Life, the Multiverse, and Fine-Tuning: Do Probabilities Matter?

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Abstract

Few topics in cosmology are as hotly debated as the multiverse: for some it is untestable and hence unscientific; for others it is unavoidable and a natural extension of previous science. Some of this disagreement might be due to misunderstanding, in particular the degree to which probability distributions are necessary to interpret conclusions based on the multiverse, especially with regard to the anthropic principle. I present undisputed facts, discuss some common misunderstandings, and investigate the role played by probability. The multiverse is perhaps an important component necessary for interpreting cosmological and other physical parameters.

The Universe *is* fine-tuned for life

The Universe[1] is fine-tuned for life in the sense that small changes in one or more physical constants would make life impossible (*e.g.* Lewis & Barnes, 2017, and references therein). The common objection that this no longer holds if one varies combinations of constants (*e.g.* Hossenfelder, 2018b, p. 114) is wrong in the sense that most of the parameter space remains hostile to life. It is also irrelevant whether some other far-removed region of parameter space could allow life as well as our region (*e.g.* Harnik et al., 2006); the fact remains that most of the parameters space spanned by the physical constants is hostile to life. *The statement that the Universe is fine-tuned for life is independent of the question whether the combination of parameters which specifies our Universe is in some sense improbable.* **This is one source of confusion in the discussion of fine-tuning in cosmology.** (In daily life, of course, many fine-tuned events are improbable, though most improbable events are not fine-tuned. One must be careful to distinguish the two concepts.)

This sense of fine-tuning is distinct from another common use of the term, namely the lack of technical naturalness in the particle-physics sense. **This is another source of confusion in the discussion of fine-tuning in cosmology.** Unless noted otherwise, I use 'fine-tuning' to mean 'fine-tuned for life'.

Possible explanations

There are several possible explanations for such fine-tuning. It could be coincidence; there are other unlikely events which, as far as I know, have no explanation, such as the equal angular sizes of the Sun and Moon (which moreover are equal only near the present time). Coincidences involving basic physics, though, are usually perceived as more puzzling, and the degree of fine-tuning in the case of life in the Universe is much greater. Or could the Universe be no other way? Perhaps, but this remains to be shown. As long as it is not possible to calculate basic quantities such as the value of the gravitational constant, mass of the electron, *etc.*, it makes sense to assume that they could have been different. Was it designed? Did it evolve? Or are there many universes in a Multiverse, and we shouldn't be surprised that we live in one which allows life?

While 'just coincidence' might be true, this is not a scientific explanation. Perhaps the most interesting possibility is that the Universe must be as it is, for reasons which we don't know. An explanation such as this has been seen as a goal of 'theories of everything', though such a theory can probably not explain *everything* in a *practical* sense (Barrow, 1991). The burden of proof is on those who favour this explanation; probably the only way to prove that such a theory exists is for the theory to be known. Perhaps the Universe somehow evolved (*e.g.* Smolin, 1997) to be fine-tuned for life, though this proposal probably creates more problems than it solves. (Evolution, of course, does explain why organisms are fine-tuned to their environment, but this is still another type of fine-tuning.) This leaves the Multiverse and a designer as possible explanations. A designer does not necessarily have to be some sort of supernatural being; this would also be the case if our Universe, or at least what we think is our perception of it, were some sort of simulation (*e.g.* Bostrom, 2003; Rees, 2003; Barrow, 2007). Leaving aside the theological case as unscientific, a simulation would move the question of fine-tuning to the universe in which the simulation is running, about which we know nothing (not even whether there is a fine-tuning problem there).

So, according to the present stage of our knowledge, the best explanation for fine-tuning is the Multiverse—more specifically, the Anthropic Principle applied to the Multiverse.

The case for the Multiverse

Almost by definition, another universe in the Multiverse cannot be observed. This is probably why Tegmark (2007, 2014) includes stuff outside of our particle horizon in his Level I Multiverse, even though, at least in some cosmological models, this horizon grows with time, *i.e.* more and more of the region now hidden comes into view. Most people wouldn't think of the stuff outside of our horizon as in another universe or as being part of the Multiverse, but at least Tegmark is consistent in his terminology. What most people refer to as the Multiverse is Tegmark's Level II Multiverse, *i.e.* a (perhaps infinite) collection of physical universes, of which our Universe is one example. (His Level III Multiverse are the many worlds in the many-worlds interpretation of quantum mechanics (Everett III, 1957) and his Level IV is his Mathematical Universe. Here, we are concerned only with his Level II Multiverse. Note that Tegmark (2014) discusses fine-tuning within the context of the Multiverse, while Lewis & Barnes (2017) discuss the Multiverse within the context of fine-tuning.)

[1] 'Universe' refers to our Universe, while 'universe' refers to a model universe in the sense of a cosmological model or to a different physical universe in the Multiverse (the most common meaning here).

One argument for the Multiverse is that it is a consequence of theories which we otherwise accept. Assuming that we accept these other theories, this is not a problem. (At least classically, we can never observe what happens in a black hole, but nevertheless we tend to believe what GR tells us about this region.) Often, the Multiverse is discussed in the context of eternal inflation (*e.g.* Linde, 1986, 2007) or the string-theory 'landscape' (*e.g.* Susskind, 2007). But what if we don't believe any theory which has the Multiverse as a consequence? There are at least two other arguments. (In these cases, the Multiverse is indeed 'just' a hypothesis, though of course there is nothing wrong with this, and it still might be shown later that it is a consequence of some theory we accept for other reasons.)

One is that there is no other good explanation for fine-tuning. This is similar to the answer to the question why the Earth is just at the right distance from the Sun for life to exist. Just as the 'plurality of worlds' (which meant not just unobserved planets but whole 'universes' in the sense the word was use in the Renaissance, *i.e.* a shell of fixed stars surrounding a solar system (or even a system with Earth at the centre)) was put forward as an idea before there was any evidence of other solar systems, one can put forward the Multiverse as a hypothesis. It is more or less an accident of history whether the observation or the theory comes first: some times theories predict things, other times they explain what is already known. (In the case of the planets in the Solar System, Kepler's mathematical 'theory of everything' explanation involving Platonic solids turned out to have no basis in reality. On the other hand, Planck's *ad hoc* hypothesis that radiation could be emitted and absorbed only in discrete packets turned out to be true.)

Another reason is 'why not?' Although not absolutely necessary, one can think of our 3+1 dimensional space as being embedded in a higher-dimensional space. Why should our Universe be the only one there? Whatever caused the origin of our Universe, why should it have happened only once?

We must assume that the constants of nature can vary from universe to universe in order to explain fine-tuning via the Anthropic Principle as long as we have no theory which has the Multiverse as a consequence and in which this is the case. This seems a valid assumption, though, as long as we have no reason to believe that they can't; this is supported by the fact that many constants of nature are consistent with being random (*e.g.* Donoghue, 2007) (Of course, if they don't vary, then we have the same problems as if there were only one universe, namely our Universe.)

A common objection to the multiverse, at least one containing an infinite number of universes, is that it explains nothing, since anything which *can* happen *will* happen. While some quantities might have fundamental explanations, there is no reason that *all* quantities, such as the temperature in this room at this moment, *must* have fundamental explanations. The burden of proof is on those who prefer a fundamental explanation to find that explanation.

The Anthropic Principle

Entire books (*e.g.* Barrow & Tipler, 1988) have been written about the Anthropic Principle. All that is needed here is the very simple, almost tautological, idea that observers must find themselves in a universe compatible with their existence; in particular, we must find that our Universe is compatible with our own existence. This is true even without the Multiverse, though in this case it provides no real explanation. *In a Multiverse where the constants of nature vary in an essentially random way from universe to universe, and where there are an infinite, or at least a very large, number of universes, then we need no further explanation for the values of the constants of nature in* our *Universe; in such cases,* it does not matter *whether our Universe is probable or not.* **This is another source of confusion in the discussion of fine-tuning in cosmology.** (The fact that many more humans live in China and India does not mean that some sort of special explanation is needed if one finds oneself living in Croatia; indeed, one would expect to be in Croatia given the additional fact that one speaks Croatian.) To be sure, in cases where a large range of values for the constants of nature are compatible with life, then of course one can use the Multiverse as an explanation for the values in our Universe only if one can show that the values we observe are those which a 'typical observer' would observe. However, this has no relation to the Anthropic Principle (except in the trivial sense that observers are alive, though if the observed value is at or near the peak of a sharply peaked distribution over *all* universes and not just those which contain life, then the Anthropic Principle is not necessary at all), so the common objection that the Anthropic Principle as applied to the Multiverse is useless unless we know the underlying probability distribution (*e.g.* Hossenfelder, 2018b, p. 115 and elsewhere) is wrong. The fact that other universes with other types of life might be much more probable than our own Universe is no more of a problem than the fact that other universes without life are much more probable than those with life; the essential idea of the Anthropic Principle as applied to the Multiverse is that one is concerned with a conditional probability (namely, that of our existence).

Some, but not all, cases of constants of nature being fine-tuned for life also involve fine-tuning in the particle-physics sense of lack of technical naturalness. If only a small range of values is anthropically allowed, then the Anthropic Principle can explain such cases. However, there are other cases, such as the strong-CP-violating angle θ, where life does not seem to be sensitive to the value, even across the entire range from 0 to 2π (*e.g.* Donoghue, 2007). The fact that the strong-CP-violating angle, at 10^{-10}, is very close to 0 cannot be explained by the Anthropic Principle, though attempts have been made to explain it using the Anthropic Principle together with additional assumptions (Tegmark et al., 2006; Wilczek, 2007). Of course, it is possible that some examples of lack-of-technical-naturalness fine-tuning can be explained by the Anthropic Principle while others have another, yet unknown, explanation. (The fact that some examples (must) have some other explanation does not rule out the fact that that for others there is no explanation other than the Anthropic Principle.)

Many expected the LHC to find new physics at the TeV scale (*e.g.* Linde, 2007), since this would allow a technically natural explanation for the small mass of the Higgs boson. Since no new physics has been found, this makes it more plausible that the small Higgs mass can be explained by the Anthropic Principle, the Higgs mass being a parameter to which life is sensitive (*e.g.* Dimopoulos & Thomas, 2007; Linde, 2007). Weinberg (1987) suggested that the observed value of the cosmological constant can be explained by the Anthropic Principle. This explanation is valid whether the one believes that the small (relative to the Planck scale) value of the cosmological constant is fine-tuned (*i.e.* the 'cosmological-constant problem') or that this value itself (apart from the fact that much larger values would be incompatible with life) is unproblematic (Bianchi & Rovelli, 2010a,b).

Objections to the Anthropic Principle are similar to those to the Multiverse. (While the two are often discussed together, one can have one without the other. For example, a theory which is able to explain the observed value of some parameter to which life is not sensitive by calculating that it occurs in a large fraction of universes makes little if any use of the Anthropic Principle, as explained above. Also, the Anthropic Principle can be invoked without invoking the Multiverse, although the interpretation is not as straightforward as when invoked with the Multiverse.) Again, there is no reason to doubt that other explanations *could* exist, but the burden of proof is on those who claim that these other explanations exist. In other contexts, such as the explanation for the distance of the Earth from the Sun being just right for life, it is clear that the Anthropic Principle is a better explanation than an explanation from first principles (which in this case doesn't exist anyway); there is no reason to believe that explanations involving the Anthropic Principle must cease to work at some scale.

Don't probabilities matter?

Even if there are not an infinite number of universes in the Multiverse, there is nothing wrong with low-probability universes being favoured by the Anthropic Principle, nor indeed with our living in such a Universe, as long as there is a reasonable probability that at least one *such universe exists.* **This is another source of confusion in the discussion of fine-tuning in cosmology.** (If the chance of winning the lottery is one in thirteen million, one shouldn't be surprised if someone wins every week as long as there are more than thirteen million players. However, one *should* be surprised—and seek a better explanation than 'just coincidence'—if someone of those thirteen million wins every week in a lottery in which the chance of winning is one in thirteen *trillion*, say.)

Special state or *improbable* state?

One could explain the m-z relation for standard candles (*e.g.* Perlmutter et al., 1998; Riess et al., 1998), say, not *via* fitting the parameters of a Friedmann–Lemaître–Robertson–Walker model to the data, but rather by a Lemaître–Tolman–Bondi (Lemaître, 1933; Tolman, 1934; Bondi, 1947) model (*e.g.* Enqvist, 2008). This requires us to be at the centre of concentric shells of varying density. Why do most discount this explanation, *when other locations within this model are just as unlikely*? The reason is clearly that the centre is not just an *unlikely* place, but is also a *special* place. *Special locations (in real or parameter space) need explanations while other locations of the same probability do not.* **This is another source of confusion in the discussion of fine-tuning in cosmology.** Thus, dismissing certain parameter combinations as being just as likely as any other, just 'choosing a value that's compatible with observation', or claiming that no statement about the likelihood can be made since the underlying probability distribution is unknown (*e.g.* Hossenfelder, 2018a,b) is not a sufficient explanation if the observed parameters are *special* in some way. For example, if $\Omega_0 + \lambda_0 \approx 1$ (meaning that the Universe is nearly spatially flat), then this *does* require an explanation, even if other sums were 'just as likely'. (In this particular case, there *is* an explanation (*e.g.* Evrard & Coles, 1995; Coles & Ellis, 1997; Adler & Overduin, 2005; Lake, 2005; Helbig, 2012; Holman, 2018).) The probability distribution is a red herr
While it is true that without knowing it we cannot explain the value of the lik
hood, *i.e.* we cannot explain why we observe a value which *a priori* looks t
unlikely, this is not the point; the point is to explain a *special* value. In other wo
the Copernican Principle (*e.g.* Harrison, 2000) says that we should not explain
observations by our being in a *special* place (in real or parameter space), not
we should demand that we are not at an improbable place: if many others are
as improbable, then nevertheless our position can still be typical. The correct
sponse after observing one-hundred coin flips come up 'heads' is that the coi
very probably not fair, even though this particular sequence is not more unlik
than *any* other sequence.

Summary and Conclusions

Perhaps no topic in modern cosmology is debated as hotly as that of the Multiv
and the distinct but related topics of the Anthropic Principle, fine-tuning (in m
than one sense of the term), and necessary conditions for the existence of life-
particular, for our existence. To some extent the debate might be due to confus
of various terms and misunderstandings about the role of probability. One sho
not be less strict in connection with these topics than with other topics in scie
but at the same time one should not be more strict just because of persona
philosophical objections. In other contexts, it is clear that not all ramifications
a theory have to be testable for the theory to gain confidence, that 'just so' is n
satisfactory explanation for *interesting* coincidences, that typical observers are
necessarily located in a typical position but rather in a typical position compat
with their existence, and that there is a difference between absolute probability
conditional probability. Perhaps less clear is whether the Universe is fine-tu
for life, especially if one takes into account that there might be more bizarre ty
of life than we can imagine. This has no bearing, however, on the fact that
Universe is fine-tuned for *our* existence. If one desires an explanation for this, t
it seems that the Anthropic Principle applied to the Multiverse is the best answ

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