THE ANTHROPIC PRINCIPLE: LIFE IN THE UNIVERSE

by Kevin Sharpe and Jonathan Walgate

Abstract. The anthropic principle, that the universe exists in some sense *for* life, has persisted in recent religious and scientific thought because it derives from cosmological fact. It has been unsuccessful in furthering our understanding of the world because its advocates tend to impose final metaphysical solutions onto what is a physical problem. We begin by outlining the weak and strong versions of the anthropic principle and reviewing the discoveries that have led to their formulation. We present the reasons some have given for ignoring the anthropic implications of these discoveries and find these reasons wanting—a real phenomenon demands real investigation. Theological and scientific solutions of the problem are then considered and criticized; these solutions provide dead ends for explanation. Finally, we pursue the path that explanation must follow and look at the physical details of the problem. It seems clear that the anthropic principle has been poorly framed. Removing the ambiguities surrounding the meaning of "life" may lead to more profitable investigations.

Keywords: anthropic principle; existence of God; many-universe theory; meaning of life; self-organized criticality.

POPULATING THE UNIVERSE

"The Universe—some information to help you live in it.

4. Population: None.

It is known that there are an infinite number of worlds, simply because there is an infinite amount of space for them to be in. However, not every one of them is inhabited. Therefore, there must be a finite number of inhabited worlds.

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> *Any finite number divided by infinity is as near to nothing as makes no odds, so the average population of all the planets in the Universe can be said to be zero. From this it follows that the population of the entire universe is also zero, and any people you may meet from time to time are merely the products of a deranged imagination."*
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> —Douglas Adams, *The Hitchhiker's Guide to the Galaxy*

What is wrong with this argument? At first glance, it might seem easier to ask, What is right with it? so appalling is the conclusion. Douglas Adams makes questionable assertions about the infinity of the universe and the finitude of its inhabited areas, but they are not at the crux of his argument. Infinities aside, the populated parts of our universe are tiny compared with the open expanses of vacuum it contains; we call the place "space," after all. In fact, the *Hitchhiker's Guide* could put up a stern defense for its advice: if you took some persons and placed them at random in the universe, then allowed them to wander as they pleased, chance is stacked against their encountering life of any kind, let alone other people. The improbabilities are so enormous that actually meeting someone would, likely as not, signal the onset of delusion.

Where does that leave me, my family, my friends, and our six billion neighbors? The answer is simply "on planet Earth." Life does not get placed at random in the universe; it gets placed very specifically indeed. Speaking as a carbon-based life form, I could guess without opening my eyes that I must live on a small planet orbiting a small star, neither too warm nor too cold. I could guess that my planet probably lay in the outer reaches of a galaxy, sufficiently distant from the intense central radiation, yet close enough to receive enough heavy elements for life chemistry to begin. I might correctly guess that my galaxy was of a certain spiral kind, with neither too many supernovae irradiating me nor too few to provide the matter to make me. I could guess that I lived in a very special, very crowded place.

We do not need to calculate the local galactic supernova rate before we risk spending money on birthday presents. The obvious existence of other persons is something we take for granted—common sense rather than a theory. But this kind of common sense conflicts with a principle that has been at the heart of science for centuries—the principle of Copernicus. Dethroning Earth from the center of the cosmos, Nicholas Copernicus asserted that we must not assume that we hold a privileged position in the cosmos. Physics trusts that the basic laws, which we observe on Earth, are the same everywhere. But the more we discover of these laws, the more they seem arranged for the fostering of life on Earth. These "convenient coincidences" are becoming hard to ignore.

Introducing the Anthropic Principle

Science is built upon observational data. The most fundamental such datum is "We observe." Descartes made this point when he said, "*Cogito ergo sum*," I think therefore I am; we can't look at the cosmos without being here in the first place. This is the content of the weak anthropic principle (WAP), as spelled out by John Barrow and Frank Tipler: "The observed values of all physical and cosmological quantities are not equally probable but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirement that the universe be old enough for it to have already done so" (1988, 16).

We can't very well expect to observe a universe incapable of supporting life. Barrow and Tipler used the analogy of telescopes. Optical telescopes can only detect radiation within a restricted band of frequencies. Looking through such a device, we will never find such phenomena as cosmic background radiation and ultraviolet rays from stars. The facts of the optical experiment place boundary conditions on what astronomers will experience. Similarly, the fact that the universe has fostered life places boundary conditions on what we will see.

This is all uncontroversial—it's an extension of common logic—but the importance of this principle depends on the restrictions it actually involves. Life might have been easy to produce, a simple and unproblematic requirement for a universe. The weak anthropic requirement might be like asking a university graduate to add 2 and 2; perhaps any mature universe can support life.

No. The anthropic principle has hit the limelight because the boundary conditions it places upon the universe are extremely restrictive. Life chemistry seems an enormously precarious procedure, vulnerable to the slightest alteration of our universe's laws. This has led many people, including Nobel laureates, to the strong anthropic principle (SAP): "The universe *must* have those properties which allow life to develop within it at some stage of history" (Barrow and Tipler 1988, 21; emphasis added). The key lies in the word *must*. SAP specifies that life cannot have been an accident or a coincidence but was a necessary outcome from the word go. From here, it is a short step to arguments about design. Religiously minded persons use the strong anthropic principle to argue that the universe is specifically designed for us to live within. The remarkable life-supporting properties of the universe could not be coincidences, they say, but are evidence of a divine intention at work: a divine whose intent was our creation. For them the universe didn't just happen, it was built.

Cosmic Coincidences: The Scientific Basis for Anthropic Reasoning

What are these coincidences that have stoked such debate and led people to claim that science has proved the existence of God? Cosmologists use the standard model of particle physics to describe the universe, involving a large number of free parameters—things such as the mass of an electron and the relative strengths of gravitational and electromagnetic forces. These factors have precise and special values in our universe, values we can measure, but the mathematics of the standard model works perfectly well if we substitute other numbers. You just get other universes. On a level playing field, you might expect that varying some of the parameters would make life more likely to occur, while other variations would reduce its chances. Not so. All possible adjustments seem to threaten our existence.

This is best demonstrated by considering stars. We couldn't live without stars. Sunlight provides the energy for life—it fuels biochemical processes—but there is an even more important consideration. Stars are the only places where the complex atoms that we are made of can be built. Carbon, oxygen, and so on simply cannot come from anywhere else. These stellar factories need to be special kinds of stars, too. Enough of them need to "go supernova" to distribute these precious supplies of elements about the galaxy. If long-lived, supernova-prone, carbon-producing stars didn't exist, neither would we.

The universe's fusion reactors glue tiny protons together to form more complicated particles and release energy in the process. The strong nuclear force is what glues nuclei together. This is very difficult for stars, because to stick protons together you must overcome their mutual electromagnetic repulsion. It is impossible to do this without first turning a proton into a neutron, a convoluted process taking billions of years. Stars live so long precisely because they have to take this slow detour—but it might not have been so. If the strong nuclear force were just a single percent stronger, it would be powerful enough to overcome the electromagnetic repulsion of protons directly. All stars would explode, compressing a billion years of nuclear reactions into a single second.

Stars must instead turn protons into neutrons via the *weak* nuclear force. This force is the controlling factor in their reactions and thus controls the death of stellar giants—supernovae. As an enormous star burns the last of its fuel, it begins to fuse heavier and heavier elements. These elements are worse power sources than hydrogen, and the star begins to lose the energy that has countered its gravity. It collapses in on itself, and the core becomes a dense neutron star. This collapse causes a shock wave to explode out from the center, blowing the heavy elements into deep space, where they may find their way into less extreme solar systems and provide the fuel for life. An explosion of neutrinos propels this shock wave from the neutron core, pushing the wave ever outward. The neutrinos "push" with the weak force. Were this force slightly weaker, the shock wave would not be strong enough to propel the vital matter away from the dead star. Were the weak force stronger, the neutrinos would waste their time trying to push apart the neutron core itself and would never reach the shock wave to help it along. Again, the heavy elements would not escape the pull of gravity. If the fuels of life are to escape imprisonment inside dead stars, the weak nuclear force must be precisely balanced.

"Carbon-based life form" is a cliché for a reason. Of all the elements that exist, none comes close to the potential for complex chemistry possessed by carbon. Science fiction writers have alluded to silicon as an alternative, but it is plainly inferior. If we are to have life, we must have carbon, and stars must produce it.

Stars fuse hydrogen to produce helium nuclei. These nuclei, consisting of two protons and two neutrons, are stable and act as the building blocks of all the heavier elements the star manufactures. So stable are the nuclei that any element built from a number of them will be stable itself. Carbon (three helium nuclei) and oxygen (four helium nuclei) are examples, but there is an unfortunate exception. The simplest compound element, beryllium, is unstable: a newly created beryllium nucleus has a life expectancy of 10^{-17} seconds. Every more complex construction must pass through the beryllium phase without decaying. How is it possible?

Fred Hoyle, a British astrophysicist, considering this problem, reasoned anthropically: We know that there is an abundance of carbon in the universe (hey, we *are* an abundance of carbon in the universe). It follows that there must be something about carbon that makes the transition from beryllium so favorable that significant numbers of nuclei can make it within 10^{-17} seconds. Hoyle proposed a previously undiscovered energy level of carbon that would resonate with the energies of helium and beryllium within a star. He also persuaded a skeptical team of nuclear physicists to test his prediction. He was right. The new energy level of carbon was just 4 percent higher than the helium-beryllium combined energy, at just the right level for resonance. The incredible heat inside a star could provide this small energy difference. Much higher, and even stellar temperatures would not provide the impetus for reaction; any lower, and the excess of energy between the helium and beryllium nuclei would cause them to bounce apart again. Oxygen, too, has a resonance close to its stellar formation requirement. Oxygen's, though, is 1 percent below threshold rather than 4 percent above, so oxygen cannot be easily manufactured. Carbon's 4-percent cushion provides all our supplies of this life-crucial element. Oxygen's 1-percent cushion is the only thing that keeps our carbon here.[1]

Hoyle's work led him to a natural conclusion: "I do not believe that any scientist who examined the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed with regard to the consequences they produce inside the stars. If this is so, then my apparently random quirks have become part of a deep-laid scheme. If not then we are back again at a monstrous series of accidents" (Hoyle 1959). Hoyle's convictions are based on an even greater chain of quirks of nature, far too detailed to mention individually. Lee Smolin, professor of physics at Pennsylvania State University, provides a compelling summary in his book *The Life of the Cosmos*. He imagines that some of the fundamental constants of the standard model, the masses of the fundamental particles and the relative strengths of three of the forces between them, were assigned randomly at the start of the universe. Then he asks how likely such a universe would be to develop long-lived stars. It is a simple piece of mathematics:

> The answer, in round numbers, comes to about one chance in 10^{229}.
>
> To illustrate how truly ridiculous this number is, we might note that the part of the universe we can see from the earth contains about 10^{22} stars which together contain about 10^{80} protons and neutrons. These numbers are gigantic, but they are infinitesimal compared with 10^{229}. In my opinion, a probability this tiny is not something we can let go unexplained. Luck will certainly not do here; we need a rational explanation of how something this unlikely turned out to be the case. (Smolin 1997, 45)

Do We Need an Explanation?

Should we really be surprised by the fantastic odds that Smolin calculates? Why are we not wiping our brows with relief that we exist at all? Some philosophers have claimed that we cannot and should not pay any attention to such probabilities, as the only ones we can calculate without inconsistency are those that presuppose our existence. Taking this argument to its logical conclusion, none of us should be surprised by our own existence, since we could never be aware of the converse. William Lane Craig provides an enlightening metaphor: "Suppose a hundred sharpshooters are sent to execute a prisoner by firing squad, and the prisoner survives. The prisoner should not be surprised that he does not observe that he is dead. After all, if he were dead, he could not observe his death. Nonetheless, he should be surprised that he observes that he is alive" (Craig 1988, 392).

We are entitled, then, to surprise at our own existence provided we understand our predicament. The prisoner's justifiable amazement derives from his acquaintance with guns, bullets, and the reliability of trained sharpshooters. The SAP would have it that our world is so unlikely that some mysterious agency must have guided its development; perhaps some intervening God has handed our executioners blanks. But the origins of our universe are much more obscure than firing squads.

John Barrow argues that we cannot fully understand our ultimate origins. "Limits are ubiquitous. Science exists only because there are limits to what Nature permits" (1998, 248). The beginning of the universe is one such limit. The problem can be expressed through our reliance upon time. When we try to understand a process, we first ask what happened when, basing our knowledge on causes and effects. There are limits to our ability to measure time, though. Any measurement has to be performed in the real world, which means it has to involve a real interaction. The most precise way to measure time employs light quanta, and the higher the precision you want, the smaller the volume you must compress the light into. Were this hypothetical volume to get too small, the energy inside would become too dense and create a miniature black hole.

Our measurement would break down at this point: the Planck time, at 10^{-43} seconds, the smallest division of time theoretically accessible. We simply cannot ask what happened before 10^{-43} seconds of the universe have elapsed—for us, $t = 10^{-43}s$ *is* the beginning. The energy density of the universe is so high beforehand that it "breaks" our current theories of spacetime. It is meaningless to talk of improbabilities in circumstances of complete ignorance like these. John Polkinghorne criticizes such reasoning in his book *Science and Creation*:

> A hypothesis will always be involved, stating that certain events are truly random, that each of them is as likely to occur as any other. That assumption might be false for reasons we have not taken into account. If you throw a die and it comes up a six ten times in succession, if I think the die is true I shall be very surprised, for the probability of that happening is 1.65×10^{-8}. However it is always possible that you are using a loaded die and I have just misunderstood the situation. This caveat applies particularly to those who seek to make a case for something like theism by purportedly showing, say, that the coming-to-be of life is so fantastically improbable an event. . . . The odds need to be calculated on a more informed basis. (1988, 29)

Better theories may yet model the universe's birth in a more revealing way, but for the time being our metaphysical speculations should stick close to the facts. This does not show, however, that there is nothing to interest us in the fundamental constants. Science has not demonstrated that this life-supporting universe is incredibly improbable. But the coincidence of so many vital phenomena remains an observable fact and demands explanation of some sort. The world need not surprise us to be an object of curiosity and wonder.

PROOF OF A CREATOR?

Theologians' interest in the anthropic principle traces back to their interest in its subject matter—the Big Bang. Big-Bang theory was a "godsend" to those trying to square the doctrine of *creatio ex nihilo* (God's creation of the universe out of nothing) with modern science. Nineteenth-century physics supposed that the universe had no discernible beginning and was simply pursuing its random motions forever from past to future. The Big

Bang posed a new question that cosmologists seemed reluctant to answer: Who lit the fuse?[2]

That the universe began did not prove that it was "pushed," and it did little to warm the overwhelming vastness of space for theologians who had, four hundred years previously, sat at its center. But the fingerprint of a divine creator molding a universe specifically for humanity would revolutionize our thinking. A fingerprint is just what some religious thinkers have held the anthropic parameterization of our universe to be.

Bluntly put, this attempt at "scientifically" proving that a creator exists fails for precisely those reasons outlined earlier. It involves the insupportable assumption that without a guiding hand a universe would have selected its fundamental parameters randomly. A divine purposive force could "explain" any perplexing quirk or oddity of nature. Experience has shown, though, that careful and sustained investigation of these quirks can reveal an elegant underlying pattern. A cosmological argument for the existence of God may seem attractive with our limited present knowledge, so it is worth recalling some previous occasions when theologians have made the same mistakes.

Medieval scholars used to believe that an arrow in flight required constant impetus to sustain its motion, and some saw the hand of God in every movement. But this did not improve our understanding of the phenomenon, for one could simply respond, *How* does God sustain all motion? When Newton framed his principle of inertia, these examples of God's action fell quietly away.

Cosmology's push for a theory of everything involves weaving together the disparate forces at work in the world and explaining their common origins. Such work might well begin to explain the haphazard allocation of values to our "fundamental" constants. Nineteenth-century thinkers might have marveled at the precise balance between the electrical and magnetic forces, but James Maxwell showed them to be different aspects of the same phenomenon.

William Paley provides the best example of a failed attempt to deduce God from the improbabilities of the natural world. A late-eighteenth-century philosopher and churchman, Paley thought the living world provided clear evidence of design. Millions of complex species abounded, each suited to its ecological niche. The chance of randomly designed life-forms being so well adapted to their environment and each other must be at least as preposterous as 10^{229}. He coined the famous analogy of the watchmaker: A man whose upbringing has taught him nothing of watches and timekeepers finds a watch lying on the ground and investigates. Examining the careful and intricate arrangement of parts and observing the complexity of the structure, this man cannot but conclude that the watch was put together by design and for a purpose. Had a blind watchmaker thrown the pieces together at random, such a perfect device could never have resulted (Paley 1818, 12–14).

Paley is drawing a distinction between the artifact and the accident. For him, fabricated things betray their creators through their orderliness and purpose. This philosophy was fatally undermined by Darwin's theory of natural selection. This procedure is a step-by-step process that slowly builds up complex designs on simpler successes. In honor of this evolution, Richard Dawkins titled one of his books *The Blind Watchmaker:*

> Natural selection, the blind, unconscious, automatic process which Darwin discovered, and which we now know is the explanation for the existence and apparently purposeful form of all life, has no purpose in mind. It has no mind and no mind's eye. It does not plan for the future. It has no vision, no foresight, no sight at all. If it can be said to play the role of the watchmaker in nature, it is the *blind* watchmaker. (Dawkins 1987, 5)

Evolution may be a blind process, but it still generates great and complex systems. Paley's mistake was to contrast purposive design with randomness and ignore the middle ground. (This was a natural assumption in the nineteenth century, when the laws of thermodynamics seemed to describe all physical processes as random fluctuations tending toward disorder.) Paley treated the complexity of biology as its final cause, or purpose, and postulated a means by which it might be brought about. His work could not advance our understanding of the living world. Darwin investigated the complexity and found within it patterns suggestive of a deeper order.

Reading Purpose into Reality

Theistic arguments are a misuse of either version of the anthropic principle, which say nothing about the creation of the universe. There are alternatives to this crude philosophizing, however. A more astute theologian, grappling with the SAP, would focus upon life: "The universe must have those properties which allow *life* to develop within it at some stage of history" (Barrow and Tipler 1988, 21; emphasis added). Life is the Aristotelian final cause of the universe. It is its purpose, as is expressed in Christian thought by humanity's special relationship with God.[3]

This final cause is the linchpin of orthodox theological thinking about the anthropic principle, which leads scholars astray. This theory of causation was framed by Aristotle more than two thousand years ago and was concreted into Catholic philosophy by the Great Scholastic, Thomas Aquinas. Aristotle described how events might have four different causes—material, formal, efficient, and final. The final cause is explicitly teleological, focused upon the end results of events. An acorn's final cause is not the branch from which it drops but the oak it may become. Aristotle's work made it clear that these "causes" are really just kinds of explanations for things. He sensibly pointed out that there are several ways to explain why we find acorns lying on the ground. Aquinas took this theory and translated it into Catholic terms, introducing God as the First Cause of everything. This doctrinal addition blurred the status of these "causes," since it was taken to imply that God actually intervened in all things to render them extant. Philosophers, who revered Aristotle, began to misunderstand his final causes—they thought he was describing a mystical, magical force that pulled objects toward their intended destiny.

Orthodox theology has always stressed both the transcendent and the personal nature of God, but the two make awkward bedfellows. Scholars have thus leapt at any indication of God's personal nature that might be read into the world. The mysterious force of a misunderstood Aristotle provides just that, because it implies a divine sense of purpose and intention. The anthropic principle then provides a cosmological stage for such a deduction. Attempts to demonstrate a creator God are rebuffed, but the overt presence of a final cause—life—surely proves the existence of a purposeful divine force. But this whole argument is based on a fallacy: one cannot read "purpose" into a simple opportunity for explanation. Aristotle would likely be turning in his grave, for in promoting his explanatory final cause for the universe, anthropic thinkers are in fact rejecting the promise of explanation in favor of a mysterious supernatural agency.

Theological approaches to the anthropic principle attempt to defeat the Copernican principle and return humans to the center of the universe. Scientific attempts to rationalize anthropic coincidences have been just the reverse—directed toward showing that our presence in this particular reality is merely a matter of chance. Their ad hoc metaphysics is vulnerable to the same objection leveled at religion—they abandon the explainable in favor of the unknowable.

Probabilities and Possible Worlds

Rather than imagining something restricting the number of *possible* universes, recent scientific explanations for the anthropic observations describe a vast number of *extant* universes. The idea of parallel worlds is now common both in science fiction and in quantum mechanics. The motivation is simple—if at least 10^{229} universes exist, it would be probable that ours existed, and therefore we should not be surprised to find it here. Craig's sharpshooters analogy becomes the lottery metaphor of John Gribbin and Martin Rees:

> Suppose a million lottery tickets are sold, and then one number out of that million is selected. The holder of that number wins the prize, so that number seems special. But in a deeper sense it is no more special than any of the other numbers in the lottery. By the nature of the lottery, *somebody* must win, and each of the numbers has an equal chance of winning. It is only after the event that one number gains a special status. The holder may feel lucky as a result; but somebody *had* to get lucky! (1991, 273)

Many suggestions have been made about just how such a huge ensemble of universes might come about. Max Tegmark, of the Institute for Advanced Study at Princeton, has proposed that all logically possible universes exist (see Chown 1998). His circular justification, though, is the anthropic principle itself. This proposal could be used to "explain" almost anything, since a multitude of unlikely situations must exist somewhere in this universe set. As Smolin says, "To argue this way is not to reason, it is simply to give up looking for a rational explanation. Had this kind of reasoning been applied to biology, the principle of natural selection would never have been found" (1997, 45).

Barrow and Tipler also argue that every logically possible universe exists and derive this result from the disputed many-worlds interpretation of quantum mechanics. Barrow and Tipler are inadvertently conflating "logically possible" with "physically possible,"[4] but it is a useful move to make. It allows them to create a quantum cosmology where one boundary condition might constrain the multiverse such that every member universe would be life supporting. Strongly anthropic indeed, but nevertheless inexplicably so. We have been asking, Why these initial conditions? Barrow and Tipler can ask themselves, Why this boundary condition?

Even if science upholds its many-universes hypotheses, the central mystery would go unanswered: Why is *this* universe the life-supporting one? Relocating the coincidence from the Big Bang to an infinite multiverse does not lessen its importance. The observation does not *explain* why we are in this relative paradise. It boils down to "We're here because we're here," and that satisfies no one. Smolin's objection still stands: this kind of reasoning is a kind of giving up. If we won a lottery with odds of 10^{229} to 1, we'd bet all our winnings that the draw was rigged. Heinz Pagels (1985) is hostile to the anthropic principle for this reason:

> Physicists and cosmologists who appeal to anthropic reasoning seem to me to be gratuitously abandoning the successful program of conventional physical science of understanding the quantitative properties of our universe on the basis of physical laws. Perhaps their exasperation and frustration . . . has gotten the better of them. . . . The influence of the anthropic principle on the development of contemporary cosmological models has been sterile. It has explained nothing, and it has even had a negative influence, as evidenced by the fact that the values of certain constants, such as the ratio of photons to nuclear particles, for which anthropic reasoning was once invoked as explanation can now be explained by new physical laws. . . . I would opt for rejecting the anthropic principle as needless clutter in the conceptual repertoire of science.

Pagels is expressing widely held sentiments, but we must not lose sight of the fundamental constants that inspired such reasoning. His admiration for the "program of . . . understanding the quantitative properties of our universe on the basis of physical laws" is well founded, but the fine-tuned pattern remains. To requote Smolin, this "is not something we can let go unexplained." Explanation cannot be accomplished by hypothesizing some metaphysical reason, be it a multiverse or a purposeful creator. Such thinking stops our reasoning dead in its tracks, for it imposes an unknowable other on top of the natural world. Instead, we must draw inspiration *from* reality, looking more closely at the details. The productive question to ask is not the popular, How did the universe guarantee these particular values of the fundamental constants? but the seldom-considered, Exactly what does this pattern of fundamental constants guarantee for the universe?

The Meaning of "Life"

The strong anthropic principle, "The universe must have those properties which allow life to develop within it at some stage of history," is meaningless unless we know what "life" signifies. How can we be sure our definition will be significant? Debate rages over the status of viruses, both biological and electronic. Philosophers ponder whether an artificial intelligence could ever become "alive." And the Starship Enterprise encounters, on a weekly basis, "life, but not as we know it." Darwin greatly increased our understanding of what it is to be alive when he overturned Paley's pseudo-anthropic argument. Richard Dawkins, in fact, introduces his book *The Selfish Gene* with the claim that evolutionary science renders meaningless all other attempts to answer the question, "Why are we here?" (1989, 1). But Dawkins is exaggerating, and we still don't understand perfectly what life is. J. L. Mackie suggests that had the balance of nature been different and life as we know it impossible, there might have been different potentialities for the organization of matter of an equally "fruitful" character (1982, 142). There is a role here for the anthropic principle.

The strong anthropic principle needn't simply be assumed or concluded. It can be used, like a hypothesis. Life of some kind exists, of this we can be sure. Working back from this, we see that the universe must satisfy certain very specific conditions. Rather than take the traditional extra leap back into metaphysics, let us look forward from the conditions themselves. If we work out precisely what it is they prescribe, we might refine our uncertain understanding of life. The universe may be fine-tuned for a family of behaviors of which life is only one member. We shall discover precisely what lifelike activity the universe is promoting.

The basic particles of the universe must be capable of fusing to form more-ordered structures: heavier elements with a complicated chemistry. But the story doesn't end there, for the universe must then locate this more-complicated material in the right place. It must find itself in orbit around a long-lived star. Why is orbiting a star so crucial? It is the only place in the universe cool enough for heavy elements to be stable, yet hot enough to provide a constant source of energy for chemical reactions. An enormous energy flux, as the heat of nuclear fusion radiates into the void, is the vital factor.

The special conditions on which the anthropic principle is based provide this guarantee: that systems capable of chemical interaction are placed within a stable flow of energy. What kind of behavior is characterized by these conditions? The answer is dissipative structures. Ilya Prigogine postulated, then discovered the existence of a certain kind of order in far-from-equilibrium conditions (Nicolis and Prigogine 1977). The immutable law of entropy decrees that all environments closed off from the rest of the world will degrade to a disordered state. An open environment, however, can use the energy flows of entropy to "ride" the boundary between order and chaos with fantastic results. These dissipative structures can develop into the intricacies of life itself, as Erwin Schrödinger describes: "This difference in structure is of the same kind as that between an ordinary wallpaper in which the same pattern is repeated again and again in regular periodicity and a masterpiece of embroidery, say a Raphael tapestry, which shows no dull repetition, but an elaborate, coherent, meaningful design traced by the great master" (1945, 3). To put it in Smolin's words, "There is no reason to believe either a galaxy or the universe as a whole remotely approaches the complexity and intricacy of the organization of a single living cell" (1997, 145).

The anthropic conditions of the universe ensure the development of dissipative structures, but it would be premature to identify such structure with life. In 1987, Per Bak, Kurt Weisenfeld, and Chao Tang developed the mathematical seeds of the mechanism that builds this order out of randomness (Bak, Weisenfeld, and Tang 1988). They called it self-organized criticality (SOC). Two features stand out. First, the same process causes both major and minor events—a falling pebble may initiate a landslide, or it might come to a halt. Second, these systems never reach equilibrium; instead, they constantly "evolve from one metastable state to the next" (1988, 364). The range of systems exhibiting this behavior is immense. Bak, in cooperation with Kan Chen, developed computer models for earthquakes, forest fires, and economies (Bak and Chen 1991). Last, but not least, they considered modeling life.

Mathematician John Conway designed "The Game of Life" in 1970. It is a simple computer simulation of a real ecosystem, played out on a grid where each square can represent "space" for an organism (or a gene taking the value 1 or 0.) A random array of squares is colored in to begin with, and this arrangement develops according to some basic rules to represent reproduction and overcrowding. After some time, a steady state emerges, with complex static and dynamic configurations. Bak, Chen, and Michael Creutz investigated what would happen when a tiny alteration was made at this stage—a single live cell being introduced (Bak, Chen, and Creutz 1989, 780–82). They found a burst of unpredictable activity following a fractal power law. In their words, "The fact that activity does not decay or explode exponentially (become chaotic) indicates that life and death are highly correlated in time and space: the system has evolved into a critical state."

Jupiter's red spot is a dissipative system governed by SOC. So are the spiral arms of galaxies. Bak and Chen theorized (1989) that fractals themselves develop by means of SOC. It seems possible that all naturally occurring complexity arises this way. "The theory of complexity and the theory of criticality may generically be one and the same thing" (Bak and Chen 1991, 33). Arthur Peacocke, thinking of Prigogine's work, wrote, "these studies demonstrate that the mutual interplay of chance and law . . . is *creative*, for it is the combination of the two that allows new forms to emerge and evolve" (1991, 468). Bak, Chen, and others have shown that this "interplay of chance and law" is not just a creative agent but *the* creative impetus of our universe, with life itself its most complex and intricate flowering.

Yet this creative mechanism is dependent upon the universe's initial conditions, as sensitive as life itself to the dictates of the fundamental constants. Had the strong force been just slightly stronger, the universe may have transformed into an inert soup of helium within moments. This is a crucial result—what we understand as life is the crowning example of the family of complex, dynamical structures. Those who attend the anthropic principles should recognize the precise message of cosmology, for it is not that the universe is special because it supports life. The universe is special because it supports order, encouraging complexity. Imposing our human sense of direction upon the cosmos is the last word in arrogance. This is the dangerous attraction of the strong "anthropocentric" principle—it flatters us to see the heavens revolve around ourselves. Our explanations and understanding will progress only when we attend to the details of reality, for the miraculous solutions exist for us to find within our world, not without. The truth will prove more attractive than any metaphysical fantasy. A better phrasing of the "anthropic" principle, one drawn from cosmic coincidences and not read into them, would be: The universe must have those properties that allow the development of complexity through self-organization. More poetically, it might read thus: The universe must be as creative and fruitful as possible.

NOTES

1. Some oxygen is produced, of course, and is in limited quantities vital to life. It is also a necessary stepping-stone on the way to calcium, magnesium, and iron. But it is not produced to the exclusion of carbon itself.

2. Whether "the cause of the Big Bang" is a meaningful or meaningless concept is a metaphysical question that will not be taken up here.

3. Many theologians have centered their attention on what this says about us as people. Nancey Murphy and George Ellis (1996) betray a common bias as they phrase the strong principle: "Intelligent life must exist in the universe; it is a necessity." Where did that quintessentially human characteristic intelligence enter the picture? It stems from the amusing version of the weak principle: We cannot but observe a universe capable of supporting life-forms clever enough

to frame this very principle. True enough, but this just shows that the WAP is logically trivial—it's a tautology. The extension from WAP to SAP is not trivial; it depended upon our many observations about the fundamental constants, which imply nothing about intelligence. They describe the exacting constraints for life chemistry *of any kind*. It is very tempting to talk about intelligence and create an "anthropocentric" principle that returns humanity to the center of the universe. There is no evidence to substantiate such talk.

4. The anthropic principle deals with 10^{229} possible modern cosmologies, not 10^{229} logically possible universes made from green cheese.

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