**A Probabilistic Upper Bound For The Likelihood Of Humans Attaining Galactic Colonization On Any Timescale Using Anthropic Reasoning**

*Sean Ghaeli, 2019*

## 1 Abstract

This text investigates the prevalence of civilizations that have attained galactic scale (type 3 Kardashev) colonization, and with it, makes an attempt to determine the likelihood of human civilization advancing to such a scale from its current status. We start by modelling a hypothetical type 3 civilization such that they satisfy two conditions: colonize all habitable planets within their galaxy and fill each planet to its respective carrying capacity. Quantifying the average value held by these two conditions and computing their product yields an average cumulative population of 40 quintillion intelligent residents. We now model a type 1 Kardashev civilization, which is defined to control the free energy of its host planet, such that it has reached its planet's carrying capacity, which we reason to be about 10 billion on average. Based on the models, a type 3 civilization is 4 billion times more heavily populated than a type 1 civilization. If, at random, we were to pick a random conscious intelligent observer in the universe at any time or place, there would need to be 40 million type 1 civilizations for every single type 3 civilization for there to be a 1% chance of selecting an observer that is a member of a civilization between type 0 and 1. Following the Copernican principle, our observation as humans need not be any more improbable than necessary to explain our observations. Knowing that we are indeed members of such a civilization between type 0 and 1, we must acknowledge that, under our modelled Kardashev civilizations, there must be at least 40 million type 1 civilizations for every type 3 civilization. Indeed, since any type 3 civilization must first start from scratch, we can also deduce that there is a negligible chance that humans go on to maximize their population within the galaxy.

## 2 Introduction

If we are to take example from our own experiences as humans, one common trait we all possess is the desire to obtain as much resources, territory, and overall control as possible. We favor control even at the expense of other lives, in many cases. Throughout all of history, our fight for control has been limited to the resources of the earth, but as time progresses and our horizon expands, our future as a civilization will shift towards the stars, as we take up extraterrestrial residence. As such, our struggle for power will no longer be limited to the resources of the earth, but rather our stellar neighborhood, and potentially one day, our entire galaxy. The "Kardashev scale" sorts civilizations into classes, or types, based on their power output [**cirkovic**]. A type 1 civilization, as rated by this scale, is one that can use and store all of the energy available on its planet. A type 2 civilization can control the energy at the scale of its solar system. A type 3 civilization can control energy at the scale of its entire host galaxy. There is quite a leap between the level of advancement of various types of civilizations, because the Kardashev scale is logarithmic. For that reason, civilizations need not fit exactly into type 1, 2, or 3. In fact, they can be some real number between 0 and 3. We justify using the Kardashev scale because the energy output of a civilization is proportionally related to its relative advancement, and is thus a reasonable metric by which to rank various civilizations. For reference, it is estimated that humans are not quite a type 1 civilization [**sagan**], and it will be at least 100-200 years before humans attain a type 1 status [**kaku**]. This begs the question: will humans ever attain galactic domination, securing themselves as a type 3 civilization?

## 3 Method and Results

Let's model a type 3 civilization that has maximized its population; such a civilization will have taken up residence wherever life can be supported across their entire galaxy. The population of such a civilization can be estimated by the amount of habitable planets within their reach multiplied by the average carrying capacity of habitable planets. It is worth keeping in mind that even this would not be the upper bound for a civilization of such advancement, because we are assuming that they only take up residence in planets abiding by today's definition of habitable. Nonetheless, let's conduct an estimate for our hypothetical type 3 civilization:

$$(\#\ of\ habitable\ planets) \times (avg.\ carrying\ capacity\ of\ habitable\ planet) = (population\ of\ type\ 3\ civilization)$$

Indeed, every planet has a carrying capacity, because resources are finite [**bearrintoul**]. With unlimited resources, exponential growth of population can continue indefinitely. However, since that is not the case, every planet, including Earth, has a maximum amount of life it can harbor. This so called carrying capacity is based on many complex factors, including surface area of habitable terrain and amount of basic resources required for life. Greatly simplifying, out of all of the factors that contribute to a carrying capacity, it would be the singular factor that can support the lowest number of people, a limiting factor, that leads to a carrying capacity. For example, if the limiting factor for a given planet is surface area of habitable terrain, which allows for a maximum of $\boldsymbol{x}$ people, then the carrying capacity of that planet would be $\boldsymbol{x}$.

Some scientists estimate that the carrying capacity of the earth will be around 10 billion humans [**taagepera**]. It would be tricky to accurately estimate what the carrying capacity of an average habitable planet is, however, we can make a guess for the lower bound. First, we must generalize what the average habitable planet may look like by discussing what counts as a habitable planet. For our purposes, we will say that any earth-sized planet orbiting in the habitable zone of sun-like stars and red dwarfs counts. Some examples that fit under the above criteria are Earth, Mars, and Kepler-442b. Let's say that the limiting factor for the carrying capacity of a given planet for a type 3 civilization is the surface area of habitable terrain, rather than the resources required to support life or another potential factor. We make this assumption because a type 3 civilization has access to the resources provided by stellar dust, meteors, stars, etc. Meaning that it will not be bounded by the resources that are found only on planets. Even still, making such an assumption, it is not easy to make an estimate for what the surface area of habitable terrain is. Since each of the planets in consideration are earth-sized, let's take an average of 10 billion as the carrying capacity, which is earth's estimated carrying capacity. This number is subject to correction as our research regarding exoplanets improves, as many earth-sized planets may be entirely covered by liquid, while some may contain far more land than earth does, an example of which being mars. Still, our number of 10 billion is quite probably a lower-bound estimate, as such a civilization will have found methods to maximize the carrying capacity of a given planet. As such, we have found one number to plug-in for the above equation and can now write:

$$(\#\ of\ habitable\, planets)\ \times\ (10\, billion)\ =\ (population\ of\ type\, 3\, civilization)$$

In the milky way galaxy, there is an estimated 200 billion stars, about 10% of which are considered to be sun-like stars. From these sunlike stars, about 20% of those host an earth-size planet in the habitable zone [**petigura**]. The following calculation gives us a number for the average amount of habitable planets:

$$200\, billion\ stars \times \frac{1\ sun-like\ star}{10\ stars} \times \frac{1\ earth-size\ planet}{5\ sun-like\ stars}\ =\ 4\, billion\ earth{-}sized\, planets\ orbiting\ sun{-}lik$$

And now we can plug in to our initial equation yielding:

$$(4\, billion)\ \times\ (10\, billion)\ =\ 40\, quintillion$$

This is our estimate for the cumulative number of intelligent beings alive in a hypothetical type 3 civilization that has maximized its population in the milky way. This estimate is on the lower end, seeing as our calculation for the carrying capacity of a planet and number of habitable planets is based on technologies achievable by humans today, not reflecting what would be possible for a type 3 civilization. Now that we have come up with an estimated lower-bound population, we can move on to the main point of the paper. For a type 1 civilization, which controls the free energy of its host planet, it follows that such a civilization has reached the carrying capacity of its planet, which we will again say is an average of ***10 billion***. We can show how many intelligent beings there are in a type 3 civilization for each intelligent being in a type 1 civilization:

$$40\, quintillion\ \div\ 10\, billion\ =\ 4\, billion$$

There are ***4 billion*** intelligent residents in a type 3 civilization for each intelligent resident in a type 1 civilization. Bear with me here, if there were an equal amount of type 1 civilizations as there are type 3 civilizations, and we were to randomly select 4 billion intelligent observers, on average only one of the selected observers would belong to a civilization between type 0 and 1. The definition of a civilization of type 0 is not traditionally defined in the Kardashev scale. It is a civilization with an energy signature equal to or less than 1 megawatt, which we will take as a non-intelligent civilization, in its microbial phase. We can model a probability density function for such a situation:

Which is a best-fit curve of the following points:

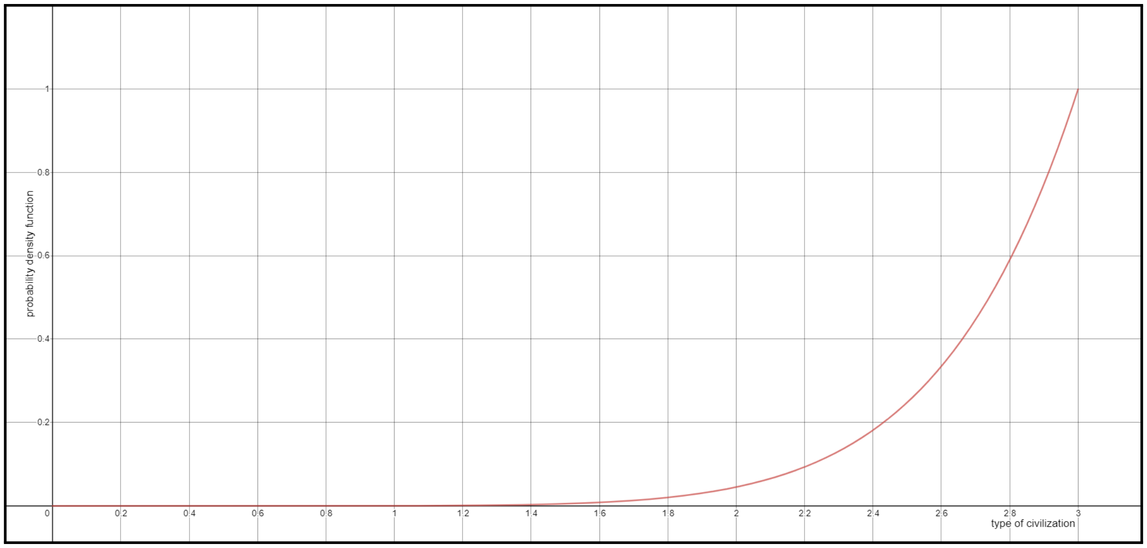



Figure 1: probability density function of population graphed across types of civilizations (kardashev scale)

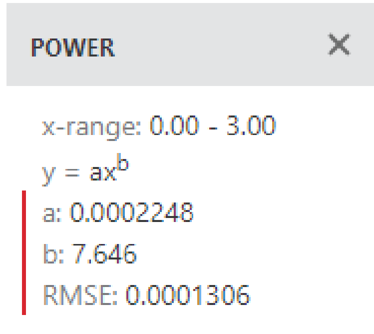
| | Data Set 1 | |
|---|---|---|
| | X | Y |
| 1 | 0 | 0.000000000 |
| 2 | 1 | 0.000000004 |
| 3 | 3 | 1.000000000 |

And yields the best-fit equation:

Now, if we were to select an observer at random in a situation where the *number* of civilizations between 0 and 3 is uniform, this probability density function represents the likelihood of selecting an intelligent observer in a civilization of a given type. Once again, if we were to randomly select 4 billion observers, on average only one of the selected observers would belong to a civilization between type 0 and 1.

However, clearly it cannot be the case that there are the same amount of type 3 civilizations as there are type 1. Before becoming type 3, a civilization must start from scratch, and extinction at any point would eliminate them. Clearly, less civilizations that make it to type 1 will make it to type 3. Therefore, the distribution between the *number* of civilizations between 0 and 3 cannot be uniform, and it must be decreasing in some fashion. If there were to be 40 million times the *number* of type 1 civilizations for every type 3 civilization, we could once again model the situation in terms of a probability density function:

Now, if we were to select an observer at random in this new distribution of the *number* of civilization types, we would only need to select 100 random intelligent observers on average for one of them to belong to a civilization between type 0 and 1. In other words, the area under the graph between type 0 and 1 is 1% and the area under the graph between type 1 and 3 is 99%. Keep in mind, humans are a civilization between type 0 and 1, and each human




is an intelligent observer. Our chance of being born at all is already unfathomably scarce. The Copernican principle, that our observations of the universe are no more unlikely than necessary, was first used to demonstrate the principle that the earth does not hold a privileged position in the universe, and in fact revolves around the sun moves rather than vice versa. Let's now use it to demonstrate that we humans, as a civilization, do not hold a privileged position in the universe. In the scenario we have laid out, if we were to run the universe 100 times through from its beginning to now, we would on average emerge within a type 0 to 1 civilization exactly one time. If it was any less likely to emerge within a civilization between type 0 and 1, it would begin to go against the Copernican principle that we are observing reality from a fundamentally improbable situation. This occurs when there are a minimum of 40 million times the amount of type 1 civilizations compared to type 3 civilizations. Seeing as any type 3 civilizations must first have been a type 1 civilization, only one in 40 million type 1 civilizations go on to make it to a type 3 civilization that maximizes its population. This is the best-case scenario too, so in all reality, it is actually far less likely than this, and quite possibly impossible. In fact, such a result is fully consistent with our complete lack of observations of a colonized galaxy, or for that matter, any extraterrestrial life at all.

## 4 Conclusion and Discussion

These results have a tremendous range of implications. One of the fundamental questions humans have been asking since the dawn of thought is, "where are we going?" Up until now, this debate has been subject to exclusively speculative arguments. This paper has provided an approach to a quantitative upper limit for the prevalence of galactic civilizations that maximize their population, and inherently, the probability of humans achieving the same feat. We see that the chance of this is astonishingly slim, hinting that such a final stage for humanity is not realistic. However, the results of this paper should not be misinterpreted: it does not provide insight as to the maximum Kardashev type that will be achieved by humans and does not indicate some sort of great filter [**to be found1**]. In all likelihood, there are many reasons for a type 3 civilization not to fill each planet to their respective carrying capacity. The primary conclusion of this paper is that a civilization of galactic scale that maximizes their population is a highly unlikely type of civilization. Considering such a civilization would be the easiest to detect throughout the universe, this conclusion is consistent with our complete lack of observation of such a civilization, which resolves one of the main points of the Fermi Paradox. This paper should not be a source of pessimism or nihilism towards the future of human civilization, but rather narrow down the spectrum of possible timelines to a more realistic scope. The following is a list of popular solutions for the course of humanity's future, which we will not attempt to analyze: biological life is partially or fully replaced by artificial life [**to be found2**] on the road to becoming type 3, or a great filter is reached such as galactic traveling being too energy costly, or we are living as boltzmann brains [**boltzmann brain**]. This paper eliminates one possible course of events for the future of humanity, but the only way to find out what will truly happen is to wait and find out.

The purpose of this paper is not to provide hard empirical numbers on the matter, but rather to provide a framework for the discussion of any civilization, including humans, colonizing their host galaxy by means of maximizing population of each habitable planet. We have built this framework through probabilistic reasoning by extending the Copernican principle. What would be interesting to find out is how many type 1 civilizations exist for every type 0 civilization, which is a civilization with an energy signature less than 1 megawatt, which we can take as a non-intelligent civilization in its microbial phase. Such information would yield the fraction of planets with life that go on to develop intelligent life, otherwise known as the $f_i$ term in the drake equation [**drake**]. Regardless of the behavior of the drake equation, which determines the relative occurrence of intelligent civilizations, we show that a galactic scale civilization that has maximized its population is still a highly unlikely destination for any civilization, including humans. This is to mean that whether the universe is teeming with life or scarcely inhabited by life at all, we invoke the Copernican principle to argue that there is a negligible chance of a civilization, throughout the entire course of the universe's future timeline, to ever inhabit their entire galaxy by maximizing its population on each planet.

## 5 Bibliography