The Nature of Technological Civilizations†

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I'm not quite sure what I'm doing talking to this audience. My role in the past few years has been to take opposite side of the argument in a series of debates with Frank Drake. In any case, I have argued that there is very little possibility that any extraterrestrial technological civilization other than ours exists. Still no matter how much I argued, I'm always left with the nagging question: "On the other hand, what if we are not alone in the universe?" I don't think anyone could ever rule out this possibility and what I will try to do today is present a few ideas which might provoke thought on different ways of thinking about hunting for extraterrestrials. Although these ideas are part of the argument which is frequently used to argue that extraterrestrials don't exist, such lines of reason can never be iron clad. Still let's see where we can learn from them. Fundamentally, the point that I would like to make is that all of our thinking about searching for extraterrestrials is based on the experience of a couple of centuries or so of technological existence in our society. Almost everyone agrees that searching for extraterrestrial intelligence is a fruitful enterprise only if technological civilizations typically last for at least a million years. We're basing our search techniques on experience which is on the order of 2×10^{-4} of the lifetime of the civilization that we're hunting for. What I'd like to do is to try to think about much longer term futures than ordinarily considered.

First, I would like to make the point which has been made mostly more strongly by Gerard O'Neill. I don't hope to convince you in two minutes of O'Neill's point of view that space is the natural place for technological civilization. (I heard O'Neill talk at the AAS meeting in Austin, Texas about ten years ago. I came away from that talk thinking he was completely crazy. Still, after returning to Charlottesville, several of us decided that maybe we should teach a course on space colonies. Even if it was a crazy idea, we could get more FTE's in our department if we taught about space technology. But after teaching the course, I ended up becoming a convert.) Let me point out a few order of magnitude arguments which show that space may be a more desirable place to live than a planet. Planets are good for evolving life. But planets, at least once we begin to think about what a technological society is like, are a dreadful place for a technological society. They are hospitable to life but bad for technology. What is technology? Really, technology amounts to using energy to manipulate matter into structures of various kinds. A planetary surface is a hostile environment, both in building and maintenance of structures. If you life on a planet, you're very limited in the amount of energy that you can use as a society. The bulk of the matter of a structure serves no utilitarian purpose other than holding the structure up. The atmosphere is corrosive. I see my car is rotting away year after year. It's a hostile environment. There are earthquakes, there are winds, there are thunderstorms which cause all kinds of problems. In space these problems are much less the case and O'Neill makes that point. I'm relatively convinced that at least some fairly large fraction of technological societies will become space dwelling societies.

O'Neill argues that colonization is possible, that it's not terribly expensive, and so on. I won't repeat that. I only wish to make an intuitive argument which requires that we consider things in appropriate units. (I started thinking about this about a month ago when I heard Eric Jones give a talk and he was talking about terawatts. What is a terawatt? While at a certain level I know what a terawatt is, I have no intuitive feel. I

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don't think anyone has an intuitive feel for anything that is bigger than megasomething or smaller than microsomething. If we want to have any kind of intuitive feel for what we are talking about, we have to find an appropriate set of units.) This morning, somebody wanted to know how much energy falls on the earth from the sun. I suggest this is an appropriate unit for the power usage of a technological civilization and (following a suggestion from Jim Trefil) define a new unit the Total Wattage Intercepted: Terrestrial which we will abbreviate as a twit. (A twit is 1.7×10^{17} watt.) It is quite instructive to use twits when discussing the energy use of a society. For instance, the total power consumption on the earth amounts to about two millitwits. You can argue that we are very near the limit of our use of energy on the earth because if we use energy, no matter what its source, at a rate of a few tens of millitwits we are going to probably screw up the climate of the earth. On a much smaller scale, a Boeing 747, depending on exactly how you figure out its power consumption, is of the order of a nanotwit at maximum thrust and a few tenths of a nanotwit at cruise.

In considering SETI we must extrapolate at least thousands of years into the future. To put some limits on the kinds of things we should be thinking about, let's go back a thousand years. The energy use in England in 1066 is in fact documented in the Doom's Day Book, in which all the waterwheels in England are cataloged. They were the dominant source of manipulable energy. Since there were about 6000 2 horsepower waterwheels, the total power was about 50 picotwits. An eleventh century Britain hearing a description of a Boeing 747 using five or six times the total energy resources of the entire country would consider it ridiculous. We must realize that energy use is likely to increase dramatically if we can get off the earth. If we move as O'Neill and others argue into space, we can ultimately manipulate energy on the order of several tens of millions twits. (Using the same fraction of L that we now use of energy on the earth.) This is one of the reasons that I think we are likely to go into space. If we cut our growth short at our current level and we sit on the earth, we are limiting ourselves at a factor of at least a million short of our ultimate ability of growth. I don't think our civilization will have the discipline to cut its growth at that level.

There's lots of energy in space, that's why we go there. The thing that space seems to be lacking is matter. But we have a very warped view of how much matter we need to live and I want to point out again an appropriate way of thinking about mass. If we follow O'Neill's argument, it requires about 10 tons per person. So I will define a new unit called the PPOM (per person O'Neill mass) which is the amount of mass required to live in a space colony. We waste mass living on the surface of the earth. You are sitting on enough matter to make space colonies for roughly about a million people, and that matter on the earth serves no useful purpose other than keeping you from falling into the center of the earth. Planetary civilizations are a terrible waste of matter. There is matter in space; the most desirable stuff is probably the asteroids because they are most easily disassembled. One iron asteroid 10 km in diameter has enough matter to build space colonies to house 3×10^{11} people. It is worth $\$5 \times 10^{13}$ (if the price of iron doesn't go to pot). The biggest unit of dollars I can think in is the increase in the debt under Reagan's administration; call that an RRD. An asteroid is about 50 RRD. As another example, one 10 km stony-iron asteroid contains enough aluminum to build a reflector $\sim$ 1 mm thick as big as the earth. With one asteroid a civilization could build enough reflectors to manipulate one twit. So it takes a very small amount of matter for a society that lives in space to manipulate energy at far greater rates than planetary dwellers.

We'll go into space and I think other civilizations will go into space. Civilizations living in space will take a very different view to interstellar travel. This leads to a problem which many people have referred to as the "Where Are They?" problem. If we or another civilization start nonrelativistic interstellar travel it takes something like 10^7 years to colonize the galaxy. To understand at gut level what this means, let's play the game that everybody teaching introductory astronomy plays, where we construct a cosmic calendar. The Big Bang happened on January 1st and now is midnight on New Year's Eve. On December 31, sometime in the afternoon dolphins go back into water, Neanderthal appears 3 minutes before midnight, and so on. Why stop at midnight? Before you pour your first glass of champagne, we'll have space colonies and we will manipulate space several twits worth of energy. And if we embark on interstellar colonization, we have colonized every star in the galaxy before the Rose Bowl games starts on New Years Day. Let's go back to when the earth was formed: about September 1. If the optimistic view about the rate of formation of extraterrestrial civilizations is true, on September 1 the Earth and 40 million other planets formed. Likewise, August 31, August 30, August 29, and so on. Any of of those that formed on August 29 could have led to a civilization which colonized the solar system sometime when the Alps were forming. The easiest explanation is that we are the first civilization in the galaxy.

Voice: First colony matured.

Or we're the first that matured or whatever.

However, there are many reasons as to why they are not here other than the fact that they don't exist. My favorite reason is Frank Drake's suggestion which several years ago he was calling the Proxmire scenario. Basically, Frank argued that in any civilization there will always be some politicians who will argue that very large amounts of money should be spent on something more practical than going to another star. To accelerate 1 kg to 0.1 c requires 10^8 kilowatt hours. That's a lot of energy; that's 10^7 dollars. Who is going to spend 10^7 dollars accelerating 1 kilogram so it can whiz through some other stellar system? But if you look at it from another viewpoint, interstellar travel starting from a mature planetary civilization which is manipulating possibly thousands or millions of twits of energy is not so ridiculous. To accelerate a space colony for 10^4 people to 0.1c requires only about a hundredth a twit year. So it's really a very small amount of energy compared to the amount of energy that a planetary wide civilization could use.

While I'm inclined to think that the interstellar colonization will take place, the fact remains that we haven't been colonized. If there are other civilizations they probably could, if the were willing to spend the money, embark on interstellar colonization. For whatever reason they have not colonized our system. But they still may be out there and we should think about what really large civilizations might look like. Years ago Dyson suggested that an advanced civilization might use all of its star's energy output which would ultimately be dumped as waste IR. I suspect that a civilization will never reach this point of energy saturation. Just as we are embarking on space colonization when our energy use is less than a millitwit, an advanced civilization would probably use only a small part of their star's output. Still one sign of an advanced civilization would be a star with an infrared excess as in this figure where there is an IR excess amounting to,say, 10^{-5} $L_\star$. The spectrum of this sort of Dyson/O'Neill civilization might look like that in Fig. 1.

Many such stars have been detected by IRAS and the spectrum shown is that of Vega. If the IR excess is due to space colonies, the first question that comes up is why it is so cold, since the IR radiation temperature is 85 K. The answer to that is contained in the first five minutes of *The Graduate* where someone says that the future can be described with one word, "PLASTIC." We're evolving already to a state where our main building materials are plastic. Where in the Solar System do we find the most material out of which to make plastics? Where it is 85 K — Jupiter, Saturn. So these guys are living in plastic space colonies out where they find most of that kind of material. How many

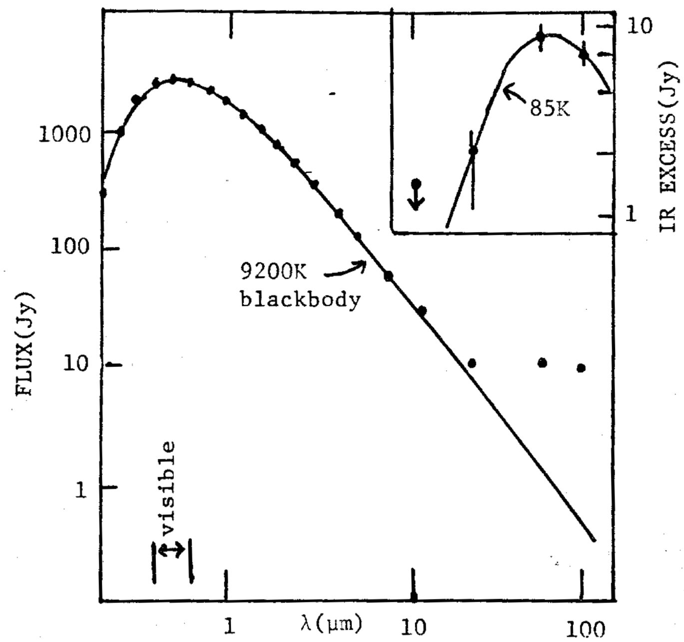

FIGURE 1. The spectrum of a hypothetical extraterrestrial civilization. Indeed we may have found such a civilization, since the plot actually shows the spectrum of Vega.

there are? If the energy use of each Vegan is expressed in units of our personal energy use (1 PPEC $\sim$ 10 kw) then the population is

$$\text{Population} = 3 \times 10^{19}/(\text{E use per Vegan/PPEC})$$

The total mount of mass in the colonies

$$M_{\text{colonies}} \sim \frac{0.05 M_{\oplus}(\text{mass per Vegan/PPOM})}{(E \text{ use per Vegan/PPEC})}$$

So the population depends on what you wish to assume about their average energy consumption but is probably huge by planetary standards. Still the mass required is modest. While it is natural to interpret infrared excess as dust, we must remember that space colonies also have a very large surface area to mass ratio.

They may be doing other things. For instance, they almost certainly are beaming energy from one place to another, probably in the form of microwaves, the frequency of which is chosen for engineering reasons. Because they don't want to waste the energy it's going to be as high a frequency as possible to achieve a narrow beam. Just as an example, suppose they have a one twit beam that they are beaming some place through their stellar system and that it has a bandwidth of 100 megahertz at an opening angle 10^{-8} radians (which is very narrow but can be done). If one happened to be pointed toward the earth, it could produce the signal 10^{16} Jy in millimeter range probably. Civilizations, once they are space dwellers, probably couldn't care less about what's happening on the planetary surfaces. They probably deal with very much higher frequencies than we are normally thinking about.

Let me bring up a final point. Could they possibly be broadcasting *SETI* signals to us? I have much less faith in the good nature of extraterrestrials than most people do. I can't help but wonder what's in it for them. We have trouble mustering funds to listen.

Can you imagine the response of the politicians today to an effort to get funds, the much larger funds, required to broadcast? To broadcast for centuries? The politicians always ask, "What's in it for us?" What's in it for the Vegans? I don't know. What kind of free radio do we get on Earth? Most is commercial, which won't apply to interstellar communication because there is no interstellar commerce. But you can have commercials for ideas. It seems to me if there are actually conscious signals directed at planetary surface dwellers, they probably fall into two classes: interstellar Jerry Falwells who are trying to sell us their religion or possibly interstellar propaganda where they are trying to sell us their politics. This brings up a paranoid side of my view of extraterrestrials. The Vegans, if they exist, are interstellar colonizers since they must have migrated from a longer lived star. Still they and all other civilizations, every one, for some reason or another have decided not to colonize the earth and probably other planets. They'd realize that any new civilization may not share that ideal. The newcomers may wish to colonize every star: to grow like cancer throughout the galaxy. Maybe they are trying to convince us that we shouldn't grow like a cancer completely throughout the galaxy. I have tried to be provocative. I present these ideas not to denigrate the current SETI effort, but to stimulate a broader approach to the problem. In particular, I think that we should think about civilizations not living on planets, and not necessarily living near solar type stars. Such civilizations may have engineering projects which make them detectable without having to rely on their good will.

W. Mook: How much energy is required to move an asteroid from one orbit to-the other? For example, what would take an asteroid and move it into orbit around the earth?

The energies are huge and that's why I think that civilization will go to where the asteroids are. Initially, as we grow away from the earth we will be attracted to the idea of capturing asteroids, but eventually we will move to where the material is.

W. Mook: So item number 2, what is the total mass required to get a self-sufficient civilization. I mean is there an estimate on the total mass required? Like if it's everybody on earth that's such a large amount.

Most of the people living in space are like most of the people living here, they're born there. You take the genetic material, not the inhabitants.

W. Mook: Right, but when Columbus came to the Americas there was, you know, the same ecosphere. I was trying to figure out what the total mass is and then relate that to the total energy requirement that would have to be input by the originating civilization. If this requirement is greater than that available to the planet dwellers for starters, then it won't get started.

C. Seeger: I have a suggestion. This evolves down to numbers somewhat and also to what I call technological religion and should be carried on outside. I would like to make one comment myself. There sometimes is the thought that civilization is defined by technology. Technology is not all of civilization but that seems to be all there is in the O'Neill scenario.