Reprint

DIRECT CONTACT AMONG GALACTIC CIVILIZATIONS BY RELATIVISTIC INTERSTELLAR SPACEFLIGHT*

double note

CARL SAGAN† (Harvard O.)

Department of Genetics, Stanford University Medical Centre,
Palo Alto, California

Stanford., Calif.

20930

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Abstract—An estimate of the number of advanced technical civilizations on planets of other stars depends on our knowledge of the rate of star formation; the frequency of favorably situated planets; the probabilities of the origins of life, of intelligence and of technical civilization; and the lifetimes of technical civilizations. These parameters are poorly known. The estimates of the present paper lead to ~10^6 extant advanced technical civilizations in our Galaxy. The most probable distance to the nearest such community is then several hundred light years.

Interstellar spaceflight at relativistic velocities has several obvious advantages over electromagnetic communication among these civilizations. One striking feature is that with uniform acceleration of 1 g to the midpoint of the journey, and uniform deceleration thereafter, all points in the Galaxy are accessible within the lifetime of a human crew, due to relativistic time dilation. Some of the technical problems in the construction of starships capable of relativistic velocities are discussed. It is concluded that with nuclear staging, fusion reactors, and the Bussard interstellar ramjet, no fundamental energetic problems exist for relativistic interstellar spaceflight.

We assume that there exists in the Galaxy a loosely integrated community of diverse civilizations, cooperating in the exploration and sampling of astronomical objects and their inhabitants. If each such advanced civilization launches one interstellar vehicle per year, the mean time interval between samplings of an average star would be 10^5 years, that between samplings of a planetary system with intelligent life would be 10^4 years, and that between sampling of another advanced civilization would be 10^3 years. It follows that there is the statistical likelihood that Earth was visited by an advanced extraterrestrial civilization at least once during historical times. There are serious difficulties in demonstrating such a contact by ancient writings and iconography alone. Nevertheless, there are legends which might profitably be studied in this context. Bases or other artifacts of interstellar spacefaring civilizations might also exist elsewhere in the solar system. The conclusions of the present paper are clearly provisional.

INTRODUCTION

In recent years there has been a resurgence of interest in the ancient speculation that civilizations exist on other worlds beyond the Earth. This question has retained a basic and widespread appeal from the beginnings of human history; but only in the past decade has it become even slightly tractable to serious scientific investigation. Work on stellar statistics and stellar evolution has suggested that a large fraction of the stars in the sky have planetary systems. Studies of the origin of the solar system and of the origin of the first terrestrial organisms have suggested that life readily arises early in the history of favorably-situated planets. The prospect occurs that life is a pervasive constituent of the universe. By terrestrial analogy it is not unreasonable to expect that, over astronomical timescales, intelligence and technical civilizations will evolve on many life-bearing planets. Under such circumstances the possibility then looms that contact with other galactic communities may somehow be established.

It has been argued that the natural channel for interstellar communication is radio emission near the 21 cm line of neutral hydrogen[1]; or between 3·2 and 8·1 cm[2]; or at

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† Department of Astronomy, Harvard University, and Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A.

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10.5 cm[3]. Alternatively, laser modulation of the intensity of core reversal in the Fraunhofer lines of late-type stars has been suggested[4]; or automatic interstellar probe vehicles transmitting a precoded message to planetary sources of monochromatic radio emission which are randomly encountered[5].

The purpose of the present paper is to explore the likelihood and possible consequences of another communications channel: direct physical contact among galactic communities by relativistic interstellar spaceflight. Part of the impetus for publishing these remarks has been a paper by von Hoerner[3] which arrives at very pessimistic estimates for the number of extraterrestrial civilizations; and three papers[6,7,8] which reach distinctly negative conclusions on the ultimate prospect of relativistic interstellar spaceflight. I feel that the information now available permits rather different conclusions to be drawn.

The line of argument to be pursued involves a number of parameters which are only poorly known. The discussion is intended to stimulate further work in a number of disciplines. The reader is invited to adopt a skeptical frame of mind, and to modify the conclusions accordingly. Only through extensive discussion and experiment will the true outlines gradually emerge in this enigmatic but significant subject.

2. DISTRIBUTION OF TECHNICAL CIVILIZATIONS IN THE GALAXY

We desire to compute the number of extant galactic communities which have attained a technical capability substantially in advance of our own. At the present rate of technological progress, we might picture this capability as several hundred years or more beyond our own stage of development. A simple method of computing this number is primarily due to F. D. Drake, and was discussed extensively at a Conference on Intelligent Extraterrestrial Life held at the National Radio Astronomy Observatory in November, 1961, and sponsored by the Space Science Board of the National Academy of Sciences†. While the details differ in several respects, the following discussion is in substantial agreement with the conclusions of the Conference.

The number of extant advanced technical civilizations possessing both the interest and the capability for interstellar communication can be expressed as

$$N = R_* f_p n_e f_l f_i f_c L. \tag{1}$$

R_* is the mean rate of star formation averaged over the lifetime of the Galaxy, f_p is the fraction of stars with planetary systems, n_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 during the lifetime of the local sun, f_c is the fraction of planets populated by intelligent beings on which an advanced technical civilization in the sense previously defined arises during the lifetime of the local sun, and L is the lifetime of the technical civilization. We now proceed to discuss each parameter in turn.

Since stars of solar mass or less have lifetimes on the main sequence comparable to the age of the Galaxy, it is not the present rate of star formation but the mean rate of star formation during the age of the Galaxy which concerns us here. The number of known stars in the Galaxy is $\sim 10^{11}$, most of which have mass equal to or less than the Sun. The age of the Galaxy is $\sim 10^{10}$ years. Consequently, a first estimate for the mean rate of star formation is ~ 10 stars/year. The present rate of star formation is at least an order of

† Attending this meeting were D. W. Atchley, M. Calvin, G. Cocconi, F. D. Drake, S. S. Huang, J. C. Lilly, P. M. Morrison, B. M. Oliver, J. P. T. Pearman, C. Sagan and O. Struve.

magnitude less than this figure, and the rate of star formation in early galactic history is possibly several orders of magnitude more[9]. According to present views of stellar nucleo-genesis[10], stars (and, by implication, planets) formed in the early history of the Galaxy are extremely poor in heavy elements. Technical civilizations developed on such ancient planets would of necessity be extremely different from our own. But in the flurry of early star formation when the Galaxy was young, heavy elements must have been generated rapidly and later generations of stars and planets would have had adequate endowments of high mass number nuclides. These very early systems should be subtracted in our estimate of R_*. On the other hand, a suspicion exists that large numbers of low mass stars may exist to the right of the main sequence in the Hertzsprung-Russell diagram[11]. Inclusion of these objects will tend to increase our estimate of R_*. For present purposes we adopt $R_* \sim 10/\text{yr}$.

There is a discontinuity in stellar rotational velocities near spectral type F5V; stars of later spectral type have very slow equatorial rotation rates. This circumstance is generally attributed to the transfer of angular momentum from the star to a surrounding solar nebula by magnetic coupling[12,13,14,15]. The solar nebula is then expected to condense into a planetary system[15,16,17,18]. The fraction of stars of later type than F5V is greater than 0·98; well over 60 per cent of these are dwarf M stars[19]. It is not known what influence the luminosity of the star has on the subsequent condensation and dissipation of the surrounding solar nebula. We might expect that stars of much earlier type than the Sun readily dissipate their solar nebulae; and that stars of much later type than the Sun dissipate very little of their solar nebulae, thereby forming large numbers of massive planets of the Jovian type. There is good evidence that many of the chemical processes in the early history of the solar system occurred at low temperature[17], and the low luminosity of late type stars is unlikely to impede condensation processes in the solar nebula. We therefore adopt $f_p \sim 1$.

Planets of double and multiple star systems are expected in general to have—over astronomical timescales—such erratic orbits that the evolution of life on them is deemed unlikely[20]. I fail to find this argument entirely convincing; but for conservative reasons it will be included in the discussion. The fraction of stars which are not members of double or multiple systems is $\sim 0·5$[21]. In our own solar system the number of planets which are favorably situated for the origin of life is at least two (Earth and Mars), and the possibility that life arose at some time on the Jovian planets[22] has recently been raised. It is sometimes argued that life cannot develop on planets of M dwarfs, because the luminosity of the local sun is too small. However, especially for Jovian type planets of M dwarfs, the greenhouse effect in a methane-ammonia-water atmosphere should produce quite reasonable temperatures. We adopt $n_e \sim 0·5 \times 2 = 1$.

The most recent work on the origin of life strongly suggests that life arose very rapidly during the early history of the Earth[22–25]. It appears that the production of self-replicating molecular systems is a forced process which is bound to occur because of the physics and chemistry of primitive planetary environments. Such self-replicating systems, situated in a medium filled with replication precursors, satisfy all the requirements for natural selection and biological evolution. Given sufficient time and an environment which is not entirely static, the evolution of complex organisms is apparently inevitable. In our own solar system, the origin of life has probably occurred at least twice. We adopt $f_l \sim 1$.

The question of the evolution of intelligence is a difficult one. This is not a field which lends itself to laboratory experimentation, and the number of intelligent species available

for study on Earth is limited. Intelligent hominids have inhabited the Earth for $\leqslant 10^{-3}$ of Earth history.

It is clear that the evolution of intelligence and manipulative ability has resulted from the product of a large number of individually unlikely events. If the history of the Earth were started again, it is highly improbable that the same sequence of events would recur and that intelligence would evolve in the identical manner. On the other hand, the adaptive value of intelligence and manipulative ability is so great—at least until technical civilizations are developed—that, if it is genetically feasible, natural selection is very likely to bring it forth. There is some evidence that surprisingly high levels of intelligence have evolved in the Cetacea[26]. Phylogenetically, these are rather close to hominids; the neuroanatomy of Cetacea brains is remarkably similar to that of the primates, although the most recent common ancestor of the two groups lived more than 10^8 years ago[26]. The Cetacea have very limited manipulative abilities.

Comparison of the rates of stellar and of biological evolution provides some perspective on the probability that intelligence will arise on an otherwise suitable planet. Terrestrial intelligence and civilization have emerged roughly midway in the Sun's residence time on the main sequence. The overwhelming majority of stars in the sky have longer lifetimes than the Sun. With the expectation that the Earth is not extraordinary in its recent evolution but allowing for the fact that apparently only one intelligent phylogenetic order with manipulative abilities has developed, and this only recently, we adopt $f_i \sim 10^{-1}$.

Whether there is one, or several, foci for the line of cultural development which has led to the present technical civilization on Earth is still an open question, depending in part on the extent of cultural diffusion over large distances some five or six thousand years in the past. It appears that little can be gained from speculation on, e.g. whether Aztec civilization would have developed a technical phase had there been no *Conquistadores*.

Recorded history—even in mythological guise—covers $\leqslant 10^{-2}$ of the period in which the Earth has been inhabited by hominids, and $\leqslant 10^{-5}$ of geological time. The same considerations are involved as in the determination of f_i. The development of a technical civilization has high survival value at least up to a point; but in any given case it depends on the concatenation of many improbable events; and it has occurred only recently in terrestrial history. It is unlikely that the Earth is very extraordinary in possessing a technical civilization among planets inhabited by intelligent beings. As before, over stellar evolutionary timescales, we adopt $f_c \sim 10^{-1}$.

The multiplication of the preceding factors gives

$$N = 10 \times 1 \times 1 \times 1 \times 10^{-1} \times 10^{-1} \times L = 10^{-1}L.$$

L is the mean lifetime in years of a technical civilization possessing both the interest and the capability for interstellar communication. For the evaluation of L there is—fortunately for us, but unfortunately for the discussion—not even one known terrestrial example. The present technical civilization on Earth has reached the communicative phase (in the sense of high-gain directional antennas for the reception of extraterrestrial radio signals) only within the last few years. There is a sober possibility that L for Earth will be measured in decades. It is also possible that international political differences will be permanently settled, and that L may be measured in geological time. It is conceivable that, on other worlds, the resolution of national conflicts and the establishment of planetary governments are accomplished before weapons of mass destruction become available. We can imagine two extreme alternatives for the evaluation of L: (a) a technical civilization destroys

itself soon after reaching the communicative phase ($L < 10^2$ years); or (b) a technical civilization learns to live with itself soon after reaching the communicative phase. If it survives $> 10^2$ years, it will be unlikely to destroy itself afterwards. In the latter case its lifetime may be measured on a stellar evolutionary timescale ($L \gg 10^8$) years. Such a society will exercise self-selection on its members; genetic changes will be unable to move the species off the adaptive peak of the technical civilization. The technology will certainly be adequate to cope with tectonic and orogenic changes. Even the evolution of the local sun through the red giant and white dwarf evolutionary stages may not pose insuperable problems for the survival of an extremely advanced community.

It seems improbable that, surrounded by large numbers of flourishing and diverse galactic communities, a given planetary civilization will retreat from the communicative phase. This is one reason that L is itself a function of N. Von Hoerner[3] has suggested another reason: he feels that the means of avoiding self-destruction will be among the primary contents of initial interstellar communications.

Gold[27] has talked of the possibility that interstellar space voyagers accidentally may biologically contaminate lifeless planets, and thereby initiate the origin of life. There is also some prospect that such initiation might be purposefully performed. In these cases $f_l = f_l(N)$. Below we will discuss the possibility that $f_c = f_c(N)$. For these reasons it should be remembered that equation (1) is in reality an integral equation.

The two choices for L ($< 10^2$ years and $\gg 10^8$ years) lead to two values of N: < 10 communicative technical civilizations per galaxy, or $\gg 10^7$. Thus the evaluation of N depends quite critically on our expectation for the lifetime of the average advanced community. Von Hoerner[3] has made very pessimistic estimates for L, and his values of N are correspondingly small. It seems more reasonable to me that at least a few per cent of the advanced technical civilizations in the Galaxy do not destroy themselves, nor lose interest in interstellar communication, nor suffer insuperable biological or geological catastrophies, and that their lifetimes, therefore, are measured on stellar evolutionary timescales. Averaged over all technical civilizations, we therefore take $L \sim 10^7$ years. For the purposes of the following discussion then, we adopt as the steady-state number of extant advanced technical civilizations in the Galaxy:

$$N \sim 10^6.$$

Thus, approximately 0·001 per cent of the stars in the sky will have a planet upon which an advanced civilization resides. The most probable distance to the nearest such community is then several hundred light years.*

3. FEASIBILITY OF INTERSTELLAR SPACEFLIGHT

The difficulties of electromagnetic communication over such interstellar distances are serious. A simple query and response to the nearest technical civilization requires periods approaching 1000 years. An extended conversation—or direct communication with a particularly interesting community on the other side of the Galaxy—will occupy much greater time intervals, 10^4 to 10^5 years.

Electromagnetic communication assumes that the choice of signal frequency will be obvious to all communities. But there has been considerable disagreement about interstellar transmission frequency assignment even on our own planet[1,2,3,4,5]; among galactic communities, we can expect much more sizable differences of opinion about what is obvious

* In the Space Science Board Conference previously mentioned, the conclusions for N spanned 10^4–10^9, and the distance to the nearest advanced community ranged from ten to several thousand light years.

and what is not. No matter how ingenious the method, there are certain limitations on the character of the communication effected with an alien civilization by electromagnetic signalling. With billions of years of independent biological and social evolution, the thought processes and habit patterns of any two communities must differ greatly; electromagnetic communication of programmed learning between two such communities would seem to be a very difficult undertaking indeed. The learning is vicarious. Finally, electromagnetic communication does not permit two of the most exciting categories of interstellar contact—namely, contact between an advanced civilization and an intelligent but pretechnical society, and the exchange of artifacts and biological specimens among the various communities.

Interstellar space flight sweeps away these difficulties. It reopens the arena of action for civilizations where local exploration has been completed; it provides access beyond the planetary frontiers.

There are two basic methods of achieving interstellar spaceflight within characteristic human lifetimes. One involves the slowing down of human metabolic activities during very long flight times. In the remainder of the paper, we will discuss relativistic interstellar spaceflight, which, in effect accomplishes the identical function, and further, permits the voyager to return to his home planet in much shorter periods of time, as measured on the home planet.

If relativistic velocities can be achieved, time dilation will permit very long journeys within a human lifetime. Consider a starship capable of uniform acceleration to the midpoint of the journey, and uniform deceleration thereafter. The relativistic equations of motion have been solved by Peschka[28] and by Sänger[29]. For our flight plan, their results are readily modified, and yield for the time t, as measured on the space vehicle, to travel a distance S, with a uniform acceleration a to $S/2$ and a uniform deceleration $-a$ thereafter:

$$t = (2c/a) \text{ arc cosh } (1 + aS/2c^2) \tag{2}$$

where c is the velocity of light. The results for such an acceleration–deceleration flight plan are shown in Fig. 1.

At an acceleration of $1\,g$—as would be appropriate for inhabitants of a planet of terrestrial mass and radius—it takes only a few years shiptime to reach the nearest stars, 21 years to reach the Galactic Center, and 28 years to reach the nearest spiral galaxy beyond the Milky Way. With accelerations of 2 or 3 g—as would be appropriate for inhabitants of a planet of Jovian mass and radius—these distances can be negotiated in about half the time. Of course there is no time dilation on the home planet; the elapsed time in years approximately equals the distance of the destination in light years plus twice the time to reach relativistic velocities. For distances beyond about ten light years, the elapsed time on the home planet in years roughly equals the distance of the destination in light years. Thus, for a round trip with a several-year stopover to the nearest stars, the elapsed time on Earth will be a few decades; to Deneb, a few centuries; to the Vela Cloud Complex, a few millenia; to the Galactic Center, a few tens of thousands of years; to M31, a few million years; to the Virgo Cluster of Galaxies, a few tens of millions of years; and to the Coma Cluster, a few hundreds of millions of years. Nevertheless, each of these immense journeys could be performed within the lifetimes of a human crew. For transgalactic and intergalactic distances, equation (2) reduces to

$$t = 2c/a \ln (aS/c^2) \tag{3}$$

and in this range the curves of Fig. 1 are straight lines on a semi-logarithmic plot.

A number of difficulties have been presented by early authors on the technical aspects of relativistic interstellar spaceflight. Even with complete conversion of mass into energy, extreme mass ratios are required if all the fuel is carried at launch. For relativistic velocities and the above flight plan, the mass ratio is approximately equal to $2/\phi$, where $\phi = 1 - (v/c)$, and v is the maximum vehicle velocity[7,30,31]. For example, to reach $v = 0 \cdot 999\ c$, the liftoff weight must be some 2000 times the payload, and it is clear that enormous initial vehicle masses are required. For the round trip with no refueling, the mass ratio is $(2/\phi)^2$. Thus, Ackeret[30,31] concluded that "even with daring assumptions," interstellar spaceflight at relativistic velocities would be feasible only for travel to the nearest stars. Furthermore, baryon charge conservation prevents the complete conversion of matter to energy, except
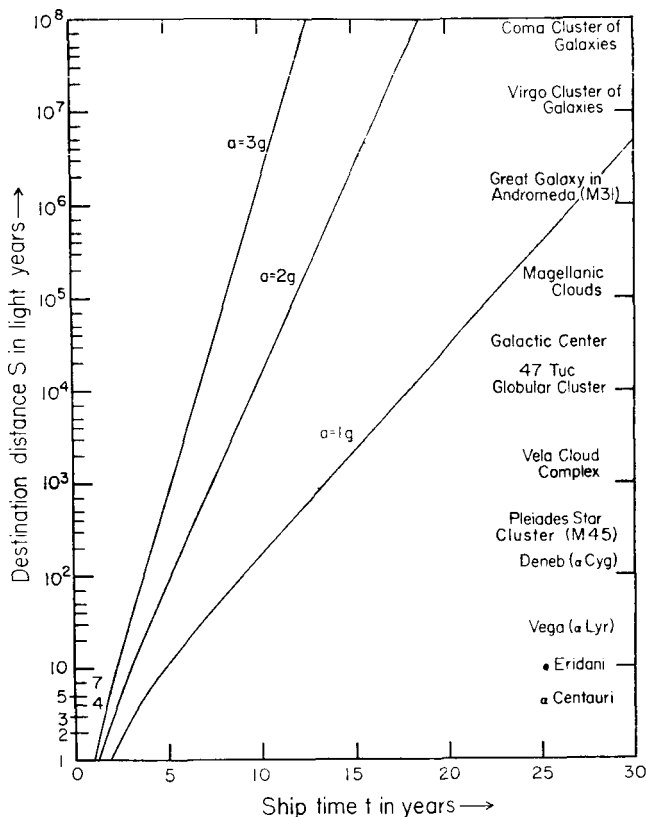

FIG. 1

if half the working fuel is antimatter[32]; the containment of the antimatter—to say nothing of its production in the quantities required—is clearly a very serious problem. An additional difficulty with such an antimatter starship drive has been emphasized by Purcell[7]; the gamma ray exhaust would be lethal for the inhabitants of the launch planet if the drive were turned on near the planet (and if atmospheric absorption is neglected). Staging of fusion rockets[33] provides some relaxation of the required mass ratios, but it appears that relativistic velocities cannot be obtained by such staging alone.

A way out of these difficulties has been provided by Bussard[34] in a most stimulating paper. Bussard describes an interstellar ramjet which uses the interstellar medium both

as a working fluid (to provide reaction mass), and as an energy source (by thermonuclear fusion). There is no complete conversion of matter into energy; the existing mass deficits and low reaction cross-sections for the conversion of hydrogen to deuterium are used. The reactor is certainly not available today; but it violates no physical principles, it is currently being very actively pursued, and there is no reason to expect it to be more than a few centuries away from realization on this planet. The Bussard interstellar ramjet requires very large frontal area loading densities: $\sim 10^{-8}$ g cm^{-2} per nucleon cm^{-3} in the interstellar medium. Thus, if the payload is 10^9 gm, the intake area must have a radius of ~ 60 km in regions where the interstellar density is as high as 10^3 nucleons cm^{-3}. In ordinary interstellar space, where the density is ~ 1 nucleon cm^{-3}, the intake area radius must be ~ 2000 km. If the latter radius seems absurdly large, even projecting for the progress of future technology, we can easily imagine the vehicle to seek trajectories through clouds of interstellar material, and vary its acceleration with the density of the medium within which it finds itself. Pierce[6] had earlier considered and rejected interstellar ramjets, but the rejection was based on much smaller intake areas than Bussard proposes.

Of course the intake area may not necessarily be material; to the extent that the ramjet sweeps up ionized interstellar material magnetic fields could be used for collection. Starships would then seek trajectories through H II regions. The Bussard interstellar ramjet also requires moderate liftoff velocities; but even presently-achievable liftoff velocities as low as 1–10 km/sec would be adequate.

Bussard does not discuss the method of funnelling the interstellar matter so it can be collected and utilized for propulsion. Indeed this is one fundamental problem which must be faced by any relativistic interstellar vehicle; otherwise the structural and biological damage from the induced cosmic ray flux will prevent any useful application of the extreme velocities achieved. The maximum velocity of the vehicle in the rest frame, after covering $S/2$, half the distance to the destination, at uniform acceleration a, is given[29,30] by

$$v = c[1 - (1 + aS/2c^2)^{-2}]^{1/2}. \tag{4}$$

Equation (4) is illustrated in Fig. 2 for the same three choices of a which have already been used. The abscissa gives the maximum velocity reached, expressed as $\phi = 1 - v/c$, during a half acceleration–half deceleration flight plan to a destination at distance S. For example, for a trip to Galactic Center, maximum velocities within 10^{-7} to 10^{-8} per cent of the velocity of light are required. Also shown in Fig. 2 are the velocities at which relative kinetic energies of 1 MeV, 1 BeV, and 1 erg are imparted to interstellar protons by the motion of the vehicle. For travel to even the nearest stars within a human shipboard lifetime, protection from the induced cosmic ray flux is mandatory. It is evident from the large mass ratios already required for boosted interstellar flight, and from the low frontal loading area surface densities required for an interstellar ramjet, that material shielding is probably not a feasible solution.

If some means of ionizing the impacting interstellar material could be found, the ions can be deflected and captured by a magnetic field. In the case that trajectories through H II regions are sought, the interstellar medium will be already largely ionized, and magnetic funnelling would be practicable. The configuration of the field would have to be designed very ingeniously, but the average field strengths required could be as low as a few hundred gauss even for very long voyages. Much higher field strengths would be required, at least in the propulsion module, for a fusion ramjet; or alternatively for a contained plasma driving a photon rocket[35]. It appears likely that superconducting flux pumps[36]

can provide the magnetic field strengths required for deflection of the induced cosmic ray flux.

Bussard's[34] concluding remarks on the size of the frontal loading area and the magnitude of the effort involved in relativistic interstellar spaceflight are worth quoting: "This is very large by ordinary standards, but then, on any account, interstellar travel is inherently a rather grand undertaking, certainly many magnitudes broader in scope and likewise more
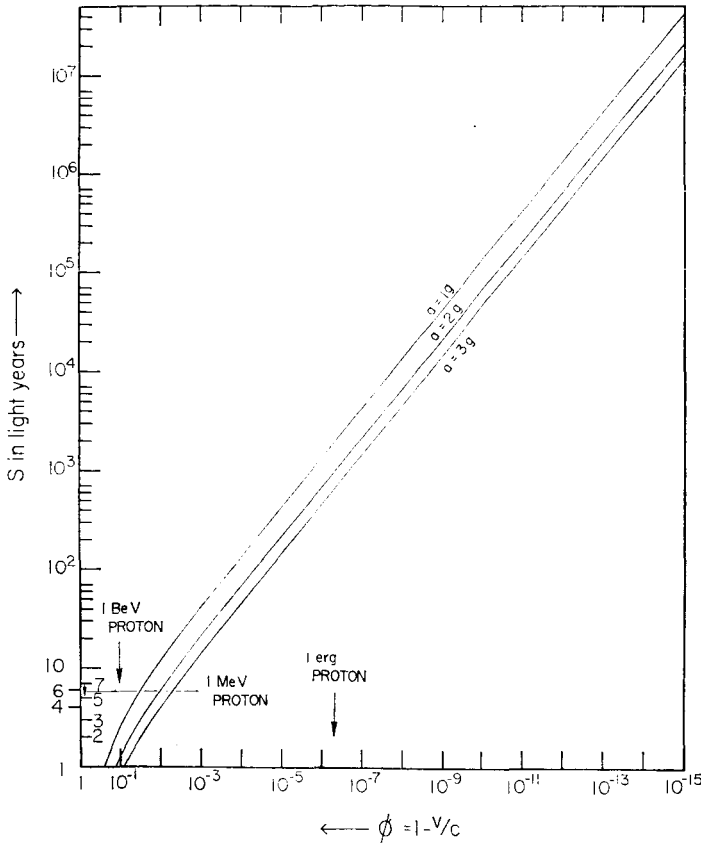

FIG. 2.

difficult than interplanetary travel in the solar system, for example. The engineering effort required for the achievement of successful short-time interstellar flight will likely be as much greater than that involved in interplanetary flight as the latter is more difficult than travel on the surface of the Earth. However, the expansion of man's horizons will be proportionately greater, and nothing worthwhile is ever achieved easily."

The purpose of this Section is to lend credence to the proposition that a combination of staged fusion boosters, large mass-ratios, ramjets working on the interstellar medium and trajectories through H II regions is capable of travel certainly to the nearest stars within a human shipboard lifetime, without appeal to as yet undiscovered principles. Especially allowing for a modicum of scientific and technological progress within the next few centuries, I believe that interstellar spaceflight at relativistic velocities to the farthest reaches of our Galaxy is a feasible objective for humanity. And if this is the case, other

civilizations, aeons more advanced than ours, must today be plying the spaces between the stars.

4. FREQUENCY OF CONTACT AMONG GALACTIC COMMUNITIES

We can expect that if interstellar spaceflight is technically feasible—even though an exceedingly expensive and difficult undertaking, from our point of view—it will be developed. Even beyond the exchanges of information and ideas with other intelligent communities, the scientific advantages of interstellar spaceflight stagger the imagination. There are direct astronomical samplings—of stars in all evolutionary stages, of distant planetary systems, of the interstellar medium, of very ancient globular clusters. There are cooperative astronomical ventures, such as the trigonometric parallaxes of extremely distant objects. There is the observation and sampling of a multitude of independent biologies and societies. These are undertakings which could challenge and inspire even a very long-lived civilization.

For the civilization lifetimes, L, previously adopted we see that interstellar space flight to all points within the Galaxy, and even to other galaxies, is possible in principle. The voyagers will return far in the future of their departure, but we have already anticipated that the civilization will be stable over these immense periods of time. There will still be a record of the departure, a repository for the information collected, and a community interested in the results. To avoid unnecessary duplication in interstellar exploration, the communicative societies will pool information and act in concert, as Bracewell[5] has already pointed out. Direct contacts and exchange of information and artifacts will exist among most spacefaring societies possessing relativistic starships. In fact, over large distances, starship communication will occur very nearly as rapidly as, and much more reliably than, communication by electromagnetic radiation. The situation bears some similarity to the post-Renaissance seafaring communities of Europe and their colonies before the development of clipper and steam ships. If relativistic interstellar space flight is feasible, the technical civilizations of the Galaxy will be an intercommunicating whole; but the communication will be sluggish.

It is of some interest to estimate the mean time interval between contacts for a given planetary system. Although the shipboard transit times at relativistic velocities are very roughly the same to any place in the Galaxy, the elapsed time on the home planet is of course approximately proportional to the distance of the voyage. Consequently contact should be greatest among neighboring communities, although we can anticipate that occasional very long journeys will be attempted.

Let each of the N planets in the communicative phase launch q relativistic starships per year. These vehicles each effect at least one contact per journey, and are most often gone some 10^3–10^4 years from the home planet per mission. In the steady state, there are then q contacts effected by each starship-launching civilization per year, and $\sim qN$ contacts per year for the Galaxy as a whole. Relative to the economic capacity of such advanced civilizations, a value of $q = 1$ yr^{-1} seems modest. (Other choices of q will modify the results in an obvious manner.) Each civilization then makes ~ 1 contact per year, and an average of 10^7 contacts during its lifetime. The number of contacts per year for the Galaxy as a whole is then 10^6; a sizable fraction of these should be between two advanced communities. The mean number of starships on patrol from each technical civilization at any given time is $\sim 10^3$–10^4*.

* It is easily shown that with the adopted values of N and q, and with even very large ramjet frontal loading areas, the exhaust from such interstellar vehicles makes a negligible contribution to the background galactic cosmic ray flux.

If contacts are made on a purely random basis, each star should be visited about once each 10^5 years. Even the most massive stars will then be examined at least once while they are on the main sequence. Especially with a central galactic information repository, these advanced civilizations should have an excellent idea of which planetary environments are most likely to develop intelligent life. With average contact frequency per planet of 10^{-5} yr^{-1}, the origin and evolution of life on every planet in the Galaxy can be monitored efficiently. The successive development of metazoa, of cooperative behavior, of the use of tools, and of primitive intraspecific communication schemes would each be noted, and would each be followed by an increase in the interstellar sampling frequency. If $f_i \sim 10^{-1}$, then, on a purely random basis, the frequency of contact with intelligent pretechnical planetary communities should be $\sim 10^{-4}$ yr^{-1}. Once technical civilization has been established, and especially after the communicative phase has come into being, the contact frequency should again increase; if $f_c \sim 10^{-1}$, to some 10^{-3} yr^{-1}. Planets of extraordinary interest will be visited even more frequently. Under the preceding assumptions, each communicative technical civilization should be visited by another such civilization about once every thousand years. The survey vehicles of each civilization should return to the home planet at a rate of about one a year, and a sizable fraction of these will have had contact with other communities. The wealth, diversity and brilliance of this commerce, the exchange of goods and information, of arguments and artifacts, of concepts and conflicts, must continuously sharpen the curiosity and enhance the vitality of the participating societies.

The preceding discussion has a curious application to our own planet. On the basis of the assumptions made, some one or two million years ago, with the emergence of *Proconsul* and *Zinjanthropus*, the rate of sampling of our planet should have increased to about once every ten thousand years. At the beginning of the most recent post-glacial epoch, the development of social structure, art, religion, and elementary technical skills should have increased the contact frequency still further. But if the interval between samplings is only several thousand years, there is then a possibility that contact with an extraterrestrial civilization has occurred within historical times*.

5. POSSIBILITY OF EXTRATERRESTRIAL CONTACT WITH EARTH DURING HISTORICAL TIMES

There are no reliable reports of contacts during the last few centuries, when critical scholarship and nonsuperstitious reasoning have been fairly widespread. Any earlier contact story must be encumbered with some degree of fanciful embellishment, due simply to the views prevailing at the time of the contact. The extent to which subsequent variation and embellishment alters the basic fabric of the account varies with time and circumstance. Brailoiu[37] records an incident in Rumanian folklore, where, but forty years after a romantic tragedy, the story became elaborately embellished with mythological material and supernatural beings. At the time as the ballad was being sung and attributed to remote antiquity, the actual heroine was still alive.

Another incident, which is more relevant to the topic at hand, is the native account of the first contact with European civilization by the Tlingit people of the Northeast Coast of North America[38]. The contact occurred in 1786 with an expedition led by the French navigator La Perouse. The Tlingit kept no written records. One century after the contact the verbal narrative of the encounter was related to Emmons by a principal Tlingit chief.

* This possibility has been seriously raised before; for example, by Enrico Fermi, in a now rather well-known dinner table discussion at Los Alamos during the Second World War, when he introduced the problem with the words "Where are they?"

The story is overladen with the mythological framework in which the French sailing vessels were initially interpreted. But what is very striking is that the true nature of the encounter had been faithfully preserved. One blind old warrior had mastered his fears at the time of the encounter, had boarded one of the French ships, and exchanged goods with the Europeans. Despite his blindness, he reasoned that the occupants of the vessels were men. His interpretation led to active trade between the expedition of La Perouse and the Tlingit. The oral tradition contained sufficient information for later reconstruction of the true nature of the encounter, although many of the incidents were disguised in a mythological framework: e.g., the sailing ships were described as immense black birds with white wings.

The encounter between the Tlingit and La Perouse suggests that under certain circumstances a brief contact with an alien civilization will be recorded in a reconstructable manner. The reconstruction will be greatly aided if (1) the account is committed to written record soon after the event, (2) a major change is effected in the contacted society by the encounter, and (3) no attempt is made by the contacting civilization to disguise its exogenous nature.

On the other hand, it is obvious that the reconstruction of a contact with an extraterrestrial civilization is fraught with difficulties. What guise may we expect such a contact myth to wear? A simple account of the apparition of a strange being who performs marvelous works and resides in the heavens is not quite adequate. All peoples have a need to understand their environment, and the attribution of the incompletely understood to nonhuman deities is at least mildly satisfying. When interaction occurs among peoples supporting different deities, it is inevitable that each group will claim extraordinary powers for its god. Residence of the gods in the sky is not even approximately suggestive of extraterrestrial origin. After all, where can the gods reside? Obviously not over in the next county; it would be too easy to disprove their existence by taking a walk. Until very subtle metaphysical constructs are developed—possibly in desperation—the gods can only live beneath the ground, in the waters, or in the sky. And except perhaps for seafaring peoples, the sky offers the widest range of opportunities for theological speculation.

Accordingly, we require more of a legend than the apparition of a strange being who does extraordinary works and lives in the sky. It would certainly add credibility if no obvious supernatural adumbration were attached to the story. A description of the morphology of an intelligent non-human, a clear account of astronomical realities for a primitive people, or a transparent presentation of the purpose of the contact would increase the credibility of the legend.

In the Soviet Union, Agrest[39] and others have called attention to several biblical incidents which they suspect to reflect contact with extraterrestrial civilizations. For example, Agrest considers the incidents related in the apocryphal book, the "Slavonic Enoch," to be in reality an account of the visitation of Earth by extraterrestrial cosmonauts, and the reciprocal visitation of several galactic communities by a rather befuddled inhabitant of Earth. However, the Slavonic Enoch fails to satisfy several of the criteria for a genuine contact myth mentioned above: it has been molded into several different standardized supernatural frameworks; there is no transparent extraterrestrial motivation for the events described; and the astronomy is largely wrong. The interested reader may wish to consult standard versions of the manuscript[40].

There are other legends which more nearly satisfy the foregoing contact criteria, and which deserve serious study in the present context. As one example, we may mention the Babylonian account of the origin of Sumerian civilization by the *Apkallu*, representatives of an advanced, nonhuman and possibly extraterrestrial society[41].

A completely convincing demonstration of past contact with an extraterrestrial civilization may never be provided on textural and iconographic grounds alone. But there are other possible sources of information.

The statistics presented earlier in this paper suggest that the Earth has been visited by various galactic civilizations many times (possibly $\sim 10^4$) during geological time. It is not out of the question that artifacts of these visits still exist, or even that some kind of base is maintained (possibly automatically) within the solar system to provide continuity for successive expeditions. Because of weathering and the possibility of detection and interference by the inhabitants of the Earth, it would be preferable not to erect such a base on the Earth's surface. The Moon seems one reasonable alternative. Forthcoming high resolution photographic reconnaissance of the Moon from space vehicles—particularly of the back side—might bear these possibilities in mind. There are also other locales in the solar system which might prove of interest in this context. Contact with such a base would, of course, provide the most direct check on the conclusions of the present paper.

Otherwise the abundance of advanced civilizations in the Galaxy could be tested by successful detection of intelligible electromagnetic signals of interstellar origin. In the next few decades mankind will have the capability of transmitting electromagnetic signals over distances of several hundreds of light years. The receipt and return of such a signal would announce our presence as a technical civilization, and, if the conclusions of the present paper are valid, would be followed by a special contact mission. Even if an intelligible interstellar signal were received and returned today, it would be several hundreds of years before the contact mission could arrive on Earth. Hopefully, there will then still be a thriving terrestrial civilization to greet the visitors from the far distant stars.

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Резюме—Оценка числа передовых технических цивилизаций на планетах других звезд зависит от: нашего знания скорости образования звезд; числа планет в подходящем положении; от вероятностей начала жизни, разума и технической цивилизации и от продолжительности существования технических цивилизаций. Эти параметры мало известны. Оценки данной статьи дают 10^6 еще существующих передовых технических цивилизаций в нашей Галактике. В таком случае наиболее вероятное расстояние от ближайшей общины—несколько сотен световых лет.

Межзвездные космические полеты релятивистскими скоростями обладают некоторыми явными преимуществами перед электромагнитной связью между этими цивилизациями. Одной замечательной особенностью является то, что с постоянным ускорением в силу тяжести до середины путешествия, а после этого с постоянным уменьшением скорости, все точки в Галактике доступны при жизни человеческого экипажа из-за релятивистского расширения времени. Рассматриваются некоторые технические проблемы строительства космических кораблей приспособленных для релятивистских скоростей. Делается вывод, что с ядерными ступенями, термоядерными реакторами и межзвездным прямоточным воздушно-реактивным двигателем Буссарда не существует никаких основных энергетических проблем для релятивистских межзвездых космических полетов.

Мы предполагаем, что в Галактике существует объединенное общество различных цивилизаций, содействующих в исследовании и испытании астрономических объектов и их жителей. Если бы каждая такая передовая цивилизация выпускала один межзвездный корабль в год, то средний временной промежуток между испытанием средней звезды равнялся бы 10^5 годам, между испытанием в планетной системе с различными видами жизни—10^4 годам, а между испытанием другой передовой внеземной цивилизации—10^3 годам. Из этого следует, что есть статистическая вероятность, что какая-то передовая внеземная цивилизация посетила Землю по крайней мере раз в исторические времена. Доказать такой контакт только древними документами и иконографией очень трудно. Тем не менее существуют легенды, которые в этом отношении полезно изучать. Базы или другие искусственные предметы межпланетных цивилизаций могут также существовать где-нибудь и в других местах солнечной системы, напр., на обратной стороне Луны. Выводы настоящей статьи несомненно предварительны.