TN2002-1: SETI's Copernican Que[1]

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10 February 2020 (V21feb20)

Abstract

The Milky Way (MW) is essentially in steady state and has been so for at least the last five billion of its 13.5-billion-year lifetime. This major assumption, as it applies to the birth of MW's new star systems, allows examination of galactic events that have been going on with great regularity for some time. Among such events are the comings and goings of ET civilizations. Here we analyze the portents of SETI from a copernican perspective taken by a typical observer civilization in a typical star system that is approaching the end of its bio-life phase, during which we have made ourselves very visible and now seek to discover other such visible ETIs. To evaluate the prospects of achieving this, we introduce tools from data networks and queing[1] theory which seem to be particularly useful and revelatory about existing strategies for capturing and classifying ET techno-signatures. The developed results provide a straightforward and plausible quantitative answer to Fermi's question, even though there may well exist millions of ETI civilizations in our galaxy.

Introduction

Since my previous foray into Fermi's famous query, I have had occasion to reconsider the numbers that I generated in [1] when first applying copernican arguments to the sound of silence experienced by the various Search for Extraterrestrial Intelligence efforts that started about the middle of the last century. My conclusion was that, albeit the dismal results I introduced on my blog (here) to explain away the SETI experience, these were still too hopeful. The previous work definitely made me a philistine among the dedicated throngs searching the heavens for evidence of ETI. Unfortunately, what I present here will reinforce my reprobate status.[2]

Support for a copernican perspective and approach to SETI were presented in [1]. A similar, but more complexified, approach [5] was published by Grimaldi et al (2018) that focused its development on estimates of Drake's *N* through a significantly different scenario of EM "shells" propagating from ETI civilizations. Here we proceed to prognosticate probabilities of Earth receiving any ETI transmissions in the current epoch.

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[1] To many of us the spelling of 'queue' and its variants arguably contain cynical, insidious, and unnecessary sprays of extra letters that serve no purpose save to confuse the young and the unwary, and cement the belief that English is a most perfidious language. A natural and readily acceptable remedy is to spell them as 'que' and 'queing', which are phonetically more proximal and semantically unoccupied literal strings that invite beneficial uses such as in this report.

[2] The overarching purpose of this technical note is to introduce a more straightforward, and hopefully more elegant approach to assess the utility of long-standing attempts to capture incoming EM techno-signatures for subsequent analysis and discovery of the existence of ETIs. The numerical values used in this treatment are part of my currently preferred scenario, and they may readily be replaced by other researchers with their own desiderata.

To review some of the salient factors, we again consider that we live in an 13.5G year-old galaxy that formed along with billions of others in that epoch after the Big Bang of 13.8G years ago. The Milky Way (MW) gave birth to our sun and its orbiting planets about 5G years ago. Today, by all counts, we see that the MW is an ordinary galaxy like billions of others, and our sun is a very ordinary G-type main-sequence (G2V) garden variety star. And its inventory of planets is of the type and with orbits replicated by more billions of exoplanets throughout the MW and countless other galaxies. In short, there is no *a priori* reason to believe that we are anything special in the universal scheme of things – ergo the copernican perspective.

To be more specific, our MW has somewhere between 200G-400G stars - in the sequel we will use the conservative lower bound. Around these stars orbit more hundreds of billions of planets of which about 11G are today considered to be of the type and in habitable or 'goldilocks' orbits that would support the kind of life found in Earth's biosphere. (more here) We take these propitious exoplanets to be distributed more or less uniformly within the MW, which for our purposes measures 160Kly in diameter, is about 2Kly thick, and has a dense central bulge (or bar?) 15Kly in diameter. The astronomy industry has been of two minds as to the formation rate of MW stars – one school sees it as having had a bursty history (here), another asserts that the formation rate has been in a steady state for some time now giving birth to about 7 new star systems per year. (more here) Here we proceed with the latter hypothesis.

Such an enduring, steady state formation rate of planetary systems supports the argument that a proportion of these systems will eventually give rise to and nurture life that ultimately then becomes intelligent in the sense experienced by Earth. And after an appropriate gestation interval – ours took about 5Gy - such life will coagulate into civilizations that develop technologically to a stage that inaugurates the transmission of EM annuli or photonic ripples (Grimaldi's shells) as described and illustrated in [1], [5]. Each such civilization will thus transmit its ripple before 'blinking out' either 1) by destroying itself, or 2) achieving a super-intelligent, post-bionic (post-Singularity?) existence wherein its communications and data exchanges no longer involve spraying energy in all directions from their home planet(s).

In our scenario the receipt, search, detection, and classification of EM techno-signatures is possible only when Earth is being bathed in one or more of such expanding ripples. Within this preamble we also conclude that the ripples which may now be transiting Earth or will transit our planet in the future are all at most 110Ky old. In cosmic time that makes such ETIs contemporaneous to our own civilization, thereby lending more weight to the copernican appeal.

To assess any approach to SETI, that involves the directed capture of such EM techno-signatures, requires estimating a joint probability of events which, for illustration purposes, we limit to the above-mentioned functions – receipt (R), search (S), detection (D), and classification (C). We express and expand this distribution formally as

$$P(R,S,D,C) = P(C \mid R,S,D)\,P(D \mid R,S)\,P(S \mid R)\,P(R) \tag{1}$$

Since the entire SETI enterprise starts with being in possible receipt of a techno-signature, in this report we will introduce a new approach to computing $P(R)$, taken variously, the probability that Earth has recently been, is now, or soon will be in at least one ETI ripple. In a future effort we will present a satisficing Bayesian search model that allows us to compute $P(S|R)$. A rich literature already exists in signal understanding – detection and classification – which can be used to calculate $P(D|R,S)$ and $P(C|R,S,D)$.

Computation of $P(R)$

The 7/yr steady state galactic birth rate must now be reduced by factors of proximity and probabilistic resources available to generate life on habitable planets. As a first cut (to be refined later), we illustrate this proximity in Figure 1 (Figure 4 in [1]) which shows the 40Kly radius circle surrounding Earth which contains roughly ¼ of the MW stars, with about 2.75G of them being habitable. We further argue that a generous estimate would have only one in a thousand of these being lucky enough (with 'probabilistic resources') to have given rise to an ETI. That means one half of these 'lucky stars', along with Earth, or 0.5*2.75e9*1e-3 = 1.375e6 (more compactly expressed as $5^{\backslash -1}2.75^{\backslash 9}1^{\backslash -3} = 1.38^{\backslash 6}$)[3] proximal stars have already served as nurseries to launch ultimately intelligent life. These ETI stars number enough to support the main thesis developed here.

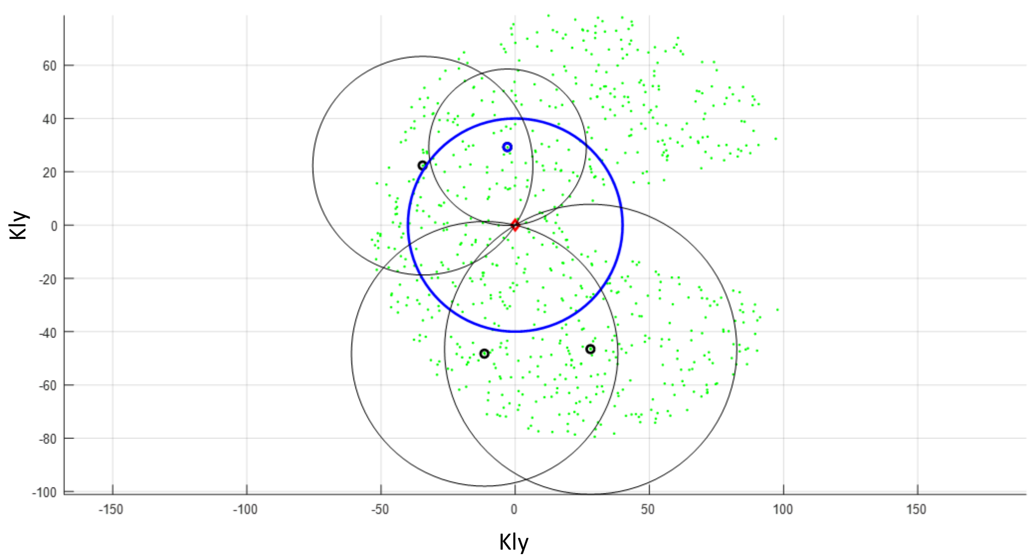

Figure 1

From Figure 1 we have a picture of Earth (red dot) being illuminated by four ripples containing ET techno-signatures. These ripples are generated randomly and independently of each other, necessarily arriving at Earth at a constant average rate λ_0 dependent on λ. Furthermore, each ripple has a random width of L (here averaging 200ly) defined by an appropriate distribution of, say, a truncated gaussian or a Weibull.

[3] As appropriate, in the sequel we will use $a^{\backslash b}$, = a*10^b (read 'a slash b'), the engineering 'backslash notation' to conveniently and compactly indicate numbers large and small.

From [2] we now view such arrivals as a stochastic process driven by a counting function $A(t)$ that takes on non-negative integer values for $t \geq 0$ such that $A(0) = 0$, and gives the total number of arrivals during the interval $(0, t]$. For $s < t$, $A(t) - A(s)$ equals the number of arrivals in (s, t]. When the number of arrivals that occur in disjoint time intervals are independent, as with the arrival of ripples in our case, then we have an ongoing Poisson process with mean rate λ. This means that the number of arrivals n within an interval τ is Poisson distributed, where for all times and intervals $t, \tau > 0$, the probability of n is given by

$$P(n) = e^{-\lambda\tau} \frac{(\lambda\tau)^n}{n!}, \quad n = 0,1,2,... \tag{2}$$

The interarrival times of a Poisson process are independent and exponentially distributed with parameter λ. This says that if t_n is the nth time of arrival, then the mutually independent intervals $\tau_n = t_{n+1} - t_n$ have the probability distribution

$$P(\tau_n \leq s) = 1 - e^{-\lambda s}, \quad s \geq 0 \tag{3}$$

The related probability density function is $p(\tau_n) = \lambda e^{-\lambda\tau_n}$ with the mean and variance of τ_n being $1/\lambda$ and $1/\lambda^2$ respectively.

This understanding of the ETI ripple arrival process immediately invites investigation of queing theory to see if any of its results can be mapped into a useful model for calculating the $P(R)$ in (1). From examination of various que/server configurations [2], it turns out that the 'system of Earth' being intercepted by ETI ripples is a perfect analog of the $M/G/\infty$ system in a data network. Here M is the above-described memoryless arrival process into a single que that is serviced by an infinite number of servers (therefore zero waiting time in que) whose non-negative random service rates can be described by any suitable or general (G) probability distribution (e.g. Weibull). (see [2] p138)

If μ is the mean service rate, then $1/\mu$ is the mean service duration, in our case the analog of this turns out to be the length of time required for any single arriving ripple to pass Earth. Using the above assumptions, this gives $1/\mu = L/c$ yr, or $\mu = 1/L$ yr^{-1} since c = 1ly/yr. Using the $M/G/\infty$ model, we can calculate the probability of n of arrivals currently being serviced 'in the system' or, in our terms, the number of ripples concurrently illuminating Earth, as

$$p_n = \left(\frac{\lambda}{\mu}\right)^n \frac{e^{-\frac{\lambda}{\mu}}}{n!}, \quad n = 0,1,2,... \tag{4}$$

Of great interest to us will be the calculation of p_0, the probability that no ETI ripples are currently passing Earth, or conversely $1 - p_0$, the probability that we are being illuminated by at least one ripple. From (4) we have $p_0 = e^{-\lambda/\mu}$. We can now write a desired form of $P(R)$ as

$$P(R) = 1 - e^{-\lambda/\mu} \quad (5)$$

And with (4) we may also calculate N, the current expected number of illuminating ripples as

$$N = E(n) = \sum_{n=0}^{\infty} np_n = \frac{\lambda}{\mu} = \frac{\lambda L}{c} \xrightarrow{c=1ly/y} \lambda L \quad (6)$$

Then using the celebrated Little's theorem of queing theory to compute T, the average 'delay' an arrival spends 'in the system', we have

$$N = T\lambda \to T = \frac{N}{\lambda} = \frac{1}{\mu} = \frac{L}{c} \ , \quad (7)$$

which is indeed the average time that it takes a ripple to pass Earth, and is consistent with the development of this approach.

With these mathematical tools in place, we can now sketch out a numerical scenario that will enable their use to answer some interesting questions. Returning to the 7/yr formation rate of star systems over the entire MW, what we need from this is the reduced actual arrival rate λ_0 that we experience from our 40Kly neighborhood of ETI civilizations. In short, we must use the proximal area fraction $f_A = 0.228$ to reduce that rate to 1.594/yr from within our detectable neighborhood – i.e. the blue circle now reduced by the noise intensive sector that looks into the central bulge in Figure 1. We then reduce this rate to account for the small fraction f_H of habitable ('goldilocks') planets therein, and then reduce it once again to account for the even smaller fraction f_{ETI} of those planets spawning civilizations that may have transmitted techno-signature ripples. We will use λ = 7/year in the sequel, and calculate $\lambda_0 = f_A\, f_H\, f_{ETI}\, \lambda$, the actual average rate of ETI ripples bathing Earth.

As noted above, in our scenario f_H = 11G/200G = 0.055, the ratio of habitable to total stars in the MW. The value of f_{ETI} is perhaps the hardest to estimate. We proceed as follows. During its 13.5G year lifetime the MW has produced at least λ13.5G = 95G new star systems. From this large population we can assume that the average birth rate of habitable systems in the MW has then stabilized after about 8G years to $f_H\, \lambda$ = 0.385/yr. It is this rate that characterizes and originates the MW's pipeline of potential ETI civilizations which ultimately then transmit their techno-signature bearing EM ripples.

To back into a usable estimate of f_{ETI}, we note that there are f_A*200G = 45.6G star systems within 40Kly of Earth. From these we expect f_H*45.6G = 2.51G exoplanets to be in habitable zones. A fraction of these incubate life and feed into the pipeline of ETI civilizations that are potentially detectable from Earth. We retain the generous[4] estimate of $f_{ETI} = 1^{\backslash -3}$ (0.001), or one in a thousand of these habitable exoplanets developing an ETI civilization. This would still yield an acceptable number of about 2,500,000 such planets. Over the last billion or so years, one half of these or 1,250,000 would already have emitted their EM ripples to sustain λ_0, the steady state average arrival rate that we experience on Earth today, and which we now calculate as

[4] Generous in the sense that it will yield a higher probability of Earth being in a ripple than would a smaller f_{ETI}.

$$\lambda_0 = f_A f_H f_{ETI} \lambda = 2.28^{\backslash-1} 5.5^{\backslash-2} 1^{\backslash-3} 7 = 8.78^{\backslash-5} /\mathrm{yr} \tag{8}$$

And this allows the calculation of $P(R)$ from (5) as

$$\begin{aligned} P(R) &= 1 - e^{-\lambda/\mu} \Rightarrow 1 - e^{-\lambda_0 L/c} \\ &= 1 - \exp\left(-8.78^{\backslash-5} 2^{\backslash 2} / 1\right) = 0.017 \end{aligned} \tag{9}$$

This says that at any time we scan the skies, there is less than 2% chance of Earth being inside one or more ETI ripples from which one may hope to capture and discover a techno-signature. Using (3), we calculate the probability that the next photonic ripple will arrive within 80 years, i.e. before the end of this century, as

$$P\left(\tau_n \le 80\right) = 1 - e^{-\lambda_0 80} = 0.007 \ . \tag{10}$$

Burke [1] has shown that Poisson processes also allow retrodiction due to their memoryless property. We can then look back in time and explain the 'SETI silence' we have experienced over the last, say, 70 years. We compute the probability that the previous ripple arrived more than $L + 70 = 270$ years ago[5] as

$$P\left(\tau_{n-1} > 270\right) = e^{-\lambda_0 270} = 0.977 \ , \tag{11}$$

which we may use as a supportive explanation for the experienced Fermi paradox.

Variations on a Theme

As recognized above, f_{ETI} is the unknown factor central to these numerical results. Above we posited $f_{ETI} = 1^{\backslash-3}$, but what if we are too conservative with this estimate – meaning, not generous enough. What if every tenth or hundredth habitable exoplanet was fortunate enough to produce an ETI civilization? On the other hand, what if ETI civilizations are much rarer than one in a thousand. In short, we should look at the impact of f_{ETI} over a range of values from, say, $1^{\backslash-1}$ to $1^{\backslash-6}$. We examine this range in Figure 2.

Similarly, we should examine the impact of a reasonable variability in the value of L (the analog of service duration for arriving ripples). Looking at our own history of barely avoiding destruction and progress toward the Singularity, a range of 50 to 500 years seems appropriate. We could have effectively destroyed ourselves as soon as 50 years after commencing radio broadcasts around 1920, and most certainly we will achieve a community of trans-humans and super-intelligent machines, if not the Singularity itself, within 400 years from now after having already completed one century of omnidirectional broadcast of EM transmissions. What is the $P(R)$ that we are within a passing ripple now if the mean value of L covered such a reasonably large range of values? This important probability is shown in Figure 3.

[5] The trailing edge of the last L = 200ly ripple would have passed 1950 at least 70 years ago.

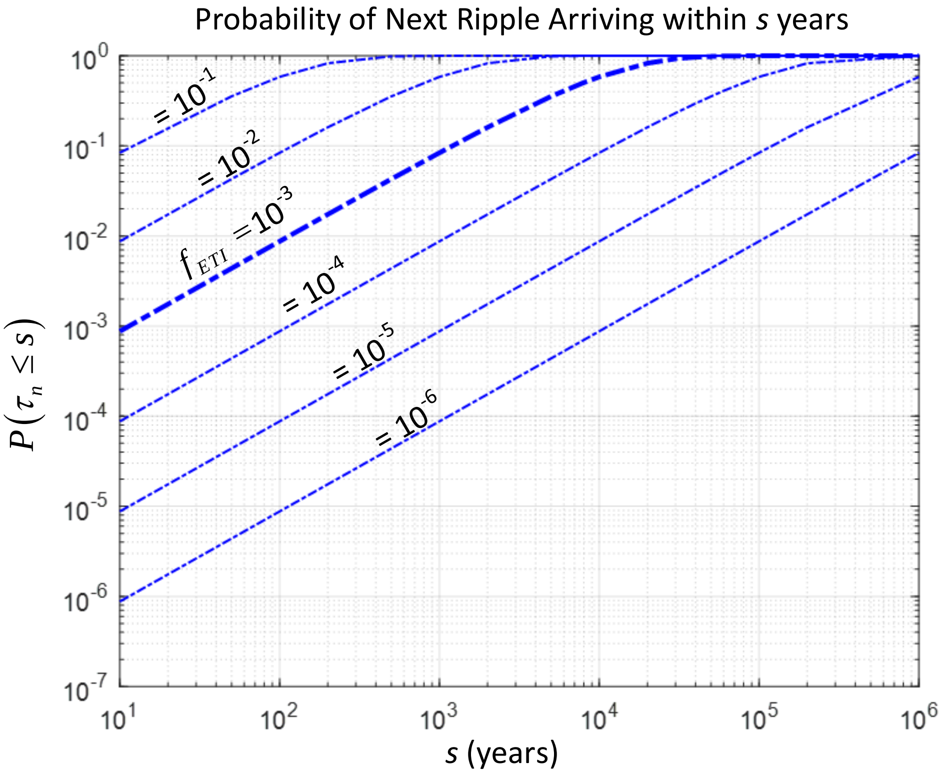

Figure 2

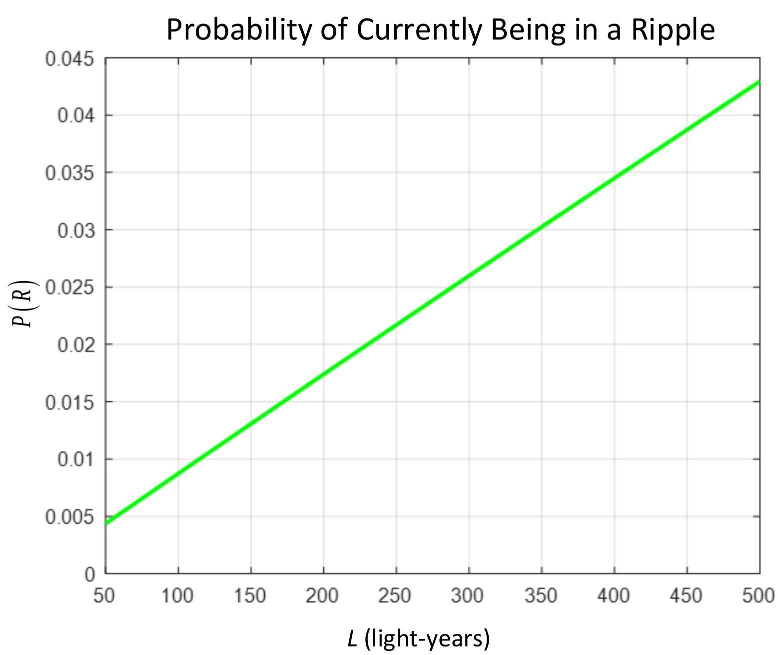

Figure 3

Conclusion

Given the parameter values used in the above nominal scenario, the Poisson process arrivals model paints a bleak picture of a successful discovery of ET techno-signatures any time in the near future. As explained, the reason is that the EM ripples emanating from ETI exo-planets are simply too few, even when we allow for millions of such life-bearing habitats within a generous detectable range in our galaxy. The main assumption that bears this out is that an ETI's continuous transmission of omnidirectional EM signals is of a relatively short duration in its course of evolution before the transmitting civilization either destroys itself (cf. 'Great Filter' [6]) or advances to lifeforms that use more directed and therefore more covert means of communication. Haqq-Misra et al also discuss the search for ET biosignatures [6]. Were the detection of such signatures sufficiently probable, then the presented model assures us that we would most certainly be illuminated by at least one such bio-ripple even if we considered that Earth-like biosignatures would take almost 5G years to develop on suitable exo-planets (e.g. L = 100Kly).

Addendum

In 1993 physicist J. Richard Gott derived a method for estimating the future time interval during which, with probability 0.95, humanity's tenure on Earth would end. The method was based on an ingenious application of the Copernican Principle. The explications of the method were somewhat cumbersome and the scope of its application seemed limited. However, upon further examination it turned out that Gott's theory is applicable to a broad range of problems that can be cast into the analysis of termination probabilities for any minimally known process (MKP). Here, an MKP is one for which we know *only* its age T. It turned out that Gott's work could be reformulated into a more accessible and intuitive format, and also extended to cover arbitrary future periods while retaining its scaling property over arbitrary time frames.[6] An added extension yielded the ability to predict termination probabilities for observed processes for which their lifetimes T_L are known. [3,4]

The reason for including this work, in the current development of techno-signature arrival probabilities, is that SETI's experienced 'sound of silence' can be viewed as an ongoing process, the age range of which we can estimate and profitably use in the reformulated and extended Gott theory (hereafter GR theory). Figure 4 shows the timeline for an MKP that started at t_S, and now at t_N is of age T and a future time interval of interest of ΔT that ends at t_F.

[6] For example, there was nothing special about Gott's confidence limits of $5.128^{\backslash 3}$ to $7.8^{\backslash 6}$ years that define the interval during which human civilization would end with probability 0.95, given that our species is now $2^{\backslash 5}$ years old. As shown in the references, one can easily calculate any number of bounded future epochs during which human civilization will disappear with probability 0.95 or any other probability for that matter. [3]

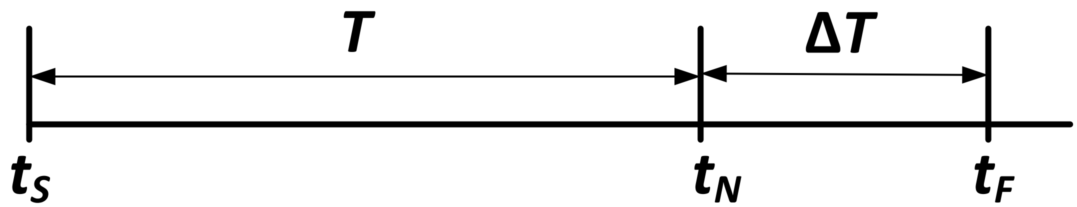

Figure 4

The probability P_E that an MKP of age T will end sometime during ΔT is shown to be

$$P_E\left(T,\Delta T\right)=\frac{\Delta T}{T+\Delta T} \tag{12}$$

An item of interest discussed above was computing the probability $P\left(\tau_n \le 80\right)$ that the silence will end with the arrival of the next ETI ripple before the end of this century – i.e. ΔT = 80. We compute the mean age of our silent period 'process' from λ_0 developed above (8), and recall that the interval between arrivals is given by the reciprocal of the arrival rate. Given the memoryless character of arrivals, this says that the last ripple arrived at Earth λ_0^{-1} years ago, or

$$T=\lambda_0^{-1}=\left(f_A f_H f_{ETI}\lambda\right)^{-1}=\left(2.28^{\backslash-1}5.5^{\backslash-2}1^{\backslash-3}7\right)^{-1}=\left(8.78^{\backslash-5}/\text{yr}\right)^{-1}=11{,}390 \text{ years.} \tag{13}$$

Which holds for our nominal scenario in which f_{ETI} = $1^{\backslash-3}$, the fraction of ETI civilizations among the Earth-proximal habitable planets. Using this value of T in (12) gives us

$$P_E\left(T,\Delta T\right)=\frac{80}{11390+80}=0.007, \tag{14}$$

Which fortuitously matches to three decimal places the value we obtained above in (10) from our application of queing theory to the ripple arrival problem. Since this value holds only for the arrival rate calculated with f_{ETI} = $1^{\backslash-3}$, the begging question is how well does GR theory comport with the above results from modeling Earth as a M/G/∞ server node in a data network. The answer is illustrated in Figure 5 where we see almost complete concordance in the arrival probabilities over the range of f_{ETI} values used in Figure 2.

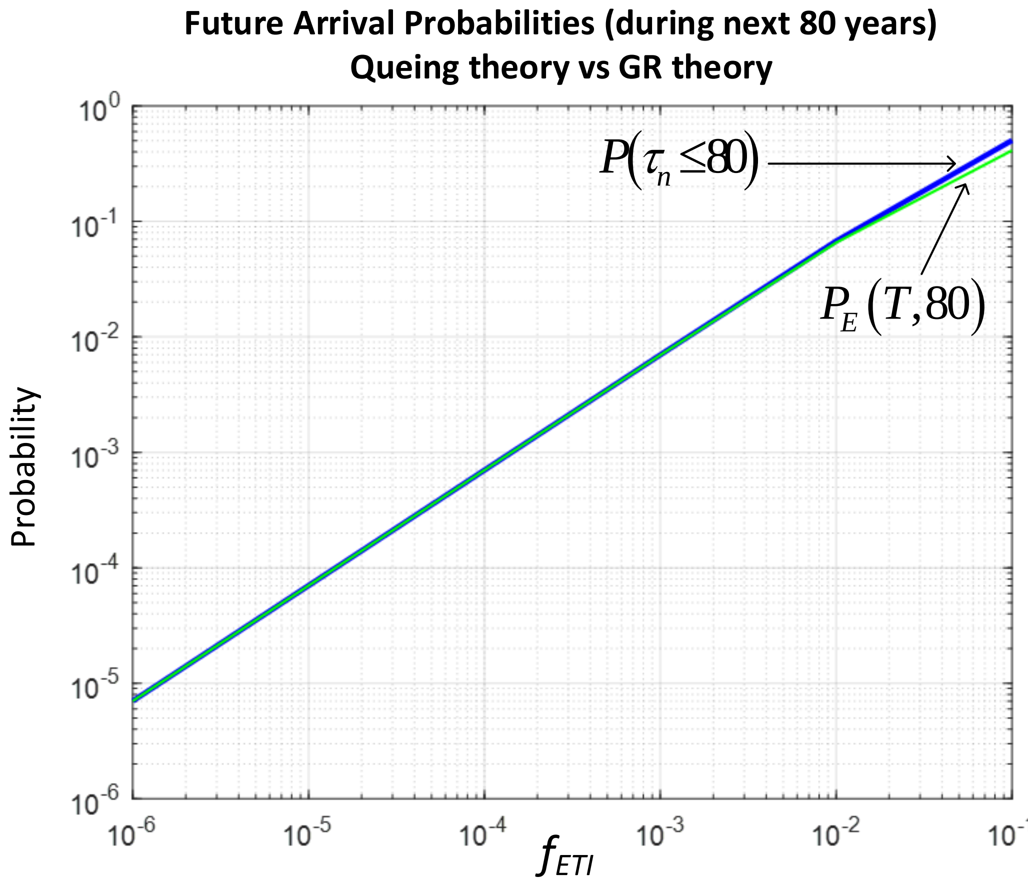

Figure 5

Upon closer examination, it turns out that the above result is to be expected when the series expansion of (10) is expressed as a function of f_{ETI} with its value approaching zero in the limit. This is shown below.

$$
\begin{aligned}
P(\tau_n) &= 1 - e^{-\lambda_0 \tau_n} = 1 - e^{-\Delta T/T} \\
&= 1 - \sum_{k=0}^{\infty} \frac{(-\Delta T/T)^k}{k!} \\
&= \frac{\Delta T}{T} - \frac{(\Delta T/T)^2}{2!} + \frac{(\Delta T/T)^3}{3!} - \ldots \xrightarrow{\Delta T \to 0} \frac{\Delta T}{T} \simeq \frac{\Delta T}{T + \Delta T} = P_E(T, \Delta T)
\end{aligned}
\tag{15}
$$

Returning to (1), we recall that our desire, and presumably SETI's objective, is to develop strategies and processes to maximize $P(R,S,D,C)$ in the near term or within the lifetime of current researchers. To base success on the receipt of ETI ripples - that must then be successfully searched (i.e. found) to yield techno-signature data from which such signatures can be detected and correctly classified - requires multiplying the above developed probabilities by these additionally indicated probabilities. That calculation would then support a more complete assessment of any contemplated and/or continuing efforts to seek ETI confirmation from the skies. And since it all starts with $P(R)$, we conclude this brief study with the reminder that the objective here has been to introduce a facile and Occam-friendly approach for computing $P(R)$, along with an invitation to redo the above calculations using updated and/or 'better' data.

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