Cosmology and Biology

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Abstract

Even as astrobiologists search for life in the universe, scientists and philosophers alike are pondering the possibility of a deep and profound relationship between cosmology and biology. The universe appears in its very essence to be biocentric, in that the laws of nature and the physical constants are finely tuned for life, giving rise to what has been termed the "anthropic principle." This in turn has given rise to the idea of an ensemble of universes, or multiverse, as an explanation for why we happen to be in a universe particularly suited for life. Exactly 20 years ago, in his book *Infinite in All Directions*, physicist Freeman Dyson speculated that the prospects are bright for a future-oriented science, joining together in a disciplined fashion the resources of biology and cosmology. Fine tuning and the multiverse are two concepts that may prove central to this task. In such a "cosmic ecology", life and intelligence would play a central role in the evolution of the universe, no less than its physical laws.

I. The Mysterious Universe: A Cosmological Enigma

Twelve years ago in my book *The Biological Universe* I proposed that, just as 400 years ago the geocentric and heliocentric world systems hung in the balance, in the late 20th century the two reigning chief world views were the physical universe and the biological universe. This remains true today. I pointed out that these were two possible outcomes for cosmic evolution: that its ultimate endpoint consists primarily of matter such as planets, stars and galaxies (the physical universe), or its ultimate outcome is life, mind and intelligence (the biological universe). I framed the biological universe as an emerging cosmology, which I called the "biophysical cosmology," similar to Barney Oliver's "biocosmology," a term he had used in his influential report Project Cyclops (1971).[1]

The physical and biological universe are obviously connected in the sense that one cannot have biology before one has the physical substrate. But it now turns out that scientists and philosophers alike are increasingly aware of mysterious and deep connections between the physical universe of planets, stars and galaxies, and the biological universe of life, mind and intelligence. When the British astronomer James Jeans 80 years ago wrote his book *The Mysterious Universe*, he was referring to the fact that the universe embodies mathematical laws, and that the human mind could comprehend this mathematical structure, a point later elaborated by Albert Einstein, Eugene Wigner and others.[2] The more we learn about the universe, the more we find that it is even more mysterious than we thought – that not only is the universe subject to mathematical laws, but also it is finely tuned for life. Or, to put it another way, the universe is "biofriendly," as witnessed by our existence, and the possible existence of other life beyond Earth – the

subject of astrobiology and SETI. As Winston Churchill said in another context, this situation "is a riddle, wrapped in a mystery, inside an enigma." "But perhaps," he added, "there is a key."[3] Churchill was talking about Russia's non-aggression pact with Germany, and the key was Russian national interest. Our key will be more difficult to discover, but the stakes are much greater, nothing less than the nature of the cosmos and its intimate relation to life. As cosmologists John Barrow and Frank Tipler wrote in their landmark volume *The Anthropic Cosmological Principle* (1986), "The realization that the possibility of biological evolution is strongly dependent upon the global structure of the Universe is truly surprising and perhaps provokes us to consider that the existence of life may be no more, but no less, remarkable than the existence of the Universe itself."[4]

Already at the turn of the 20th century there was some realization of the strange connections between the nature of the universe and the existence of life. In the last chapter of his volume *Man's Place in the Universe, A. R.* Wallace – the co-founder with Darwin of the theory of natural selection – wrote in 1903:

> … I submit that the whole of the evidence I have here brought together leads to the conclusion that our earth is almost certainly the only inhabited planet in our solar system; and, further, that there is no inconceivability--no improbability even--in the conception that, in order to produce a world that should be precisely adapted in every detail for the orderly development of organic life culminating in man, such a vast and complex universe as that which we know exists around us, may have been absolutely required.[5]

Because he believed no life existed outside the solar system either, Wallace thus intimated that the universe was made for life on Earth, an anthropocentric and true "anthropic" principle (as we would now call it) in that it centered on humans: "the supreme end and purpose of this vast universe was the production and development of the living soul in the perishable body of man."[6] Based on what was known at the turn of the 20th century, there was some justification for this anthropocentric world view – the solar system was still considered to be at or near the center of the observed universe.

The idea of a connection between the universe and life was also anticipated by Wallace's American contemporary, the Harvard biochemist Lawrence J. Henderson, who marveled at the fitness of the terrestrial environment for life, especially because of the properties of water. In the final paragraph to his book *The Fitness of the Environment*, Henderson extended his argument to the universe at large:

> The properties of matter and the course of cosmic evolution are now seen to be intimately related to the structure of the living being and to its activities; they become, therefore far more important in biology than previously suspected. For the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric.[7]

In Henderson's formulation, the "biocentric principle" is a better term for the fitness of the universe for life, since it does not imply that terrestrial life forms, including humans,

could be the only form of life. The universe was fine-tuned for life, including beings of higher consciousness, not only for humans, even if the only intelligent life in the universe we yet know is human. Others have gone even further and suggested that what is really indicated is a "Complexity Principle," that the universe is fine-tuned for complexity, not just biology.[8]

Unfortunately, when these questions were once again pondered six decades later, the term "anthropic principle" was coined, almost by accident. This occurred in a path breaking article on the subject by the British astronomer Brandon Carter, who first formulated what he called the weak anthropic principle: "what we can expect to observe must be restricted by the conditions necessary for our presence as observers."[9] Thus the gravitational constant is constrained by the fact that we exist, otherwise the conditions for life could never have arisen. Carter went on to expound a "strong anthropic principle," namely, "that the universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage," a much more problematic claim. Although such reasoning turned the deductive method on its head, Carter argued that it might be considered a kind of explanation for why our universe is the way it is. He later admitted that "anthropic" was an unfortunately limiting term.

Five years after Carter's paper, Bernard Carr and Martin Rees wrote a paper bringing together all the known constraints on the physical characteristics of the universe that seemed necessary for the emergence of life.[10] Over the last several decades the British Astronomer Sir Martin Rees, physicist and astrobiologist Paul Davies and many others have explored the ramifications of this possibly deep and profound relationship between biology and cosmology.[11] In his book *Just Six Numbers* Rees crystallized the mystery as encapsulated in the following six numbers:[12]

1) N, a ratio equal to ten to the 36^{th} power (1 with 36 zeros), the strength of electrical forces that hold atoms together divided by the force of gravity between them. "If N had a few less zeroes, only a short-lived miniature universe could exist: no creatures could grow larger than insects, and there would be no time for biological evolution."

2) Epsilon, .007, defining the binding power of holding nuclei together, controlling the transmutation of hydrogen into the other elements of the periodic table. If Epsilon were .006 or .008, Rees points out, we could not exist because the proper elements would not exist.

3) Omega, the amount of material in our universe, including dark matter, a measure of gravity vs expansion energy. If the universe expanded too slowly, no galaxies or stars would have formed; too fast and the universe would have collapsed long ago. "The initial expansion speed seems to have been finely tuned," Rees comments.

4) Lambda, a cosmic antigravity that controls the expansion rate of the universe. Its small value allowed cosmic evolution to take place.

5) Q, the ratio of two fundamental energies, which accounts for the seeds of all cosmic structures imprinted in the Big Bang, with a value of about 1/100,000.

6) D, the number of spatial dimensions in the world, equal to 3. Life could not exist if D were 2 or 4, Rees comments.

In addition to these numbers, there are fundamental constants at another level that are crucial to life, sometimes related to the numbers above, such as the Newtonian gravitational constant (G), Planck's constant (h), the charge of the electron and the mass of the proton.[13] So the bottom line is, we live in a "Goldilocks universe," where conditions for life are not too bad and not too good, but just right!

There are a number of ways to explain why the universe is so biofriendly:

1. It's just a coincidence. For some this is enough, but for most people who have thought deeply about the problem, it's too good to be true and requires an explanation.
2. A supernatural intelligence fine-tuned the universe. This is better known as the God hypothesis
3. A highly evolved natural intelligence fine-tuned the universe. This possibility has received some attention, but not a great deal.
4. A "multiverse" exists, an ensemble of universes, and we happen to live in a universe that is suitable for life. Such a multiverse could exist sequentially or simultaneously.

In the remainder of this paper, I will review these last three options, and in the process analyze the arguments and offer my own thoughts on the connections between the physical universe and the biological universe.

II. Supernatural Intelligence: The God Hypothesis

The God Hypothesis as related to our subject has a long history in the form of the design argument, the history of which has been written many times, including chapter 2 of Barrow and Tipler's book *The Anthropic Cosmological Principle* (1986). In my first book on the extraterrestrial life debate, *Plurality of Worlds*, I showed how already in the late 17th and early 18th centuries Newtonians intimately wedded the idea of an abundance of life beyond Earth to the munificence of an omnipotent God; this was one form of the widespread argument and ideology known as "natural theology."[14] The Englishman William Derham even wrote a well known treatise *Astro-Theology: or, a Demonstration of the Being and Attributes of God, from a Survey of the Heavens* (1715), in which he utilized every variety of argument, from the magnitude of the universe to the size, shape and motion of its bodies, as evidence of the Deity. Though yet undiscovered, he favored the idea of inhabited planets and numerous solar systems as completely in line with this natural theology view of the world.[15] From William Paley's famous "watchmaker" argument in the late 18th century to John Polkinghorne in the 20th century, this argument has been made again and again. Most recently Robert Collins has given it a more nuanced view.[16] The design argument is not one that most scientists embrace, and the "God of the gaps" argument is not even one that most theologians today embrace, history demonstrating that most "gaps" are filled in as science progress. It is, however, the core

of the Intelligent Design movement that has made some headway in the United States by invoking the idea of "irreducible complexity," even if its proponents are often vague about the nature of the designing intelligence, not always pronouncing it as the canonical "God."[17]

While the God Hypothesis would be interesting if true, it remains by definition unprovable, since it is supernatural and thus outside the realm of science (which to its proponents is precisely the point). For those who seek a scientifically verifiable explanation based on the natural world, it is unsatisfactory.

III. Natural Intelligence

Returning from the supernatural to the realm of science, how about the idea of a "natural intelligence" as a designer? As Paul Davies has pointed out, this idea could be traced back as far as Plato, whose Demiurge had to work within the laws of nature to create the universe.[18] Olaf Stapledon's Star Maker, in his famous science fiction novel by that name from the 1930s, would presumably also be in this tradition.[19] More recently the idea has been developed in the context of the extraterrestrial life debate. After all, most SETI proponents consider advanced extraterrestrial intelligence to be very old and wise; why not have the ultimate superintelligence, a product of natural selection, create the universe? This is exactly what the British astronomer Fred Hoyle proposed in his book *The Intelligent Universe* in 1983. Here Hoyle, a self-proclaimed atheist, concluded that the simplest explanation for the biofriendly universe was that a natural (not supernatural) superintellect had engineered the universe to make it fit for carbon-based life and intelligence. Edward Harrison proposed a similar scenario in 1995, as did I in one of the Templeton conferences in 1998.[20] More recently James Gardner has elaborated this theme in a book with the same title as Hoyle's, following up on his book *Biocosm*. His "selfish Biocosm Hypothesis" is that life and intelligence are the primary cosmic phenomena, and that "the capacity of the universe to generate life and to evolve ever more capable intelligence is encoded as a hidden subtext to the basic laws and constants of nature," and the biofriendly laws of nature are equivalent to DNA in living creatures, "providing a recipe for development of a living universe and a blueprint for the construction of offspring (baby universes).[21]

Such thoughts raise the question of the nature of such a super-intelligence, a question necessarily speculative but that can be discussed based on what little we know about cultural evolution on Earth. In the context of SETI strategies, I have proposed by a series of arguments that extraterrestrial intelligence may be postbiological, so the superintelligence may be some form of artificial intelligence.[22] There are other possibilities, but in any case, in a universe 13.7 billion years old in which we treat astronomical and biological evolution as a known fact, we must take equally seriously cultural evolution. As we see on Earth, cultural evolution completely dominates other forms of evolution in terms of its rapidity. If extraterrestrial intelligence has been around for millions or billions of years, it too will have undergone cultural evolution, the ultimate form of which is the improvement of its own intelligence. A highly evolved

natural intelligence is unlikely to be biological, least of all humanoid. As a natural intelligence, this explanation for the fine-tuning of the universe holds out the possibility of being proved at least in principle; as such it is very different from the God Hypothesis and the Intelligent Design movement.

IV. The Multiverse

In contrast to the God Hypothesis and the Natural Intelligence explanations for the intimate relation between cosmology and biology, there is one explanation where the parameters are not "chosen" by a Designer, whether natural or supernatural. This is the so-called multiverse idea, "the possibility that there could be other universes (either connected or disconnected from ours) in which the constants of physics (and perhaps even the laws of nature) are different."[23] The general idea of an ensemble of universes has been around for a long time, going back to the ancient Greek atomists, who believed in an infinite number of *kosmoi,* ordered worlds separated in space, some larger or smaller, some with life or devoid of life, and so on.[24] The idea is also notable in the Leibnitzian discussion of the best of all possible worlds, and the more physically-grounded many worlds interpretation of quantum mechanics.[25] John Barrow cites the Cambridge biologist Charles Pantin as the first to articulate the many worlds approach in the modern sense. In 1965 Pantin wrote "… the properties of the material Universe are uniquely suitable for the evolution of living creatures … If we could know that our own Universe was only one of an indefinite number with varying properties we could perhaps invoke a solution analogous to the principle of Natural Selection, that only in certain Universes, which happen to include ours, are the conditions suitable for the existence of life, and unless that condition is fulfilled there will be no observers to note the fact."[26] This is not the only example of how biology can lend fruitful concepts to astronomy.

The origin of the term "multiverse" is more recent, not becoming widespread until the 1990s. The word is not found in Paul Davies' early book on the subject, *The Accidental Universe* (1982), for example, where he spoke of "the many universes theory," nor in the 1986 Barrow and Tipler volume. The first use of the term I have seen is in the work of the Canadian philosopher John Leslie, whose 1989 book *Universes* begins its first chapter with the question "God or multiverse?" Leslie points out that he borrowed the term from, of all places, *The Education of Henry Adams*, published in 1918, where Adams used the term in quite a different context.[27] But the term 'multiverse' came into its own in the late 1990s after British Astronomer Royal Martin Rees championed the idea of multiple universes, and used the term in his books beginning as early as 1997. With the recent publication of a definitive set of papers edited by Bernard Carr and titled *Universe or Multiverse?* the term is assured a long existence, though the term "parallel universes" is also used.[28]

Logically speaking, a multiverse could be a large number of actually existing universes, or could refer to the philosophical problem of all possible worlds/universes, either actually existing or not all existing. The late Princeton philosopher David Lewis made a career of elucidating the philosophical problem of all possible worlds, and arguing that all

possible worlds do exist in actuality. His book *On the Plurality of Worlds* (1986), although titled very similarly to my first book and published only four years after it, is very different in the sense that while it argues that all possible universes are real, it says very little about the only universe we know for sure is real – our own.[29] Nevertheless, it stands as a monument to rigorous philosophical thinking, is widely known and cited in philosophical circles, and is in fact relevant to the multiverse idea from a foundational point of view.

But why raise such a seemingly non-empirical idea as the multiverse in the first place? From the point of view of science there are several reasons to think many universes might exist, though none of these rise to the level of firm evidence.[30]

1) Current cosmology indicates that the universe is infinite, and that universes may exist beyond our observable cosmic horizon, though it is open to question whether one should really classify these as different universes.[31]

2) Physicist Lee Smolin has argued in his book *The Life of the Cosmos*, the formation of black holes may spawn baby universes with different fundamental constants.[32] He even proposes a kind of cosmological natural selection, in which after many generations the production of black holes is maximized by selecting certain values of constants. In this view the fundamental constants provide the "variation" on which selection acts, just as variation of physical traits are the essence of Darwinian biological evolution. Even Smolin himself, however, has argued recently that this idea is neither falsifiable nor testable, though not everyone agrees.[33]

3) Some models of the inflationary theory of the Big Bang, a leading theory of the origin of our universe initiated by Alan Guth, indicate that inflationary processes happen more than once, leading to a scenario known as "chaotic" or "eternal inflation." Such multiple inflations might lead to the creation of other universes. Eternal inflation is especially associated with the work of Andre Linde.[34]

4) Superstring theory hypothesizes "landscapes" with large numbers of vacua, which could constitute universes. These vacua arise because in string theory there are more than three dimensions, which are "compactified" into what we see as three dimensions. This compactification of dimensions can be done in many ways, and our universe corresponds to just one such compactification. This idea is associated with Leonard Susskind.[35] As Paul Davies says in his latest book *Cosmic Jackpot*, other universes "Might have ten rather than three species of neutrino, of five sorts of photon. Others might have only four quarks, or as many as forty. There could be worlds in which electromagnetism is stronger than the strong nuclear force, or where there are eight fundamental forces instead of four – and so on. Obviously our world is just one among a dizzying number of alternatives."[36] Of course, despite the large number of physicists working on it, the validity of string theory is widely questioned; Lee Smolin, for one, has enumerated its problems and associated methodology in his book *The Trouble with Physics*.[37]

5) Many universes could also be generated from cosmic branching according to what is known as the Everett-Wheeler interpretation of quantum theory, the original of several formulations of the many worlds interpretation of quantum mechanics.[38]

Cosmologist Max Tegmark argues that the idea of the multiverse is grounded in well-tested theories such as relativity and quantum mechanics, and that it is empirical science because it makes predictions and can be falsified. The key question, he says, is not whether the multiverse exists, but how many levels it has. Accordingly, he has described four possible levels of multiverse, according to how different they would be from ours, ranging from those similar to ours but beyond our observable horizon, to those having different physical laws (see Table I).[39] A Level I multiverse comprises those universes currently beyond our observable universe, which grows at the rate of 1 light year per year as light from farther away reaches us. It is in the Level I multiverse that you are supposed to find your doppelganger, as all possible permutations are played out in the infinite space. The Level II multiverse, associated with black holes, inflation or string theory, might have different physical constants, different space-time dimensionality and different elementary particles. The Level III multiverse is the one associated with the many worlds interpretation of quantum mechanics, where all possibilities based on human action are played out. As Tegmark notes, whereas in the Level I multiverse your doppelganger exists in three-dimensional space, in Level III "they live on another quantum branch in infinite-dimensional Hilbert space."[40] At Level IV, the multiverse is a form of radical Platonism in the sense that Plato's "realm of ideas" is considered to be reality. These multiverses and their characteristics are summarized in Table I.

Table I Tegmark's Multiverse Levels

Level	Theoretical Basis	Proponents	Characteristics
I	Big Bang cosmology	Numerous	Universes beyond our light horizon. Same laws & dimensions; different initial conditions
II	Black Hole Generation	L. Smolin	Different physical constants; Different space-time dimensions Different elementary particles
	Oscillating universe	J. Wheeler	ditto
	Chaotic Inflation theory	A. Linde	ditto
	String theory	Susskind	ditto
III	Quantum Mechanics	H. Everett, III	multiverses in infinite
	Many worlds interpretation	J. Wheeler	dimensional Hilbert space
IV	Plato vs Aristotle	M. Tegmark	different physical laws
	Pi in the sky	J. Barrow	different fundamental equations
	Principle of fecundity	R. Nozick	
	Modal realism	D. Lewis	

None of the theoretical mechanisms listed in Table I, it should be noted, constitute direct evidence for the existence of a multiverse, though the fine-tunings for life might be considered indirect evidence. In this context it should also be noted that the ideas of a multiverse and the fine-tunings of the anthropic principle are separable; the fine-tunings could have nothing to do with a multiverse, and a multiverse could exist without the fine-tunings. Like the God Hypothesis, they are interesting if true, but also unprovable.

V. Philosophical Issues

The three primary explanations for the biofriendly universe beg an important question: are they verifiable? For those who believe in the supernatural, the God Hypothesis is acceptable, but not verifiable; even the design argument does not uniquely point to a supernatural explanation – that is precisely why some favor the multiverse hypothesis as an alternate explanation.[41] For those who believe many universes exist and we just happen to be in one that is biofriendly, the multiverse is acceptable, but almost by definition other universes beyond our own are not verifiable by normal scientific standards.[42] This leaves a highly evolved natural intelligence as the leading theory. As a natural entity in our own universe this would be verifiable in principle, though admittedly difficult. I therefore recommend that more attention be paid to cultural evolution in the cosmos, and its possible endpoints, of which postbiologicals are one manifestation. Creation by a natural intelligence raises intriguing possibilities, one of which has been played out in the movie The Matrix.

Lest we be accused of unbridled speculation, let us recall that we have been led to these conclusions by the empirically observed fine-tuning of the universe, inelegantly and erroneously named the anthropic principle. As others have noted, it is neither anthropic nor a principle, but by whatever name it is an enigma. But is it science? Bernard Carr in his book *Universe or Multiverse* admits the concept has earned the disdain of many physicists in the past. For example in his book *Perfect Symmetry* Heinz Pagels (who has thought deeply about these matters in his book *The Cosmic Code*) asserts "the influence of the anthropic principle on contemporary cosmological models has been sterile. It has explained nothing and it has even had a negative influence. I would opt for rejecting the anthropic principle as needless clutter in the conceptual repertoire of science."[43] However, in favor of the anthropic principle Carr cites a fundamental change in the epistemological status of multiverse proposal and the anthropic principle because of the many ways in which we now realize other universes could originate. Still, the discomfort remains and Carr says the reason is clear: "The idea is highly speculative and, from both a cosmological and a particle physics perspective, the reality of a multiverse is currently untestable. Indeed, it may always remain so, in the sense that astronomers may never be able to observe the other universes with telescopes and particle physicists may never be able to observe the extra dimensions with their accelerators."[44] He holds out hope for empirical verification only if the effects of other dimensions became visible at TeV scales.

There is another way in which the anthropic principle and its teleological underpinnings may be scientific, and it is encapsulated in the comment of Freeman Dyson: "I do not feel like an alien in this Universe. The more I examine the Universe and examine the details of its architecture, the more evidence I find that the Universe in some sense must have known we were coming."[45] Could the universe have known we were coming? Physicist Paul Davies has discussed this possibility of "backwards causation" in the context of quantum theory. He points out some famous theories of physics involve backward causation: the Wheeler-Feynman theory of electrodynamics, the Hoyle-Narlikar theory of gravitation, and the Gellmann-Hartle-Hawking theory of quantum cosmology. Unfortunately, none of these, he hastens to add, have any experimental evidence.[46]

In my view, in the end the concept of an advanced natural intelligence tuning our own universe tops the other two explanations in terms of verifiability according to normal scientific practice. But all three explanations for the biofriendly universe suffer from the same inherent weakness. If God fine-tuned the universe, who created God? If a natural intelligence did the fine tuning, it evolved from a more primitive intelligence and more primitive life, but what is the origin of that life? And if the multiverse explains fine tuning, who created the multiverse, or the first universe that spawned all others? Those questions lead to a broader, deeper and age-old philosophical problem: Why is there something rather than nothing?

VI. Conclusions

Twenty years ago the physicist Freeman Dyson called for the need to build bridges between biology and cosmology. "Only a few heretics … dare to express the view that the structure of the universe may not be unambiguously reducible to a problem of physics," he wrote in his iconoclastic book *Infinite in All Directions*. "Only a few romantics like me continue to hope that one day the links between biology and cosmology may be restored." He suggested further that

> The prospects are bright for a future-oriented science, joining together in a disciplined fashion the resources of biology and cosmology. When this new science has grown mature enough to differentiate itself clearly from the surrounding farrago of myth and fiction, it might call itself "cosmic ecology," the science of life in interaction with the cosmos as a whole. Cosmic ecology would look to the future rather than to the past for its subject matter, and would admit life and intelligence on an equal footing with general relativity as factors influencing the evolution of the universe.[47]

Fine tuning and the multiverse are two concepts that may prove central to this task. In such a "cosmic ecology", life and intelligence do indeed play a central role in the evolution of the universe, no less than its physical laws. If the universe indeed "saw us coming" life may be its ultimate purpose for existing, returning to physics a kind of teleology that had been banned from science. This lends all the more importance to the current disciplines of astrobiology and SETI, which will determine just how abundant life

is in the universe – or (perhaps in the very long run!) the multiverse. The biological universe may be not the result but the cause of the physical universe, part of its very fabric, and more surprisingly fundamental than we have ever realized.

Notes

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[1] Steven J. Dick, *The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science* (Cambridge: Cambridge University Press: 1996), pp. 34-35, 541-542; Steven J. Dick, "The Concept of Extraterrestrial Intelligence - An Emerging Cosmology," *Planetary Report ,* 9 (March-April, 1989), 13-17; Bernard Oliver, *Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligent Life*, 1973, reprinted, 1996, p. 30.

[2] Einstein's statement was "The most incomprehensible thing about the world is that it is at all comprehensible." Wigner's thoughts on the subject are in "The Unreasonable Effectiveness of Mathematics in the Natural Sciences," in *Communications in Pure and Applied Mathematics*, vol. 13, No. I (February 1960). New York: John Wiley & Sons, Inc. Copyright © 1960 by John Wiley & Sons, Inc. Available at http://www.dartmouth.edu/~matc/MathDrama/reading/Wigner.html

[3] Churchill's comment came in a radio address in 1939, two months after Russia's non-aggression compact with Germany.

[4] John Barrow and Frank Tipler, *The Anthropic Cosmological Principle* (New York: Oxford University Press, 1986).

[5] A. R. Wallace, *Man's Place in the Universe: A Study of the Results of Scientific Research in Relation to the Unity or Plurality of Worlds*. (New York: McClure, Phillips and Co. (1904), p. 306. Online at http://www.wku.edu/~smithch/wallace/S728-1.htm. See also Steven J. Dick, "The Universe and Alfred Russel Wallace," in *Natural Selection and Beyond: The Intellectual Legacy of Alfred Russel Wallace*, edited by Charles H. Smith and George W. Beccaloni (Oxford: Oxford University Press), in press.

[6] "Man's Place in the Universe, as Indicated by the New Astronomy," *The Fortnightly Review*, March 1, 1903, 396. Online at http://www.wku.edu/~smithch/wallace/S602.htm. This was the article on which Wallace's book (note 5) was based.

[7] Lawrence J. Henderson, *The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter* (Cambridge, Mass.: Macmillan, 1913) reprinted in 1970 with an introduction by George Wald, Gloucester, Mass: Peter Smith. p. 312. See also Iris Fry, "On the Biological Significance of the Properties of Matter: L. J. Henderson's Theory of the Fitness of the Environment," *Journal of the History of Biology*, 29 (1996), 155-196.

[8] Bernard Carr, "The Anthropic Principle Revisited," in *Universe or Multiverse?* ed. Bernard Carr (Cambridge: Cambridge University Press, 2007), p. 88.

[9] Brandon Carter, "Large Number Coincidences and the Anthropic Principle in Cosmology," in M. S. Longair, ed. *Confrontation of Cosmological Theories with Observational Data* (Dordrecht, 1974), 291-298. Carter also went on to apply the anthropic principle to biology and quantum theory, in addition to cosmology; Carr, 2007, 285).

[10] B. J. Carr and M. J. Rees, "The Anthropic Principle and the Structure of the Physical World," *Nature*, 278 (April 12, 1979), 605-612.

[11] Martin Rees, *Before the Beginning: Our Universe and Others* (New York: Perseus Books, 1997); *Just Six Numbers: The Deep Forces that Shape the Universe* (New York: Basic Books, 1997); *Our Cosmic Habitat* (Princeton, N.J.: Princeton university Press, 2001). One of the earliest books on the subject (which drew on the Carr-Rees 1979 article) was Paul Davies, *The Accidental Universe* (Cambridge: Cambridge University Press, 1982), followed by *The Mind of God* (New York: Simon and Schuster, 1992), and most recently *Cosmic Jackpot: Why Our Universe is Just Right for Life* (Houghton Mifflin: Boston and New York, 2007).

[12] Rees, *Just Six Numbers* (note 11), pp. 2-4, with elaboration throughout the book.

[13] See John D. Barrow, *The Constants of Nature* (New York: Vintage Books, 2002), and Barrow and Tipler, pp 224 ff. The constants of nature have been a fascinating problem since the "Large Number Coincidences" that Arthur S. Eddington and P. A. M Dirac studied in the 1930s. But these authors did not relate to the fine-tuning problem. See Arthur I. Miller, Empire of the Stars (Boston: Houghton Mifflin, 2005), especially pp. 67-72 and 143-146, and A.V. Douglas, The Life of Arthur Stanley Eddington (London: Thomas Nelson and Sons, 1956).

[14] Steven J. Dick, *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant* (Cambridge University Press: Cambridge, 1982), chapter 6, "Newton, Natural Theology, and the Triumph of the Concept of Other Worlds."

[15] Ibid, pp. 151-154.

[16] On Paley see Barrow and Tipler (note 4), pp. 76-82; J. Polkinghorne, *The Faith of a Physicist* (Princeton U Press, 1994); Robert Collins, "The Multiverse Hypothesis: A Theistic Perspective," in Carr (note 8), pp. 459-480.

[17] R. Numbers, *The Creationists: From Scientific Creationism to Intelligent Design.* (Cambridge, Mass.: Harvard University Press, 2006).

[18] Davies, *Cosmic Jackpot* (note 11), p. 201.

[19] Olaf Stapledon, *Last and First Men* and *Star Maker* (New York, 1968).

[20] Fred Hoyle, *The Intelligent Universe: A New View of Creation and Evolution.* (New York: Holt, Rinehart and Winston, 1983); E. W. Harrison, "The Natural Selection of Universes Containing Intelligent Life," QJRAS, 36, no. 3 (1995), 193; Steven J. Dick, "Cosmotheology: Theological Implications of the New Universe," in Steven J. Dick, ed, *Many Worlds. The New Universe, Extraterrestrial Life and the Theological Implications*. Philadelphia and London: Templeton Foundation Press (2000), pp. 191-210.

[21] James Gardner, *The Intelligent Universe: AI, ET and the Emerging Mind of the Cosmos* (Franklin Lakes, N.J.: New Page Books, 2007), 159; Gardner, *Biocosm: The New Scientific Theory of Evolution: Intelligent Life is the Architect of the Universe* (Makawao, Maui, Hawaii: Inner Ocean Publishing, 2003).

[22] Steven J. Dick, S. J. Dick. Cultural evolution, the postbiological universe and SETI, International Journal of Astrobiology, 2 (2003), 65-74

[23] Carr, *Universe or Multiverse* (note 8), xv.

[24] Steven J. Dick, *Plurality of Worlds: The Extraterrestrial Life Debate from Democritus to Kant* (Cambridge: Cambridge University Press, 1982), pp. 6-11

[25] See the review by philosopher George Gale, "Cosmological Fecundity: Theories of Multiple Universes," in John Leslie, ed., Modern Cosmology & Philosophy (Prometheus Books: Amherst, NY, 1998), pp. 195-212. Gale distinguishes three categories of multiple worlds: spatially multiple, temporally multiple, and other-dimensional multiple.

[26] J. D. Barrow, *The Constants of Nature* (note 13), p. 276; Pantin also added "But even if there were any conceivable way of testing such a hypothesis we should only have put off the problem of why, in all those Universes, our own should be possible?!" See also Barrow and Tipler, *The Anthropic Cosmological Principle*, p. 250.

[27] John Leslie, *Universes* (Routledge, London and New York), p. 1. Leslie's quote from Adams is "If he were obliged to insist on a Universe, he seemed driven to the Church," which he follows with his own paraphrase "so he opted for a 'multiverse' of largely or entirely separate worlds with very different characteristics." Adams does use the word "multiverse", but these worlds for Adams were not physical universes. Leslie refers to the 1931 edition of Adams, but it was first published in 1918. As the references in his volume show, Leslie is the philosopher who has written most on the subject of other universes, beginning with his ideas in the 1970s that the universe is "ethically required." See also the collection of articles in Leslie, ed., *Modern Cosmology & Philosophy* (Prometheus Books: Amherst, NY, 1998).

[28] Bernard Carr, *Universe or Multiverse* (note 8). Another important set of papers is found in a special issue of the *International Journal of Astrobiology*, on "Fine Tuning in Living Systems," volume 2, issue 2 (April, 2003).

[29] David Lewis, *On the Plurality of Worlds* (Oxford: Blackwell, 1986).

[30] There have been several taxonomies of the multiverse idea: Leslie, *Universes* (note 27), pp. 6-7; Max Tegmark, "Parallel Universes," *Scientific American* (May, 2003) 41-51; and most elaborately Robert Lawrence Kuhn, "Why This Universe? Toward a Taxonomy of Possible Explanations," *Skeptic,* vol. 13, no. 2 (2007), pp. 30-41.

[31] On the concept of cosmic horizon, and the differences between the observed universe, the observable universe, and the entire universe see , *Cosmic Jackpot* (note 11), pp. 30-40.

[32] Smolin, *The Life of the Cosmos*, (New York: Oxford University Press, 1997; for his most recent analysis, which pans the anthropic principle, but not the multiverse, see Smolin, "Scientific Alternatives to the Anthropic Principle, in Carr, Universe or Multiverse (note 8), pp. 323-366: 335-336.

[33] Lee Smolin, "Scientific Alternatives," (note 32),

[34] Andre Linde, "The Inflationary Multiverse," in Carr (note 8), 127-149. See also Alan Guth, *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins* (Reading, Mass.: Addison Wesley, 1997)

[35] Leonard Susskind, "The Anthropic Landscape of String Theory," in Carr (note 8), 247-266.

[36] Davies (note 11), p. 112

[37] Lee Smolin*, The Trouble with Physics* (Boston and New York: Houghton and Mifflin, 2007)

[38] Hugh Everett, III, "Relative State Formulation of Quantum Mechanics," *Reviews of Modern Physics*, 29, no. 3 (July, 1957); Carr (note 8), p. 450; Davies, *Cosmic Jackpot* (note 11), p. 228. The sometimes-accurate Wikipedia reports that according to a poll at a Quantum Mechanics workshop in 1997, "the Copenhagen interpretation is the most widely-accepted specific interpretation of quantum mechanics, followed by the many-worlds interpretation. Although current trends show substantial competition from alternative interpretations, throughout much of the twentieth century the Copenhagen interpretation had strong acceptance among physicists. Astrophysicist and science writer John Gribbin describes it as having fallen from primacy after the 1980s."
http://en.wikipedia.org/wiki/Copenhagen_interpretation

[39] Max Tegmark, "Parallel Universes," *Scientific American* (May, 2003) 41-51; and Tegmark, "Parallel Universes," in *Science and Ultimate Reality: From Quantum to Cosmos*, J. D. Barrow, P.C.W. Davies, and C.L. Harper, eds. (Cambridge: Cambridge University Press, 2003).

[40] Tegmark (2003), p. 48.

[41] Carr points out that, while Cosmic Design should not be confused with Intelligent Design, "atheists might hope that the multiverse theory will have the same impact in the context of cosmic design as the theory of evolution did in the context of biological design." Carr (note 8), p. 16, note 2.

[42] The Jesuit astronomer William R. Stoeger offers the possibility that multiverses are testability through the concept of "retroduction," an idea proposed by the philosopher C. S. Peirce and supported by Notre Dame philosopher/historian Ernan McMullin. He defines retroduction as "inference based on the success or fruitfulness of an hypothesis in accounting for better understanding of a set of phenomena." Thus, if an hypothesis accomplishes the following, it may be true despite the inability to actually see its hidden properties (such as a multiverse): 1) account for empirical data (empirical adequacy); 2) provide long-term explanatory success and stimulate productive lines of further enquiry (theory fertility); and 3) bring together previously disparate domains of facts (unifying power). Stoeger, "Are Anthropic Arguments, Involving Multiverses and Beyond, Legitimate?," in Carr, *Universe or Multiverse* (note 8) 445-457: 450-451. James Gardner uses "retrodiction" in his Selfish Biocosm Hypothesis; see "The Physical Constants as Biosignature: An Anthropic Retrodiction of the Selfish Biocosm Hypothesis," in Gardner, *The Intelligent Universe* (note 21), 197-211.

[43] Heinz Pagels, *Perfect Symmetry: The Search for the Beginning of Time*, (New York: Simon and Schuster, 1985), p. 359. See also the *The Cosmic Code: Quantum Physics as the Language of Nature* (New York: Simon and Schuster, 1982).

[44] Carr, *Universe or Multiverse*, 3, 14; see also Davies, *Cosmic Jackpot* (note 11), 204-205

[45] Dyson, *Reviews of Modern Physics*, 51 (1979), 447.

[46] Davies, *Cosmic Jackpot* (note 11), 242-249

[47] Freeman Dyson, *Infinite in all Directions.* New York: Harper and Row (1988), pp. 50-51.

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