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UNCERTAINTY IN ESTIMATES OF THE NUMBER OF EXTRATERRESTRIAL CIVILIZATIONS

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ABSTRACT

Estimation of the number N of communicative civilizations by means of Drake's formula involves the combination of several quantities, each of which is to some extent uncertain. The uncertainty in any quantity may be represented by a probability distribution function, even if that quantity is itself a probability. The uncertainty of current estimates of N is derived principally from uncertainty in estimates of the lifetime of advanced civilizations. It is argued that this is due primarily to uncertainty concerning the existence of a "Galactic Federation" which is in turn contingent upon uncertainty about whether the limitations of present-day physics are absolute or (in the event that there exists a yet-undiscovered "hyperphysics") transient. It is further argued that it is advantageous to consider explicitly these underlying assumptions in order to compare the probable numbers of civilizations operating radio beacons, permitting radio leakage, dispatching probes for radio surveillance or dispatching vehicles for manned surveillance.

> The Master said, Yu, shall I tell you what knowledge is? When you know a thing, to know that you know it, and when you do not know a thing, to recognize that you do not know it. This is knowledge.
> Analects of Confucius (Waley's translation).

1. REPRESENTATION OF UNCERTAINTY BY DISTRIBUTION FUNCTIONS

The preceding contributions to this chapter have been concerned with various estimates of N, which denotes the number of extant advanced technical civilizations in our galaxy possessing both the interest and capability for interstellar communication (Shklovskii and Sagan, 1966). This number is estimated on the basis of a formula first presented by F.D. Drake when participating in a conference held at the National Radio Observatory at Green Bank, West Virginia, in 1961 (Shklovskii and Sagan, 1966, pp. 409 et seq.):

$$N = R\, f_p\, p_e\, f_\ell\, f_i\, f_c\, L. \qquad (1)$$

In this expression, R ($year^{-1}$) is the mean rate of star formation; f_p is the fraction of stars with planetary systems; p_e is the mean number of planets in each planetary system with environments favorable for the origin of life; f_ℓ is the fraction of such favorable planets on which life does develop; f_i is the fraction of such inhabited planets on which intelligent life with manipulative abilities arises; f_c is the fraction of planets populated by intelligent beings on which an advanced civilization arises; and L (year) is the lifetime of the technical civilization possessing both the interest and capability for interstellar communication. (For reasons which will become clear later, I use p_e in place of the usual term n_e.)

It is standard procedure that, in presenting experimental or observational results, a scientist clearly indicates the uncertainty in his estimates, usually by the simple procedure of ascribing a standard deviation to the estimate. It is usually implicitly assumed that the distribution of the estimates is "normal" but of course this may not in fact be the case. In the absence of a statement concerning the form of the distribution (normal or otherwise), a statement of the standard deviation gives only a fragmentary representation of the estimated error.

It is not customary to present similar estimates of the uncertainty of theoretical calculations. Nevertheless, there is always uncertainty, if only because the theoretical model may or may not be a fair representation of the real physical system under consideration. The importance of this concept is discussed further in an article dealing with the evaluation of astrophysical hypotheses (Sturrock, 1973).

For the problem in hand, our knowledge of N is due to calculations, made for instance by means of the Drake formula (equation 1). Since there have been discussions in this chapter of the possibility that "N is very small" or "N is very large," etc., it is clear that there is in fact considerable uncertainty in our knowledge of N. It is therefore worthwhile to consider the sources of this uncertainty, how these sources contribute to the final uncertainty, and if possible to make some estimate of the final uncertainty.

If one were to take an estimate of N at face value, it would seem appropriate to adopt $N^{1/2}$ as a measure of the uncertainty, in accordance with the usual formulas of Poisson statistics (e.g. Wall, 1979). Since a typical estimate of N is 10^6 (Shklovskii and Sagan, 1966), this would imply that the accuracy of our estimate is 0.1%, whereas--as we have already seen--the uncertainty is very much greater. This fact underlines the need for a formalism which will lead to a more realistic estimate of the uncertainty. I suggest that an appropriate generalization of the Drake formula is one which replaces an estimate of each quantity by a distribution for that quantity.

It will be somewhat more convenient to work in terms of logarithms of the various quantities. We shall therefore write

$$\nu = \log N,\ \rho = \log R,\ \phi_p = \log f_p,\ \text{etc.},\ \tilde{\omega}_e = \log p_e,\ \lambda = \log L. \quad (2)$$

We now characterize our assessment of a quantity x by the distribution P(x), such that P(x')dx' is the probability, according to one's analysis of specified information, that the quantity x lies in the range x' to x' + dx'.

Noting that, in terms of our new variables, equation (1) becomes

$$\nu = \rho + \phi_p + \tilde{\omega}_e + \phi_\ell + \phi_i + \phi_c + \lambda, \quad (3)$$

we see that our generalization of the Drake equation becomes

$$P(\nu) = \int \ldots \int d\rho \ldots d\lambda\ P(\rho) \ldots P(\lambda)\delta(\nu - \rho - \ldots - \lambda). \quad (4)$$

A distribution function P(x) gives much more information about an assessment of a quantity than is given by a simple estimate of that quantity. Although one may present an assessment of the uncertainty by means of the width of the distribution function (as measured, for instance, by the standard deviation), the distribution-function representation is a more flexible way of characterizing uncertainty. For instance, we may note that Sagan (Shklovskii and Sagan, 1966), in his discussion of L, considers two possibilities: an "optimistic" one that $L \sim 10^9$, to which he ascribes a probability of order .01; and the alternative (probability 0.99) "pessimistic" possibility that $L \sim 10^2$. He forms from these lifetimes the mean lifetime $\langle L \rangle \sim 10^7$ and uses this in the Drake formula, as is quite appropriate if one is simply trying to determine the expectation value of N. If, however, one is interested in estimating the probability that N falls in some range of values (for instance, N in a range of very small values, such as would follow from the short lifetime $L \sim 10^2$), it is preferable that one retain the two alternatives explicitly. It is furthermore desirable that each of the two possibilities (optimistic and pessimistic) should be represented by a distribution function. Even if one pursues only one chain of argument to estimate a quantity, there will normally be a certain range of uncertainty about the estimate which should be represented by a distribution function.

In scientific work, one is continually relying on information supplied by one's colleagues. For instance, the best estimates of the seven quantities R, f_p, etc., might be obtained from seven different specialists. However, it often happens that one obtains information about the same quantity from two or more sources. If, as is likely, these sources do not agree, one then has the problem of somehow combining these estimates. If each of a large number of scientists makes a simple estimate of the quantity, then one effectively obtains a distribution of that quantity which one may be able to represent simply by a mean value plus a standard deviation. Suppose, however, that estimates are obtained from a small number of sources--say two. Suppose also that one source has a great deal more information and experience than the other. How then should one combine the two different estimates?

The use of distribution functions offers a possible answer to this question. Each scientist can represent his estimate by a distribution function. If one scientist is (presumably for good reasons) very sure of his estimate, his distribution function may be quite sharp. If the other scientist is uncertain of his estimate, his distribution function will be broad. Following arguments given elsewhere (Sturrock, 1973), we can combine two (or more) estimates $P_1(x)$ and $P_2(x)$ for the same quantity x as follows:

$$P_{12}(x) = \frac{P_1(x)\ P_2(x)}{\int dx' P_1(x')\ P_2(x')} . \tag{5}$$

It normally happens that the confidence which a scientist places in each of his sources differs (perhaps substantially) from the confidence which each source places in himself. In this case, the scientist would not accept the distribution functions $P_1(x)$, $P_2(x)$, at face value. As a guide to a possible procedure to use in this case, we may note that if two independent estimation procedures were to lead to the same function $P_1(x)$, the resulting estimate is represented (to within a normalization factor) by $[P_1(x)]^2$. This suggests the generalization that, if it is necessary to "weight" an estimate, this may be done by replacing $P_1(x)$ by $[P_1(x)]^{w1}$.

This rule would be particularly helpful if two sources give estimates which are so different and so sharp that they are irreconcilable. It would then be prudent to replace P_1 and P_2 by P_1^w and P_2^w where w is made sufficiently small that the resulting functions have a reasonable chance of representing the same quantity--i.e., they have a healthy amount of overlap.

In order to present a brief numerical discussion, we now assume that each distribution function on the right-hand side of equation (4) has a gaussian form. Strictly speaking, this assumption cannot be correct since f_p, f_ℓ, f_i and f_c lie in the range zero to unity, and p_e takes non-negative integer values. Nevertheless, by virtue of the Central Limit Theorem (Wall, 1979), it is likely that our final distribution for N will be insensitive to this deficiency in our assumptions, and in fact that it will be approximately gaussian. With this simplifying assumption, the mean values of the quantities are related by

$$\bar{\nu} = \bar{\rho} + \ldots + \bar{\lambda}, \tag{6}$$

and the standard deviations are related by

$$\sigma^2(\nu) = \sigma^2(\rho) + \ldots + \sigma^2(\lambda). \tag{7}$$

As is clear from earlier contributions to this chapter, estimates of N vary considerably due to variations in the estimates of the quantities R, f_p, etc. A few estimates of these quantities have been gathered together in Table 1. Based on this information alone, we may obtain estimates of $\bar{\rho}$, $\sigma(\rho)$, etc. These estimates are given in the last comumn of Table 1. However, one should regard these estimates of the uncertainty of each quantity as being underestimates, for two reasons: (1) the proposed values were derived from the same body of current data and current theories which are to some extent (perhaps to a considerable extent) uncertain; (2) it is to be expected that authors making later estimates were aware of earlier estimates and were influenced by them, so that the estimates given in Table 1 are not really independent.

Table 1

	a	b	c	d	e
ρ	1	1.1	1.3	1.0	1.1 ± 0.1
ϕ_p	0	0	-0.3	-0.3	-0.1 ± 0.2
$\tilde{\omega}_e$	0	-0.5	0	0.5	0 ± 0.3
ϕ_ℓ	0	0	-0.7	0	-0.2 ± 0.3
ϕ_i	-1	0	0	0	-0.2 ± 0.4
ϕ_c	-1	-0.3	-0.3	-2	-0.9 ± 0.7
λ	2-8	6	8	7	6.3 ± 1.9

Estimates of quantities occurring in the text. Estimates a,b,c, and d are taken from Shklovskii and Sagan (1966), Cameron (1963), Billingham and Oliver (1973), and Sagan (1974), respectively. Values in column e are derived from estimates a to d.

Using the estimates of $\bar{\rho}$, $\sigma(\rho)$, etc., given in the last column of Table 1, we may estimate $\bar{\nu}$ and $\sigma(\nu)$ by using equations (6) and (7). We find that $\bar{\nu} \approx 6$ and $\sigma(\nu) \approx 2$. We see that the 1σ range of values of N is 10^4 to 10^8. That is, on the basis of the information presented, we have only 70% confidence that N lies in the range 10^4 to 10^8. We may have 95% confidence that N lies in the 2σ range which is seen to be 10^2 to 10^{10}. On remembering that our estimate of the range is conservative, we see that there is an enormous uncertainty in current estimates of N.

We see from Table 1 that 80% of the variance of ν, $\sigma^2(\nu)$, is due to our uncertainty of the "lifetime" λ, and more than half of the remainder of the variance is due to the uncertainty of ϕ_c. This is not surprising, since these are the most speculative estimates involved in the Drake formula. As Bracewell (1978) has pointed out, it is a gross simplification to think of a single mean lifetime for civilizations. Bracewell recommends that we consider the division of civilizations into groups. It certainly makes sense to try to expose the major assumptions underlying estimates of L and also to inquire into how these assumptions influence the probability that a civilization will establish radio beacons or be a source of "leakage" radio emission, since these are the two possibilities which must be considered in assessing whether or not it makes sense to conduct a search for extraterrestrial intelligent radio signals. This question will be discussed in the next section.

2. ESTIMATES OF THE COMMUNICATIVE LIFETIME

Much of present-day discussion of the possible existence of advanced civilizations in the Galaxy hinges on the possibility that such civilizations might be detected through their radio emission. (See, for instance, Morrison, Billingham and Wolfe, 1977.) From a certain viewpoint, this makes good sense. For instance, if scientists were to be given the definite charge of searching for extraterrestrial civilizations, they would have no choice but to carry out their search using known physical principles and current or "accessible" technology. There is no doubt that, if we were to try to send signals from earth to civilizations many light-years away, we would use radio transmission for reasons which have been thoroughly explored and persuasively presented.

However, if scientists are instead attempting to assess the likelihood that a contemplated search may be successful, or if they are trying to compare the prospects of success of two or more strategies, then we must face the possibility that civilizations much more advanced than our own (more advanced perhaps by many millions of years) may use communication technologies far superior to those we know, based on physical principles of which we are now utterly ignorant. This concept will be described in shorthand form as the proposition that there exists a "hyperphysics" of which we are now ignorant. As one possibility, this hypothesis would include the case that our familiar four-dimensional space-time is really a section of a hyperspace, and that it is possible to obtain access to other sections of this hyperspace by technological means. Since our known laws of physics refer only to the familiar four-dimensional space, we have no reason to believe that familiar limitations of travel time, etc., would have any relevance to such a hyperspace. Clearly, if an advanced civilization discovers a way to send messages at speeds much greater than the speed of light, radio waves would not be used for interstellar communication.

However, consideration of a possible "hyperphysics" carries with it even more profound implications for the SETI debate. According to present-day physics, interstellar travel would be very slow and extraordinarily expensive in energy and money. (See, for instance, Marx, 1973.) In that same volume, Kardashev (1973) writes "In dealing with extraterrestrial intelligence, we must concern ourselves with certain definite models; if we are considering a model of a super civilization, that is, a civilization that is far ahead of ours, in looking for it we must take into account things we know nothing about. Many people think that nowadays in astrophysics we know a great deal about all objects. In my opinion this is not so at all." Kardashev goes on to consider the possibility that it will at some time be possible to pass from one "space" to another, basing his discussion on present-day theories of black holes. These opening remarks by Kardashev were followed by extensive discussion involving Ginzburg, Gold, Sagan, Townes and von Hoerner about the possibility that there exist as yet undiscovered laws of physics. The possibility that we live in a hyperspace, or that there exists some other form of still undiscovered hyperphysics, has profound implications for discussion of interstellar travel as well as for discussion of interstellar communication.

In recent years, several authors (Bracewell, 1974; Schwartzman, 1977; Kuiper and Morris, 1977; Jones, 1976, 1978) have considered the concept of "Galactic Colonization." Even using means of space travel which are consistent with present-day physics, it has been argued that if a single civilization were to develop even to our current level of technological sophistication, it would be only a matter of time (perhaps one million years) before all habitable planets in the Galaxy would be colonized. This argument is taken sufficiently seriously that the absence of obvious evidence that we are a colony is taken to imply that we are the only advanced civilization in the Galaxy (Hart, 1975). If colonization is possible or likely even with present-day physics, how much more likely it must be for any civilization which discovers a hyperphysics and the means to exploit it.

It appears from the preceding discussion that the fundamental question underlying consideration of a search for extraterrestrial civilizations or communication with them is whether or not it is possible that advanced civilizations will discover a hyperphysics such as the discovery that we live in a hyperspace and the discovery of techniques to navigate that hyperspace. We therefore introduce the following symbol:

H = actuality of hyperphysics
$\overline{H}$ = no actuality of hyperphysics (limitations of current physics are absolute)

Since, for reasons which will become apparent, it will be necessary to use a more complex notation for probabilities, we shall in this section not work in terms of probability distributions although it is implicitly recognized that such distributions are necessary. As we saw in Section 1, we may give a simple representation of the uncertainty of any estimate of a probability by ascribing a standard deviation to the estimate of the probability or, better, to the estimate of the logarithm of the probability or of the "odds" defined by $P/(1-P)$ (Good, 1950).

We shall denote by $(A|B)$ the probability that proposition A is true on the basis of proposition B (Sturrock, 1973). Since our assessment of the probability of H is based more on ignorance than on knowledge, it will be denoted by $(H|-)$ and the probability of $\overline{H}$ by $(\overline{H}|-)$.

The next consideration with important implications for a search strategy appears to be whether or not a Galactic Federation (or, as Bracewell [1974] calls it, a "Galactic Club") comes into existence. We will denote by G the proposition that a Galactic Federation exists and by $\overline{G}$ the proposition that it does not. Since rapidity of communication and travel would promote exploration and peaceful or nonpeaceful visitation, it seems that $(G|H)$, the probability of there being a Galactic Federation in the hyperphysics scenario, would be much larger than $(G|\overline{H})$, the probability of there being a Galactic Federation if the limitations of present-day physics are absolute.

We can now distinguish four expected lifetimes for advanced civilizations: $L(G,H)$ (the expected lifetime [in years] if H is true and if G is true), $L(G,\overline{H})$, $L(\overline{G},H)$ and $L(\overline{G},\overline{H})$. By including these estimates in equation (1), we arrive at $N(G,H)$, the expected number of advanced civilizations in the Galaxy if both G and H are true, $N(G,\overline{H})$, etc. It will be convenient to write

$$N(G,H) = K\, L(G,H), \text{ etc.}, \tag{8}$$

where

$$K = Rf_p\, p_e f_\ell f_i f_c. \tag{9}$$

We denote by $(R_B|G,H)$ the probability that, if both G and H are true, an advanced civilization will operate radio beacons; similarly for $(R_B|G,\overline{H})$, etc. Then $N(R_B)$, the expected number of civilizations operating radio beacons in the Galaxy, is given by

$$N(R_B) = K\Big[(R_B|G,H)\tilde{L}(G,H) + (R_B|\overline{G},H)\tilde{L}(\overline{G},H) + (R_B|G,\overline{H})\tilde{L}(G,\overline{H}) + (R_B|\overline{G},\overline{H})\tilde{L}(\overline{G},\overline{H})\Big] \tag{10}$$

in which

$$\tilde{L}(G,H) = (G,H|-)\; L(G,H), \text{ etc.} \tag{11}$$

where

$$(G,H|-) = (G|H)\; (H|-), \text{ etc.} \tag{12}$$

Similarly, if R_L denotes the leakage of "domestic" radio waves, the expected number of advanced civilizations leaking radio waves is given by

$$N(R_L) = K\Big[(R_L|G,H)\tilde{L}(G,H) + \ldots\Big]. \tag{13}$$

It has been argued persuasively on many occasions (see, for instance, Wolfe, 1977) that on the basis of present-day physics $(\overline{H})$ "manned interstellar flight is out of the question not only for the present but for an indefinitely long time in the future." For these reasons, most discussions of search strategies for extraterrestrial life, being based on $(\overline{H})$, ignore the possibility that advanced civilizations may undertake exploration and, subsequently, "manned" surveillance (S_M) by means of space vehicles. However, Bracewell (1974) has pointed out that, even within the context of $\overline{H}$, it is possible for an advanced civilization to carry out surveillance by artificial means such as surveillance by means of a space vehicle "parked" near a star such as the sun, and equipped to detect radio signals (S_R). Bracewell conceives that, once the probe has detected radio signals, it immediately engages in open dialogue with terrestrial civilizations. However, this scenario runs counter to the practice of all terrestrial intelligence organizations, which set out to learn as much as possible about other societies but divulge no real information although they may disseminate disinformation. Since a radio probe could learn a great deal simply by listening and runs the risk of being captured if it transmits radio signals from near the earth, it seems much more likely that, for some considerable time, such a probe would merely maintain radio surveillance, transmitting whatever it learns back to its home base.

Formulas analogous to equations (10) and (13) give estimates of the number of advanced civilizations in the Galaxy practicing surveillance either by "manned" vehicles or by radio means:

$$N(S_M) = K\left[(S_M|G,H)\tilde{L}(G,H) + \ldots\right] \tag{14}$$

$$N(S_R) = K\left[(S_R|G,H)\tilde{L}(G,H) + \ldots\right] \tag{15}$$

One could imagine that such probes may search for signals of a type we are not now using, but this consideration would not figure in present-day strategy for extraterrestrial intelligent life and so may be ignored.

The above formalism can be helpful in laying out the possible scenarios which might lead to detectable radio signals and for seeing what judgments are involved in estimating probabilities of these scenarios. We also see that, even though many factors are involved in estimating each quantity $N(R_B)$, etc., the quantities which have been combined together as K (equation 9) will cancel out in comparing one number with another, e.g., $N(R_B)$ with $N(R_L)$.

In order to make numerical estimates of these quantities, it is desirable that a number of scientists should make estimates of the various quantities involved, so that one could then assign a value with an error bar to each quantity, as was done in Table 1 of Section 1. It is hoped that this can be done at a later date. However, at this time, the best that I can do is to present my own estimates of the various quantities and the resulting estimates of $N(R_B)$, etc.

The quantity K may be derived from Table 1. It is found that

$$\log K = 10^{-0.3\pm 1}. \tag{16}$$

The most difficult estimate to make is that of $(H|-)$ and $(\bar{H}|-)$. On the one hand we clearly have no reason to believe that there is a "hyper-physics" with laws transcending those in current use. On the other hand, science as we know it dates back only about 2,000 years; the laws of gravitation and motion have been known for only about 300 years, electromagnetism for about 100 years, and quantum theory and relativity for only about 50 years. Why should we believe that, if scientists were to continue working for another million years, there would not be comparable revolutions or revelations? My own attitude is to assign maximum uncertainty to the proposition H by assigning to its probability a uniform distribution over the range zero to unity. With this distribution, we find that

$$(H|-) = (\overline{H}|-) = 10^{-0.4\pm0.4}. \quad (17)$$

We must next consider the probability of the existence of a "Galactic Federation." Within the context of hyperphysics, which is assumed to facilitate rapid communication and travel, it seems more likely than not that there would be a Galactic Federation. However, this issue is so speculative that the following very conservative estimates will be adopted:

$$\left[(G|H)/(\overline{G}|H)\right] = 10^{1\pm1} \quad (18)$$

If, on the other hand, there is no hyperphysics so that communication is limited by the speed of light and travel is very slow and extraordinarily expensive, the development of a federation with enforceable conformity seems highly unlikely. We therefore adopt

$$\left[(G|\overline{H})/(\overline{G}|\overline{H})\right] = 10^{-4\pm2}. \quad (19)$$

It follows from these equations that, to accuracy sufficient for our purposes, $(G|H) \approx 1$ and $(\overline{G}|\overline{H}) \approx 1$.

We next consider the probable lifetime L for each of the four cases. Case $(\overline{G},\overline{H})$ is the one implicitly considered in Section 1, so that we may use the estimate given in Table 1, $L(\overline{G},\overline{H}) = 10^{6\pm2}$. Within the context of $\overline{H}$, it is unlikely that the existence of a Galactic Federation would make much difference, so that we may adopt also $L(\overline{G},\overline{H}) = 10^{6\pm2}$. Within the context of H, the existence of a Galactic Federation may be very effective in preserving civilizations, so that we may adopt the more optimistic estimate $L(G,H) = 10^{8\pm2}$. Within the context of H, but in the absence of a Galactic Federation, civilizations may be as precarious as they are in the context of $\overline{H}$, so that we may again set $L(\overline{G},H) = 10^{6\pm2}$.

The probabilities $(G,H|-)$ etc., given by equation (12), are listed in column 1 of Table 2. The lifetimes L are listed in column 2, and the "reduced" lifetimes, given by equation (11), are listed in column 3. From these estimates, (G,H) appears to be the most important possibility, followed by $(\overline{G},\overline{H})$, $(\overline{G},H)$ and $(G,\overline{H})$. This puts us in the uncomfortable situation that the most important scenario appears to be that of which we know least.

We must now turn to estimates of the probatilities $(R_B|G,H)$, etc.

If the limitations of present-day physics are absolute ($\overline{H}$), civilizations are not subject to easy attack from their interstellar neighbors, yet there is some interest and possible advantage in communication. It seems therefore that the establishment of radio beacons would not be unlikely. Nor would there be any harm in allowing for radio leakage. On the other hand, it would still be prudent to begin by radio surveillance. "Manned" surveillance would be exceedingly difficult. If there is a Galactic Federation, there may be somewhat more interest in setting up beacons and in arranging for radio surveillance, but these tasks may be assigned to a fraction of the civilized worlds. In any case, the existence of a Galactic Federation would not do much to facilitate manned surveillance. For these reasons, estimates for the probability of R_B, etc., on the assumption $\overline{H}$, are taken to be independent of the alternatives $G, \overline{G}$. The values are listed in columns 4 through 7 of Table 2.

Table 2

	P	L	$\tilde{L}$	R_B	R_L	S_M	S_R
G H	-0.4±0.4	8±2	7.6±2	-4±2	-2±2	-1±1	-4±2
$\overline{G}$ H	-1.4±1	6±2	4.6±2	-4±2	-2±2	-1±1	-4±2
G $\overline{H}$	-4.4±2	6±2	1.6±3	-1±1	-1±1	-5±2	-0.5±0.5
$\overline{G}$ $\overline{H}$	-0.4±0.4	6±2	5.6±2	-1±1	-1±1	-5±2	-0.5±0.5
N				4.5±2.5	5.5±3	6.5±2.5	4±2

In the column headed P are listed the logarithms of $(G,H|-)$, etc.; under L, the logarithms of the lifetimes $L(G,H)$, etc.; under $\tilde{L}$, the logarithms of $\tilde{L}(G,H)$, etc; and under R_B, etc., the logarithms of the probabilities $(R_B|G,H)$, etc. Also under R_B, etc., are the final estimates of $N(R_B)$, etc.

If, on the other hand, there exists a hyperphysics which we have yet to discover but which is available for exploitation by more advanced civilizations, making possible rapid communication and interstellar travel, the strategies are likely to be quite different leading to quite different estimates for the probabilities of R_B, etc. If manned surveillance is possible, there would be little reason to set up radio beacons or to establish probes equipped for radio surveillance. Hence the probability of S_M is likely to be high and the probabilities of R_B and S_R are likely to be low. It is quite possible that electromagnetic waves will be superseded as a mechanism for domestic communication, in which case there would be no leakage. However, electromagnetic waves may be retained for certain specialized purposes: the question then is whether the civilization would or would not take pains to suppress this evidence of its existence. If there is no Galactic Federation, each civilization may be somewhat wary of advertising its existence and location. If there is a Galactic Federation, each civilization may feel sufficiently secure to allow for radio leakage. In scenario (G,H), radio leakage would seem somewhat more likely than radio beacons or radio probes. Since it is not clear how the existence of the Galactic Federation would influence the probabilities of R_B, etc., these are taken to be the same for the two cases $G, \bar{G}$. The proposed values are listed in Table 2.

On using equations (10), etc., and the values given in the first four rows of Table 2, we may estimate $N(R_B)$, etc. These values are given in row 5 of Table 2.

3. DISCUSSION

It is not the purpose of this article to present and defend any particular set of numerical estimates of $N(R_B)$, etc. The aim is, rather, to present a formalism which can be used as a "bookkeeping procedure" allowing us to list what appear to be possible scenarios leading to possible communication with extraterrestrial civilizations and to identify the decisions which must be made in estimating the probability of any particular mode of contact, and which shows how the various decisions may be combined to arrive at the final estimates. A further goal is to show how one may represent the uncertainty in each decision and carry it through to the final estimates.

I have argued that the most important decision to be made is whether one considers it likely that the laws of present-day physics are absolute or whether one considers that there exists an as-yet-undiscovered "hyperphysics," possibly involving hyperspace, which makes it possible to escape from the limitations of physics as it is now understood.

It may well be argued that this is not a scientific question, since science deals with what we know about the universe, to which one might respond that in any scientific discipline an assessment of our ignorance is just as important as an assessment of our knowledge. However, it seems to me that the question does lie outside science; if it belongs to any discipline at all, it is likely to be the philosophy of science. Since it is unlikely that the exponents of this branch of learning have any way of arriving at a concensus on this question, one must leave the probability H as a purely subjective estimate. Fine (1973), in discussing the nature of probability statements in discussions of the prevalence of extraterrestrial intelligent life, presents his judgment that "the concept of subjective probability is at present the only basis upon which probability statements can be made about ETIL [extraterrestrial intelligent life]."

Even though we cannot expect conformity in estimates of the various probabilities figuring into our final estimates, it is possible that we can solicit estimates from a number of scientists and then represent their collective judgment by means of a distribution function, as indicated in Section 1. In this way we will at least be able to represent the "collective subjective estimates" of interested scientists, rather than just one scientist's conjectures.

Given the preceding caveats, we may now turn to the estimates presented in Table 2. In comparing the probable numbers of civilizations operating radio beacons or allowing radio leakage, we see that the latter appears to be larger, but not by a statistically significant amount. What is more significant is that the principal contribution to $N(R_B)$ comes from the case $(\overline{G},\overline{H})$ and the principal contribution to $N(R_L)$ comes from the case (G,H).

The number of civilizations likely to be operating radio probes seems to be almost as large as those operating beacons or allowing leakage, substantiating Bracewell's (1960) proposal that we search for such devices. The principal contribution to our assessment of $N(S_R)$ comes from the case $(\overline{G},\overline{H})$.

We see, however, that the assumptions set out in the first four lines of Table 2 lead to an estimate of $N(S_M)$ somewhat larger than the others. The question which now arises is the following: if we are under active surveillance by manned craft, would we know it? Hart (1975) asserts categorically that we now are not being visited. Most scientists involved in the SETI program appear to agree with him. However surveillance, even within our terrestrial civilization, can be covert and hard to detect--due not merely to paucity of public information but also to the dissemination of disinformation. This implies that the assessment of whether or not we are under covert surveillance by extraterrestrial civilizations is not a purely scientific question--it spills over into scientific intelligence.

Although we cannot infer from present-day physics and astronomy that we are--or are not--under covert surveillance by extraterrestrial civilizations, we can place some credence in the following argument. If we are under manned surveillance, the transportation is not likely to be effected by spacecraft as we know them (Markowitz, 1967). The fact of manned surveillance (if it is ever established) would in itself argue for the existence of "hyperspacecraft" which would in turn imply the actuality of a hyperphysics (Sturrock, 1975, 1978).

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