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RESEARCH ARTICLE

The future of intelligence in the Universe: a call for humility

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Abstract
Recent astrophysical findings suggest that the era during which the Universe is habitable has just begun. This raises the question whether the entire Universe may at some point in the future be filled with intelligent life. Hanson *et al.* (2021, *The Astrophysical Journal* **922**, 182) argued that we can be confident that the Universe will, by cosmic standards, soon be dominated by imperialist civilizations which expand rapidly, persist long and make drastic changes to the volumes they control. The main motivation for this 'grabby civilizations' hypothesis is that it supposedly provides a good explanation of why we are so early in cosmic history. In this paper, we criticize this motivation and suggest that it fails, for reasons analogous to why the notorious Doomsday argument fails. In the last part of the paper we broaden our discussion and argue that it may be rational to assign a rather low prior probability to the grabby civilizations hypothesis. For instance, if there are any civilizations that expand rapidly and indefinitely, they may well *not* make any drastic changes to the volumes they inhabit, potentially for strategic reasons. Hence, we call for epistemic caution and humility regarding the question of the long-term evolution of intelligence in the Universe.

Contents

Introduction

Humans have long been fascinated by our place in the overall history and geography of the Universe, asking questions such as: Is there life elsewhere in the Universe? Will we ever encounter evidence of life that has an extraterrestrial origin? What will become of our civilization in the long run?

In view of recent developments in astrophysics, these questions appear in a new light. Since 1980, it has been established that the Earth formed 4.54 billion years ago (Dalrymple, 2001). The first lifeforms on Earth appeared relatively shortly afterwards (Dodd *et al.*, 2017). Relative to the rest of the Milky Way, Earth formed around the median time for the giant planets that exist now, but after 80% of

Earth-like planets had already formed (Behroozi and Peeples, 2015). This finding suggested that the appearance time of life on Earth was typical or late.

More recently, however, new insights suggest that the Universe might be hospitable to life for a very long time in the future. The Universe may form more than a tenfold of planets compared to the current number (Behroozi and Peeples, 2015). If rocky planets orbiting low-mass stars – so-called red and orange dwarf stars – are habitable, life will be able to exist several trillion (up to 10^{13}) years in the future (Loeb *et al*., 2016; Haqq-Misra *et al*., 2018). Indeed, there are clues that red dwarves do exhibit key features that are necessary for life (Wandel and Gale, 2020). Even if orange dwarves are inhospitable to life, the moment in the history of the Universe where we find ourselves seems to be comparatively early in the period where life on planets is possible (Lingam and Loeb, 2018).

There are radically different scenarios of the role that life will play in the – according to the research just mentioned, potentially very long – future during which the Universe remains hospitable to life. At one end of the spectrum there are scenarios where life remains rare and sporadic: where it appears only locally on habitable planets, almost never branches out from these and typically disappears once these planets become uninhabitable or even before.

At the other end of the spectrum there are scenarios where long-lasting and rapidly expanding civilizations will soon 'control' (to use the expression of Hanson *et al*., 2021) every Galaxy and will continue to do so as long as the Universe remains habitable. Recently, Olson (2015, 2017, 2018) as well as Hanson *et al*. (2021) have studied and argued for such scenarios. Hanson *et al*. refer to the scenario that they advocate as the 'grabby civilizations' (GC) scenario. This scenario, according to them, is highly plausible because it elegantly explains why we are so early in overall cosmic history: soon all regions of the Universe will be controlled by GC, and new civilizations like ours can no longer arise. The otherwise unexpectedly early moment of our appearance as a civilization becomes an entirely typical one.

Our goal in this paper is to demonstrate that the inference drawn by Hanson *et al*. from our being early in cosmic history to the truth (or high probability) of the GC scenario is invalid. In fact, as we argue, it is fallacious in a manner analogous to how the notorious Doomsday argument is fallacious according to a persuasive objection by Dieks (2007). Dieks' objection, like ours, focuses on implicit assumptions about background evidence used in anthropic reasoning. It is not aimed against the use of anthropic reasoning *per se*. Moreover, we argue that even if the Universe will one day be dominated by rapidly and indefinitely expanding civilizations, these civilizations may end up being rather different from how Hanson *et al*. envisage them. Focusing on indefinite expansion they may strive for coexistence with other rapidly expanding civilizations, and the best strategy for achieving this might include *not* making any dramatic changes to volumes. We should hence not discard the possibility that rapidly and indefinitely expanding civilizations could be difficult to detect. This gives us reasons for being humble and for not jumping to quick conclusions regarding whether the Universe will once be completely controlled by intelligent beings and, if so, what these beings will be like. In fact, our analysis shows that any confidence about what the future of life in the Universe will be like is misplaced.

The structure of the remaining sections of this paper is as follows: In Section 'Candidate properties of civilizations that will dominate the Universe', we review candidate properties of civilizations favoured by cosmic selection effects. In Section 'The power law of civilization births and human earliness', we review an argument due to Carter (1983) according to which the cumulative probability of intelligent life having appeared on any given habitable planet plausibly follows a power law. We also explain why, following Hanson *et al*. (2021), this makes our appearance even more surprisingly early. In Section 'Can GC really explain our earliness?', we criticize the suggested inference from our earliness to the GC scenario. In Section 'Why the GC hypothesis is intrinsically improbable', we review considerations as to why the rational prior probability of the scenario may be small, perhaps close to zero. There may simply not be any civilizations that expand rapidly and indefinitely and, even if there are such civilizations, they may not make drastic changes to volumes and may be hard to detect. We conclude the paper in the final section with a call for epistemic humility regarding the future of intelligence in the Universe.

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Candidate properties of civilizations that will dominate the Universe

Following other contributions to the literature, we discuss scenarios for the future of intelligence in the Universe in terms of candidate properties of 'civilizations'. Any such civilization is assumed to have one (potentially several) planet(s) (or moon(s)) of origin, a clearly defined duration of existence, and a cosmic volume that it inhabits at any given time. We preface our discussion of candidate properties of such civilizations with two caveats:

- While 'civilizations' may always originate from life in the sense of biology as a science, they may at later point be made up of engineered objects such as 'artificial intelligence systems', potentially long after biological life has vanished.
- Life in the broad sense of this paper may spread in such a way that the characterization in terms of distinct civilizations becomes inapplicable. In what follows, we explore scenarios that are based on civilizations with distinct numerical identities and clearly identified volumes that they inhabit, but we acknowledge that scenarios which are not based on civilizations in that sense may also be considered and studied.

In this context, human-instigated society counts as one civilization (but see the end of the 'Conclusion' section for critical discussion). We are interested in civilizations that are prime candidates for being the long-term most prevalent ones in the Universe. Accordingly, it does not matter so much which properties any arbitrary civilization, born on some random habitable planet, is likely to have. The future of the Universe will be shaped, in particular, by those civilizations, if there are any, that spread most far and wide. This motivates considering civilizations with the following two properties:

- FAST civilizations perpetually expand close to a maximum velocity of expansion, limited only by hard physico-technical constraints.
- UNDYING civilizations last long by the standards of cosmic timescales and, in particular, do not disappear before becoming or encountering other FAST civilizations.

In the long term, civilizations that lack either FAST or UNDYING will populate comparatively far smaller volumes than civilizations with these properties, unless they are far, far more numerous. Cosmic selection, in other words, will favour civilizations that are FAST and UNDYING (provided they exist). Olson makes the case for the assumption, encoded in FAST, that there is a (near-) universal maximum expansion velocity:

> [A]ll technologically mature civilizations with advanced energy resources will quickly discover the same (approximate) practical speed limit, whatever it may be. If such a civilization is ambitious, seeking to acquire maximum resources, their net expansion speed will be close to this limit. This means that a model including only a single expansion velocity parameter, v, common to all ambitious civilizations, is a plausible assumption for extragalactic SETI. (Olson, 2018: 2)

Interstellar travel and intergalactic travel in particular may, as argued by Drake and Sobel (1992), forever remain impractical or even outright impossible for biological organisms such as us. However, a civilization's expansion in space could be driven or spearheaded by self-replicating von Neumann probes (Von Neumann, 1966; Tipler, 1994; Matloff, 2022). Therefore, its expansion speed need not be constrained by biology-related factors. According to Armstrong and Sandberg (2013), harnessing only a tiny share of the energy and materials in any given Galaxy would be sufficient for a civilization to fuel its intergalactic travel.

Due to the fundamental limit on the speed of communication in our Universe, rapidly expanding civilizations may break up into different civilizations, perhaps not all striving for further rapid expansion (as has been discussed in the context of percolation models as a potential answer to the Fermi paradox; see Landis, 1998 and Galera *et al.*, 2019). However, as long as a fraction of the descendant

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civilizations keep expanding, due to selection effects, the model of Hanson *et al*. (2021) still captures the main dynamics.

According to Olson as well as Hanson *et al*., civilizations that will be most widespread can be expected to also have a third property, namely:

- LOUD civilizations make clearly visible changes to the volumes that they populate[1].

Hanson *et al*. (2021: 6) suggest that making drastic changes to volumes may be necessary to extract the resources needed to enable fast expansion, a suggestion that they see as supported by human history. If this is true, being LOUD is indirectly favoured by the same selection effect as FAST. However, as we argue in Section 'Can GC really explain our earliness?', there are good reasons to seriously consider not only LOUD but also non-LOUD civilizations, i.e. civilizations that do *not* make clearly visible changes to the volumes that they populate. Such civilizations might actually be favoured by selection effects over LOUD ones in the longer term.

The distinction between LOUD and non-LOUD civilizations is a matter of degree and depends on how exactly one spells out 'making visible changes'. Civilizations that can be identified across astrophysical distances due to their technosignatures (Socas-Navarro *et al*., 2021) qualify as LOUD. A paradigmatic visible change to some planetary system would be the construction of a Dyson sphere (Dyson, 1960) around its central star, to harvest a large share of its 'solar' energy. Changes made on a planetary scale – such as inducing anthropogenic climate change – may or may not be considered 'clearly visible', e.g. one may debate whether humanity is currently LOUD and, if so, when it became LOUD. An extreme example of a non-LOUD civilization would be one that makes changes only on micro-scales and/or in such a way that the changes are inaccessible with current human (and perhaps more advanced) technology. Conceivably, there might be civilizations that are LOUD for some periods or in some regions and non-LOUD in others.

As LOUD civilizations dramatically change the volumes they control they may also interfere with the births of new civilizations in these volumes. A particularly simple type of interference is to prevent any new civilization births, either intentionally or as a side effect:

> SUPPRESSIVE civilizations do not permit the birth of any new civilizations in regions that they control.

Evidently, for humanity to appear on Earth, Earth had to be outside any volume controlled by a civilization with the property SUPPRESSIVE.

The power law of civilization births and human earliness

According to Hanson *et al*. (2021), drawing on an influential argument by Carter (1983), civilizations that will come to dominate the Universe will likely have one further property, beside FAST, UNDYING, LOUD and SUPPRESSIVE, namely, that their collective frequency of births in time is approximately given by a power law. We now review and motivate this property, which we call POWER-LAWED.

Carter's original argument applies to the appearance of intelligent life on any planet that is in principle hospitable to life. According to Carter, the appearance of intelligent life on any such planet plausibly requires passing a number of critical 'hard steps'. These include 'try-indefinitely steps', which can be 'tried' indefinitely, and 'try-once steps', which only occur at a specific stage of evolution with a particular chance of success.

Let us first consider try-indefinitely steps (or 'try-try steps' in the terminology of Hanson *et al*., 2021). The probabilities with which they, differentially, succeed can be expressed in terms of the specific characteristic timescales, t_i, where i ranges over try-indefinitely steps, on which they typically

[1]Hanson *et al*. use the term 'loud' somewhat differently than we do, namely, to refer to civilizations that simultaneously have the three properties FAST, UNDYING and (our) LOUD.

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occur. Candidate try-indefinitely steps in the appearance of intelligent life in Earth history include the appearance of life itself, the appearance of eukaryotes, the appearance of sexual reproduction and the evolution of humanity as an intelligent species.

Earth is estimated to become uninhabitable due to deoxygenation of the atmosphere in around 1 billion years (Ozaki and Reinhard, 2021), and so far we have not found any signs of intelligent life on other planets. We can therefore confidently exclude the possibility that the sum of all timescales t_i associated with try-indefinitely steps is significantly shorter than the total time interval during which Earth is habitable, about 5.5 billion years. For if that sum had been significantly shorter than 5.5 billion years, intelligent life would in all likelihood have appeared orders of magnitude earlier on Earth than it did. Moreover, if the sum of all timescales t_i, for Earth were much smaller than the interval during which Earth is habitable, the same would be true, one might conjecture, for at least some exoplanets in the causally accessible Universe. So the fact that we have not detected any signatures of extraterrestrial intelligence also, at least somewhat, speaks against the sum of all timescales t_i being significantly smaller than Earth's duration of habitability.

At the same time, there is no reason to expect any correlation between the astronomical processes determining planet lifetimes and the biological processes determining the timescales of try-indefinitely steps, t_i. It would be a curious coincidence if the longest timescales, t_i, happened to be of the same order of magnitude as the time duration during which Earth is habitable. As Carter argues, it is rational to expect that at least some try-indefinitely steps have characteristic timescales t_i that are larger by several, perhaps many, orders of magnitude than the habitability duration of planets such as Earth. This means that, on any given planet, the appearance of intelligent life will, in all likelihood, be exceedingly improbable. The fact that we have not detected any signs of intelligent life on other planets fits this hypothesis well.

However, if the total number of habitable planets in the Universe is large enough, intelligent life is bound to appear on a number of planets nevertheless, even if these planets may remain rare compared with lifeless planets. Carter (1983) showed that, if n is the number of try-indefinitely steps with timescales, t_i, that are longer than a planet's habitability duration, the probability $P(t)$ of intelligent life having appeared on it until some time t follows a power law:

$$P(t) \sim t^n. \tag{1}$$

This formula makes intuitive sense: many 'hurdles' have to be taken for intelligent life to appear. When the first planets form, life is still absent completely, and its appearance starts very slowly, then accelerates as the hurdles are taken on more and more planets. The pattern of slow start and steep acceleration is more pronounced as the number n of try-indefinitely steps is increased.

What about try-once steps, which unlike try-indefinitely steps cannot be tried again in case of failure? Try-once steps affect the probability of life having appeared at some point, but they do not change the power-law form of equation (1) if there are also try-indefinitely steps.

Hanson *et al*. assume that civilizations which will come to dominate the Universe arise randomly from civilizations that start on arbitrary habitable planets such as Earth, by going through one or more additional try-indefinitely steps or try-once steps. If the probability of their birth on any specific planet is determined by a power law of the form (1), with a planet-specific power n, then the overall frequency distribution of GC births across all galaxies can also be approximated by a power law of the form (1) with a suitably chosen n (Hanson *et al*., 2021, Appendix A). This means that GC will, collectively, have the property POWER-LAWED:

> POWER-LAWED civilizations arise with a frequency which, as a function in time, approximately follows a power law of the form (1).

Hanson *et al*. argue that if we follow the line of thought just reviewed and assume that the appearances or 'births' of civilizations in time are characterized by a power-law function, our earliness becomes

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even far more remarkable than previously appreciated. According to the power law, the vast majority of civilizations appear towards the end of the lifespan of their planet of origin, and the larger the number n of hard steps is, the more pronounced this tendency is. Neither the maximal habitability span of in-principle habitable planets nor the correct number n are known. According to the calculations of Hanson *et al.*, even if we assume comparatively short maximal planet habitability durations (not much longer than the habitability of Earth) and a very low number of hard steps ($n = 1$ or 2), humans are among the first 10% of intelligent civilizations to arise. If longer planet habitability durations and a larger number n of hard steps are assumed, both of which appear plausible in the light of what we know, we look even more dramatically early.

If the appearance of humans is indeed (very) early compared to the cosmic average for intelligent civilizations, we are highly atypical in this respect. Hanson *et al.* (2021) aim to provide an explanation for our atypical-seeming arrival time, or rather: they stipulate an additional mechanism by which our arrival time is rendered typical after all, namely, they propose the

> Grabby civilizations (GC) scenario: From a certain point in the future, civilizations with properties POWER-LAWED, FAST, UNDYING, LOUD, and SUPPRESSIVE ('grabby civilizations' – GCs) will control all galaxies in the entire universe.

We are atypically early only under the assumption that civilizations such as ours appear throughout cosmic history on habitable planets, roughly following the power law (1). The situation is radically different if the GC scenario holds and civilizations will soon (on cosmic timescales) control the entire Universe which are FAST, UNDYING, LOUD, SUPPRESSIVE and whose appearance follows a power law. According to Hanson *et al.* (2021), the GC scenario thus provides an elegant explanation of why we have appeared so early – an explanation which renders our appearance as a civilization on a habitable planet typical in time rather than stunningly early.

Hanson *et al*. provide a more specific estimate of *how* the GC scenario will likely come to pass. Due to GCs having the property SUPPRESSIVE, we can rule out being in a volume controlled by some GC. *A fortiori*, due to SUPPRESSIVE we can rule out that GCs are already controlling the entire Universe. Moreover, due to the assumption LOUD, we would presumably clearly see any area controlled by a neighbouring GC as distinct from its environment, which is not currently the case.

Using a simple three-parameter model and assuming that we have been born at a typical time of civilization birth, Hanson *et al*. predict that human civilization, if it survives long enough, will most likely first encounter a GC in around 200 million to 2 billion years. Furthermore, they conclude from their modelling that each GC will control between around 10^5 and 10^7 galaxies before encountering other GCs at all their boundaries. Finally, if p is the probability of any given civilization to become grabby, unless p is lower than 10^{-4} (i.e. unless any given civilization is exceedingly unlikely to ever become grabby) we cannot expect there to have been even one civilization in our own Galaxy's past. Had there been any, the probability of at least one GC having made it to Earth already would have been close to 1. Hanson *et al*. conclude from this that, in the light of the plausibility of the GC scenario, it is unlikely that SETI-type attempts will succeed, i.e. we are unlikely to ever detect any extraterrestrial (non-grabby) civilization.

In the next section, we criticize the inference to the GC scenario as the alleged best explanation of our earliness based on which Hanson *et al*. draw these conclusions.

Can GC really explain our earliness?

An obvious worry about the suggested inference to the GC scenario as the best 'explanation' of our current existence is that the hypothesized takeover of our Galaxy by some GC, if it takes place, takes place in the future. But, absent any retrocausality, future events cannot cause present events. Therefore, at least by the standards of a causal account of explanation such as the influential one by Woodward (2003), the GC hypothesis cannot possibly 'explain' why we have appeared so early.

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Hence, there cannot be an argument for the GC scenario based on our earliness in the form of an inference to the best explanation.

Proponents of the GC scenario can react to this observation by arguing that, even though the GC scenario does not *explain* why we are early, at least not by the standards of a causal account of explanation, it nevertheless makes our earliness expected, unlike other, competing, accounts of the future of life in the Universe. Therefore, the GC scenario gets evidentially boosted by the observation that we are early compared with those other scenarios. This line of reasoning can be reconstructed using the language of Bayesian epistemology. It requires defining self-locating probability distributions $P(i \mid \mathrm{GC}, B)$ and $P(i \mid {\sim}\mathrm{GC}, B)$ over one's own 'birth rank' i, as a civilization, conditional on the GC scenario occurring ('GC') and conditional on it not occurring ('∼GC'). The variable B denotes suitably chosen background evidence that is common ground for the assessment of both scenarios. Suppose that n and N are the total numbers of civilizations ever to be born according to GC and ∼GC, respectively, with $n \ll N$, and assume self-locating indifference (Bostrom's (2002) *Self-Sampling Assumption*), namely,

$$P(i \mid \mathrm{GC},\ B) = 1/n \ \text{ and } \ P(i \mid {\sim}\mathrm{GC},\ B) = 1/N. \tag{2}$$

The evidence that we condition on in this Bayesian reconstruction of the argument given by Hanson *et al*. (2021) is that we are very early ('E') in the history of the Universe, i.e. that our birth rank i is smaller than n. Due to (2) – or, more generally, unless $P(i \mid {\sim}\mathrm{GC}, B)$ is heavily biased towards low values $i < n$ – this finding is far more likely conditional on GC than conditional on its negation, that is:

$$P(E \mid \mathrm{GC},\ B) \gg P(E \mid {\sim}\mathrm{GC},\ B). \tag{3}$$

As a consequence of (3), unless the prior probabilities assigned to GC and ∼GC dramatically favour ∼GC – that is, provided that $P({\sim}\mathrm{GC} \mid B)$ is not many orders of magnitude larger than $P(\mathrm{GC}, B)$ – the posterior probabilities assigned to GC and ∼GC after conditioning on the evidence E 'We are early' will favour the GC hypothesis.

Anthropic reasoning and, more generally, reasoning taking into account indexical evidence along the lines just discussed is controversial (Norton, 2010, for instance, is very critical) and has raised vivid debates in the Bayesian literature (for instance, in relation to the sleeping beauty toy problem)[2]. We are not putting forward (2) and (3) in order to implicitly advocate particular positions in these debates. Our modest goal here is to give a charitable formal reconstruction of the argument made by Hanson *et al*. (2021).

In the light of our reconstruction of that argument, readers familiar with the Doomsday argument (Carter, 1983; Leslie, 1989) will recognize that both these arguments have the same form. In a simple exposition of the Doomsday argument, two hypotheses about the totality of human history (past and future) are compared: hypothesis H_{short} says that humanity will go extinct relatively soon and hypothesis H_{long} says that there will be trillions of future humans. Finding ourselves to have a birth rank which is sufficiently early (again, 'E') to be compatible with H_{short} suggests a likelihood inequality analogous to (3), namely,

$$P(E \mid H_{\mathrm{short}},\ B) \gg P(E \mid H_{\mathrm{long}},\ B). \tag{4}$$

Similar to the argument in favour of the GC hypothesis outlined above, the Doomsday argument concludes that – unless H_{long} happens to have a dramatically higher prior probability than H_{short} – the

[2]An alternative approach to anthropic reasoning is the *Self-Indication Assumption* (SIA) (Bostrom, 2002), which amounts to considering not merely all past, present and future observers, but all possible observers who could exist in the entire Universe for all of time and assigning prior probabilities to hypotheses proportional to the numbers of possible observers that come into existence according to them. The SIA avoids the Doomsday problem (Olum, 2002), but it has counterintuitive consequences (Bostrom and Ćirković, 2003). It has recently been applied to questions concerning the long-term survival of humanity and the probability of meeting extragalactic civilizations (Olson and Ord, 2021), but we do not focus on this approach in our paper.

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posterior probability of H_{short} is far larger than that of H_{long}. Accordingly, we should be confident that – especially since a considerable share of humans ever to have lived is alive now and we are not currently experiencing a rapid decline – the future of humanity will be short and Doomsday is imminent.

Many people have the intuition that something must be wrong with the Doomsday argument. Unsurprisingly, there are many criticisms of it in the philosophical literature. Here, we criticize the argument that the GC hypothesis is plausible in the light of the finding that we are early in cosmic history by drawing inspiration from a criticism of the Doomsday argument that accepts the Bayesian framework for studying self-locating belief and that we find particularly insightful (Dieks, 2007; for a recent defence, see Friederich, 2021: Ch. 9). Dieks' core observation is that the background evidence B in (4) must have very specific properties to fulfil its role in the Doomsday argument. We now apply this analysis directly to the argument for the GC scenario, where the background evidence plays a fully analogous role.

On the one hand, the background evidence B in (3) must include enough information about basic physics and cosmology to entail several facts about overall cosmic history – notably, which stars (will) have habitable planets, when, and for how long. On the other, this evidence B must not include any evidence that gives away our own place in overall cosmic history – that is, that we are on a planet orbiting a main sequence star around 13.8 billion years after the Big Bang (according to measurements of the cosmic microwave background; Aghanim *et al*., 2020). If B did include such evidence, it would entail E, so both $P(E \mid \text{GC}, B)$ and $P(E \mid {\sim}\text{GC}, B)$ would be trivially 1, contrary to (3). It is by no means obvious what should be part of this hypothetical background evidence B. Whatever exactly belongs in this B, it is clearly very different from our actual evidence – the scientific knowledge that humans have accumulated.

The ratio that is ultimately of interest in our reconstruction of the argument by Hanson *et al*. is the one between the posteriors $P(\text{GC} \mid E, B)/P({\sim}\text{GC} \mid E, B)$. From Bayes' theorem in odds form,

$$\frac{P(\text{GC} \mid E,\ B)}{P({\sim}\text{GC} \mid E,\ B)} = \frac{P(E \mid \text{GC},\ B)}{P(E \mid {\sim}\text{GC},\ B)} \times \frac{P(\text{GC} \mid B)}{P({\sim}\text{GC} \mid B)}, \tag{5}$$

we see that the posterior odds don't only depend on the likelihood ratio that we discussed thus far, but also on the priors $P(\text{GC} \mid B)$ and $P({\sim}\text{GC} \mid B)$. But since B is so elusive, it is very difficult to see why $P({\sim}\text{GC} \mid B)$ might not be many orders of magnitude larger than $P(\text{GC} \mid B)$. And we should not accept the inference from our earliness to the GC hypothesis based on the likelihood inequality (3) alone, by default, without considering what would be reasonable assignments of priors. For by that standard, we could also run a structurally analogous argument *against* the GC scenario.

This can be seen as follows: note that, if the GC scenario holds, grabby aliens will be extremely widespread, numerous and exist for a very long time. Accordingly, the 'typical' intelligent observer in our Universe will be some member of a GC and exist far later in cosmic history than we do. By reasoning structurally analogous to equations (1)–(3), finding ourselves to be early and not as members of a GC (yet), far from confirming the GC hypothesis, actually disconfirms it.

To spell this out formally, consider background evidence B^* which leaves open whether we might be grabby. Conditional on this B^* and the GC hypothesis the probability of finding ourselves to be as early as we are will be extremely low, far lower still than the probability of finding ourselves so early conditional on assuming that there will only ever be non-GC[3]. Thus, for such evidence B^*, the inequality

$$P(E \mid \text{GC},\ B^*) \ll P(E \mid {\sim}\text{GC},\ B^*) \tag{6}$$

[3]We are not advocating scepticism, i.e. we do not claim that we do not really know whether we are a GC (we know that we are not, at least not yet), but merely illustrating the effect of not including this piece of knowledge in the background evidence B^*.

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seems plausible, with the orientation of '≪' now in the opposite direction as in (3). If we could reasonably take (3) alone, without further consideration of *B*, to establish that our earliness confirms the GC scenario, we could equally well take (6) to establish that our earliness disconfirms the GC scenario.

We conclude that finding ourselves to be early does not make it rational to be confident that the majority of volumes in the Universe will become dominated by GC.

Why the GC hypothesis is intrinsically improbable

As we have seen, proponents of the GC scenario don't merely have to argue that the likelihood ratio favours their hypothesis, they also have to establish that the prior probability of their hypothesis isn't zero or very small, given background evidence *B* for which (3) holds. The structure of the GC scenario makes that a difficult task: the hypothesis takes the form of a conjunction of at least five separate assumptions (as spelled out in Sections 'Candidate properties of civilizations that will dominate the Universe' and 'The power law of civilization births and human earliness') and each conjunct makes the GC hypothesis less likely. If merely one of these five assumptions turns out to be unrealizable or exceedingly rare, the prior of the full GC hypothesis is zero or close to zero. So, while the specificity of the GC scenario is a strength for modelling purposes, since it allows Hanson *et al*. to run quantitative simulations based on their assumptions, it is also a challenge from a Bayesian point of view. In this section, we give reasons to doubt the assumptions from the start and hence to assign a rather low prior to the GC scenario.

Why there may be no civilizations that are both FAST and UNDYING

In the previous section we have argued that our earliness is no good reason to expect that the entire Universe will not far in the cosmic future be dominated by GCs: civilizations that are POWER-LAWED, FAST, UNDYING, LOUD and SUPPRESSIVE. Here we briefly review reasons why there may simply not be any civilizations that are both FAST and UNDYING at all – or so few of them that they never encounter each other. This could be due to a variety of factors: to begin with, the baseline probability for intelligent life to appear on any given habitable planet might be almost inconceivably low. Recent work by Snyder-Beattie *et al*. (2021) persuasively argues that, in the light of the arguments that led Carter (1983) to consider the power-law equation (1), an unbiased prior estimate of characteristic timescales of key steps in the evolution of intelligent life, taking into account the geological record, is compatible with some of these timescales being far larger than the habitable era of the entire Universe. We may well be the only intelligent beings in the visible Universe for a long time to come – even if, in accordance with the power-law equation (1) applied to habitable planets collectively, the abundance of intelligent civilization is set to increase.

Even if intelligent life is not rare and becomes more abundant, there may not be civilizations that are both FAST and UNDYING. To this date, no constructive demonstration has been given that interstellar, let alone intergalactic, travel is possible. The considerations reviewed in Section 'Candidate properties of civilizations that will dominate the Universe' on cosmic expansion using von Neumann probes are highly speculative. Being FAST could be impossible.

Another possible reason for there not being any FAST and UNDYING civilizations is that there might be no UNDYING ones. Nascent intelligent civilizations may universally succumb to existential risks from advanced technologies (Webb, 2002: Ch. 4), as has also been hypothesized for the future of human civilization (Bostrom, 2013; Ord, 2020), including risks from (at present hypothetical) 'black ball technologies' (Bostrom, 2019). A black ball technology is one that is so difficult to handle that its discovery almost inevitably causes the discovering civilization's rapid extinction.

Finally, a possibility worth noting is that the properties FAST and UNDYING might both be instantiated but mutually exclusive in practice. This idea can be motivated by considerations due to Sagan and Newman who argue that only civilizations which have left behind aggression and colonialism (and, one may add, fast expansion) can achieve longevity:

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> Those civilizations devoted to territoriality and aggression and violent settlement of disputes do not long survive after the development of apocalyptic weapons. Civilizations that do not self-destruct are pre-adapted to live with other groups in mutual respect. This adaptation must apply not only to the average state or individual, but, with very high precision, to every state and every individual within the civilization […] [T]he result is that the only societies long-lived enough to perform significant colonisation of the Galaxy are precisely those least likely to engage in aggressive galactic imperialism. (Sagan and Newman, 1983: 120)

A more recent version of this idea, proposed by Haqq-Misra and Baum (2009) as a 'sustainability solution' to the Fermi paradox, is that civilizations expanding indefinitely may inevitably undermine their own resource basis. In a similar spirit, Wong and Bartlett (2022) have recently suggested that civilizations inevitably either collapse at some point or purposefully turn towards a homoeostatic state that rules out cosmic expansion.

Observe that, in order for these arguments to work against the proposal of Hanson *et al*. (2021), these obstacles need to be truly insurmountable. If they are merely hard to overcome, they can be modelled as extra try-once or try-indefinitely steps and, in the latter case, taken into account by the power law. Provided that this leaves the expected number of civilizations that do overcome the challenges above a certain threshold, selection effects will make those civilizations dominant. However, even if we assign only a small prior probability to these obstacles being insurmountable, that still adds to the prior of ∼GC and detracts from the intrinsic plausibility of the GC hypothesis.

Some of the factors working against the appearance of FAST and UNDYING civilizations just reviewed could also work in tandem. We do not endorse any of them as particularly likely, but in the light of them the possibility must be taken seriously that there are no FAST and UNDYING civilizations – or so few that Earth's chances of ever encountering one, or of them encountering each other, are essentially zero.

Why FAST and UNDYING civilizations may not be LOUD

In this section, we argue that, even if the Universe indeed will at some point be dominated by FAST and UNDYING civilizations, these civilizations may not also be LOUD.

We find two substantive reasons in the literature for expecting that rapidly expanding civilizations will be LOUD. In what follows, we outline those reasons and explain why we do not find them persuasive.

The first reason, already mentioned in Section 'Candidate properties of civilizations that will dominate the Universe', is that rapidly expanding civilizations may need to harvest significant shares of the energy provided by the stars close to their current expansion frontier and perhaps other resources, in order to sustain further rapid expansion. Harvesting that energy may require erecting large-scale constructions such as Dyson spheres, and this would mean making dramatic changes to the solar systems subjected to control.

It is not clear to us how compelling this reason is. Erecting Dyson sphere-type objects and, more generally, making drastic changes to the volumes that one controls may take time, thereby slowing down expansion[4]. Also, energy may not be the main constraint on the speed of interstellar and intergalactic expansion. To the extent that it is, energy harvested from stars may not be the most suitable source for fuelling rapid and indefinite expansion. Suggested von Neumann probe designs include ones driven by on-board nuclear fission, fusion or matter–antimatter reactions, with fuel harvested from planets and their atmospheres and/or solar winds (Matloff, 2022: Section 'Propulsion options for von Neumann probes'). With such sources and miniaturized probe designs, expansion with von

[4]But see Armstrong and Sandberg (2013) for a confident take that there are no principled obstacles to the construction of Dyson sphere-type structures within timescales that are short compared to those required for intergalactic travel.

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Neumann probes could conceivably proceed in an effectively undetectable way, enabling FAST and UNDYING civilizations to be non-LOUD after all.

A second reason for expecting a rapidly expanding civilization to be LOUD is that, in order to be motivated to expand rapidly, a civilization may need to be driven by a value system that brings with it a drive to completely transform as much of the Universe as possible into something that it regards as having high moral value. A candidate example of such a value system might be a version of total utilitarianism that sees the highest attainable moral value realized if as much matter as possible is converted into nano-scale digital sentient beings. Everything not (yet) transformed, from the perspective of such a civilization, would be 'astronomical waste' (Bostrom, 2003). Mutatis mutandis, the same could hold for civilizations motivated by optimizing other types of value (i.e. non-moral) that require similar transformations. In any case, civilizations with the motivation and capability to enact such encompassing dramatic changes to the volumes they control would presumably be LOUD.

This reason strikes us as even more speculative than the first. We do not deny that there could conceivably be civilizations driven by, say, sentience-oriented total utilitarianism that have the technological capacity to carry out such a cosmic transformation project. But one can easily think of other motivations for being FAST and UNDYING, e.g. curiosity, striving for cosmic dominance, pre-emptive self-defence through early threat detection of threats. And it may well be the case that cosmic selection effects *disfavour* being LOUD, just as they favour being FAST and UNDYING.

This can be seen by considering that, whatever the exact motivation of civilizations that are FAST and UNDYING to rapidly expand and persist, that motivation may well extend to the time after they have already encountered other FAST and UNDYING civilizations (if they do). If so, civilizations that are FAST and UNDYING may design their rapid expansion such that they maximize their chances at continued expansion when this requires expanding into volumes that are already populated by other FAST and UNDYING civilizations.

Broadly speaking, there are two contrasting strategies of how FAST and UNDYING civilizations may strive for continued expansion after having encountered others. One is a strategy of monopolizing volumes and eliminating other civilizations. The other is a strategy of striving for coexistence in some form with those other civilizations. Intermediate types of strategy, e.g. ones that seek coexistence unless being threatened with elimination, are also conceivable.

An obvious difference between coexistence-oriented strategies and monopoly oriented ones is that the former can create win–win outcomes for all sides involved, whereas the latter cannot[5]. We therefore conjecture that the most successful strategies – in terms of volume populated – aim at coexistence at least in some circumstances (e.g. those where others also signal a willingness to coexist). If this is correct, it means that civilizations which are highly motivated to pursue rapid expansion indefinitely will tend to design their expansion, from the outset, in such a way that it enables coexistence (under conditions) with other civilizations that also aim at rapid indefinite expansion.

This, in turn, may well give such civilizations a strong incentive not to be LOUD, for various reasons. First, making drastic changes to the volumes they control may make such volumes inhospitable and/or unattractive to other civilizations, making coexistence no longer win–win. Second, drastic changes, if they are clearly visible from far away, may flag the location as a resource-rich one and therefore attract more advanced colonizing species. Third, being LOUD may predictably be interpreted by other civilizations as indicating a monopolizing disposition and may provoke a hostile approach that makes coexistence impossible. Moreover, being easily visible from afar may make LOUD civilizations vulnerable to other civilizations which prefer elimination of other civilizations to coexistence by allowing them to prepare for a hostile encounter[6].

[5]Yet, striving for coexistence does not necessarily require benevolence: after all, parasitism is a form of coexistence, too. In the context of cosmic civilizations, parasites may expand fast by exploiting structures created by other civilizations, without giving similar services in return.

[6]This hypothetical reason for civilizations (though not FAST and UNDYING ones specifically) to keep themselves as invisible as possible is considered in the science fiction bestseller 'The Dark Forest' by Cixin Liu (2008). This 'Dark Forest hypothesis' is sometimes suggested as a solution to the Fermi paradox.

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Any of these incentives, or a combination of them, may prevent civilizations that are FAST and UNDYING from also being LOUD. All of them are admittedly highly speculative, but arguably not more so than the reasons considered above for expecting FAST and UNDYING civilizations to also be LOUD.

We suggest one final further broadening of the space of scenarios to be considered for the future (and actually present) of life in the Universe, namely, non-LOUD civilizations may not be motivated to prevent new civilizations from being born in their volumes in the first place. After all, civilizations that developed independently up to some point may give rise to new solutions to common problems, which may be shared once contact is established. Alternatively, not being LOUD may require abstaining from being SUPPRESSIVE as a matter of practical necessity, if being SUPPRESSIVE for some reason requires making dramatic changes to volumes. This means that civilizations that are FAST and UNDYING, in addition to not being LOUD, may also not be SUPPRESSIVE.

Once coexistence and cooperation are on the menu, many types of hybridization between civilizations are possible, including cultural and biological. Compared to the approach taken in Section 'Candidate properties of civilizations that will dominate the Universe', these possibilities make it harder to individuate civilizations and the volumes they occupy. However, more complex to model does not mean intrinsically less plausible. After all, various species on Earth do occupy the same volumes and are often codependent on each other for maintaining their niches, some biological species arose due to crossbreeding and other forms of hybridization, and humans share cultural products, practices and other resources across civilizations (as usually understood).

A further complication of taking into account the possibility that FAST and UNDYING civilizations may be non-LOUD and non-SUPPRESSIVE is that it makes such civilizations into much harder targets to detect empirically. In fact, it seems doubtful whether we could detect or correctly attribute any signs of civilizations that are not LOUD and not SUPPRESSIVE even if they were in our own immediate environment, in the Solar System or even on Earth itself, whether in the past or even today. Responses to the Fermi paradox such as the zoo hypothesis (Ball, 1973) and the interdict hypothesis (Fogg, 1987) that have this consequence have understandably been criticized for being hard or even impossible to test empirically, somewhat akin to scenarios of philosophical scepticism. But being hard to test is, again, not the same as being intrinsically implausible. Moreover, the panspermia theory, according to which life on Earth could have developed from organic molecules or microscopic organisms deposited by space dust or meteors, can be reinterpreted as a von Neumann-probe-like strategy by expansive civilizations. In that case, we might in some sense be part of a GC without being aware of it.

Conclusion

As mentioned, this paper has been a plea for epistemic caution and humility regarding the future of life in the Universe. The insight that the cosmic era in which the Universe is habitable has just begun makes it exciting to speculate what the future has in store for life in the Universe. The sobering message of this paper is that such speculations are just that: speculations.

The preceding sections have been littered with 'could's, 'may's and 'might's. This is no accident. The only intelligent civilization of which we have clear evidence is our own. A Bayesian analysis resulting in conclusions that can be believed with high confidence requires reasoning from a type of background information that is quite distant from our actual epistemic situation and raises a reference class problem (known from the literature on the Doomsday argument). Moreover, the conjunctive nature of the GC hypothesis, which allows Hanson *et al*. (2021) to derive quantitative predictions from it, also renders its prior probability low compared to the negation of that hypothesis, which can be thought of as a broad family of vastly different sub-hypotheses.

The hypothesis of Hanson *et al*. (2021) may be taken to suggest relatively clear recommendations for current human society: we can better expand fast lest we be suppressed. However, because a conjunctive hypothesis is comparatively unlikely, we have to remain open-minded about its negation, which unfortunately does not offer a clear guide for action due to its disjunctive structure.

Indeed, there are several dozens of coherent candidate explanations of why we have not yet observed any other civilizations, as manifested in the vast literature on the Fermi paradox, making it impossible to be confident about what to make of this (lack of) observation. And our level of scientific and technological achievement is still far too limited to make any confident calls about hard limits on our own longevity as a civilization on the one hand and the speed of future space exploration on the other.

Admittedly, any hypothesis that is specific enough to allow for numerical simulations, and hence to derive quantitative predictions and candidate explanations for pieces of evidence, will suffer a similar penalty in terms of low prior probability. Our conclusion is not that building models such as Hanson *et al.*'s is futile but rather that interpreting the outcomes of such models should be done with due caution (because of the background information and reference class problem) as well as humility (because of the direct dependence of the posterior odds on the prior odds).

Hilbert's dictum, 'We must know – we will know', as inscribed on his tomb, may ultimately come true with respect to the future of life in the Universe. But it may well take a couple of millions, perhaps billions or trillions, of years until 'we' know what that future will be like. If so, 'we' will not be humans by then. In fact, given that our species has existed for less than half a million years, and current civilizations are more recent still, this may well be the most confident prediction that can be made on this topic.

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