# The role of the galactocentric distance of a civilization on its chance of contacting other intelligent civilizations

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**Resumen** / El número de civilizaciones inteligentes en la Galaxia es una de las preguntas sin respuesta más importantes de la ciencia moderna. Un problema relacionado es determinar las chances de que se produzcan contactos entre civilizaciones, asumiendo que las mismas existen. Utilizamos un modelo para la red de comunicaciones que permite estimar las probabilidades de contactos causales restringidos a un alcance máximo en la red. El modelo tiene tres parámetros que contienen el mínimo número posible de hipótesis para determinar las propiedades estadísticas de la red de comunicaciones, y donde el tiempo es una variable clave. El modelo no asume las chances de la aparición de la vida ni los demás factores de la Ecuación de Drake, excepto la vida media de una civilización inteligente capaz de comunicarse. Analizamos muchas simulaciones Monte Carlo del modelo mediante la implementación del método de eventos discretos. El conjunto de simulaciones también permite estimar las probabilidades de contacto en función de la ubicación de un nodo en la Galaxia, la distribución de tiempos de espera para el primer contacto y la distribución del número de contactos en función de los parámetros del modelo. Encontramos que un nodo tiene una baja probabilidad de hacer contactos en un tiempo de unas pocas décadas, excepto para los modelos con alta densidad de civilizaciones antiguas. La probabilidad de contactos disminuye levemente hacia el borde exterior de la Galaxia.

**Abstract** / The number of intelligent civilizations in the Galaxy is one of the most important unanswered questions in modern science. A related problem is to assess the chance of contacts among locations with communication capability, assuming they exist. Here we present a model for a communication network that allows to estimate the probabilities of causal contacts constrained to a maximum separation between the nodes in the network. The model has three parameters, which we argue comprise the minimum number of assumptions about the statistical properties of the distribution of intelligence in the Galaxy, considering the time variable as a key factor. We make no assumptions about the origin of life or any other factor in the Drake equation, except for the mean lifetime of a node. The model also considers the maximum distance a signal can be detected and the density of active nodes in time, and assumes statistical patterns that are observed in a plethora of phenomena in nature. We analyze many numerical Monte Carlo simulations of the model through a discrete events implementation. The simulation suite allows to estimate probabilities of contacts, the distributions of the waiting times for the first contact and the distributions of the number of contacts as a function of the model parameters, among other quantities. We find that a node has a low probability, for an observing time of some decades, to make contacts to other nodes in the network, except for models that resemble a densely populated Galaxy with longstanding civilizations. The probability of contacts slowly decreases towards to outer region of the Galaxy.

*Keywords* / extraterrestrial intelligence — methods: numerical — methods: statistical

## 1. Introduction

The chance of making contact with another intelligences is related to the unknown abundance of intelligent civilizations in the Galaxy, and also with the times at which these civilization aquire and lose their communication capabilities. In this work we address the problem of the temporal and spatial structure of the distribution of communicating civilizations, by exploring the hypothesis space of the SC3Net model (Stochastic Constrained Causally Connected Network Lares et al., 2020a) over a minimal set of three parameters and a suite of numerical simulations. In this model we consider a set of nodes, in the habitable zone of a model galaxy, which represent hypothetical locations of communicating extraterrestrial emitters and receivers. A causal contact is produced when the horizon of the light cone of a node arrives at the position of another node that is active at that time. Note that we do not make assumptions about the nature of the nodes or of the potential messages. Instead, we are interested in the properties of a communication network constructed on the basis of simple statistical considerations. We avoid the frequentist approach of the Drake equation and explore the parameter space. Instead of computing a final number we obtain empirical statistical distributions of parameters of interest, including the number of contacts in the lifetime of a node or the time interval between two con-

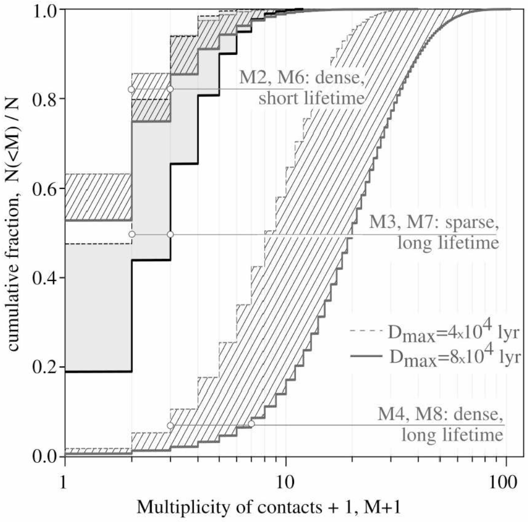


Figure 1: Number of contacts for the models in Table 1.

secutive contacts. This is an exploratory analysis that aims at providing a numerical tool to discuss not the several theoretical problems summarized by the Drake equation factors, and the different scenarios on the basis of statistical heuristics. We also intend to gain insight for the formulation of a statistical model with prediction capabilities. The approach proposed here should be considered as a compromise between the uncertainties of the frequentist approach and the detailed recipes required on the simulation approach (e.g. Forgan, 2017), both requiring a large number of hypothesis, models, or parameters with large uncertainties. We use a numerical framework (Lares et al., 2020b) to explore via simulations, a parameter space of unknown observables. we then discuss different scenarios and their consequences in terms of the probability of causal contacts as a function of the position of the nodes in the Galaxy. The simulations are performed using a discrete event simulation approach, which allows to study the behavior of complex systems that evolve through a stochastic process, by considering and tracking a sequence of well defined discrete events. A simulation is carried out by following all the variables that describe and constitute the state of the system, and the evolution of the process is described as a set of changes in that state. For example, when a new causal contact is produced between two nodes in the simulated galaxy, the numbers of active communication lines and of active communicated nodes change. The process involves following the changes on the state of the system, defining the initial and final states, defining a method that allows to keep track of the time progress in steps, and maintaining a list of the relevant events. The details of the model are described in Lares et al. (2020a) and in the documentation of the code (Lares et al., 2020b). In particular, we consider a galactic habitable zone wich ranges from $2 \times 10^4$ to $6 \times 10^4$ lyr, with negligible width and with uniform probability for the spatial distribution of the nodes. This hypothesis is justified by considering a homogeneous and stationary distribution of nodes which leads to a Poisson process to model their spatial probability distribution.

Table 1: Models used to analyze the simulation outputs and their dependence on simulation parameters. Time intervals are expressed in $1 \times 10^4$yr and distances in $1 \times 10^4$lyr.

| Model | $D_{max}$ | $\tau_a$ range | $\tau_s$ range |
|---|---|---|---|
| M1 | 4 | 1, 3 | 1, 5 |
| M2 | 4 | 17, 19 | 1, 5 |
| M3 | 4 | 1, 3 | 40, 44 |
| M4 | 4 | 17, 19 | 40, 44 |
| M5 | 8 | 1, 3 | 1, 5 |
| M6 | 8 | 17, 19 | 1, 5 |
| M7 | 8 | 1, 3 | 40, 44 |
| M8 | 8 | 17, 19 | 40, 44 |

## 2. Discrete events simulations suite

We have implemented a suite of simulations following a stochastic approach, to explore the hypothesis space of the SC3Net model that accounts for the causal connections between communicating civilizations on a simplified galaxy. The different models can be generated with three free parameters, namely, the mean lifetime of a node, $\tau_s$, the mean density of nodes at a given time (related to the mean time span between the consecutive emregence of nodes, $\tau_a$) and the maximum distance a signal could be detected. Using simple generalizations of known physical processes, we propose an exponential distributions for both $\tau_s$ and $\tau_s$. We also assume the size of the galactic habitable zone with a simplied geometry, a two–dimensional ring. We argue that these parameters can be used to describe a variety of situations, ranging from a galaxy model where an intelligent civilization is very rare, to a galaxy model populated with plenty of civilizations in causal contact. We estimate several quantities as a function of the parameters on the hypothesis space, and explored the outcomes of different models that arise as by–products of the simulations. For instance, it is possible to estimate the averaged number of causal contacts in terms of different model parameters that reflect different, so far unknown, scenarios for the appearance of intelligent life in the Galaxy. We take advantage of the simplicity of the model to explore the hypothesis space, in order to gain insight on the consequences of different scenarios for the search of intelligent life. Our analysis is not centered in obtaining the odds for the Earth to make contact with another intelligent civilization. We focus on obtaining a statistical, parameter-dependent description of the possible properties of the communication networks that comprise sets of nodes and how advantageous the location of Earth is to favor a contact. This causally connected nodes are sparsely distributed in both space and time, making difficult an analytical treatment and justifying the simulation approach.

## 3. Impact of the location of a node on the probability of contacts

Under the hypotheses of our experiments, we conclude that a causal contact is extremely unlikely unless the galaxy is heavily populated by intelligent civilizations with large average lifetimes. This can be derived from the probability distribution of the multiplicity of contacts for several models (see Fig. 1 and Table 1). Roughly, in order to have at least one contact in the entire lifetime of the node, there should appear a mean of at least one node every $\sim 2 \times 10^4$ yr, with a mean active period of at least $\sim 3 \times 10^4$ yr. This result is qualitatively similar to the results presented by several authors, which state that a contact between the Earth and another intelligent civilization in the Galaxy is quite unlikely, provided the maximum distance of the signal and the lifetime of the emitter are not large enough. We stress the fact, however, that our analysis is not Earth–centered. We treat all nodes equally and analyze how advantegeous a node in the outskirts of the galactic disk is with respect to the nodes at lower galactocentric distances to be reached by the causally connected spheres of other nodes. This analysis supports the idea that, in order to increase the possibilities of a contact, more active strategies of the emitter would be required. Some proposals in this direction include interstellar exploration, colonization and settlement (e.g. Brin, 1983) although it would require large temporal scales. According to the timescales involved, the results could explain the Fermi paradox (Đošović et al., 2019) Although our work does not take into account the colonization hypothesis, it does consider catastrophic events implicitly in the mean value and distribution of the lifetime. Other strategies could also increase the probability of contacts, for example panspermia (e.g. Starling & Forgan, 2014) or self–replicating probes (e.g. Barlow, 2013), although they would be too slow to make a significant impact on the communication network among intelligent civilizations. Our results are also consistent with those presented by Grimaldi (2017), who estimate an upper bound for the mean number of extraterrestrial civilizations that could contact Earth using Monte Carlo simulations, from a statistical model where the width of the Galactic disk is not negligible. Remarkably, most of the studies using statistical models or simulations are based on the Drake equation (Ćirković, 2004; Smith, 2009; Bloetscher, 2019) Our approach does not relay on the Drake equation, and thus is not motivated by the detailed physical processes that give rise to intelligent life. However, we argue that it is a valid empirical formulation to discuss the probabilities of contact, and mainly time scales involved in the problem. Ours is an alternative to the method proposed by Balbi (2018), who perform an analysis based on the Earth and use a different model, although our results agree in general. We explored how the position of a node in the radial distance to the center of the galaxy affects its probability of making contacts. In the Fig. 2 we show the fraction of nodes that make zero, one, two or three contacts as a function of the radial distance to the galaxy center for model M6. As it can be seen, the odds of making contact slightly increases towards the inner region of the galactic habitable zone, but this variation is at most a factor of two. There is a balance between the density of nodes and the mean lifetime since, as expected, a lower density can be compensated by a longer active time period. However, a large number of nodes does not easily compensate their short lives to reach the same probability of causal contact than in the case of a less populated galaxy but with very ancient civilizations. In all cases, for a short period of time (for instance, the time SETI programs have been active on Earth), the maximum probability of making a contact occurs at the moment of emergence of a node (Lares et al., 2020b). This suggests the possibility that an alternative SETI strategy could be the search for alternative message carriers, for the case in which the search has not been performed on the adequate channels. It should be noticed, however, that our analysis does not take into account the nature of the message, its power or the encoding/decoding process. According to the model, if a contact is produced for the first time, the origin of the signal is more likely to be very old. Instead of making a number of assumptions, we have explored the hypothesis space, reducing the problem to only three parameters and a few simple hypothesis to perform a complete model for the population and communication network in the galaxy. This allows to consider the Fermi paradox from a new perspective, and to propose an alternative treatment for the number of intelligent emitter/receivers with emphasis on the temporal dimension, which limits the probabilities of contacts due to the short time interval for rise and fall of civilizations compared to the age and extension of our Galaxy.

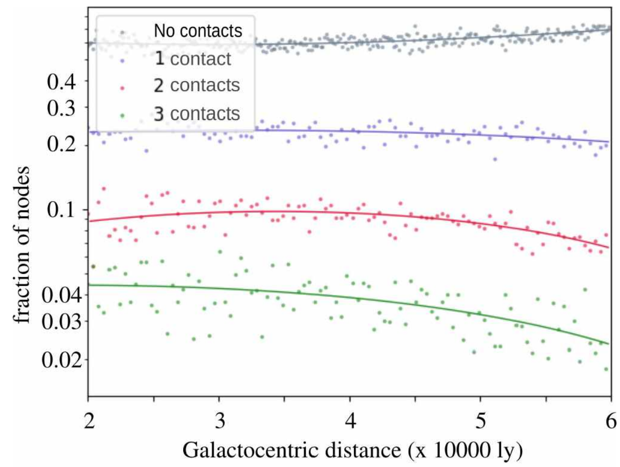


Figure 2: Effect of the position of the Earth on the Galaxy.

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