

NATURAL EXPLANATIONS FOR THE ANTHROPIC COINCIDENCES

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ABSTRACT

The anthropic coincidences are widely claimed to provide evidence for intelligent creation in the universe. However, neither data nor theory supports this conclusion. No basis exists for assuming that a random universe would not have some kind of life. Calculations of the properties of universes having different physical constants than ours indicate that long-lived stars are not unusual, and thus most universes should have time for complex systems of some type to evolve. A multi-universe scenario is not ruled out since no known principle requires that only one universe exist.

THE ANTHROPIC COINCIDENCES

In 1919, Weyl expressed his puzzlement that the ratio of the electromagnetic force to the gravitational force between two electrons is such a huge number, $N_1 = 10^{39}$.¹ He wondered why this should be the case, expressing his intuition that pure numbers like π appearing in the description of physical properties should occur within a few orders of magnitude of unity. Unity, or zero, you can expect "naturally." But why 10^{39} ? Why not 10^{57} or 10^{-123} ? Some principle must select out 10^{39} .

In 1937, Dirac discovered that N_1 is the same order of magnitude as another pure number N_2 that gives the ratio of a typical stellar lifetime to the time for light to traverse the radius of a proton.² If one number being large is unlikely, how much more unlikely is for another to come along with about the same value?

In 1961, Dicke pointed out that N_2 is necessarily large in order that the lifetime of typical stars be sufficient to generate heavy chemical elements such as carbon. Furthermore, he showed that N_1 must be of the same order of N_2 for our universe to have elements heavier than lithium.³

According to the big bang theory, only hydrogen, helium, and lithium were formed in the early universe. Carbon, nitrogen, oxygen, iron, and all the other elements of the chemical periodic table were not produced until billions of years later. These billions of years were needed for stars to form and assemble the nuclei of these elements out of neutrons and protons. When the more massive stars expended their hydrogen fuel, they exploded as supernovae, spraying the manufactured elements into space. Once in space, the material cooled and accumulated into planets.

Billions of additional years were needed for our home star, the sun, to provide a stable output of energy so that at least one of its planets could develop life. But if the gravitational attraction between protons in stars had not been many orders of magnitude weaker than the electrical repulsion, as represented by the very large value of N_1 , stars would have collapsed and burned out long before nuclear processes could build up the periodic table from the original hydrogen and helium.

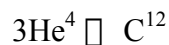
The element-synthesizing processes in stars depend sensitively on the properties and abundances of deuterium (heavy hydrogen) and helium produced in the early universe. Deuterium would not exist if the difference between the masses of a neutron and a proton were just slightly displaced from its actual value. The relative abundances of hydrogen and helium also depended strongly on this parameter. They also required a balance of the relative strengths of gravity and the weak interaction, the force responsible for nuclear beta decay. A slightly stronger weak force and the universe would be 100 percent hydrogen. In that case, all the neutrons in the early universe will have decayed leaving none around to be saved in helium nuclei for later use in the element-building processes in stars. A slightly weaker weak force and few neutrons would have decayed, leaving about the same numbers of protons and neutrons. In that case, all the protons would have been bound up in helium nuclei, with two protons and two neutrons in each. This would have led to a universe that was 100 percent helium, with no hydrogen to fuel the fusion processes in stars. Neither of these extremes would have allowed for the existence of stars and life, as we know it, based on carbon chemistry.

The electron also enters into the tightrope act needed to produce the heavier elements. Because the mass of the electron is less than the neutron-proton mass difference, a free neutron can decay into a proton, electron, and anti-neutrino. If this were not the case, the neutron would be stable and most of the protons and electrons in the early universe would have combined to form neutrons, leaving little hydrogen to act as the main component and fuel of stars. The neutron must be heavier than the proton, but not so much heavier that neutrons cannot be bound in nuclei, where conservation of energy prevents them from decaying. Without these bound neutrons, complex nuclei would not be possible.

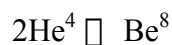
THE HOYLE PREDICTION

In 1952, Hoyle used anthropic arguments to predict that the carbon nucleus has an excited energy level at around 7.7 MeV. He looked closely at the nuclear mechanisms involved and found that they were inadequate in the absence of this energy level.

The basic mechanism for the manufacture of carbon is:



However, the likelihood of three bodies coming together simultaneously is very low and some catalytic process in which only two bodies interact at a time must be assisting. A two-step process had earlier been suggested:



Hoyle showed that this still was not sufficient unless the carbon nucleus had an excited state at 7.7 MeV to provide for a high reaction probability. A laboratory experiment was undertaken and a previously unknown excited state of carbon was found at 7.66 MeV.⁴

More recently, Agrawal et al have shown that the Higgs vacuum expectation value, one of the most important parameters in the standard model of elementary particles and forces, cannot be more than five times its current measured value or else complex nuclei would be unstable.⁵ Jeltema and Sher have shown that this same parameter cannot be less than 90 percent of its measured value for the 7.7 MeV carbon excited energy level to occur.⁶

THE COSMOLOGICAL CONSTANT PROBLEM

One final example of an "anthropic coincidence" is the very low value that is observed for the energy density of the vacuum. Einstein's cosmological constant, an arbitrary parameter from general relativity, has been taken to be zero for most of the twentieth century for the simple and adequate reason that this value was consistent with the data. However, the cosmological constant resurfaced around 1980 in the inflationary model of the early universe. Additionally, recent observations indicate the universe may in fact be accelerating, which has no explanation within existing physics other than the universe possessing some residual value of the cosmological constant.

A non-zero cosmological constant is equivalent to an energy density in a vacuum otherwise empty of matter or (what is the same thing) energy. Quantum fluctuations will also result in a non-zero vacuum energy density, and so the total energy density of the vacuum is the sum of two contributions. Weinberg pointed out, from dimensional arguments, that the standard model implies a quantum energy density of the order of 10^8 GeV^4 (in units where $\hbar = c = 1$).⁷ Observations, on the other hand, indicate that the total vacuum energy density is of the order of 10^{-48} GeV^4 or less. In order to cancel the quantum fluctuations, the value of the cosmological constant had to be "fine-tuned" to some 56 orders of magnitude. If this had not happened, the universe would look vastly different than it does now and, no doubt, life, as we know it would not exist.

THE ANTHROPIC PRINCIPLES

In 1974, Carter introduced the catchy notion of the anthropic principle, which hypothesizes that the coincidences we have discussed, and many others, are not the result of chance but somehow built into the structure of the universe.⁸ Barrow and Tipler have identified three versions of the anthropic principle:⁹

Weak Anthropic Principle (WAP): The observed values of all physical and cosmological quantities are not equally probable but 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.

The WAP simply says that if the universe were not the way it is, we would not be here talking about it. The fact that we are here allows us to make predictions about physical phenomena, such as the 7.7 MeV nuclear energy level in carbon, and place limits on many physical parameters.

Strong Anthropic Principle (SAP): The Universe must have those properties, which allow life to develop within it at some stage in its history.

This is a rewording of what was originally suggested by Carter, who proposed that the anthropic coincidences are not accidental but the result of a law of nature. But it is a strange law indeed, unlike any other in physics. It suggests that life exists as some Aristotelian "final cause."

Barrow and Tipler identify three interpretations of the SAP:

(A) There exists one possible Universe 'designed' with the goal of generating and sustaining 'observers.'

This is the interpretation that has been adopted by theists as a new argument from design.

(B) Observers are necessary to bring the Universe into being.

This is traditional solipsism, but also is a part of today's New Age mysticism.

(C) An ensemble of other different universes is necessary for the existence of our Universe.

The current dialogue focuses on the choice between (A) and (C), with (B) not taken seriously in neither the scientific nor theological communities.

Final Anthropic Principle (FAP): Intelligent, information-processing must come into evidence in the Universe, and, once it comes into existence, it will never die out.

In The Anthropic Cosmological Principle, Barrow and Tipler speculated only briefly about the implications of the FAP. Tipler later propounded its consequences in a controversial book with the provocative title: The Physics of Immortality: Modern Cosmology, God and the Resurrection of the Dead. Here Tipler carries the implications of the FAP about as far as one can imagine they could go. He adapts the fantasy of Teilhard de Chardin, suggesting that we will all live again as emulations in the cyber mind of the Omega Point God who will ultimately evolve from today's computers.¹⁰ I will not consider this scenario in this paper.

EVIDENCE FOR DESIGN?

A new convergence of science and religion has been widely reported in the media.¹¹ Many theists see the anthropic coincidences as evidence for purposeful design to the universe. They ask: how can the universe possibly have obtained the unique set of physical constants it has, so exquisitely fine-tuned for life as they are, except by purposeful design--design with life and perhaps humanity in mind? Edward Harrison has stated it this way:

"Here is the cosmological proof of the existence of God--the design argument of Paley--updated and refurbished. The fine-tuning of the universe provides prima facie evidence of deistic design. Take your choice: blind chance that requires multitudes of universes or design that requires only one."¹²

The fine-tuning argument is a probabilistic one, as was Paley's. The claim is that the probability for anything but external, intelligent design is vanishingly small. However, based on the data, the number of observed universes $N_o = 1$ while the number of observed universes with life $N_L = 1$. Thus, the probability that any universe has life = $N_L / N_o = 1: 100$ percent! Admittedly, the statistical error is large. The point is that data alone cannot be used to specify whether life is likely or unlikely, and no probability argument can be made that rests on data. It can only rest on theory, and, as we will see, neither physical nor cosmological theories, as we currently know them, require design.

Ultimately fatal to the design argument is the unwarranted assumption that only one type of life is possible--a chemistry-based life such as we have here on earth. This would not exist except for the narrow range of parameters in our universe. Ross typifies this narrow perspective on the nature of life:

"As physicist Robert Dicke observed thirty-two years ago, if you want physicists (or any other life forms), you must have carbon. Boron and silicon are the only other elements on which complex molecules can be based, but boron is extremely rare, and silicon can hold together no more than about a hundred amino acids. Given the constraints of physics and chemistry, we can reasonable assume that life must be carbon based."¹³

Carbon would seem to be the chemical element best suited to act as the building block for the type of complex molecular systems that develop lifelike qualities. However, other possibilities than amino acid chemistry and DNA cannot be ruled out. Given the known laws of physics and chemistry, we can imagine life based on silicon or other elements chemically similar to carbon.

Computer chips, after all, are made of silicon, and these operate a billion times faster than carbon-based biological systems. The network of computer chips known as the World Wide Web resembles the neural network of the brain, and seems to have taken on a life of its own. However, all elements heavier than lithium require cooking in stars and thus a universe old enough for star evolution. The $N_1 = N_2$ coincidence would still hold in this case.

Only hydrogen, helium, and lithium were synthesized in the early big bang. These are probably chemically too simple to be assembled into diverse structures. So, it seems that any life based on chemistry would require an old universe, with long-lived stars producing the needed materials.

Still, we have no basis for ruling out other forms of matter than molecules in the universe as building blocks of complex systems. While atomic nuclei, for example, do not exhibit the diversity and complexity seen in the way atoms assemble into molecular structures; perhaps they might be able to do so in a universe with different properties. This is only speculation, but I am not claiming to have a theory of such systems, merely pointing out that no known theory says that such life forms are impossible.

Sufficient complexity and long life may be the only ingredients needed for a universe to have some form of life. Those who argue that life is highly improbable fail to admit that life could be possible with many different configurations of laws and constants of physics.

GENERATING ALTERNATE UNIVERSES

I have made a preliminary attempt to obtain some feeling for what a universe with different physical constants would be like. It happens that the properties of matter, from the dimensions of atoms to the lifetime of stars, can be estimated from the values of just four fundamental constants. Two of these constants are the strengths of the electromagnetic and strong nuclear interactions. The other two are the masses of the electron and proton.

Of course, many more constants are needed to fill in the details of our universe. And our universe, as we have seen, might have had different physical laws. We have little idea what those laws might be; all we know are the laws we have. Still, varying the constants that go into our familiar equations will give many universes that do not look a bit like ours. They still have atoms and stars, but the dimensions of these objects will appear weird by our standards.

I have created a program, MonkeyGod, which can be executed on the World Wide Web.¹⁴ Try your own hand at generating universes! Just choose different values of the four constants and see what happens. While these are really only "toy" universes, the exercise illustrates that many different universes are possible, even within the existing laws of physics.

The four adjustable parameters of the program are:

- α the electromagnetic interaction strength $e^2/\hbar c$
- α_s the strong nuclear interaction strength at low energy
- m_e the mass of the electron
- m_p the mass of the proton

The constants \hbar , c , G , k_B are not considered parameters. They just define the units you choose to use and can all be set to unity with no change in the physics.

Only "low energy" physics is used in MonkeyGod. Effects of the weak interactions, for example, are not included.

The following are textbook equations:

Bohr radius:

$$r_B = \hbar (\alpha m_e c)^{-1}$$

Ground state of hydrogen atom:

$$E_B = \alpha^2 m_e c^2 / 2$$

Radius of nucleon:

$$r_N = \hbar (\alpha_s m_p c)^{-1}$$

Ground state energy of a nucleon:

$$E_N = \alpha_s^2 m_p c^2 / 2$$

Dimensionless gravitational strength:

$$\alpha_G = G m_p^2 (\hbar c)^{-1}$$

The following is from Salpeter¹⁵ and Carr and Rees¹⁶:

Lifetime of a main sequence star:

$$t_s = (\alpha^2 / \alpha_G) (m_p / m_e)^2 \hbar (m_p c^2)^{-1}$$

The following are from Press and Lightman¹⁷:

Maximum mass of cold, degenerate star (Chandrasekhar mass):

$$M_C = \alpha_G^{-3/2} m_p$$

Minimum mass and radius of planet:

$$M = m_p (\alpha / \alpha_G)^{3/2} (m_e / m_p)^{3/4}$$

$$R = r_B (\alpha / \alpha_G)^{1/2} (m_e / m_p)^{1/4}$$

Length of a "universal day":

$$T_{\text{day}} = 2\pi (2)^{3/2} r_B / c (m_p / m_e)^{1/2} (\alpha \alpha_G)^{-1/2}$$

Year for a habitable planet:

$$T_{\text{year}} = 0.2 r_B / c (m_p / m_e)^2 \alpha^{13/2} \alpha_G^{-1/8}$$

Finally, the large numbers are:

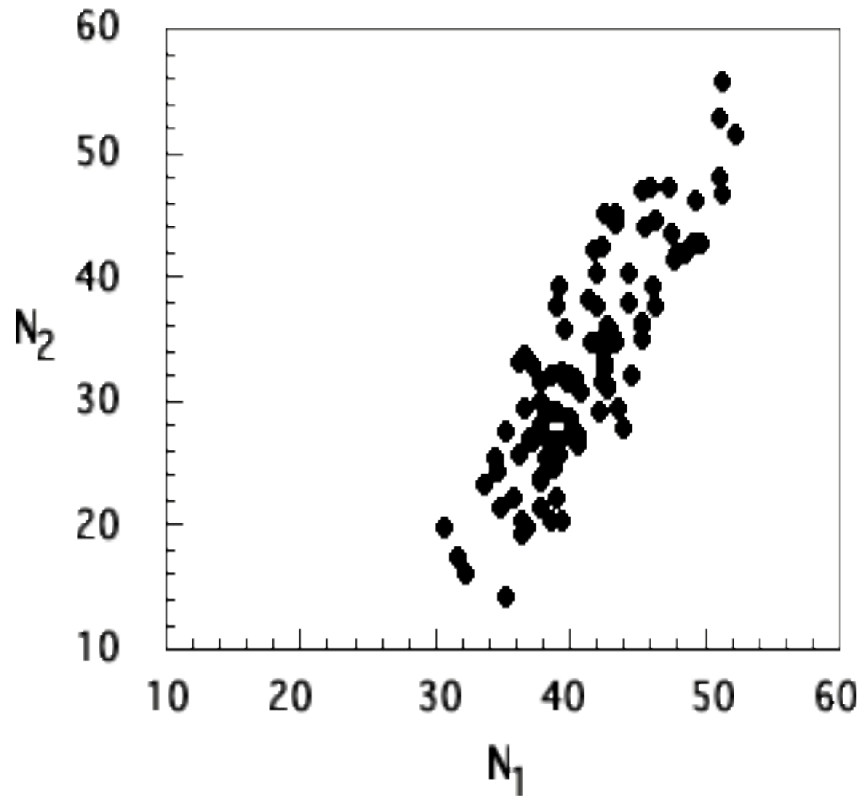
$$N_1 = (\rho / \rho_G) (m_p / m_e)$$

$$N_2 = \rho_s (m_p / m_e) N_1$$

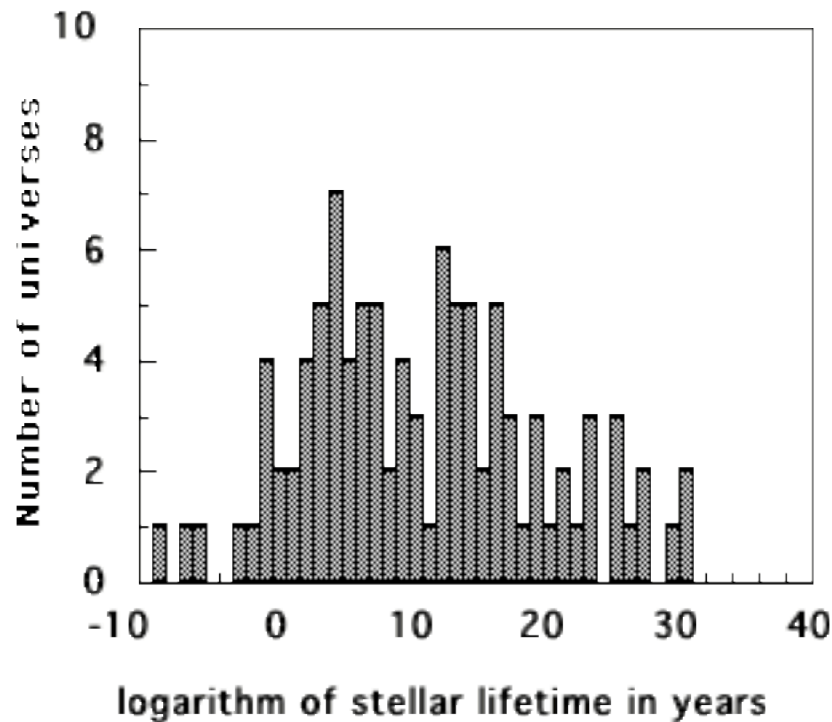
As an example, I have analyzed 100 universes in which the values of the four parameters were generated randomly from a range five orders of magnitude above to five orders of magnitude below their values in our universe, that is, over a total range of ten orders of magnitude. Over this range of parameter variation, N_1 is at least 10^{33} and N_2 at least 10^{20} in most cases, as seen in Figure 1. That is, both are still very large numbers. Although many pairs do not have $N_1 = N_2$, an approximate coincidence between these two quantities is not very rare.

The distribution of stellar lifetimes for these same 100 universes is shown in Figure 2. While a few lifetimes are low, most are probably high enough to allow time for stellar evolution and heavy element nucleosynthesis. Over half the universes have stars that live at least a billion years. Long life may not be the only requirement for life, but it certainly is not an unusual property of universes.

Recall Barrow and Tipler's option (C), which held that an ensemble of other, different universes is necessary in any natural explanation for the existence of our universe. Another claim that has appeared frequently in the literature (see, for example, Swinburne¹⁸) holds that only a multiple-universe scenario can explain the coincidences without a supernatural creator. No doubt this can do it, as we will see below. If many universes beside our own exist, then the anthropic coincidences are a no-brainer. But even if only one universe exists, the likelihood of some form of life in that single universe is not provably small.



The fine-tuning argument rests on the assumption that any form of life is possible for only a very narrow, improbable range of physical parameters. We can safely conclude that this assumption is completely unjustified. None of this rules out option (A) as the source of the anthropic coincidences. But it does show that the arguments that are used to support that option are very weak and certainly insufficient to rule out of hand all alternatives. If all those alternatives are to fall, making (A) the choice by default, then they will have to fall of their own weight.



INTERPRETING THE COINCIDENCES: THEY ARE NATURAL

Let us now move to the possibility that we can understand the anthropic coincidences naturally. Since all scientific explanations until now have been natural, then it would seem that the best bet is a natural explanation for the anthropic coincidences. Such an explanation should demand the fewest in the way of extraordinary hypotheses.

The standard model of elementary particles and fields has, perhaps for the first time in scientific history, given us a powerful theory that is consistent with all experiments performed to-date. More than that, in developing the standard model physicists have gained significant new insights into the nature of the so-called laws of nature.

Prior to these recent developments, the physicist's conception of the laws of nature was pretty much that of most lay people: those laws were assumed to be rules for the behavior of matter and energy that are part of the very structure of the universe, laid out at the creation. However, in the past several decades we have gradually come to understand that what we call "laws of physics" are basically our own descriptions of certain symmetries observed in nature and the way in which these symmetries, in some cases, happen to be broken. The particular laws we have identified do not require a supernatural agent to bring them into being.

The most powerful of the laws of physics are the great conservation principles of energy, momentum, angular momentum, charge, and other quantities that are measured in fundamental interactions. These apply whenever a system of bodies is sufficiently isolated from its environment.

For over a century now, physicists have known that whenever their description of the motion of a body does not depend on a particular generalized coordinate q , then the generalized momentum p conjugate to that coordinate is conserved. That generalized coordinate can be a spatial coordinate, time, or an angular coordinate. The corresponding conjugate momentum can

be a component of linear momentum, energy, or a component of angular momentum. The conjugate momenta act as generators of the transformations made along or around particular coordinate axes. This description applies in both classical and quantum mechanics.

Thus, time translational symmetry implies energy conservation. Space translational symmetry implies momentum conservation. Rotational symmetry implies angular momentum conservation. Furthermore, the Lorentz invariance of special relativity follows as an expression of rotational symmetry in four-dimensional space-time.

Now consider the objects in the universe. Unless acted on by some outside agent, they will behave the same regardless of where we position the origin of coordinate axes used to place them in space-time, or how we orient those axes. It follows, from their very definitions, that energy, momentum, angular momentum, and any other quantities of the type that are conjugate to these coordinates will be conserved. Furthermore, all of special relativity (time dilation, Lorentz-Fitzgerald contraction, $E = mc^2$) is explained "naturally."

In other words, the universal conservation "laws" are exactly what will occur in an isolated universe with no outside agent acting. They derive from global symmetries, such as space translation and time translation. Only a violation of these laws would imply an outside agent. The data so far are consistent with the absence of an agent.

In the last few decades, the importance of spontaneously broken local symmetries has come to be recognized. This has been combined with our understanding of unbroken global symmetries to produce a coherent scheme in which everything we now know seems to broadly fit.

Broken symmetry is very common at the everyday scale. Not all cars travel in straight lines at constant speed. They roll to a stop when the engine cuts off, as energy is lost to friction. Neither are the material structures we see around us fully symmetric. The earth is not a sphere but a flattened spheroid. A tree looks different from different angles. Our faces look different in a mirror. Mirror symmetry is broken when a system is not precisely left-right or mirror symmetric, like our faces. That is no surprise, and indeed we can view much of what we call material structure as a combination of broken and unbroken symmetries. Think of a snowflake. Structure and beauty seem to be combinations of both unbroken and broken symmetries, of order and randomness.

The big revelation to physicists in the 1950s was that a few, rare nuclear and fundamental particle interactions are not mirror symmetric. This discovery triggered an awakening to the possibilities of symmetry breaking at the fundamental scale in other situations. In many cases, this was merely an expression of old facts in a new language. For example, a symmetry such as momentum conservation can be broken locally without destroying the overall space-translation symmetry of the universe. When momentum conservation is locally broken, as with a falling body, we say we have a force acting. Indeed Newton's second law of motion specifies that force is equal to the time rate of change of momentum. In this case, global momentum conservation is maintained as interacting bodies in an isolated system have an equal and opposite reaction, as expressed by Newton's third law.

Thus the forces of nature have come to be recognized--and described theoretically--as spontaneously broken local symmetries. The standard model of elementary particles and forces was built on a framework of broken symmetry.

IN THE BEGINNING

For almost two decades, the inflationary big bang has been the standard model of cosmology.^{19,20} This model offers a plausible natural scenario for the uncaused origin and evolution of the universe, including the formation of order and structure, without the violation of

any laws of physics.²¹ Indeed, as we saw above, these laws themselves are now understood far more deeply than before and we are beginning to grasp how they too could have come about naturally. This particular version of a natural scenario for the origin of the universe has not yet risen to the exalted status of a scientific "theory." However, the fact that it is consistent with all current knowledge and cannot be ruled out at this time demonstrates that no rational basis exists for introducing the added hypothesis of supernatural creation. Such a hypothesis is simply not required by the data.

According to the natural scenario, by means of a random quantum fluctuation the universe tunneled from pure vacuum ("nothing") to what is called a false vacuum, a region of space that contains no matter or radiation but is not quite nothing. The space inside this bubble of false vacuum was curved, or warped. A small amount of energy (approximately the rest energy of 20 micrograms of matter) of was contained in that curvature, somewhat like the energy stored in a strung bow. This ostensible violation of energy conservation is allowed by the Heisenberg uncertainty principle for sufficiently small time intervals.

The bubble then inflated exponentially and the universe grew by many orders of magnitude in a tiny fraction of a second. As the bubble expanded, its curvature energy was converted into matter and radiation, inflation slowed to a stop by a kind of friction (this all follows from the equations²²), and the more linear big bang expansion we now experience commenced. The universe cooled and its structure spontaneously froze out, as formless water vapor freezes into snowflakes whose unique patterns arise from a combination of symmetry and randomness.

In our universe, the first galaxies began to assemble after about a billion years, eventually evolving into stable systems where stars could live out their lives and populate the interstellar medium with the complex chemical elements such as carbon that are needed for the formation of life.

So how did our universe happen to be so "fine-tuned" as to produce wonderful, self-important carbon structures? As explained above, we have no reason to assume that ours is the only possible form of life. Some sort of life could have happened in a universe of greatly different form--however the crystals on the arm of the snowflake happened to be arranged by chance.

At some point, according to this scenario, the symmetries of the initial nothingness were spontaneously broken. Those of the current standard model of elementary particles and forces were among the last broken, when the universe was about 10^{-12} second old and much colder than earlier. The distances and energies involved at this point have been probed in existing colliding beam accelerators, representing the deepest into big-bang physics we have so far been able to explore in detail. Higher energy colliders will be necessary to push farther, but we are far from directly probing the earliest time scales where the ultimate symmetry breakdown can be explored. Nevertheless, at least the physical principles which have been in place since a trillionth of a second after the universe began are now very well understood and we can at least extrapolate in general terms to earlier times.

By about a millionth of a second, the early universe had gone through all the symmetry breaking required to produce the fundamental laws and constants we still observe today, 13-15 billion years later. Nuclei and atoms still needed more time to get organized, but after 300,000 years the lighter atoms had assembled and ceased to interact with the photons that went off on their own to become the cosmic microwave background. The first galaxies began to assemble after about billion years, evolving eventually into stable systems where stars could live out their

lives and populate the interstellar medium with the heavier elements like carbon needed for the formation of life.

Regardless of the fact that we cannot explore the origin of the universe by any direct means, the undoubted success of the theory of broken symmetry, as manifested in the standard model of particle physics, provides us with a mechanism that we can apply, at least in broad terms, to provide a natural explanation for the development natural law within the universe. No lawgiver need be invoked to institute those laws from the outside. I am not claiming that cosmologists have a complete theory of the origin of the universe, just describing a scenario that is consistent with current knowledge and does not require a creator.

We have seen that the conservation laws correspond to global symmetries that require no outside agent. The total chaos that was likely the state of the universe at the earliest definable time possessed space translation, time translation, rotation, and all the other symmetries that result when a system depends on none of the corresponding coordinates. For these we clearly have no need to introduce the uneconomical hypothesis of external design.

The force laws, as exist in the standard model, are represented by spontaneously broken symmetries, that is, symmetries that are broken randomly--again without cause or design. As an analogy, consider what happens when a ferromagnet cools below a certain critical temperature called the Curie point. The iron undergoes a change of thermodynamic phase and a magnetic field suddenly appears that points in a specific, though random, direction. This field breaks the original symmetry in which no direction was singled out ahead of time. The resulting direction is not predictable by any known theory.

The forces of nature, in the natural scenario, are akin to the magnetic field of a ferromagnet. The "direction" they point to after symmetry breaking was not determined ahead of time. The nature of the forces, specified by this direction, was not pre-specified. They just happened to freeze out the way they did. And so, just as no agent is implied by global symmetries, in fact quite the opposite, none is implied by broken symmetries, which in fact look very much like the opposite.

Now theists may argue that I am simply assuming the absence of divine causation and not proving it. I am not claiming to prove that such causation does not exist. Rather I am simply demonstrating that, based on current scientific knowledge, none is necessary. Theists have the burden of proving otherwise since theirs is the less economical alternative, postulating forces that are not required to exist.

In the natural scenario I have provided, the values of the constants of nature in question are not the only ones that can occur. A huge range of values are in fact possible, as are all the possible laws that can result from symmetry breaking. The constants and forces that we have were selected by accident, when the expanding universe cooled and the structure we see at the fundamental level froze out. Just as the force laws did not exist before symmetry breaking, so too the constants did not exist. They, after all, come along with the forces. In the current theoretical scheme, gauge bosons also appear as the carriers of the quantities like mass and charge and indeed the forces themselves. They provided the means by which the broken symmetries materialize and manifest their structure.

AN INFINITY OF UNIVERSES

Within the framework of established knowledge of physics and cosmology, our universe could be one of many in an infinite super universe or "multiverse." Each universe within the multiverse can have a different set of constants and physical laws. Some might have life of a different form than us, others might have no life at all, or something even more complex or so different that we cannot even imagine it.

Several commentators have argued that a multiverse cosmology violates Occam's razor (see, typically, Ellis²³). This is disputable. The entities that Occam's law of parsimony forbids us from multiplying beyond necessity are theoretical hypotheses, not universes. For example, although the atomic theory of matter multiplied the number of bodies we must consider in solving a thermodynamic problem by 10^{24} or so per gram, it did not violate Occam's razor. Instead, it provided for a simpler, more powerful, more economic exposition of the rules that were obeyed by thermodynamic systems, with fewer hypotheses.

Tegmark has argued that a theory in which all possible universes exist is actually more parsimonious than one in which only one exists.²⁴ Just as was the case for the breaking of the global conservation laws, a single universe requires more explanation--additional hypotheses. However, each side in the argument claims that their set of hypotheses is the more parsimonious and is not likely to be convinced on the basis of Occam's razor alone.

Multiple random universes within a larger multiverse are suggested by modern inflationary cosmology. As we have seen, a quantum fluctuation can produce a tiny, empty region of curved space that will exponentially expand, increasing its energy sufficiently in the process to produce energy equivalent to all the mass of a universe in a tiny fraction of second. Linde proposed that a background space-time "foam," empty of matter and radiation, will experience local quantum fluctuations in curvature, forming many bubbles of false vacuum that individually inflate into mini-universes with random characteristics.²⁰ In this view, our universe is one of those expanding bubbles, the product of a single monkey god banging away at the keys of a single word processor.

THE DESCENT OF THE UNIVERSE

Smith²⁵ and Smolin²⁶ have independently suggested a mechanism for the evolution of universes by natural selection. They propose a multi-universe scenario in which each universe is the residue of an exploding black hole that was previously formed in another universe.

An individual universe is born with a certain set of physical parameters--its "genes." As it expands, new black holes are formed within. When these black holes eventually collapse, the genes of the parent universe get slightly scrambled by fluctuations that are expected in the state of high entropy inside a black hole. So when the descendant black hole explodes, it produces a new universe with a different set of physical parameters--similar but not exactly the same as its parent universe. (To my knowledge, no one has yet developed a sexual model for universe reproduction.)

The black hole mechanism provides for both mutations and progeny. The rest is left to survival of the survivor. Universes with parameters near their "natural" values can easily be shown to produce a small number of black holes and so have few progeny to which to pass their genes. Many will not even inflate into material universes, but quickly collapse back on themselves. Others will continue to inflate, producing nothing. However, by chance some small fraction of universes will have parameters optimized for greater black hole production. These will quickly predominate as their genes get passed from generation to generation.

The evolution of universes by natural selection provides a mechanism for explaining the anthropic coincidences that may appear far out, but Smolin suggests several tests. In one, he predicts that the fluctuations in the cosmic microwave background should be near the value expected if the energy fluctuation responsible for inflation in the early universe is just below the critical value for inflation to occur. He also predicts a so-far unobserved connection between black holes and carbon production in stars.

It is no coincidence that the idea of the evolution of universes is akin to Darwin's theory of biological evolution. In both cases we are faced with explaining how unlikely, complex, non-equilibrium structures can form without invoking even less likely supernatural forces. Natural selection may offer a natural explanation.

TEGMARK'S ENSEMBLES

Tegmark has recently proposed what he calls "the ultimate ensemble theory" in which all universes that mathematically exist also physically exist.²³ By "mathematical existence," he means "freedom from contradiction." So, universes cannot contain square circles, but anything that does not break a rule of logic exists in some universe. Where do the rules of logic come from? They come from human language and the way we define the terms we use. They do not necessarily imply a platonic reality.

Tegmark claims his theory is scientifically legitimate since it is falsifiable, makes testable predictions, and is economical in the sense that I have already mentioned above--a theory of many universes contains fewer hypotheses than a theory of one. He finds that many mathematically possible universes will not be suitable for the development of what he calls "self-aware structures," his euphemism for intelligent life. For example, he argues that only a universe with three spatial and one time dimension can contain self-aware structures. In order that the universe be predictable to its self-aware structures, only a single time dimension is deemed possible. In this case, one or two space dimensions are regarded as too simple, and four or more space dimensions are reckoned as too unstable. However, Tegmark admits that we may simply lack the imagination to consider universes radically different from our own.

Tegmark examines the types of universes that would occur for different values of key parameters and concludes, as have others, that many combinations will lead to unlivable universes. However, the region of the parameter space where ordered structures can form is not the infinitesimal point only reachable by a skilled artisan, as asserted by proponents of the designer universe.

CONCLUSION

The new convergence of science and religion that has been reported in the media is more between believing scientists and theologians than believers and nonbelievers. Theistic scientists who wish to find evidence for design and purpose to the universe now think they have. Many say that they see strong hints of purpose in the way the physical constants of nature seem to be exquisitely fine-tuned for the evolution and maintenance of life. Although not so specific that they select out human life, these properties are called the "anthropic coincidences" and various forms of the "anthropic principle" have been suggested as the underlying rationale.

Theists argue that the universe seems to have been specifically designed so that intelligent life would form. Some have gone so far as to claim that this is already proved by the existence of the anthropic coincidences. The theist claim translates into a modern version of the ancient argument from design for the existence of God. However, the new version is as deeply flawed as its predecessors, making many unjustified assumptions and not being required by existing knowledge. One gross and fatal assumption is that only one kind of life, ours, is possible in any configuration of possible universes.

We have examined possible natural explanations for the anthropic coincidences. A wide variation of constants of physics has been shown to lead to universes that are long-lived enough for complex matter to evolve, though human life would certainly not exist in such universes.

The most powerful "laws of physics," the laws of conservation of energy, linear momentum, and angular momentum, argue against design rather than for it. They are directly related to the space-time symmetries that require no external design. Furthermore, the observed forces, particles, and other structure in our universe are consistent with the accidental, or spontaneous, breaking of symmetries at local points in space-time. This also militates against design or creation.

Although not needed to negate the fine-tuning argument, which falls of its own weight, from all that we know of fundamental physics and cosmology other universes besides our own are not ruled out. Theists claim that the notion of many universes is not parsimonious. However, it can be argued that a multiverse composed of many universes with different laws and physical properties is more consistent with Occam's razor than a single universe. We would need to hypothesize a new principle to rule out all but a single universe. If multiple universes exist, then we are simply in that particular universe which necessarily contained all the logically consistent possibilities that had the properties needed to produce us.

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