WHERE ARE THEY? IMPLICATIONS OF ANCIENT AND FUTURE MIGRATIONS

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Some of my more strident space-enthusiast friends wear T-shirts that say, "The meek shall inherit the Earth...the rest of us are going to the stars!" That may strike some as being overly optimistic at best, but I believe there is a grain of truth to it. Whenever I talk about space colonization or one-way voyages to the stars someone usually asks, "Who would want to go?" Usually someone else will the chime in, "I'll go!" Not only do people come in various sizes and shapes and colors, they look at the world in many different ways. I grew up in the suburbs of New York and knew people who had literally never been west of the Hudson River and had no intention of ever going. New York was comfortable. There is nothing wrong with that attitude. It is just that for many people such a life is not right for them. I went west as soon as I had the chance. I do not regret having left and am much more comfortable where I am now. As I have gotten older, I have found myself settling in and, although I like to travel, I am beginning to understand how those sedentary New Yorkers felt. The only difference is that I settled down a little later in life and in a different place from where I started. But some people never lose that need for adventure, that wanderlust, that need for a radical change, and new places. These are the people who will blaze the trail to the stars.

My colleague Ben Finney, who is an anthropologist at the University of Hawaii and one of the few social scientists currently thinking about space colonization, has said that, "Man is an animal that has professionalized exploration" (Finney and Jones 1983). Many of us do retain a youthful curiosity long into adulthood. Some--the Captain Cooks, the Roald Amundsens, the Jacques Cousteaus of this world--spend their entire lives in physical adventure and exploration. Others turn to science and books and become armchair explorers. But whatever its manifestation, this need to explore the unknown runs deep in our species.

Of course, the urge to explore is not enough to explain why we are going into space any more than it can completely explain how we spread out of East Africa more than a million years ago. Physically, we are adapted to the warmth of the tropics, but today the more than four billion of us are spread across the face of the planet. A few hardy souls even winter over the South Pole. The key, of course, is

M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 465–475.

technology. Beginning with simple tools made of wood or grass or stone, our ancient ancestors carved out a technological lifestyle that enabled them to overcome the limitations of their bodies. Simple containers enabled food gathered from scattered sources to be brought home (itself a radical invention); water could be carried from distant springs and streams; and sticks and stones became weapons that made man a hunter. Later, the agricultural revolution made humanity less dependant on the vagaries of nature so that today there are billions of us. That same technological prowess fueled a steady migration that led first out of Africa into the colder climes of Eurasia, then to the Americas, and then across the seas to Australia, the islands of the Pacific, and even to Antarctica. This progression of technological and cultural adaptation to new environments may soon lead to a wide-spread human presence in the Solar System and to interstellar journeys (Finney and Jones 1983).

Those of us who are close to modern thinking about space colonization have a fairly clear mental picture of how it might come about. We sometimes forget that there are those who do not share our passionate interest. For these people space is an utterly alien environment suited only for astronauts willing to take enormous risks. In 1983, when Finney and I were organizing (with the help of Carl Sagan) a conference on space migration at Los Alamos, I approached a famous historian who had long since settled into a comfortable life in a New England college town. He had not heard much about plans for space colonies. The one thing he wanted to know was, "Will they be able to get the New York Times?" I tried to assure him that space colonists would have access to just about any information they might want--including facsimiles of the Times--but he did not seem to be comforted. Living and working in space may seem new and different and strange, but then, after living the last fifteen years in a small research town (Los Alamos) in the mountains of northern New Mexico, the prospect of living and working in a big city like New York would seem strange to me. A lot depends on what you are used to. We are all utterly dependent on technology. The technology for living in space is just another variety. As we get better at it, get better at living and working in space, it will become "natural" to those who live off planet.

Making a living in space is currently a very expensive proposition. The things you need to make a living anywhere are energy and material resources. Both are abundant in space but, with the exception of solar energy used to power some satellites, we have not yet tapped any of that wealth. What we do now is haul everything we need up from the surface of Earth and that is what makes everything so expensive. Let us imagine that we want to build a small facility in orbit around the Moon. There are two nearby sources of raw materials: Earth and the Moon. If you think of the Command and Service Module of Apollo as such a small facility, it took an enormous rocket (the Saturn V) to place one in lunar orbit from the Earth. Yet a craft smaller than the Command Module, the Lunar Excursion Module, both descended to the lunar surface and returned to lunar orbit. The difference between lunar and terrestrial gravity means that getting raw materials into space from the Moon costs about one twentieth the cost of launch from Earth. If that were the only difference we would have a large, thriving lunar base today. But doing almost anything requires a capital investment. Thus far, we have made huge capital investments on Earth, but few in space.

Getting started is going to be expensive, like any new enterprise, but we should remember that we have made big capital investments before: railroads, the oil industry, utilities, highways, airlines, and communications. All of these have price tags at least as large as that of the basic industries we must establish in space. The only real difference is likely to be the payoff period. Waiting a few decades before space enterprises begin to pay for themselves and return a profit is going to require some patience, but there are plenty of people around with the required foresight. The Chinese, Japanese, and Russians may be good examples.

The list of things we need in space is fairly long, but the basics can be summarized in a few sentences. A lot can be accomplished by bootstrapping, building up from the basic investments. We need an operations base in near-Earth orbit (a large space station) to serve as a transfer point for crews and materials going between Earth and Moon. The Shuttle will serve nicely as a ferry to and from the Earth's surface, but we will need a small fleet of orbit transfer vehicles to get from the operations base to lunar orbit. A lunar-orbiting space station may be justified economically although it is possible that the transfer vehicles might serve as lunar landers as well, bypassing the need for a lunar space station and for a fleet of specialized lunar landers. Time and the engineers will tell. The next big-ticket item is the lunar base itself. That must have living quarters, mining equipment, smelters, and a power station. The mining equipment need not be very sophisticated at first because the ore will be lunar soil (Gertsch 1983). The power station could be a large array of solar collectors. Once things get set up, the first major product may well be rocket fuel (oxygen and hydrogen) extracted from lunar dirt. That first big step will cut down operating costs because fuel to operate the transfer vehicles will be a major expense as long as fuel must be brought up from Earth.

With the lunar facility in place, many more things become possible and relatively cheap. Building materials transferred up from the Moon could be used to construct manufacturing facilities in space. There, unprocessed soil delivered from the Moon by a catapult called a mass-driver (designed by Gerard O'Neill of Princeton University) could be used to build large solar-power satellites, orbital habitats, and expanded manufacturing facilities (O'Neill 1974). Somewhere in this progression the final step toward permanence of our space enterprises will have happened. Large, permanently inhabited settlements will be built on the Moon and in space (habitats). Men and women will put down roots in space much as our ancestors established themselves in the New World and became Americans. Just as modern America was not possible before people had decided to "go native," large-scale activities in space will not be started until people begin their careers and start raising families off-planet.

Once we are firmly established in the Earth-Moon system (and perhaps a little before), we can start looking outward for fresh territory. The asteroids, many of which wander relatively near us and some of which are even easier to get to than the Moon, offer rich resources of carbon and platinum-group metals rare on the Moon (O'Leary 1982). The technology we will develop to extract asteroidal resources could be used to settle the main asteroid belt that circles the Sun between Mars and Jupiter and the comet cloud that orbits far beyond Pluto. The technology we will develop to exploit lunar resources can be transferred to Mercury and to the moons of Jupiter and Saturn. Mercury occupies a special place in the Solar System. It is the most closely held of the Sun's family, and its soil could provide the building materials for gigantic power stations in close orbit about our star (Clarke 1973).

The five hundredth anniversary of Columbus's voyage is nearly upon us, and I suspect that before another five centuries have passed we will be ready for journeys to the stars. Before that time, our descendants may well be spread throughout the Solar System from the near-solar power stations to the comet cloud, just as we are now spread across our planet. Population doubling once a generation (25 years) is not uncommon in frontier circumstances (early America and Australia are recent examples) (Birdsell 1985), so we can imagine a total Solar System population approaching a trillion in five hundred years assuming a seed population of one million emigrants from Earth. I doubt that more than a few billion people would live on the planets; the Earth is already full and the others do not offer much elbow room. Most people will live in habitats scattered within the asteroid belt and the comet cloud. O'Neill (1974) and others have described the habitats as roomy structures--villages interspersed with agricultural areas and parklands.

A trillion people with the resources of the entire Solar System at their disposal should be capable of interstellar journeys. At present there appear to be two basic ways of getting to the stars. Finney and I have called these "fastships" and "nomad communities." First, let us consider fastships.

The stars are very far apart and to get to the nearest ones in a reasonable time takes a lot of energy. If we assume that the voyages must take less than a lifetime, the fastships must travel at about ten percent of light speed. If we further assume that each emigrant needs 100 metric tonnes of payload (living quarters, computers, deceleration engines, and all the other needs of a self-sufficient community) and 900 tonnes of deceleration fuel, acceleration to one-tenth light speed at one-tenth of terrestrial gravity requires that 300 terawatts of power must be delivered to the ship per passenger for a year. To put the power requirements in perspective, the U.S. currently generates a total of only 4 terawatts. Obviously, the U.S. could not outfit an interstellar settlement voyage. Something like 500 years must pass before our descendants are ready for such an undertaking and by then I expect that they will have at their command a noticeable fraction of the 100 trillion terawatts our star produces. Already we can sketch out how to build automatic, self-replicating construction robots. Imagine setting them loose (with built in controls), to convert a bit of Mercury into a swarm of near-Sun power stations. With one percent of the Sun's output at their command, our trillion descendants could easily afford to send a stream of emigrants to the stars.

How would they do it? One very attractive scheme has been proposed by Freeman Dyson (1983, unpublished notes). If the output of a

Clarke Station with a 1000-kilometer-diameter collector (150,000 terawatts at 20 solar radii) were converted to microwaves, a large sail could be used to accelerate a 500-passenger ship. (A party of 500 has been chosen because this seems to be the smallest, socially and genetically self-sufficient communities found among surviving hunting and gathering populations [Birdsell 1957].) The sail would be a gossamer-thin web of submicron, silicon carbide or diamond fibres (metal-coated to reflect the microwaves) spaced a few tenths of a centimeter apart (see Forward 1984 for an analysis of Dyson sails). The sail would mass a few hundred tonnes, but would be only slightly smaller than the planet Mars. The fascinating thing about all this is that the key component, the single-crystal fibres, can already be grown in terrestrial laboratories (Milewski, et al. 1983). They are incredibly strong, and that is their key feature because of the stress induced by hauling the half-million tonne ship behind the sail.

Specifically, we can set a lower limit to the required cable strength (S) if we assume that the mass of connecting cables (M_c) must be less than the payload mass (M_p). If the cross section is A, the strength is given by

$$S = M_p a/A \tag{1}$$

where a is the acceleration, assumed to be 10^2 cm/s^2. The cable mass is

$$M_c = \rho AL \tag{2}$$

where ρ is the density of the cable material (3.2 g/cm^3 for SiC), and L is the length of each cable, assumed to be roughly the sail diameter D. Because the operation of the sail is dispersion limited, its diameter is approximately

$$D^2 = 2.74\ \lambda\ell \tag{3}$$

where λ is the microwave wavelength (3 cm at x-band) and ℓ is the acceleration distance given by

$$\ell = \frac{1}{2}\frac{v^2}{a} = \frac{1}{2}\frac{(0.1c)^2}{a} = 3000 \text{ A.U.} \tag{4}$$

With the assumed mission parameters we obtain

$$D = L = 5700 \text{ km} \tag{5}$$

and [from Equation (1) and (2)]

$$S = \frac{M_p}{M_c} a\rho L = 180 \frac{M_p}{M_c} \text{ kbars} \quad . \tag{6}$$

Measured strengths of SiC whiskers (~5 μm diameter) are of this order (Milewski 1983). Although about a factor of two in strength would be lost by spinning the fibres into a cabling yarn (Milewski, private communication), significant increases could be achieved by using finer

https://doi.org/10.1017/S0074180900146844 Published online by Cambridge University Press

fibers and/or diamond. Cables exceeding these design requirements may be manufactured aboard the space station before the 20th Century ends.

I could be way off base in my description of fastship propulsion. In the next five hundred years our descendants may prove far cleverer than we have been so far. But I think it is important to show that fastship travel is plausible for the Solar Society that may arise in the next few centuries. My timescales could be off in either direction, but I do think that fastship travel is in the cards.

Let us imagine that in 2492, the first party of interstellar settlers leaves the Solar System for Barnard's Star, a rather unassuming red dwarf that happens to be one the Sun's nearest neighbors. (The nearest stars, the Alpha Centauri system, comprise a multiple system and may not have the orbiting junk the settlers will need to build habitats when they arrive. Space telescopes and/or automatic star probes will have answered the question of nearby planetary systems long before the settlers leave.) Because Barnard's Star is about six light years from here, the settlers should arrive in 2552, give or take a year or two. For the last year of the voyage, they will have used fusion-powered engines to slow down and enter an orbit about the star. Because their stocks of supplies brought from the solar system were probably adequate to support only the 500 of them, their first order of business would be to scout out a suitable asteroid or small moon. They would then turn loose their pack of semi-intelligent robots to start building habitats and procuring supplies for a human population that should soon start growing. I do not imagine that the crew will do much physical labor. No hammering rocks to be hand-fed to small solar-powered smelters. If any of this is to happen, a very important member of the crew must be a very capable computer. (The reader should consult Edward Feigenbaum and Pamela McCorduck's book "The Fifth Generation" which describes Japan's plan to construct an "intelligent" computer within the next 10 years.) The main computer would do most of the robot supervision. People will be principally employed as trouble-shooters.

With attention to careful planning, the settlement, perhaps supplemented by later arrivals, should be well-established within a generation or two. The early years may be difficult (Hodges 1985), as the community struggles to expand its technological base from information stored in the master computer. But once the initial hurdle has been cleared, the settlement should grow toward the scale of the solar society. Much the same resources should be available: energy from the star and building materials from asteroids, comets, and moons.

Eventually, descendants of the first settlers will be ready to migrate to stars still farther from the Solar System. I do not imagine that the Sun will spawn only one stellar colony nor that the Barnard Settlement will itself spawn only one daughter colony. If each stellar settlement spawned a pair of daughters 750 years after its own foundation, virtually every star in the galaxy would support a human settlement within eight millions years.

The velocity of a settlement wave is given by

$$v = \frac{\Delta}{t_T + t_S} \tag{7}$$

where Δ is the average separation of settlement sites, t_T is the travel time and t_S is time required for a settlement population to grow large enough to support secondary settlement ventures (Newman 1979, Jones 1981, Newman and Sagan 1981). Under the assumption that the space-faring culture of our descendants will require only stars for energy and small objects (asteroids, comets, moons) for building materials, Δ is probably the average separation of late-type, single stars--roughly six light years in the solar neighborhood. With this separation and an assumed ship speed of 0.1 c, the travel time is negligible at 60 years. (Note that if terrestrial planets are required, Δ may be much larger and a search time approaching a Hubble time may come to dominate the calculation.) The most controversial factor in the calculation is the population growth time. Newman and Sagan (1981) have argued that the very low-growth rates characteristic of the developed nations will carryover into space. However, I assume that generation-doubling, which has been characteristic of human population in frontier circumstances, will be common in new space settlements (Birdsell 1957). If this is the case, a seed population of 500 would grow to a trillion in about 30 generations or 750 years. The expansion velocity is then 0.0074 light years/year and the time to cross the 60,000 light year diameter of the galaxy is eight million years. Newman and Sagan (1981) argue that the filling time could be 100 times longer.

And that brings me to the point of this essay: the implications of a human interstellar migration for our proposed searches for extraterrestrial intelligence. The point is this: if humanity may fill the Galaxy in eight million years (a time very short compared to the age of the Galaxy), why has not a similar migration begun elsewhere reached the Solar System by now? This is the question, due in its modern form to Michael Hart (1975), that Fermi is supposed to have asked over lunch 40 years ago in Los Alamos. He asked, "Where are they?" Drs. Drake and Sagan have estimated that several hundred million intelligent species have arisen in the history of the Galaxy. It would only take one as expansionist as humanity seems to be to have long since filled the Galaxy. Surely, they are not all sedentary, philosopher-kings! Where are they?

Many solutions have been proposed, and they each have their merits (Tarter 1985). The one I favor is that we really are alone or, for some reason, first. Before I go on to discuss a few of the most prominent of the other solutions, let me say that I firmly believe that this is not a question that can be answered by argument. Fermi's question can be a lot of fun, but we should not lose sight of the fact that we will not know the answer until either our search for extraterrestrial communications have succeeded or we have filled the Galaxy ourselves and found no one else home. The question is profound, whichever way it turns out, and it is worth a search.

On to the alternatives.

One of the older arguments has been outlined by Asimov (1978 a, b), among others. The Galaxy is a big place. A hundred billion stars or more. Finding the Sun in that swarm would be a very tough job if you do not known which star is ours. It would be a little like agreeing to meet a friend at a popular beach on a hot July 4, but forgetting to

https://doi.org/10.1017/S0074180900146844 Published online by Cambridge University Press

agree on a time or place. Finding your friend in that sea of humanity would not be at all easy. However, I think this is the wrong way to look at the "Where are they" question. We are not asking for the probability that one small exploratory party from the far side of the Galaxy could find the Solar System, but rather the probability that any extraterrestrials had arrived. Returning to the analogy, imagine that you arrive on the beach in the predawn hours and sit down with your blanket to wait. No one else is around and it is very lonely. But before long comes the migrating horde from the nearby city. Soon your isolation is broken, and you are surrounded by fellow sunbathers.

An interstellar migration is a diffusion process, the spread of a growing population that touches virtually every speck of useful territory before it is over.

A useful paradigm is the Polynesian settlement of the Pacific. The Pacific basin is filled with islands, and when Captain Cook conducted the first thorough survey in the late 1700's, he found people on virtually every island, or at least signs that people had lived on them (Beaglehole 1974). What amazed the Cook expedition is that everywhere they went they found people speaking dialects of a single language. A simple explanation, since supported by archeological research, is that these far-flung Polynesians were the descendants of a single group of people, possibly only a few dozen, who first arrived in Fiji from points farther west in about 1500 B.C. After establishing population centers in Fiji and the neighboring Tongan and Samoan groups, the ancestral Polynesians spread eastward in stages, eventually settling virtually every island in the world's largest ocean (Bellwood 1979). To be sure, some of those settlements failed, as in the case of Pitcairn Island of "Mutiny of the Bounty" fame. But wherever the later European explorers went in the Pacific, they found either people or signs of prior habitation, such as stands of coconut palms imported from Asia by the Polynesian migrants.

On a larger scale, we should remember that our species originated in East Africa, yet is now found all over the world. Diffusive migrations, particularly by a species that can adapt through technology rather than biological adaptation, tend to fill all the available territory. We have done it before, and when we go into space, we will do it again. If the Galaxy is, in Jill Tarter's phrase, "a Cosmic Haystack," we will divide the task of searching it among countless settlement parties. No straw or needle will long remain unexamined.

If the needle-in-a-haystack solution to the Fermi Paradox does not work, there are others. Suppose for instance that a stellar settlement takes a very long time to grow rich enough to spawn further migration ventures. If the waiting time were millions of years rather than hundreds as I have argued, an interstellar migration wave might not have reached us yet. Newman and Sagan (1981) point to the very low population growth rates in the technologically advanced nations. However, demographer Kenneth Wachter (1985) has argued that demographic rates characteristic of one time and place do not long persist when circumstances change. I believe that as we move into space we will recreate the frontier environment that has characterized past expansions and with it, large population growth rates. As the frontier moves outward the population will stabilize in the settled places, but high growth rates will follow the frontier and, with our basic curiosity, fuel further expansion.

The last objection I will discuss is cost. Earlier I argued that the technology and energy resources needed for fastship migration will be available when our descendants are ready to go to the stars. But suppose I am very wrong. Suppose that we never tap enough solar energy to make fastships economical. Would we then never gain the stars? I think we will.

Earlier I mentioned the comet cloud that surrounds the Solar System. It contains something like ten trillion comets (Hills 1981) and, providing we do establish a population and technological base off Earth, reaching the comet cloud is a relatively low-tech enterprise. Gerard O'Neill (1981) has described communities living in the comet cloud supported by solar energy collected with large mirrors and by deuterium extracted from cometary ice. They would not live on comets, but in habitats built from cometary material. The same technologies that may soon support near-Earth habitats could support cometary communities.

However, not all comets are permanent residents of the comet cloud. There is good circumstantial evidence that comets wander through interstellar space. Freeman Dyson (1979) has written that, if such interstellar comets exist, "the galaxy is a much friendlier place for interstellar travelers than most people imagine." Finney and I imagine that small groups of people living in the comet cloud might hitch their fortunes to these interstellar wanderers and themselves become interstellar nomads (Jones and Finney 1983). Groups of about 500 people might live indefinitely off the resources of a single comet. They might, for instance, gather starlight for energy, with giant mirrors built of cometary materials. They, like the Polynesians who learned the seafarers' trade among the islands north of New Guinea, would have learned the nomad life in the comet cloud and then might move outward. Drifting through interstellar space, the nomad groups would "fission" from time-to-time and gradually spread toward the distant stars. Even if there were no fastships, by drifting with the comets our descendants could reach the nearest stars in 100,000 years and fill the galaxy in a billion, a time still short compared with the Galactic age.

I have tried to sketch the course of a human migration that began millions of years ago in East Africa. I do not believe that it will end until millions of years from now, when our descendants are spread through the Galaxy, living both near stars reached by fastships and among the drifting interstellar comets. If we are true to our origins we, both meek and adventurous, will inherit the stars.

And if we can, why not those others with whom we hope to communicate? Where are they? I suspect we are them. Alone, and with a grand adventure before us.

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