

The Fine-Tuning Argument

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Abstract

Our laws of nature and our cosmos appear to be delicately fine-tuned for life to emerge. First, if the initial conditions prevailing immediately after the Big Bang had been ever so slightly different, then the universe would either have recollapsed immediately, or would have expanded far too quickly into a chilling, eternal void. Second, if any one of the fundamental forces of nature had been a tiny bit different in strength, or if the masses of some elementary particles had been a little unlike they are, there would have been no stars and no recognizable chemistry, and hence no Sun, no Earth, no carbon, et cetera (let alone the complex human brains to study these matters).

These highly special conditions and numbers suggest some sort of a conspiracy of literally cosmic proportions, which seems rather hard to attribute to chance. Some theologians and religiously oriented scientists and philosophers have taken advantage of this apparent fine-tuning of the clockwork of the universe to revive the scholastic Argument from Design, but also secular thinkers have felt the need to explain fine-tuning, typically by proposing the existence of a ‘Multiverse’, i.e., a vast family of universes existing in parallel, of which ours is merely one, singled out by the (weak) ‘Anthropic Principle’ to the effect that it is the only one that can possibly contain observers and hence can be observed (at least in principle).

We analyze this issue from a sober perspective. Having reviewed the literature and having added several observations of our own, we conclude that cosmic fine-tuning turns out to support neither Design nor a Multiverse, both of which fail to explain fine-tuning or even to increase its likelihood (although there might be other reasons to believe in these ideas, to be found in religion and in inflation and/or string theory, respectively). In fact, fine-tuning and Design rather seem to be at odds with each other, except when one makes an additional assumption that is practically indistinguishable from Design and hence renders the whole argument circular. Likewise, the inference from fine-tuning to a Multiverse only works if the latter is underwritten by a startling metaphysical hypothesis we consider unwarranted. Instead, we conclude that fine-tuning requires no special explanation at all, since it is not the Universe that is fine-tuned for life, but life that has been fine-tuned to the Universe.

Motto

A mild form of satire may be the appropriate antidote. Imagine, if you will, the wonderment of a species of mud worms who discover that if the constant of thermometric conductivity of mud were different by a small percentage they would not be able to survive. (Earman, 1987, p. 314)

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1 Introduction

Twentieth Century physics and cosmology have revealed an astonishing path towards our existence, which appears to be predicated on a delicate interplay between the short-range forces that govern the behavior of matter at very small distances and the long-range force of gravity. The former control chemistry and hence (in a modern scientific view) life as we know it, whereas the latter is responsible for the overall evolution and structure of the Universe, whose apparent sensitivity to the conditions reigning immediately after the Big Bang further contributes to the suggestion that life (or even the existence of galaxies, stars, and planets) is a result of some kind of fine-tuning in the architecture of Nature.

Broadly, five different responses to the impression of fine-tuning have been given:

1. *Design*: updating the scholastic *Fifth Way* of Aquinas (1485), the Universe has been fine-tuned with the emergence of (human) life among its designated purposes.¹
2. *Multiverse*: the idea that our Universe is just one among innumerable many, each of which is controlled by different parameters in the (otherwise fixed) laws of nature.²
3. *Blind Chance*: constants of Nature and initial conditions have arbitrary values, and it is just a matter of coincidence that their actual values turn out to enable life.³
4. *Blind Necessity*: the Universe could not have been made in a different way or order, yet producing life is not among its goals since it fails to have any (Spinoza, 1677).⁴
5. *Misguided*: there is little to explain, since the fine-tuning problem is hardly an issue.

¹ “The Fifth Way is based on the directedness of things. We observe that some things which lack awareness, namely natural bodies, act for the sake of an end. This is clear because they always or commonly act in the same manner to achieve what is best, which shows that they reach their goal not by chance but because they tend towards it. Now things which lack awareness do not tend towards a goal unless directed by something with awareness and intelligence, like an arrow by an archer. Therefore there is some intelligent being by whom everything in nature is directed to a goal, and this we call ‘God.’” Translation in Kenny (1969, p. 96), to whom we also refer for a critical review of Aquinas’s proofs of the existence of God. It is a moot point whether the Fifth Way is really an example of the medieval Argument of Design, which Aquinas expresses elsewhere as: “The arrangement of diverse things cannot be dictated by their own private and divergent natures; of themselves they are diverse and exhibit no tendency to form a pattern. It follows that the order of many among themselves is either a matter of chance or must be attributed to one first planner who has a purpose in mind.” (Kenny, 1969, p. 116). Everitt (2004) distinguishes between the Argument *to* Design and the Argument *from* Order, respectively, both of which may still be found in modern Christian apologists such as Holder (2004), Swinburne (2004), Küng (2005), and Collins (2009), rebutted by e.g. Everitt (2004) and Philipse (2012). It is clear from his writings (such as the General Scholium in *Principia*) that Isaac Newton supported the Argument from Design, followed by Bentley (1692). Throughout early modern science, the gradual ‘reading’ of the ‘Book of Nature’, seen as a second ‘book’ God had left mankind next to the Bible, was implicitly or explicitly seen as a confirmation of Design (Jorink, 2010). Paley (1802) introduced the famous watchmaker analogy obliterated by Dawkins (1986). See also Barrow & Tipler (1986) and Manson (2003) for overviews of the Argument from Design.

² This seemingly outrageous idea is actually endorsed by some of the most eminent scientists in the world, such as Martin Rees (1999) and Steven Weinberg (2007). The underlying idea was nicely explained by Rees in a talk in 2003, raising the analogy with ‘an ‘off the shelf’ clothes shop: “if the shop has a large stock, we’re not surprised to find one suit that fits. Likewise, if our universe is selected from a multiverse, its seemingly designed or fine-tuned features wouldn’t be surprising.” Quoted by Mellor (2002).

³ In the area of biology, a classical book expressing this position is Monod (1971).

⁴ The most prominent modern Spinozist was Albert Einstein: “there are no *arbitrary* constants of this kind; that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur (not constants, therefore, whose numerical value could be changed without destroying the theory.” (Einstein in Schilpp, 1949, p. 63).

We will argue that whatever reasons one may have for supporting the first or the second option, fine-tuning should not be among them. Contemporary physics makes it hard to choose between the third and the fourth option (both of which seem to have supporters among physicists and philosophers),⁵ but in any case our own sympathy lies with the fifth.

First, however, we have to delineate the issue. The *Fine-Tuning Argument*, to be abbreviated by FTA in what follows, claims that the present Universe (including the laws that govern it and the initial conditions from which it has evolved) permits life only because these laws and conditions take a very special form, small changes in which would make life impossible. This claim is actually quite ambiguous, in (at least) two directions.

1. The FTA being counterfactual (or, in Humanities jargon, being ‘what if’ or ‘alternate’ history), it should be made clear what exactly is variable. Here the range lies between raw Existence itself at one end (Rundle, 2004; Holt, 2012; Leslie & Kuhn, 2013) and fixed laws of nature and a Big Bang with merely a few variable parameters at the other (cf. Rees, 1999; Hogan, 2000; Aguirre, 2001; Tegmark et al., 2006).

Unless one is satisfied with pure philosophical speculation, specific technical results are only available at the latter end, to which we shall therefore restrict the argument.

2. It should be made clear what kind of ‘life’ the Universe is (allegedly) fine-tuned for, and also, to what extent the emergence of whatever kind of life is deemed merely possible (if only in principle, perhaps with very low probability), or likely, or absolutely certain. For example, should we fine-tune just for the possible existence of self-replicating structures like RNA and DNA,⁶ or for “a planet where enough wheat or rice could be cultivated to feed several billion people” (Ward & Brownlee, 2000, p. 20), or for one where morally (or indeed immorally) acting rational agents emerge (Swinburne, 2004), perhaps even minds the like of Newton and Beethoven?

It seems uncontroversial that at the lowest end, the Universe should exhibit some kind of order and structure in order to at least enable life, whereas towards the upper end it has (perhaps unsurprisingly) been claimed that essentially a copy of our Sun and our Earth (with even the nearby presence of a big planet like Jupiter) is required, including oceans, plate tectonics, and a magnetic field helping to stabilize the atmosphere (Ward & Brownlee, 2000).⁷ For most of the discussion we go for circumstances favoring simple carbon-based life; the transition to complex forms of life will only play a role in discussing the fine-tuning of our solar system.⁸

⁵The ending of *The First Three Minutes* by the physicist Weinberg—“The more the universe appears comprehensible, the more it also appears pointless.”—could be bracketed under either. Weinberg’s qualification of his pessimistic view also deserves to be quoted: “But if there is no solace in the fruits of our research, there is at least some consolation in the research itself. Men and women are not content to comfort themselves with tales of gods and giants, or to confine their thoughts to the daily affairs of life; they also build telescopes and satellites and accelerators, and sit at their desks for endless hours working out the meaning of the data they gather. The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy.”

⁶See e.g. Smith & Szathmáry (1995) and Ward & Brownlee (2000) for theories of the origin of life.

⁷The conservatism—perhaps even lack of imagination—of such scenarios is striking. But science-fiction movies such as *Star Trek*, *Star Wars*, *E.T.*, *My Stepmother is an Alien* (not to speak of *Emmanuelle*, *Queen of the Galaxy*) hardly do better. Conway’s *Game of Life* suggests that initial complexity is not at all needed to generate complex structures, which may well include intelligent life in as yet unknown guise.

⁸Reprimanding the late Carl Sagan, who expected intelligent life to exist in millions of places even within our own Galaxy, Ward & Brownlee (2000) claim that whereas this might indeed apply to the most basic forms of life, it is the move to complex (let alone intelligent) life that is extremely rare (because of the multitude of special conditions required), perhaps having been accomplished only on Earth.

According to modern cosmology based on the (hot) Big Bang scenario,⁹ this means that the Universe must be sufficiently old and structured so that at least galaxies and several generations of stars have formed; this takes billions of years. The reason (which may be baffling on first reading) is that in addition to the light elements formed in Big Bang nucleosynthesis (i.e., about 75% hydrogen and 25% helium, with traces of other elements up to Lithium, see Galli & Palla, 2013), the heavier elements in the Periodic Table (many of which are necessary for biochemistry and/or the composition of the Earth and its atmosphere) were formed in stars, to be subsequently blown into the cosmos by supernova explosions. In that way, some of these elements eventually ended up in our solar system, where they are indispensable in constituting both the Earth and ourselves.¹⁰

2 Evidence for fine-tuning

Thanks to impressive progress in both cosmology and (sub)nuclear physics, over the second half of the 20th Century it began to be realized that the above scenario is predicated on seemingly exquisite fine-tuning of some of the constants of Nature and initial conditions of the Universe. We just give some of the best known and best understood cases here.¹¹

One of the first examples was the ‘Beryllium bottleneck’ studied by Hoyle in 1951, which is concerned with the mechanism through which stars produce carbon and oxygen.¹² This was not only a major correct scientific prediction based on ‘anthropic reasoning’ in the sense that some previously unknown physical effect (viz. the energy level in question) *had* to exist in order to explain some crucial condition for life; it involves dramatic fine-tuning, too, in that the nucleon-nucleon force must lie near its actual strength within about one part in a thousand in order to obtain the observed abundances of carbon and oxygen, which happen to be the right amounts needed for life (Ekström et al., 2010).

Another well-understood example from nuclear physics is the mass difference between protons and neutrons, or, more precisely, between the down quark and the up quark (Hogan, 2000).¹³ This mass difference is positive (making the neutron heavier than the proton); if it weren’t, the proton would fall apart and there would be no chemistry as we know it. On the other hand, the difference can’t be too large, for otherwise stars (or hydrogen bombs, for that matter) could not be fueled by nuclear fusion and stars like our Sun would not exist.¹⁴ Both require a fine-tuning of the mass difference by about 10%.

⁹See e.g. Rees (1999), Ellis (2007), and Weinberg (2008), at increasing level of technicality.

¹⁰See Arnett (1996) for a technical account and Ward & Brownlee (2000) for a popular one.

¹¹See Barrow & Tipler (1986), Leslie (1989), Davies (2006), Ellis (1997), and Barnes (2012) for further examples and more detailed references. Stenger (2011) and Bradford (2011, 2013) attempt to play down the accuracies claimed of fine-tuning, whilst Aguirre (2001) casts doubt on its limited scope.

¹²In order to make carbon, two ^4He nuclei must collide to form ^8Be , upon which a third ^4He nucleus must join so as to give ^{12}C (from which, in turn, ^{16}O is made by adding another ^4He nucleus). This second step must happen extremely quickly, since the ^8Be isotope formed in the first step is highly unstable. Without the exquisitely fine-tuned energy level in ^{12}C (lying at the $^8\text{Be} + ^4\text{He}$ reaction energy) predicted by Hoyle, this formation process would be far too infrequent to explain the known cosmic abundances. Opponents of anthropic reasoning would be right in pointing out that these abundances as such (rather than their implications for the possibility of human life) formed the proper basis for Hoyle’s prediction.

¹³Quarks are subnuclear particles that come in six varieties, of which only the so-called ‘up’ and ‘down’ quarks are relevant to ordinary matter. A neutron consists of one up quark and two down quarks, whereas a proton consists of two up quarks and one down quark. The electric charges (in units where an electron has charge -1) are $2/3$ for the up quark and $-1/3$ for the down quark, making a neutron electrically neutral (as its name suggests) whilst giving a proton charge $+1$. Atoms consist of nuclei (which in turn consist of protons and neutrons) surrounded by electrons, whose total charge exactly cancels that of the nucleus.

¹⁴Technically, the fundamental ‘ pp -reaction’ (i.e., $\text{proton} + \text{proton} \rightarrow \text{Deuteron} + \text{positron} + \text{neutrino}$),

Moving from the realm of fundamental physics to initial conditions, the solar system seems fine-tuned for life in various ways, most notably in the distance between the Sun and the Earth: if this had been greater (or smaller) by at most a few percent it would have been too cold (or too hot) for at least complex life to develop. Furthermore, to that effect the solar system must be stable for billions of years, and after the first billion years or so the Earth should not be hit by comets or asteroids too often. Both conditions are sensitive to the precise number and configuration of the planets (Ward & Brownlee, 2000).

Turning from the solar system to initial conditions of our Universe, but still staying safely within the realm of well-understood physics and cosmology, Rees (1999) and others have drawn attention to the fine-tuning of another cosmological number called Q , which gives the size of inhomogeneities, or ‘ripples’, in the early Universe and is of the order $Q \sim 0.00001$, or one part in a hundred thousand.¹⁵ This parameter is fine-tuned by a factor of about ten on both sides (Rees, 1999; Tegmark et al., 2006): if it had been less than a tenth of its current value, then no galaxies would have been formed (and hence no stars and planets). If, on the other hand, it had been more than ten times its actual value, then matter would have been too lumpy, so that there wouldn’t be any stars (and planets) either, but only black holes. Either way, a key condition for life would be violated.¹⁶

The expansion of the Universe is controlled by a number called Ω , defined as the ratio between the actual matter density in the Universe and the so-called critical density. If $\Omega \leq 1$, then the universe would expand forever, whereas $\Omega > 1$ would portend a recollapse. Thus $\Omega = 1$ is a critical point.¹⁷ It is remarkable enough that currently $\Omega \approx 1$ (within a few percent); what is astonishing is that this is the case at such a high age of the Universe. Namely, for Ω to retain its (almost) critical value for billions of years, it must have had this value right from the very beginning to a precision of at least 55 decimal places.¹⁸

This leads us straight to Einstein’s cosmological constant Λ , which he introduced into his theory of gravity in 1917 in order to (at least theoretically) stabilize the Universe against contracting or expanding, to subsequently delete it in 1929 after Hubble’s landmark

which lies at the beginning of nuclear fusion, would go in the wrong direction.

¹⁵The Universe is approximately 13.7 billion years old (which is about three times as old as the Earth). Almost 400,000 years after the Big Bang, the Universe (which had been something like a hot soup of elementary particles until then) became transparent to electromagnetic radiation (which in everyday life includes light as well as radio waves, but whose spectrum is much larger) and subsequently became almost completely dark, as it is now. The so-called cosmic microwave background (CMB, discovered in 1964 by Penzias and Wilson), which still pervades the Universe at a current temperature of about 3K ($= -270^\circ$ C), is a relic from that era. It is almost completely homogeneous and isotropic, except for the ripples in question, whose (relative) size is given by the parameter Q . This provides direct information about the inhomogeneities of the Universe at the time the CMB was formed, i.e., when it was 400,000 years old.

¹⁶As analyzed by the Planck Collaboration (2014), variations in the constants of Nature would also affect the value of Q , which is ultimately determined by the physics of the early universe. Hence its known value of 10^{-5} constrains such variations; in particular, the fine-tuning of Q necessary for life in turn fine-tunes the fine-structure constant α (which controls electromagnetism and light) to within 1% of its value ($1/137$).

¹⁷Roughly, the physics behind this is that at small matter density the (literally ‘energetic’) expansion drive inherited from the Big Bang beats the gravitational force, which tries to pull matter together.

¹⁸If not, the expansion would either have been too fast for structures like galaxies to emerge, or too slow to prevent rapid recollapse due to gravity, leading to a Big Crunch (Rees, 1999). This fine-tuning problem is often called the *flatness problem*, since the Universe is exactly flat (in the sense of Einstein’s Theory of General Relativity) when $\Omega = 1$ (otherwise it either has a spherical or a hyperbolic geometry). The fine-tuning problem for Ω is generally considered to be solved by the (still speculative) theory of cosmic inflation (Liddle & Lyth, 2000; Weinberg, 2008), but even if this theory is correct, it merely shifts the fine-tuning from one place to another, since the parameters in any theory of inflation have to be fine-tuned at least as much as Ω ; Carroll & Tam (2010) claim this would even be necessary to ten million decimals. In addition, the flatness problem may not be a problem at all, like the horizon problem (McCoy, 2015).

observation of the expansion of the Universe (famously calling its introduction his “biggest blunder”). Ironically, Λ made a come-back in 1998 as the leading theoretical explanation of the (empirical) discovery that the expansion of the Universe is currently accelerating.¹⁹ For us, the point is that even the currently accepted value of Λ remains very close to zero, whereas according to (quantum field) theory it should be about 55 (some even say 120) orders of magnitude larger (Martin, 2012). This is often seen as a fine-tuning problem, because some compensating mechanism must be as work to cancel its very large natural value with a precision of (once again) 55 decimal places.²⁰

The fine-tuning of all numbers considered so far seems to be dwarfed by a knock-down FTA given by Roger Penrose (1979, 2004), who claims that in order to produce a Universe that even very roughly looks like ours, its initial conditions (among some generic set) must have been fine-tuned with a precision of one to $10^{10^{123}}$, arguably the largest number ever conceived: all atoms in the universe would not suffice to write it out in full.²¹ Penrose’s argument is an extreme version of an idea originally due to Boltzmann, who near the end of the 19th Century argued that the direction of time is a consequence of the increase of entropy in the future but not in the past,²² which requires an extremely unlikely initial state (Price, 1997; Uffink, 2007; Lebowitz, 2008). However, this kind of reasoning is as brilliant as it is controversial (Callendar, 2004, 2010; Earman, 2006; Eckhardt, 2006; Wallace, 2010; Schiffrin & Wald, 2012). More generally, the more extreme the asserted fine-tuning is, the more adventurous the underlying arguments are (or so we think).

To be on the safe side, the fine-tuning of Ω , Λ , and Penrose’s initial condition should perhaps be ignored, leaving us with the other examples, and a few similar ones not discussed here. But these should certainly suffice to make a case for fine-tuning that is serious enough to urge the reader to at least make a bet on one the five options listed above.

3 General arguments

Before turning to a specific discussion of the Design and the Multiverse proposals, we make a few critical (yet impartial) remarks that put the FTA in perspective (see also Sober, 2004; Manson, 2009). Adherents of the FTA typically use analogies like the following:

- Someone lays out a deck of 52 cards after it has been shuffled. If the cards emerge in some canonical order (e.g., the Ace of Spades down to 2, then the Ace of Hearts down to 2, etc.), then, on the tacit assumption that each outcome is equally (un)likely, this very particular outcome supposedly cannot have been due to ‘luck’ or chance. Therefore (or so the argument goes), the shuffling must either have been extremely inferior (in case that the given order was the original one), or done by a con man.

¹⁹The Physics Nobel Prize in 2011 was awarded to Perlmutter, Schmidt, and Riess for this discovery. The cosmological constant Λ can theoretically account for this acceleration as some sort of an invisible driving energy. Thus reinterpreted as ‘dark energy’, Λ contributes as much as 70% to the energy density of the Universe and hence it is currently also the leading contributor to Ω (Planck Collaboration, 2015).

²⁰The broader context of this is what is called the *naturalness problem* in quantum field theory, first raised by the Dutch Nobel Laureate Gerard ’t Hooft in 1980. His claim was that a theory is unnatural if some parameter that is expected to be large is actually (almost) zero, unless there is a symmetry enforcing the latter. This generates its own fine-tuning problems, which we do not discuss here; see Grinbaum (2012).

²¹The number called “googol” that the internet company Google has (erroneously) been named after is ‘merely’ 10^{100} ; Penrose’s number is even much larger than a one with googol many zeroes.

²²This is a technical way of saying that heat flows from hot bodies to cold ones, that milk combines with tea to form a homogeneous mixture, that the cup containing it will fall apart if it falls on the ground, etc.; in all cases the opposite processes are physically possible, but are so unlikely that they never occur.

- Alternatively, if a fair die is tossed a large number of times and the number 6 comes up every time, one would expect the die to be loaded, or the person who cast it to be a very skillful con man. Once again, each outcome is assumed equally likely.

First, there is an underlying assumption in the FTA to the effect that the ‘constants’ of Nature as well as the initial conditions of the Universe (to both of which the emergence of life is allegedly exquisitely sensitive) are similarly variable. This may or may not be the case; the present state of science is not advanced enough to decide between chance and necessity concerning the laws of nature and the beginning of the Universe.²³

Second, granted that the ‘constants’ etc. are variable in principle (in the sense that values other than the current ones preserve the existence and consistency of the theories in which they occur), it is quite unclear to what extent they can vary and which variations may be regarded as ‘small’; yet the FTA relies on the assumption that even ‘small’ variations would block the emergence of life (Manson, 2000). In the absence of such information, it would be natural to assume that any (real, positive as appropriate) value may be assumed, but in that case mathematical probabilistic reasoning (which is necessary for the FTA in order to say that the current values are ‘unlikely’) turns out to be impossible (McGrew et al., 2001; Colyvan et al., 2005; Koperski, 2005).²⁴ But also if a large but finite number of values (per constant or initial condition) needs be taken into account, it is hard to assign any kind of probability to any of the alternative values; even the assumption that each values is equally likely seems totally arbitrary (Everitt, 2004; Norton, 2010).

Nonetheless, these problems may perhaps be overcome and in any case, for the sake of argument we will continue to use the metaphors opening this section.

²³Our own hunch tends towards necessity, for reasons lying in constructive quantum field theory (Glimm & Jaffe, 1987): it turns out to be extremely difficult to give a mathematically rigorous construction of elementary particle physics, and the value of the constants may be fixed by the requirement of mathematical existence and consistency of the theory. For example, the so-called scalar φ^4 theory is believed to be trivial in four (space-time) dimensions, which implies that the relevant ‘constant of Nature’ must be zero (Fernandez, Fröhlich, & Sokal, 1992). This is as fine a fine-tuning as anything! Similarly, in cosmology the Big Bang (and hence the initial conditions for the Universe it gives rise to) actually seems to be an illusion caused by the epistemic fact that we look at the quantum world through classical glasses. In this case, the requirement that cosmology as we know it must actually emerge in the classical limit of some quantum theory (or of some future theory replacing quantum mechanics) may well fix the initial conditions.

In this context, it is worth mentioning that the familiar endorsement of the Big Bang by modern Christian apologists (see footnote 1) as a scientific confirmation of the creation story in *Genesis* 1 seems wishful thinking based on a common mistranslation of its opening line as “In the beginning God created the heavens and the earth” (and similarly in other languages), whereas the original Hebrew text does not intend the “beginning” as an absolute beginning of time but rather as the starting point of the action expressed by the following verb, whilst “created” should have read “separated” (Van Wolde, 2009). More generally, the world picture at the time of writing of *Genesis* was that of a disk surrounded by water, the ensuing creation story not being one of *creatio ex nihilo*, but one in which God grounds the Earth by setting it on pillars. This led to a tripartite picture of the Cosmos as consisting of water, earth, and heaven. See also Van Wolde’s contribution to this volume, as well as Noordmans (1934). The remarkable *creatio ex nihilo* story introduced by the Church Fathers therefore lacks textual support from the Bible.

²⁴Suppose some constant takes values in the real axis. In the absence of good reasons to the contrary, any alternative value to the current one should have the same probability. But there is no flat probability measure on the real numbers (or on any non-compact subset thereof). Even if there were such a measure, any finite interval, however large or small, would have measure zero, so that one could not even (mathematically) express the difference between some constant permitting life if it just lies within some extremely small bandwidth (as the FTA has it), or in some enormously large one (which would refute the FTA).

4 Critiquing the inference of Design from fine-tuning

The idea that cosmic fine-tuning originates in design by something like an intelligent Creator fits into a long-standing Judeo-Christian tradition, where both the Cosmos and biology were explained in that way.²⁵ Now that biology has yielded to the theory of Evolution proposed by Darwin and Wallace in the mid 19th Century,²⁶ the battleground has apparently moved back to the cosmos. Also there, Design remains a vulnerable idea.

First,²⁷ Smith (1993) made the point that the combination of the FTA with a theist picture seems quite inconsistent: if (granted that he exists) God's aim is to create a Universe in which life evolves, why would he choose a design (i.e., laws of nature and a Big Bang) that with very high probability would evolve contrary to his intentions (the low probability of realizing his intentions being the core of the FTA), so that he, so to speak, has to override the overall design by fine-tuning it in order to achieve his goal? It would seem far more efficient to create an architecture that is robust towards the stated goal.

Second, as noted by Barnes (2012), the FTA does not claim, or support the conclusion, that the present Universe is *optimal* for intelligent life, which it clearly seems not to be. Even granted the existence of our earth with its relatively favorable conditions (Ward & Brownlee, 2000), evolution has been walking a tightrope so as to produce as much as jellyfish, not to speak of primates (Dawkins, 1996). This fact alone casts doubt on the FTA as an Argument of Design, for surely a benign Creator would prefer a Universe optimal for life, rather than one that merely permits it, with questionable likelihood at that?

Third, the inference to Design from the FTA seems to rest on a decisive tacit assumption whose exposure makes it all but circular (Bradley, 2001). In the cards analogy, the two given explanations (i.e., either no actual shuffling or fraud) model two possibilities of Design vis-à-vis fine-tuning: either Spinoza was right that only one Universe is possible so that the Creator had no choice in his/her design (in which case the FTA cannot be launched in the first place), or he/she did have a choice and opted for the configuration that would eventually enable life. The second explanation *presupposes* that there was such a thing as a canonical order; if there weren't, then any particular outcome would be thought of in the same way and would of course be attributed to chance. Similarly, the dice metaphor *presupposes* that it is special for 6 to come up every single time; probabilistically speaking, every other outcome would have been just as (un)likely as the given sequence of sixes.²⁸

In the case of independently tunable constants of Nature and/or initial conditions, one (perhaps approximate) value of each of these must first be marked with a special label like 'life-permitting' in order for the analogy with cards or dice (and hence the appeal of the FTA) to work. The FTA is predicated on such marking, which already *presupposes* that life

²⁵See footnote 1 and refs. therein. Note that a fine-tuning intelligent Creator is still a long shot from the Christian God whom Holder (2004), Swinburne (2004), Küng (2005), and Collins (2009) are really after!

²⁶The Dutch primatologist De Waal (2013) recently noted how reasonable Creationism originally was: animals known to the population of the Middle East (where Judeo-Christian thought originated) included camels etc. but no primates, and hence all living creatures appeared very different from mankind.

²⁷For the sake of argument we do not question the coherence of the idea of an intelligent Creator as such, although we agree with the doubts expressed by e.g. Everitt (2004) and Philipse (2012).

²⁸Entropy arguments do not improve the case for Design. It is true that although the probability of a sequence of all sixes is the same as the probability of any other outcome, the former *becomes* special if we coarse-grain the outcome space by counting the number of sixes in a given long sequence of throws and record that information only. The outcome with sixes only then becomes extremely unlikely, since it could only have occurred in one possible way, whereas outcomes with fewer sixes have multiple realizations (the maximum probability occurring when the number of sixes is about one-sixth of the total number of throws). The point is that the very act of coarse-graining again *presupposes* that six is a special value.

is something special. It is irrelevant to this objection whether or not life is indeed special; the point is that the assumption that life be special has to be made *in addition* to the FTA in order to launch the latter on track to Design. But the inference from the (assumed) speciality of life to Design does not need the FTA: even if all values of the constants and initial conditions would lead to a life-permitting Universe, those who think that life is special would point to a Creator (and, both by the arguments recalled at the beginning of this section and those below, their case would actually be considerably stronger).

In sum, fine-tuning is not by itself sufficient as a source for an Argument of Design; it is the *combination* with an assumption to the effect that life is somehow singled out, preferred, or special. But that assumption is the one that carries the inference to Design; the moment one makes it, fine-tuning seems counter-productive rather than helpful.

Attempts to give the Design Argument a quantitative turn (Swinburne, 2004; Collins, 2009) make things even worse. Such attempt are typically based on *Bayesian Confirmation Theory*. This is a mathematical technique for the analysis and computation of the probability $P(H|E)$ that a given hypothesis H is true in the light of certain evidence E (which may speak for or against H , or may be neutral). Almost every argument in Bayesian Confirmation Theory is ultimately based on *Bayes' Theorem*

$$P(H|E) = P(E|H) \cdot P(H)/P(E),$$

where $P(E|H)$ is the probability that E is true given the validity of the hypothesis H , whilst $P(H)$ and $P(E)$ are the probabilities that H and E are true without knowing E and H , respectively (but typically assuming certain background knowledge common to both H and E , which is very important but has been suppressed from the notation).²⁹

In the case at hand, theists want to argue that the Universe being fine-tuned for Life makes Design more likely, i.e., that $P(D|L) > P(D)$, or, equivalently, that $P(L|D) > P(L)$ (that is, Design favors life). There are (at least) two problems with this. The first (Bradley, 2002; Halvorson, 2014) is that theists do not merely ask for the latter inequality; what they really believe is that $P(L|D) \approx 1$, for the existence of God should make the emergence of life almost certain.³⁰ This may or may not be the case (granting the whole discussion makes any sense); to see why it makes the FTA towards Design self-defeating, it is sufficient to assume that $P(L|D) \geq 1/2$, or, equivalently, that $P(L|D) \geq P(\neg L|D)$, where $\neg L$ is the proposition that life does not exist. If (D, L) is the conjunction of D and L , we then have

$$P(D) = P(D, L) + P(D, \neg L) \leq 2P(D, L) \leq 2P(L),$$

since $P(D, \neg L) \leq P(D, L)$ by assumption. Thus a negligible probability of life as such (on which assumption the FTA is based) implies a hardly less negligible probability of Design!

The second problem (Halvorson, 2014) is that the Design hypothesis even fails to imply that $P(L|D) > P(L)$. Consider an urn filled with 1 Lilac-colored ball and 99 purple balls.

²⁹This implies, in particular, that $P(H|E) > P(H)$, i.e., E confirms H , if and only if $P(E|H) > P(E)$, which is often computable. The probabilities in question are usually (though not necessarily) taken to be *epistemic* or (inter)subjective, so that the whole discussion is concerned with probabilities construed as numerical measures of *degrees of belief*. For technical as well as philosophical background on Bayesianism see e.g. Howson & Urbach (2006), Sober (2008), and Handfield (2012).

³⁰Swinburne (2004), though, occasionally assumes that $P(L|D) = 1/2$ as a subjective probability (based on our ignorance of God's intentions), which still makes his reasoning vulnerable to the argument below. In Swinburne (2004), arguments implying $P(L|D) > P(L)$ are called *C-inductive*, whereas the stronger ones implying $P(L|D) > 1/2$ are said to be *P-inductive*. Swinburne's strategy is to combine a large number of *C-inductive* arguments into a single overarching *P-inductive* one, but according to Philipse (2012) every single one of Swinburne's *C-inductive* arguments is actually invalid (and we agree with Philipse).

The probability $P(L)$ of picking the lilac one equals 0.01. Now to people who believe in the existence of a *Deity* who designed and filled the urn, the *probability* $P(L|D)$ remains 0.01; all that has changed is the *story* about it. The point of this metaphor is that whatever his powers, within Theistic reasoning the Deity has created the Laws of Nature himself and will not override them, including the probability of life. Therefore, if the latter is vanishingly small, as the FTA has it, then this is the case, full stop. If, on the other hand, the Deity has made the pertinent probability large, as the Argument of Design wishes to conclude, then this is the case, full stop, too, and there is no FTA to begin with.

5 Critiquing the inference of a Multiverse from fine-tuning

The idea of Design may be said to be human-oriented in a spiritual way, whereas the idea of a Multiverse more technically hinges on the existence of observers, as expressed by the so-called (weak) *Anthropic Principle* (Barrow & Tipler, 1986; Bostrom, 2002). The claim is that there are innumerable Universes (jointly forming a ‘Multiverse’), each having its own ‘constants’ of Nature and initial conditions, so that, unlikely as the life-inducing values of these constants and conditions in our Universe may be, they simply must occur within this unfathomable plurality. The point, then, is that we *have to* observe precisely those values because in other Universes there simply are no observers. This principle has been labeled both ‘tautological’ and ‘unscientific’. Some love it and some hate it, but fortunately we do not need to take sides in this debate: all we wish to do is find out whether or not the FTA speaks in favour of a Multiverse, looking at both an explanatory and a probabilistic level. Thus the question is if the (alleged) fact of fine-tuning is (at least to some extent) explained by a Multiverse, or if, in a Bayesian context, the evidence of fine-tuning increases the probability of the hypothesis that a Multiverse exists.³¹

In an explanatory context we side with Mellor (2002) in claiming that if anything, a Multiverse would make fine-tuning even more puzzling. Here Leslie’s (1989) Dostoyevskian firing squad analogy provides a nice context for discussing precisely the conceptual link between a Multiverse and anthropic reasoning that is relevant. Someone is going to be executed by a firing squad, consisting of many marksmen (say hundreds of them), but they all miss. Metaphorically, the fortunately surviving convict is in the tiny corner of the Multiverse permitting life (i.e., our own Universe); if he had been killed, his habitat would have been in one of the numerous other Universes. There is no doubt this outcome is unexpected, but the question is whether it may be explained (or, at least, whether it becomes less unexpected) by the assumption that simultaneously, many other ‘successful’ executions were taking place. From one point of view, this fact has no bearing on the case of the lone survivor, whose luck remains as amazing as it was. From another, *it makes his survival even more puzzling*, since we now know from this additional information about the other executions that apparently the marksmen usually do kill their victims.

³¹Although fine-tuning has been claimed (notably by Rees, 1999) to provide independent motivation for believing in a Multiverse, the existence of a Multiverse may be a technical consequence of some combination of string theory (Susskind, 2005; Schellekens, 2013) and cosmological inflation (Liddle & Lyth, 2000; Weinberg, 2008). Both theories are highly speculative, though (the latter less so than the former), and concerning the ‘landscape’ idea it is hard to avoid the impression that string theorists turn vice into virtue by selling the inability of string theory to predict anything as an ability to predict everything (a similar worry may also apply to inflation, cf. Smeenk, 2014). Let us also note that even if it were to make any sense, the ‘emergent multiverse’ claimed to exist in the so-called Many-Worlds (or Everett) Interpretation of quantum mechanics (Wallace, 2012) is a red herring in the present context, for, as far as we understand, all its branches have exactly the same laws of nature, including the values of the constants.

Furthermore, those who use the firing squad analogy to defend the Multiverse make a mistake similar to the one pointed out by Bradley (2001) in the context of Design, as discussed in the previous section: for they tacitly assume that the aim of the marksmen is to kill, making it surprising and hence worthy of explanation if they miss. However, ‘purpose’ is an *additional* assumption that is not contained in or implied by the data underlying the FTA. If there is no such purpose, then the analogy loses whatever thrust it might have; if there is, it would rather point towards Design rather than a Multiverse.

In a probabilistic setting, a telling metaphor related to the Multiverse is the *Inverse Gambler’s Fallacy* (Hacking, 1987).³² In its simplest version, this is the mistake made by a gambler who enters a casino or a pub, notices that a double six is thrown at some table, and asks if this is the first roll of the evening (his underlying false assumption being that this particular outcome is more likely if many rolls preceded it; the answer to his question is of course irrelevant). Hacking’s claim that this is precisely the error made by those who favor a Multiverse based on the FTA has led to some debate on what in the philosophical literature is called *self-locating belief* (Leslie, 1988; White, 2000; Bostrom, 2002; Manson & Thrush, 2003; Bradley, 2012), which may be succinctly summarized as follows.

Proponents of a Multiverse are satisfied with the (correct) statement that its existence would increase the probability of life existing in *some* (not necessarily our) Universe, whereas their opponents (equally correctly) point out that a Multiverse does not increase the probability of life in *this* Universe,³³ unless one believes that the existence of life in *some* branch, whose probability is duly raised by a Multiverse (and is in fact considered almost certain by its proponents), in fact implies *our* existence. But this implies that we would have been the same persons if, under otherwise identical circumstances, we had existed in some other branch of the Multiverse! One should realize that the inference of a Multiverse from the FTA implicitly hinges on this mind-boggling philosophical assumption, which anyhow seems solidly wrong to us, as explained well by Hartle & Srednicki (2007):

“This notion presupposes that we exist separately from our physical description. But we are not separate from our physical description in our data; we *are* the physical system described (...)

It is *our data* that is used in a Bayesian analysis to discriminate between theories. What other hypothetical observers with data different from ours might see, how many of them there are, and what properties they might or might not share with us (...) are irrelevant for this process.”

Thus it turns out that the naive probabilistic intuition behind the Multiverse alone is insufficient to carry the day, and that the above assumption, which is needed to supplement it, is so far-fetched that in our view the entire argument has become highly suspect.

³²The *Gambler’s Fallacy* is the mistake that after observing say 35 throws of two fair dice without a double six, this preferred outcome has become more likely (than 1/36) in the next throw.

³³In Rees’ analogy of the clothes shop (see footnote 2), what needs to be explained is not that *some* suit in the shop turns out to fit the customer, but that the one *he happens to be standing in front of* does.

6 Conclusion

Already the uncontroversial examples that feed the FTA suffice to produce the fascinating insight that the formal structure of our current theories of (sub)nuclear physics and cosmology (i.e., the Standard Model of particle physics and Einstein’s theory of General Relativity) is insufficient to predict the rich phenomenology these theories give rise to: the precise values of most (if not all) constants and initial conditions play an equally decisive role. This is a recent insight: even a physicist having the stature of Nobel Laureate Glashow (1999, p. 80) got this wrong, having initially paraphrased the situation well:

“Imagine a television set with lots of knobs: for focus, brightness, tint, contrast, bass, treble, and so on. The show seems much the same whatever the adjustments, within a large range. *The standard model is a lot like that.*”

Who would care if the tau lepton mass were doubled or the Cabibbo angle halved? The standard model has about 19 knobs. They are not really adjustable: they have been adjusted at the factory. Why they have their values are 19 of the most baffling metaquestions associated with particle physics.”

In our view, the insight that *the standard model is not like that at all* is the real upshot of the FTA.³⁴ Attempts to draw further conclusions from it in the direction of either *Design* or a *Multiverse* are, in our opinion, unwarranted. For one thing, as we argued, at best they fail to have any explanatory or probabilistic thrust (unless they rely on precarious additional assumptions), and at worst fine-tuning actually seems to turn against them.

Most who agree with this verdict would probably feel left with a choice between the options of *Blind Chance* and *Blind Necessity*; the present state of science does not allow us to make such a choice now (at least not rationally), and the question even arises if science will ever be able to make it (in a broader context), expect perhaps philosophically (e.g., à la Kant). However, we would like to make a brief case for the fifth position, stating that the fine-tuning problem is *misguided* and that there is really nothing to explain.

There are analogies and differences between cosmic fine-tuning for life through the laws of Nature and the initial conditions of the Universe, as discussed so far, and Evolution in the sense of Darwin and Wallace. The latter is based on random (genetic) variation, survival of the fittest, and heritability of fitness. All these are meant to apply locally, i.e., to life on Earth. We personally feel that arguments to extend these principles to the Universe in the sense that the Cosmos may undergo some kind of ‘biological’ evolution, having descendants born in singularities, perhaps governed by different laws and initial conditions (some of which, then, might be ‘fine-tuned for life’, as in the Multiverse argument), as argued by e.g. Wheeler (in Ch. 44 of Misner, Thorne, & Wheeler, 1973) and Smolin (1997), imaginative as they may be, are too speculative to merit serious discussion. Instead, the true analogy seems to be as follows: as far as the emergence and subsequent evolution of life are concerned, the Universe and our planet Earth should simply be taken as given.³⁵ Thus the fundamental reason we feel ‘fine-tuning for life’ requires no explanation is this:³⁶

Our Universe has not been fine-tuned for life: life has been fine-tuned to our Universe.

³⁴Callender (2004) understandably misquotes Glashow, writing: “The standard model is *not* like that.”

³⁵That is, at least until mankind started to ruin the planet.

³⁶Form this point of view, what we see as the essential mistake made by those who feel fine-tuning does require an explanation is similar to what Butterfield (1931) famously christened ‘Whig History’, i.e., “the tendency in many historians to write on the side of Protestants and Whigs, to praise revolutions provided they have been successful, to emphasize certain principles of progress in the past and to produce a story which is the ratification if not the glorification of the present.” (quoted from the Preface).

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References

- Aguirre, A. (2001). The Cold Big-Bang cosmology as a counter-example to several anthropic arguments. *Physical Review D* 64, 083508.
- Aquinas, Th. (1485). *Summa Theologica*. Basel: M. Wenssler. Written 1268–1274.
- Arnett, D. (1996). *Supernovae and Nucleosynthesis: An Investigation of the History of Matter, From the Big Bang to the Present*. Princeton: Princeton University Press.
- Barnes, L.A. (2012). The fine-tuning of the Universe for intelligent life. *Publications of the Astronomical Society of Australia* 29, 529–56.
- Barrow, J.D., Tipler, F. (1986). *The Anthropic Cosmological Principle*. Oxford: Clarendon Press.
- Bentley, R. (1692). *A Confutation of Atheism from the Origin and Frame of the World*. London: Mortlock.
- Bostrom, N. (2002). *Anthropic Bias: Observation Selection Effects in Science and Philosophy*. New York: Routledge.
- Bradford, R. (2011). The inevitability of fine tuning in a complex Universe. *International Journal of Theoretical Physics* 50, 1577–1601.
- Bradford, R. (2013). Rick’s critique of cosmic coincidences. Website (consulted April 6th, 2015), www.rickbradford.co.uk/Coincidences.html.
- Bradley, D. (2012). Four problems about self-locating belief. *Philosophical Review* 121, 149–177.
- Bradley, M.C. (2001). The fine-tuning argument. *Religious Studies* 37, 451–466.
- Bradley, M.C. (2002). The fine-tuning argument: the Bayesian version. *Religious Studies* 38, 375–404.
- Butterfield, H. (1931). *The Whig Interpretation of History*. London: Bell.
- Callender, C. (2004). Measures, explanations and the past: Should ‘special’ initial conditions be explained? *The British Journal for the Philosophy of Science* 55, 195–217.
- Callender, C. (2010). The Past Hypothesis meets gravity. *Time, Chance, and Reduction: Philosophical Aspects of Statistical Mechanics*, eds. Ernst, G., Hütteman, A., pp. 34–58. Cambridge: Cambridge University Press.
- Carroll, S.M., Tam, H. (2010). Unitary evolution and cosmological fine-tuning. [arXiv:1007.1417](https://arxiv.org/abs/1007.1417).
- Collins, R. (2009). The teleological argument: An exploration of the fine-tuning of the Universe. *The Blackwell Companion to Natural Theology*, eds. Craig, W.L. & Moreland, J.P., pp. 202–281. Chichester: Wiley–Blackwell.
- Colyvan, M., Garfield, J.L., Priest, G. (2005). Problems with the argument from fine tuning. *Synthese* 145, 325–338.
- Davies, P. (2006). *The Goldilocks Dilemma: Why is the Universe Just Right for Life?* New York: Mariner.
- Dawkins, R. (1986). *The Blind Watchmaker*. New York: Norton.
- Dawkins, R. (1996). *Climbing Mount Improbable*. New York: Norton.
- De Waal, F. (2013). *The Bonobo and the Atheist*. New York: Norton.
- Earman, J. (1987). The SAP also rises: A critical examination of the anthropic principle. *American Philosophical Quarterly* 24, 307–317.

- Earman, J. (2006). The “Past Hypothesis”: Not even false. *Studies in History and Philosophy of Modern Physics* 37, 399–430.
- Eckhardt, W. (2006). Causal time asymmetry. *Studies in History and Philosophy of Modern Physics* 37, 439–466.
- Ekström, S. et al. (2010). Effects of the variation of fundamental constants on Population III stellar evolution. *Astronomy & Astrophysics* 514, A62.
- Ellis, G.G.R. (2007). Issues in the philosophy of cosmology. *Philosophy of Physics Part B*, eds. Butterfield, J. & Earman, J., pp. 1183–1286. Amsterdam: Elsevier.
- Everitt, N. (2004). *The Non-Existence of God*. London: Routledge.
- Fernandez, R., Fröhlich, J., Sokal, A.D. (1992). *Random Walks, Critical Phenomena, and Triviality in Quantum Field Theory*. Heidelberg: Springer.
- Glimm, J., Jaffe, A. (1987). *Quantum Physics: A Functional Integral Point of View*. New York: Springer.
- Galli, D., Palla, F. (2013). The dawn of chemistry. *Annual Review of Astronomy and Astrophysics* 51, 163–206.
- Glashow, S.L. (1999). Does quantum field theory need a foundation? *Conceptual Foundations of Quantum Field Theory*, ed. Cao, T.Y., pp. 74–88. Cambridge: Cambridge University Press.
- Grinbaum, A. (2012). Which fine-tuning problems are fine? *Foundations of Physics* 42, 615–631.
- Hacking, I. (1987). The inverse gambler’s fallacy: The argument from design. The Anthropic Principle applied to Wheeler Universes. *Mind* 96, 331–340.
- Halvorson, H. (2014). A probability problem in the fine-tuning argument. philsci-archive.pitt.edu/11004/.
- Hartle, J.B., Srednicki, M. (2007). Are We Typical? *Physical Review D* 75, 123523.
- Handfield, T. (2012). *A Philosophical Guide to Chance*. Cambridge: Cambridge University Press.
- Hogan, C.J. (2000). Why the universe is just so. *Reviews of Modern Physics* 72, 1149–1161.
- Holt, J. (2012). *Why Does the World Exist? An Existential Detective Story*. New York: W.W. Norton.
- Howson, C., Urbach, P. (2006). *Scientific Reasoning: The Bayesian Approach*. Third Edition. Chicago: Open Court.
- Jorink, E. (2010). *Reading the Book of Nature in the Dutch Golden Age, 1575–1715*. Leiden: Brill.
- Kenny, A. (1969). *The five ways: St Thomas Aquinas’ proofs of God’s existence*. London: Routledge & Kegan Paul.
- Koperski, J. (2005). Should we care about fine-tuning? *The British Journal for the Philosophy of Science* 56, 303–319.
- Küng, H. (2005). *Der Anfang aller Dinge: Naturwissenschaft und Religion*. München: Piper.
- Lebowitz, J.L. (2008). From time-symmetric microscopic dynamics to time-asymmetric macroscopic behavior: An overview. *Boltzmann’s Legacy*, eds. Gallavotti, G., Reiter, W.L., Yngavson, J., pp. 38–62. Zürich: European Mathematical Society.
- Leslie, J. (1988). No Inverse Gambler’s Fallacy in Cosmology. *Mind* 97, 269–272.
- Leslie, J. (1989). *Universes*. London: Routledge.
- Leslie, J., Kunh, R.L. (2013). *The Mystery of Existence: Why is there Anything at All?*. Chichester: Wiley–Blackwell.
- Liddle, A.R., Lyth, D.A. (2000). *Cosmological Inflation and Large-scale Structure*. Cambridge: Cambridge University Press.
- Manson, N.A. (2000). There is no adequate definition of ‘fine-tuned for life’. *Inquiry* 43, 341–352.

- Manson, N.A., ed. (2003). *God and Design*. London: Routledge.
- Manson, N.A. (2009). The fine-tuning argument. *Philosophy Compass* 4, 271–286.
- Manson, N.A., Thrush, M.J. (2003). Fine-tuning, multiple Universes, and the “this Universe” objection. *Pacific Philosophical Quarterly* 84, 67–83.
- Martin, J. (2012). Everything you always wanted to know about the cosmological constant problem (but were afraid to ask). *Comptes Rendus Physique* 13, 566–665.
- McCoy, C. (2015). What is the horizon problem? Preprint.
- McGrew, T., McGrew, L., Vestrup, E. (2001). Probabilities and the Fine-Tuning Argument: a Sceptical View. *Mind* 110, 1027–1038.
- Mellor, D.H. (2002). Too many Universes. *God and Design: The Teleological Argument and Modern Science*, ed. Manson, N.A., pp. 221–228. London: Routledge.
- Misner, C., Thorne, K., Wheeler, J.A. (1973). *Gravitation*. San Francisco: Freeman.
- Monod, J. (1971). *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology*. New York: A. Knopf.
- Noordmans, O. (1934). *Herscheping*. Zeist: De Nederlandsche Christen-Studenten-Vereeniging.
- Norton, J.D. (2010). Cosmic confusions: Not supporting versus supporting not. *Philosophy of Science* 77, 501–523.
- Paley, W. (1802). *Natural Theology: Or Evidences of the Existence and Attributes of the Deity Collected from the Appearances of Nature*. London: J. Foulder.
- Penrose, R. (1979). Singularities and time-asymmetry. *General Relativity: An Einstein Centenary Survey*, eds. Hawking, S.W., Israel, W., pp. 581–638.
- Penrose, R. (2004). *The Road to Reality: A Complete Guide to the Laws of the Universe*. London: Jonathan Cape.
- Philipse, H. (2012). *God in the Age of Science? A Critique of Religious Reason*. Oxford: Oxford University Press.
- Planck Collaboration (2014). *Planck* intermediate results. XXIV. Constraints on variation of fundamental constants. *Astronomy & Astrophysics*, in press. [arXiv:1406.7482](#).
- Planck Collaboration (2015). *Planck* 2015 results. XIII. Cosmological parameters. [arXiv:1502.01589](#).
- Price, H. (1997). *Time’s Arrow & Archimedes’ Point*. Cambridge: Cambridge University Press.
- Rees, M. (1999). *Just Six Numbers*. London: Weidenfeld & Nicolson.
- Rundle, B. (2004). *Why There Is Something Rather Than Nothing*. Oxford: Oxford University Press.
- Schellekens, A.N. (2013). Life at the interface of particle physics and string theory. *Reviews of Modern Physics* 85, 1491–1540.
- Schiffrin, J.S., Wald, R.M. (2012). Measure and probability in cosmology. *Physical Review D* 86, 023521.
- Schilpp, P.A. (1949). *Albert Einstein: Philosopher-Scientist*, Vol. 1. La Salle: Open Court.
- Smeenk, C. (2014). Predictability crisis in early universe cosmology. *Studies in History and Philosophy of Modern Physics* 46, 122–133.
- Smith, J.M., Szathmáry, E. (1995). *The Major Transitions in Evolution*. Oxford: Freeman.
- Smith, Q. (1993). *Theism, Atheism and Big Bang Cosmology* (with Craig, W.L.), pp. 203–204. Oxford: Clarendon Press.
- Smolin, L. (1997). *The Life of the Cosmos*. Oxford: Oxford University Press.
- Sober, E. (2004). The Design Argument. *Blackwell Guide to the Philosophy of Religion*, ed. Mann, W.E., pp. 117–147. Oxford: Blackwell.

- Sober, G. (2008). *Evidence and Evolution*. Cambridge: Cambridge University Press.
- Spinoza, B. de (1677). *Ethica Ordine Geometrico Demonstrata*. Amsterdam: J. Rieuwertsz.
- Stenger, V. (2011). *The Fallacy of Fine-Tuning: Why the Universe Is Not Designed For Us*. Amherst (NY): Prometheus.
- Susskind, L. (2005). *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*. New York: Little, Brown.
- Swinburne, R. (2004). *The Existence of God*. Second Edition. Oxford: Oxford University Press.
- Tegmark, M., Aguirre, A., Rees, M.J., Wilczek, F. (2006). Dimensionless constants, cosmology, and other dark matters. *Physical Review D* 73, 023505.
- Uffink, J. (2007). Compendium of the foundations of classical statistical physics. *Philosophy of Physics Part B*, eds. Butterfield, J. & Earman, J., pp. 923–1074. Amsterdam: Elsevier.
- Van Wolde, E. (2009). Why the verb *bārā'* does not mean 'to create' in Genesis 1.1-2.4a. *Journal for the Study of the Old Testament* 34, 3–23.
- Wallace, D. (2010). Gravity, entropy, and cosmology: In search of clarity. *The British Journal for the Philosophy of Science* 61, 513–540.
- Wallace, D. (2012). *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation*. Oxford: Oxford University Press.
- Ward, P., Brownlee, D. (2000). *Rare Earth*. New York: Copernicus Books.
- Weinberg, S. (1977). *The First Three Minutes*. New York: Basic Books.
- Weinberg, S. (2007). Living in the Multiverse. *Universe or Multiverse*, ed. B. Carr, pp. 29–42. Cambridge: Cambridge University Press.
- Weinberg, S. (2008). *Cosmology*. Oxford: Oxford University Press.
- White, R. (2000). Fine-tuning and multiple Universes. *Noûs* 34, 260–276.