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# Interstellar Archaeology and the Prevalence of Intelligence

J. FREEMAN AND M. LAMPTON

*Space Sciences Laboratory, University of California, Berkeley, California 94720*

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Simple calculations indicate that the spatial density in the galaxy of extinct civilizations, and of planets inhabited by intelligent creatures who do not have technical civilizations, may be quite large.

Drake, Oliver *et al.* (1972), Huang (1959), Shklovskii and Sagan (1966), and others have developed formalisms to estimate the chances of success of attempted radio communication with extraterrestrial civilizations. Extension of these formalisms here indicates that throughout cosmic time the galaxy may have harbored several hundred million technically advanced civilizations, and thousands of millions of intelligent species. These conclusions do not depend on conjectures about the average lifetimes of advanced civilizations.

The number of advanced civilizations which have arisen in the galaxy can be estimated in three steps. First, after Drake, write the probability that an advanced civilization ever evolves at a given star as

$$P = f_g f_p n_e f_l f_i f_a, \tag{1}$$

where $f_g$ = fraction of stars at which suitable planets are not precluded by spectral class or by multiple-star orbital dynamics, $f_p$ = fraction of suitable stars which have planetary systems, $n_e$ = number of Earth-like planets per planetary system, $f_l$ = fraction of Earth-like planets on which life evolves, $f_i$ = fraction of biospheres in which a family of creatures evolves intelligence, and $f_a$ = fraction of families of intelligent creatures in which at least one species develops an advanced technical civilization.

Second, note that during the early stages of star formation in the galaxy, nucleosynthesis probably had not produced enough atoms heavier than helium for biospheres to be possible. Approximate this effect by assuming that $P$ becomes zero for stars formed before some characteristic time $T_I$.

Third, observe that evolution takes time; hence stars formed closer to the present than some characteristic evolution time $T_E$ will be too young to possess advanced civilizations.

Then the number of advanced civilizations which have arisen thus far in the galaxy is

$$B_a = (T - T_E - T_I) R_* f_g f_p n_e f_l f_i f_a, \tag{2}$$

where $T$ is the age of the galaxy and $R_*$ is the rate of star formation between $T_I$ and $T - T_E$. The number of families of intelligent creatures which have arisen in the galaxy differs only by the absence of the factor $f_a$ (assuming the same $T_E$ is approximately correct for both cases),

$$B_i = (T - T_E - T_I) R_* f_g f_p n_e f_l f_i. \tag{3}$$

The form of (2) and (3) was inspired by a formalism that Oliver *et al.* (1972) developed for other purposes.

$T$ is about $10^{10}$ yr. If the history of our own planet is representative, then $T_E = 4.5 \times 10^9$ yr is satisfactory. And although the early history of nucleosynthesis in our galaxy is not well known, a value of $T_I = 3 \times 10^9$ yr seems reasonable. Values given by Pearman (1963), Shklovskii and Sagan (1966), and Oliver *et al.* (1972) for the other factors are approximately $R_* = 20\,\mathrm{yr}^{-1}$, $f_g = 0.25$, $f_p = 1$, $n_e = 1$, $f_l = 0.2$, $f_i = 1$, and $f_a = 0.1$, so that

$$B_a = 2.5 \times 10^8, \; B_i = 2.5 \times 10^9. \tag{4}$$







An estimate of how many advanced civilizations presently exist depends on the average lifetime of such civilizations, and that number appears uncertain to at least five orders of magnitude, from $10^2$ yr to $10^7$ yr (Pearman, 1963) or perhaps even $10^9$ yr. But if the experience of the primates on Earth is typical, then the average lifetime $L_i$ of families of intelligent creatures (who do not necessarily have advanced technical societies) is at least $3 \times 10^6$ yr. Hence a formula of the form due to Drake for the number of such families in the galaxy,

$$N_i = R_* f_g f_p n_e f_l f_i L_i, \tag{5}$$

gives $N_i = 3 \times 10^6$.

So if there are $10^{11}$ stellar systems in the galaxy, then the fraction where intelligence exists $\gtrsim 3 \times 10^{-5}$, the fraction where intelligence once existed $\approx 2.5 \times 10^{-2}$, and the fraction where advanced civilization once existed $\approx 2.5 \times 10^{-3}$. And, assuming a local star density of 0.06 parsec$^{-3}$, the expected distances from the Sun to the nearest such stars are: $\gtrsim 50$, $\approx 5.5$, and $\approx 12$ parsec, respectively. These conclusions are independent of the average lifetime of advanced civilizations.

An extinct advanced civilization might have left behind space-borne artifacts which could survive for a very long time.

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