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On Opening the Gate to the Stars and the Drake Equation

Luis F. Copertari

Computer Engineering Program, Autonomous University of Zacatecas (UAZ), Zacatecas, México
Email: copertari@yahoo.com

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Abstract

Introduction. The future of humanity depends on its ability to explore and colonize new worlds, either in the Solar system or even beyond, in exostar systems with habitable exoplanets. **Purpose.** The objective of this paper is to explore different (hypothetical) technological scenarios and what the circumstances of each scenario mean to the possible exploration and colonization efforts to be carried out. **Design and development of experiments.** Experiments using simulation have been designed in order to try to determine the number of alien civilizations we may encounter in our exploration and colonization efforts as well as the likelihood of such occurrence happening. **Main outcomes.** If only conventional rocket-like thrusting is achievable, we will hardly be able to colonize some planets and moons in the Solar system; if Einstein-like space-jumping is possible, we will be able to easily colonize our Solar system, but hardly other star systems; and if wormhole-like space jumping is possible, there are no limits to what humanity will eventually be able to achieve in its interstellar exploration and colonization efforts within the Milky Way Galaxy. **Results.** It is very unlikely that we will find alien civilizations in our exploration and colonization efforts. It is even possible that at the moment humanity is the only "advanced technological" civilization in the Milky Way galaxy. **Conclusion.** The main obstacles in humanity's exploration and colonization efforts are our own efforts and technology, rather than the possible existence of alien civilizations that could threaten us.

Subject Areas

Anthropology

Keywords

Space, Exploration, Colonization, Milky Way Galaxy, Civilization, Alien, Drake Equation

1. Introduction

Discovery and the search for new worlds and new horizons are at the heart of human nature. When the natural resources of a given area are exhausted, humans naturally search for new places to settle in. Clearly, our planet is reaching its limits. Although new technologies and innovations could allow to accommodate more people using the same cities and settling areas, new worlds offer the golden opportunity to create new spaces for people to occupy. Earth will undoubtedly continue to be the cradle of humanity and its root, but new worlds in other star systems (or at least new worlds in the Solar system) would allow humanity to thrust itself into new horizons and a new future. People tired of the same places could find in new worlds the opportunity to grow and develop into new societies and to create new trading opportunities with goods and services never heard of before. The most important source of inspiration and research background for writing this paper is Carl Sagan's Cosmos [1].

This paper explores three scenarios for the exploration and colonization of new worlds. Also, it considers the possibility of alien civilizations and attempts to quantify their numbers. How many alien civilizations exist in our Milky Way galaxy? How many worlds suitable for colonization are out there? What are the chances of encountering alien civilizations? These are the basic questions being answered in this paper.

2. Space Traveling Technology Speculations

There are three kinds of possible ways for space travel to unveil: 1) Traditional rocket-like thrusting technology, 2) Einstein-like space-jumping technology, and 3) Wormhole-like space jumping technology. We will consider each of these possibilities. The reader needs to keep in mind the fact that all of these technological possibilities are still speculation, since the world has not yet embarked on any kind of serious space exploration effort other than robotic missions within the Solar system.

2.1. Traditional Rocket-Like Thrusting Technology

The most commonly known form of space travelling is by relying on rocket-like technology. By rocket-like technology I mean all forms of ships powered by rockets. Please keep in mind that a rocket can be as the usual rockets used in launching satellites from Earth to low-Earth orbit or geostationary orbit to more exotic forms of rockets such as low acceleration ion-thrusting deep space engines. In any case, all of these technologies rely on Newton's third law: action and reaction. In order to provide forward thrusting, one needs to make some form of fuel to exit the ship from the opposite direction. In the case of a regular rocket, the fuel is a chemical compound that typically requires oxygen for its controlled explosion. In the case of ion-like thrusting, the fuel is a single atom that is expelled at nearly the speed of light out of the rear of the spaceship. Since a single atom has a very low mass, even if the expelling speed from the ship is almost the speed of light, it takes considerable time for the ship to accelerate to useful space traveling speeds. In the case of Solar system exploration and colonization, the travelling times are considerable. Even if one considers the colonization of the Moon or even Mars, a considerable amount of fuel is required and the distances are not large enough for an ion-thrusting engine to gain enough speed so as to make the trip short enough, both for the passengers inside the ship as well as the people left on Earth, Mars or whatever other colonized world in the Solar system we could imagine.

We could also consider interstellar colonization, like the kind portrayed in the movie *Passengers* [2]. In this case, and assuming we somehow already know of a very distant planet on some stellar system within a reasonable distance (from several tenths to several hundreds of light-years distance) having a human-compatible atmosphere and gravitational pull, it would be impossible to accelerate faster than one half the speed of light because half of the distance would be achieved by accelerating and the other half has to be used to decelerate. This kind of interstellar colonization effort would require an Earth-based civilization spanning several hundreds of years if not thousands of years in order to be able to wait for the ships to go back and forth. And since the distances are given in light-years, within this scenario, not even laser-based broadcasting back and forth to/from Earth would be fast enough to reach home. Clearly, the traditional rocket-like thrusting technology scenario is not useful for interstellar exploration and colonization efforts.

We would be left to trying to colonize Solar system planets like Mars or maybe even Solar system moons in the Solar system like Europa or Ganymede, both in Jupiter's orbit or Titan in Saturn's orbit [3]. Or perhaps the answer, although not too promising for massive colonizing efforts, could be closer to home by colonizing Earth's Moon.

2.2. Einstein-Like Space-Jumping Technology

To understand what I mean by Einstein-like space-jumping technology, we need to understand Einstein's time dilation factor. In Newton's motion, if a train moves forward at a speed of 100 kilometers per hour and a bullet on the roof of the train is moving at a speed of 1,000 kilometers per hour with respect to the roof of the train, then the bullet, with respect to a witness on the train station, moves at a speed of 1000 + 100 = 1100 kilometers per hour forward and at a speed of 1000 − 100 = 900 kilometers per hour backwards (see **Figure 1**).

However, as Einstein imagined in his mental experiments, what occurs in Newton's motion, does not occur in Einstein's motion, as explained in Einstein's special theory of relativity [4]. In the special theory of relativity, light moves at the same speed, regardless of the frame of reference. If a train is moving close enough to the speed of light, say at a speed of $v = 240{,}000$ kilometers per second, and a ray of light is shot from the roof of the train (which moves at approximately

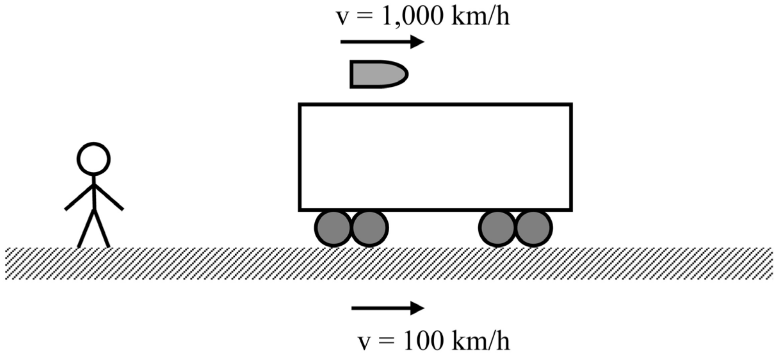

Figure 1. Newton's motion.

c = 300,000 kilometers per second), then for both a person in the train and a witness standing on the train station, light moves at the same speed both forward and backward (see **Figure 2**).

This apparently innocent observation has huge repercussions when it comes to time dilation. Imagine now that a ray of light is shot from the floor of the train to its roof. The person standing inside the train sees the ray of light going upwards in a vertical line. However, the bystander at the train station sees the ray of light moving diagonally (see **Figure 3**).

Thus, the ray of light moves a distance h according to the person inside the train and a distance d according to the bystander at the train station. The train moves a distance x going forward (see **Figure 4**). However, regardless of the frame of reference, light in both cases moves at the same speed of light (at a speed of approximately c = 300,000 kilometers per second).

It is common understanding that speed equals distance divided by the time it takes to travel that distance, as shown in Equation (1). Solving for the distance from Equation (1) yields Equation (2).

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \tag{1}$$

$$\text{Distance} = \text{Speed} \times \text{Time} \tag{2}$$

According to the Pythagorean theorem [5], and referring to **Figure 4**, we know that Equation (3) holds.

$$d^2 = x^2 + h^2 \tag{3}$$

Now, referring both to **Figure 3** and **Figure 4**, it is clear that if distance d is greater than distance h, even though light moves at a constant speed regardless of frame of reference (approximately c = 300,000 kilometers per second), then something else needs to be affected. In this case, such else must be time. Thus, we will consider two different times, the time for the person inside the train (t_I) and the time for the bystander at the train station (outside the train) as well as the time at which speed the train moves forward (v), also according to the bystander at the train station (in both cases t_O).

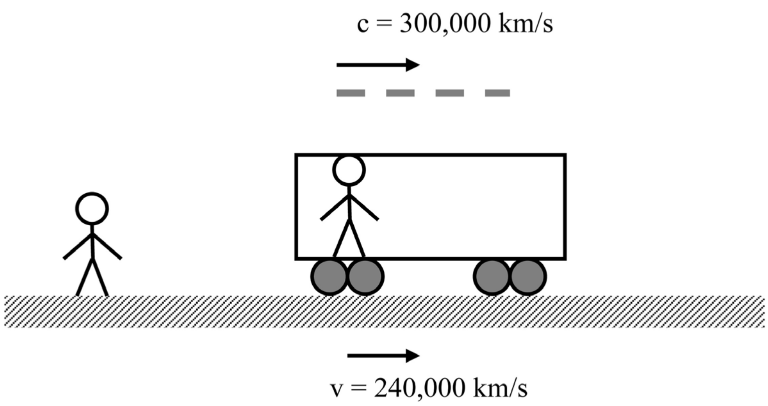

Figure 2. Einstein's motion.

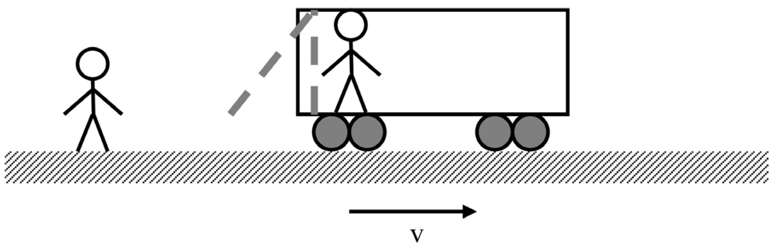

Figure 3. Einstein's train.

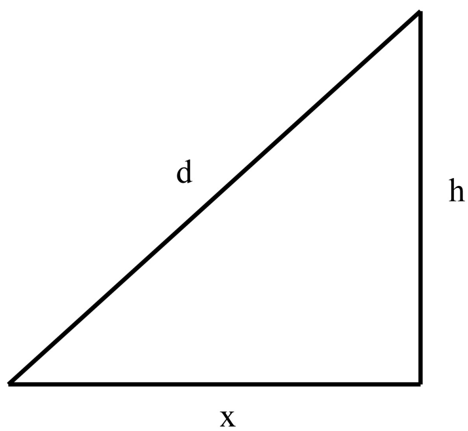

Figure 4. Distances scheme from Einstein's train.

Consequently, Equations (4), (5) and (6) must hold for the distance light travels for the bystander outside the trains station (d), the distance light travels for the person inside the train (h) and the distance the train travels forward (x), respectively.

$$d = ct_O \tag{4}$$

$$h = ct_I \tag{5}$$

$$x = vt_O \tag{6}$$

Applying Equation (3) and substituting d, h and x from Equations (4), (5) and (6), respectively, into Equation (3) results in Equation (7).

$$\left(ct_O\right)^2=\left(vt_O\right)^2+\left(ct_I\right)^2 \tag{7}$$

Equation (7) becomes Equation (8) by doing the squaring.

$$\left(c^2t_O^2\right)=\left(v^2t_O^2\right)+\left(c^2t_I^2\right) \tag{8}$$

Dividing both sides of Equation (8) by c^2 results in Equation (9).

$$\left(t_O^2\right)=\left(\frac{v^2}{c^2}t_O^2\right)+\left(t_I^2\right) \tag{9}$$

Factorizing t_O from Equation (9) results in Equation (10).

$$t_O^2\left(1-\frac{v^2}{c^2}\right)=t_I^2 \tag{10}$$

Solving for t_O^2 from Equation (10) results in Equation (11).

$$t_O^2=\frac{t_I^2}{1-\frac{v^2}{c^2}} \tag{11}$$

Taking the square root on both sides of Equation (11) yields Equation (12).

$$t_O=\frac{t_I}{\sqrt{1-\frac{v^2}{c^2}}} \tag{12}$$

If the speed of the train is the speed of light ($v = c$), then the time for the observer outside the train (t_O) becomes infinite for any given time for the observer inside the train (t_I). If, on the other hand, the speed of the train (v) is close to zero compared with the speed of light (c), then both times are the same. Thus, the time for the outside observer has a dilation factor given by Equation (13).

$$\text{Factor}=\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{13}$$

Assuming the speed of the train is given by some percentage (p) of the speed of light (where $0 \le p \le 1$), such that Equation (14) holds, then Equation (13) becomes Equation (15).

$$v = pc \tag{14}$$

$$Factor=\frac{1}{\sqrt{1-\frac{(pc)^2}{c^2}}}=\frac{1}{\sqrt{1-\frac{p^2c^2}{c^2}}}=\frac{1}{\sqrt{1-p^2}} \tag{15}$$

Figure 5 charts the percentage of the speed of light (p) on the horizontal axis and the time dilation factor on the vertical axis (Factor) from Equation (15).

We can see in **Figure 5** that if p = 0.01 = 1% in Equation (15), then Factor = 1.00005000375031, whereas if p = 0.99 = 99% in Equation (15), then Factor = 7.08881205008359. That is, at very close of zero times the speed of light, time outside the traveling vehicle occurs at almost the same rate as the time inside the traveling vehicle, whereas for speeds very close to the speed of light, time outside

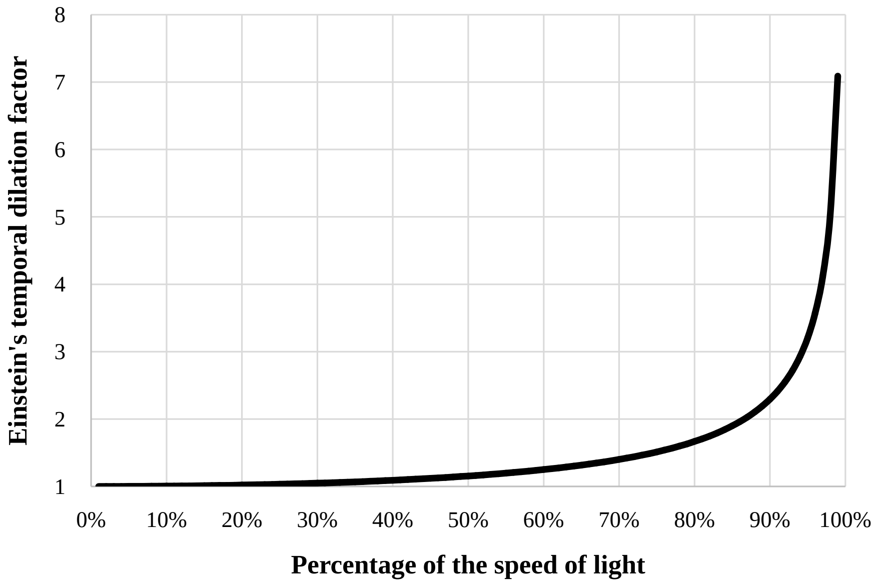

Figure 5. Einstein's temporal dilation factor.

the traveling vehicle occurs at approximately seven times the speed of light. It is clear that if the value $p = 0$, then Factor = 1, whereas if $p = 1$, then Factor → ∞.

Now, what about the implication of Einstein's time dilation factor when it comes to Einstein-like space-jumping technology? The closest star system to Earth in our Milky Way galaxy is the Alpha Centauri star system, which is composed of three stars at a distance of 4.2 to 4.4 light-years [6]. The closest to Earth of these three stars is the one called Proxima Centauri, at a distance of 4.2 light-years. These three stars share our view of the Milky Way galaxy. Nevertheless, light takes between 4.2 to 4.4 light years to reach Earth from these stars. A light-year is the distance light travels in one year. Considering lights travels at a speed of approximately 300,000 kilometers per second, and that a year has (365 days) × (24 hours/day) × (60 minutes/hour) × (60 seconds/minute) = 31,536,000 seconds, then one light-year has (300,000 kilometers/second) × (31,536,000 seconds) = 9.4608×10^{12} kilometers = 9,460,800,000,000 kilometers or approximately 9.5 billion kilometers[1].

The only way to have a chance at exploring and colonizing star systems in Earth-like exoplanets[2] in these hugely distant star systems is by assuming the eventual creation of a technology which I call space-jumping. Space-jumping means being able to create a vehicle such that it jumps from one place in space to another place in space. There is no mental experiment we can think of that would make space-jumping contradictory with common sense. To illustrate what I mean by that, consider time travelling. Time travelling (assuming it occurs in the same one Universe we all share, as opposed to the possibility of multiverses) is im-

[1]Notice that in this case billion is used as it is used in Science, not as it is used in Economics. Thus, one billion is one million million, and not a thousand million.

[2]By Earth-like exoplanets I mean planets suitable for human colonization such that they have a reasonable temperature range for water and oxygen to exist in their surface and atmosphere, respectively, without toxic gases on their atmosphere so as to make it impossible for humans to breath.

possible because it leads to contradictions. Say I travel to the past, to a time before I was born. Then, if I kill my parents, I would not be born but, if I am not born, how could I have travelled to the past to kill my parents in the first place? This kind of common-sense contradictory arguments do not occur with space-jumping. If I manage to travel to Proxima Centaury in a space jump, I would arrive at Proxima Centaury "now". However, if I manage to send a message back home (back to Earth) from Proxima Centaury, such message would travel at the speed of light and it would take 4.2 years for such ray of light to reach Earth. Even if I manage to somehow orientate myself in order to go back home "instantaneously", I would arrive back home after I left, because the two consecutive events (departing and returning) would only occur for space traveling, not time traveling.

However, there is a very important distinction to make. If I travel "instantaneously" to Proxima Centaury, it is plausible that time would occur instantaneously for the passenger or passengers inside the traveling vehicle. But, assuming an Einstein-like time dilation factor, would that mean people back on Earth would have to wait 4.2 years for the ship to reach Proxima Centauri and another 4.2 years for the ship to go back? If that is the case, and considering Earth-like exoplanets would probably be tens if not hundreds or thousands of light years away, even a human exploration effort of other possible Earth-like exoplanets would take decades, hundreds or thousands of years for going back and forth these star systems. Although this kind of possibility would make interstellar exploration within the Milky Way galaxy possible, it would take a lot of time for going back and forth for exploration efforts, not to mention colonization efforts.

Also, what we see now as stars in a given position on the night sky would be in a different position if we travel to another star system several thousands of light years away. Thus, we would need to build three-dimensional maps of the Galaxy. Also, the Galaxy is rotating, which makes orientation within the Milky Way galaxy for returning back to Earth even more difficult. However, it is not impossible, because the Galaxy does have a galactic center and it may be possible to establish a three-dimensional cartesian system of coordinates by using the center of the Milky Way galaxy and pulsars on other very distant galaxies as guides for such three-dimensional orientation system.

But the fact in this speculative interstellar travelling scenario remains. If there is a time-dilation factor due to Einstein's time dilation, the exploration and colonization effort would take considerable time.

2.3. Wormhole-Like Space Jumping Technology

But what if space-jumping can occur "instantaneously" both for the crew of the traveling vehicle as well as the people left back on Earth, without a time-dilation factor? This is what I call wormhole-like space jumping, and it is the most promising possibility for a serious (and practical) space exploration and colonization effort. I call this other scenario wormhole-like space-jumping because the result of space travelling would be as if space were folded between the point of origin and the point of destination, making the trip between these two points "instantaneous" both for the crew of the travelling vehicle and the people left back on Earth or at least the Solar system.

It would mean that it is somehow possible to travel instantaneously from one point in space to another. Of course, it is not clear whether or not it would be necessary to leave Earth's orbit for such travelling purpose. If it is necessary to leave Earth's orbit, traditional rockets would be necessary, making space exploration and colonization somewhat more expensive.

Also, it is very important to know where such hypothetical explorers and colonizers would be going. For that, data from several Earth-like exoplanet star systems would be necessary. Additionally, the creation of very accurate three-dimensional star maps would be essential to be able not to get lost in the Milky Way galaxy. Clearly, intergalactic travel would not be possible because there is no known center to the Universe. Galaxies accumulate in bubble like clusters, but the overall picture does not seem to have a center. On the other hand, the Milky Way galaxy does have a center and it seems, at least in principle, possible to draw a three-dimensional cartesian system based on the center of the Milky Way galaxy and at least two other clear points of reference from other galaxies.

Figure 6 shows three points of view of Ursa Major by traveling around it at a distance of approximately 150 light-years [1]. **Figure 6(a)** shows Ursa Major from the front. **Figure 6(b)** shows Ursa Major from the side, and **Figure 6** shows Ursa Major from the back. **Figure 6** illustrates the difficulty of orientating inside the Milky Way galaxy in the case of interstellar space travelling using Milky Way star maps.

We would have to rely on a different system of coordinates, such as the center of the Milky Way galaxy and two very distant but easy to locate other galaxies. Good news is that the bulk of the Milky Way galaxy is 100,000 light-years in radius [6]. The typical distance to other galaxies in our Cosmos is in the order of 8 thousand million light-years [1]. The distances to these other galaxies are considerable when compared to the relatively small size of our Milky Way galaxy

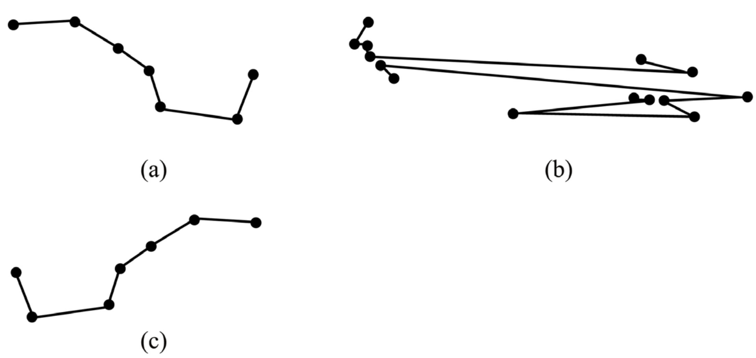

Figure 6. Ursa Minor seen from different points of view around it. (a) Ursa Major seen from the front. (b) Ursa Major seen from the side. (c) Ursa Major seen from the back.

within which interstellar travelling would take place (100,000/8,000,000,000 = 0.0000125 = 0.00125%). Thus, considering other galaxies as referencing points in space makes sense for Milky Way interstellar space-jumping wormhole-like traveling.

3. The Drake Equation

The Drake equation is a serious attempt at determining the number of "advanced civilizations" in the Milky Way galaxy [1]. By "advanced civilizations" we mean civilizations that have developed radio-astronomy. There may be entire civilizations of poets or mathematicians, but without radio-astronomy we would neve hear of them. The Drake equation calculates such N number of "advanced civilizations" as a multiplication of the number of stars (N_*) in the Milky Way galaxy (which we know with reasonable certainty) by a series of factors. Each of these factors that start with f is a number between 0 and 1 which filters N_* by reducing it. The variables in the Drake equation are as follows:

N_* Number of stars in the Milky Way galaxy.

f_p Fraction of stars with planetary systems.

n_e Number of planets in a given system ecologically suitable for life.

f_l Fraction of planets suitable for life in which life actually occurs.

f_i Fraction of planets in which an intelligent life form evolves.

f_c Fraction of planets inhabited by intelligent beings where a communicative intelligent life develops.

f_L Fraction of planets with a technical civilization.

The Drake equation is shown in Equation (16).

$$N = N_* f_p n_e f_l f_i f_c f_L \tag{16}$$

We know the value of N_* with reasonable certainty. Some recent estimations provide a value of $N_* = 4 \times 10^{11}$ stars. Most of these stars are long lasting stars spanning thousands of millions of years in which they provide a stable source of energy suitable for life. We have some knowledge about the fraction of these star systems with planets. A reasonable guess is $f_p = 1/3$, although we will run a simulation with values between 1/2 and 1/5 uniformly distributed. The number of planets ecologically suitable for life is harder to guess. But based on our own solar system, we will consider $n_e = 2$, because in our solar system Mars is likely to have been suitable for life. The simulation will consider values between 1 and 4 because at the very worst Earth is the only planet suitable for life and at the very best there could be (or had been) Mars, Europa and Titan suitable for life.

Experiments show that the molecular basis for life should be considered to be common in the usual cosmic conditions. We are using a value of $f_l = 1/3$, although the simulation considers a uniformly distributed value ranging between 1/2 and 1/5.

The choice for f_i and f_c are harder to make. On the one hand, a series of very fortuitous events in human history had to occur to take us to the present situation. On the other hand, it is reasonable to assume there could be several ways for intelligent life to arise. We are considering $f_i = 1/10$ and $f_c = 1/10$. In the simulation we are using for f_i and f_c a value between 1/2 and 1/20 uniformly distributed for each one of them.

What percentage of the life of a planet is characterized by a technical civilization? As far as it is the case for Earth, we have had a technical civilization with radio-astronomy since only a few decades out of the approximately 100,000,000 $= 10^8$ years where humans have inhabited this planet. And since there is no guarantee we would destroy ourselves within a small amount of time, we will consider $f_L = 1/10^8$. Our simulation will assume uniformly distributed values for f_L between 1/1,000,000 and 1/100,000,000 because if we assume our civilization has 100 year with radio-astronomy, that is $100/100,000,000 = 1/1,000,000 = 1/10^6$. The other extreme is considering a lifetime for a civilization of $1/100,000,000 = 1/10^8$. Consequently, the simulation will assume uniformly distributed values for f_L between $1/10^6$ and $1/10^8$.

By using the initial conservative estimates, we would have Equation (17).

$$N = \left(4\times10^{11}\right)\left(\frac{1}{3}\right)(2)\left(\frac{1}{3}\right)\left(\frac{1}{10}\right)\left(\frac{1}{10}\right)\left(\frac{1}{10^8}\right) = 8.\overline{8} \approx 9 \tag{17}$$

The absolute minimum boundary for the simulation ($\lfloor N \rfloor$) is given in Equation (18) and the absolute maximum boundary for such simulation ($\lceil N \rceil$) is given in Equation (19).

$$\lfloor N \rfloor = \left(4\times10^{11}\right)\left(\frac{1}{5}\right)(1)\left(\frac{1}{5}\right)\left(\frac{1}{20}\right)\left(\frac{1}{20}\right)\left(\frac{1}{10^8}\right) = 0.4 \approx 1 \tag{18}$$

$$\lceil N \rceil = \left(4\times10^{11}\right)\left(\frac{1}{2}\right)(4)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)\left(\frac{1}{10^6}\right) \approx 100000 \tag{19}$$

Equations (18) and (19) mean that we should expect in the Milky Way galaxy to exist between 1 (our own) and 100,000 "advanced civilizations".

What is the probabilistic behavior of the Drake equation? Making the assumption for a simulation with 5000 runs, we obtain behaviors similar to the ones shown in **Figure 7**. **Figure 7** shows the calculated number of "advanced civilizations" and the respective total number for which such ranges of N occur in a total of 9 re-run simulations, each with 5000 runs of possible values for the parameters of the Drake equation.

Notice that there is not much difference in the shape of the histograms. The question is, however, what would the expected value of N be?

In order to answer such question, a total of 10 re-runs where performed. In each re-run of 5,000 runs each, the average number of N (μ) as well as its standard deviation for such average (σ) was calculated. Also, the minimum and maximum values for each re-run are shown. Finally, the average of these re-runs (μ again, but with a different meaning) as well as the standard deviation for such average (also σ, but for the 10 calculated values of μ) were calculated. Assuming a normally distributed behavior for the average of N, due to the central limit theorem, 95% of results should always be between $\mu - 2\sigma$ and $\mu + 2\sigma$ if we assume a normal behavior for the statistic N. The results obtained are shown in **Table 1**.

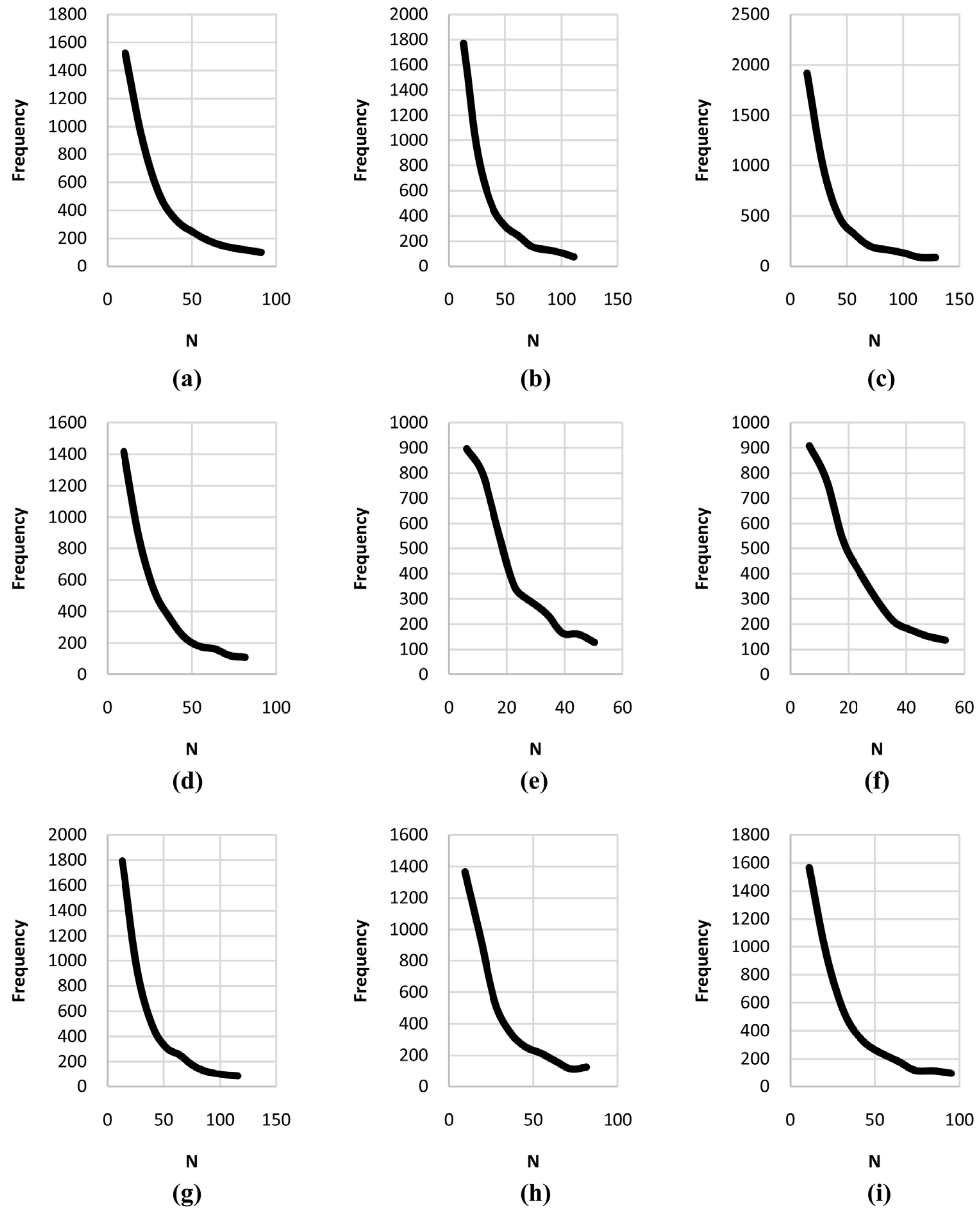

Figure 7. Alternative probabilistic behaviors of the Drake equation. (a) Simulation 1. (b) Simulation 2. (c) Simulation 3. (d) Simulation 4. (e) Simulation 5. (f) Simulation 6. (g) Simulation 7. (h) Simulation 8. (i) Simulation 9.

Table 1. Probabilistic behavior for trending *N*.

Re-run	μ	σ	Minimum	Maximum
1	78	259	1	7992
2	90	328	1	12297
3	90	440	0	19590
4	88	373	1	15606
5	89	308	1	6692
6	84	289	1	7035

Continued

7	80	280	1	7984
8	92	397	1	13076
9	93	362	1	10234
10	89	327	1	12625
	μ	σ	$\mu - 2\sigma$	$\mu + 2\sigma$
	87	5	77	97

We can see from Table 1 that, according to the parameter for this simulation, the expected number of "advanced civilizations" in the Milky Way galaxy (N) is 87 with a minimum expected range of [77, …, 97].

4. Alien Civilization Encountering Simulation

Assuming we start a serious interstellar exploration and colonization effort within the next decades, that such exploration and colonization effort can be carried out under the wormhole-like space-jumping scenario, and that all other civilizations do the same starting at the same time we do, it is possible to carry out simulations in order to try to ascertain approximately when we would encounter an alien civilization in our exploration and colonization efforts.

Assuming the conservative scenario from Equation (17), there would be 9 "advanced civilizations" doing wormhole like space jumping throughout the Milky Way galaxy. But, how many planets in Milky Way star systems we should consider for such simulation? We are looking at the number of star systems with life sustaining planets (N_l), as given in Equation (20).

$$N_l = N_* f_p n_e f_l \tag{20}$$

Following the conservative estimates from Equation (16) we can estimate a conservative value for N_l as indicated in Equation (21).

$$N_l = \left(4\times10^{11}\right)\left(\frac{1}{3}\right)(2)\left(\frac{1}{3}\right) = 8.\overline{8}\times10^{10} \approx 9\times10^{10} \tag{21}$$

This is the total number of potentially colonizable exoplanets in the Milky Way galaxy, that is, $N_l \approx 9\times10^{10}$. However, not all of these planets would be discovered or be suitable for human settlement. Let f_D be the fraction of planets that are actually discovered and suitable for human (and/or alien) settlement. Then, the Drake part of the equation used in Equation (20) becomes Equation (22) to calculate the number of planets for human (and alien) settlement (N_S).

$$N_S = N_* f_p n_e f_l f_D \tag{22}$$

Assuming $f_D = 1/10^7$, we obtain the total number of planets in star systems that need to be considered for the alien civilization encountering simulation as indicated in Equation (23).

$$N_S = \left(4\times10^{11}\right)\left(\frac{1}{3}\right)(2)\left(\frac{1}{3}\right)\left(\frac{1}{10^7}\right) = 8.\overline{8}\times10^{3} \approx 9\times10^{3} \approx 9000 \tag{23}$$

Figure 8 shows a rendering of the Milky Way galaxy and the position of the Sun in it. We can see in Figure 8(a) that the size of the Milky Way galaxy containing stars is of a diameter of 100,000 light-years. Also, the bulk, which cannot be considered for exploration and colonization efforts due to its density, as estimated from Figure 8(b) is of 1/5 of the diameter, which is (1/5) × 100,000 = 20,000 light-years. That means that the simulation to use, centered at the center of the Milky Way galaxy, should have a void in the center with a radius of 20,000/2 = 10,000 light-years and a total size of 100,000/2 = 50,000 light years.

Then, the 9000 colonizable star systems are assumed to be normally distributed with a mean of zero (0) and a variance of 50,000/2 = 25,000 light-years. That is because in a normally distributed system of randomly generated stars, due to the central limit theorem, 95% of the stars would be between $0 + 2\sigma$ and $0 - 2\sigma$, so that $2\sigma = 50{,}000$ and $\sigma = 50{,}000/2 = 25{,}000$ light-years.

A standardized normally distributed random variable (z) can be generated based on Equation (24), where R_i is a uniformly distributed random variable for values of i going from 1 to 12 [7].

$$z = \sum_{i=1}^{12} R_i - 6 \tag{24}$$

Then, a randomly generated normal variable X with mean μ and standard deviation σ, obeys Equation (25). Consequently, the normally distributed random variable X, by algebraic manipulation of Equation (25) obeys Equation (26).

$$z = \frac{X - \mu}{\sigma} \tag{25}$$

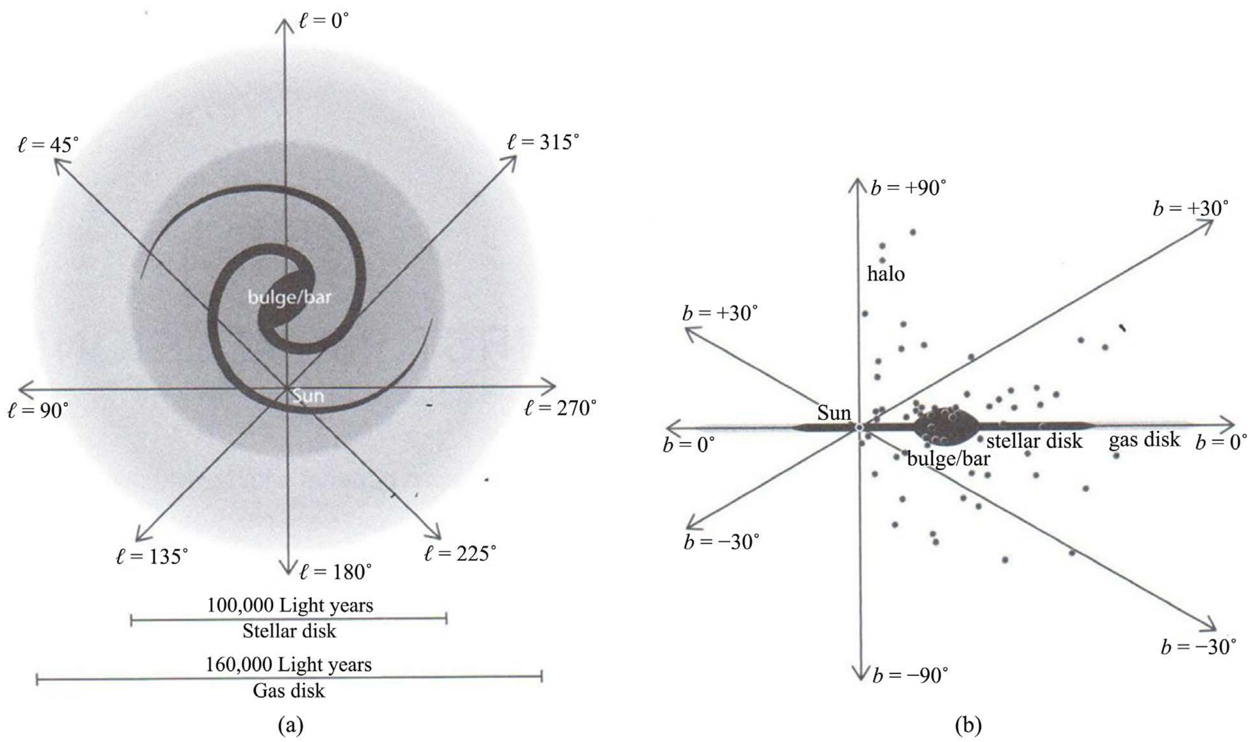

Figure 8. Size of the Milky Way galaxy. (a) Milky Way galaxy top. (b) Milky Way galaxy side.

$$X = \mu + \sigma z \tag{26}$$

For the simulation, the values are $\mu = 0$ and $\sigma = 25{,}000$. For what value of X, stars would be inside the bulk of the Milky Way galaxy? Since we are generating normally distributed random variables with $\mu = 0$ and $\sigma = 25{,}000$, then, if we have that $X \leq 10{,}000$, then the star system would not be drawn for being considered to be inside the bulk of the Milky Way galaxy.

As it can be seen in **Figure 8(b)**, the Sun is located 1/5 from the outer Milky Way galaxy boundary. Since we are considering the size of the Milky Way galaxy to be 100,000 light-years in diameter, then the Sun is approximately located (1/5) × 100,000 = 20,000 from the boundary, that is at a distance from the center of the Milky Way galaxy of 10,000 + 20,000 = 30,000 light-years.

All the possible 9000 colonizable worlds are marked with yellow stars. Earth is randomly located in the simulation at a distance from the galactic center of 30,000 light-years (in practice between 29,000 and 31,000 light-years). All other 8 civilizations (alien ones) are located at random. We use black to denote Earth and its colonies. For all other 8 alien civilizations, we use the colors listed in **Table 2**.

The Milky Way galaxy has a width of approximately 1.7 light-years, so we assume it to be flat in the simulation and the view is from the top of the simulated Milky Way galaxy's 9000 colonizable worlds.

We will assume Earth based civilizations can make space jumps of up to 2000 light-years. For all other eight alien civilizations, refer to **Table 3** for maximum leap sizes. The galactic clock ticks every 100 years. In each tick, a new world, from the existing worlds, is colonized. The colonization effort can be made from any of the already colonized worlds. If a given world that has already been colonized by an alien civilization is colonized by an Earth based colony, a black diamond mark is made and the simulation ends. Also, if a planet occupied by an Earth based colony receives an alien civilization trying to colonize it, a red diamond mark is made and the simulation ends. Such notes will be exported in a file called "Output.txt". The last line will contain the value of the galactic clock,

Table 2. Colors for the eight alien civilizations.

Alien 1	Blue	Alien 5	Fuchsia
Alien 2	Lime	Alien 6	Gray
Alien 3	Purple	Alien 7	Green
Alien 4	Olive	Alien 8	Red

Table 3. Maximum leap sizes for colonizing new worlds by the eight alien civilizations.

Alien 1	2000 light-years	Alien 5	4000 light-years
Alien 2	10000 light-years	Alien 6	4000 light-years
Alien 3	4000 light-years	Alien 7	5000 light-years
Alien 4	2000 light-years	Alien 8	5000 light-years

measuring how many years have passed for an Earth colony (or Earth itself) to become in contact with an alien civilization (anyone of the eight alien civilizations being considered) or the other way around (an alien civilization contacting an Earth based civilization).

Such simulations are carried out [8]. Figure 9 shows Earth in black and eight other alien civilizations positioned throughout the Milky Way galaxy. After running the simulation for 2300 years, Earth has colonized 23 exoplanetary star systems and around the year 2050 + 2300 = 4350 (assuming we start colonizing other star systems by the year 2050), the simulation shows Earth trying to colonize a world previously colonized by alien civilization number 1. Figure 10 shows the colonization process until that point in time. However, this is only one simulation. A total of 20 simulations were carried out. The year in the galactic clock in which an Earth based civilization meets an alien civilization is shown in Table 4. Also, the average of the galactic clock as well as the standard deviation for such galactic clock are calculated in Table 4.

The ramifications of Figure 10 indicate the expansion process followed by Earth (in black) and all other eight (alien) civilizations.

What is the ideal situation? The best scenario for space-jumping is the one corresponding to a wormhole-like space-jumping, that is, instantaneous space-jumping for both passengers and people left behind. Furthermore, it

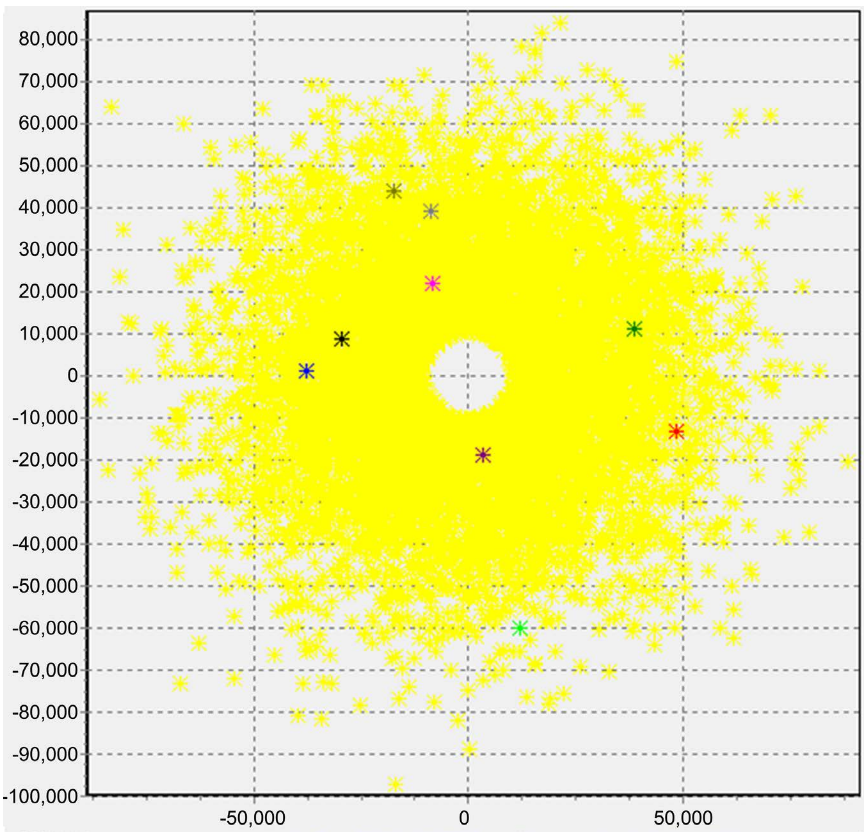

Figure 9. Beginning of the simulation of a multi-civilization Milky Way colonization process.

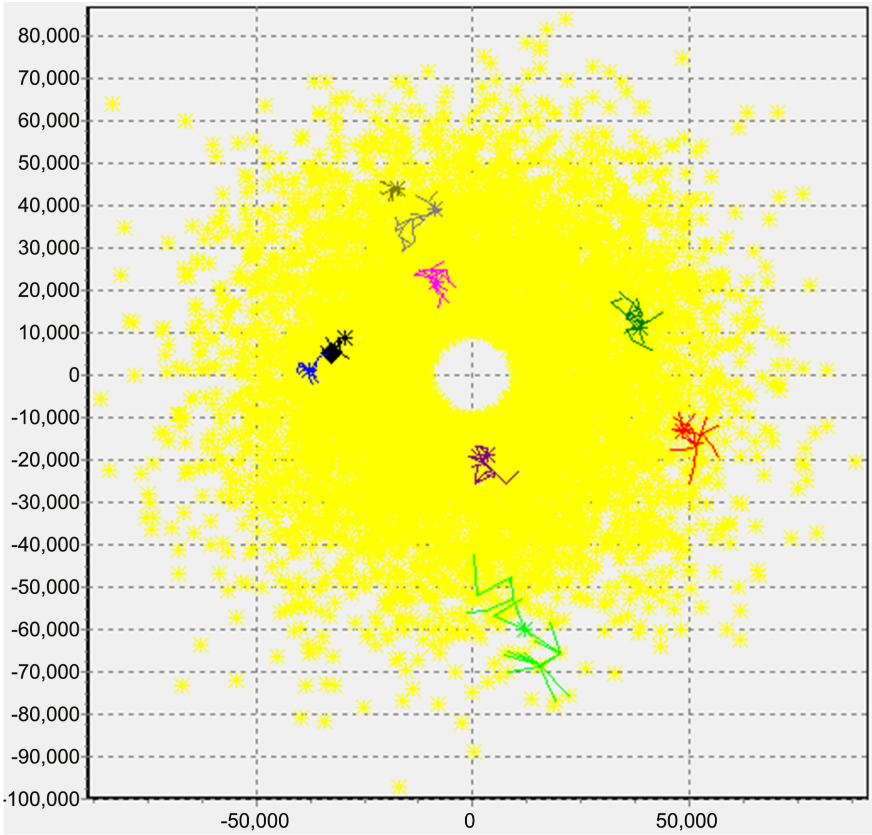

Figure 10. Earth based civilization meets alien civilization number 1.

Table 4. Results of the galactic clock of 20 galactic colonization processes simulations when Earth meets an alien civilization.

Simulation number	Galactic clock stops	Simulation number	Galactic clock stops
1	2300	11	79,300
2	3700	12	67,300
3	11,500	13	22,400
4	30,900	14	7400
5	18,100	15	99,200
6	6700	16	51,800
7	9900	17	3200
8	85,700	18	56,500
9	1500	19	53,400
10	25,100	20	7200
Average:	32,155	Standard deviation:	32,521

would be best if it is possible to space-jump from the surface of planets and moons. Beyond Mars exploration and the potential testing of space-jumping between the Earth and Mars in order to perfect the technology, lies the challenge of making space-jumping a technology that could actually take us to other worlds in other star systems, thus opening what I call the gate to the stars.

5. Discussion

The Earth is approximately 8 light minutes away from the Sun. Mars is approximately 3 light minutes away from Earth when it is closest to Earth [5]. Assuming circular trajectories (instead of the elliptical ones) and also assuming that Mars circles the Sun once every two years (which is a reasonable approximation), whereas the Earth circles the Sun once in a year, we could assume Mars can be located between 3 light minutes to 8 + 8 + 3 = 19 light minutes away. Refer to Figure 11 for an intuitive explanation of the situation.

There are numerous problems with the space-jumping scenario assumptions. The exploration of Mars could be the perfect opportunity to set up a space-jumping experiment because of the fact that during the exploration effort a very accurate system for location would be installed. This and the fact that there is a several minutes distance between Earth and Mars would allow to ascertain whether or not space-jumping occurs instantaneously inside the traveling vehicle and whether or not there is an Einstein's temporal dilation factor for the people waiting for the vehicle to arrive. Certainly, all of this is hypothetical, but possible. If it is determined that there is no temporal dilation factor, the path for the stars and interstellar traveling would only be a matter of time and effort. The question is that if for some reason the traveler inside experiences the space jump as anything other than instantaneous travelling, the Einstein's time dilation factor would make such trip that many times more time consuming. However, if

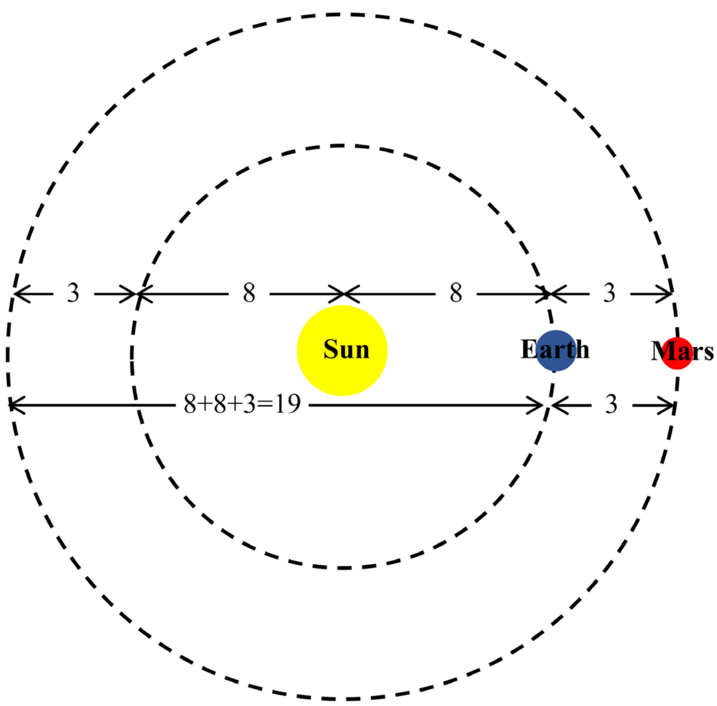

Figure 11. Earth and Mars trajectories and minimum and maximum distances from each other.

the time of travelling experienced by the space jumper inside the space jumping vehicle is zero or infinitesimally close to zero, then no mater how high the Einstein space jumping factor is, that factor times zero would equal zero. Except, of course, that zero multiplied by infinity could be an undetermined amount of time that could have a value of anything between zero and the amount of time light takes to travel between the two space jumping points. If the latter is the case, then interstellar space exploration and colonization would be out of the question for requiring hundreds of years or even millennia.

In any case, the Mars exploration effort using conventional rockets would create the need to design new technologies and put to the test existing ones. Keep in mind that most of todays technological advances making the economy in which we live possible originated with the space exploration race to the Moon.

How should we proceed in trying to open the gate to the stars assuming space-jumping is wormhole-like? We need to consider two scenarios. The first attempt should be to consider the Sun as the center of the space-jumping coordinates. In that case, we should try to space jump from the surface of the Moon to the surface of Titan. The orbit of the Moon is not exactly along the ecliptic, nor it is the orbit of Titan around Saturn. But in this case, we have a star as the center of the coordinate system being use and a space jump from a body orbiting the planet orbiting the Sun (that is, the Moon) to a body (Titan, one of Saturn's moons) orbiting another planet (in this case Saturn), the latter orbiting the Sun. This first attempt scenario is illustrated in Figure 12.

The advantage of achieving wormhole-like space-jumping from the Moon to Titan is that the situation in Figure 12 would be in gravitational terms, analogous to a wormhole-like space-jumping between the surface of the Earth and the surface of an Earth-like exoplanet orbiting a distant star. This is because, in this second attempt scenario, the center of the coordinate system would be the center of the Milky Way galaxy. The Sun orbits such galactic center while the Earth orbits the Sun, just as the distant star also orbits the galactic center and the Earth-like exoplanet destination orbits such star. This other situation is pictured in Figure 13. We can see that both Figure 12 and Figure 13 are similar in terms of the number of celestial bodies that need considering.

The space jump in the case of the second attempt shown in Figure 13 would

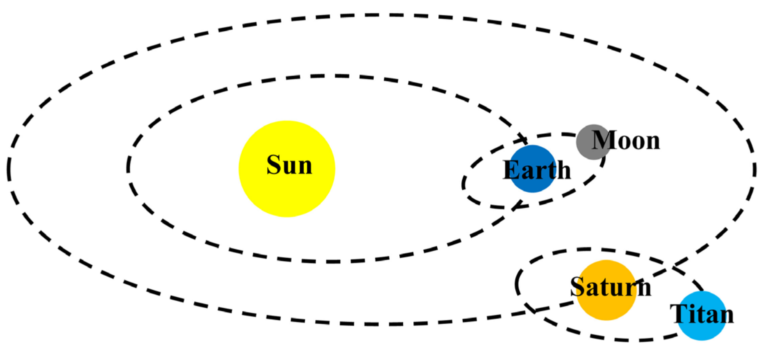

Figure 12. First attempt scenario for opening the gate to the stars.

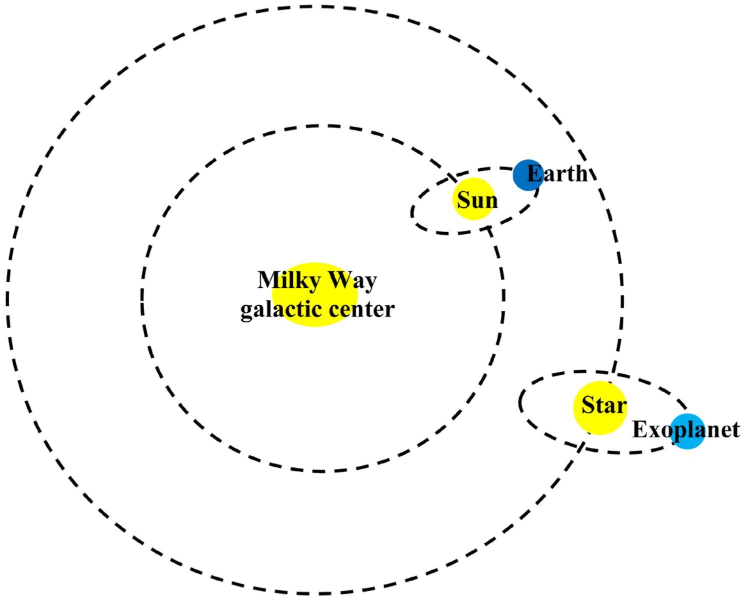

Figure 13. Second attempt scenario for opening the gate to the stars.

be between the surface of Earth to the surface of the exoplanet. This case would be the ideal situation, because it should allow the movement of people and merchandise between the surfaces of the two planets in consideration without needing to use conventional rockets for leaving Earth orbit nor shuttles for landing in the exoplanet and vice versa.

If space jumping is possible, but it is subject to Einstein's time dilation factor, then the answer for the expansion of humanity could be in colonizing other worlds in the Solar system, where distances would be several light-minutes away or a few light-hours away at the most. The effort for colonizing Mars will promote the development of technologies for a more rational use of natural resources and even the creation of self-sustainable environments. Then, in trying to colonize the frozen world of Europa or the toxic environment of Titan, the effort to conquest deep sea ecosystem worlds to live in would promote the development of technology for such endeavors.

Although the expected number of civilizations to consider in the Milky Way galaxy according to our Drake equation simulation is 87 having a range of [77, …, 97] we only considered Sagan's conservative estimate of 9 civilizations. In this simulation scenario, and assuming the galactic clock time until alien encountering behaves probabilistically following a normal distribution, the mean of such normal distribution is μ = 32,155 years with a standard deviation of σ = 32,155 years. Thus, according to the central limit theorem, we should expect alien encountering between 32,155 − 2 × 32,521 = −32,887 years and 32,155 + 2 × 32,521 = 97,197 years, that is, 32,887 years ago and 97,197 years into the future.

6. Conclusions

The only path to the stars would be close to zero time travelling between two very distant space points. It is essential that a special program be established for ascertaining whether or not a space jump of X light-years would take X light-years or zero light years. The best way to do that would be as part of a Mars exploration effort, since the time light takes to go back and forth from the Earth to Mars is several light minutes, which would allow scientists to do precise estimations.

If it turns out that the Einstein time dilation factor is unavoidable, at least it should be possible to establish a Solar system space exploration and colonization program using space-jumping technology.

What does it mean to space jump? To understand that, we need an example. Considering we have a car moving around us in a circular motion at some given speed, as the car increases its speed, the image we see of it in front of us becomes fuzzier and fuzzier. At infinite speed, the car disappears. That is precisely what a space jump means. The space-jumping vehicle disappears from one place and appears at another because it is moving at infinite speed between the origin and destination points.

In Einstein's general theory of relativity, celestial bodies move because they follow the path of least resistance within the spacetime fabric they are in. Thus, Einstein considers three dimensions of space, which can be traveled in any direction (back and forth) and one additional dimension, time, which can only be traveled in the forward direction, that is, from the past to the present and the present to the future. Why do I call my idea space-jumping and not spacetime jumping? Because I believe that for distant traveling (hundreds if not thousands of light-years away), we should leave time behind in the wormhole-like space-jumping scenario. Figure 14 schematically illustrates this kind of traveling. Since we are limited to a flat sheet of paper (or flat computer screen) to represent only two dimensions,

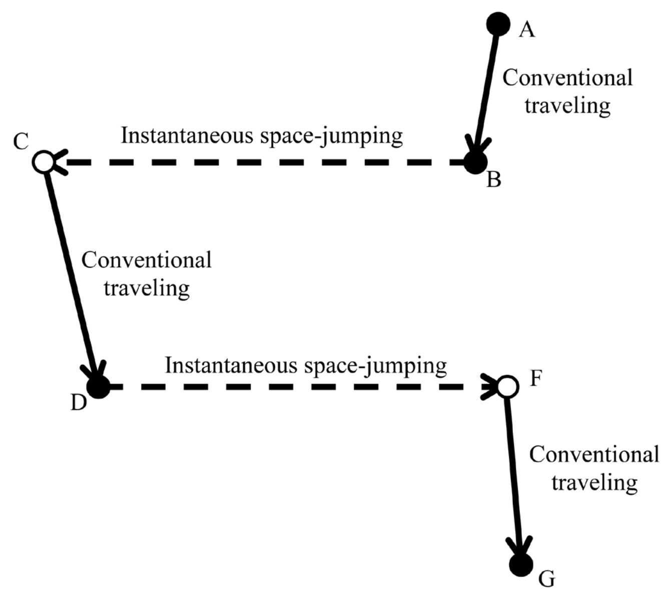

Figure 14. Space-jumping schema considering the time dimension in the vertical axis and only one space dimension in the horizontal axis.

I will consider only one dimension for space in the horizontal direction (which can be travelled right or left) and the time direction in the vertical direction (which can only be travelled downward in the forward time direction).

In **Figure 14**, the path traveled by the space-jumping vehicle in one space dimension and the time dimension is illustrated. From point A to point B only conventional traveling is considered (being that rocket or ion thrust impulse or simply following an orbital trajectory). Then, between points B and C there is space-jumping traveling. Notice that the point in B is market by a black dot, whereas the point in C is market using a white dot. This is because there is a discontinuity in time at the space-jumping event, although such discontinuity is hoped to be instantaneous both for the passenger and the people left behind. Then, between point C and point D there is conventional travelling, only to return (although not exactly to the same space point) in a space-jumping event between points D and F. Finally, the vehicle continues its course through conventional traveling between points F and G. The motion in the space dimensional is exactly horizontal in the space-jumping events (marked with dotted lines) because there is expected not to be time motion in these events, whereas for the conventional traveling motions there is both space and time motions, although the space motion is considerable smaller because traditional thrust or orbiting means are used.

Finally, a Mars exploration effort would also allow to investigate what happens if the Sun, for example, is exactly between the two space jumping points. In this case, such space jumping points would be exactly on Earth's orbit and on Mar's orbit. What conditions are required for optimal space jumping? Do stars or other massive objects between the two space-jumping points matter? Is space-jumping instantaneous for the traveler inside the space-jumping vehicle? What about the people waiting for the vehicle to arrive or return? How much time would they have to wait? What factors determine these waiting times? These are among the many questions requiring answer.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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