiver efficiency factor; T is the system noise temperature (kelvins); B is the bandwidth (hertz); and τ is the integration time (seconds). Let us consider what beacons might be detected with a 26-m antenna, this aperture being selected because several antennas in the range 20 to 30 m are now underutilized and could be dedicated

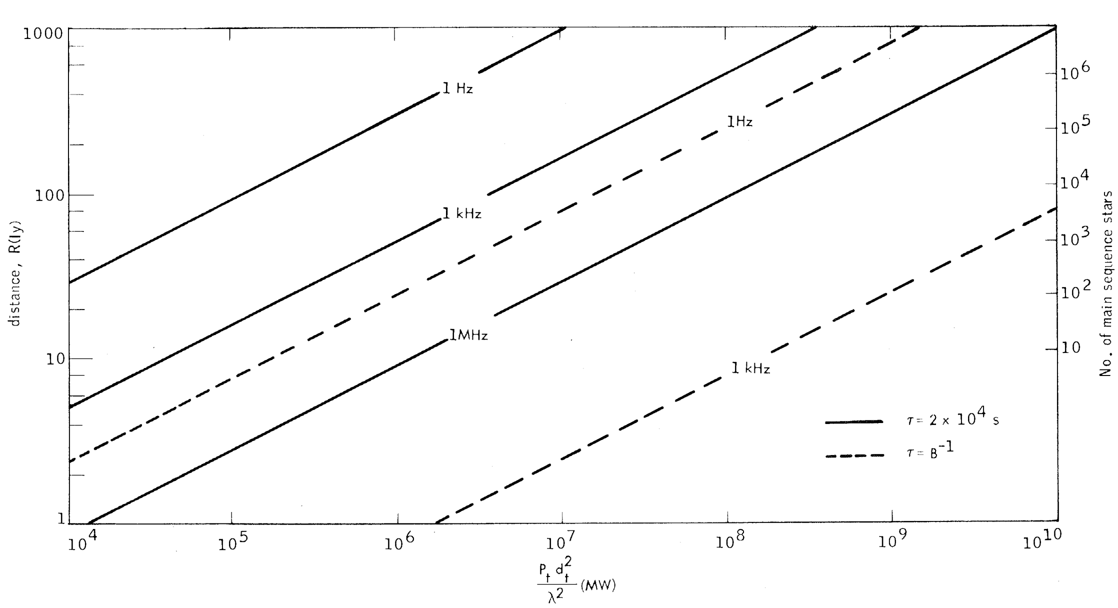

Fig. 1. Distance over which a transmitter is detectable with a 26-m antenna as a function of its effective radiated power and the bandwidth of the signal. The assumed receiver parameters are specified in the text. Abbreviation: *ly*, light years.

to a SETI. For the purpose of discussion, we set $\eta_T = \eta_R = 0.6$, $k_D = 5$, $k_R = 2$, $T = 20°K$, and $d_r = 26$ m, so that Eq. 1 takes the form

$$\frac{d_t^2 P_t}{\lambda^2 R^2} = 1.64 \times 10^3 \left(\frac{B}{\tau} \right)^{1/2} \tag{2}$$

We have plotted Eq. 2 in Fig. 1. for (i) simple detection with $\tau = 2 \times 10^4$ seconds and (ii) demodulation of a simply encoded beacon for which $\tau = B^{-1}$. On the graph we have also noted the number of main sequence stars in the solar neighborhood as a function of distance, of which approximately 0.3 are in the spectral classes F0 to K7.

We can see that a directed beacon would be readily detectable. If the transmitting facility consisted of a 1-megawatt transmitter on a 100-m antenna radiating at a frequency of 12 centimeters (see appendix B) then we would be able to detect a 1-hertz signal out to a distance of 200 light years and demodulate it out to 20 light years. If we expect, by our previous arguments, that the transmitter is located on one of the nearest, say, ten stars, we could demodulate signals with bandwidths as high as 10 hertz. Even if the transmitter agency were operating on a low budget ($d_t = 26$ m and $P_t = 0.25$ Mw), we could still demodulate a 0.1-hertz signal from one of those stars and could detect (after 6 hours of integration) such a signal at a distance exceeding 40 light years. At shorter wavelengths, of course, the range would be greater.

The possibility of intercepting communications with an alien outpost in the solar system can be assessed by asking how large an alien antenna in our solar system would have to be to be able to demodulate signals that we could not detect with, say, 6 hours of integration on a 26-m antenna. If we assume similar noise temperatures for the alien receiver and our receiver, we see by Eq. 1 that

$$\left(\frac{B}{\tau} \right)^{1/2} \frac{1}{d_r^2} = \text{constant}$$

for both systems. If the bandwidth of the alien communication channel does not greatly exceed its capacity (see below), then $\tau \sim B^{-1}$. If our receiver has $\tau = 2 \times 10^4$, we find

$$d_r(\text{alien}) > 309.2 B^{1/4} \text{ m}$$

(This is an underestimate since the extraterrestrials would presumably expect a higher signal-to-noise ratio in their communications than we would consider sufficient for detection.) In this case, we see that it is probable that alien communications would be detected by a 26-m antenna: a 1-km aperture receiving at a data rate of 100 hertz, or a 10-km aperture receiving at a data rate of 1 Mhz, would imply signals at the detection threshold. A 100-m antenna, or at most an array of several such antennas, should be sufficient to detect such a signal.

However, there is reason to believe that the detection of alien communications may be more difficult. The maximum capacity of a communications channel, obtained when the transmitted signal has white noise characteristics, may be expressed as (*21*)

$$C = B \ln \left(1 + \frac{P_r}{kTB} \right)$$

where k is the Boltzmann constant. For a given system noise temperature and received signal power level, the capacity is maximized at

$$C \simeq P_r / kT$$

when $B \gtrsim 10C$. Thus, the alien signals may be spread so widely in frequency that they would be very difficult to detect with a modest antenna.

In searching for a directed beacon, we may feel we are able to restrict the frequencies to be examined (appendix B), but this cannot be the case for attempting to intercept communications. Nevertheless, a wide frequency search could be conducted within a reasonable time span. Using technology now planned or under development, we can modestly envision examining 100 Mhz at a time with 100-hertz resolution. Spending 6 hours on each of 100 candidate stars, we could scan the spectrum at the rate of 250 days per gigahertz or 35 years to cover the spectrum up to the oxygen absorption band above 55 Ghz. Less time or more stars would be covered in a search that was aimed only at restricted frequency intervals. Thus, a search for directed transmissions from nearby stars using a single 26-m antenna would not be of unreasonable duration.

Summary

We have argued that planning for a search for extraterrestrial intelligence should involve a minimum number of assumptions. In view of the feasibility (at our present level of understanding) of using nuclear fusion to effect interstellar travel at a speed of $0.1c$, it appears unwarranted (at this time) to assume that it would not occur for at least some technologically advanced civilizations. One cannot even conclude that humans would not attempt this within the next few centuries. On the contrary, the most likely future situation, given the maintenance of technological growth and the absence of extraterrestrial interference, is that our civilization will explore and colonize our galactic neighborhood.

A comparison of the time scales of galactic evolution and interstellar travel leads to the conclusion that the galaxy is either essentially empty with respect to technological civilizations or extensively colonized. In the former instance, a SETI would be unproductive. In the latter, a SETI could be fruitful if a signal has been deliberately directed at the earth or at an alien outpost, probe, or communication relay station in our solar system. In the former case, an existing antenna would probably be sufficient to detect the signal. In the latter case, success would depend on the way in which the communications were coded.

Failure to detect a signal could permit any of the following conclusions: (i) the galaxy is devoid of technological civilizations, advanced beyond our own, (ii) such civilizations exist, but cannot (for some reason which is presently beyond our ken) engage in interstellar colonization, or (iii) such civilizations are not attempting overt contact with terrestrial civilizations and their intercommunications, if present, are not coded in a simple way. To plan at this time for a high-cost, large-array SETI based on the last two possibilities appears to be rather premature.

Appendix A: On the Present Lack of Contact with Extraterrestrial Beings

If the cost and speed of interstellar travel are practicable, and the probability of the evolution of intelligent life in 10^{10} years is not very small, then, following the arguments in this article, there should be some explanation why we are not in open contact with extraterrestrial beings. The most common explanation is that one of the two premises is incorrect. However, we have argued that interstellar travel is practicable. Therefore, either the probability of the evolution of intelligent life is extremely small (that is, we are essentially unique in the galaxy), or we must seek an alternative explanation. Indeed, the possibilities that we are being ignored, avoided, or discreetly watched are logically possible and have been discussed previously (*22, 23*).

In considering these alternative possibilities, we must address ourselves to the reasons an advanced civilization might have for contacting us (we assume that alien beings from an advanced society are constrained to act primarily on reasoned principles). To do this we must identify the general class of resources that are most likely to be of value to an advanced society. Bell (*24*) has pointed out that in preindustrial societies, the strategic resource is raw materials. The industrial society centers around capital and labor (which may in a general sense be equated). In the postindustrial society, knowledge is the most valued resource. Thus, an industrial society is able to adjust to the unavailability of a particular raw material by transforming some other material. (The World War II period offers a wealth of examples.) In a postindustrial society, the practical application of theoretical or empirical knowledge is able to compensate for a shortage of labor and, in many cases, can even replace labor. Thus we suggest that knowledge, in a general sense that encompasses science and culture, is likely to be most highly prized by an advanced civilization. This could be formal, codified knowledge, or experiences whose value we have not yet appreciated. Furthermore, this resource is one that grows with time. We believe that there is a critical phase in this. Before a certain threshold is reached, complete contact with a superior civilization (in which their store of knowledge is made available to us) would abort further development through a "culture shock" effect. If we were contacted before we reached this threshold, instead of enriching the galactic store of knowledge we would merely absorb it. Consider, for example, that the motivation a terrestrial researcher (or research funder) might have for pursuing new ideas would be considerably diminished, as the best human minds could be occupied for generations digesting the technology and cultural experiences of a society advanced far beyond our own. Thus, by intervening in our natural progress now, members of an extraterrestrial society could easily extinguish the only resource on this planet that could be of any value to them.

Opposed to the advantage of letting our civilization achieve some level of maturity may be the possibility that the earth has some other critical resource. In many cases, however, the needs of the aliens could be satisfied without undue impact on our civilization. The removal of rare elements or chemicals, of genetic material, or of samples for biological or psychological studies (including even an occasional human) could be effected with no more attention from us than a UFO article or a missing person's report. To establish that avoidance of open contact is not the most likely alien behavior, one would need to identify a resource that does not fall into this category.

There remains the possibility that members of an extraterrestrial society might choose limited contact without offering their store of knowledge. They might wish to do this (i) as part of an experiment to gauge the reaction of our society, (ii) in an attempt to stabilize terrestrial civilization to prevent an impending crisis of self-annihilation, or (iii) to plant selected information in order to stimulate our evolution in some preferred direction. In none of these cases can it be concluded that contact would necessarily occur in an overt way, so that we would immediately recognize it as such.

Finally, one must consider why the earth was not colonized by another civilization well before the advent of human or even animal life. Out of a wealth of possibilities, we offer three: (i) the earth has been a preserve for a long time, as the extraterrestrials would not want to halt natural evolution completely by occupying all suitable environments, (ii) extraterrestrial technology has advanced beyond the stage where a planetary base is required or even desired, or (iii) the biology on the earth is incompatible with or even hostile to that of the species which dominate our part of the galaxy.

In considering the subject matter of this appendix, we have ventured far beyond the realm proper to physics and astronomy. We hope that experts in relevant disciplines will address these questions and address their impact on the search for extraterrestrial intelligence.

Appendix B: Frequencies for Interstellar Beacons

Although it might ultimately be desirable to cover the entire range from 1 to 100 Ghz or more (perhaps simultaneously), the preliminary phases of SETI should involve choosing specific frequencies, or frequency bands, which there is some rationale for believing an extraterrestrial civilization would transmit at to attract our attention. At least, in a search intended eventually to cover a large portion of frequency space, these are the frequencies that would logically be chosen first.

The 21-cm hydrogen line, first suggested by Cocconi and Morrison (*25*), has received the most attention. Many cogent arguments in favor of a search at this frequency have been put forward, although it has been generalized into the "water hole" band lying between 1420 and 1720 Mhz (*3*, p. 63). This frequency band is attractive because (i) lying between the frequencies of the most fundamental or noticeable transitions of H and OH, the constituents of water, it might be used for a contact beacon if water is universally basic to the chemistry of life, and (ii) it minimizes the combination of galactic background noise, receiver quantum noise, and atmospheric absorption. For similar reasons, the 22,235 Mhz line of H_2O, ubiquitous in the galaxy as maser radiation, has been suggested as an equally likely carrier of intelligent signals. (Although atmospheric absorption is higher at the frequency of the H_2O line, this cannot be considered to have a great impact on the sender's choice of frequency, especially since it may be more cost-effective in the near future to build large antenna systems in space.) Since we have argued that isotropic beacons of the kind envisioned by Project Cyclops (*3*, p. 60) are unlikely, Eqs. 1 and 2 and Fig. 1 show that there is a distinct advantage in operating at the higher frequencies: the effective range is inversely proportional to the wavelength for particular transmitting and receiving systems. Given this consideration, the water line has an advantage over the lower frequencies that have been suggested.

We propose a frequency of a rather different nature, but which may be considered fundamental and universal. This is a frequency constructed from fundamental natural constants. Examples of frequencies constructed in this way are

$$1)\quad \frac{c}{2\pi\, r_e} = 1.7 \times 10^{22} \text{ hertz}$$

where $r_e = e^2/m_e c^2$ is the classical electron radius; m_e and e are the mass and charge of the electron, respectively.

$$2)\quad \frac{m_e c^2}{h} = \frac{c}{2\pi\, r_c} = 1.2 \times 10^{20} \text{ hertz}$$

where r_c is the compton wavelength of the electron. Note that $m_e c^2/h$ is the "intrinsic" frequency of the electron.

$$3)\quad \frac{c}{2\pi\, r_B} = 9.0 \times 10^{17} \text{ hertz}$$

where $r_B = h^2/m_e e^2$ is the Bohr radius.

(Note: The 2π's are inserted to yield cyclical frequencies instead of angular frequencies when physical interpretations are applied to each expression.)

Two things are apparent from this compilation of frequencies.

1) The frequencies are all very high (well above the radio regime).

2) They differ only by integral powers of the (dimensionless) fine structure constant, $\alpha \approx 1/137$. This suggests that, by scaling with further powers of α, one can

find a unique frequency that lies in the reasonable radio range. Thus we arrive at the "fundamental" frequency

$$2556.8 \text{ Mhz} = \alpha^4\left(\frac{c}{2\pi\, r_B}\right)$$
$$= \alpha^5\left(\frac{c}{2\pi\, r_c}\right) = \alpha^6\left(\frac{c}{2\pi\, r_e}\right)$$

The following arguments support the unique character of this frequency.

1) A different integral power of α applied to the sequence above would yield a frequency far from the range that one can presently consider appropriate for interstellar communication.

2) Use of similar constants for the proton, for example, would not be nearly as physically meaningful as those in the sequence above, mostly because the proton is a relatively complex particle, and entities such as the "classical proton radius" have little relevance.

3) One could consider using the gravitational constant, G, but frequencies derived from it [such as $(c^5/Gh)^{1/2} \approx 7.4 \times 10^{42}$ hertz, where h = Planck's constant] generally have no apparent physical meaning, and cannot be scaled to the radio range by some appropriate dimensionless number, such as $e^2/Gm_e^2 \approx 4.2 \times 10^{42}$.

The motivations that a transmitting civilization might have for choosing this frequency include (i) the lack of interference arising naturally from atomic or molecular species in the galaxy [for example, there are no recombination lines with a change in the principal quantum number $(\Delta n) < 6$ near this frequency, nor are there known molecular lines], (ii) the minimization of galactic background noise, receiver quantum noise, and atmospheric absorption, (iii) the presupposition of a modest breadth in the technical capacity of the receiving civilization, and (iv) the absence of any assumptions about the chemistry of life throughout the galaxy.

References and Notes

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13. E. M. Jones, *Icarus* **28**, 421 (1976).
14. Similar discussions have previously been published by Viewing (*15*), Hart (*16*), and Jones (*13*). The reader is referred to these papers for further cogent argument on the likelihood of interstellar travel and colonization. The implications that Hart draws differ from ours, whereas Viewing reaches the same conclusions as those presented in this article without discussing the broad implications for possible tests of the presence of advanced civilizations.
15. D. Viewing, *J. Br. Interplanet. Soc.* **28**, 735 (1975).
16. M. H. Hart, *Q. J. R. Astron. Soc.* **16**, 128 (1975).
17. This is a rather arbitrary figure. However, increasing it to, say, 10,000 years does not significantly alter the argument [for example, see Viewing (*15*)].
18. S. von Hoerner, in *Einheit und Vielheit*, E. Scheibe and G. Süssman, Eds. (Vandenhoeck and Ruprecht, Göttingen, 1972); *J. Br. Interplanet. Soc.* **28**, 691 (1975). Von Hoerner suggests that advanced civilizations may be rare or nonexistent because they tend either to annihilate themselves (or their technological capacity) or to undergo developmental stagnation crises at certain stages in their development. However, fear of annihilation or of irreversible stagnation of the home society may, in fact, prove a motivation for starting the colonization process: self-preservation on the species level.
19. R. N. Bracewell, *Nature (London)* **186**, 670 (1960).
20. An example of this might be "leakage radiation" from nearby inhabited systems (*3*, p. 59), but it seems likely that an advanced civilization would conduct their internal communications in an efficient manner. For example, accurate oscillators in the receivers would remove the need for strong carriers, the only part of a signal we might expect to detect.
21. C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (Univ. of Illinois Press, Urbana, 1964); see theorems 16 and 17 and the discussion in between.
22. C. Sagan, *Icarus* **19**, 350 (1973).
23. J. A. Ball, *ibid.*, p. 347.
24. D. Bell, *Phys. Today* **29**, 46 (February 1976).
25. G. Cocconi and P. Morrison, *Nature (London)* **184**, 844 (1959).

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