# Fermi's Paradox and Mathematical Theory of Rumours: A Possible New Solution?

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**Abstract.** We propose that Fermi's Paradox about "Where are the Extraterrestrials?" can be solved on the basis of the mathematical theory of spread of stochastic rumours developed by Daley & Kendal (1965), Maki & Thompson (1973) and Belen & Pierce (2004). Analytical formulations and their simulations show that a certain fraction of possible expansion space of a rumour can never be reached; similarly, Earth may had also fallen into this category of never-reachable planets in a possible network of communicating civilizations in the Milky Way.

**Key words:** Stochastic rumour models and their simulations, Fermi's Paradox, Drake's Equation

## Парадоксът на Ферми и математическата теория за разпространение на слухове: Едно възможно ново решение?

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Предлагаме решение на Парадокса на Ферми "Щом има извънземни, къде са те?" чрез математическата теория за разпространение на стохастични слухове, развита от Дейли и Кендал (1964), Мейки и Томпсън (1973), както и Вилин и Пийрс (2004). Теоретичните резултати и техните компютърни симулации показват, че част от възможното пространство на разпространение не може никога да бъде достигнато. Земята също може да попада в категорията на планетите, които никога не могат да бъдат достигнати от възможна мрежа на комуникиращи цивилизации в Млечния път.

## 1 Introduction

The solar type stars with planets having different surface conditions seem to be abundant in the Milky Way and the appropriate chemical elements and molecules for life are also known to exist in abundance throughout the Universe, implying that life may not be a phenomenon unique to Earth and rather widespread in the cosmos (Nicholson, 1999; Sullivan & Baross (Edts), 2007; Billings (Edt), 2014). Thus it would be quite plausible to assume that life and its advanced (i.e. intelligent and technically capable) forms presently exists in the Galaxy and some of them could have evolved to have the ability to communicate and/or travel over interstellar distances. Why then, we have not met or communicated with any of such extraterrestrials (ETs) is the essence of the conundrum known as the Fermi's Paradox (FP). The problem was first introduced by Enrico Fermi in 1950's as a lunch-time discussion topic at Los Alamos and various solutions to the "paradox" has already been proposed (Sullivan & Baross (Edts), 2007).

Recent development in the theory of spread of stochastic rumours by Pierce, Belen and others (Pierce, 2000; Pittel, 1990; Belen & Pierce, 2004; Belen, 2008; Belen et al., 2010) has prompted us to look at the possibility of applying these results for a possible solution, in ways not explored previously.

## 2 Theory of Spread of Stochastic Rumours

We will give, first, some relevant details of the theory and modeling results of spread of rumours. The rumour models were considered as part of the epidemic theory for long time (Daley & Gani, 1999). First deterministic mathematical work to determine the spread size of rumours was given by Rappaport and Rebbun, and Rappaport in 1950's (Rappaport & Rebbun, 1952; Rappaport, 1953). Afterwards, spread of rumours has been worked on independently from epidemic theory. The most important and seminal work for the topic has been introduced by Daley & Kendal (DK, 1965), which is also the first extensive and non-epidemic approach to the topic.

After some time, a second classical model has been introduced by Maki & Thompson (MT, 1973). More recently, a third approach was developed by Pierce and Belen (PB), after the year 2000, based on the probability generating functions and matrix methods developed (Pierce, 2000; Pittel, 1990; Belen & Pierce, 2004; Belen, 2008; Belen et al., 2010).

Here, a short background and summary for the spread theory of stochastic rumours will first be provided. Basic motivations and formulations were already mentioned to be due to DK and MT. In both models, it is assumed that there exists a number of villages ($n_0 + 1$ in number) far from each other and only means of communication between them is conducted by a primitive wired-telephone system. It is also assumed that each village has only one telephone machine and only one telephone conversation can be carried out between any two villages at a time.

In the classical DK model, spread of a rumour starts from one village, the initial spreader (source of rumour or the "news"), calling another village, chosen randomly, at time $t_0$, and thus the process of spread of the rumour is initiated. For enumeration and analysis of the process, the village making the call is named as a "Spreader" (designated by Sp); all the rest of the villages are Ignorants (designated by Ig) at the start. The target village learning the "news", will either be another spreader and its status will be transformed into a spreader (Ig $\Rightarrow$ Sp) if it chooses to spread the rumour; or to a silent (Stiffler, St) village which decides not to participate in the spreading process (Ig $\Rightarrow$ St). The ones who continue making new calls, until a caller meets a village is not an original Ignorant, but has already learned the rumor, that is, either a spreader (Sp) or a stiffler (St). At this point, the caller (an Sp) converts to a stiffler (Sp $\Rightarrow$ St) thinking that the "news" has already been spread all over the villages. The newly called village (an Ig) can either become an Sp or an St depending on the two models DK or MT. By giving up the spreading of the rumour, the number of spreaders is also reduced by 1.

When all calls and all combinations of Sp-Ig, Sp-Sp, Sp-St interactions are properly accounted, we reach at the unexpected conclusion that, in both classical DK and MT models a final ratio of Igs ($n_f$) to their initial number ($n_0$) for a high number of encounters:

$$F_1 = n_f/n_0 = 0.203, \tag{1}$$

i.e. approximately a fifth of total number of villages has not yet been informed (see Fig.1).

In the Pierce and Belen (PB) model, using the same interaction rules but including the multiple spreading centers at the start, in the rumour spreading process, one gets the result that

$$F_2 = 0.368 \tag{2}$$

that is, larger than a third of "Ignorant" population stays as unexplored or undiscovered. This unexpectedly larger fraction is understood to be due to earlier encounters when spreading of the rumour starts from more than one center, spreaders meet another spreader (who knows the gossip) much earlier, resulting with a higher percentage of unreached ignorants when rumour spreading process ends (when all spreaders become silent members).

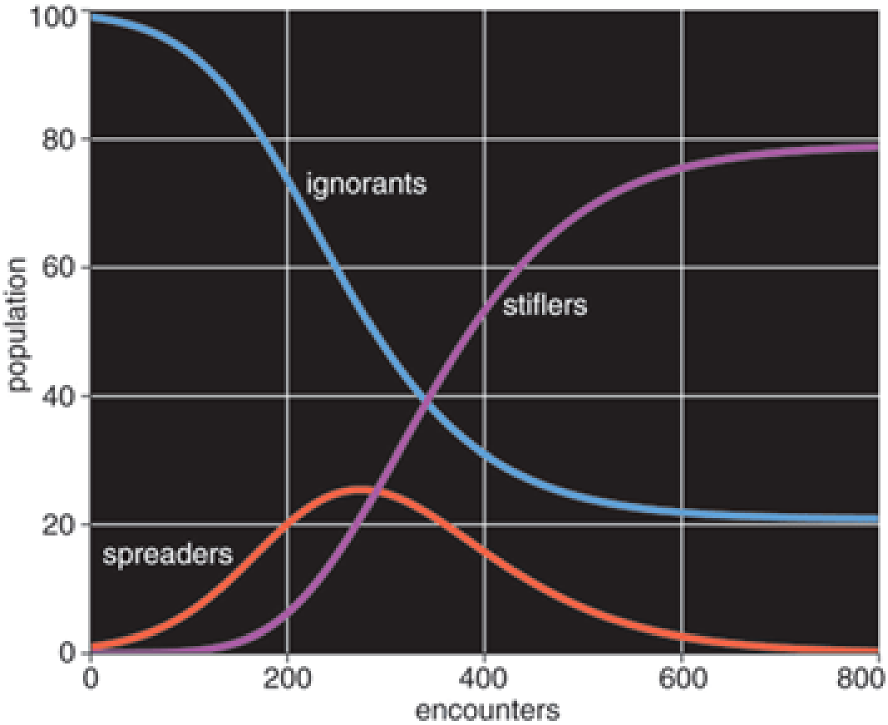


**Fig. 1.** Representation of 3 classes of participants in the classical theory of spread of rumours for the case of classical DK and MT models. The figure is adapted from (Hayes, 2005). In the asymptotic limit, as the line of "ignorants" indicates, good fraction (~20%) of total population of initial ignorants can not be reached by the active spreaders. This will also indicate the undiscoverable fraction of civilizations in the discussion of present work.

One extra condition in all the process was that total number of percentages at any moment of the spreading process has to satisfy

$$Sp + Ig + St = 1. \tag{3}$$

Computer simulations by Belen (2008) and BP (Belen & Pierce, 2004) confirm these results with some further elaborations for rumours with general initial conditions. For example, an error analysis made by Runga-Kutta method shows that, when the size population of number of villages (in the Fermi Paradox solution application, the number of civilizations in the Galaxy, trying to contact each other)

$$n_l + 1 = 259 \tag{4}$$

is reached, error terms in the final percentages reduces to zero.

This can be taken as the limiting number of villages (or in our parlance, the civilizations) where the analysis in the theory of stochastic rumours becomes valid. Low value of limiting number, $n_l$ of villages (or civilizations) who can contact each other for the validity of rumour spread results is also unexpected, since this number is quite within or below the possible number of communicating civilizations in the Galaxy (see Table 1).

## 3 Spread of Rumours Applied to Interstellar Communications

The assumptions used in the analysis of theory of rumours are quite compatible with the conditions under which interstellar communications could have been carried out:

1. Setting of distant villages with only one means of (wired) telephone communication is rather quite parallel with the large distances between communicable civilizations preventing their frequent and direct contacts. We can also quite reasonably assume that the only possible way of communication among them would be the use of electromagnetic waves (probably, the radio). The behaviour of a capable but ignorant civilization after the first contact is quite uncertain; however, responses similar to the explorative-villagers who become the new spreaders (development or acquisition of necessary means for further exploration acting as a new explorer civilization) are quite reasonable and possible.

2. Since the Earth has not yet received any call (no ETs were yet met or communicated with), we are in the position of an ignorant village who will not learn about the "news" (i.e., the existence of ETs) until a call is to be made. This way, we also assume that, there are already some types of communicating civilizations that can make such a "call", probably inviting us to the "Galactic Club".

Therefore, we can assume that, even though we have no c clue about it, there may still exist an interstellar civilization(s), even a communication network (because, we eagerly and scientifically expect extraterrestrials to exist and wonder why we have not met them!) unaware of existence of dwellers of Earth.

## 4 The Number of Civilizations in the Galaxy: Drake's Equation

In 1961, radio astronomer Frank Drake devised an equation –now known as Drake's Equation (DE) - attempting to identify various parameters that would help us decide the number of communicative civilizations in the Milky Way, at the present time. There are several versions of its expression and we will follow that of Nicholson's (Nicholson, 1999). Drake provides a useful focus for debating the key questions that has to be resolved in relation with the Fermi's Paradox.

The equation provides us with numerical examples to draw parallels with the "communicating villagers" of the rumour theory. First, a short review of (DE) as discussed in Nicholson (1999) and Sullivan & Baross (Edts, 2007) will be given. The DE can be expressed as

$$N_c = R_* \times f_p \times n_l \times f_l \times f_i \times fc \times L, \tag{5}$$

where:

$N_c$: the number of communicative civilizations in the Milky Way Galaxy;

$R_*$: the star formation rate in the galaxy, in units of (number of stars)/year, or (*/yr) which is quite well known for the Galaxy, usually considered a number between 1-10 */yr;

$f_p$: fraction of stars with planetary systems, for which better estimates are available after the discovery of high number of transiting planets discovered by *Kepler* spacecraft (Lemonick, 2014). It is a number probably near to 0.1 or higher;

$n_l$: number of planets in a planetary system, suitable for life which can be as high as 2 and as small as 0. Recent advances in planet hunting by *Kepler* satellite and other means indicate that multi-planet systems do exist (Wikipedia, 2015); However, there are many stars with no planets detected yet (by the present methods); Therefore the average number could be something $\approx 0.5$ or smaller.

$f_l$: fraction of suitable planets on which life actually have started; another difficult parameter to estimate: it may range from 1 (certainty) to 0,001 (very difficult).

$f_i$: fraction of life-starting planets which develops intelligence; probably most difficult of all parameters, ranging from 1 (certainty) to 0.0001 (very very difficult). There are indications that this number is nearer to high side (Behroozi & Peeples, 2015);

$f_c$: how probable is that intelligent species will develop a communicative technology with interest in other interstellar civilizations; here we are also in the realm of speculative guesses. Most cited numbers lie in the range 1 to 0.;.

$L$: lifetime (in yr) of a communicative civilization with interest in interstellar communication. With the only example of Earth, we have proposals ranging 100 yrs (this phase is almost over, see (Rees, 2004), to a million yr or more, as suggested by Sagan and others (Sagan, 1980);

Existence of $R_*$ and $L$ indicates that civilizations come and go in the history of Galaxy. What really matters is the communicative civilizations still alive at the present era (up to several 100 years from our time) of Earth's history;

We will present, in Table 1, results of some optimistic, pessimistic and also, the more likely estimations for $N_c$. Table also includes possible number of communicating (spreaders) and non-participating (ignorants) civilizations, in the context of theory of rumour spread with general initial conditions.

In accordance with Table 1, most likely number of civilizations communicating in the Galaxy is about 1000.

It could go as high as $N_c \approx 2.5$ millions ("Saganesque" estimation). Then if a single supercivilization is in search of other communicable civilizations, it can discover about $N_c - M_1 \approx 2$ million of them, leaving $M_1 \approx 500\ 000$ of them undiscovered, only to give up, assuming that all has been discovered. If more than one civilizations already in the phase of a galactic search of others, they will give up the search after about discovering $N_c - M_2 \approx 1{,}5$ million of them, leaving about $M_2 \approx 1$ million of them unexplored.

When these estimations are refined using the "More Likely" numbers (partly due to recent planet discoveries and related analysis (Wikipedia, 2015), we reach at the number of possible communicable civilizations in the Milky Way Galaxy "contemporary" with us, to a mere $N'_c \approx 1000$, about a fifth (actual fraction is 0.203) of them ($M'_1 \approx 200$) will have to go undiscovered, if a search is to be conducted by one of them, in order to discover the others. For the case where search space is to be searched by more than 1 civilization, undiscovered number will increase to $M'_2 \approx 300$, in line with Eqn (2) above.

**Table 1.** Number of communicating civilizations, $N_c$, in the Galaxy

| Parameters values | Optimistic values | Pessimistic values | More likely values |
|---|---|---|---|
| $C_0$ | $C_1$ | $C_2$ | $C_3$ |
| $N_c$ | $2.5 \times 10^6$ | 1 | 780 ($\approx 1000$) |
| $M_1 = N_c \times F_1$ | 500 000 | $\approx 1$ | 150 |
| $M_2 = N_c \times F_2$ | 920 000 | $\approx 1$ | 275 ($\approx 300$) |

The used combinations of parameters and their values follow:
$C_0 : (R_*, f_p, n_l, f_l, f_i, f_c, L)$
$C_1 : (10, 1/2, 1, 1, 1, 1/2, 10^6)$
$C_2 : (1, 1/2, 1/2, 0.2, 0.2, 0.1, 10^2)$
$C_3 : (5, 1/2, 1, 1/4, 1/4, 1/2, 10^4)$

A recent estimate for the number of Earth-size planets in the Galaxy goes as high as 1 billion (Behroozi & Peeples, 2015). However, other uncertainties about life and civilizations are still valid. Therefore, we will not diverge from our line of conclusions for the present discussion.

## 5 Conclusions

We can find parallels in the assumptions in the workings of the theoretical and simulation results of spread of stochastic rumours and contacting interstellar civilizations (if any) in the Galaxy. Results show that high fractions of search space by advanced civilizations have to always include undiscovered regions due to the inherent uncertainties if the rumour theory has any applicability to the case. Since almost all the conditions for the theory of spread of rumours seems to be valid in a possible SETI type search, this is likely to be applicable to the Fermi Paradox case. Probably, the Earth falls (or, has fallen) into this undiscovered group of planets, that is, either not searched due to the pitfalls that exist in such a search, or we will be discovered by time, if such an advanced civilization has already started such a search.

Existence of unexplored regions in any search space may have other implications not easy to guess. One unexpected example, which comes to mind, is the "Second foundation" concept of Isaac Asimov in its "Foundation" series of novels (Asimov, 1991). In the sequel, a Galactic empire is built by distant future human descendants and there exist "psycho-historians" (a kind of guardians for the Galactic Empire) of the "Foundation" ruling the Empire, decided (at some level of development of the Empire) to create a "Second Foundation" in the Galaxy in a distant, (and not-so-easily discoverable!) part of the Galaxy. Its aim was to save the Galactic State, when long "dark ages" were foreseen by "the guardians", quite before its fall. It is not clear if Dr Asimov had something in his mind for a place which was also "theoretically undiscoverable" (as in the case of spread of rumours theory) when he was creating the sequels to the series!

A recent claim that our Galaxy may contain a Type II civilization being capable of most of the energy emitted by their host star (Boyajian et al., 2015) brings forward the classification of civilizations by Soviet physicist Nikoli Kardashev in early 1960's (Kardashev, 1964), again. In this schema, our civilization is on the way of being a Type I civilization, that will be capable of using all (or, most) of the energy that falls on their surface from our star, the Sun, probably in about several centuries.

In the case we are the first galactic civilization that will be capable of such a search (by wireless communication (as in SETI) or by direct visits (as in Asimov's "Galactic Empire" style), we must be careful before concluding that any search space is fully exhausted. If one considers present minuscule fractions of phase space covered by various active SETI programs, we can see that there is indeed a very long way to go before discovering any new civilizations. Even when we think we must have covered most the phase space, we may indeed be wrong for reasons we have never anticipated. Or, we do need to find ways to overcome this apparently inherent mishap (due to such an apparently unrelated topic as the spread of stochastic rumours implies!).

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