A Comparative Analysis of Space Colonization Enterprises

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Abstract: It is shown that the energy requirements for interstellar colonization exceed that for intraplanetary colonization by a factor of ten million or perhaps much more. This is offered as an argument against extensive interstellar colonization as a means of dealing with population expansion, and as a possible explanation of the Fermi paradox.

Impressive arguments that we may be the first technical civilization in the galaxy have been built on the hypothesis that interstellar colonization would be an imperative for technical civilizations of our level of achievement. In these arguments, it is pointed out that even a modest rate of expansive interstellar colonization would cause the colonies of a civilization to occupy essentially every habitable planet in a galaxy in a time very short compared to the age of the galaxy or to the time scales of biological evolution. Typical time scales to occupy a galaxy are of the order of 100 million years or less. It is then argued that it is not necessary for a significant fraction of civilizations to embark on colonization enterprises for the entire galaxy to be occupied; if only one civilization embarks on such an enterprise, the entire galaxy is colonized.

But no interstellar colonists have come to the earth, to our knowldge. Therefore, despite the fact that are current scientific information suggests that many technical civilizations should have developed before us, it is concluded that we must be the first technical civilization in the galaxy.

The conflict between the hypothesis that there should be many technical civilizations older than ours and the hypothesis of the inevitability of interstellar colonization is known as the "Fermi Paradox", since it was apparently first recognized as an intellectual problem by Enrico Fermi.

A number of solutions to the Fermi paradox have been proposed:

1) We are the first technical civilization in the galaxy, the solution mentioned above.

2) There are severe hazards to interstellar travel. It is proposed that there are dangerous hazards to interstellar travel which are as yet undiscovered by us. For example, there may be occasional interstellar particles much larger than those well-known to astronomers, with dimensions of, say a centimeter or so. These could

M. D. Papagiannis (ed.). The Search for Extraterrestrial Life: Recent Developments, 443–447.

be lethal projectiles to a spacecraft travelling at velocities of the order of a few percent or more of the velocity of light, velocities which seem desirable for interstellar spacecraft. The many studies of meteors which have been made do not support this idea, or at least seem to indicate that such interstellar particles are not present in the inner solar system.

3) Large scale interstellar colonization spreads throughout a galaxy by a process similar to gaseous diffusion (Newman and Sagan, 1981). In this scenario, the "frontier" of the colonized portion of a galaxy does not move outward at the speed with which a colony moves from one star to the next, but at a much lower speed. Calculations by Newman and Sagan have shown that the time required to colonize the entire galaxy in these circumstances is of the order of the age of the galaxy, and thus it is not surprising that no colonists have yet arrived at the earth.

4) Civilizations in the galaxy are afraid to support a colonization enterprise because they fear that some of their colonies, no longer under their governmental control, may turn on them with military force. There is much in human history to support this kind of thinking, but it is unknown whether the human example is relevant to the galaxy at large.

5) There is an ethic prohibiting one intelligent civilization from intervening in the lives of other civilization. In this hypothesis, colonizing expeditions, upon finding that there is intelligent life on earth, abstain from colonizing the earth or otherwise intefering in the civilization on this or other planets. Human history does not support this idea, of course, nor is there any evidence that we would embrace such an ethic if we were engaged in interstellar colonization. Thus there is no case for this hypothesis so far.

6) We are a "zoo" (Ball, 1973). In this hypothesis, the human civilization is a source of wonder and perhaps amusement to other civilizations. Rather than colonize the earth, other civilizations have decided to set it aside as a preserve to be studied surreptitiously, just as we often study varieties of wild life from "blinds" and by other means which conceal our presence from the objects of study. There is no direct evidence to support this rather speculative hypothesis.

A seventh possibility, which I favor, and which can be analyzed quantitatively, is that interstellar colonization is simply an outrageously inefficient and uneconomical means to deal with the problem of gaining habitable space. The costs of the enterprise, compared to the costs of simpler options, are so much greater that even the most technically sophisticated civilization would eschew such an endeavor.

If the purpose of colonization is to provide habitable space for an ever increasing population, there are two main options. One is interstellar colonization of the planets of distant stars; the other is the construction of space colonies in the home planetary system, as advocated by Gerard O'Neill. The latter option can in principle provide space for an enormous number of residents similar to human beings. The total amount of solar energy available from the sun is adequate to support something like 10^{22} individuals, which is surely not a limiting number.

Let us compare as best we can the relative amounts of energy required to pursue these two options. To obtain the minimal energy required for interstellar colonization, let us assume that a colonization spacecraft is going to proceed in interstellar space at a velocity sufficient to move 10 light years in 100 years. This is a reasonable assumption, since it is unlikely that stars possessing habitable planets are closer to one another than ten light years. A minimum transit time of 100 years is perhaps palatable, if only barely so, to creatures with lifetimes of the order of human lifetimes. The implied velocity is 0.1 of the speed of light, or 30,000 kilometers per second. This is very much faster than can be achieved by existing propulsion systems. Note that if the separation between stars with habitable planets is greater than 10 lights years, which is not out of the question, or if transit times of less than 100 years are desired, as is likely, the required velocity is greater. In any case, with this assumption, the required kinetic energy per kilogram is about 4 10^{14} joule. This must be delivered by the propulsion system.

In contrast, the energy required to move the same mass to an orbit in the home planetary system is very much less. Let us take the solar system and the earth as an example. Let us assume that we are going to move mass to a distance from the earth equal to the moon's distance and give it orbital velocity there, as we would with a space colony. The required energy is

$$\frac{GMm}{R} + \frac{mv^2}{2}.$$

Here G is the universal gravitational constant, M is the mass of the earth, m is the mass of the spacecraft, R is the distance from the center of the earth, and v is the orbital velocity of the spacecraft. With the required orbital velocity of about 1 kilometer per second, the required energy per kilogram is about 6 10^7 joule. To the accuracies which are relevant here, this is very nearly the energy required to establish a mass in orbit anywhere in the inner solar system.

Thus the ratio of energies required for the two types of colonization are:

$$\frac{\text{Energy per kilogram for interstellar colonization}}{\text{Energy per kilogram for home-system colonization}} = 7\ 10^6$$

This enormous ratio would obviously cause civilizations to favor colonization in their own systems.

In fact, there are additional, less calculable factors which would cause the ratio to be considerably larger than the above. The mass per colonist in an interstellar spacecraft might be much larger than for an interplanetary spacecraft since longer flight durations would have to be supported, and there would probably be additional hazards of spaceflight calling for additional protection systems. This point, for first colonies, might be countered by the fact that the mass of an entire interplanetary colony may be lifted from the equivalent of earth for at least the first colony, whereas with interstellar colonies no such transport of final habitat is required. However, as pointed out by O'Neill, the material to construct space colonies is most cheaply obtained from asteroids and satellites, with which the required energy is negligibly small. Thus the mass per colonist which must be lifted from a deep potential well will be much less for the interplanetary colonies which follow the first to be built, and perhaps for all the colonies.

The propulsion systems required to obtain relativistic velocities could well be less efficient than those required to obtain the much lower velocities required of interplanetary missions.

Of certain importance is the fact that, as assumed above, we have provided only for the kinetic energy of transit of the interstellar craft, and we have provided no energy to stop it once it approaches a suitable star. With the assumed velocities of the order of 0.1c, this is a major problem. The dissipation of kinetic energy through close passes to objects in the stellar system, or by aerodynamic braking, are not feasible. To stop the vehicle reliably, it will be necessary to use the propulsion system to remove about as much kinetic energy as was delivered to the spacecraft in the beginning. Assuming rocket system carrying its own fuel, this means the the overall mass ratio for the rocket will have to be the square of the mass ratio of a rocket which simply accelerates to full velocity with no provision for braking. If we assume a mass ratio per stage of the order of 10, as is probably reasonable, this means that the total amount of energy which must be expended is increased by about a factor of ten in order to provide for braking at the destination. Thus it would seem reasonable, taking all these effects into account, that the ratio

$$\frac{\text{Energy required for interstellar colonization}}{\text{Energy required for interplanetary colonization}} = 10^8$$

The enormous disparity established by this number would strongly inhibit any movement to adopt interstellar colonization as a mode of territorial expansion.

This conclusion is valid, of course, only if the amounts of energy required are quite substantial. They are. As shown previously (Drake, 1980), the amount of energy required to mount even a minimal interstellar mission of the kind assumed above is of the order of 8 10^{21} joules, or 100 times the annual energy production of all energy sources in the United States. If we allow the interstellar colony to brake, as described above, the amount of energy required for a mission becomes probably greater than 8 10^{22} joules, or more than the energy produced by the United States in 1000 years. Although it may be argued that far better or cheaper sources of energy than now available on earth may be available to advanced civilizations, the means of storing and transporting energy will never be cheap, and so the economic consequences of such huge energy budgets will be significant, I believe, no matter what the level of technical sophistication of civilizations.

It has been argued that intelligent creatures, at least humans, conduct costly enterprises which may not seem rational. We have built pyramids, and we have climbed Mount Everest. It is argued that a psychological motivation might cause civilizations to ignore the economics, and embark on interstellar colonization anyway. But there are counter examples. We have built a few Concorde aircraft, but upon learning of their poor economy, we build them no more. We have had for decades the ability to build a building a mile high, but no such building has been built. The last of the U. S. manned missions to the moon were cancelled because of their high cost. Thus it is possible that advanced extraterrestrial creatures do occasionally launch a colonization mission, or a few such missions. But I would deem it likely that, upon seeing the resultant high cost-benefit ratios of these missions, they turn away from such endeavors. They may launch missions of scientific exploration after judging the enormous costs to be acceptable. But in neither of these cases, which I consider entirely reasonable, would a all-encompassing colonization of all the stars in the galaxy occur. We would not know of the existence of these enterprises, even if very many of them had occurred.

Based on the above considerations, I feel that a truly intelligent civilization would not embark on a grand project of interstellar colonization. Colonization of the home planetary system is rational, colonization of the stars is irrational. Perhaps our radio searches will provide evidence that, after all, intelligent civilizations behave intelligently.

REFERENCES

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