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# The Many-Worlds Hypothesis As an Explanation of Cosmic Fine-Tuning: An Alternative to Design?

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# THE MANY-WORLDS HYPOTHESIS AS AN EXPLANATION OF COSMIC FINE-TUNING: AN ALTERNATIVE TO DESIGN?

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The most common objection to fine tuning arguments for theism is that there are, or might be, multiple universes among which the fundamental physical constants and parameters vary. This essays describes the two main variants of this objection and argues that they both fail.

## *I. Introduction*

In the last thirty years, the argument from the *fine-tuning* of the cosmos has steadily gained in popularity, often being considered the strongest single argument for the existence of God. One particularly important category of fine-tuning is that of the *constants* of physics. The constants of physics are a set of fundamental numbers that, when plugged into the fundamental equations of physics, determine the basic structure of the universe. An example of such a constant is the gravitational constant G that is part of Newton's law of gravity, F = GM1M2/r2. G essentially determines the strength of gravity between two masses. If one were to double the value of G, for instance, then the force of gravity between any two masses would double. The "fine-tuning" of the constants of physics for life refers to the claim that these fundamental constants of physics are set just right for life to occur. More precisely, to say that a constant is fine-tuned for life is to say that its life-permitting range r is very small compared to some nonarbitrarily chosen comparison range R.

Two examples of this fine-tuning are the fine-tuning of the strength of gravity and the fine-tuning of the cosmological constant. So far, physicists have discovered four forces in nature — gravity, the weak force, electromagnetism, and the strong nuclear force that binds protons and neutrons together in an atom. Each of these forces has its own coupling constant that determines its strength, in analogy to the gravitational constant G. Using one of the standard dimensionless measures of force strengths (Barrow and Tipler, 1986, pp. 293-295), gravity is the weakest of the forces, and the strong nuclear force is the strongest, being a factor of $10^{40}$ — or ten thousand billion, billion, billion, billion—times stronger than gravity.

Various calculations show that the strength of each of the forces of nature must fall into a very small life-permitting region for intelligent life to exist, but here we will only look at the example of gravity. If we increased the strength of gravity on earth a billionfold, for instance, the force of gravity would be so great that land-based organisms anywhere near the size of human beings would be crushed. (The strength of materials depends on the electromagnetic force via the fine-structure constant, which would not be affected by a change in gravity.) As astrophysicist Martin Rees notes, "In an imaginary strong gravity world, even insects would need thick legs to support them, and no animals could get much larger." (Rees, 2000, p. 30). Now, the above argument assumes that the size of the planet on which life formed would be an earth-sized planet. Could life forms of comparable intelligence to ourselves develop on a much smaller planet in such a strong-gravity world? The answer is no. In our strong gravity world, a planet with a gravitational pull of a thousand times that of earth — which would make the existence of organisms of our size very improbable — would have a diameter of about 40 feet or 12 meters, once again not large enough to sustain the sort of large-scale ecosystem necessary for organisms like us to evolve.

Of course, a billion-fold increase in the strength of gravity is a lot, but compared to the total range of strengths of the forces in nature (which span a range of $10^{40}$ as we saw above), this still amounts to a fine-tuning of one part in $10^{31}$. Indeed, other calculations show that even if we increase the strength of gravity by only a thousandfold, no viable stars could exist that had life-times greater than a billion years, which would seriously decrease the likelihood of intelligent life evolving on any given earthlike planet.[1]

One of the most impressive and discussed cases of fine-tuning is that of the cosmological constant, a term in Einstein's equation of general relativity that governs the rate at which space expands. It is estimated that unless the cosmological constant were near zero to one part in $10^{120}$ of its "natural" value derived from current theories in particle physics, the universe would either expand too rapidly, or collapse too quickly, for life to develop (Guth, 1997, p. 284). To get an idea of how precise this is, it would be like throwing a dart at the surface of the earth from the moon, and hitting a bull's-eye one trillionth of a trillionth of an inch in diameter, less than the size of an atom!

In light of these type of scientific findings, many theists have argued that the fine-tuning of the cosmos strongly supports the hypothesis that the universe was intelligently designed for life, arguing that it is highly implausible to attribute this sort of fine-tuning to chance or to claim that it needs no explanation. In response to this theistic or intelligent design explanation of the fine-tuning, however, many atheists have offered an alternative explanation, what I will call the *many-universes hypothesis,* but which in the literature goes under a variety of names, such as many-worlds hypothesis, the many-domains hypothesis, the world-ensemble hypothesis, the multi-universe hypothesis, etc. According to this hypothesis, there are a very large — perhaps infinite — number of regions of space-time, with the fundamental parameters of physics varying from region to region. Of course, in the vast majority of these regions (which I will henceforth refer to as universes) the parameters of physics would not have life-permitting values. Nonetheless, in a small proportion of universes they would. Consequently, it is no longer improbable that universes such as ours exist that are fine-tuned for life to occur, just as it would be no surprise that some lottery ticket turns out to be a winning number given that enough lottery tickets are produced.

A subtle point should immediately be noted about the many-universes explanation of the fine-tuning. It is best thought of as not trying to explain why *our* universe has life-permitting values for the constants, but rather as attempting to render unsurprising the fact that a life-permitting universe exists at all. To see this, note that it might be the case that the laws of nature, along with the particular values for the constants of physics, are part of the essence of our universe, and hence necessarily our particular universe must have constants with these values. Any universe in a possible world with different values for the fundamental constants would not be identical to our universe. Given this assumption, there would be no mystery as to why *our* universe has life-permitting values. Nonetheless, it would still need to be explained why a universe exists with life-permitting values, when it seems that the vast majority "of nearby" possible universes whose constants fall within the total comparison range R — such as the total range of strengths of the forces of nature in the case of the gravitational constant—would not have life-permitting values.

Likewise, neither the design nor many-universes hypothesis is supposed to explain why *we observe* our universe to have life-permitting values for the constants. This fact is explained by the weak anthropic principle: it would be impossible for an embodied observer to exist in a universe without life-permitting values for its constants, and hence of necessity all embodied observers, including ourselves, must observe their universe to have life-permitting values for the constants. In sum, all the many-universes hypothesis is supposed to explain, or render unsurprising, is why there exists a universe with life-permitting values for its constants.

There are two major versions of the many-universe hypothesis, what could be called the *physical* or "*universe-generator*" versions and what could be called *metaphysical* versions. In the physical or universe-generator versions, some particular real physical process is postulated that generates the many universes, whereas in the metaphysical versions the universes are thought to exist on their own without being generated by any physical process. We will first focus on the physical versions.

Although a variety of physical many-universe hypotheses have also been offered, since the early 1980's, what could be called the *inflationary many-universe hypothesis* has steadily gained popularity. This many-universes hypothesis is based in so-called *inflationary cosmology*, which is the cosmological theory first proposed independently by Alan Guth and Andrie Linde in the late 1970's to explain the big bang and various features of the universe, such as the large-scale uniformity of matter in space.

Despite the variety of many-universe scenarios that have been proposed, both metaphysical and physical, the inflationary scenario is the only one that goes beyond mere speculation. The reason is twofold. First, unlike the other scenarios, inflationary cosmology has significant scientific evidence in its favor, being widely regarded as the most viable theory of the origin of the universe available today. Second, a many-universe scenario naturally arises out of what are widely considered the most plausible models of inflationary cosmology, the so-called chaotic inflation models. So, although speculative, an inflationary many-universe hypothesis deserves to be taken particularly seriously.[2] Thus, because it is widely considered to be by far the most physically plausible scenario, we will focus on the inflationary many-universe scenario here as our example of a many-universe generator hypothesis.

## *II. InflationaryMany-Universes Generator*

Inflationary cosmology is a currently widely discussed cosmological theory that attempts to explain the origin of the universe. Essentially, it claims that our universe was formed by a small area of pre-space being massively blown up by an hypothesized *inflaton* field, in much the same way as a soap bubble would form in an ocean full of soap. In chaotic inflation models — widely considered the most plausible — various points of the pre-space are randomly blown up, forming innumerable bubble universes. Further, because of the inflaton field, the pre-space expands so rapidly that it becomes a never ending source of bubble universes, much as a rapidly expanding ocean full of soap would become a never ending source of soap bubbles. Thus, inflationary cosmology can naturally give rise to many universes.[3]

In order to get the initial conditions and constants of physics to vary from universe to universe, as they must do if this scenario is going to explain the fine-tuning, there must be a further physical "mechanism" to allow for the variation. Such a mechanism *might* be given by superstring theory (or its successor, M-theory), but it is too early to tell. Superstring theory is currently one of the most hotly discussed hypotheses about the fundamental structure of the physical universe (Greene, 1999, p. 214). According to superstring theory, the ultimate constituents of matter are strings of energy that undergo quantum vibrations in a 10 (or 11) dimensional space-time, six or seven dimensions of which are "compactified" to extremely small sizes and are hence unobservable. The shape of the compactified dimensions, however, determines the modes of vibration of the strings, and hence the types and masses of fundamental particles, along with many characteristics of the forces between them. Thus, universes in which compactified dimensions have different shapes will have different constants of physics and differing lower-level laws governing the forces. It is presently controversial whether superstring theory allows for significant variation in the shape of the compactified dimensions. If it does, however, it is then possible that an inflationary/superstring scenario could be constructed in which the shape of the compactified dimensions, and hence the constants of physics, underwent enough variation from universe to universe to explain the fine-tuning.4

Thus, it is in the realm of real physical plausibility that a viable inflationary/superstring many-universes scenario could be constructed that would account for the fine-tuning of the constants of physics. Nonetheless, it should be noted that despite the current popularity of both inflationary cosmology and superstring theory, both are highly speculative. For instance, as Michio Kaku states in his recent textbook on superstring theory, "Not a shred of experimental evidence has been found to confirm . . . superstrings" (1999, p. 17). The major attraction of string theory is its mathematical elegance and the fact that many physicists think that it is the only game in town that offers significant hope of providing a truly unified physical theory of gravitation with quantum mechanics, the two cornerstones of modern physics (Greene, 1999, p. 214).

It should be stressed, however, that even if superstring theory or inflationary cosmology turn out to be false, they have opened the door to taking the many-universes explanation of the fine-tuning as a serious physical possibility since some other physical mechanisms could give rise to multiple universes with a sufficiently large number of variations in the constants of physics. The only way we could close this door is if we discovered that the ultimate laws of physics did not allow either many-universes or much variation in the constants and laws of physics among universes.

*A Theistic Response toMany-Universe Generator Scenario*

One major possible theistic response to the many-universe generator scenario, whether of the inflationary variety or some other type, is that the "many-universes generator" itself seems to need to be "well-designed" in order to produce life-sustaining universes. After all, even a mundane item like a bread machine, which only produces loaves of bread instead of universes, must be well designed as an appliance and must have the right ingredients (flour, water, yeast, and gluten) to produce decent loaves of bread. If this is right, then invoking some sort of many-universe generator as an explanation of the fine-tuning only kicks the issue of design up one level, to the question of who designed the many-universe generator.

The inflationary scenario discussed above is a good test case of this line of reasoning. The inflationary/superstring many-universe generator can only produce life-sustaining universes because it has the following "components" or "mechanisms:"

1) *A mechanism to supply the energy needed for the bubble universes:* This mechanism is the hypothesized inflaton field. By imparting a constant energy density to empty space, as space expands the inflaton field can act "as a reservoir of unlimited energy" for the bubbles (Peacock, 1999, p. 26).

2) *A mechanism to form the bubbles*: This mechanism is Einstein's equation of general relativity. Because of its peculiar form, Einstein's equation dictates that space expand at an enormous rate in the presence of a field, such as the inflaton field, that imparts a constant (and homogenous) energy density to empty space. This causes both the bubble universes to form and the rapid expansion of the pre-space (the "ocean") which keeps the bubbles from colliding.

3) *A mechanism to convert the energy of inflaton field to the normal mass/energy we find in our universe.* This mechanism is Einstein's relation of the equivalence of mass and energy combined with an hypothesized coupling between the inflaton field and normal mass/energy fields we find in our universe.

4) *A mechanism that allows enough variation in constants of physics among universes:* Currently, the most physically viable candidate for this mechanism is superstring theory. As explained above, superstring theory *might* allow enough variation in the variations in the constants of physics among bubble universes to make it reasonably likely that a fine-tuned universe would be produced.[5]

Without all these "components," the many-universe generator would almost certainly fail to produce a single life-sustaining universe. For example, Einstein's equation and the inflaton field harmoniously work together to enormously inflate small regions of space while at the same time both imparting to them the positive energy density necessary for a universe with significant mass-energy and causing the pre-space to expand rapidly enough to keep the bubble universes from colliding. Without either factor, there would neither be regions of space that inflate nor would those regions have the mass energy necessary for a universe to exist. If, for example, the universe obeyed Newton's theory of gravity instead of Einstein's, the vacuum energy of the inflaton field would at best simply create a gravitational attraction causing space to contract, not to expand.

In addition to the four factors listed above, the inflationary/superstring many-universe generator could only produce universes in which highly complex intelligent life could evolve because the right background laws are in place. Specifically, the background laws must be such as to allow the conversion of the mass-energy into material forms that allow for the sort of stable complexity needed for complex intelligent life. For example, without the principle of quantization, all electrons would be sucked into the atomic nuclei and hence atoms would be impossible; without the Pauli-exclusion principle, electrons would occupy the lowest atomic orbit and hence complex and varied atoms would be impossible; without a universally attractive force between all masses, such as gravity, matter would not be able to form sufficiently large material bodies (such as planets) for life to develop or for long-lived stable energy sources such as stars to exist.[6]

In sum, even if an inflationary/superstring many-universe generator exists, it must have just the right combination of laws and fields for the production of life-permitting universes: if one of the components were missing or different, such as Einstein's equation or the Pauli-exclusion principle, it is unlikely that any life-permitting universes could be produced. In the absence of alternative explanations, the existence of such a system counts as evidence for design since it seems very surprising that such a system would exist with just the right components under the hypothesis that the universe exists as a brute fact without any explanation, but not surprising under the theistic hypothesis.[7] Thus, it does not seem that one can completely escape the evidence of design merely by hypothesizing some sort of many-universe generator.

It must be admitted, however, that if such a many-universe generator could be verified, the sort of *quantitative* evidence for design based on the fine-tuning of the constants would be eliminated. Whereas the degree of fine-tuning of the constants could be assigned a number — such as one part in $10^{31}$ as we did above in the case of the gravitational constant — we cannot provide a quantitative estimate for the degree of apparent design in the cases mentioned above. All we can say is that if certain seemingly highly specific sorts of laws were not in place, no life sustaining universes could be generated. Thus, the case for design would perhaps be mitigated, although not completely eliminated.

Finally, I should note that I am not in principle opposed to the many universe generator scenario, just the atheistic version of it. Indeed, the fact that so many factors in contemporary cosmology and particle physics conspire together to make the above many-universe scenario viable significantly tempts one to seriously consider a theistic version of it. This temptation is strengthened by the fact that science has progressively shown that the visible universe is vastly larger than we once thought, with a current estimate of some 300 billion galaxies with 300 billion stars per galaxy. Thus, it makes sense that this trend will continue and physical reality will be found to be much larger than a single universe. Finally, since God is infinite and infinitely creative, it also makes sense that creation would reflect these attributes of God, and hence that physical reality might be much larger than one universe. One only has to think of the first chapter of the Apostle Paul's letter Romans in which Paul states that creation reflects the power and eternality of God.

### *III.Metaphysical Many-Universes Hypotheses*

As mentioned above, some have proposed what could be called a *metaphysical* many-universe hypothesis, according to which many universes are thought to exist without being generated by any physical process. Typically, advocates of this view — such as the late Princeton University philosopher David Lewis (1986) and University of Pennsylvania astrophysicist Max Tegmark (1998, 2003) — claim that every possible world exists. According to Lewis (1986), every possible world actually exists parallel to our own. Thus, for instance, there exists a reality parallel to our own in which objects can travel faster than the speed of light. Dream up a possible scenario, and it exists in some parallel reality, according to Lewis. On the other hand, according to Tegmark's hypothesis, "everything that exists mathematically exists physically," (1998, p. 1) by which he means that every self-consistent mathematical structure is in one to one correspondence with some physical reality (1998, 1,3). Tegmark calls this hypothesis the "ultimate ensemble hypothesis," and claims it explains why there exists a universe such as ours in which the laws of nature and the parameters of physics are life-permitting.

Both of these metaphysical many-universes hypotheses run into at least two disadvantages compared to the theistic hypothesis. The first major disadvantage is what I will call the *natural extrapolation problem*, which arises from the following general rule: *everything else being equal, we should prefer hypotheses for which we have independent evidence or which involve natural* *extrapolations from the (verified) causal powers of known entities.* Let's first illustrate and support this principle, and then apply it to the case of the fine-tuning.

Most of us take the existence of certain big, fossilized bones to count as very strong evidence that dinosaurs existed in the past. But suppose a dinosaur skeptic claimed that she could explain the bones by postulating a "dinosaur-bone-producing-field" that simply materialized the bones out of thin air. Moreover, suppose further that, to avoid objections such as that there are no known physical laws that would allow for such a mechanism, the dinosaur skeptic simply postulated that we have not yet discovered these laws or detected these fields. Surely, none of us would let this skeptical hypothesis deter us from inferring to the existence of dinosaurs. Why? Because although no one has directly observed dinosaurs, we do have experience of other animals leaving behind fossilized remains, and thus the dinosaur explanation is a *natural extrapolation* from our common experience. In contrast, to explain the dinosaur bones, the dinosaur skeptic has invented a set of physical laws, and a set of mechanisms, that are *not* a natural extrapolation from the causal powers of anything we know or experience.

In the case of the fine-tuning, we already know that minds often produce fine-tuned devices, such as Swiss watches. Postulating God — a "supermind"—as the explanation of the fine-tuning, therefore, is a natural extrapolation from of what we already observe minds to do. In contrast, it is difficult to see how the metaphysical many-universes hypothesis could be considered a natural extrapolation either from what we observe or from the entities postulated by our well-established scientific theories. Moreover, unlike the metaphysical many-universes hypothesis, we have some experiential evidence for the existence of God, namely religious experience. Thus, by the above principle, we should prefer the theistic explanation of the fine-tuning over the metaphysical many-universes explanation, everything else being equal.8

To be fair to Lewis, he does not hypothesize the existence of these many-universes to explain the fine-tuning, but as part of his overall metaphysical project of providing a theory of what philosophers call possible worlds. Along with most other philosophers, I think that his view is not even close to being an adequate account of possible worlds. The above objection, however, is not against Lewis's or Tegmark's views in and of themselves; it only purports to show that unless there is some sort of independent motivation for their views, we should prefer the theistic explanation of the fine-tuning over that given by Lewis's or Tegmark's metaphysical many-universes hypothesis.

Second, these metaphysical hypotheses have a difficult time explaining the stability, uniformity, and predictability of nature. To see this, consider those possible universes like ours in whichmass-energy is the fundamental physical substance. The set of such universes will consist of every possible four-dimensional configuration of mass-energy. Now, for any given universe, some set of mathematical equations or rules will describe its distribution of mass-energy, and thus the distribution of mass-energy in that universe can be put in one to one correspondence with some mathematical structure. Thus, every one of these universes is real both under Lewis's hypothesis and under Tegmark's hypothesis.

Now, it seems, the vast majority of such universes will have a highly chaotic configuration of mass-energy compared to our universe. If this is right, then a universe like ours, with a configuration of mass-energy that is describable by simple, fundamental laws is bound to be rare. Of course, only universes with sufficient regularity and predictability could support intelligent life. Thus, if we consider ourselves to be generic observers, we should expect to find ourselves in a universe with a high degree of *local* order. But, it seems, a generic observer should not expect to find itself in a universe that is orderly throughout, since it seems there would be a much larger proportion of universes with merely local islands of order than of universes with a highly ordered arrangement of mass-energy throughout. To see this, consider an analogy of a very large scrabble-board. If one were to shake the scrabble board at random, it would be much more likely to get an ordered, meaningful arrangement of letters in one small region, with the arrangement on the rest of the board essentially chaotic, then for all the letters on the entire board to form meaningful patterns. Or, as another analogy, consider a thousand coins lined up in a row, which are then shaken at random. Define a local island of order to be any consecutive sequence of five coins which all are on the same side — that is, either all heads or all tails. It is much more likely for the sequence of a thousand coin tosses to contain one or more subsequences of five consecutive heads or tails than for it to be all heads or all tails. Indeed, it is likely that such a sequence of coins will have at least one such island of five consecutive heads or tails; the probability of the coins coming up all heads or all tails, however, is around one in $10^{40}$, or one in ten thousand, billion, billion, billion, billion.

Thus it seems, under both Lewis's and Tegmark's hypothesis, we should expect to find ourselves, *qua* generic observers, in a universe with a very small island of order and regularity surrounded by a vast sea of chaos. Further, even within that island, we would not expect the arrangement of mass-energy to be describable by a set of simple, underlying laws, since it is only the degree of order and regularity of the world of everyday objects that is relevant to the formation of intelligent life. Yet as we know from quantum mechanics and general relativity, the underlying laws of nature are highly simple and elegant. Accordingly, not only do Lewis's and Tegmark's hypothesis fail to explain the uniformity of nature, they seem to predict just the opposite—at least for other parts of the universe.[9]

The problem here is very similar to that faced by Ludwig Boltzmann, who attempted to explain the relatively low entropy of the universe—that is, the relatively high degree of spatial order of mass-energy — by claiming that it was the result a fluctuation from the normal "chaotic," equilibrium state, and that a fluctuation with a high degree of order was necessary for intelligent life. As theoretical physicist Paul Davies and many others have pointed out in responding to Boltzmann's view, a fluctuation "the size of the solar system would be sufficient to ensure the existence of life on Earth, and such a fluctuation is *far* more probable than one of cosmic proportions" (Davies, 1974, p. 103.).

One might worry here that I have not considered the laws of nature, which might be claimed to add some degree of order. The answer to this worry is that the laws of nature for any given universe could be thought of as simply the mathematical rules and equations (or the simplest set of such rules) that describe the temporal development of the arrangement of matter and energy in that universe. Thus, since even the "chaotic" worlds will have some set of mathematical equations or rules that describe their development, even if they are highly complex, they will "obey" some set of laws. Further, every possible consistent set of laws will be represented by some subset of these universes. The set of universes in Lewis's and Tegmark's hypothesis, therefore, could be thought of as equivalent to the set of all possible universes with mass-energy as the fundamental substance and which have some law-like structure.

Before ending, I would like to sketch a final criticism that applies to both types of many-universes hypotheses discussed above: namely, I would argue that neither type of many-universes hypothesis can explain the apparent elegance and beauty of the laws of nature. Many physicists, such as Albert Einstein, have observed that the basic laws of physics exhibit an extraordinary degree of beauty, elegance, harmony, and ingenuity. Nobel Prize winning physicist Steven Weinberg, for instance, devotes a whole chapter of his book *Dreams of a Final Theory* (Chapter 6, "Beautiful Theories") explaining how the criteria of beauty and elegance are commonly used to guide physicists in formulating the right laws. Indeed, one of most prominent theoretical physicists of this century, Paul Dirac, went so far as to claim that "it is more important to have beauty in one's equations than to have them fit experiment." (1963, p. 47).

Now such beauty, elegance, and ingenuity make sense if the universe was designed by God. Under the atheistic version of the many-universes hypothesis, however, there is no reason to expect the fundamental laws to be elegant or beautiful. Now, one could always claim that the beauty of the laws of nature is simply a brute fact that requires no explanation. Given that theism naturally explains these features of the laws of nature, however, the atheist must admit that theism offers a better explanation of them than atheism, and thus that they support theism over atheism. Why? Because a natural, non-ad hoc explanation of a phenomenon *x* is always better than no explanation at all. And theism does seem to offer such a natural explanation: for example, given the Anselmian conception of God as the greatest possible being, and hence a being with a perfect aesthetic sensibility, it is not surprising that such a God would create a world of great subtlety and beauty at a fundamental level.[10]

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NOTES

1. For a careful presentation of six solid cases of fine-tuning, along with a critique of some prominent purported cases of fine-tuning, see Collins, 2003. For a presentation of the fine-tuning argument for design, see Collins, 2002a and Leslie,1989.

2. For a critique of inflationary cosmology, see John Earman and Jesus Mosterin, 1999. For an accessible introduction to inflationary cosmology, see Alan Guth, 1997. For recent experimental confirmation of inflationary cosmology, see "Cosmology from Maxima_1, Boomerang and COBE/DMR CMB Observations," July 2000, at the astrophysics website, http://arXiv.org/abs/astro_ph/0007333.

3. For a good, accessible overview of inflationary cosmology, see Guth, 1997.

4. I am indebted to Gerald Cleaver, a string theorist at Baylor University, for helpful discussions of this issue. The sort of inflationary/superstring many-universe explanations of the fine-tuning discussed above have been suggested by a number of authors, such as Linde, (1990, PP&IC, p. 306; 1990, IQC, p.

6) and Greene (1999, pp. 355 - 363). To date, however, no one has adequately verified or worked-out the physics of superstring theory or inflationary cosmology, let alone the combination of the two, so this scenario remains highly speculative.

5. The other leading alternatives to string theory being explored by physicists, such as the currently proposed models for Grand Unified Theories (GUTS), do not appear to allow for enough variation. The simplest and most studied GUT, SU(5), allows for three differing sets of values for the fundamental constants of physics when the other non-SU(5) Higgs fields are neglected (Linde, PP&IC, p. 33). Including all the other Higgs fields, the number of variations increases to perhaps several dozen (Linde, IQC, p. 6). Merely to account for the fine-tuning of the cosmological constant, however, which is estimated to be fine-tuned to one part in $10^{53}$, would require on the order of $10^{53}$ variations of the physical constants among universes.

6. Although some of the lower-level laws of physics can vary from universe to universe in string theory, these background laws and principles are a result of the structure of string theory and therefore cannot be explained by the inflationary/superstring many-universes hypothesis since they must occur in all universes. Further, since the variation among universes would consist of variation of the masses and types of particles, and the form of the forces between them, complex structures would almost certainly be atomlike and stable energy sources would almost certainly require aggregates of matter. Thus, the above background laws seem necessary for there to be highly complex life in any of the many universes generated in this scenario, not merely a universe with our specific types of particles and forces.

7. The rule of inference used here is what could be called the *surprise principle*. Let $H^1$ and $H^2$ be two competing non-ad-hoc hypotheses, which can be roughly be thought of as hypotheses that were not constructed merely to account for the data E in question. According to the surprise principle, if a body of data E is less surprising under one of the hypotheses $H^1$ than under the other, $H^2$, then the data E provides evidence in favor of $H^1$ over $H^2$. The best way, I believe, of explicating what the notion of surprise is here is in terms of what philosophers call *conditional epistemic probability*, in which case the above principle would reduce to what is often called the *likelihood principle* or the *principle of relevance*, which is a standard principle of probabilistic confirmation theory. That is, E provides evidence for $H^1$ over $H^2$ if the conditional epistemic probability of E is greater under $H^1$ than $H^2$, given that the epistemic probability of $H^1$ is not already zero.

8. Advocates of the metaphysical many-universes hypothesis often claim that one of its virtues is that it is an extremely simple hypothesis. Since theists claim the same thing about the theistic hypothesis, however, it is initially unclear whether the criterion of simplicity provides a reason to prefer this hypothesis over the theistic hypothesis, or vice versa.

9. Lewis responds to this sort of objection by first noting that since both the class of largely chaotic possible worlds and highly ordered possible worlds have the same cardinality, the worlds that are largely chaotic can be put into one to one correspondence with the worlds that are highly ordered. Hence, one cannot say that the largely chaotic worlds outnumber the ordered worlds; at best, one could argue that there exists some natural measure over the space of possible worlds such that highly ordered worlds turn out to be rare. Lewis then claims that there is no objective way of placing such a measure of proportion over possible worlds. (See 1986, pp. 115-123). Although I cannot provide a detailed response to Lewis's suggestion here, I would claim that the above argument does not require that there exists an objective, natural metaphysical measure over possible worlds. Rather, since the sort of probability we are dealing with here is epistemic probability, all we require is a natural, epistemic measure: that is, a measure induced by the way our epistemic faculties represent the world. Then I would go on to argue that our epistemic faculties do represent the highly ordered worlds as being extremely rare, indeed infinitely rare, though I do not have space to present this argument here. The situation here is analogous to the case of tossing a six sided die: we can meaningfully speak of the epistemic probability of the die landing on four as being one in six even though (i) the members of the class of possible worlds in which the die lands on six can be put into one to one correspondence with the members of the class of possible worlds in which the die does not land on six, and (ii) there is no natural metaphysical measure over possible worlds such that the class of worlds in which the die does not land on four has six times the measure as the class in

which the die does land on four. The reason we can speak of the epistemic probability being one in six in this case is that the symmetry of the die induces an epistemic measure over these classes of worlds.

10. This argument from the beauty and elegance of the laws of nature is presented in more detail in Collins, 2002b.