The Fermi Paradox, Galactic Mass Extinctions and the Drake Equation

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(Dated: February 27, 2007)

The Drake equation predicts the number of extraterrestrial civilizations (N) in our galaxy who could feasably communicate with one another. Conservative estimates predict N $\gg$ 1. this conflicts with the currently observed value of N = 1. This conflict is commonly referred to as the Fermi paradox and suggests that some other factor is involved to suppress the development of intelligent space-faring life. This paper suggests that the Drake equation may, indeed require an extra parameter reflecting the possibility that an entire galaxy may suffer huge mass extinction events periodically, restraining the expansion of any intelligent life throughout the galaxy.

I. INTRODUCTION

The Drake equation allows us to estimate the number of advanced civilizations in our galaxy which may communicate with each other through technological means[1]:

$$N = R^* f_n n_e f_l f_i f_c L \tag{1}$$

Here, N represents the number of civilizations in our galaxy with which we might be to communicate at any given time, R^* is the rate of star formation in our galaxy, f_n is the fraction of those stars that have planets, n_e is average number of planets that can potentially support life per star that has planets, f_l is the fraction of the above that actually go on to develop life, f_i is the fraction of the above that actually go on to develop intelligent life, f_c is the fraction of the above that are willing and able to communicate and L is the expected lifetime of such a civilization.

The remarkable thing about the Drake equation is that by plugging in apparently fairly plausible values for each of the parameters above, the resultant expectant value of N is generally often $\gg$ 1. This has provided considerable motivation for the SETI (Search for Extra-Terrestrial Intelligence) movement.

Given the lifetime of our galaxy and the possibility of even one space faring civilization one might ask the question, how long would it take to colonize our galaxy.

In models of colonization which rely on sub-light interstellar travel, it is assumed that a colonization wavefront advances through the Galaxy as a result of each new colony sending out colonists of its own. In this case it can be shown[2] that the speed of the colonization wavefront can be approximated by

$$v_{col} = \frac{D}{(t_{travel} + t_{con})} \tag{2}$$

Where D is the average spacing between the colonies, t_{travel} is the travel time between colonies t_{con} is the consolidation time that each colony requires before it is to establish colonies of its own. t_{travel} can be expressed by $t_{travel} = \frac{D}{v_s}$, where v_s is the ship speed.

According to Crawford[3], this model would predict a colonization timescale on the order of 10^6 years regardless of whether the space vehicles used traveled at a fraction of the speed of light, or infinitely fast. This is due to the fact that for $v_s \gg 0.1c$ the t_{con} term dominates.

Current estimates put the age of the universe at around 13.6 Billion years $\pm$ 800 million. Given this huge lifetime and the comparatively short amount of time required to colonize the galaxy by a space faring civilization it seems curious that we have no evidence of a single civilization beyond our own, especially when one considers the number of civilizations predicted by the Drake equation.

II. GALACTIC MASS EXTINCTIONS

One possible explanation for the 'cosmic silence', is that life is periodically wiped out on a *galactic* scale by some super-energetic astrophysical event causing a 'Galactic Mass Extinction' (GME)[4].

A mass extinction is defined as an event which destroys more than 50% of the Earths species. On Earth, fossil evidence confirms that as many as ten mass extinctions[4] have occurred, the last being the Cretaceous period extinction some 65 million years ago. There has also been several other, less drastic waves of extinctions over the last 2.5 million years.

The cause of these extinctions has not been verified with absolute certainty but popular scenarios include asteroid impact, sea level change, continental flood-basalt volcanism and changing climate[5]. One scenario that is lacking in traditional explanations is the possibility that a mass extinction on earth is, in fact a product of a far wider reaching cataclysmic astrophysical event that destroys not only Earth life, but life within a swath of hundreds, thousands or even tens of thousands of *light years*.

A GME will hence be defined as an event which wipes out at least 50% of species within a galaxy. The cause of a GME may be a *single* super-energetic astrophysical event which single-handedly wipes out life in a galaxy, or a series of smaller, distributed events which occur with

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such frequency so that within some given time period the entire galaxy is eventually effected.

The following two sections outline astrophysical events which could, potentially, play a role in galactic mass extinctions.

III. GAMMA RAY BURSTS

An interesting possibility for the cause of the mass extinctions is a Gamma Ray Burst(GRB). Annis[4] has shown that gamma-ray bursts have the correct rates of occurrence and energetics to have destructive consequences for the evolution of life on a galactic scale.

Under this scenario a GRB occuring somewhere within the Milky Way galaxy would have a catastrophically disruptive effect on the atmospheres of planets. In the case of Earth, the possibility is that the ozone layer would be stripped leaving surface dwelling lifeforms unprotected from harmful solar radiation.

Gamma-ray bursts are the most luminous physical phenomena in the universe known to the field of astronomy. They consist of flashes of gamma rays that last from seconds to hours, and may be followed by several days of X-ray, ultra violet or optical afterglow. These flashes occur at apparently random positions in the sky about once per day.

Astrophysically plausible models suggest the present mean time between bursts within a given galaxy to be $\approx 10^8$ years, and evolutionarily plausible models suggest the rise of intelligence takes $\approx 10^9$ years.

The energy output during a burst is enormous, 10^{45} Joules over a few seconds. This is comparable to that released by supernovae. The energy output is so great that if a gamma-ray burst occurs anywhere inside the observable universe, we will eventually see it. The observed rate of about one burst a day is consistent with each galaxy having a gamma-ray burst every 3×10^6 years, given about 10^9 galaxies in the universe.

Supernova are known astrophysical events which create high energy gamma ray emissions. There are several different types of supernova, broadly classified by their rate of occurence and the amount of energy they release. Type II supernova occur with the highest frequency, about one every one hundred years within our galaxy. Their energy release is such that any Earth-like planet within a one hundred light year radius would likely experience massive ozone layer depletion and extinctions on a massive scale. Type Ia supernova have a far larger lethal range of about three thousand light years and occur with a frequency of about one every ten million years. So called hypernova are even more powerful and have a lethal range of about six thousand light years. These hypernova or 'collapsars' occur approximately once every one hundred million years. Gamma ray bursts of unknown origin occur with a frequency of approximately once every million years in out galaxy. Their lethal influence is hypothesized to be in excess of six thousand light years. Table I summarizes the different astrophysical events.

With this possibility in mind, it is interesting to note that gamma ray bursts would not only affect the Earth, but presumably other star systems which may also harbor intelligent life. It is thus plausible that the reason for the cosmic silence is quite sinister, that life is frequently destroyed by powerful astrophysical events.

IV. OTHER HIGH ENERGY EVENTS

The mechanics of GRB's as a GME mechanism has been studied in detail by Annis. There are, however, numerous events that could be responsible for destroying life. Supernova are certainly potential candiates. Type II supernova occur frequently within the Mily Way, but have limited scope for destruction (see table I). Rarer, but more devastating are the type Ia supernova which have the capacity for destruction of thousands of light years. Another, recently discovered, powerful astrophysical phenomenon is the 'hypernova'. A hypernova is a term used to describe an explosion with the energy of over 100 supernova (10^{46} Joules) and are probably caused by explosions of Wolf-Rayet stars. Hypernova are rare and it is estimated that a hypernova would occur once in our galaxy every 200 million years. It has been propsed that there is a connection between hypernova and GRB's[6].

One might even go so far as to conjecture that there are, as of yet, undiscovered exotic high energy astrophysical processes. While this is purely speculation, it is insightful to note that it was only in the last decade that hypernova were discovered. Certainly, the discipline of astrophysics is not a 'closed book' and may yet contain surprises.

The following table categorizes some potentially GME inducing astrophysical events along with an associated 'lethal influence' and frequency. Any planet within the lethal influence sphere would suffer potential deadly effects. The frequency column is a rough estimate of how often these events occur within the Milky Way.

TABLE I: High Energy Events

Event	Lethal Influence (light years)	Frequency (years)
Type II Supernova	25	10^2
Type Ia Supernova	3,000	10^7
Hypernova	6,000	10^8
GRB	6,000+	10^6

V. CONSEQUENCES

GME events would have dire consequences for intelligent life. Even civilizations which might have reached a level of technological sophistication where they may have colonized planets in their own solar system and perhaps even planets surrounding neighboring solar systems. Due to the nature of the lethal radiation, which would travel at the speed of light, it is not even feasable that some sort of early warning system would be applicable as the signal would travel only as fast as the lethal radiation itself.

If the proposition of GME is correct then the Drake equation would require appropriate modification. This would be reflected in the following:

$$N = R^* f_n n_e f_l f_{gme} f_i f_c L \quad (3)$$

In this equation, f_{gme} represents the fraction of planets with intelligent life which have developed *after* the last (hypothetical) GME event.

As discussed in Section II a GME may be one single extremely high energy astrophysical event, or a series of smaller, distributed events whose effects cover the entire galaxy within some predictable timescale.

If a GME event is indeed a consequence of numerous GRB's then f_{gme} will be *probabilistic*. If, on the other hand, a GME is a single exotic high-energy astrophysical event then it will be a function of time, i.e. $f_{gme} = f_{gme}(t)$.

Immediately proceeding a GME of this nature$f_{gme}(t) \rightarrow 0$, indicating the fact that there are no remaining intelligent species left in the galaxy. Clearly in time, life once again begins to develop and so $f_{gme}(t) \rightarrow 1$

Let us, for a moment, asssume that the GME event is due to a number of distributed smaller events. In Drake's original estimates for the parameters he obtained a value of N=10,000. Given the fact that, to date, we know N=1, a crude estimate for the parameter f_{gme} would be $f_{gme} = 1 \times 10^{-4}$, which simply reduces N from 10'000 to 1.

VI. CONCLUSIONS

It is argued in some circles that the human race should consider a permanent presence on Mars and perhaps even attempt terraforming of the surface at some point in the future[7]. It is also certainly not outside the realms of possibility that humanity might even consider interstellar missions over the coming centuries[8] and may even endevour to colonize planets outside of our own solar system should a sufficent candidate be discovered.

A common argument for why we should devote resources to this endevour is that the entire human race is located on Earth, which, should some catastrophe hit us (a massive asteroid impact for example) would be completely wiped out. The typical argument in support of this is that we should colonize other planets to serve as a safegaurd against the possible extinction of the human race.

Under the GME hypothesis this endevour would be fruitless because the GME event, if it occured, would destroy life on Earth, Mars and presumably any other colonies we might have been able to set up in the neighborhood of the solar system.

Should the galactic mass extinction hypothesis be correct then the human race would be faced with the dilema that even if we were to establish multiple worlds for humans to live on, that we might still be annihilated by a GME event.

One interesting possibility to counter this menacing prospect would be to establish permanently manned settlements deep underground that would have the capacity to support a cross section of the human race for an indefinite period of time. Given the current 'cosmic silence' it may well be worth pursuing this idea further.

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