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# Temporal Aspects of the Interaction among the First Galactic Civilizations: The "Interdict Hypothesis"

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Simulations of the origin, expansion, and interaction of the first galactic civilizations to arise suggest a chronology of events which have possible implications for the resolution of Fermi's Paradox. These are considered and an "Interdict Hypothesis" is proposed to explain the absence of any obvious signs of extraterrestrial presence in the Solar System. © 1987 Academic Press, Inc.

## 1. INTRODUCTION

A long-standing and exciting problem concerns the possible existence of intelligent life in the Galaxy/Universe, and specifically of extraterrestrial technical civilizations (ETTCs).

Given the apparent insignificance of the Sun and Solar System, many early investigators of the problem did not address the question of the existence or nonexistence of ETTCs but sought merely to establish their possible number. Even a low probability for a given star system hosting intelligent life implied a Galaxy of $\sim 10^{11}$ stars potentially rich in ancient civilizations. Estimates of the abundance of ETTCs of independent origin (Shklovskii and Sagan, 1966; Freeman and Lampton, 1975) suggested that there might be $>10^6$ in the Galaxy, at an average separation of $\sim 160$ LY. Although some investigators were optimistic about the prospects of interstellar space travel (Sagan, 1963), interstellar travel was considered by many to be largely impractical (Purcell, 1963; Von Hoerner, 1963). Hence intelligent life was seen as evolving at numerous, but widely separated, sites in the Galaxy. Remaining within their original star systems, alien civilizations in this "island model" would search for and seek to communicate with other civilizations by radio transmission rather than slow interstellar probes. Even the highly advanced ETTCs proposed by Kardeshev (1964) were viewed as isolated entities, with the implications of large-scale expansion of, or interaction among, civilizations largely ignored. A recent island model calculation (Fogg, 1986b), using the probabilities for suitable extra-solar planetary systems according to Fogg (1985), gives a population estimate for the Galaxy of between 90 and 90000 ETTCs separated by distances within a range of $\sim 5000$ to $\sim 520$ LY. These values are lower than those in Shklovskii and Sagan (1966) and Freeman and Lampton (1975), but radio or laser communication between ETTCs would still be possible.

A weakness of the island model is the assumption that interstellar travel and colonization never take place on a large scale. Hart (1975) pointed out that the reason that many investigators had regarded interstellar travel as largely impractical was because only relativistic velocities had been considered. To achieve velocities at which time dilatation would become significant, colossal fuel to payload mass ratios are necessary, making such missions unfeasible. A nonrelativistic velocity of 0.1 c requires significantly smaller mass ratios, and although nonrelativistic missions to other stars might last several generations, this need not rule out the possibility of interstellar colonization. Using the standard model of galactic

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intelligence, Hart reasoned that as many civilizations would have originated millions to billions of years ago, the entire Galaxy should have been colonized by the earliest, that is the oldest, civilizations, even if only a very small number embarked on sustained interstellar travel and settlement. Thus an explanation for the absence of extraterrestrials on Earth is needed. Attempts to provide such an explanation can be classified under four broad headings, viz.:

*Physical explanations*. These state that some physical, biological, or engineering factor makes interstellar travel impossible. These are now untenable. Even if the duration of any interstellar journey exceeds a human lifespan, voyages could be undertaken by self-sufficient "world ships" (Martin, 1984) housing generations of occupants in a near-natural environment.

*Temporal explanations*. These suggest that ETTCs exist but have not yet had time to reach us; this is very unlikely as it would be possible for a colonization wave to cross the Galaxy in only a small fraction of the galactic lifetime. The earliest civilizations would have had ample time to find and explore the Solar System.

*Sociological explanations*. These propose (i) that ETTCs lack interest, motivation, or organization to undertake large-scale diffusion into the Galaxy; or (ii) that all ETTCs rapidly self-destruct in a nuclear war; or (iii) that powerful economic disincentives prevent the building of star ships; or (iv) that the Solar System is being preserved and monitored by philanthropic aliens until our cultural maturity admits us into the "galactic club." The weakness of sociological explanations is that they have to apply universally to every ETTC throughout its entire history. Unless every extraterrestrial civilization was prevented from colonizing the Earth when inclined to do so, the sociological explanation fails.

*Perhaps they have come*. This possibility was dismissed by Hart because of the lack of convincing evidence of past ET visits to the Earth or the Solar System and the need for a sociological explanation of why, if they did visit, they failed to remain.

Hart concluded that previous estimates of the number of ETTCs were too large by some six orders of magnitude, and that the Earth is host to the only technologically capable life form in the Galaxy.

The question, "Where is everybody?" originally posed decades ago by Fermi (see Jones, 1985) and hence known as the "Fermi Paradox," has led to the ET debate becoming polarized into two camps: the "Copernican" view that the Earth is not in any way remarkable and that life and intelligence are widespread in the Galaxy, and the "Geocentric" position that it is the destiny of man one day to settle an empty Galaxy. A comprehensive review of the arguments relating to the ET debate has been made by Brin (1983).

The rate of spread of an interstellar colonizing ETTC is crucial in the Geocentric argument and the rapid expansion velocity of the colonization wavefront proposed by Hart has been criticized as unrealistically rapid (Newman and Sagan, 1981). A number of models have been developed to simulate the expansion wavefront; for estimates of the galactic filling time for a single ETTC and the associated colonization wave velocity, see Table I. Two of the most detailed models are the Monte Carlo simulation of Jones (1976, 1978, 1981, 1982) and the nonlinear diffusion model of Newman and Sagan (1981). As both models give similar results with identical input parameters, debate over interstellar colonization has centered largely on the values to be assigned to the parameters.

Some estimates of the expansion velocity are so low that the Galaxy need not yet have been entirely colonized; i.e., a temporal explanation of the Fermi Paradox is possible. Newman and Sagan (1981) argue that limitation of population growth is essential for the long-term survival of any species on a planet and that zero population growth (ZPG) might become so ingrained a social philosophy that very little interstellar ex-

TABLE I

GALACTIC COLONIZATION TIMES AND EXPANSION WAVESPEEDS DERIVED BY VARIOUS AUTHORS

| Author | Time for one civilization to colonize the Galaxy ($T$) | Wavespeed (c) |
| --- | --- | --- |
| Hart (1975) | $10^6$ | 0.1 |
| Jones (1976)[a] | $5 \times 10^6$ | 0.02 |
| Kuiper & Morris (1977) | $6.25 \times 10^6$ | 0.016 |
| Jones (1978)[a] | $1.75 \times 10^7$ | $5.7 \times 10^{-3}$ |
| Tipler (1980)[b] | $4 \times 10^6$ | 0.025 |
| | $3.3 \times 10^8$ | $3 \times 10^{-4}$ |
| Newman & Sagan (1981)[a,c] | $7.7 \times 10^8$ | $1.3 \times 10^{-4}$ |
| Smith (1981) | $10^{10}$ | $10^{-5}$ |
| Jones (1981, 1982)[a] | $6 \times 10^7$ | $1.67 \times 10^{-3}$ |
| Jones (1982)[a] | $3 \times 10^8$ | $3.3 \times 10^{-4}$ |

[a] Only these estimates are arrived at through a simulation of plausible galactic colonization; the remainder merely divide the diameter of the Galaxy by an assumed flight velocity.
[b] Expansion of "Von Neumann" probes only.
[c] The Newman and Sagan values for the non-ZPG case.

pansion and colonization occur at all. Those races that do colonize might take so long to do so that they may possibly become extinct before extending very far into the Galaxy. The low to zero population growth rates proposed by Newman and Sagan rest on the reasonable assumption that the unconstrained population growth rates on the Earth over the last half millenium are unsustainable and hence a transient anomaly. However, this constraint applies only to the "home base" colonizing planet. Each new colony will be under initial pressure for rapid population expansion and hence each will pass through a period of unconstrained growth. Thus, in galactic terms, a nonzero population growth is to be expected until the Galaxy is substantially filled with colonies whose individual populations have reached the ZPG level. Hence the entire Galaxy should be filled in a time $<10^9$ years. Similarly the suggestion that colonization will be terminated by extinction seems highly unlikely as a race that had expanded to colonize several systems would be ensured against exterior or sociological disasters that might cause extinction on a single planet.

Smith (1981) suggests that human expansion into the Galaxy will be limited by difficulties in transporting complete ecosystems to other barren planets and that a similar constraint may well apply to extraterrestrials. Walters *et al.* (1980) hold that limited interstellar colonization does occur but dies out because of the extreme rarity of habitable planets and limited ship range. However, both of these conclusions are based on the assumption that extra-solar planets are necessary for colonization to be successful. This need not be the case, for world ships are likely to be constructed by a society well used to building giant space habitats in the home system (see Johnson and Holbrow, 1977). It should be possible therefore to construct artificial habitats in any star system with easily exploitable resources. To quote Jones (1976), "An extrapolation from the space colonies in Earth orbit proposed by O'Neill and co-workers to the sort of vessel envisaged by Arthur C. Clarke in *Rendezvous with Rama* would permit colonists to set up shop in orbit about the new star without depending on a habitable planet."

Using different values for population growth and emigration rate, Jones has arrived at an estimated range of 5 to 300 myr for a single expanding ETTC to fill the Galaxy. Jones prefers a period of 60 myr, a time much greater than that assumed by Hart, but still less than 1% of the age of the Galaxy. Thus, unless ZPG has been universally applied by all ETTCs, including frontier populations, the temporal explanation remains inadequate.

Thus the problem is unresolved. Reasonable manipulations of Drake's equation and computer simulations (Fogg, 1986b) suggest that ETTCs should exist, but they give no obvious signs of their presence. Freitas (1985) disputes the logic and validity of the Fermi Paradox on the grounds that it is unsupported by observations: only a minute volume of the Solar System has been explored and the evidence of alien artifacts may await detection (Freitas, 1983). This possibility, however, also requires a sociological explanation as to why the Earth was left alone. As outlined above, physical and temporal explanations for their absence are inadequate: to reconcile observation with expectation a universal sociological explanation is required.

What if numerous and some long-established ETTCs do exist, and some of these civilizations attempted interstellar colonization long ago; how would this scenario allow for our existence today? Previous interstellar colonization models have restricted themselves to simulating the expansion of a single civilization. To examine alternatives, a microcomputer model was used to simulate the origin of intelligent life at a number of separate and isolated foci and the subsequent expansion of the first galactic civilizations. The implications for the Fermi Paradox were then considered.

## 2. THE COMPUTER SIMULATION

The simulation of a multicivilization expansion model (designated "Outreach") was based on the following assumptions.

### 2.1. General Assumptions

(i). The first galactic civilizations are born into a Galaxy devoid of intelligent life, and thus their origins can be simulated by an island model.

(ii). Some fraction of these initial civilizations embark upon large-scale interstellar colonization. The boundary of space occupied by a colonizing civilization expands at a constant wavespeed.

(iii). In an area already colonized, no new civilization origins can occur.

(iv). When two wavefronts of a different origin meet, colonization halts as all local sites become occupied; i.e., wavefronts do not interpenetrate.

(v). When all areas of the Galaxy containing a substantial number of Population I stars are occupied, colonization on a galactic scale terminates.

### 2.2. The Model Galaxy

The Galaxy was defined as being a disk $10^5$ LY in diameter and $10^3$ LY thick. All but a central bulge of Population II stars $2 \times 10^4$ LY across were considered as suitable for colonization. A hexagonal grid was used to simulate a circular wavefront expansion. Using a term borrowed from ecology, each cell of the grid is termed a "quadrat" and represents an area of space ~1000 LY across.

### 2.3. Emerging Civilizations

As the results of the analysis by Fogg (1986b) lie well within the upper and lower estimates made by other investigators, they were used to estimate the birth rate of new civilizations required for assumption (i).

In Fogg (1986b) it was assumed that a period of $4 \times 10^9$ years would be necessary for life to originate on a suitable planet and to evolve to the equivalent level of complexity that has existed on the Earth since the beginning of the Cambrian Period. On those planets that actually developed on ETTC, the average evolution time from first complex organism to civilization was very roughly estimated to be $1.6 \times 10^9$ years. As most models of galactic evolution place the age of the first Population I stars at the time of the formation of the galactic disk $10^{10}$ years ago (Trimble, 1982), the first civilizations would start to appear in large numbers after about $5.6 \times 10^9$ years of galactic disk history (yr GDH), $4.4 \times 10^9$ yr B.P. The very earliest ETTC to be born could appear after only $4 \times 10^9$ yr GDH, $6 \times 10^9$ B.P. The starting point of the simulation was therefore set between these two dates at $5 \times 10^9$ yr GDH, $5 \times 10^9$ yr B.P. It is interesting to note that this date is antecedent to the formation of the Solar System. Figure 1 shows the temporal framework of the model.

Approximately $9 \times 10^6$ ETTCs were estimated to have come into existence over galactic disk history. However, because of low metallicity, and on the assumption that

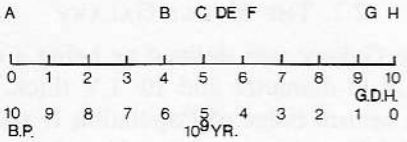


FIG. 1. The temporal framework of the computer model. (A) Formation of the galactic disk, (B) first possible ETTC, (C) start of simulation, (D) formation of the Solar System, (E) ETTC birth rate substantial according to Fogg (1986b), (F) origin of life on the Earth, (G) complex life on the Earth (Cambrian Period), (H) terrestrial civilization.

no life forms exist on gas giant planets (see Sagan and Salpeter, 1976), the earliest Population I stars were only about half as likely to possess a suitable planet for the origin of an ETTC than a star of similar age to the Sun. The civilization birth rate for this simulation was taken therefore to be $5 \times 10^9 / 4.5 \times 10^6 \approx 1$ per $10^3$ years, While this value is lower than that estimated from Shklovskii and Sagan (1966) or Sagan (1980), it is a higher value than most Geocentric advocates would be prepared to contemplate.

Assigning a value to the small proportion of civilizations to undertake sustained interstellar colonization is a matter of choice. The literature includes much speculation on the probable average lifetime of an ETTC, especially by Copernican scientists who need to derive a value for the final coefficient of the Drake equation. Sagan (1980) speculates that maybe only one percent of civilizations survive the hazards of technological adolescence and that these may then persist over vast periods of time. Erring on the side of conservatism, therefore, it was decided to fix the fraction of ETTCs that attempt to colonize the Galaxy at 0.01. Since it would be quite easy to extrapolate the effects of altering this fraction from the results in Section 3, it was not treated as a variable in the particular analysis presented here, as many more run sets would have been necessary. Colonizing civilizations are henceforth referred to in this paper as "empires" (although of course they would not be empires in the true sense as the vast distance between stars would prevent the exercise of planetary imperialism). Civilizations that do not colonize are referred to as "communities."

The question of preemption of new civilizations by older ones is also important. Natural evolution of intelligent species on a planet settled by an alien civilization is likely to be upset. Hence assumption (iii). Alternative scenarios where interstellar colonization takes place without preemption of new civilizations are crucial for any possible reconciliation of the Copernican and the Geocentric viewpoints and are discussed later.

### 2.4. Simulation of Colonization Expansion

A wide range of wavespeeds, from the rapid colonization of Hart (1975) where wavespeed is equal to ship speed to the sedentary interstellar diffusion of Newman and Sagan (1981), was examined. Five run sets of five runs each were performed, each corresponding to a different value chosen for the colonization wavefront velocity (see Table II). As the empire birth rate was assumed fixed at 1 per $10^5$ years each program step represents the time for a wavefront to cross 1 quadrat.

## 3. RESULTS OF THE SIMULATION RUNS

Output data for the five "Outreach" run sets are presented in Tables III and IV. A number of interesting characteristics of the results are apparent.

TABLE II

Run Sets Chosen for the Simulation

| Set | Wavespeed (c) | Time per step (in years) | Empire origins per step[a] | Community origins per step |
|---|---|---|---|---|
| 1 | 0.1 | $10^4$ | 0.1 | 10 |
| 2 | 0.02 | $5 \times 10^4$ | 0.5 | 50 |
| 3 | $1.67 \times 10^{-3}$ | $6 \times 10^5$ | 6 | 594 |
| 4 | $3.33 \times 10^{-4}$ | $3 \times 10^6$ | 30 | 2970 |
| 5 | $1.3 \times 10^{-4}$ | $7.7 \times 10^6$ | 77 | 7623 |

[a] Empire birth rate at 1 per $10^5$ years.

TABLE III

"OUTREACH" MODEL RESULTS

| Set | $T$ | $T_{\text{fill}}$ | $N_{\text{emp}}$ | $N_{\text{com}}$ | $N$ | $P$ | $F$ |
|---|---|---|---|---|---|---|---|
| 1 | $10^6$ | $6.78 \times 10^5$ | 3.8 | 328 | 678 | 0.49 | 0.68 |
| 2 | $5 \times 10^6$ | $2.36 \times 10^6$ | 10 | 1,044 | 2,360 | 0.45 | 0.47 |
| 3 | $6 \times 10^7$ | $1.37 \times 10^7$ | 55 | 5,567 | 13,680 | 0.41 | 0.23 |
| 4 | $3 \times 10^8$ | $4.52 \times 10^7$ | 156 | 15,339 | 45,200 | 0.34 | 0.15 |
| 5 | $7.7 \times 10^8$ | $8.01 \times 10^7$ | 278 | 27,605 | 80,100 | 0.35 | 0.104 |

*Note.* $T$ = Time in years for a single civilization to occupy the Galaxy. $T_{\text{fill}}$ = "Outreach" result for the average time in years for the Galaxy to be occupied. $N_{\text{emp}}$ = Average number of "empires." $N_{\text{com}}$ = Average number of "communities." $N$ = Number of civilizations expected to arise in $T_{\text{fill}}$ with no preemption; i.e., assumption (iii) does not apply. $P = 1 - (N_{\text{emp}} + N_{\text{com}})/N$: a "preemption" factor, the fraction of $N$ civilizations preempted by galactic colonization. $F = T_{\text{fill}}/T$: "Outreach" result for the fraction of time $T$ taken to fill the Galaxy.

### 3.1. TIME

$F$, the fraction $T_{\text{fill}}/T$ for colonization of the Galaxy, is always less than 1, and decreases with increasing value of $T$. A good empirical approximation to the numerical data is

$$T_{\text{fill}} \approx 7 \times 10^5 \left(\frac{T}{10^6}\right)^{0.724} \qquad (1)$$

where the wavespread parameterization is contained within "$T$," the diameter of the Galaxy divided by the wavespeed.

The reason for this "power law" behavior is readily apparent. With low expansion wavespeeds a greater number of empires originate and contribute to the colonization of the galactic disk.

TABLE IV

GALACTIC REAL ESTATE

| Set | Extent of "Empires" (quadrats) | | | $\sim N_*$ | $\sim N_{\text{HP}}$ |
|---|---|---|---|---|---|
| | Largest | Smallest | Average | | |
| 1 | 4277 | 301 | 1911 | $2.6 \times 10^{10}$ | $2.3 \times 10^7$ |
| 2 | 1966 | 31 | 726 | $10^{10}$ | $8.6 \times 10^6$ |
| 3 | 459 | 1 | 132 | $1.8 \times 10^9$ | $1.6 \times 10^6$ |
| 4 | 194 | 1 | 46 | $6.3 \times 10^8$ | $5.4 \times 10^5$ |
| 5 | 94 | 1 | 26 | $3.6 \times 10^8$ | $3.1 \times 10^5$ |

*Note.* $N_*$ = Number of stars in an "empire" of average extent. $N_{\text{HP}}$ = Number of habitable planets in an "empire" of average extent.

In every run the time required to populate the Galaxy was less than the time interval between the start of the colonization and the formation of the Solar System. The temporal explanation that slow expansion into the Galay has prevented extraterrestrials from yet reaching the Solar System thus looks even more unlikely. A single, slowly expanding Newman/Sagan civilization would take nearly a billion years to occupy the Galaxy. However, the Set 5 results show that a few hundred such civilizations scattered throughout the galactic disk reduce this expansion to only 10% of the time calculated in Newman and Sagan (1981). Applying Eq. (1) to the even slower time $T$ proposed by Smith (see Table I) gives values of $T_{\text{fill}} \approx 5.5 \times 10^8$ and $F \approx 5.5 \times 10^{-2}$. Even with the most pessimistic wavespeeds therefore, Outreach gives a galactic filling time of circa half a billion years, approximately 5% of the age of the galactic disk. Only if one is prepared to contemplate the extreme scenario of universal and permanent ZPG would the Outreach results be invalidated.

### 3.2. "EMPIRES" AND "COMMUNITIES"

In none of the runs did any empire preempt the entire Galaxy. The averaged values of a preemption factor $P$ are given in Table III; there is a gradual decrease in $P$ with decreasing wavespeed. This is because the civilization birth rate per step is greater and so less early preemption takes place. The number of empires, $N_{\text{emp}}$, increased with $T$ but not linearly because of a lower value of $F$. The following empirical relationship gives a reasonable fit to the results:

$$N_{\text{emp}} \approx 4 \left(\frac{T}{10^6}\right)^{0.635}. \qquad (2)$$

The number of communities, $N_{\text{com}}$, follows a similar relation with $N_{\text{com}} \approx 10.N_{\text{emp}}$, so a fully colonized Galaxy might be expected to exhibit a considerable diversity of intelligent life forms, with hundreds to tens

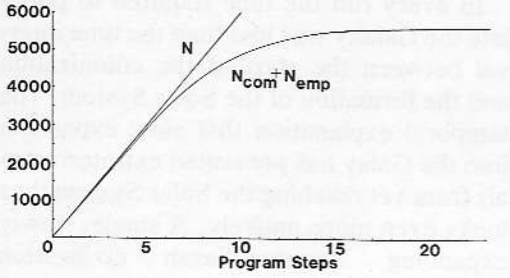


FIG. 2. "Outreach": Civilization birth rate. From the results of a Set 3 run. The number of civilizations on the $y$-axis is plotted against time; one program step $= 6 \times 10^5$ years. The curve labeled $N_{com} + N_{emp}$ represents the total number of civilizations produced in the run. Line N represents the approximate birth rate of civilizations in an "island model."

of thousands of independently arisen civilizations. With preemption, however, the millions of independently arisen civilizations predicted by island model calculations, such as in Shklovskii and Sagan (1966) and Freeman and Lampton (1975), seem unlikely.

The behavior of the civilization birth rate for a Set 3 run can be seen in Fig. 2. As saturation occurs and preemption increases, the number of new civilizations created each program step decreases. Only if preemption does not occur would the curve approach line N. Advocates of the Copernican viewpoint believe that the Earth lies on line N, way off the top of Fig. 2, corresponding to a $y$-axis value of $\sim 10^6$–$10^8$. The space between the curve and line N represents the gulf between the opposing sides of the ET debate.

The characteristics of the colonization rate (Fig. 3) are shown as the occupied percentage of the galactic disk area plotted against time. The curve is a typical sigmoid "curve of growth." By the end of the simulation wavefront colonization has ceased. Any further colonization will be restricted to clusters of new stars or reoccupation of old star systems where previous civilizations have become extinct. In a relatively short period of time the Galaxy has moved from one steady state to another: from a Galaxy devoid of intelligence, to one where most star systems have been visited or occupied by intelligent life.

The extent of this "galactic real estate" is shown in Table IV. The number of stars within an empire of average extent, $N_*$, are on the assumption of $10^{11}$ stars in the galactic disk. The number of habitable planets within an empire of average extent, $N_{HP}$, is calculated from the fraction $N_{HP}/N_* \approx 8.6 \times 10^{-4}$ obtained by Fogg (1986a), a figure that falls between the previous estimates of Dole (1964) and Pollard (1979). While $N_{HP}$ is a value for the fraction of stars accompanied by a planet habitable for Man, it is assumed here that a similar fraction would apply for planets habitable by the average extraterrestrial species.

The largest empire generated was from a Set 1 run where well over half the Galaxy was occupied by the descendants of a single, original, space-faring race. The smallest empire occupied just 1 quadrat (the limiting resolution of Outreach), which is still a very large volume of space containing approximately 14 million stars and 12,000 habitable planets.

If the preferred expansion velocity of Jones (1981) (equivalent to a Set 3 run) is taken as the most realistic value, then typical empires would contain over a billion stars and over a million habitable planets. If

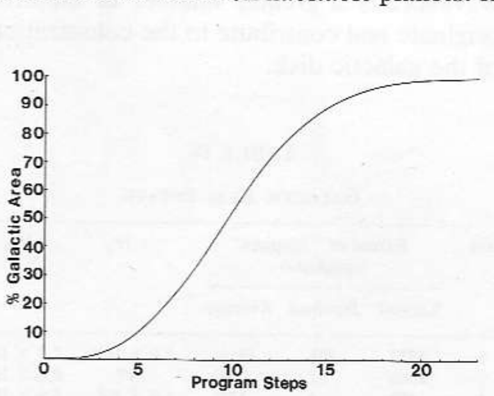


FIG. 3. "Outreach": Civilization growth. From the results of a Set 3 run. The percentage of occupied galactic disk area on the $y$-axis is plotted against time. Colonization is completed in Step 23, $1.38 \times 10^7$ years after initiation.

the population capacity of such an area is examined in human terms, then if only habitable planets are occupied, a population of $\sim 10^{16}$ is possible. If star systems without habitable planets can be occupied too, then an empire of average extent could maybe host a colossal number of $\sim 10^{19}$ beings!

### 3.3. Summary

The behavior illustrated by the Outreach model suggests a number of tentative conclusions regarding a possible scenario for multicivilization interstellar colonization.

(1) The colonization rate of suitable sites in the Galaxy by expanding civilizations would exhibit exponential growth, over a period of millions to hundreds of millions of years, followed by saturation and an end to large-scale expansion.

(2) If preemption of new civilizations takes place, then thousands of independently evolved civilizations are still able to arise before a colonization wavefront of an older civilization reaches them.

(3) If no preemption occurs (i.e., a universal sociological explanation exists for why life-bearing planets are left undisturbed), then the millions of civilizations predicted by island model calculations are possible.

(4) Long galactic filling times, calculated on the basis of a single expanding civilization, are not realistic in the context of a Galaxy where intelligent life is not exceptionally rare.

(5) The Galaxy could have been colonized before the Solar System was even formed, as long as $\sim 5 \times 10^9$ yr B.P.

### 3.4. The Aftermath of the Colonization Era, the "Steady State" Era

When nearly every possible star supports intelligent life forms, a colonized Galaxy has entered a new steady state of existence. If the results of Outreach are realistic, then this "Steady State" period could have already existed for $\sim 5$ byr.

Differential galactic rotation will have the effect of smearing out settled areas and will result in the gradual intermixing of stars colonized by different civilizations. At its present distance from the center of the Galaxy, the galactic orbital period of the Sun is $\sim 250$ myr. Thus the Galaxy could have been occupied some 20 solar "galactic years," long enough to disrupt the largest empire and disperse its component stars along and throughout a spiral arm. Unless a star that is the host to a vigorous civilization is carried close to a new born cluster of stars, there will be few cases of renewed exponential interstellar expansion during the Steady State Era. Instead societies would have to settle down to a more static existence within their individual star systems, in a Galaxy where the distribution of intelligence becomes increasingly well mixed and homogeneous. There has been much speculation about how advanced civilizations confined to their star systems might make best use of their resources to support as great a population as possible. Terraforming lifeless worlds, colonizing comets (Dyson, 1973), and disassembling planets (Dyson, 1966) and even stars (Criswell, 1985) to construct vast clouds of space habitats (so-called "Dyson Spheres") have been suggested. On a cosmic time scale, however, such industry would do little to postpone the ultimate need for a cessation of growth and the establishment of a quasi-steady state within individual systems as well as within the Galaxy as a whole.

The word "civilization" has been used in this paper to denote both empires and communities. However it is important when speculating about the aftermath of the colonization phase to reiterate that unless there is large-scale interstellar communication, the rapid pace of cultural drift would ensure that an individual culture could never expand beyond its own stellar system. Even those original civilizations that colonize millions of stars would in practice give rise to millions of seperate cultures and not just one supercivilization. The eventual consequence of this isolation would not just be the creation of numerous new daughter civilizations, as over a long period of time evolutionary divergence could give rise to millions of distinct new species of intelligent beings, descended from just a few hundred original space-faring races. Once the Galaxy has been settled, what might be the effects on the nature of galactic civilization now that expansionist ways have to be set aside?

Newman and Sagan (1981) believe that very advanced and old civilizations may have conquered many of the problems, such as aggression, territoriality, population growth, old age, and death that afflict our immature technological society on the Earth. They conjecture that the net result might be a civilization with a profound commitment to stasis and antithetical to further colonization, thus by nature these civilizations would be well adapted to a steady state condition. Aggressive cultures would have ample time to destroy themselves in civil war, civilizations unable to control population growth would collapse in a chaos of competition for remaining resources. Von Hoerner (1975) has listed a number of crises that could extinguish civilizations. Apart from the dramatic causes of demise cited above, he also proposes that genetic degeneration or irreversible stagnation could terminally "harden the arteries" of an ancient culture. This need not imply extinction of the species or a loss of technical ability, but Von Hoerner considers the choice might lie between the lifestyles of *1984* or *Brave New World*. We do not know if all civilizations have relatively short lifetimes and are prone to Von Hoerner's catastrophes. However, it seems more likely that out of the millions of daughter civilizations produced during the colonization phase of the Galaxy, many would be capable of surviving at least some of the identifiable crises and remaining vigorous for long periods of time. Star systems where civilizations have become extinct might be recolonizable by a more stable neighboring culture, and over the billions of years of the Steady State Era Newman/Sagan-type civilizations would thus be favored by selection.

Kuiper and Morris (1977) have argued that the principle resource of a very advanced technological society would be knowledge rather than raw materials. Stephenson (1982) concurs and points out that an advanced civilization with well-developed energy resources and an economy based on universal constructors (von Neumann machines) might regard material wealth as irrelevant. Information and variety would be the capital of such a society and it is in precisely these commodities that a Galaxy, rich with intelligent life, would abound. The Steady State Era could be expected to be an age of communication, as the millions of cultures in the Galaxy trade in their most valuable resource. A radio message could have crossed a distance equal to the diameter of the galactic disk ~50,000 times since the end of the colonization phase. Rescher (1985) holds that interstellar discourse is highly unlikely to occur because different intelligent races will be so alien to each other, and their sciences will be mutually incomprehensible. This argument does not hold for intelligent races, however, as the fundamental basis of science is the universality of the laws of nature. Doubtless, communication between alien races may pose translation problems, but these are unlikely to be insoluble. Although evolved in isolated and unique environments, the same constraints will operate for any intelligence when solving problems (Minsky, 1985). All species that leave their home planet also leave the environment to which they are adapted. The new environment of space will be equally alien and common to all. The advantages that communication with other races would have on knowledge and information are unquantifiable, but over billions of years might strongly favor convergent mental evolution. Tang, (1982) reaches a similar conclusion by a different route, but considers that convergent mental evolution between communicators will reduce the drive for interstellar colonization.) Thus paradoxically the physical isolation of colonies could lead to biological evolutionary divergence of once similar species, yet over the same time period communication could force a mental evolutionary convergence and integration of intellectual activity into a pangalactic network, where information is exchanged at mutually comprehensible levels of complexity. The result would not be a galactic wide monoculture, but communication could lead to an enhanced level of understanding, mutual agreement, and some common policies where there is shared interest. The Outreach simulations suggest that there should be ample time for galactic civilizations to perfect satisfactory methods of communication.

To summarize then, the pattern of galactic colonization revealed by Outreach is a Galaxy fully settled by thousands of civilizations of independent origin. Over billions of years subsequent to the colonization phase, divergent physical evolution leads to a great increase in the number of intelligent species. Because of the desirability of information exchange, interstellar communication leads to a convergent mental evolution and a greater level of understanding between alien species. Values such as altruism and restraint would best allow civilizations to attain stability over cosmic time periods.

How can we justify this scenario of intelligence in the Galaxy with our terrestrial civilization and with the Fermi Paradox?

## 4. Implications for the Fermi Paradox

### 4.1. The Paradox Reassessed

The nature of Fermi's paradox was outlined earlier.

Two possibilities accord with the known facts (from Kuiper and Morris, 1977):

(i) ETTCs that survive long enough to colonize are very rare. The Galaxy is largely empty.

(ii) There are several such civilizations and the Galaxy has been largely settled.

The initial assumptions of the Outreach model were based upon the second of these possibilities. The results of Outreach imply that the Galaxy could have been settled by ETTCs billions of years ago. On one hand this may be interpreted to confirm and emphasize the conclusions of many of the previous expansion models, but not necessarily their conclusions about the uniqueness of human intelligence.

The central tenet of the Geocentric ethos is that "Every species extends itself as far as physically possible." If false, then the logic of the proponents of uniqueness could well be flawed. Expanding ETs are envisaged as colonizing every star system, every planet, and every asteroid in the Galaxy in a ceaseless quest for additional "lebensraum." What would be the logical outcome of this philosophy applied on the Earth? Can we expect man to colonize every inch of his home planet, similar to Asimov's "Trantor" (Asimov, 1953)? The need for a planet to be a largely closed and self-sustaining system must effectively rule out this extreme scenario. Even if some ETs are as continually expansionist as the Geocentric argument can be taken to imply, their expansion would eventually be blocked when their colonization wavefront met that of another civilization. To survive into the Steady State Era, such expansionism would have to be discarded for the reasons already outlined in Section 3.4. By the time that galactic rotation has thoroughly intermixed stars of different empires together, the expansion urge would have long become redundant. The principal evidence in support of the Geocentric viewpoint is the so-called "fact" that ETs or their self-reproducing "von Neumann probes" (Tipler, 1980) are not present in the Solar System. This fact is of course not possible at this time to demonstrate, and is less than convincing when weighted against the many arguments that intelligent lie should be relatively common in the cosmos. To quote Tang (1982), "Absence of evidence of ETs may make little sense, but absence of ETs makes no sense at all!"

If possibility (ii) is correct then three consequences ensue from it (again from Kuiper and Morris, 1977):

(1) A galactic community exists in which one or several different civilizations communicate with each other, and we are located within a sphere of influence of one or more of these civilizations.

(2) The Solar System has probably been visited.

(3) An advanced civilization will probably have representatives in the solar neighborhood.

### 4.2. The "Zoo Hypothesis"

If physical and temporal explanations for our unknowing presence in a colonized Galaxy are unsatisfactory, and even if alien artifacts are hidden somewhere in the Solar System, then only a sociological explanation can be put forward to account for the Earth being left undisturbed by ETs. Such sociological explanations must apply to all visitors to the Solar System at all times. Ball (1973) proposed the well-known Zoo Hypothesis in which the Earth is kept as a "wilderness preserve" where we are studied in our ignorance by benevolent extraterrestrials. He gave no reasons as to why this should be so, or why the Earth was not colonized long before Homo sapiens, or his semi-intelligent hominid precursors, appeared. The Zoo Hypothesis has been criticized as being unscientific (Hart, 1975) as it is currently "unprovable," a criticism applicable to all ET arguments. Newman and Sagan (1981) and Stephenson (1982) believe that the Zoo Hypothesis could nonetheless be a valid description of the reaction of visiting ETs to the discovery of life on our planet. How then to universalize the Zoo Hypothesis? The results of the Outreach simulation may be used as a foundation for an expanded Zoo Hypothesis, here termed the "Interdict Hypothesis."

### 4.3. The "Interdict Hypothesis"

It is first necessary to be clear that if the Interdict Hypothesis is to hold for the Earth, and be the universal response to all interstellar travellers upon locating a life-bearing planet, then it must also apply to all other life-bearing planets in the Galaxy. This means that preemption levels in the Outreach model may be much too high, and the civilization birth rate may not have declined as shown in Fig. 2.

> If pre-emption ends after the Colonization Era, once civilizations become largely static and participants in the galactic communication network, then the separate origin of new life and intelligence in star systems born subsequently is still possible (e.g. around the Sun.)

There are a number of reasons why life-bearing planets might not be an ideal abode for the members of an advanced alien civilization.

#### *4.3.1. Life-Bearing Planets May Be Unihabitable*

Cox (1976) has suggested that life may evolve so many different varieties of biochemistry, that alien biosystems may all be mutually incompatible and even toxic. In this scenario, a planet's biosphere might be seen as a deterrent and poisonous coating to potential alien colonists. An analysis of planetary systems by Fogg (1986b) concluded that only 29% of life-bearing planets, which were also potential sites for the origin of a civilization, might possess physical conditions which were within the range of human tolerance. If the average extraterrestrial were able to tolerate a similar deviation from the norm in physical conditions on his home planet, to that tolerable to humans, then the Earth itself may only be habitable to less than a third of visiting ETs. The point must be made also that "xenoforming" (the ET equivalent of terraforming) a life-bearing planet may be even more difficult than xenoforming a sterile world. Many proposed terraforming techniques involve modification of planetary conditions through the agency of artificially introduced microorganisms. Alien organisms may not thrive in the face of competition from indigenous organisms perfectly adapted for survival and success on their own planet.

### 4.3.2. *Information and Variety*

The hypothesis that knowledge would likely be the most valuable resource of an advanced culture has already been mentioned in Section 3.4. If this is so, then we have a valid reason for leaving life-bearing planets fallow for long-term study as valuable nonrenewable sources of information.

Stephenson (1982) puts it thus, "If it is accepted that information is the universal criterion of value for species more advanced than ourselves, then information gathering probes would not disturb the complex information filled system that is the Earth."

An apparent weakness of this argument is the observation that a single advanced civilization more interested in eliminating competition than in information gathering would invalidate it. However, the conduct of a policy of cosmic genocide would be almost totally impracticable, on logistic, temporal, and economic grounds, as well as being unrealistic when the Galaxy is already occupied with intelligent life.

Any observation of a life-bearing planet, especially of a planet that has new born intelligence, must avoid perturbing the free development and evolution of the information system away from its natural course. Thus observers might also decide to leave the entire stellar system of the planet they are studying uncolonized, as it would be possible for any intelligent life forms that originated on the planet to achieve a high degree of civilization, and even interplanetary space travel, before becoming, or being made, aware of other races in the Galaxy. It is maybe not surprising therefore that any "park rangers" have left the Solar System in its natural state.

### 4.3.3. *The "Galactic Club"*

It is through a network of galactic communication that such a common cause might be agreed upon.

To quote Newman and Sagan (1981), "The establishment of an unbreakable 'Codex Galactica', imposing strict injunctions against colonization of or contact with already populated planets, is by no means excluded."

Asimov (1981), speculating on the exploration of the Galaxy by world ships (freeworlds) has written, "Or it may be that freeworlds, on principle, avoid sunlike stars with habitable planets. After all, for freeworld purposes, almost any star would do." Initially, all new born stars between $0.8M$–$1.3M_{\odot}$, with potential life-bearing planets, would have to be left fallow for say a billion years. However, as only a minority of these new systems would develop new life of their own, the majority of K, G, and F stars could eventually be settled by outsiders.

It seems likely that, as there are no fundamental objections to constructing habitats in space, and as the vast majority of stars would not possess a habitable planet, that planet dwelling as a lifestyle could be discarded by most advanced civilizations. How much galactic real estate would have to be discarded in order to leave stellar systems with life-bearing planets alone? According to Fogg (1986a) a possible figure for the fraction of galactic disk stars possessing a life-bearing planet is $N_{\text{life}}/N_{*} \approx 6 \times 10^{-3}$, which is only about 0.6% of the stars, a tiny fraction to leave untouched for the potential information content they harbor. Wildlife preserves are set aside on the Earth for much the same reason. Taking the United

Kingdom as an example: the National Trust is in possession of some 187,000 hectares of land; the Nature Conservancy Council has about 127,000 hectares; the surface area of the United Kingdom is 244,000 km$^2$, so roughly 1.29% of the United Kingdom is set aside for conservation. Admittedly, this land is hard pressed, and is not unoccupied by human beings. However, does it really seem inevitable that advanced ETTCs would be prepared to snuff out the natural evolution of new life forms for such a minute fraction of extra lebensraum? Many scientists reject out of hand any notion of a uniformity of purpose among ETTCs and yet, when the benefits of maintaining natural evolution can be obtained by the minimal sacrifice of leaving only 0.6% of stars undisturbed, and taking into account the likely philosophical predisposition of long-lived civilizations after millions of years of stability and communication, the Zoo Hypothesis does not appear as improbable as many of the Geocentric advocates believe.

#### 4.3.4. *A Chronology*

A possible chronology for the Inderdict Hypothesis is as follows:

(1) first Population I stars formed in the galactic disk ($\sim 10^{10}$ yr B.P.);

(2) origin of the first primitive forms of life ($\sim 9 \times 10^9$ yr B.P.);

(3) origin of the first galactic civilizations and the onset of the Colonization Era ($\sim 5 \times 10^9$ yr B.P.);

(4) Galaxy is colonized, Steady State Era begins ($\sim 4.9 \times 10^9$ yr B.P.);

(5) information is the most valuable resource, transgalactic communication is established, common policy for common interests, agreement on "Codex Galactica";

(6) formation of the Solar System ($\sim 4.6 \times 10^9$ yr B.P.);

(7) Earth is visited, primitive organisms are discovered ($\sim 3.5 \times 10^9$ yr B.P.);

(8) Solar System is placed under interdict.

## 5. CONCLUSIONS

If the Galaxy was already colonized before the Solar System existed, then the Interdict Hypothesis provides a feasible resolution of Fermi's Paradox. Thus the possibility of interstellar colonization does not necessarily imply the nonexistence of extraterrestrial civilizations, and the presence of life and intelligence on Earth is not necessarily in conflict with a colonized Galaxy.

The Interdict Hypothesis also has implications for SETI search strategies. Almost any nearby stable Population I star would be a good candidate. However, if isolation of planets with new born civilizations is ET policy, then the sky may remain silent . . . for the time being.

In the scenario of the Interdict Hypothesis, the likely disposition of mature extraterrestrial civilizations is well summed up in the words of Gregory Benford (1984):

> A kind of being might come into the universe that did not want to finally eat everything or to command all or to fill every niche and site with its own precious self. It would be a strange thing, with enough of the brute biology in it to have the quick, darting sense of survival. But it would also have to carry something of the machine in it, the passive and accepting quality of duty, of waiting, and of thought that went beyond the endless eating or the fear of dying. To such a thing the universe would not be a battleground but a theater, where eternal dramas were acted out and it was best to be in the audience. Perhaps evolution, which had been at the beginning a blind force that pushed against everything, could find a path to that shambling, curiously lasting state.

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