Fermi Paradox versus Problem of Induction

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Abstract.
This paper explores the relationships between some the problems of the Fermi Paradox (FP), with its variety of possible answers; and the Problem of Induction, and thus the possibility of a Theory of Everything.
We seek to improve the hierarchy of plausibility within answers to FP, given by what we call "preference criteria", among which we particularly highlight culture-independence. We argue that, if the question of whether a Theory of Everything is possible is answered negatively, then FP becomes much more serious than otherwise, and this makes many of FP's solutions less preferable. This constitutes a further preference criterion.
Armed with this tool, we try to outline a network of relative truths between FP and the Problem of Induction, in the form of a cross-answer table. Only two or three combinations of answers survive as preferable: 1) degenerate, pure solipsistic metaphysics; 2) accept Induction and the Anthropic Principle at the same time, thus saying that the human condition is a very rare one in the universe; or 3) that the Theory of Everything exists and its discovery is the Great Filter. This latter possibility is discussed with its implications for the current scientific and economic progress of our civilization.

1 Introduction and state of art

Scientists carry out a finite, always expandable, number of observations and, assuming the existence of some regularity in natural phenomena, formulate a sequence of theories with the inductive method. We do not know what this regularity, or Law of Nature, is. We cannot claim to know it with certainty, ever, since that would mean that the theory describing the Law would not be falsifiable. However, scientists suppose that the Law *exists*; otherwise, it cannot be researched and approximated better and better.
The existence of an absolute Law of Nature – a regularity independent of human knowledge and intrinsic to reality - is not a scientific principle. It is rather a *meta-scientific* principle; it is an axiom, necessary to the scientific method itself. This is also called Cosmological Principle (CP): the uniformity of all phenomena, in space, time and with respect to other parameters (e.g. the frame of reference). This "uniformity" with respect to the Law is just another way of expressing the regularity, which constitutes the Law itself.
The Problem of Induction [1], i.e. the question of whether the CP is true or not, is therefore an open philosophical problem. It cannot admit scientific or empirical proof (something like: "centuries of successes confirm the validity of the inductive method"), since any such proof would be circular.

Here we want to consider the relationships between the Problem of Induction and another open problem, the Fermi Paradox (FP). It consists in the fact that, according to some common assumptions, we expect to detect the presence of extraterrestrial intelligent beings (called sophonts from here on); but this expectation is betrayed by the data (see however [2]), according to which our entire past light cone is totally devoid of intentional [3] or unintentional [4] traces of such civilizations. From now on, we will refer to FP in this most general formulation, following [5], who dubs it the "strong Fermi Paradox" (sFP).
From an astrophysics point of view, FP consists of the discrepancy between two time-scales. One is the time

plausibly required for a technological civilization to colonize the whole galaxy. According to our scientific knowledge it must be at least 10^5 years, since this is the diameter of the Milky Way (MW) in light years and it is not possible to travel faster than light. On the other hand, with our current technological capabilities, we would be able to colonize the Galaxy in a maximum of 10^8 years – or even faster, with the use of self-replicating Von Neumann probes [6]. During this time, we can expect our technology and scientific knowledge to increase, making colonization techniques faster. This "Fermi-Hart time-scale" ΔT_{FH} (in honour of [7] and [8]) is therefore limited between these three orders of magnitude.
The other time-scale describes how late humanity reached a technological level (i.e. radio technology, and the construction of other tools that allow to us to detect technosignatures and biosignatures [9]) compared to other sophonts. Assuming that the time required on Earth for the emergence of complex life and intelligence is about the usual time (as a consequence of Mediocrity Principle), humanity appeared as quickly as the formation of our planet compared to other habitable rocky planets. Researches such as [10] has estimated the median age of planets of this type as $\bar{T_{pl}} = (6.4 \pm 0.9) \cdot 10^9$ years. Hence, the late of humanity can be evaluated by the Lineweaver timescale $\Delta T_L := \bar{T_{pl}} - T_{\oplus} = (1.8 \pm 0.9) \cdot 10^9$ years.
Stochastic models can be elaborated to describe in greater detail the expected rise and expansion of extraterrestrial civilizations, but they will always have to deal with the discrepancy between these two scales, according to which some sophonts should have had time to build a Kardashev III empire (for the Kardashev levels, see [11] and [12]) at least for eighteen times (or 18000 times, in the worst case) in our galaxy. But such an empire clearly does not exist, according to what we can see.

1.1 The Fermi quadrilemma

The Fermi Paradox is a multi-lemma. A di-lemma is a class of paradoxes that admits two possible answers, both paradoxical, that is, both breaking some deep-rooted belief. Sometimes, when there are three paradoxical possibilities allowed, we speak of a "tri-lemma". Numerous answers to FP have been proposed [13], and each of them challenges one of our long-held beliefs. Following again [5], it is possible to classify these numerous possible solutions by looking at the long-established philosophical and scientific assumptions on which FP is based: every attempt at a solution must violate at least one of these assumptions, and this is what gives it a paradoxical nature.
The fundamental assumptions of FP are:

1. Scientific Realism: there is an objective reality and empirical data (essentially) describe it;
2. Mediocrity (or Copernican) Principle: the human condition is not special, neither for the planet nor for the time in which we appeared, nor for being a living creature, an intelligent being, or a member of a technological society. The Mediocrity Principle is called into question by the Anthropic Principle, according to which the very fact that we exist and are capable thinking about our condition gives a selection effect that should be taken into account, so that our special role, for one or from the other aspect, it can be justified;
3. Gradualism: there are no essential differences between the phenomena we see today and those that happened in the past, or that will happen in the future. We can hence extend our current observation to explain evolution throughout time, without the need for catastrophic *deus ex machina*;
4. and some economic assumptions, i.e. that it is convenient and plausible for a civilization to undertake a path of evolution that increasingly increases its detectability.

Looking at this taxonomy, we say that FP is a "quadri-lemma". Violation of each assumption allows for a corresponding class of answers. Respectively:

1. Solipsistic Solutions: They can be more or less respectable, from the Bostrom's simulated universe [14], to conspiracy theories according to which governments are hiding aliens to us. All of these reject empirical data, for some reason.
   Absolute solipsism, that is, the denial of an objective reality, is a philosophical answer of this class. Note

that solipsism negates the Cosmological Principle, but one can refuse CP without denying the existence of reality, if the real world has no regular Laws.

2. The Rare Earth: These are answers such as that planetary systems are not common in the universe [15]; or that planets are usually unsuitable for life; or that abiogenesis is very rare [16]; or the development of complex life forms is rare [17, 18]); or it is the emergence of intelligent species [19]; or building a technological society [20]. In any case, this class of solutions suggests that there is something unique, or at least very rare, in the situation we are experiencing today as humanity, and we should not imagine a universe teeming with similar civilizations.
   In this class we can find all religious answers, [21] e.g., which violate not only the Mediocrity Principle, but also the Naturalistic Principle.

3. Catastrophes: That some extreme event commonly destroys intelligent species before they are able to manifests themselves to us; see [22, 23, 24, 25, 26, 27], and also [28]. If the destruction is triggered by the level of advancement of civilization (to a level lower than that required for interstellar contact), it is usually called Great Filter [29, 28].

4. Logistic Solutions: If technological civilizations are common and do not end prematurely, and it is true that we do not see them, then we should fall in a class of answers according to which their development usually follows a path that hides them from us. Here we find, e.g., the Hermit Hypothesis [30] – which the average civilization actively hides from others – the Dark Forest Hypothesis [31] and the Zoo Hypothesis [32].

1.2 Preference criteria

Although FP is an open problem and numerous answers are possible, given our current knowledge it must be stressed that not all of them equally plausible, or *preferable*. A rational method of investigation can include not only criteria of truth – that is, intellectual instruments with which some options can be excluded – but also criteria of preference, which cannot totally exclude possibilities, but which establish a hierarchy within the range of all possible options, indicating which ones should be considered first, while the others can be ignored until proven otherwise. A well-known preference criterion in science and philosophy is the

- Occam's Razor.

It cannot say anything about the truth. It cannot exclude that the world may follow a very complicated set of laws, with totally unnecessary elements (e.g., the second and third generations of Standard Model particles would not be necessary to explain the phenomena known until the early XX century, but they were found to exist nevertheless).
Occam's Razor can also be applied to FP, and other similar criteria can be sought, to build a hierarchy of preference within the numerous proposed and admissible answers to the Paradox. Namely, the Razor is a consequence of the broader

- Principle of Rationality,

according to which those solutions that are worse than the problem itself should be disfavoured. This is the case with most conspiracy answers: such a mentality poses worse problems than FP, since it would not be allowed to start from consolidated scientific knowledge to think about the world. The same can be said for religious and mystical answers (according to which life and/or intelligence were created only once by a supernatural being), which violate Naturalism as well as Copernicanism.
Another consequence of the Principle of Rationality, which applies above all to FP, was introduced by Brin in '83. He called it

- Non-Exclusivity,

according to which “diversity tends to prevail, unless there exists a mechanism to enforce conformity” [33]. The extreme variety of forms of life, psychologies and societies that can arise (according to our current knowledge on the matter), compared to the uniformity of the Great Silence in the universe, points out to a unique and uniform explanation for such a Silence. If the right explanation is not uniform and has something to do with diversity, then it is natural to imagine that diversity prevails, giving room to exceptions – but we see none of such exceptions. Hence, it is natural to believe in some mechanism that imposes the inexorable uniformity observed.
This means, in particular, that mixed answers are disfavoured, and this reinforces the taxonomy we sketched in the last paragraph. A “preferable answer” to PF should fall entirely in one of the four classes, making the classes themselves better defined. And this is natural: choosing a class means (paradoxically) rejecting one of the deeply-believed philosophical assumptions of FP; so choosing two or more classes at the same time means violating two or more of these assumptions, which is even more paradoxical and less preferable.
We want to stress a noteworthy consequence of Non-Exclusivity that we will call

- Cultural Independence.

That is to say that a good answer to FP should be independent from the cultural characteristics of sophonts – because the extreme biochemical, anatomical, psychological and cultural variety of imaginable civilizations indicates that such a common feature that should solve FP does not exist. Remembering Brin’s words, the “mechanism than enforces conformity” cannot have a cultural nature, otherwise it would not be uniform.
Almost all the Catastrophic and the Logistic Solutions turn out to be culture-dependent. The choice to focus on qualitative development and live like hermits [30]; or migrate to unexpected regions of space [34]; or try to exploit the energy of a rotating black hole [35, 36], without having the skills to control it safely; or to build and use weapons [26]; or to exhaust the environment [25]; or to build a static utopic or dystopian society; these are all culturally determined.
Before concluding this Section, we note that additional preference criteria cannot be found among the FP’s assumptions. E.g., it would not be legitimate to appeal to the Mediocrity Principle to deny preference to some possible solution. The very point of FP is exactly that at least one of its assumptions must be false, so, from this point of view, any answer must be “unpreferable”, for one reason or another. But, since all answers share this minimum unpreferability, then it is not useful for tell which are least worse; therefore this fact can be neglected and does not provide preference criteria.

2 Theories of Everything and FP

Let us now consider the possible answers to the Problem of Induction (PoI) – whether we decide to believe in the Cosmological Principle (CP), or not – and their respective consequences for FP. Let’s start from the first possibility: that the Law of Nature actually exists.

2.1 If the Cosmological Principle is assumed

Then, we call a scientific theory that describes it “Theory of Everything” (ToE). We must stress the difference between the Law and the ToE. All scientific theories must be falsifiable [37]. They are models; merely human attempts to describe the very Laws of Nature. The theory does not coincide with the Law; it is just an effort, an approximation. A ToE would be the best possible approximation. The same Law can admit many different formulations for its ToE, with different languages (even in non-mathematical language?), but ToEs still have the property to be *unimprovable*.
If a theory were effectively the Theory of Everything, it will never be falsified. Nevertheless, even if scientists formulate it, they will never have the epistemological certainty that it is the true ToE. One must always consider the possibility of an experiment or observation that confute it. Thus, they will always have to contemplate the possibility that the ToE does not truly describe the Law of Nature.
Such a situation would mean the end of the scientific progress – due to the ultimate success of science. This may be astounding in a society that usually takes for granted that progress is limitless. This myth of an unlimited

scientific progress comes from the principle (in philosophy of science) that all scientific theories are falsifiable, and from the fact (in history of science) that almost all past theories have eventually been falsified. However, even if all theories *can* fall, this does not mean that they *must* fall. In particular, a ToE would not fall.
Continuing along this line of thought, we can observe that any scientific theory consists of a prohibition, of a claim of *impossibility* - rather than of *possibility* of building new technologies and progressing. Any scientific theory claims that only the phenomena allowed by the theory itself can occur: among all the other phenomena we can imagine, none of them can happen. The broader is the exclusion, the more noteworthy and advanced the theory, and the more falsifiable, in the Popperian sense. The ToE should be seen as the ultimate obstacle, for society discovering it, rather than a source of technical applications.

The technological development of humankind has so far supported by scientific progress. Knowledge of new aspects of nature has allowed us to exploit them. Each of these phenomena has a maximum of possible exploitation but, each time, another scientific discovery arrives to relaunch progress, before the previous discovery has exhausted its potential.
In other words: any system, with a given law, has a Malthusian limit of development. Science allows us, every time, to discover that this law is not the definitive one, and that there is a greater system for developing, with a higher limit. Scientific progress continually breaks the Malthusian ceiling, allowing for (seemingly) infinite development.
We can give a quantitative evaluation of this mechanism by plotting the growth of humankind's Kardashev value over the last two centuries (since Industrial Revolution initiated the current auto-catalysis [38]); data taken from [39, 40].
If we take the Energetic Determinism as valid (compare with [41]), we see that human progress is well approximated by an exponential: see Figure 2.1. Since Kardashev's is a logarithmic scale, this is equivalent to a linear time dependence $K(t) \cong \frac{t-t_0}{T}$.
This exponential is the superposition of many exponential explosions (i.e., the five successive Industrial Revolutions of these centuries [42, 43, 44]; Moore's Law is another particular example [45, 46]), refuelled again and again by science.
Exponential progress will end when a ToE is discovered. The Malthusian limit of a ToE cannot be broken, because the ToE cannot be improved with a broader theory. Once the (accessible) universe is exhaustively described by a ToE, its model gives a closed system, with fixed resources. These resources may be exploited for a while, after the discovery of the ToE, but sooner or later the exponential explosion must end.
The analysis above was done for human civilization, but it can be generalized for any sophont. We can't know if other civilizations have a scientific method similar to ours, and assuming this would introduce a cultural dependence; but nevertheless, we can say that climbing the Kardashev scale always requires extracting new resources, from new phenomena in the universe. For the Mediocrity Principle, we should believe that the typical technological society grows with an exponential regime, as we are doing; and with a similar characteristic time-scale of approximately $T = 1370^{+2862}_{-553}$ years, needed to grow by each entire Kardashev degree. This is coherent with the recent research [47]. A consequence of Scientific Realism is that the universe, and its Law, is the same for any intelligence that investigates it, regardless of method and language; it is culture-independent. We must therefore conclude that any technological society must end its exponential progress, once it discovers a ToE (expressed in its own language).

Two notes need to be made here. First, the end of the exponential regime does not necessarily mean the end of civilization, nor the end of its development. Growth may continue (for example by reaching more and more stars and exploiting their energy), and may even be unlimited, but it will no longer be exponential over time. This becomes clear if we try to extend our linear regression $K(t)$ into the future. Humankind is predicted to reach the III Kardashev level in the year 5145^{+6774}_{-1308} A.D. But it is not physically possible to colonize a galaxy with a diameter of 10^5 light years in less than ten millennia, according to all our scientific knowledge: there would not even be time to reach most of the stars. In fact, the Fermi-Hart time-scale is assumed to be less than 10^5 years. Reducing the Fermi-Hardt time-scale would mean breaking the speed of light limit. This can't be ruled out, in principle, because Special Relativity is also a falsifiable scientific theory, and could be improved with a future theory. But, even if this were to happen to Special Relativity, sooner or later a ToE will be reached, and its limits to the growth cannot be exceeded. If we take for example as the speed of light limit is valid, the colonized volume can grow at most as $(ct)^3$, and the same for the number of the stars reached, and

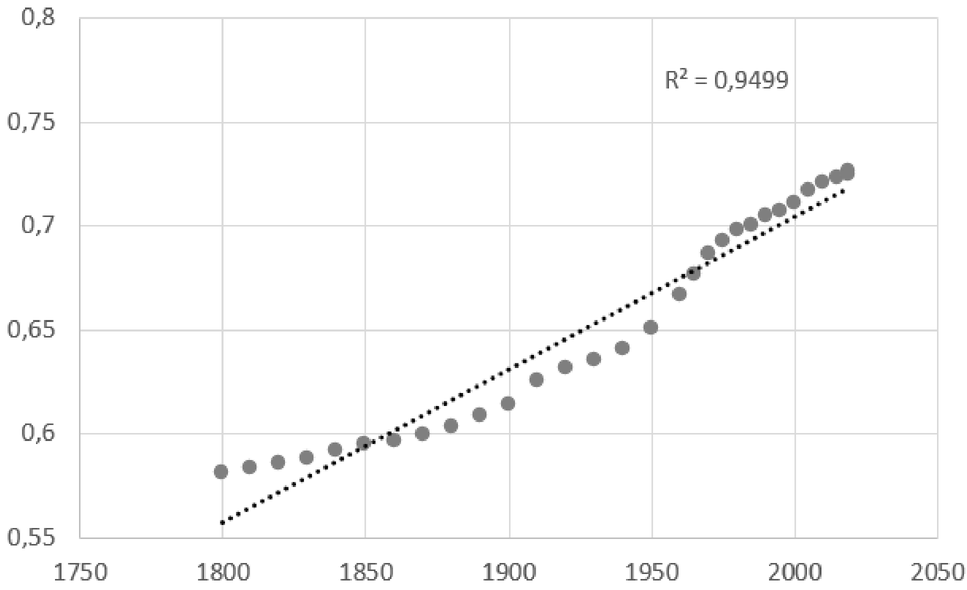

Figure 1: Regression line for K(t) data, from 1800 to 2019

for energy production. This would be a power law increase, and no longer exponential.
Secondly, it must be stressed that technological progress does not coincide with scientific progress. Even if the resources and phenomena unlocked by a theory are limited, this is not necessarily the case for the possible applications of the theory, and for its logical consequences. This also applies to a ToE. However, physical limitations remain. No incompleteness theorem [48] or computer development can allow us to reach 10^{10} stars, a hundred thousand of light years away, within ten millennia from today, if the speed of light limit holds.

2.2 If the Cosmological Principle is refused

Let's now investigate the other option, that is, that the Law of Nature does not exist.
This is the case implied by solipsism, according to which there is not "real world", so the theories we propose starting from our data are only apparent and fallacious.
In any case, if CP does not hold, a ToE will never be found. No ToE means no obstacles. There is no reason, in principle, why the regime in Figure 2.1 should eventually end. We must believe that the typical technological society can proceed indefinitely with the exponential technological explosion, and with a characteristic time-scale that is similar to ours $T = 1370^{+2862}_{-553}$ years.
As we have seen, this forces us to reduce the evaluation of the Fermi-Hart time-scale to $\Delta T_{FH} \cong 3T = 4110^{85586}_{-1659} \cong 2450 \div 12700$. As we said above, FP consists of the discrepancy between the Lineweaver and Fermi-Hart time-scales, and we see how in this case the discrepancy becomes more serious, of at least two orders of magnitude.
This is our crucial observation: that PoI has a close correlation with FP. If CP does not hold, the "seriousness" of FP becomes $\Delta T_L/\Delta T_{FH} \cong (0.79 \div 1.1) \cdot 10^6$; while, if CP holds, the same "seriousness" evaluation returned $\Delta T_L/\Delta T_{FH} \cong 9 \div 27000$. FP is a quadri-lemma; the temporal discrepancy suggests us to drop, or at least weaken, one of the four assumptions we deeply believe in.
The more serious is the discrepancy, the more the assumptions must be weakened to justify it. FP assumptions do not have a binary truth value. A (relatively) not very severe FP can be solved by changing the truth value of one of these assumptions in a non-radical way, after all. But the more serious the FP, the more radically the value of truth must have changed, and the more counterintuitive (i.e. paradoxical) the result. If CP does not hold, FP has a seriousness of $\sim 10^6$, then a Great Filter, a rarity mechanism for Earth, or a Logistic mechanism, needs to be applicable to at least $\sim 99.9999\%$ of sophonts, for solve it.

What we describe here is an extreme version of the Fermi Paradox (eFP), worse even than the strong formulation (sFP) that we gave in the Introduction following Cirkovic's formulation. This version of the paradox can be more clearly enunciated in this way: "If any scientific theory can be eventually confuted (this is the case in which the Clarke's Third Law [49] or the Shermer's Last Law [50] apply), then at least one of the four FP's fundamental assumptions must be negated with absolute certainty"; namely:

1. Our empirical data are totally uncorrelated to an objective reality; or
2. Life, or intelligence, or technology at least, present on Earth, constitute a unique exception and nothing similar to us can exist in the entire universe (including regions beyond our visible universe); or
3. It exists a Great Filter, it is completely inevitable and it will occur to human species; or
4. Intelligence and technology leads inevitably to avoid any contact with other intelligent and technological beings.

We have to deal with it in the case the CP is violated and, under this hypothesis, this adds a new preference criterion:

- An FP answer is preferable if it also resolves eFP.

Most answers in the Rare Earth, Catastrophic and Logistic categories do not meet this requirement, because their "mechanism to enforce conformity" is not sufficiently inexorable. The same can be said for conspiracy theories: the "strong powers" may hide contact with one alien species, or with ten of them, but it would be too difficult to hide thousands or millions of contacts, without any exception.
On the other hand, the religious versions of the Rare Earth give an answer to eFP. Creationism, for instance, states that life has intrinsic features that cannot emerge spontaneously from non-living matter; so that all the life on our planet (as well as any eventual life on other planets) must be created through a free act of a supernatural being, namely "God". If "God" is unique, and if they choose to create life only once, on our Earth - and these are beliefs usually held among creationists - then the Earth cannot have an analogous in the entire (visible or not) universe. The total arbitrariness and exceptionality of divine creation reduces the probabilities of the appearance of sophonts to exactly zero. However, remember that these answers violate the Principle of Rationality.
Finally, we can here take into consideration the most Solipsistic solution with new eyes. In this subsection, we are under the hypothesis that CP is not valid, which is already implied by Solipsism. In particular, if the CP is rejected because there is no objective world, then we are led to choose pure solipsism as the right solution of FP. It is just the logical consequence of our hypothesis, and a logical criterion of truth prevails over a criterion of preference, as is the Principle of Rationality.

2.3 A cross-answer table

Here we add a couple of remarks. First, that the rejection of CP is a sufficient, but not necessary, condition to generate the extreme Fermi Paradox. We can in fact imagine the case in which the real world exists, and is subjected to a regular Law of Nature, but such that this Law does not forbid unlimited exponential development. Or even such that it imposes a Malthusian limit on growth, but with a limit so high that FP is still promoted to eFP. Let's say, a limit for civilizations of the type XX for Kardashev [51].
To describe the relationships between PoI and FP, we should therefore distinguish, for the former, between different degrees of answers. Namely:

0. CP does not hold, because there is no objective world (pure solipsism);
1. CP does not hold, because the objective world exists, but has no regularity;
2. CP is valid, but the Law of Nature imposes a limit on exponential growth above Kardashev degree III;
3. CP is valid and the limit of the Law is less than the III degree Kardashev.

Each of them returns different consequences for FP.

As a second remark, let us remember that sFP does not limit itself to excluding a type III civilization in the Milky Way (MW), but applies to all possible traces of sophonts on our past light cone, also taking into account other galaxies. An analogue of the Fermi-Hart time-scale $\Delta T_{FH}(\Omega)$ can be defined for any region Ω of space containing the Earth, larger or smaller than our galaxy.

The larger the space considered, the longer the time-scale of colonization, but the more numerous the places where civilizations can arise, in Lineweaver time. E.g., for the Local Group, the possible spots are approximately ten times more than those of the MW alone; but the diameter is a hundred times greater, so that this amplitude of space it is ten time less probable to be completely colonized by sophonts. If the speed of light limit is considered valid, the visible universe is the largest region to be considered, containing $\sim 10^{10}$ galaxies, and the time needed to colonize it diverges to infinity, it is impossible that occur in Lineweaver time (but see [52] about that).

On the other hand, the density of stars in the MW is almost homogeneous, so that, if we consider a smaller spherical region of space the possible sophont sources decrease with the cube of the diameter, and the probability of complete colonization becomes increasingly smaller, proportionally to the square of the diameter. MW is the region of space for which this probability (that a sophont that arose within it, colonized it completely) is maximum, and it is the region that must naturally be taken into consideration, if one wants to solve FP independently from the scale.

The above scenario is valid as long as the light speed limit is taken for granted. Otherwise, for CP violations of degree 0, 1 or 2, a civilization sufficiently developed to overcome the Theory of Relativity is expected. The analogue of the Fermi-Hart time-scale $\Delta T_{FH}(\Omega)$, required to colonize the whole Ω :=visible universe (i.e. to reach the IV Kardashev degree), would be $4T \cong 3300 \div 17000$ years. Again, this is five orders of magnitude less than Lineweaver time but, within the same ΔT_L time interval, there are $\div 10^{10}$ more possible sophont sources to consider. Now, the question is: why has not a type *IV* civilization (instead of III) already colonized the whole visible universe (instead of just MW); and, if it did, why don't we see this fact? But it is a question $\sim \frac{3}{4}10^{10}$ times more serious than FP on MW.

This generalization is not limited by the edge of the visible universe. In fact, this obstacle is also due to the speed of light limit. For a developed enough technology, it can be broken [53, 54]. Hence, we have to consider FP over regions of space much larger than our visible universe, without any limit. The seriousness of eFP increases as $\propto \frac{3}{K}10^{10(K-3)}$, with the Kardashev degree K. If we are in case 2 of violation of CP, and if the ToE places an absolute Malthusian limit at a given $K_M > 3$, then substituting this K_M returns the highest seriousness of FP. For cases 1 and 0, a cut-off can be only be given if the universe is topologically compact, i.e. if its spatial curvature is positive. For a spatially infinite universe which does not meet the Copernican Principle, FP is *infinitely* serious, and the truth value of (at least) one of its assumptions must be *exactly* zero. Here we note how FP and PoI can be linked to another open scientific and philosophical question: whether the universe is infinite or not.

Anyway, we must face the fact that eFP is more serious than sFP by at least tens of orders of magnitude, instead of just three to six orders of magnitude, as we calculated in preliminary estimates in the last subsection. This is the "extreme" feature of eFP. So, if you decide to answer to PoI with a degree 2, 1 or 0 answer, then you are forced not to prefer FP solutions in the Rare Earth, Catastrophes or Logistic classes, since (as we already said) almost none of these mechanisms is efficient enough to justify a discrepancy of tens or orders of magnitudes; so they are pushed aside by the eFP preference criterion.

In the speculations of this Section, we have considered many options for both the problems of Induction and FP, and have discussed their mutual implications. We can now summarize our findings with a cross-answer table: see Figure 2.3.

For what we dubbed degree 0 of PoI, i.e. a purely solipsist picture, we are led by tautology to choose a Solipsistic Solution: pure solipsism, in fact. For the other degrees there is an objective world, so that the Principle of Rationality prevails, which suggest us not to prefer Solipsistic Solutions.

For degrees higher than 0 we then consider the other three classes of answers to FP, asking ourself whether they are preferable or not, according to our criteria. We have already said in the previous Section that almost all proposed Catastrophic and Logistic Solutions depend on culture and should be set aside. Furthermore, for degrees 1 and 2 of PoI the new preference criterion from eFP must be taken into account. It is infinitely serious

Induction Problem \ FP	Solipsistic Solutions	Rare Earth Solutions	Catastrophic Solutions	Logistic Solutions
Degree 0	V	X	X	X
Degree 1	*	†, *	**, †	**, †
Degree 2	*	†, *	**, †	**, †
Degree 3	*	V	**, V?	**

Figure 2: Cross-answer table between Induction Problem and FP. Legend:
X: excluded by logic
V: preferable answer
*: unpreferable answer, because Rationality Principle
**: unpreferable answer, because culture-dependent
†: unpreferable answer, because eFP

at degree 1 and still very very serious at degree 2. A Rare Earth, Catastrophic or Logistic solution can only address eFP if it offers no chances of avoiding it. No mechanism like this has ever been proposed, as far as we know. The only exception is the religious answer, ruled out by the Principle of Rationality.

After all the preference criteria have been applied, only two boxes in the table remain preferable. One is the degenerate case of pure solipsism, which answers to all real-world problems by saying that such a thing simply doesn't exist. Technically it belongs to the realm of possibilities, but it doesn't tell us much about the topic. However, it is interesting how far this degenerate option is from the other survived box. That is to say that if you want to put a little solipsism in your answer, then you are forced to fall in the absolute solipsism; otherwise, solipsism should be totally avoided. The intermediate degrees 1 and 2 do not have any preferable boxes.

The second preferable option prescribes abandoning the Mediocrity Principle and to accepting the Copernican Principle, in his strongest form. Not only does a Law of Nature exist, but this Law must induce some inevitable obstacle to the exponential development of technological societies, an obstacle that occurs at a Kardashev degree $K_M < 3$, thus exorcising eFP. We have no way of predicting what the Law consists of (both for the reasons of philosophy of science we mentioned above, and for inadequacy of current human knowledge). In any case, the formulation we have presented, in terms of the Kardashev scale, and therefore of energy control, suggests that the Law should have something to do with energy. If, for example, a sufficiently developed civilization could discover the perpetual motion of first kind, then the Kardashev scale may lose its *raison d'être*. Likewise, the speed of light limit was one of the most natural obstacles we imagined, in our line of thinking, to exponential development up to Kardashev's III degree. This suggests that Special Relativity, or something similar, may be a component of ToE. However, guessing the components of ToE is a hopeless effort. Indeed, it is totally unreliable what a "natural" obstacle seems to us, or what form our formulation of eFP has taken, since these once again derive from inadequate, current human knowledge.

Finally, it is perhaps possible to find a third preferable combination, which will be discussed extensively in the next Section. This is the case where a ToE exists and somehow constitutes the Great Filter. We are therefore once again in degree 3 of PoI. Most Great Filters are swept aside due to their dependence on cultural choices, but this is not the case with a Great Filter that is a consequence of ToE. The Law of Nature is intrinsic to the universe, regardless of the cultures that live within it and the formulation they can give it; hence, a mechanism resulting from the Law would "enforce conformity" on these cultures.

3 Can the Theory of Everything be the Great Filter?

In the last Section we argue that the discovery of a ToE would soon put an end to the exponential development, observable in the last two centuries of human civilization, with a characteristic time-scale of a few millennia; what should hence be considered a common developmental regime among sophonts. We have stressed the fact that *a priori* we see no reason why ToE should destroy the society that discovers it, nor should it stop its development. The only consequence that we can deduce with certainty is the end of the exponential regime, while the growth may continue with a less rapid profile, as can be a power law.

Well, in this Section we will consider the possibility that, due to some currently unknown mechanism, the discovery of a ToE has more severe consequences. Namely, the possibility that it could activate a Great Filter. Recall that a Great Filter is a catastrophic event – that is, an event that breaks Gradualism in the history of life, intelligence and technology – triggered by the achievement of an adequate level of development, which is unavoidable or almost, which affects a high percentage of technological societies. Recall, moreover, that the catastrophe does not necessarily have to consist in the elimination of the civilization. A radical change may be sufficient, whereby the sophonts involved never become detectable sources of technosignatures or biosignatures; and, in particular, for which they do not continue to expand their energy consumption, until they control of all the suns of MW.

Looking at the exponential curve of energy versus time, what we are conjecturing is that the discovery of a ToE occurs at a certain cut-off $K_M < 3$ and that the curve cannot grow further. When the cut-off is reached, the curve drops to zero; or at least it tends to be constant.

A ToE naturally indicates a level of development, as is required of a Great Filter. It is culture-independent. These are the reasons for studying this possibility. The puzzle is to identify a mechanism that leads from a ToE to a catastrophe.

The effort to imagine such a mechanism presents the same difficulty that is encountered in formulating a solution to FP: we have only one example of an intelligent species and technological society. It is not trivial to tell if a certain characteristic is intrinsic to intelligence itself, or whether it is limited to Homo sapiens.

We will try anyway, and we are forced to look at human society as a starting point.

We see that our technological explosion, of the last two centuries or more, is not decoupled from the rest of the society [55]. In particular, a virtuous circle has been established between scientific research and financial investments. Such rapid scientific discovers, and above all their industrial applications, are guaranteed by increasingly solid economic support. At the same time, companies and investors can also increase their success thanks to the profits obtained from new technologies. The more this machinery works and demonstrates its own reliability, the more the markets have confidence in it and are willing to invest in science.

Indeed, the very notion of investment is consistent with the scientific mentality. The essence of science is admitting our ignorance. We recognise that there is something we don't know and that it could be something important, so we make an effort to find out. In a similar way (and almost in the same period, i.e. around the XVII century) European economics recognized that the production system in a given year does not necessarily provide all the wealth that can be expect. Non-negligible increases in wealth may occur in the future, whenever someone has a good enough idea and is able to put it in practice. So, instead of simply accumulating cash – which is a good strategy if the wealth were constant – it is profitable to invest in such developments. This way investors get a fraction of the new wealth and entrepreneurs are supported, so that the financial system works faster.

We can say that investments are the economical evaluation of trust in the future [55]. This trust confirms itself because, as long as finance works, it gives reasons to trust it. It depends on expectations, i.e. on human psychology. Nevertheless, finance is not totally decoupled from the physical world. Investment money, which by far represents the money that currently exists, is "imagined" money, which has value because enough peoples believe that these are good investments. But some unimagined proof must be provided. Otherwise, sooner or later, the financial bubble bursts. It happens sometimes, but these are temporary events, due to contingent causes and specific unreliable products. On a larger scale, human economy has been growing for centuries and its products are overall reliable.

General trust in future and its material evidence derives mainly from scientific and technological progress. The fact that total wealth is not a fixed cake (which can simply be cut and divided among the guests), but that it always increases (so that everyone's portion can grow simultaneously), is fundamentally guaranteed by new technologies, each one with a new value; by the discovery of new lands, deposits and materials; and by inventing more efficient and convenient ways for each step.

In almost all scientific communities it is widely taken to be obvious that there cannot be an unlimited growth, for any quantity, in any system; because, as we discussed above, a Malthusian limit of the system must always hold. This perception of obviousness has rare exceptions. It is not a It is no coincidence that the economics community is the biggest exception. The intuition among economists says exactly the opposite: that unlimited growth is not only possible, but *necessary*. Furthermore, exponential growth, expressed as a certain percentage per year, is usually assumed, and an economy that grows of only 1 or 2% is considered "sick", stagnant, or otherwise abnormal. Exponential growth is considered *the standard*. Note that a 1% per year means a factor 10^{10} over 23 centuries: this is similar to the energy production rate we estimated from Figure 2.1, which generates eFP. Of course economists are perfectly aware of Conservation of Mass and Energy and the limit of light speed, but such obstacles to growth are really too far away for the scopes of their science, and can be neglected.

A society structured in this way is vulnerable to the discovery of a ToE. If our trust in future and our economic system are based on unlimited scientific progress, the end of this progress would be a serious blow for the functioning of the entire society. What we are saying is that, in the light of a degree 3 answer to PoI, the very nature of the human progress in the Modern Era looks like a huge financial bubble.

When a ToE is reached, it will likely take some time for the system to suffer the extreme consequences. First of all because scientific method can never confirm that a theory is actually a ToE. However, after a certain period in which no better theories have been found, common sense will consider this as a conclusion reasonable. It will still take some more time for the ToE's applications to run out. After few centuries from the discovery of ToE, energy production will be forced to increase to the maximum according to a power law $\propto t^n$. The annual percentage will hence be something like $\propto n/t$, tending to zero. We could once again discuss whether other kinds of innovation can nevertheless support the economy; but assuming that this is not the case, we can conclude that the rate of economic growth will similarly tend to zero, proportionally to n/t. Trust in future, once supported by technological progress and by the success of finance itself, will be undermined. Interest rates will increase overall, returning to pre-modern levels, because the future will no longer have the same economic value. Investors will start to imagine again the total wealth as a fixed pie, and to believe that, if any increase occurs, it is predictably negligible. *A fortiori*, investments in science and technology will almost stop, and our Kardashev degree will become almost constant. Such a radical and rapid regime change can be considered a catastrophe, and possessed the characteristics one would like to find in a Great Filter or in a Logistic Solution. Note that to avoid the discover of ToE by stopping scientific research would not protect humanity from this crisis, but rather cause it prematurely; see also [56].

An even more pessimistic scenario can be proposed if we also consider the coupling between economy and politics. The exponential economic regime in the Modern Era is believed to be one of the causes of reduction of wars around the world [57]. In fact, still using the cake analogy, in a pre-modern economy a guest has no way increasing her/his own portion except by taking from another: in a zero-sum game, aggressive strategies are favoured [58]. In the modern economy, the total pie can grow, the game is not zero-sum, and collaborative strategies can be more profitable, accelerating the growth of the pie. Post-modern economy will once again be a zero-sum game, and aggression will once again become a profitable choice. However, post-modern wars will be different from pre-modern ones, due to the destructiveness of weapons built in the modern technology phase. This again opens to a nuclear holocaust scenario – possibly involving weapons more destructive than current thermonuclear bombs. Even if humanity would not be completely wiped out by such a war, post-modern zero-sum economy will lead society to such holocaust again and again, still preventing humanity from resuming its development.

Recall that this last scenario is only the most pessimistic one. A definitive halt to progress may be peaceful, but it would still be a "catastrophe".

From the above analysis, we say that ToE can conceivably trigger a catastrophe for humankind. This is not enough to conclude that it is the Great Filter, since we don't know whether this analysis can be generalized to any civilization. Many steps of our reasoning depend strongly on the features of human culture, so that this mechanism does not seems to satisfy the culture-independence criterion.

However, humankind is the only example of a technological society we currently know, as we have stressed previously. It can be conjectured that each sophont experiencing a technological explosion must support it with its own version of "investments", and its "trust in future" vanishes after the discovery of a ToE, leading its development to halt, or at least to slow down a lot. If this is the case, then the Theory of Everything is the Great Filter, and the corresponding box in Figure 2.3 is the correct cross-answer to both the Problem of Induction and the Fermi Paradox.

4 Conclusions, criticisms and future perspectives

The Fermi Paradox probably constitutes a sort of Rorschach Test [59], bringing out the personal psychology of those who propose the solutions, with their relationship with diversity, or their deep fears towards society and nature, rather than objectively plausible proposals. This caveat should be taken into account when any proposed solution for FP is discussed. For instance, during the Cold War, the attempt to identify the Great Filter with a nuclear holocaust got a lot of attention. Its plausibility was strengthened by witnessing of the international politics of that time. In the same period, the mindset of the sphere of influence and interstellar colonialism it was widespread, in relation to the predictable development models of the sophonts. And in fact European colonialism then saw its last act, and geopolitics was dominated by two opposing spheres of influence. Subjective opinions about human nature are too easily generalized to be believed for a generic sophont.
In the same spirit, it should be remembered that the present article is written by an author who lived through the Great Recession of 2007-2009 and its aftermath; and warns the ecologic emergency, linked to the depletion of environmental resources. Such fundamental fears could lead to the ToE Great Filter being granted more plausibility than it deserves. This criticism is even more justified as Section 3 suffers from too anthropocentric a point of view. We have argued that this flaw is seemingly unavoidable (as long as we have only one case study of technological species), but it is a flaw nonetheless, and it makes the risk of approaching FP as a Rorschach Test more serious. The speculations in Section 3 will have no more value than any other imaginative attempt to divine the Great Filter, until a culture-independent mechanism is found that necessarily leads from a ToE to a catastrophe.
As for Section 2, we believe it suffers less from personal arbitrariness, although the idea of limited resources still plays a certain role in the interpretation of scientific laws as obstacles for development. The discussion could be improved if some other preference criterion were formulated; or if new facts emerge, modifying the hierarchy of preferences within the range of possibilities. Another way of improvement would be to move from qualitative to a more quantitative models for rise and development of sophonts. The Fermi-Hart and Lineweaver time-scales should be formalized in appropriate stochastic models, especially as regards their calculation on the generic region Ω of space, which was roughly discussed in subsection 2.3. These estimations should subsequently be applied to the quantitative evaluation of the "seriousness" of FP, and of how much the Mediocrity Principle, Gradualism and the other assumptions of FP have to be violated. These are all matters for future work.

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References

[1] C. Howson, *Hume's Problem: Induction and the Justification of Belief.* New York: Oxford University Press, 2000.

[2] M. Schuetz, D. A. Vakoch, S. Shostak, and J. Richards, "Optical seti observations of the anomalous star kic 8462852," *The Astrophysical Journal Letters*, vol. 825, p. L5, jun 2016.

[3] D. Oberhaus, *Extraterrestrial languages.* Cambridge: MIT Press, 2019.

[4] F. J. Dyson, "Search for artificial stellar sources of infrared radiation," *Science*, vol. 131, no. 3414, pp. 1667–1668, 1960.

[5] M. Ćirković, *The Great Silence: Science and Philosophy of Fermi's Paradox.* Oxford University Press, 2018.

[6] B. McMullin, "John von Neumann and the Evolutionary Growth of Complexity: Looking Backward, Looking Forward," *Artificial Life*, vol. 6, pp. 347–361, 10 2000.

[7] E. M. Jones, “’where is everybody?’: An account of fermi’s question.” `http://www.fas.org/sgp/othergov/doe/lanl/la-10311-ms.pdf`, 2007. Accessed: Feb 10, 2023.

[8] M. H. Hart, “Explanation for the Absence of Extraterrestrials on Earth,” *QJRAS*, vol. 16, p. 128, June 1975.

[9] G. Cocconi and P. J. Morrison, “Searching for interstellar communications,” *Nature*, vol. 184, pp. 844–846, 1959.

[10] C. H. Lineweaver, “An estimate of the age distribution of terrestrial planets in the universe: Quantifying metallicity as a selection effect,” *Icarus*, vol. 151, no. 2, pp. 307–313, 2001.

[11] N. S. Kardashev, “Transmission of Information by Extraterrestrial Civilizations.,” *SOVAST*, vol. 8, p. 217, Oct. 1964.

[12] C. Sagan and J. Agel, *The Cosmic Connection: An Extraterrestrial Perspective.* Papermac, 1981.

[13] S. Webb, *If the Universe Is Teeming with Aliens ... WHERE IS EVERYBODY?: Seventy-Five Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life.* Science and Fiction, Springer International Publishing, 2015.

[14] N. Bostrom, “Are We Living in a Computer Simulation?,” *The Philosophical Quarterly*, vol. 53, pp. 243–255, 04 2003.

[15] I. P. Williams and A. W. Cremin, “A Survey of Theories Relating to the Origin of the Solar System,” *QJRAS*, vol. 9, p. 40, Mar. 1968.

[16] P. Ward and D. Brownlee, *Rare Earth: Why Complex Life is Uncommon in the Universe.* Copernicus Series, Springer New York, 2000.

[17] N. Lane, “Life: Inevitable, or just a fluke?,” *New Scientist*, vol. 214, no. 2870, pp. 32–37, 2012.

[18] B. Gordon and W. Dembski, *The Nature of Nature: Examining the Role of Naturalism in Science.* Intercollegiate Studies Institute (ORD), 2014.

[19] C. H. Lineweaver, “Paleontological tests: human-like intelligence is not a convergent feature of evolution,” *From fossils to astrobiology*, pp. 353–368, 2008.

[20] A. Loeb, “Are alien civilizations technologically advanced?,” *Scientific American*, vol. 29, no. 1, 2018.

[21] V. Lytkin, B. Finney, and L. Alepko, “Tsiolkovsky - Russian Cosmism and Extraterrestrial Intelligence,” *QJRAS*, vol. 36, p. 369, Dec. 1995.

[22] S. D. Baum, “Is humanity doomed? insights from astrobiology,” *Sustainability*, vol. 2, no. 2, pp. 591–603, 2010.

[23] J. Haqq-Misra, R. K. Kopparapu, and E. Schwieterman, “Observational constraints on the great filter,” *Astrobiology*, vol. 20, no. 5, pp. 572–579, 2020. PMID: 32364797.

[24] M. Garcia, “Space debris and human spacecraft.” `https://www.nasa.gov/mission_pages/station/news/orbital_debris.html`, 2021. Feb 10, 2023.

[25] L. Billings, “Alien anthropocene: How would other worlds battle climate change?,” *Scientific American*, vol. 28, no. 3, 2018.

[26] P. R. Ehrlich, J. Harte, M. A. Harwell, P. H. Raven, C. Sagan, G. M. Woodwell, J. Berry, E. S. Ayensu, A. H. Ehrlich, T. Eisner, S. J. Gould, H. D. Grover, R. Herrera, R. M. May, E. Mayr, C. P. McKay, H. A. Mooney, N. Myers, D. Pimentel, and J. M. Teal, “Long-term biological consequences of nuclear war,” *Science*, vol. 222, no. 4630, pp. 1293–1300, 1983.

[27] A. Turchin and D. Denkenberger, "Classification of global catastrophic risks connected with artificial intelligence," *AI Soc.*, vol. 35, p. 147–163, mar 2020.

[28] N. Bostrom, "Where Are They? Why I hope the search for extraterrestrial life finds nothing," *MIT Technology Review*, vol. May/June issue, p. 72–77, 2008.

[29] R. Hanson, "The great filter - are we almost past it?." `http://hanson.gmu.edu/greatfilter.html`, 1998. Sept. 1, 2023.

[30] A. Zaitsev, "The seti paradox," 2006.

[31] P. Musso, "The problem of active seti: An overview," *Acta Astronautica*, vol. 78, pp. 43–54, 2012. Searching for Life Signatures.

[32] J. A. Ball, "The zoo hypothesis," *Icarus*, vol. 19, no. 3, pp. 347–349, 1973.

[33] G. D. Brin, "The great silence - the controversy concerning extraterrestrial intelligent life," *Quarterly Journal of the Royal Astronomical Society*, vol. 24, no. 3, pp. 283–309, 1983.

[34] M. M. Ćirković, "Stellified Planets and Brown Dwarfs as Novel Dysonian SETI Signatures," *Journal of the British Interplanetary Society*, vol. 69, pp. 92–96, Jan. 2016.

[35] R. Penrose and R. M. Floyd, "Extraction of rotational energy from a black hole," *Nature*, vol. 229, pp. 177–179, 1971.

[36] W. E. East and F. Pretorius, "Superradiant instability and backreaction of massive vector fields around kerr black holes," *Phys. Rev. Lett.*, vol. 119, p. 041101, Jul 2017.

[37] K. Popper, *The Logic of Scientific Discovery.* Routledge Classics, Taylor & Francis, 2005.

[38] I. McNeil, *An Encyclopedia of the History of Technology.* Routledge, 1990.

[39] O. W. in Data, "Global direct primary energy consumption." `https://ourworldindata.org/grapher/global-primary-energy?country=~OWID_WRL`, 2022. Accessed: Sept. 1, 2022.

[40] V. Smil, *Energy Transitions: Global and National Perspectives.* Bloomsbury Academic, 2017.

[41] A. V. Belyi, "Limitations of resource determinism in international energy studies," *Energy Research & Social Science*, vol. 12, pp. 1–4, 2016.

[42] C. Bai, P. Dallasega, G. Orzes, and J. Sarkis, "Industry 4.0 technologies assessment: A sustainability perspective," *International Journal of Production Economics*, vol. 229, p. 107776, 2020.

[43] J. Hull, "The second industrial revolution: The history of a concept," *Storia Della Storiografia*, vol. 36, p. 81–90, 1999.

[44] D. S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present.* Cambridge: Press Syndicate of the University of Cambridge, 1969.

[45] G. E. Moore, "Cramming more components onto integrated circuits, reprinted from electronics, volume 38, number 8, april 19, 1965, pp.114 ff.," *IEEE Solid-State Circuits Society Newsletter*, vol. 11, no. 3, pp. 33–35, 2006.

[46] M. M. Waldrop, "The chips are down for Moore's law," *Nature*, vol. 530, pp. 144–147, Feb. 2016.

[47] J. H. Jiang, F. Feng, P. E. Rosen, K. A. Fahy, P. Das, P. Obacz, A. Zhang, and Z.-H. Zhu, "Avoiding the great filter: Predicting the timeline for humanity to reach kardashev type i civilization," *Galaxies*, vol. 10, no. 3, 2022.

[48] K. Gödel, “Über formal unentscheidbare sätze der principia mathematica und verwandter systeme i,” *Monatshefte für Mathematik*, vol. 38, no. 1, pp. 173–198, 1931.

[49] A. Clarke, *Profiles of the Future: An Inquiry Into the Limits of the Possible.* Harper & Row, 1973.

[50] M. Shermer, “Shermer’s last law,” *Scientific American*, vol. 286, no. 1, pp. 33–33, 2002.

[51] Z. Galántai, “Long futures and type iv civilizations,” *Periodica Polytechnica Social and Management Sciences*, vol. 12, no. 1, p. 83–89, 2004.

[52] S. Armstrong and A. Sandberg, “Eternity in six hours: Intergalactic spreading of intelligent life and sharpening the fermi paradox,” *Acta Astronautica*, vol. 89, pp. 1–13, 2013.

[53] M. S. Morris, K. S. Thorne, and U. Yurtsever, “Wormholes, time machines, and the weak energy condition,” *Phys. Rev. Lett.*, vol. 61, pp. 1446–1449, Sep 1988.

[54] M. Alcubierre, “The warp drive: hyper-fast travel within general relativity,” *Classical and Quantum Gravity*, vol. 11, p. L73, may 1994.

[55] Y. N. Harari, *Sapiens: A Brief History of Humankind.* Israel: Dvir Publishing House Ltd, 2011.

[56] S. Hossenfelder, *Lost in Math: How Beauty Leads Physics Astray.* Basic Books, 2018.

[57] S. Pinker, *The Better Angels of Our Nature: Why Violence Has Declined.* Civil War campaigns and commanders series, Viking, 2011.

[58] W. Poundstone, *Prisoner’s Dilemma.* Doubleday, 1992.

[59] G. Groth-Marnat, *Handbook of psychological assessment.* Hoboken: John Wiley and Sons, 2003.