GALACTIC COLONIZATION AND COMPETITION IN A YOUNG GALACTIC DISK

Edwin L. Turner*
Princeton University Observatory
Princeton, NJ 08544
USA

ABSTRACT. Even if long-lived advanced technical civilizations arise very frequently and interstellar colonization is possible and common among them, it is argued that this colonization process is unlikely to fully occupy the Galaxy (i.e., saturate it) due to interactions between the colonizing civilizations. This argument is supported by the analysis of population dynamics equations based upon those of theoretical ecology which are believed to be applicable to an extremely wide range of behavior patterns. It is also pointed out that recent astronomical evidence suggests that the disk of our Galaxy may be substantially younger than previously thought, thus making a non-saturated colonization model more plausible.

*Alfred P. Sloan Research Fellow

1. INTRODUCTION

The Fermi paradox and its attendant debate are fundamentally issues of three timescales: Δ = the inverse of the production rate of new advanced civilizations (given by Drake equation arguments usually), τ_C = the time required for a civilization to spread by colonization throughout the Galaxy, and τ_G = the time since such civilizations first began appearing in the Galaxy (i.e., the age of the Galaxy minus some genesis time). Under one set of plausible arguments Δ is in the range of 10 to 10^5 years so that $\Delta \ll \tau_G$ and a Galaxy populated by numerous independent civilizations is deduced (1). An alternate plausible analysis indicates that τ_C is in the range of 10^6 to 10^9 years and a barren (or at least very sparsely populated) Galaxy is inferred from the apparent absence of extraterrestrials in our locale (2). The apparent incompatibility of $\Delta \ll \tau_G$ with $\tau_C \ll \tau_G$ is termed the Fermi paradox.

The usual reaction to this "paradox" has been to reject one of the underlying sets of arguments and put forward the opposing conclusions that either $\Delta \gg \tau_G$, perhaps even infinite, and thus that the Galaxy is dead (save only our anomalous selves) (3) or that $\tau_C \gg \tau_G$, perhaps even

M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 477–482.

https://doi.org/10.1017/S0074180900146856 Published online by Cambridge University Press

infinite, and thus that colonization cannot occur (4). Given the whistling-in-the-dark nature of our speculations on ETI, it would be unwisely dogmatic to deny the possibility of either of these alternatives. This paper seeks, however, to explore the third possibility that both Δ and τ_C are indeed very small compared to τ_G.

Adopting for the sake of discussion the small values of Δ and τ_C advocated by proponents of both points of view, it is interesting to explore the implications of the third extreme inequality in this trio of timescales, namely that $\Delta \ll \tau_C$. This result implies that no civilization can spread throughout the Galaxy (which requires a time τ_C) without encountering and interacting with many other colonizing civilizations (which will be emerging at a rate of $1/\Delta$). The main point of this paper is that these interactions are very likely to prevent the Galaxy from being fully colonized regardless of the details of the nature of the interactions. If correct, this view allows a Galaxy in which intelligent life is abundant and interstellar colonization is important but in which the Earth has simply escaped extraterrestrial occupation so far, thus resolving the Fermi paradox.

2. THE NATURE AND EFFECT OF INTERACTIONS

Since it is nearly impossible to predict the motives and behavior of unknown extraterrestrial intelligences (or even other human beings!) with any confidence, it is clearly out of the question to try to say how two or more of them will interact in any detail. The simplest possibilities clearly include co-operation and competition, economic trade and military conflict, assistance and exploitation, and so forth. Even the nature of the results of cross-cultural exchange of knowledge, philosophy, technology, religion, forms of government, art, modes of behavior, et cetera cannot be foreseen. Furthermore, it is likely that extraterrestrial cultures will have modes of interaction which human cultures do not or cannot.

Despite this overwhelming complexity, or in a sense because of it, there may still be a reasonable hope of predicting the general effect of such interactions on the Galactic colonization rate. To be specific, the attention, resources, effort, etc. expended on these interactions will very frequently be at the expense of those devoted to colonization. Thus, once the Galaxy begins to approach full colonization, it is to be expected that the activities of the various interacting civilizations will be largely distracted away from the occupation of the remaining virgin territory. In such a situation, it is quite possible that a modest fraction of the Galaxy will remain as uncolonized backwater areas for periods of time very long compared to τ_C. If we wish to contemplate both small Δ and small τ_C values, we can reasonably assume the Earth to be such a Galactic backwater.

3. MATHEMATICAL POPULATION DYNAMICS AND THEORETICAL ECOLOGY

Stated in the form given above this particular scenario seems possible but not inevitable. In fact one can argue on quite general grounds that it is probably the most reasonable scenario for Galactic colonization so long as significant interactions between civilizations are considered. This is because the interactions can be viewed as providing a source of feedback in a complex system with special boundary states (i.e., zero occupation and total occupation). Such systems often exhibit very non-intuitive dynamical behavior with timescales very different from their "natural" one. In particular it is easy to give both physical and mathematical examples of such systems which avoid saturation for very long periods of time or even indefinitely.

In a forthcoming paper, J. P. Ostriker and I will explore the consequences of various models of interactions between extraterrestrial civilizations in some quantitative detail. This section summarizes some of the ideas and results which that paper will put forward.

One of the tasks of modern theoretical ecology is understanding the incredibly diverse dynamical behavior of biological populations, including their colonization of new habitats, in a general way which is independent of the specific behavior patterns of individual species (5). A primary approach to this problem has been the modeling of such populations in terms of sets of simple coupled differential equations. Such models enjoy some success in explaining at least the general features of the extensive empirical data. The most impressive feature of these models is the very slight mathematical complexity (feedback) required to produce complex dynamical behavior which may include multiple equilibrium states, damped and undamped oscillatory responses to perturbations, complex oscillatory patterns, and even "chaotic" time histories. A second and somewhat more relevant feature is that they only rarely give saturation behavior for realistic values of the parameters. Biological populations do not often reach the limiting environmental carrying capacities; various interactions and nonlinear effects prevent it. These general statements apply to species as diverse as insect pests spreading through an orchard, high altitude adapted plants propagating along a mountain range, or birds colonizing island archipelagos (6). Analyses of this sort have even been applied to human populations and could well describe the colonization of Polynesia (7).

We have investigated a mathematical model for Galactic colonization based on the ideas of theoretical ecology. Essentially it contains only an exponential growth term, a linear logistic term, and a linear density dependent death (= cessation of colonization) term. In addition to Δ and τ_C, the model contains four other scalar parameters. Even for a fixed set of Δ and τ_C values (e.g., 10^3 and 10^8 years, respectively), the variation of the other four parameters within plausible limits produces a wide range of complex behavior such as that discussed above. This includes many cases in which a modest fraction (e.g., 10%) of the Galaxy remains uncolonized for times of order τ_G. This detailed calculation illustrates (but does not prove, of course) the general argument put forward in section 2.

4. THE AGE OF THE GALACTIC DISK

However believable or unbelievable one finds the incomplete colonization model described above, it is clear that smaller values of τ_G make it more plausible since they reduce the time for which we must have fortuitously escaped colonization. In this connection it is interesting to note that recent astronomical results bearing on the age of the Galactic disk suggest ages smaller than the conventionally assumed 10 billion years. There are two basic age indicators involved. First, the stellar evolutionary age of the open cluster NGC 188, whose subgiant branch bounds solar neighborhood disk subgiants, appears to be in the range of 5 to 6 billion years (8). Second, recent work on degenerate dwarf cooling rates seems to indicate that there are few if any degenerate dwarfs older than about 5 billion years in the solar neighborhood (9). Furthermore, current views on the values of the fundamental cosmological constants indicate a total age of the Universe of only 8 billion years (10), a value which is not excluded by the nucleocosmochronometers (11).

None of the determinations quoted above are very certain, and ages of 10 billion years or more are not decisively ruled out at this point. Nevertheless, the trend of all available indicators is clearly toward smaller ages for the Galactic disk stars; a value as small as only 5 to 6 billion years is plausible. If the Solar System genesis time of 4.6 billion years were not atypically long, τ_G could thus be reduced to a value of order 10^9 years with a considerable impact on Fermi paradox arguments and, in particular, the scenario presented above. Such a small value of τ_G is not a necessary requirement of the incomplete colonization scenario of course.

5. CONCLUSION AND DISCUSSION

The primary conclusion of this paper is that the Fermi paradox is not really a paradox; it could easily be that technically advanced life is common in the Galaxy and that it engages in substantial interstellar travel and colonization. In other words, both Δ and τ_C could be small compared to τ_G. This conclusion is not actually very remarkable; it simply admits the possibility that the spread of life through the Galaxy might follow a pattern somewhat like that followed in the propagation of many terrestrial species.

The mere possibility of incomplete colonization renders the Fermi paradox vacuous, but it does not follow of course that the scenario is a reality. It simply remains as an appealing possibility that we live in a Galaxy populated by numerous independent advanced civilizations with which we will someday be able to directly interact.

Whether one imagines the sky as peopled by wise and beneficent beings anxious to help us solve the many intractable problems of life (12) or postulates a virgin Galaxy which our descendants have the "manifest destiny" of occupying (13), the importance of emotional appeal to ETI scenarios is apparent though rarely stated explicitly. The former view restores "gods" to the heavens (with SETI researchers as their "high priests"!) while the latter restores humanity to its pre-Copernican position at the "crown of creation". Perhaps objectivity would be better served by giving these emotional value judgements openly. In this sense, both of the standard resolutions of the Fermi paradox are unsatisfying. If $\Delta \gg \tau_G$ and the Galaxy is dead, it is also ultimately dull and much less rich and exciting than it might have been, the enthusiasm of astronomers, planetary scientists, and other aficionados notwithstanding. On the other hand, if $\tau_C \gg \tau_G$ and interstellar travel is impossible, the Galaxy may be very fascinating but it is also painfully remote; we are condemned to stand forever with our noses pressed against the window of the cosmic bakery beholding its wonders but never tasting them. The scenario described here is more hopeful in that it allows for a Galaxy at once accessible and exciting. If this were a reality, ETI might be likened to a Zen view of the Buddha of the Future (14):

> "Maitreya! Maitreya!
> Forever dividing
> Here, there, everywhere-
> Yet scarcely noticed."

J. P. Ostriker provided several stimulating discussions of this topic, permitted the description of results from our forthcoming paper in section 3, and is responsible for the idea of using the tools of theoretical ecology on this problem. R. M. May provided an introduction to the theoretical ecology literature and several useful comments. J. R. Gott and S. J. Lilly gave encouragement and made detailed comments on the manuscript.

REFERENCES

1) Shklovskii, I. S., and Sagan, C. 1966, Intelligent Life in the Universe, San Francisco: Holden-Day; Sagan, C. 1973, Icarus, 19, 350.
2) Hart, M. H. 1975, QJRAS, 16, 128; Jones, E. M. 1982, in Extraterrestrials: Where Are They?, eds. M. H. Hart and B. Zuckerman, New York: Pergamon Press, 66; Newman, W. I., and Sagan, C. 1981, Icarus, 46, 293.
3) Hart, M. H. 1979, Icarus, 37, 351; Argyle, E. 1977, Orig. Life, 8, 287; Tipler, F. J. 1981, QJRAS, 22, 133; and see E. Jones in this volume.
4) Drake, F. D. 1980, in Strategies for the Search for Life in the Universe, ed. M. D. Papagiannis, Boston: D. Reidel, 27; Oliver, B. M. 1980, ibid, 79; and see F. D. Drake in this volume.

https://doi.org/10.1017/S0074180900146856 Published online by Cambridge University Press

5) May, R. M. 1981, in Theoretical Ecology: Principles and Applications, ed. R. M. May, Sunderland, Mass.: Sinauer, Chpt. 2; May, R. M. 1976, Nature, 261, 459.
6) Gilpin, M. E., and Diamond, J. M. 1982, Oecologia, 52, 75; Diamond, J. M., and May, R. M. 1981, in Theoretical Ecology: Principles and Applications, ed. R. M. May, Sunderland, Mass.: Sinauer, Chpt. 10; Diamond, J. M., and Karr, J. R. 1972, Ecology, 53, 330.
7) Swick, K. E. 1981, SIAM J. Appl. Math., 40, 266; and see B. R. Finney in this volume.
8) Demarque, P., and McClure, R. D. 1977, in The Evolution of Galaxies and Stellar Populations, eds. B. M. Tinsley and R. B. Larson, New Haven: Yale University Observatory, 199.
9) Liebert, J., Dahn, C. C., Gresham, M., and Strittmatter, P. A. 1979, ApJ, 233, 226.
10) de Vaucouleurs, G. 1981, Proc. N. Y. Acad. Sci., 375, 90; Aaronson, M., Mould, J., Huchra, J., Sullivan, J. T., Schommer, R. A., and Bothum, G. D. 1980, ApJ, 239, 12; Guth, A. H. 1984, Proc. N. Y. Acad. Sci., 422, 1.
11) Schramm, D. N. 1974, Ann. Rev. Ay. Astroph., 12, 383.
12) Drake, F. D. 1976, Tech. Rev., 78, No. 7, 22; Oliver, B. M. (ed) 1973, Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligent Life, NASA CR114445, 29; Sagan, C. 1979, Broca's Brain, New York: Random House, 276.
13) Bracewell, R. 1982, in Extraterrestrials: Where Are They?, eds. M. H. Hart and B. Zuckerman, New York: Pergamon, 34; Jones, E. M. 1981, Icarus, 46, 328; Hart, M. H. 1983, preprint of paper presented at Los Alamos Conference on Interstellar Migration.
14) Hotei 917, death poem as translated in Zen Poems of China and Japan: The Crane's Bill, trans. L. Stryk and T. Ikemoto, New York: Grove (1973), 20.