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 support 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 lead 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:

$$3He^4 \rightarrow C^{12}$$

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:

$$2He^4 \rightarrow Be^8$$

$$He^4 + Be^8 \rightarrow C^{12}$$

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 is 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] Observation, 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 have 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 focusses 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 Teillard 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 Salpeter[15] and Carr and Rees[16]:

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 Lightman[17] :

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":

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

Year for a habitable planet:

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

Finally, the large numbers are:

$$N_1 = (\alpha / \alpha_G)\, (m_p / m_e)$$

$$N_2 = \alpha\, \alpha_s\, (m_p / m_e)\, N_1$$

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, Swinburne[18]) 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.

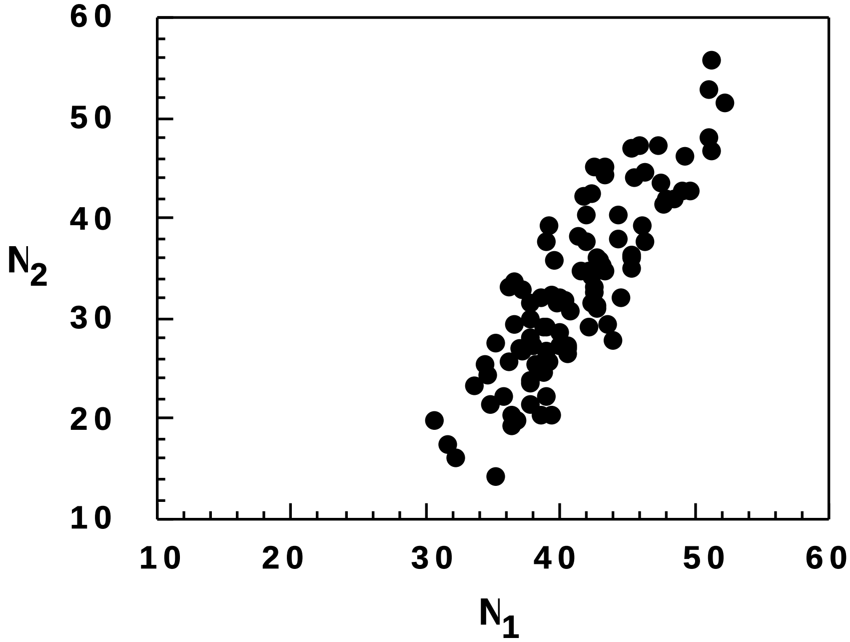

Figure 1 . Scatter plot of N_2 vs. N_1 for 100 universes in which the values of the four parameters were generated randomly from a range five orders of magnitude above and five orders of magnitude below their values in our universe.

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.

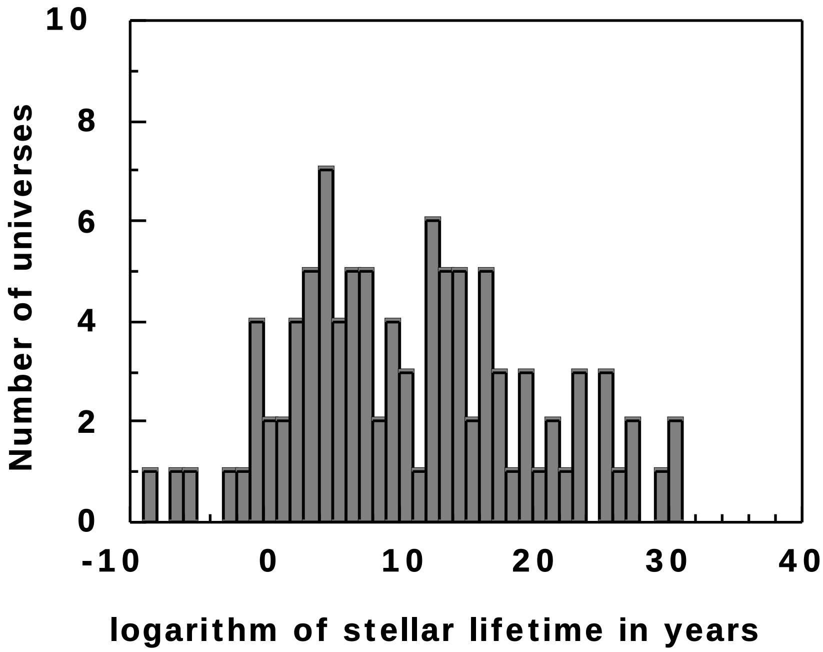

Figure 2 . Distribution of stellar lifetimes for the 100 random universes described in the text.

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 spacetime.

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 spacetime, 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, $E = mc^2$) are 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 a reexpression 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 equations[22]), 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 which 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 which 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, Ellis[23]). 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 are 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 spacetime "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

Smith[25] and Smolin[26] 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? The 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 is regarded as too simple, and four or more space dimensions is 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 spacetime 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 spacetime. This also mitigates 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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The Universe: the ultimate free lunch

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Abstract. It is commonly believed that the origin of the Universe must have involved the violation of natural laws, particularly energy conservation and the second law of thermodynamics. Here is it shown that this need not have been the case, that the Universe could have begun from a state of zero energy and maximum entropy, and then naturally evolved into what we see today without violating any known principles of physics. The fundamental particles and the force laws they obey then come about through a series of random symmetry-breaking phase transitions during the period of exponential expansion in the first fraction of a second after the Universe appears as a quantum fluctuation.

Zusammenfassung. Es wird allgemain angenommen, dass der Ursprung des Universums die Verletzung von Naturgesetzen bedingt, insbesondere die Verletzung des Energiesatzes und des zweiten Gesetzes der Thermodynamik. Hier wird jedoch gezeigt, dass das nicht der Fall sein muss, dass das Universum von einem Zustand mit null Energie und maximaler Entropie hätte beginnen können, und durch natürliche Evolution, ohne Verletzung bekannter physikalischer Prinzipien, sich in die heutige Form entwickelte. Die Elementarteilchen und die Kraftgesetze, denen sie gehorchen, folgen durch eine Reihe zufälliger symmetriebrechender Phasenübergänge während der exponentiellen Expansion in einem Bruchteil der ersten Sekunde, nachdem das Universum als eine Quantenfluktuation in Erscheinung tritt.

1. Introduction

Can the origin of the Universe be understood as a natural process? Recent work in particle physics and cosmology suggests that it can. Common sense seems to dictate that the Universe could not have just happened, that some transcendent force violating known principles of physics was required to bring it into existence. The commonsense arguments are basically twofold.

(1) *The no free lunch argument*:
'You can't get something for nothing.'

(2) *The argument from design*:
'How could all of this (gesturing to the world around us) have happened by chance?'

Here I will show that the physical law equivalents of these two commonsense statements need not have been violated to bring about the Universe. By means of a random quantum fluctuation, the Universe could have begun in maximum disorder, as an empty space-time of arbitrary negative curvature that then exponentially inflates, spontaneously forming structure by breaking the symmetries that existed initially.

Clearly the origin of the Universe is a subject of abiding general interest. Unfortunately, most of the recent developments that have provided enormous insight into this question are buried in the esoterica of theoretical particle physics and cosmology, making them inaccessible to all but those few trained in these fields. In a recent book, I tried to communicate some of these new ideas, in particular the notion of spontaneous origins, to the general reader (Stenger 1988). Here I try to strike a balance between the two extremes by using physics concepts that should be familiar to a wide audience, yet provide sufficient rigour to at least make the basic ideas clear.

2. The first and second laws of thermodynamics

The no free lunch argument can be translated into the language of physics as follows. When we say 'You can't get something for nothing we are giving the vernacular version of the *first law of thermodynamics*: the total heat energy added to a system equals the increase in internal energy minus any work done by the system. This is equivalent to the principle of conservation of energy. Since the Universe can reasonably be regarded as an isolated system, and since it now contains energy, then energy conservation must have been violated at some time presumably at the beginning when that energy was generated out of nothing.

The argument from design can similarly be associated with an apparent violation of the *second law of thermodynamics*: the total entropy of an isolated system cannot decrease with time. Thus the Universe, according to this argument, cannot have begun in chaos—maximum entropy—without an act of creation violating the second law to produce order, decreasing the entropy of the Universe.

Both of these principles, the first and second laws of thermodynamics, are believed to be such fundamental statements about the Universe that they are expected to have been valid at or near the beginning of time. The violation of either could reasonably be defined as a supernatural event—if by supernatural we mean the transcending of natural law.

3. The failure of common sense

Much of what constitutes commonsense knowledge of the Universe had been systematically incorporated into natural law by the end of the nineteenth century. Three nineteenth century concepts strongly implied that the origin of the Universe violated natural law.

(1) The Universe was believed to be a *firmament*. The Earth and other planets moved about the Sun, but the Sun and other stars were assumed essentially fixed in space.
(2) The second law appeared to require that the Universe started out in a state of maximum order, or minimum entropy, and was evolving toward a final end of total chaos—the *heat death*. Thus there had to be original order at the beginning of the Universe, a *grand design*.
(3) It was believed that matter could not be created or destroyed. Since matter exists, it must have been created supernaturally.

The revolutions in physics and astronomy that occurred in the early twentieth century turned these conclusions on their heads. There was three relevant developments.

(1) The Universe is not a firmament. Rather it is expanding as if it began in an explosion, the *big bang*, 10 or 15 billion years ago. Since the maximum entropy of an expanding volume increases as the volume increases, it becomes possible to begin in a state of maximum entropy —total chaos—and still obtain the formation of local order in the Universe without violating the second law as the Universe expands.
(2) $E = mc^2$. Matter can be created and destroyed.
(3) Quantum mechanics showed that certain events, such as atomic transitions and nuclear decays, happen spontaneously. Accidents happen (including accidental violations of the first law). Everything that occurs in the Universe is not predetermined by natural law. In fact, our so-called laws just apply to ensembles of systems, only guaranteeing the statistical behaviour of the ensemble while leaving the behaviour of an individual system to the vagaries of chance.

If anything characterises these three statements, it is that each violates our common sense as derived from our everyday observations about the world. Thus it should come as no surprise that they make possible a Universe whose origin also fails to follow our commonsense prejudices.

4. Order from chaos

Let me first demonstrate that the production of order in the Universe is not in violation of the second law of thermodynamics, even in the case where the Universe starts out of total chaos. The second law says that, for any closed system, the total entropy cannot decrease:

$$\Delta S = \sum_i \Delta S_i \geqslant 0 \tag{1}$$

where ΔS_i is the change in entropy of subsystem i. An individual subsystem can be ordered, $\Delta S_j < 0$, as long as the decrease in entropy is compensated by increases in other subsystems.

Entropy is defined as

$$S = k \ln\{\text{number of states}\}$$

which, for N particles of the same type, will be

$$\begin{aligned} S &= k \ln\{(\text{no of one-particle states})^N\} \\ &= kN \ln\{\text{a not-too-big number}\} \\ &\simeq kN. \end{aligned} \tag{2}$$

This provides a very simple definition of entropy adequate for cosmological problems. Working in units where $k = 1$ (temperature is measured in energy units), the entropy of a system of like particles is just the number of particles in the system:

$$S = N \qquad (k = 1). \tag{3}$$

In words, the more particles, the more disorder.

The current visible Universe has about 10^{22} stars. Each star contains about $N_A M_* = 10^{57}$ nucleons (or quarks) and electrons, where M_* is the mass of the star and N_A is Avogadro's number. Since the stars constitute a large fraction of the visible mass, the entropy of the visible matter $S_V \simeq 10^{79}$.

As we will now see, this is negligible compared to the entropy of the 3 K microwave background. From Stefan's law, the total kinetic energy in the background is that radiated by a 3 K black body of radius ct in a time t:

$$E_B = \sigma T^4 4\pi c^2 t^3 \simeq 10^{84}\ \text{eV} \tag{4}$$

where $t \simeq 10$ billion years is the age of the Universe and σ is the Stefan–Boltzmann constant. Since the average photon kinetic energy $kT = 2.6 \times 10^{-4}$ eV, the entropy of the photon background is $S_B \simeq 10^{87}$.

Since $S_B \gg S_V$, the entropy of the Universe is, for all practical purposes, given by the entropy of the relic photons (plus neutrinos and possible dark matter particles of comparable number) left over from the big bang. Since that entropy is so large, and the change in entropy required to order galaxies, stars, and planets is so small by comparison, the second law provides no problem for the production of tiny pockets of order in the Universe.

For example, consider ordering the Earth. This is done by energy from the Sun in the form of photons with an average energy kT_S, where $T_S = 5000$ K. Infrared photons with average energy kT_E, where $T_E = 300$ K, are then radiated back into space. For every photon absorbed from the sun, $5000/300 = 17$ are emitted back into space. Thus the Earth loses 16 units of entropy, the Sun one unit, and the two bodies become correspondingly more orderly while the rest of the Universe becomes more disorderly in the amount of 17 units of entropy.

The Earth absorbs 2.5×10^{36} photons from the Sun each second, so in the 4–5 billion years ($\simeq 10^{17}$ seconds) of the Earth's existence, the entropy of the Universe has increased by $(17)(2.5 \times 10^{36})(10^{17}) \simeq 10^{54}$. This is a tiny fraction of the total entropy of the Universe, which as we saw above is about 10^{87}.

5. The entropy of the early Universe

We are not so much interested in the current entropy as that of the early Universe. Supposing the Universe begins in total chaos, how is it possible for order even to form, consistent with the second law? To answer this, we need to determine how the entropy of the Universe changes as the Universe expands. When the Universe has a radius R, its entropy will be that of an expanding relativistic gas of total energy E. This will depend on the temperature of the gas. However, the maximum entropy will be simply (Frautschi 1982)

$$S_U^{\max} = \frac{E}{\varepsilon_{\min}} = \frac{E}{hc/\lambda_{\max}} = \frac{2\pi RE}{hc} = RE \qquad (5)$$

where $\varepsilon_{\min} = hc/\lambda_{\max}$ is the minimum energy of an individual photon, $\lambda_{\max} = 2\pi R$ is the corresponding maximum photon wavelength, and in the final step we switch to natural units: $\hbar \equiv h/2\pi = c = 1$.

6. The Planck length, time and mass

The smallest distance that can be operationally defined is the *Planck length*, $R_{PL} \simeq 10^{-33}$ cm. Within a sphere of this radius, the de Broglie–Compton wavelength of a particle equals the circumference of a black hole of the same mass.

$$2\pi R_{PL} = h/mc \qquad (6)$$

where, for a black hole, the rest energy equals the potential energy

$$mc^2 = Gm^2/R_{PL} \qquad (7)$$

and so, in natural units,

$$R_{PL} = \sqrt{G}. \qquad (8)$$

In addition to the Planck length, we define the Planck time $t_{PL} = R_{PL}/c \simeq 10^{-43}$ s and the Planck mass, as given by (7), $m_{PL} = 1/\sqrt{G} = 10^{19}$ GeV.

7. The entropy of a black hole

For reasons that will become clear, we also need to know the entropy of a black hole of mass M and radius R. Basically, the entropy will be given by the number of particles, or equally probably quantum levels, that can fit inside (Bekenstein 1973, Hawking 1976). From an argument similar to that given above for an expanding relativistic gas (Frautschi 1982),

$$S_{BH}^{\max} = \frac{Mc^2}{\varepsilon_{\min}} = \frac{Mc^2}{hc/\lambda_{\max}} = \frac{Mc^2 2\pi R}{hc} = RM \qquad (9)$$

in natural units. Now, $Mc^2 = GM^2/R$ as in (7), so $M = R/G = R/R_{PL}^2$ and

$$S_{BH}^{\max} = \frac{R^2}{R_{PL}^2}. \qquad (10)$$

Since we cannot see inside a black hole, we have no way of obtaining information about what is inside. The only properties of a black hole that can be described are those measurable from the outside, like mass, size, angular momentum and charge. Operationally, a black hole thus can have no internal structure so its inside must be total chaos. If a black hole has no internal structure, it must have maximum entropy. It follows that the maximum entropy of a body of radius R is that of a black hole of the same radius, as given in equation (10).

8. Complete chaos at the Planck time

If the inside of a black hole is total chaos, then any system with some degree of order must have an entropy less than that of a black hole of the same size. From (10), the maximum entropy of a black hole of radius $R = R_{PL}$ is unity. From (5), the maximum entropy for an expanding sphere of relativistic gas of that radius will exceed unity unless its total energy $E \leqslant m_{PL}$. However, from the uncertainty principle, the uncertainty in the momentum of a particle confined to a region of Planck dimensions will be $\Delta p \geqslant 1/R_{PL} = m_{PL}$, so its energy cannot be less than something of the order of m_{PL}. Thus, at $R = R_{PL}$, the entropy of an expanding relativistic gas must equal that of a black hole of the same radius. Since the entropy of the Universe is given by the number of relativistic particles regardless of epoch, the maximum entropy of the Universe at any radius R can be written:

$$S_U^{max} = R/R_{PL}. \tag{11}$$

The simple relations (10) and (11) make a profound point. Suppose we extrapolate back to the time when the Universe was a sphere of radius R_{PL}. The entropy of the Universe at that time was as great as it could possibly be, equal to that of a Planck-sized black hole. The Universe then was in complete chaos, with no structure, design or order. So instead of starting at a high level of order, as once was thought, we are forced to conclude that not only is a high level of order unnecessary at the origin of the Universe, the opposite —maximum disorder—is *required* if the Universe was ever as small as a Planck length. If the Universe was created with any grand design, it would have had to come into being with a size greater than the Planck length. Thus, the creation model of the origin of the Universe is reminiscent of the anti-evolutionist view that the Earth was created with all its structure and living species in place. Unsurprising, it is similarly *ad hoc*.

At $R = R_{PL}$, the Universe is operationally indistinguishable from a black hole. As Hawking (1974) has shown, quantum mechanics implies that a black hole is unstable, with a mean lifetime τ determined only by its mass M: $\tau = (M/m_{PL})t_{PL}$. So we can view the Universe beginning as a chaotic black hole of Planck dimensions that then explodes into an expanding relativistic gas at the Planck time. How can the order we clearly observe today then have resulted, consistent with the second law of thermodynamics? From (10) and (11), the entropy of the Universe is less than maximum once $R > R_{PL}$. As soon as the Universe becomes an expanding gas, order can form without violating the second law. Although, from (11), the entropy of the expanding relativistic gas from the initial explosion increases with R, the maximum allowable entropy of the Universe, from (10), is increasing faster, as R^2, allowing room for structure to form (Frautschi 1982). Since the Planck time, the Universe has expanded 61 orders of magnitude in radius, and so now has an entropy at least 61 orders of magnitude below its maximum possible value.

The structure of the Universe, at the most fundamental level, is described by the properties of the elementary constituents of matter and the force laws that govern how these constituents interact. We will now see how this structure can come about as a series of symmetry-breaking spontaneous phase transitions during the first fraction of a second of the expansion. In the process, we will see that the first law of thermodynamics is also not violated.

9. The Universe of matter and radiation

Suppose the Universe to be an expanding sphere of uniform mass density ρ. In general relativity, space itself is expanding and the radius of the sphere R is a scale factor that multiplies all distances. However we can avoid the formalism of general relativity and get many of the same results from a suitably modified Newtonian approach that I will use here. Also, since all reference frames are equivalent, we can work in the egocentric one in which we Earthlings are the centre of the Universe.

Let us neglect all except radial motions. Consider a body at a distance r. The Newtonian equation of motion for the body can be written:

$$\ddot{r}/r = -\tfrac{4}{3}\pi G\rho. \tag{12}$$

Since ρ is the fourth component of a 4-vector, (12) is not relativistically invariant. In general relativity, gravity couples to momentum as well as mass–energy through the stress–energy tensor and (12) is modified by replacing ρ with the invariant density, $\rho + 3P$, where P is the pressure in units where the speed of light $c = 1$. Then

$$\ddot{r}/r = -\tfrac{4}{3}\pi G(\rho + 3P). \tag{13}$$

When non-relativistic matter dominates, $P = 0$ and we get Newton's result (12). When the matter becomes extreme relativistic (speed $v \to c$), people unfortunately rename it 'radiation,' like photons, for which the equation of state is $P = \rho/3$. In that case,

$$\ddot{r}/r = -\tfrac{8}{3}\pi G\rho. \tag{14}$$

That is, extreme relativistic matter (like light) interacts via gravity with twice the strength as non-relativistic matter.

We are primarily interested in the early Universe, where all matter is extreme relativistic and we can expect (14) to apply. In that case, the total energy of a body of relativistic mass m at a distance r will be

$$E = mc^2 - \tfrac{4}{3}\pi mG\rho r^2. \tag{15}$$

Recall that mc^2 contains both rest and kinetic energy in general, but the rest energy is negligible when the particles are extreme relativistic.

The body will have zero total energy when the Universe has the critical density

$$\rho_c = 3H^2/8\pi G \tag{16}$$

where $H = v/r$ is the Hubble constant and $v = c$ in this case. Since we considered any arbitrary body interacting with the rest of the Universe, an exact balance between the total kinetic and gravitational potential energies of the universe will occur when $\rho = \rho_c$.

10. The empty Universe

One of the curiosities of Einstein's general theory of relativity is the *cosmological constant*. In Newtonian gravity, the stars cannot remain eternally at fixed points in space (for a finite Universe, and Olber's paradox rules out an infinite firmament). Eventually everything must collapse to a point. Einstein found that his equations allowed for an additional repulsive term, which he used to balance the attraction of gravity and provide for the firmament of stars. When Hubble later discovered that the Universe was not a firmament, the cosmological constant was put aside. Einstein never liked it anyway, since it seemed to violate Mach's principle, and called it his 'biggest blunder.'

Interest in the cosmological constant has been revived in today's investigations of the early Universe. Its role can best be seen from a very simple argument that does not require any of the technical detail of relativity. In general relativity, gravity results from the curvature of spacetime. For cosmological purposes, this curvature can be represented by the quantity $-\ddot{R}/R$, where R is the scale factor that multiplies distances as the Universe expands. In the usual case, the presence of matter results in positive curvature, as near a star or as with the homogeneous fluid in equation (13), which can be applied for $r = R$. However, a perfectly good solution of Einstein's equations is an empty Universe with constant spacetime curvature,

$$\ddot{R}/R = \Lambda/3 \tag{17}$$

where Λ is the cosmological constant that Einstein originally added to (13) to provide the repulsion needed to cancel the attraction of normal gravity and give a steady state universe. In the empty universe, the cosmological constant acts alone.

In that case, we can solve (17) to give the time dependence of R:

$$R(t) = R_0 \mathrm{e}^{Ht} \tag{18}$$

where $H = \dot{R}/R = (\Lambda/3)^{1/2}$ is the Hubble constant (though not the current one). So an empty (de Sitter) universe with negative constant curvature (positive Λ) will exponentially inflate with a Hubble constant determined by the cosmological constant.

As the volume of space expands, the total energy increases. This would seem to violate energy conservation; however, it does not. All that is required is for no heat to be added or subtracted for an isolated system, that is, the process of expansion must be adiabatic. From the first law of thermodynamics, the increase in the internal energy for an adiabatic expansion is equal to the work done on the system:

$$\mathrm{d}E = -P\,\mathrm{d}V. \tag{19}$$

Thus $P = -\mathrm{d}E/\mathrm{d}V = -\rho$, where ρ is the energy density (equal to the mass density in units where $c = 1$). Going back to (13) and substituting $P = -\rho$, we see that we get (17) with $\Lambda = 8\pi G\rho$. So a vacuum of negative spacetime curvature has a positive energy density but *negative* pressure. This is called the *false vacuum*. Normally we think of an expanding gas with positive pressure doing work on the outside world, lowering its internal energy if no heat is added. Here we have curved empty spacetime with constant negative pressure doing work on itself, adiabatically raising its own total internal energy as it expands. As we see, this does not violate the first law of thermodynamics. We can get something for nothing, if by nothing we mean no matter or radiation.

11. Starting the Universe from nothing

So can we understand how the Universe could have started from nothing? First we must free ourselves from the instinct of looking for a causal explanation for everything. If we extrapolate back in time to the Planck time, $t_{PL} = 10^{-43}$ s, the Universe was within the Planck radius, $R_{PL} = 10^{-33}$ cm. We have seen that this was *required* to be a situation of maximum chaos. As such, it could not have been the result of any causal process; or if it was, all the memory of that causal process would have been wiped out and the situation would be indistinguishable from one that is purely spontaneous. So the Universe had to have begun as a random fluctuation at the Planck time. The alternative theory is that it was created with a grand design after the Planck time, but this is *ad hoc* and can be ruled out by the law of parsimony: the supernatural creation of the Universe is a hypothesis not required by the data.

Now in a time interval $\Delta t = t_{PL}$, the uncertainty principle, $\Delta E \Delta t \geqslant \hbar/2$, implies that the initial energy of the Universe E_0 will have a (positive or negative) random value chosen from a normal distribution with a mean of zero and standard deviation $\Delta E = m_{PL}/2$. Thus we expect that, by accident, E_0 will be of the order of m_{PL}. The initial energy density ρ_0 then is of the order $\pm m_{PL}/R_{PL}^3 = \pm m_{PL}^4$. Since the Universe is empty, this energy density is contained in the curvature of spacetime, or, equivalently, we can say that the Universe began with a random cosmological constant Λ of the order of $\pm 8\pi G m_{PL}^4$. Suppose Λ was accidentally positive. Then the Universe exponentially inflated according to $R = \mathrm{e}^{Ht}$, where the Hubble factor $H = (\Lambda/3)^{1/3}$.

Now let me indulge in a little further magic. The Planck radius determines our basic units of distance, time and mass. Thus we can choose $R_{PL} = t_{PL} = \sqrt{G} = 1$, so Newton's constant $G = 1$ and the Planck mass $m_{PL} = 1$. I will call these *Planck units* ($\hbar = c = k = G = 1$). The advantage of working in Planck units is twofold. First it is simpler, with fewer symbols to carry around. But more important, it manifestly specifies that the value of G, like $\hbar$, c and k, is arbitrary. We do not need to find some grand principle to calculate the value of G. It has the only value it can have. As we will next see, the only quantity that is not arbitrary at the start of the Universe is Λ, and that is random but required to be of the order of unity in Planck units.

Later I will discuss the mechanism by which inflation stops, but for now let me assume that it does so at some time t'. At that time the volume of the Universe will have expanded by a factor $\exp(3Ht')$ and so the energy contained in the volume will have increased by the same factor.

This energy was available to produce the matter of the Universe. If, as is now commonly believed, the current mass density of the Universe is equal to the critical density given by (16), which is $10^{-30}\ \mathrm{g\,cm^{-3}}$ using the current value of the Hubble constant (around 10^{-61} in Planck units), and if the radius of the Universe is 10 billion light years, then the total current mass is 10^{55} g, corresponding to an energy of 10^{88} eV $= 10^{60}$ in Planck units. If the Universe started out with unit energy and unit radius, then it must have gone through 20 orders of magnitude of radial expansion before stopping at a radius of $10^{20}\ R_{PL} = 10^{-13}$ cm. Hey! That's the radius of the proton! This is an interesting coincidence, but I am not sure how profound it is. It says that, if you ask what radius a sphere must have to contain all the mass of the universe at the Planck density, you get the proton radius. In any case, $e^{Ht'} = 10^{20} = e^{46}$, and since $H \simeq (8\pi/3)^{1/3} = 3$ in Planck units, $t' \simeq 15$ Planck times or around 10^{-42} s.

12. The inflaton field

We have seen how a spontaneously appearing empty universe can inflate just as the result of the vacuum energy density it initially accidentally contains by virtue of the uncertainty principle. And, if it is allowed to inflate to the size of a proton, sufficient energy will have been pumped into the system, by the work done on itself by the negative pressure associated with this vacuum energy density, to create all the matter in the Universe. But, why doesn't the Universe just continue to inflate, remaining empty of matter forever? Some mechanism must exist to stop inflation and produce the particles and forces of Nature. Let us proceed to discuss the mechanism.

Since the energy density of the vacuum is associated with the scalar (that is, one-component) cosmological constant Λ, we can think of it as being carried by a scalar field ϕ. This is called the *inflaton* field. As a first approximation, we assume the field is real and classical, with quantum effects introducing statistical fluctuations. A classical scalar field can be treated as a unit mass particle with a Lagrangian density:

$$l = \tfrac{1}{2}(\dot{\phi})^2 - u(\phi) \tag{20}$$

where $u(\phi)$ is the potential energy density that describes the self-interaction of ϕ. Multiplying by the volume to get the Lagrangian, and using Lagrange's equations (making sure we take into account the expansion of the Universe: volume $\sim R^3$), we get the equation of motion:

$$\ddot{\phi} + 3H\dot{\phi} = -\partial u(\phi)/(\partial\phi) \tag{21}$$

where $H = \dot{R}/R$ is the Hubble constant, as before. Thus the expansion of the Universe adds a friction term $3H\dot{\phi}$ to the equation of motion of the inflaton field.

So, depending on the functional form of $u(\phi)$, ϕ will evolve with time. And, if and when the energy density $\rho = \frac{1}{2}(\dot{\phi})^2 - u(\phi)$ goes to zero, the inflation described by (18), where $H = (8\pi G\rho/3)^{1/2}$, will stop.

To get some idea of the form of $u(\phi)$, let us consider the example of a ferromagnet. In the Landau theory of phase transitions, the free energy density of a system like a ferromagnet can be written:

$$f = \tfrac{1}{2}\alpha M^2 + \tfrac{1}{4}\beta M^4 \tag{22}$$

where M is the magnetisation, or more generally, the *order parameter*. There is nothing very profound about (22); this is what you would get for the first two terms in a Taylor expansion around $M = 0$. The coefficient α is assumed to have a temperature dependence, $\alpha = a(T - T_c)$, so that the free energy is minimum at $M = 0$ when $T > T_c$. When the temperature drops below T_c, α becomes negative and the phase transition to ferromagnetism occurs with minimum free energy now at a non-zero value of $M = \pm(-\alpha/\beta)^{1/2}$.

Suppose that the free energy of the inflaton field has some similar properties to the magnetic field of a ferromagnet. That is, the self-interaction of the field contains short-range correlations that tend to minimise the free energy at a field value other than zero. Assuming the same form for $u(\phi)$, which can be interpreted as the free energy density with order parameter ϕ, we have

$$u(\phi) = u_0 + \tfrac{1}{2}\alpha\phi^2 + \tfrac{1}{4}\beta\phi^4 \tag{23}$$

where I have added a constant term at $\phi = 0$ to correspond to the initial state of the Universe with the energy density $\rho_0 = u_0$, which we have seen is of the order of unity in Planck units. If, like the ferromagnet, we are below the transition temperature where α is negative, we will have the potential energy density shown in figure 1, where the minima are at $\phi = \pm\sigma$, with $\sigma = (-\alpha/\beta)^{1/2}$.

The form (23) will hold for small deviations of ϕ from zero for any analytic even function of ϕ. The function must be even if ϕ is scalar, but otherwise the shape is arbitrary and σ is another accidental parameter, like ρ_0. The value it happens to have, gives us the universe we have. Another value would have given another universe, and perhaps did.

The spontaneously empty universe starts out at the top of the potential hill with no order, $\phi = 0$, but with random energy of the order of m_{PL} contained in its spacetime curvature so it begins to exponentially inflate. However the situation is not a stable one. Quantum fluctuations send the universe rolling down one side of the hill or the other, towards one of the valleys at $\phi = \pm\sigma$. As ϕ evolves, the energy density ρ decreases so the inflation is no longer a simple exponential, but the universe still grows enormously with the friction term in (21) acting to slow the fall to equilibrium.

Near the bottom of the hill, ϕ will oscillate and the universe will continue to inflate until ϕ is brought to rest by friction. This will eventually happen from the friction due to expansion alone. However this just produces a Universe filled with a uniform scalar field. Some additional mechanism must have existed—one that resulted in the production of the matter of the Universe.

13. Spontaneous symmetry breaking

The ferromagnet is an example of *spontaneous symmetry breaking*, in which the system relaxes to a state that does not preserve the symmetry of the underlying dynamics. Broken symmetry is order. Thus order appears, as measured by the order parameter M, where none previously existed. That order is accidental, since all orientations of magnetisation are initially equally likely. When the ferromagnet cools below the critical temperature, an arbitrary direction in space is randomly selected for the direction of magnetisation.

Now obviously the early Universe was not a ferromagnet and this is just an analogy. What is the actual nature of the inflaton field ϕ and what does it have to do with particle production and the spontaneous generation of the 'laws of Nature?' To explain, I must finally connect the discussion to recent developments in particle physics—a subject I have been able to studiously avoid so far.

Currently all experimental data are consistent with the *standard model* of elementary particles and forces. In this model, interactions between quarks and leptons are mediated by vector (spin 1) particles called *gauge bosons*: the photon, W, Z and gluon. The gauge bosons are intrinsically massless, but gain mass through their interaction with a background scalar field, called the Higgs field, which spontaneously breaks the underlying symmetry (Higgs 1965, 1966). This results in short-range forces, since the range of an interaction is inverse to the mass of the exchanged boson. The Higgs mechanism has been applied with greatest success in the Glashow–Weinberg–Salam unification of the infinite-range electromagnetic interaction with the weak interaction, whose range is a fraction of a proton diameter (Glashow 1961, Salam 1968, Weinberg 1967).

Linde (1979) proposed that the phase transition associated with the spontaneous symmetry breaking process could have cosmological implications, leading to a time dependence of particle masses, coupling constants and the cosmological term. Kazanas (1980) argued that the vacuum energy of the early Universe could lead to an exponential expansion in the way I have outlined here, resulting in a symmetry breaking phase transition. He suggested that this could explain the fact that the Universe is far more homogeneous than can be explained by the normal big bang expansion. Shortly thereafter, Guth recognised the fuller implications of these developing ideas and showed how exponential inflation explains why the Universe is now so flat and solves a number of other problems associated with the standard big bang (Guth 1981). Some problems with Guth's original scenario were resolved by the 'new inflationary model' independently proposed in 1982 by Linde in the Soviet Union (Linde 1982) and Albrecht and Steinhardt in the USA (Albrecht and Steinhardt 1982). Alternate ways in which inflation could have been triggered randomly from nothingness were proposed by Vilenkin (1983) and Linde (1983). A fuller discussion of these topics can be found in any number of reviews (e.g., Guth and Steinhardt 1984, Unruh and Semenoff 1986, Kolb *et al* 1986).

In the original inflationary models, the scalar field ϕ was taken to be the Higgs field specifically associated with grand unification theories (GUT) that attempted to bring the strong nuclear interaction into the unification scheme (Georgi and Glashow 1974, Georgi 1981). However, the simplest GUT, minimal SU(5), was falsified by the failure of its prediction of the proton lifetime and strong–electroweak unification is no longer fashionable as unification schemes, such as superstrings, attempt to include gravity in the picture. At the time of writing, the exact structure of the inflaton field is still unknown. However, it can be shown that the form (23) results from Higgs-type fields from general considerations not limited to any particular unification scheme (Linde 1979, Sher 1989).

14. The production of order

The association of the inflaton field ϕ with a Higgs-type field, not necessarily that of GUT, is a reasonable one and allows us to at least qualitatively understand how both matter and the 'laws of Nature' come about spontaneously. There are basically two types of laws of physics: conservation principles and force laws. Conservation of energy, momentum, angular momentum, charge and other quantities derive from fundamental symmetries of spacetime and the inner dimensions that account for certain degrees of freedom such as spin, charge and baryon number. These would exist as basic symmetries when spacetime and the inner dimensions first spontaneously appear.

Rather than representing order, symmetry principles actually correspond to a state of high disorder; they describe situations where no particular axis is preferred and thus a system has no structure. Order is not symmetry—order is broken symmetry. It occurs as the result of a phase transition from more symmetric but less orderly states, as with the freezing of a cloud of water vapour into a six-pointed snowflake. Force laws result from broken symmetry. Thus Newton's law of gravity describes how space trans-

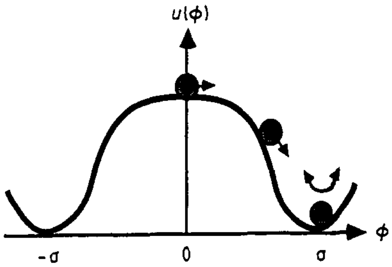

Figure 1. The Universe starts out empty with zero order, $\phi = 0$, and an energy density of the order of m_{PL}^4. This corresponds to a negative spacetime curvature, or negative pressure, and the Universe exponentially inflates. Since the free energy is not minimum, the Universe is in unstable equilibrium. A quantum fluctuation then sends it rolling down one side of the potential energy density hill or the other toward a minimum at $\phi = \pm\sigma$. Before stopping at the bottom, it oscillates about the minimum, dissipating its energy in the form of particle production. Since ϕ is an order parameter, $\phi = \pm\sigma$ corresponds to a broken symmetry. By the Higgs mechanism, the background field can give mass to vector bosons resulting in short range forces.

lation symmetry, or momentum conservation, is broken as a body falls to Earth.

Complex and unique structures exist in the Universe because of the variety of fundamental particles from which they are assembled, and the variety of the forces between these particles. Starting out alike in the early symmetric and chaotic Universe, diverse properties result as the Universe cools and passes through a series of symmetry breaking phase transitions.

At the Planck time there is maximum disorder, so the order parameter ϕ is initially zero, give or take quantum fluctuations. By analogy with the ferromagnet, and from our association of ϕ with the Higgs field, $u(\phi)$ can be assumed to be of the form shown in figure 1. Particle production then occurs when the ϕ field oscillates around the potential minimum before coming to rest, in a way analogous to the production of spin waves in a magnet by the oscillation of the magnetisation about equilibrium. These are called Goldstone oscillations. Just as the oscillation of an electromagnetic field can product photons, Goldstone oscillations will produce massless vector bosons. These vector bosons then gain mass through the Higgs mechanism which results from the non-zero equilibrium value of the background scalar field $\phi = \pm\sigma$ that is left when the oscillations cease. Once the vector bosons exist, they can interact producing pairs of fermions—quarks and leptons or some precursors—which then interact with one another via vector boson exchange.

At this point the Universe is no longer in the state of chaos that initially existed. Order exists, as manifested by the non-zero value of ϕ. This order, like that of the ferromagnet, was accidental, resulting from the spontaneous breaking of the original symmetry of the system.

Thus we imagine the complex array of particles and forces of Nature appearing, by chance, through a series of phase transitions in the early Universe, as the Universe is heated by particle production, cooled by expansion below the critical temperature for the next phase transition, and then reheated again for the next stage. Finally the sequence stops with the quarks, leptons and forces we know today, the curvature becoming negligible and the linear expansion of the big bang takes over. Because the symmetry between matter and antimatter that initially existed was broken by one of the early phase transitions, the annihilation of particles and antiparticles into the photons now part of the microwave background was not perfect, leaving a small residue of one part in a billion quarks and electrons that then stuck together in the clumps that we call galaxies, stars, planets, rocks, trees and people.

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Defending *The Fallacy of Fine-Tuning*

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Abstract

In 2011, I published a popular-level book, *The Fallacy of Fine-Tuning: Why the Universe is Not Designed for Us*. It investigated a common claim found in contemporary religious literature that the parameters of physics and cosmology are so delicately balanced, so "fine-tuned," that any slight change and life in the universe would have been impossible. I concluded that while the precise form of life we find on Earth would not exist with slight changes in these parameters, some form of life could have evolved over a parameter range that is not infinitesimal, as often claimed. Postdoctoral fellow Luke Barnes has written a lengthy, highly technical review of the scientific literature on the fine-tuning problem. I have no significant disagreement with that literature and no prominent physicist or cosmologist has disputed my basic conclusions. Barnes does not invalidate these conclusions and misunderstands and misrepresents much of what is in the book.

1. Introduction

In 2011, I published a popular-level book, *The Fallacy of Fine-Tuning: Why the Universe is Not Designed for Us*.[1] It investigated a common claim found in contemporary religious literature that the parameters of physics and cosmology are so delicately balanced, so "fine-tuned," that any slight change and life in the universe would have been impossible. I concluded that while the precise form of life we find on Earth would not exist with slight changes in these parameters, some form of life could have evolved over a parameter range that is not infinitesimal, as often claimed.

The simplest solution to the fine-tuning problem, and the favorite among scientific experts, is that our universe is just one in a multitude of universes and we just happen to live in the one suited for us. While I fully respect this possibility, I have limited my investigation to a single universe.

Postdoctoral fellow Luke Barnes has written a lengthy, highly technical review of the scientific literature concerning the fine-tuning problem titled "The Fine-Tuning of the Universe for Intelligent Life"[2] *The Fallacy of Fine-Tuning* did not address the scientific literature. Barnes' paper is written for experts in the field, who were not my intended audience and with whom I have no significant scientific disagreements. Barnes does not challenge my basic conclusions. Nor, to my knowledge, has anyone on the long list of reputable physicists and cosmologists who Barnes insists believe in fine-tuning. In fact, several were consulted in writing the book.

Fallacy was concerned with the widespread argument found in theological and religious apologetic writings that the putative fine-tuning of the parameters of physics and cosmology cannot be the product of purely natural forces.[3] I agree that life, as we know it on Earth, would not exist with a slight change in these parameters. However, there is no reason to limit ourselves to earthly life but consider the possibility of other forms of life, carbon-based or otherwise.

Depending on what you count, about thirty parameters are generally suggested as being fine-tuned. Of these, some theists have claimed that five parameters exist that are so exquisitely fine-tuned that changing any single one by one part in 10^{40} or more would mean that *no* life of any kind was possible. These crucial parameters are:

1. The ratio of electrons to protons in the universe
2. The expansion rate of the universe
3. The mass density of the universe
4. The ratio of the electromagnetic and gravitational forces
5. The cosmological constant

In *Fallacy,* I give plausible reasons for the values of each within existing, well-established physics and cosmology.

The remaining parameters are also supposed to be fine-tuned to many orders of magnitude. I show that they are at best fine-tuned, if you want to call it that, to 10-20 percent. Barnes seems to want me to reduce this to maybe 1-5 percent. But nowhere does he show that they should be 10^{-40}. My essential point is, when all parameters are taken together the region of parameter space that should allow some form of life to evolve is not the infinitesimal point that the theist literature would want us to believe.

In *Fallacy*, I formulate some of my arguments with certain simplified assumptions, such as semi-Newtonian cosmology. Barnes attacks these by using higher-level arguments that are quite irrelevant. He fails to explain why my simplifications are inadequate for my purposes.

In short, Barnes objections are largely superfluous. However, I cannot leave it at that since he has in several places misrepresented and misunderstood what I have said. In what follows, I will attempt to clarify these issues.

2. Point-of-View Invariance (Chapter 4)

Barnes writes, "Are the laws of nature themselves fine-tuned? Stenger defends the ambitious claim that the laws of nature could not have been different because they can be derived from the requirement that they be *Point-of-View Invariant* (hereafter, PoVI)."

He continues, "We can formulate Stenger's argument for this conclusion as follows:

LN1. If our formulation of the laws of nature is to be objective, it must be PoVI.

LN2. Invariance implies conserved quantities (Noether's theorem).

LN3. Thus, "when our models do not depend on a particular point or direction in space or a particular moment in time, then those models must necessarily contain the quantities linear momentum, angular momentum, and energy, all of which are conserved. Physicists have no choice in the matter, or else their models will be subjective, that is, will give uselessly different results for every different point of view. And so, the conservation principles are not laws built into the universe or handed down by a deity to govern the behavior of matter. They are principles governing the behavior of physicists."

Barnes continues, "This argument commits the fallacy of equivocation—the term 'invariant' has changed its meaning between LN1 and LN2. The difference is decisive but rather subtle, owing to the different contexts in which the term can be used. We will tease the two meanings apart by defining covariance and symmetry, considering a number of test cases." He follows with a lengthy example:

"Galileo's Ship: We can see where Stenger's argument has gone wrong with a simple example, before discussing technicalities in later sections. Consider this delightful passage from Galileo regarding the brand of relativity that bears his name:

> Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though doubtless when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still.

"Note carefully what Galileo is not saying. He is not saying that the situation can be viewed from a variety of different viewpoints and it looks the same. He is not saying that we can describe flight-paths of the butterflies using a coordinate system with any origin, orientation or velocity relative to the ship. Rather, Galileo's observation is much more remarkable. He is stating that the two situations, the stationary ship and moving ship, which are externally distinct are nevertheless internally indistinguishable. "

Barnes carries on for another page with this lesson from Galileo. But I need not quote it any further, because I don't have any quarrel with Galileo. Barnes has grossly misrepresented me if he is claiming that I have said that "the situation can be viewed from a variety of different viewpoints and it looks the same." In fact, he quotes exactly what I did say: "The models of physics cannot depend on the point of view of the observer." These statements are not equivalent.

Of course, different observers see different things. Suppose someone drops a rock from the top of the mast of Galileo's moving ship. An observer on the ship will see it fall in a straight line, while an observer on shore will see it fall along a parabolic path. My point is that these paths cannot be built into the models of physics since they depend on point-of-view. And, by applying this principle, the working models of physics do not have these different paths built in. In freshmen physics, students learn to calculate projectile paths from the same set of equations and apply them in different frames of reference.

Also, I have never claimed that *all* the laws of physics follow from point-of-view invariance. PoVI is a necessary principle, but it does not by itself determine all the laws of physics. There are choices of what transformations are considered and any models developed must be tested against the data. However, it is well established, and certainly not my creation, that conservation principles and much more follow from symmetry principles. Other principles can be connected to spontaneously broken symmetries. I include gauge symmetry as an application of PoVI. The notion here is that physicists are not completely free to invent any model they want when discussing this or any hypothetical other universe. For example, if they are to maintain the notion that there is no special point in space, then they can't suggest a model that violates momentum conservation.

Barnes quotes my statement, "Physicists are forced to make their models Lorentz invariant so they do not depend on the particular point of view of one reference frame moving with respect to another." (p. 82) He says, "This claim is false. Physicists are perfectly free to postulate theories which are not Lorentz invariant, and a great deal of experimental and theoretical effort has been expended to this end."

Of course, physicists are free to postulate all the theories they want. But no physicist is going to propose a model that depends on his location and his point of view. Events that depend on time and place are discrete incidences like history and geography, not the universal processes described by physics. Quite simply, much of existing, empirically verified physics follows from a principle in which physicists force themselves to construct their models to be independent of the observer's point of view. If, someday, experiment shows a violation of this principle, then we will have to discard it. So far, this has not happened, as Barnes points out. However, the standard model of elementary particles does include the breaking of gauge symmetry at low energies in order to describe observations from that special point of view. The underlying principles of the model, however, remain point-of-view invariant.

Barnes objects to my association of gauge invariance with PoVI, but gives no reason. Instead, he quotes various authors to the effect that gauge invariance could be wrong. Of course, it could be wrong. In all my books I emphasize that I am perfectly at home with all scientists who are ready to change their ideas the moment the data require them to do so.

3. Gravity is "Fiction" (Chapter 7)

Barnes disagrees with my referring to gravity as a "fictitious" force. We call the centrifugal and Coriolis forces "fictitious" because we can find a reference frame in which they are not observed. I point out the same is true for the gravitational force. An observer in a falling capsule, such as a spacecraft in orbit, experiences no gravitational force.

The disagreement here is over our differing philosophical views on the nature of physics. Barnes is a *Platonic realist* who considers the laws of physics as inherent ingredients of reality. I am a *commonsense realist* who holds that the so-called "laws of physics" are simply the human-invented ingredients of models that physicists introduce to describe observations. They are all fictitious, as far as

I am concerned, and while they must agree with the data, we have no way of knowing precisely what they have to do with reality.

In his theory of general relativity, Einstein replaced the gravitational force with paths along geodesics in curved space-time. That is, there is no gravitational force in general relativity. Certainly, gravity is a real phenomenon. However, the gravitational force is fiction. In this and most of Barnes' other comments, we don't disagree on the physics so much as how to characterize and interpret it.

4. Entropy at the Beginning of the Universe (pp. 107-113)

Barnes says, "Stenger's assertion that 'the universe starts out with maximum entropy or complete disorder' is false. A homogeneous, isotropic spacetime is an incredibly low entropy state."

Here Barnes fails to grasp the argument being made, that a volume of space can have maximal entropy and still contain very low entropy as compared to the visible universe. Assume our universe starts out at the Planck time as a sphere of Planck dimensions. Its entropy will be as low as it can be. However, at the same time, a Planck sphere is akin to a black hole whose entropy is maximal for an object of the same radius. It is not logically inconsistent to be both low and maximum at the same time.

In short, the universe could have started out in complete disorder and still produced organized structures. The reason is, as the universe expands its maximum allowed entropy grows with it so that order can form without violating the second law of thermodynamics.

5. Carbon and Oxygen Synthesis In Stars (Chapter 9)

Barnes says that I have failed to "turn back the force" of the claim that the parameters of physics are fine-tuned to allow carbon and oxygen to be synthesized in stars. However, he quotes Weinberg (as I do) as saying that this phenomenon "does not seem to me to provide any evidence for fine tuning." The best Barnes can do is to refer to some additional studies that are what he calls "highly suggestive" that carbon and oxygen production would be "drastically curtailed by a tiny change in the fundamental constants."

I have shown, based on published calculations of others, that carbon and oxygen synthesis do not, as Weinberg says, "provide any evidence for fine tuning."

6. Expansion Rate of the Universe

The energy density and expansion rate of the universe are two of five parameters of the universe that, as mentioned, are said to be fine-tuned to over forty orders of magnitude.

Theistic fine-tuners, such as William Lane Craig[4] and Dinesh D'Souza,[5] often quote Stephen Hawking out of context in this regard. On page 121 of his 1988 blockbuster bestseller, *A Brief History of Time,* Hawking said "If the rate of expansion one second after the big bang had been smaller by even one part in a hundred thousand million million, the universe would have recollapsed before it ever reached its present size."[6]

The fine-tuners fail to mention that a few pages later, on page 128 of *Brief History*, Hawking said, "The rate of expansion of the universe would automatically become very close to the critical rate determined by the energy density of the universe. This could then explain why the rate of expansion is still so close to the critical rate, without having to assume that the initial rate of expansion of the universe was very carefully chosen."[7]

The expansion rate and energy density are not independent parameters. In *Fallacy,* I provided the equations that demonstrate this, showing that neither is fine-tuned for life. (Chapter 5).

Barnes does not challenge this essential point, but rather goes into detail on the problems of inflation, showing that it could be wrong. Of course, but again I am limiting myself to existing knowledge and so far inflationary cosmology has not been falsified and helps explain many observations. Here I simply reiterate the point made by Hawking in 1988 that inflation could account for the fact that the expansion rate seems to be fine-tuned.

7. Gravity and the Masses of Particles (Chapter 7)

Barnes similarly misrepresents the case I make against one of the most common, fine-tuning claims, that gravity is 39 orders of magnitude weaker than electromagnetism, and, if this were not so, we would not exist. I point out the elementary physics fact that this is only true for a proton and electron. In general, the relative strength of the two forces depends on the masses and charges of the particles involved. I explain that the reason gravity is so much weaker than electromagnetism for elementary particles is because of their low mass compared to the Planck mass. I then propose a plausible explanation for this low mass, namely, in the standard model the masses are intrinsically zero and their observed masses are the result of small corrections, such as the Higgs mechanism.

Barnes reacts, "Stenger is either not aware of the hierarchy and flavour problems, or else he has solved some of the most pressing problems in particle physics and not bothered to pass this information on to his colleagues." So, Barnes will not accept my argument until I solve the hierarchy and flavor problems, certainly a daunting task. But I claim I don't have to. I just have to suggest a plausible reason, consistent with our best existing knowledge, why the masses of particles are small. As long as no one can disprove this explanation, I win the argument.

Similarly, I give plausible reasons for the mass differences of protons, neutrons, and electrons. Barnes again misrepresents me, claiming that my statement that "the mass difference between the neutron and proton results from the mass difference between the d and u quarks" is "false, as there is also a contribution from the electromagnetic force." He ignores the fact that I explicitly attribute the mass differences of the d and u quarks to the electromagnetic force (*Fallacy* p. 178).

8. Strengths of Forces

On page 189 of *Fallacy* I said, "All the claims of the fine-tuning of the forces of nature have referred to the values of the force strengths in our current universe. They are assumed to be constants, but, according to established theory (even without supersymmetry), they vary with energy." Barnes says the first sentence is "false by definition—a fine-tuning claim necessarily considers different values of the physical parameters of our universe." Once again, he is accusing me of saying something I did not say. I did not say different values are not "considered." Of course they are. The point is that all the studies I have looked at (remember, I focus on the theistic literature) treat these force parameters as constants, when they are not.

Barnes also fails to grasp the point I make that the force constants are thought to be related to one another and expected to come together at some high unification energy (See Fig. 10.4, p. 189). The fact that they only differ now by a factor of six should not be regarded as fine-tuning.

Barnes says, "to show (or conjecture) that a parameter is derived rather than fundamental does not mean that it is not fine-tuned." Right. And the fact that we can't prove that Bertrand Russell's teapot is not orbiting the sun between Mars and Jupiter does not mean it is.

9. Charge Neutrality

Another fine-tuning claim is the ratio of protons to electrons in the universe (p. 205). I argue that this parameter results from charge conservation and quote from a book on cosmology written by an astronomer. Barnes agrees that this is not a good fine-tuning argument, but objects to my explanation, it seems, because I relate it to PoVI. He says, "Charge conservation follows from gauge invariance, but gauge invariance does not follow from 'point of view invariance' as Stenger claims."

In my 2006 book *The Comprehensible Cosmos,* I argued that gauge invariance is a form of point-of-view invariance.[8] Barnes disagrees, but again his disagreeableness does not change the conclusion here.

10. MonkeyGod (Chapter 13)

Barnes finds much fault with my simple program *MonkeyGod,* which I put on my website years ago to allow people to "create their own universe." I included a description of it in *Fallacy* so that readers could see exactly what the program does. I clearly called these "toy universes" (p. 236), but figured they were still useful for giving us some feel for the dependence of certain quantities on the basic parameters of physics. One quantity of significant relevance to the fine-tuning question is stellar lifetime. I claim no deep results, but find it interesting that a wide range of fundamental physics constants will give long lifetime stars, a likely prerequisite for life.

Barnes makes his usual objections to my admitted oversimplifications. Does he really expect me to simulate entire universes?

11. Conclusion

Barnes objections to *The Fallacy of Fine-Tuning* result from a misunderstanding of my intention in writing the book, and both a misunderstanding and misrepresentation of much that is in it. My intent was to investigate the claim found in much theistic literature that carbon-based life, as we know it, would be impossible if any one of thirty or so parameters of physics and cosmology changed by an infinitesimal amount. Five of these are critical parameters for which it is claimed no form of life would be possible without the posited fine-tuning.

I have never denied that life, as we know it on Earth, would not have evolved with slight changes in parameters. In *Fallacy* I showed (1) that plausible explanations, consistent with existing knowledge, can be made for the observed values of the five critical parameters and, (2) plausible ranges for the other parameters exist that are far from infinitesimal, contrary to what is claimed in the theistic literature.

Nothing in Barnes' paper changes my basic conclusion: The universe is not fine-tuned for us. We are fine-tuned to the universe.

Acknowledgements

Many thanks to Raymond Briggs, Kim Clark, Jonathan Colvin, Yonatan Fishman, Craig James, Bill Jefferys, John Kole, Don McGee, Brent Meeker, and Bob Zannelli for helping me prepare this paper.

References

[1] Victor J. Stenger, *The Fallacy of Fine-Tuning: Why the Universe is Not Designed for Us*, (Amherst, NY: Prometheus Books, 2011).

[2] Luke Barnes, "The Fine-Tuning of the Universe for Intelligent Life," arXiv:1112.464v1[physics.hist-ph] (2011).

[3] Quotations and extensive references can be found in *Fallacy.*

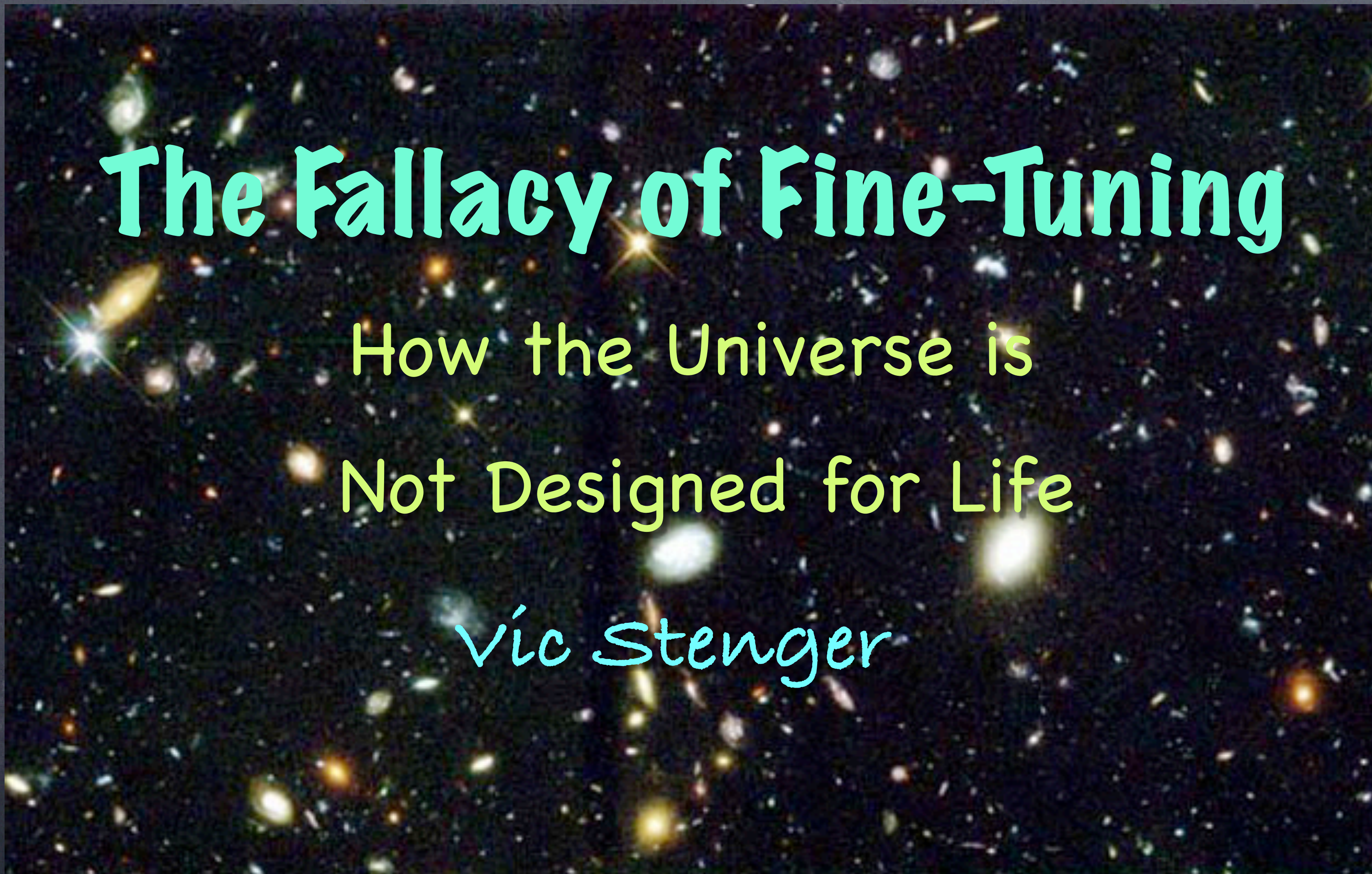
[4] William Lane Craig, "The Craig-Pigliucci Debate: Does God Exist?" http://www.leaderu.com/offices/billcraig/docs/craig-pigliucci1.html (accessed February 13, 2010).

[5] Dinesh D'Souza, *Life After Death: The Evidence*, (Washington, D.C. New York: Regnery Pub, 2009), p. 84.

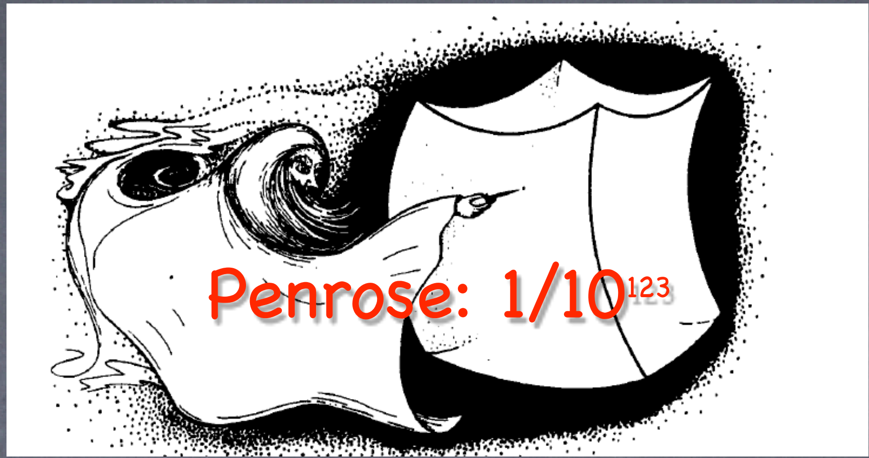
[6] Stephen W. Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam, 1988), p. 121.

[7] Ibid, p. 128.

[8] Victor J. Stenger, *The Comprehensible Cosmos: Where Do the Laws of Physics Come From?* (Amherst, NY: Prometheus Books, 2006).


The Fallacy of Fine-Tuning
How the Universe is
Not Designed for Life
Vic Stenger

Is the universe fine-tuned for life?



If the constants of physics had been slightly different, life as we know it would not have evolved.

"Anthropic principle."

Some obvious fallacies of fine tuning claims

Speed of light c
Planck's constant h
Gravitational constant G

Fine tuned?

Arbitrary constants—just establish system of units

Only meaningful parameters are dimensionless ratios

Another trivial fallacy

Masses of neutrinos

Claim: If slightly bigger or smaller stars and galaxies would not form in ways conducive to life.

Assumes number of neutrinos is fixed. **NOT!**

Number of neutrinos depends on mass of neutrino. Higher mass—smaller number.

Gravitational effect same for wide range of masses.

Hoyle coincidence

$He^4 + He^4 \rightarrow Be^8$

$Be^8 + He^4 \rightarrow C^{12}$

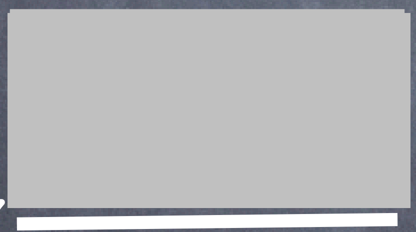
Synthesis of carbon in stars

Prediction!

Carbon energy levels

7.68

7.644



Hoyle 1953

7.3667

$Be^8 + He^4$

MeV

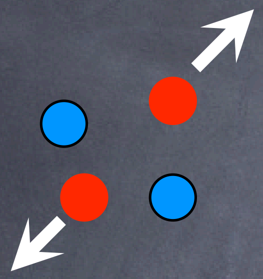
Livio et al 1989

$\Delta T = 1.393$ billion degrees

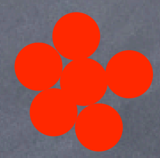
More carbon

No fine tuning evident

Strength of Nuclear Force

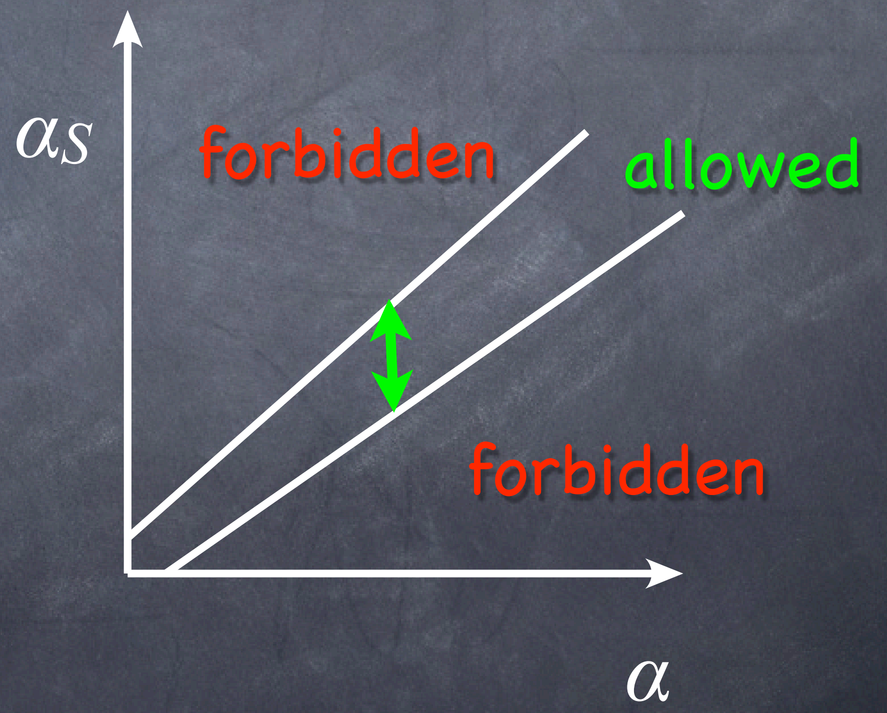


α_S lower
no stable
nuclei



α_S higher
no hydrogen

But this assumes
EM strength α =
constant = 1/137



Allow α to vary

How fine-tuned is our universe?

Four dimensionless parameters determine major large-scale features of universe:

- Strength of gravity $\alpha_G = \dfrac{Gm_p^2}{\hbar c}$ ← Note: gives proton mass
- Strength of electromagnetic force α
- Strength of strong nuclear force α_S
- Ratio of electron to proton masses m_e / m_p

Other forms of life

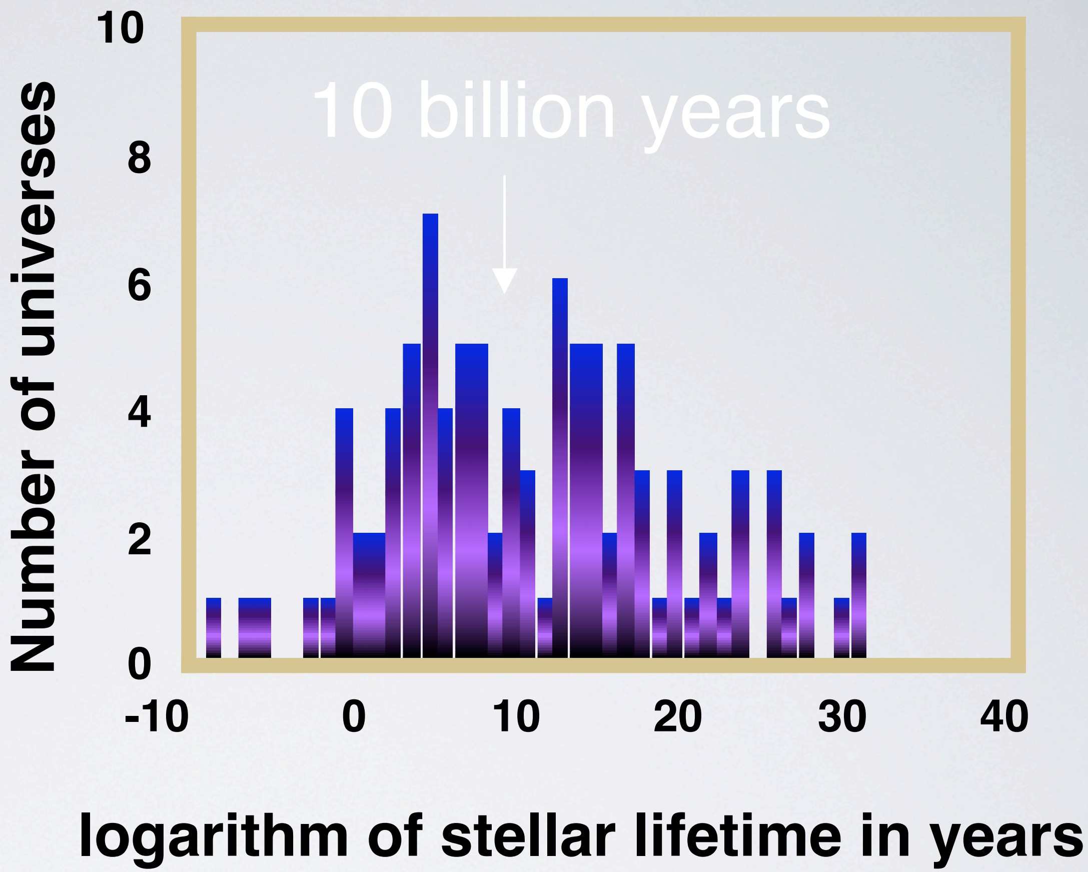
Some other form of life might be possible with many other variations of physical constants.

MonkeyGod

Generates universe for given set of parameters.

Can run from my web site

Generated 100 random universes.



Most universes have stars with long lives (> 1 By) needed for evolution of complex elements.

20 % universes "livable"

Extreme examples

Without which it is claimed any form of life would be impossible.

Ratio of electron to protons	$1/10^{37}$
Ratio of e-m force to gravity	$1/10^{40}$
Expansion rate of the universe	$1/10^{55}$
Energy density of the universe	$1/10^{59}$
Cosmological constant	$1/10^{120}$

Ratio of number of electrons to number of protons in universe

$$\boxed{n_e = n_p}$$

Just what it should be if total electrical charge of universe is

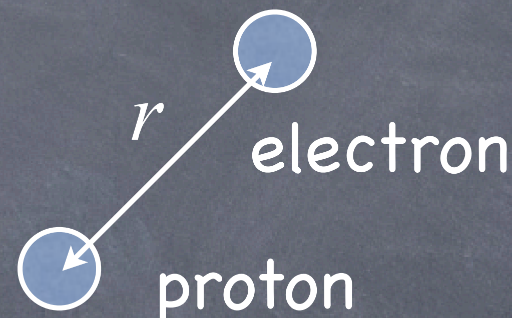
zero

Which is just what it should be if the universe came from nothing (zero charge).

Not fine tuned.

Gravity and electromagnetism

$$N_1 = \frac{F_E}{F_G} = \frac{k_E \dfrac{e^2}{r^2}}{G\dfrac{m_p m_e}{r^2}} = \frac{k_E e^2}{G m_p m_e}$$



$$= 10^{39}$$

Weyl 1919: Why so big?

Let $m_1 = m_2 = 1.85\text{x}10^{-9}\ \text{kg}$

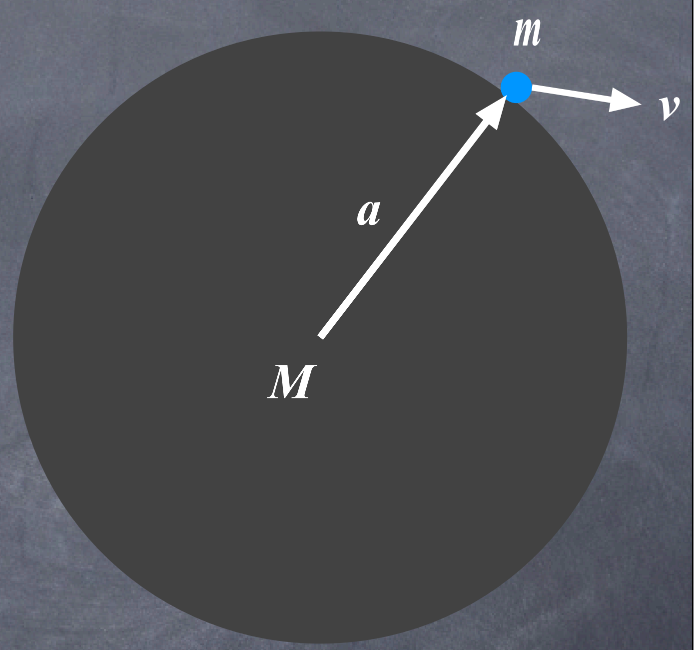
Then $\dfrac{F_E}{F_G} = 1$

N_1 is big because masses of particles are small

Not fine tuned.

Energy density of the universe

$$E = \frac{1}{2}mv^2 - \frac{GmM}{a} = -\frac{1}{2}mk$$



Data: $k = 0$

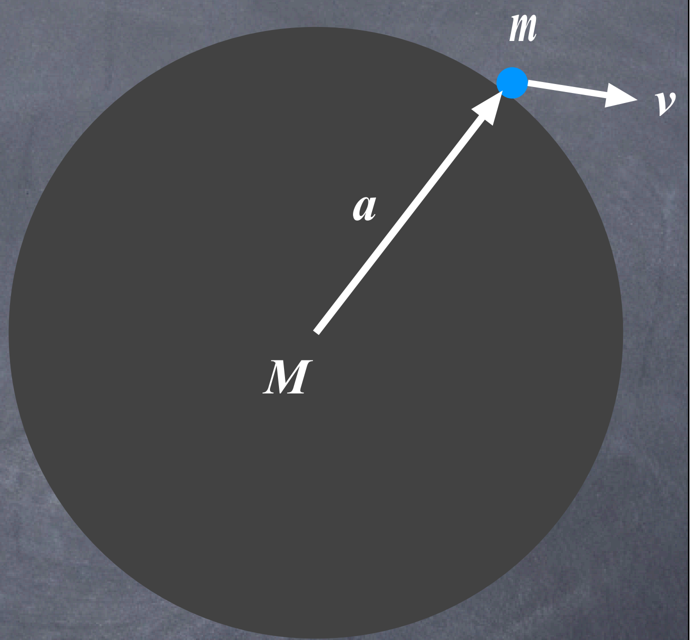
$$\rho_E = \rho_{KE} + \rho_{PE} = 0$$

Just what you expect if the universe came from nothing (zero energy).

Not fine tuned.

Expansion rate of the universe

$$H = \frac{1}{a}\frac{da}{dt}$$ Hubble parameter



$$H^2 = \frac{8\pi}{3}\rho_{KE} - \frac{k}{a^2}$$

Data: $k = 0 \quad \Rightarrow H^2 = \frac{8\pi}{3}\rho_{KE} \leftarrow$ critical density

Expansion rate depends on critical density

Not fine tuned.

Cosmological constant

Cosmol. constant

$$\frac{1}{a}\frac{d^2a}{dt^2} = -\frac{4\pi G}{3}\left(\rho_{mat} + 2\rho_{rad}\right) + \frac{\Lambda}{3}$$

Friedmann equation

$\boldsymbol{c = 1}$

$$\frac{\Lambda}{3} = \frac{8}{3}\pi G\rho_{vac}$$

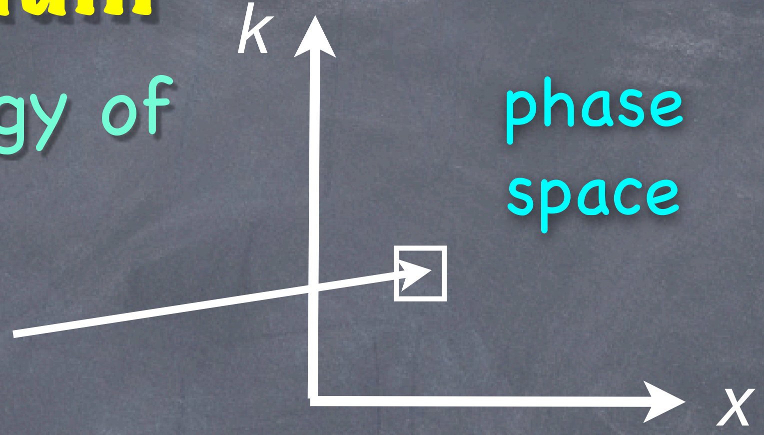
vacuum energy density

dark energy?

Energy of the vacuum

Assume zero-point energy of particle fields

$$dN = \frac{g}{h^3} d^3k\, d^3x$$



phase space

$$\rho_{vac} = \frac{dE}{dV} = \pm \int \left(\frac{1}{2} \hbar \omega \right) \frac{g}{h^3} d^3k = \pm \frac{g}{16\pi^2 \hbar^3 c^3} E^4_{cutoff}$$

\+ bosons

\- fermions

E_{cutoff} = Planck energy

$$\rho_{vac} = 10^{124} \frac{eV}{cm^3} \quad \text{Observed value } < 10^4 \frac{eV}{cm^3}$$

Worst calculation in physics history!

120 orders of magnitude lower

Solving cosmological constant problem

Anthropic principle:

multiple universes

Supersymmetry:

ZPE of fermions and bosons exactly cancel

but...

SUSY broken in current universe

$$E_{cutoff} = 1\ \mathrm{TeV} \quad \rho_{vac} = 10^{64}\,\frac{eV}{cm^3}$$

Only 60 orders of magnitude off!

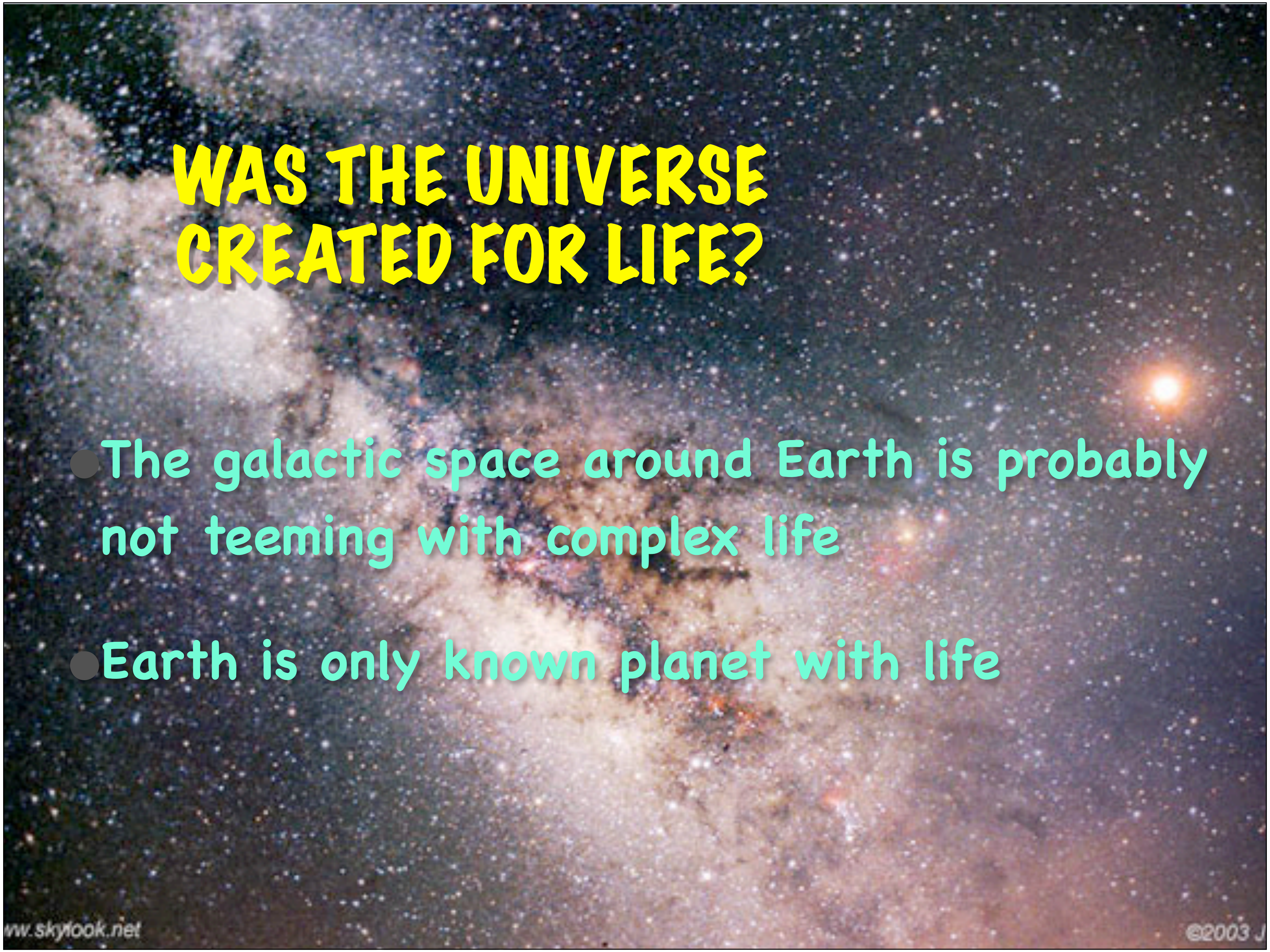
Early universe?

Include negative energy states

ZPE= 0

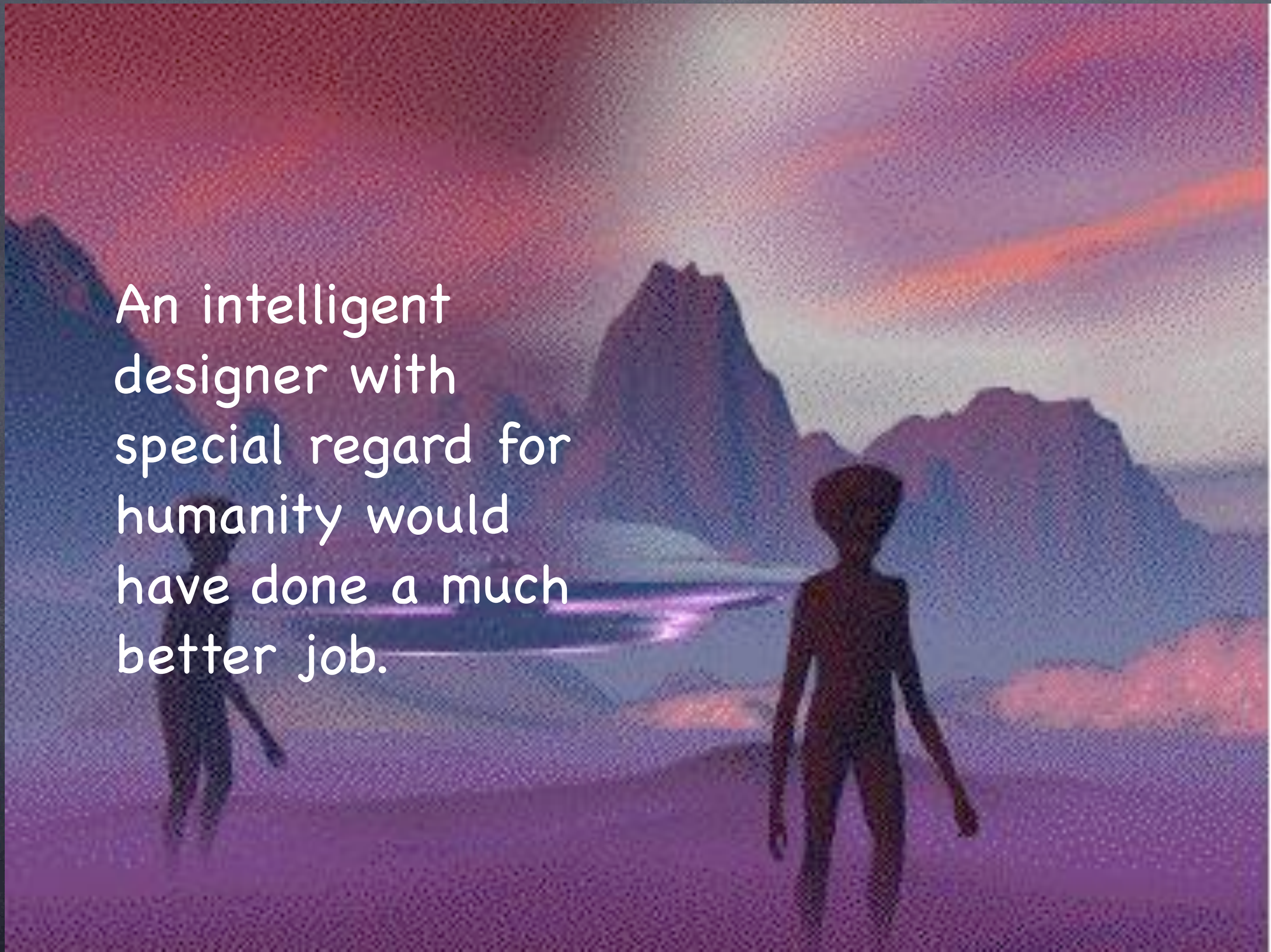
WAS THE UNIVERSE CREATED FOR LIFE?

- The galactic space around Earth is probably not teeming with complex life
- Earth is only known planet with life



The underprivileged planet

- Earth is not all that well suited for human life
- ⅔ ocean
- We are restricted to surface
- Atmosphere does not block UV
- Natural disasters, disease, famine kill thousands yearly


An intelligent designer with special regard for humanity would have done a much better job.

Wasted Space

Distances are immense

- Nearest star: 4.22 light-years
- Nearest galaxy: 2.44 million light years
- Galaxies within our horizon are now 40 billion light-years away
- Universe beyond horizon: 10 to the 10 to the 100 times bigger

Wasted time

- Universe 13.7 billion years old
- Earth 4.5 billion years old
- Modern humans 150 thousand years old

0.001 %

Wasted Matter

Most of the matter of the universe is not atomic-the component of life

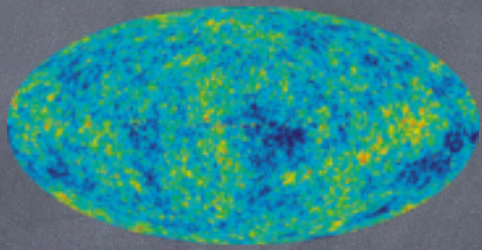
- Visible atomic matter in galaxies: 0.005 of mass of universe.
- Total carbon: 0.0002
- Dark matter: 0.22
- Dark energy: 0.74

Wasted energy

Only two photons of every billion emitted by sun are used to warm Earth

Most of universe is in random motion

Cosmic microwave backround



Photons are a billion times more numerous than atoms

Random to one part in 100,000

A tiny pocket of complexity

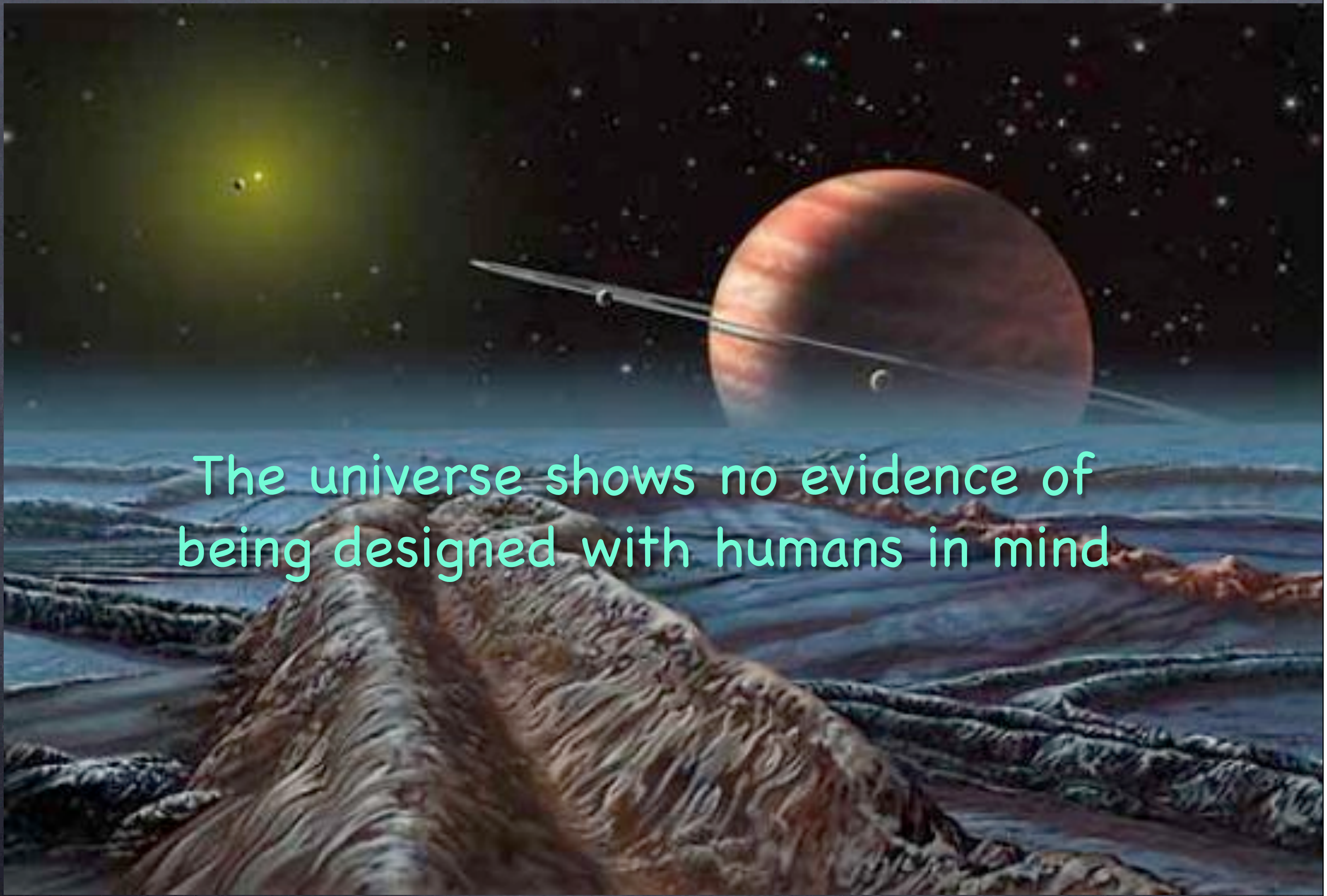
Humans in space

Humans cannot live in space or on any known planet or moon without extensive life support.

Even so-called "earth-like" planets are not likely to be able to support human life.

Cosmic radiation prevents humans from spending years in space.


We are marooned on
spaceship Earth


The universe shows no evidence of
being designed with humans in mind

Are we doomed to extinction?

Yes, as a species.

But, perhaps our successors will carry on.

The Myth of Quantum Consciousness

Victor J. Stenger

Published in *The Humanist,* May/Jume 1992, Vol. 53, Number 3, pp. 13-15.

A new myth is burrowing its way into modern thinking. The notion is spreading that the principles embodied in quantum mechanics imply a central role for the human mind in determining the very nature of the universe. Not surprisingly, this idea can be found in New Age periodicals and in many books on the metaphysical shelves of book stores. But it also can appear where you least expect it, even on the pages of that bastion of rational thinking,*The Humanist* .

In an article in the November/December 1992 issue entitled "The Wise Silence," Robert Lanza says that, according to the current quantum mechanical view of reality, "We are all the ephemeral forms of a consciousness greater than ourselves." The mind of each human being on earth is instantaneously connected to each other - past, present and future - as "a part of every mind existing in space and time."[1]

To my ear, these sound very much like the ideas of physicist and New Age guru Fritjof Capra, as expressed most recently in the film "Mindwalk." They also resonate with the "cosmic consciousness" promoted by Maharishi Mahesh Yogi and his Transcendental Meditation movement. Like Lanza, these sages claim modern physics as their authority. The Maharishi associates cosmic consciousness with the Grand Unified Field of particle physics. Maharishi University "quantum physicist" John Hagelin, Natural Law Party candidate for President in last year's election, has spoken frequently about quantum consciousness.

In Lanza's interpretation, quantum mechanics tells us that all human minds are united in one mind and "the entities of the universe - electrons, photons, galaxies, and the like - are floating in a field of mind that cannot be limited within a restricted space or period . . ."

Unlike traditional myths, which call on scripture or the utterances of charismatic leaders as their authorities, this latest version of ancient Hindu idealism is supposedly based on up-to-date scientific knowledge. The assertion is made that quantum mechanics has ruled invalid the materialistic, reductionist view of the universe, introduced by Newton in the seventeenth century, which formed the foundation of the scientific revolution. Now, materialism is replaced by a new spiritualism and reductionism is cast aside by a new holism.

The myth of quantum consciousness sits well with many whose egos have made it impossible for them to accept the insignificant place science perceives for humanity, as modern instruments probe the farthest reaches of space and time. It was bad enough when Copernicus said that we were not at the center of the universe. It was worse when Darwin announced that we were not angels. But it became intolerable when astronomers declared that the earth is but one of a hundred billion trillion other planets, and when geologists demonstrated that recorded history is but a blink of time - a microsecond of the second of earth's existence.

In a land where self-gratification has reached heights never dreamed of in ancient Rome, where self-esteem is more important than being able to read, and where self-help requires no more effort than putting on a cassette, the myth of quantum consciousness is just what the shrink ordered.

But, alas, quantum consciousness has about as much substance as the aether from which it is composed. Early in this century, quantum mechanics and Einstein's relativity destroyed the notion of a holistic universe that had seemed within the realm of possibility in the century just past. First, Einstein did away with the aether, shattering the doctrine that we all move about inside a universal, cosmic fluid whose excitations connect us simultaneously to one another and to the rest of the universe. Second, Einstein and other physicists proved that matter and light were composed of particles, wiping away the notion of universal continuity. Atomic theory and quantum mechanics demonstrated that everything, even space and time, exists in discrete bits - quanta. To turn this around and say that twentieth century physics initiated some new holistic view of the universe is a complete misrepresentation of what actually took place.

The belief in a universal, cosmic fluid pervading all space is an ancient one. To the Greeks, *aether* was the rarified air breathed by the gods on Olympus. Aristotle used this term for the celestial element - the stuff of the heavens - and said it was subject to different tendencies than the stuff of earth. When Newton was prompted to explain the nature of gravity in non-mathematical terms, he replied that gravity might be transmitted by an invisible aether. He further suggested that the aether also may be responsible for electricity, magnetism, light, radiant heat, and the motion of living things that he, like his contemporaries, thought was the consequence of some source beyond inanimate matter. Even today, despite the preponderance of evidence unavailable to Newton that life is a purely material phenomenon, people still speak of immaterial{,} vital forces such a *ch'i*, *ki*, *prana*, and*psychic energy* which have no scientific basis.

Newton also had proposed that vibrations of the aether might be excited by the brain. This speculation forms the conceptual foundation for the modern myth of quantum consciousness and the related belief that the human mind commands special powers - psychic forces - that transcend the material universe.

Newton had envisioned matter and light to be particulate in nature, though they appear continuous to the human eye. Gravity, however, seemed to be something else, acting invisibly - holistically - over the entire universe. In the mid-nineteenth century, the mathematical concept of the *field* was developed to describe the apparent continuity of matter, light, and gravity. A field has a value at each point in space, in contrast to the properties of a particle which are localized to a tiny region of space. To some current observers, fields are holistic entities while particles typify the reductionist view of nature, where everything is reduced to its parts. Holists, with great profundity, inform us that the whole is greater than the sum of its parts and so the reductionist view must be discarded. Note, however, that fields were not invented last week, after some great burst of intuition by a Capra or a

Lanza, but appeared in reductionist physics over a century ago. Little in the new holism is really very new, or very logical.

Pressure and density are two examples of matter fields. In continuous elastic media, pressure an density propagate as sound waves when the media are excited. As the phenomena of electricity and magnetism became better understood, they were also described in terms of fields. When Maxwell discovered that the equations which united electricity with magnetism called for the propagation of electromagnetic waves in a vacuum at the speed of light, it was suggested that the vacuum was not empty but filled with an elastic medium - the aether - whose excitation produced the phenomenon of light.

Electromagnetic waves beyond the narrow spectrum of visible light were predicted and soon observed and put to use in “wireless telegraphy.” One of the early workers in wireless telegraphy was the English physicist Oliver Lodge. While making major contributions to physics and engineering, Lodge joined William Crookes, Alfred Russel Wallace (co-discoverer of evolution) and other notable nineteenth century scientists in searching for phenomena that transcended the world of matter. If wireless telegraphy was possible, why not wireless telepathy? If electrical circuits could generate and detect ethereal waves, why not the human brain? Coincidentally, certain people who seemed to possess the ability to communicate with other minds, living and dead, had just appeared on the scene. They were called mediums a century ago; today their spiritual descendants are known as psychics or channellers.

Unfortunately, most scientists lack the specific skills needed to distinguish fact from illusion in the world of magic. The universe does not lie; people lie. Lodge and other psychical researchers allowed themselves to be fooled by the tricks of professional fortune-tellers and sleight-of-hand artists posing as spiritualists. Lodge desperately wanted to believe in life after death, writing passionately about communications with his son Raymond who was killed in Flanders in 1915. Sadly, he accepted the wildest claims of mediums.

Near the turn of the century, Michelson and Morley sought to find experimental evidence for the aether and succeeded in showing instead that it did not appear to exist. Shortly thereafter, in 1905, Einstein developed his theory of relativity which demonstrated that the concept of an aether was logically inconsistent with Maxwell's equations of electromagnetism. Einstein concluded that electromagnetic waves, including light, could not be the vibrations of an aether. Still, Oliver Lodge remained firm in his belief that a universal cosmic fluid existed that could be excited by the human mind. To Lodge, the aether was a necessity, the cosmic glue without which "there can hardly be a material universe at all."[2]

Lodge was similarly unhappy with what he was hearing young quantum physicists, like Bohr and Heisenberg, say about the fundamentally discrete, quantized, nature of all phenomena. He deplored "the modern tendency . . . to emphasize the discontinuous or atomic character of everything."[3] But progress passed him by, as evidence accumulated that matter is composed of discrete atoms, that electricity is the flow of electrons or other charged particles, and that light is a current of particles called photons. When Oliver Lodge died in 1940, continuity was already long in its grave.

Einstein wasn't comfortable with quantum mechanics either, calling it "spooky." He and two collaborators, Podolsky and Rosen, wrote a paper in 1935 arguing that quantum mechanics was "incomplete" because it seemed to allow for the propagation of signals faster than the speed of light, a result forbidden by Einstein's relativity.[4] Like so many of the strange effects of quantum mechanics, this was a consequence of the wave-particle duality in which physical systems behave either like waves or particles, depending on which type of property you are trying to measure. Again the distinction is between the discrete, localized properties of a particle and the continuous, distributed properties a field.

The EPR paradox remained a curiosity until 1964 when John S. Bell showed how it provided a way to experimentally test the conventional, "Copenhagen" interpretation of quantum mechanics.[5] Earlier, physicist David Bohm had proposed an alternative to Copenhagen in which invisible “hidden variables” were responsible for the wave-like behavior of particles.[6] Bell showed the way to experimentally decide the issue. Now, after a series of precise experiments, the issue has been decided: The Copenhagen interpretation quantum mechanics has been convincingly confirmed, while the most important class of hidden variables is ruled out.[7]

David Bohm, who died in October, 1992, had been the foremost proponent of a new holistic paradigm to take the place of reductionist quantum physics.[8] The failure of his related hidden variable theory did not cause the proponents of the new continuity to loose faith. Rather they have turned the experimental confirmation of conventional quantum mechanics on its head by arguing that a basis has been found for the superluminal signals needed in a holistic universe.

Einstein’s principle that no signals can move faster than light implies that separated events in the universe, even those an atomic diameter apart, cannot be simultaneously connected. This fundamentally contradicts the holistic view of an instantaneous interconnectedness among all things. Rather, relativity paints quite the opposite picture: a universe of localized particles that at any instant depend only on the other particles with which they are in direct contact. What is going on elsewhere in the universe at that instant can have no effect until the particles carrying the necessary information can get there, moving no faster than the speed of light. This is a far more complete form of reductionism than is present in pre-Einsteinian mechanics, where motions at superluminal or even infinite speeds were not ruled out by any known theory. Incompatible with the claims of the new holists, relativity not only supports the reductionist view - it makes it mandatory{!} A universal cosmic field like the aether, providing a mechanism for interconnectedness, requires a violation of Einstein’s relativity. But relativity has passed every experimental test that has been put to it since being introduced in 1905, so it cannot be casually discarded.

Similarly, the interpretation of quantum mechanics to which Einstein objected, and which Bohm sought to replace, still reigns supreme after being subjected to a similar period of rigorous experimental test, including the tests of Bell's theorem. The EPR paradox thus would seem to suggest that quantum mechanics and relativity cannot be made compatible, and so one or the other must go. Before the experimental results confirming conventional quantum mechanics came in, Bohm and his supporters had argued that conventional quantum mechanics should be discarded. Now that the results are in, the new holists argue that relativity must yield, since quantum mechanics provides a mechanism by which signals can move faster than light. Quantum mechanics is indeed "spooky." So, bring out the spooks! An ethereal, universal field that allows for the simultaneous connection between events everywhere in the universe must exist after all.

Quantum mechanics is called on further to argue that the cosmic field, like Newton's aether, couples to the human mind itself. In Robert Lanza's view, that field is the universal mind of all humanity - living, dead, and unborn. Ironically, this seemingly profound association between quantum and mind is an artifact, the consequence of unfortunate language used by Bohr, Heisenberg and the others who originally formulated quantum mechanics. In describing the necessary interaction between the observer and what is being observed, and how the state of a system is determined by the act of its measurement, they inadvertently left the impression that human consciousness enters the picture to cause that state come into being. This led many who did not understand the physics, but liked the sound of the words used to describe it, to infer a fundamental human role in what was previously a universe that seemed to have need for neither gods nor humanity.

If Bohr and Heisenberg had spoken of measurements made by inanimate instruments rather than "observers," perhaps this strained relationship between quantum and mind would not have been drawn. For, nothing in quantum mechanics requires human involvement.

Quantum mechanics does not violate the Copernican principle that the universe cares not a whit about the human race. Long after humanity has disappeared from the scene, matter will still undergo the transitions that we call quantum events. The atoms in stars will radiate photons, and these photons will be absorbed by materials that react to them. Perhaps, after we are gone, some of our machines will remain to analyze these photons. If so, they will do so under the same rules of quantum mechanics that operate today.

But even without human involvement, with inanimate instruments doing the observing, do the rules of quantum mechanics allow for superluminal motion? A careful analysis of the experiments that tested Bell's theorem shows that the only objects that move faster than light are mathematical creations of our imagination, like the quantum wave function, which are not physical objects. It can be demonstrated that no signal carrying actual information moves faster than the speed of light{.} Neither conventional quantum mechanics nor Einstein's relativity are violated.[9]

The overwhelming weight of evidence, from seven decades of experimentation, shows not a hint of a violation of reductionist, local, discrete, non-superluminal, non-holistic relativity and quantum mechanics - with no fundamental involvement of human consciousness other than in our own subjective perception of whatever reality is out there. Of course our thinking processes have a strong influence on what we perceive. But to say that what we perceive therefore determines, or even controls, what is out there is without rational foundation. The world would be a far different place for all of us if it was just all in our heads - if we really could make our own reality as the New Agers believe. The fact that the world rarely is what we want it to be is the best evidence that we have little to say about it. The myth of quantum consciousness should take its place along with gods, unicorns, and dragons as yet another product of the fantasies of people unwilling to accept what science, reason, and their own eyes tell them about the world.

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Notes

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A Scenario for a Natural Origin of Our Universe

Using a Mathematical Model Based on Established Physics and Cosmology

Victor J. Stenger

Abstract: A mathematical model of the natural origin of our universe is presented. The model is based only on well-established physics. No claim is made that this model uniquely represents exactly how the universe came about. But the viability of a single model serves to refute any assertions that the universe cannot have come about by natural means.

Why is there something rather than nothing? This question is often the last resort of the theist who seeks to argue for the existence of God from physics and cosmology and finds all his other arguments fail. Philosopher Bede Rundle calls it "philosophy's central, and most perplexing, question." His simple (but book-length) answer, "There has to be something."[1]

Clearly many conceptual problems are associated with this question. How do we define "nothing"? What are its properties? If it has properties, doesn't that make it something? The theist claims that God is the answer. But, then, why is there God rather than nothing? Assuming we can define "nothing," why should nothing be a more natural state of affairs than something? In fact, we can give a plausible scientific reason based on our best current knowledge of physics and cosmology that something is more natural than nothing!

It is commonly believed that the universe cannot have come about naturally. Although many authors writing at both the popular and academic levels have described various scenarios for a natural origin, usually based on the vague notion of "quantum fluctuations," even they admit that their ideas are speculative and surrender to the prevailing wisdom that the origin of our universe remains unexplained.[2]

What is it that science does when it "explains" some phenomenon? At least in the case of the physical sciences, it builds a mathematical model to describe the empirical data associated with the phenomenon. When that model works well in fitting the data, has passed a number risky tests that might have falsified it, and is at least not inconsistent with other established knowledge, then it can be said to successfully explain the phenomenon. Further discussion on what the model implies about "truth" or "ultimate reality" falls into the area of metaphysics rather than physics, since there is nothing further the scientist can say based on the data. What is more, nothing further is needed for any practical applications. For example, not knowing whether or not electromagnetic fields are real does not prevent us from utilizing the theory of electromagnetic fields.

We have no direct observations of the event we identify as the origin of our universe, "our universe" being the one we live in but with the far greater portion that arose from the same source now out of sight beyond our horizon. This has led some to insist that, as a consequence, science can say nothing about the origin. Here they parrot the familiar creationist argument that because we did not observe humans evolving we can't say anything about human evolution.

But, of course science can and does talk about unobserved and unobservable events. We have plenty of indirect data by which we can test human evolution. We can reconstruct crimes from forensic evidence. In the case of the universe, the inflationary big-bang model nicely accounts for a wide range of increasingly precise observations that bear on the nature of the early universe.[3] When we extrapolate the model back to the earliest moments, we find that the picture becomes surprisingly simple. Assuming the universe came from nothing, it is empty to begin with so we do not have to deal with the complications of matter and its interactions of which we have only incomplete understanding. In fact, to understand an empty universe we need only apply general relativity and quantum mechanics, theories that have enjoyed almost a century of empirical corroboration.

What I will show is that a mathematical model of the origin of our universe based on no more than these well-established theories can be precisely specified. This model is essentially the "no boundary" model proposed over twenty years ago by Hartle and Hawking.[4] I will present a simplified version, following closely the development of Atkatz in his excellent pedagogical review of quantum cosmology.[5] More details are given in the mathematical supplements of my 2006 book, *The Comprehensible Cosmos,* which can also be referred to for a layperson's discussion.[6] The mathematics used is about at the level of a bachelor's degree in physics from an American university. A pedagogical discussion along the same lines can also be found in the paper by Norbury.[7]

No claim will made that the model I will describe is actually how our universe actually came about. The model contains no proof of uniqueness. The purpose of this essay is simply to show explicitly that at least one scenario exists for a perfectly natural, nonmiraculous origin of our universe based on our best scientific knowledge. In other words, science has at least one viable explanation for the wholly natural origin of our universe, thus refuting any claim that a supernatural creation was required.

1. The Wave Function of the Universe

Although we do not yet have a complete theory that unites quantum mechanics and general relativity, nothing prevents us from attempting to combine the two. Consider the Lagrangian

$$L = \frac{3\pi}{4G}\left[-\left(\frac{da}{dt}\right)^2 a + a\left(1 - \frac{a^2}{a_o^2}\right)\right] \tag{1}$$

where a is some coordinate in one dimension and G is Newton's gravitational constant. This looks rather arbitrary, but is chosen in hindsight. The canonical momentum conjugate to a is

$$p = \frac{\partial L}{\partial\left(\frac{da}{dt}\right)} = -\frac{3\pi}{2G} a \frac{da}{dt} \tag{2}$$

The Hamiltonian then is

$$\begin{aligned} H &= p\frac{da}{dt} - L \\ &= -\frac{3\pi}{4G} a\left[1 + \left(\frac{da}{dt}\right)^2 - \frac{a^2}{a_o^2}\right] \end{aligned} \tag{3}$$

Consider the case where $H = 0$. Then

$$1 + \left(\frac{da}{dt}\right)^2 - \frac{a^2}{a_o^2} = 0 \tag{4}$$

This is precisely one of the Friedmann equations of cosmology that can be derived from Einstein's theory of general relativity:

$$\left(\frac{da}{dt}\right)^2 - \frac{8\pi\rho G}{3}a^2 = -k \tag{5}$$

where a is the radial scale factor of the universe, $a_o^2 = \dfrac{3}{8\pi\rho G}$, ρ is the energy density (c = 1), and k is the parameter indicating whether the universe is open (k = –1), critical (k = 0), or closed (k = 1). Here k = 1, indicating a closed universe.

If the universe is empty, then $\rho = \dfrac{\Lambda}{8\pi G}$, where Λ is the cosmological constant, and thus $a_o^2 = \dfrac{3}{\Lambda}$ is constant. In this case, the scale factor varies with time as

$$a(t) = a_o \cosh\left(\frac{t}{a_o}\right) \quad a > a_o \tag{6}$$

where the origin of our universe is at t = 0. Nothing forbids us from applying this for earlier times. For t < 0 the universe contracts, reaching a_o at t = 0. Thereafter it expands very rapidly providing for what is called *inflation* (see Fig. 1). Note that the scale factor is never smaller than a_o.

While not precisely the exponential usually associated with inflationary cosmology, which occurs when k = 0, it amounts to the same thing. The fact that k = 1 may seem to contradict the familiar prediction of inflationary cosmology that k = 0, that is, that the universe is flat. Actually, a highly flat universe is still possible with k = 1. Such a universe is simply very large, like a giant inflated balloon, with the part within our horizon simply a tiny patch on the surface. It eventually collapses in a "big crunch" but so far in the future that we can hardly speculate about it except to conjecture that maximum entropy or "heat death" is likely to happen before the collapse is complete. Models for a closed universe exist that are consistent with all current data.[8] In fact, now that we know the universal expansion is accelerating, such models are even more viable.

Now, let us write the Friedmann equation

$$p^2 + \left(\frac{3\pi}{2G}\right)^2 a^2 \left(1 - \frac{a^2}{a_o^2}\right) = 0 \tag{7}$$

This is a classical physics equation. We can go from classical physics to quantum physics is by means of *canonical quantization* in which we replace the momentum p by an operator:

$$p = -i\frac{d}{da} \tag{8}$$

$(\hbar = 1)$ and introduce a wave function ψ, where $H\psi = E\psi$, and $E = 0$.

$$\left[\frac{d^2}{da^2} - \left(\frac{3\pi}{2G}\right)^2 a^2 \left(1 - \frac{a^2}{a_o^2}\right)\right]\psi = 0 \tag{9}$$

This is a simplified form of the *Wheeler-DeWitt equation*, where ψ is grandly referred to as the *wave function of the universe*.[9] Using the conventional statistical interpretation of the wave function, $|\psi(a)|^2\, da$ represents the probability of finding a universe in an ensemble of universes with a in the range a to $a + da$.

In general, the wave function of the universe described by the Wheeler-DeWitt equation is a function of functions (that is, it is a *functional*) that specifies the geometry of the universe at every point in 3-dimensional space, with time puzzlingly absent as a parameter. Here we consider the situation where the geometry can be described by a single parameter, the radial scale factor a. This should be a reasonable approximation for the early universe and greatly simplifies the problem. Note that zero energy is consistent with the universe coming from "nothing," which presumably has zero energy, without violating energy conservation. In fact, current cosmological observations indicate that the average density of matter and energy in the universe is, within measurement errors, equal to the critical density for which the total energy of the universe was exactly zero in the early universe.

2. Quantum Tunneling

Mathematically speaking, the Wheeler-DeWitt equation in this case is simply the time-independent Schrödinger equation for a non-relativistic particle of mass m = 1/2 (in units inverse to the units of a) and zero total mechanical energy, moving in one dimension with coordinate a in a potential

$$V(a) = \left(\frac{3\pi}{2G}\right)^2 a^2 \left(1 - \frac{a^2}{a_o^2}\right) \tag{10}$$

This potential is shown in Fig. 2. Note that it includes the region $a < a_o$.

The mathematical solution of the Friedmann equation for this region is

$$a(\tau) = a_o \cos\left(\frac{\tau}{a_o}\right) \quad 0 < a < a_o \tag{11}$$

where τ is a real number and the "time" $t = i\tau$ is an imaginary number. Thus the region $a < a_o$ cannot be described in terms of the familiar operational time, which is a real number read off a clock. This is an "unphysical" region, meaning it is a region not amenable to observation. However, meaningful results can still be obtained when our equations are extended into the physical region.

This is a common quantum mechanical procedure, as in the familiar problem of tunneling through a square barrier (see Fig. 3). Inside the barrier the wave function is

$$\psi(x,t) = Ce^{i(px-Et)} + De^{i(-px-Et)} \quad -b/2 < x < b/2 \tag{12}$$

where $p = i\left[2m\left(V-E\right)\right]^{1/2}$ is an imaginary number. Using imaginary time is analogous to using imaginary momentum in this case.

The probability for tunneling through a square barrier, found in textbooks, is

$$P = \exp\left\{-2\left[2m\left(V-E\right)\right]^{1/2} b\right\} \tag{13}$$

The potential in the Wheeler-DeWitt equation resembles the kind of potential barriers encountered, for example, in nuclear physics where α-decay is explained as a quantum tunneling process. A variable barrier $V(x)$ in the range $x_1 < x < x_2$ can be treated as a sequence of infinitesimal square barriers of the type above. The probability for transmission through the barrier will then be,

$$P \approx \exp\left(-2\int_{x_1}^{x_2} dx 2m\left|V(x)-E\right|^{1/2}\right) \tag{14}$$

Here, $2m = 1$, $E = 0$, $x_1 = 0$, and $x_2 = b = a_o$, so

$$P \approx \exp\left(-2\int_{o}^{a_o} daK(a)\right) \tag{15}$$

where

$$K(a) = \left(\frac{3\pi}{2G}\right)^2 a \left(\frac{a^2}{a_o^2} - 1\right)^{1/2} \tag{16}$$

The above integral can be shown to yield,

$$P \approx \exp\left(-\frac{3}{8G^2\rho}\right) \tag{17}$$

At the earliest definable moment, the Planck time (1.61×10^{-43} second), we estimate from the uncertainty principle that ρ will be on the order of the Planck density, $\rho = 1/G^2 = 3 \times 10^{129}$ electron-volts per cubic meter. In that case, the tunneling probability is exp(-3/8) = 68.7 percent. This suggests that the unphysical region is unstable and that 68.7 percent of all universes will be found in the physical state.

The region $a < a_o$ is a classically disallowed region that is allowed by quantum mechanics and described by a solution of the Wheeler-DeWitt equation. The particular solution will depend on boundary conditions. In their no-boundary model, Hartle and Hawking propose equal amounts of incoming and outgoing waves, which Atkatz writes

$$\psi_{HH}(a > a_o) = K(a)^{-1/2} \cos\left[\frac{\pi}{2} a_o^2 \left(\frac{a^2}{a_o^2} - 1\right)^{3/2}\right] \tag{18}$$

$$\psi_{HH}(0 < a < a_o) = \left|K(a)\right|^{-1/2} \exp\left[-\frac{\pi}{2} a_o^2 \left(1 - \frac{a^2}{a_o^2}\right)^{3/2}\right] \tag{19}$$

These solutions have been obtained using WKB approximation and do not apply for the regions around $a = 0$ and $a = a_o$. The wave function is shown in Fig. 4, where I have extrapolated to zero at $a = 0$ and smoothly connected the inside and outside solutions at $a = a_o$.

3. Interpretation

The simplified Hartle-Hawking model gives one possible scenario for the universe to come about naturally. In this picture, another universe existed prior to ours that tunneled through the unphysical region around $t = 0$ to become our universe. Critics will argue that we have no way of observing such an earlier universe, and so this is not very scientific. However, the model is based on well-established theories that make no distinction between the two sides of the time axis. Nothing in our knowledge of physics and cosmology requires the non-existence of that prior universe, so it would be a violation of Occam's razor to exclude it.

However, if you insist on no prior universe you can use an alternate solution to the same Schrödinger equation provided by Vilenkin where the universe simply starts at $t = 0$. It is just a matter of setting a boundary condition.[10] Vilenkin interprets his solutions as tunneling from "nothing," where he takes the classically unphysical region $a < a_o$ to represent nothing.

While not crucial to our scenario of a natural origin for our universe, it is interesting to note that the earlier universe in the Hartle-Hawking case is only earlier from our point of view, where the arrow of time points away from the big bang in the direction of increased entropy. Our sister universe will have an arrow of time pointing opposite to ours since that is the direction of increased entropy on the negative side of the time axis. The two universes, then, are mirror images of one another, both emerging simultaneously from the same point in space and time. They are not likely to be identical, however, since we expect from our current models of cosmology and particle physics that random processes play a major role in the development of structure.

This scenario then provides another way of looking at the origin of the universe. Two universes "begin" in the unphysical region around $t = 0$ that Vilenkin calls "nothing." These universe then evolve along the opposite directions of the time axis.

4. How Can Something Come from Nothing?

Nature is capable of building complex structures by processes of self-organization; simplicity begets complexity. Consider the example of the snowflake. Our experience tells us that a snowflake is very ephemeral, melting quickly to drops of liquid water that exhibit far less structure. But that is only because we live in a relatively high temperature environment, where heat reduces the fragile arrangement of crystals to a simpler liquid. Energy is required to break the symmetry of a snowflake.

In an environment where the ambient temperature is well below the melting point of ice, as it is in most of the universe far from the highly localized effects of stellar heating. In such an environment, any water vapor would readily crystallize into complex, asymmetric structures. Snowflakes would be eternal, or at least will remain intact until cosmic rays tear them apart.

What this example illustrates is that many simple systems of particles are unstable, that is, have limited lifetimes as they undergo spontaneous phase transitions to more complex structures of lower energy. Since "nothing" is as simple as it gets, we would not expect it to be very stable. This is consistent with the estimate given above that a universe is about twice as likely to be found in the physical state than the unphysical state we are identifying with nothing. The unphysical state undergoes a spontaneous phase transition to something more complicated, like a universe containing matter. The transition nothing-to-something is a natural one, not requiring any agent. As Nobel laureate physicist Frank

Wilczek has put it, "The answer to the ancient question 'Why is there something rather than nothing?' would then be that "nothing" is unstable."[11]

In short, the natural state of affairs is something rather than nothing. An empty universe requires supernatural intervention—not a full one. Only by the constant action of an agent outside the universe, such as God, could a state of nothingness be maintained. The fact that we have something is just what we would expect if there is no God.

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Notes

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[1] Bede Rundle, *Why there is Something rather than Nothing* (Oxford: Clarendon Press, 2004.

[2] The original idea is usually attributed to E. P. Tryon, "Is the universe a quantum fluctuation?" *Nature* 246 (1973): 396-97.

[3] Alan Guth. "The Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," *Physical Review* D23 (1981): 347-56; *The Inflationary Universe*, New York: Addison-Wesley, 1997; Linde, André. "A New Inflationary Universe Scenario: A Possible Solution of the Horizon, Flatness, Homogeneity, Isotropy, and Primordial Monopole Problems." *Physics Letters 108B* (1982): 389-92; "Quantum Creation of the Inflationary Universe," *Lettere al Nuovo Cimento* 39 (1984): 401-05.

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[7] John W. Norbury, "From Newton's Laws to the Wheeler-DeWitt Equation," *European Journal of Physics* 19 (1998): 143-50.

[8] Marc Kamionkowski and Nicolaos Toumbas, "A Low-Density Closed Universe, *Physical Review Letters* 77 (1996): 587-90.

[9] B.S DeWitt, “Quantum Theory of Gravity. I. The Canonical Theory,” *Physical Review* 160 (1967): 1113-48, J.A. Wheeler, “Superspace and the nature of quantum geometrodynamics,” in C. DeWitt, and J.A. Wheeler, eds., *Battelle Rencontres*: *1967 Lectures in Mathematics and Physics*, (New York:W.A. Benjamin, 1968).

[10] Alexander Vilenkin, "Boundary conditions in quantum cosmology," *Physical Review* D33 (1986): 3560-69. The Vilenkin wave function is given in *The Comprehensible Cosmos*.

[11] Wilczek, Frank, "The Cosmic Asymmetry between Matter and Antimatter." *Scientific American* 243, No. 6 (1980): 82-90.

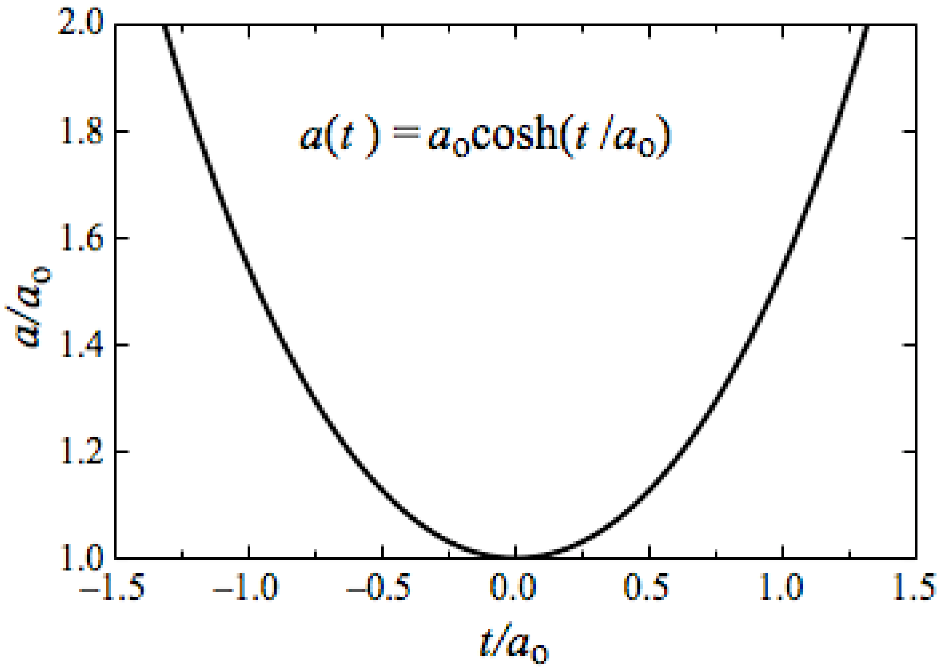

Fig. 1. The solution of Friedmann's equation for and empty universe with $k = 1$. The region $t < 0$ is not forbidden by any known principle.

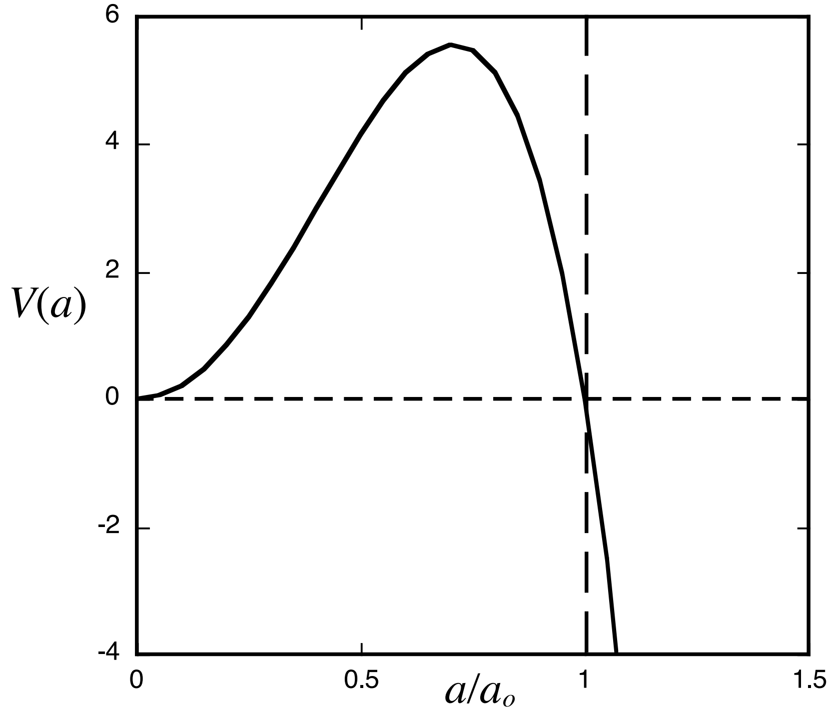

Fig. 2. The potential energy in the Wheeler-DeWitt equation. The vertical scale is in units of $\left(\frac{3\pi}{2G}\right)^2$.

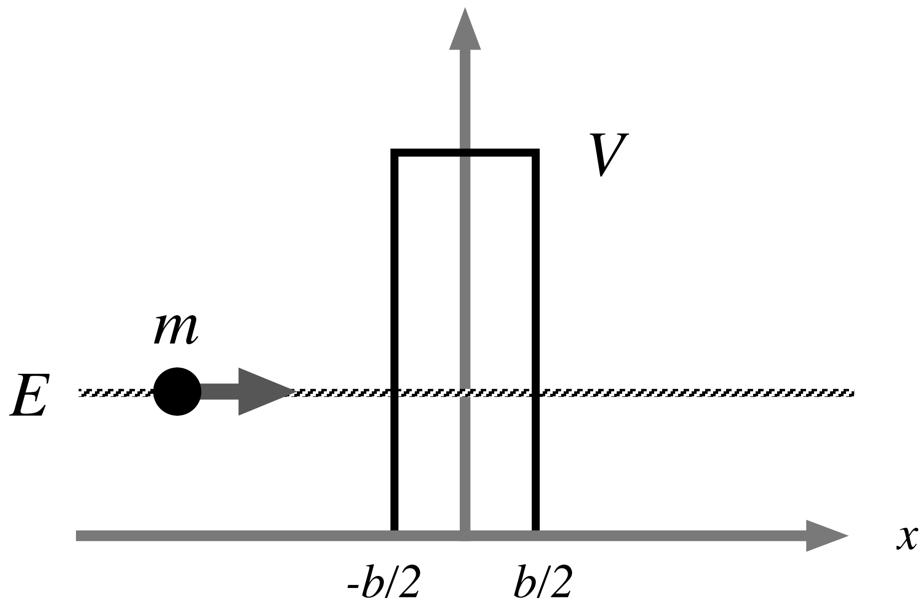

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Fig. 3. A particle of mass *m* and energy *E* inc

.ident on a potential energy barrier of height *V* and width *b*. Quantum mechanics allows for particles to tunnel through the barrier with a calculable probability. The region inside the barrier is "unphysical," that is, unmeasurable, with the particle’s momentum being an imaginary number.

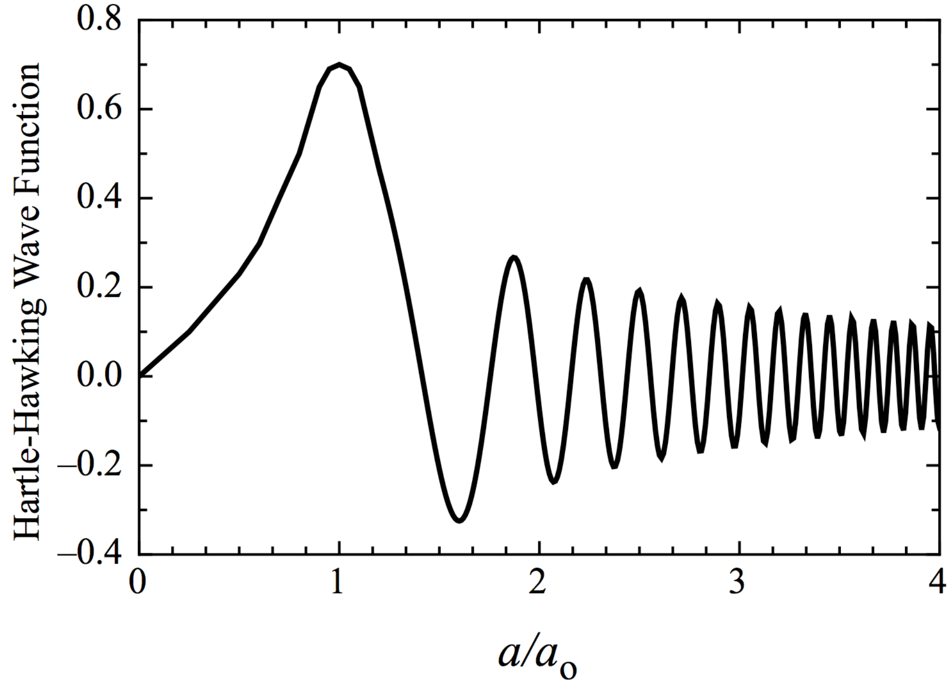

Fig. 4. The Hartle-Hawking wave function of the universe.

In Defense of New Atheism:

A Response to Massimo Pigliucci

Victor J. Stenger

Abstract

Philosopher Massimo Pigliucci has written an article highly critical of the new atheists and accusing them of scientism. He implies that only professional philosophers like himself are qualified to discuss the subject. However, the books Pigliucci criticizes were not intended to be philosophical treatises. They are popular books addressed to a public that is becoming increasingly disenchanted with organized religion and its negative influence on society. The new approach takes a harder line in criticizing religion than was previously the case amongst secularists. The new atheists question whether faith, which is belief despite the absence of evidence or even in the presence of contrary evidence, has any moral or intellectual authority. New Atheism recognizes religion for what it is—a set of unfounded superstitions that have been the greatest hindrance to human progress that ever existed on this planet.

Philosopher, biologist, “a-theist,” and “a-unicornist” Massimo Pigliucci has written an article titled “New Atheism and the Scientistic Turn in the Atheism Movement”(2013) that is highly critical of four of the five authors who founded the movement with their bestselling popular books published in the period 2004 to 2007: Sam Harris (2004), Richard Dawkins (2006), Christopher Hitchens (2007), and me (Stenger 2007). He does not refer to my book *The New Atheism* that summarizes the views of these authors and responds to the many criticisms that bombarded their books as soon as they appeared (2009).

Pigliucci seems to think that only professional philosophers, such as him, are qualified to write on the subject of atheism. So, he goes easy on new-atheist founder, philosopher Daniel Dennett (2006) and also praises Alain De Botton (2012) and A.C Grayling (2013), whom he calls “post-new atheists.” As Pigliucci notes, they are “not coincidentally, both philosophers.” (2013, 153)

Pigliucci also has little regard for the writings of new-atheist biologists, and non-philosophers, Jerry Coyne and P.Z. Myers, whose blogs have huge followings. Coyne’s book *Why Evolution Is True* (2009) was also an instant new-atheist bestseller. Certainly the popularity of all these authors testifies that New Atheism has struck a responsive chord among the reading public.

The books Pigliucci criticizes were not intended to be philosophical treatises, which are read mainly by other philosophers. They are popular books addressed to a public that, as polls continue to show, is becoming increasingly disenchanted with organized religion and its negative influence on society. That audience was clearly open to proposals for a different approach to atheism than the one provided by most atheist authors prior to 2004.

Need I remind Pigliucci that Socrates did not write at all but walked the streets.

The new approach takes a harder line in criticizing religion than was previously the case amongst secularists. The new atheists question whether faith, which is belief despite the absence of evidence or even in the presence of contrary evidence, has any moral or intellectual authority. New Atheism recognizes religion for what it is—a set of unfounded superstitions that have been the greatest hindrance to human progress that ever existed on this planet.

The celebrated paleontologist Stephen Jay Gould, an avowed atheist, exemplified the older, softer approach to religion in his last book, *Rocks of Ages*, published in 1999, the year he died. There he introduced the term NOMA, *Non-Overlapping Magisteria*, to describe a suggested demarcation between science and religion (1999).

Gould, full of good intentions, was trying to minimize conflicts between science and religion by carving out separate “magisteria” for each. He suggested that science should limit itself to the empirical world while religion should deal with moral values. In Gould’s phrase, religion deals with the “rock of ages,” while science deals with the “ages of rocks.”

As many reviewers pointed out, Gould was trying to limit the scope of religion by redefining it as moral philosophy. But religion is more than moral philosophy; it has always made and continues to make doctrinal statements about how the natural world supposedly works. And as moral philosophy, religion has relied more on Bronze-Age revelations than the study of humanity and society and consequently has long been a drag on the improvement of moral philosophy.

Various Christian sects do not hesitate to take positions contrary to science on empirical topics such as evolution, contraception, stem cell research, and climate change. At the same time, science is not precluded from considering moral issues, which involve observable human behavior in response to different types of social and personal stimulations.

Pigliucci severely misrepresents the views expressed by Harris in his 2010 book, *The Moral Landscape: How Science Can Determine Human Values* (2012), presenting them as examples of the New Atheism's *scientism.* Pigliucci defines scientism as "a totalizing attitude that regards science as the ultimate standard and arbiter of all interesting questions; or alternatively that seeks to expand the very definition and scope of science to encompass all aspects of human knowledge and understanding." (2013, 144)

With religion always having intruded into the realm of natural phenomena, and science learning more and more about the foundations of human moral and ethical behavior, it seems odd for Pigliucci to claim that questions of atheism and belief should be the exclusive province of philosophers. His failure to successfully grapple with these points severely hobbles his thinking.

Nowhere does Harris's book claim that moral questions should be settled *exclusively* by science. Rather he argues that science should be allowed a place at the table, where it has been previously excluded. In an email message to me, Harris explained (2014):

> The *Moral Landscape* wasn't a claim that current science, narrowly defined, can answer all our moral questions. It was an argument against moral relativism—the idea that questions of right and wrong have no answers, or that such answers are merely made up, culturally constructed, etc. More generally, the new atheists are not arguing that science covers all of human knowledge. We are saying that in every domain of knowledge there is an important distinction between having good reasons for what one believes and having bad ones. Religion consistently falls on the wrong side of that divide. In fact, it even has a doctrine that appears to justify staying on the wrong side (faith).

Indeed, one of the common themes of New Atheism is to persuade scientists, the majority of whom are atheists, to play a larger role in many contested issues that affect the future of humanity on this planet. Left to their own devices, many scientists—perhaps most—would rather not be bothered, so that they can concentrate on their own, narrowly specialized research. How is it "scientism" to encourage the members of an important group in society to more widely apply their discipline and analytic skills for human betterment?

Most scientists are all too willing to trust other institutions to handle matters that do not directly concern them. They fail to realize that many of these matters do affect them, directly and indirectly. Already we can see antiscientific policies, promoted by morally corrupt corporations and egged on by the equally morally corrupt religious right, resulting in drastically reduced funding for many types of important basic scientific research. While still the leader in technology, the United States no longer leads the world in basic research. If current policies continue, the lead in technology will surely also be lost, resulting in serious consequences for the U.S. economy.

Furthermore, how can scientists sit back and ignore forces at work that, if allowed to continue, will make this planet unlivable for their grandchildren?

The new atheists do not reject the important roles played by social institutions other than science. However, it is not outside the bounds of science or atheism to be highly critical of those institutions, especially religion, that promote detrimental policies based on ignorance and superstition.

In yet another misrepresentation, Pigliucci wrongly sees scientism in the writings of the (non-philosopher) new atheists. Specifically, he objects to the independent proposal by Dawkins and me that we can treat God as a falsifiable scientific hypothesis. Here’s what Pigliucci says: “There is no coherent or sensible way in which the idea of god can possibly be considered a “hypothesis” in any sense remotely resembling the scientific sense of the term. The problem is, that the supernatural, by its own (human) nature, is simply too swishy [I think he meant “squishy”] to be pinpointed precisely enough.” (2013, 144)

Here Pigliucci, like Gould, is trying to deal with religion by redefining it. If religion made no claims about how the world actually works, and made no claim that God intervenes in the world to create or avoid particular real effects, then Pigliucci might have a bit of a point. But religion as understood and experienced by most believers entails explicit or implicit claims about the real world and God’s supposed role in controlling and influencing the real world. It is Pigliucci, not religion, that is being “squishy” on this point.

And, I don’t think the idea of the supernatural is “squishy” at all. It is clearly understood as referring to phenomena beyond the natural world. Science can be said to have begun in the sixth century BCE when Thales of Miletus and the other Presocratic Greek philosophers sought to find causes for phenomena that were based on observable entities rather than imaginary gods and spirits. Instead of an earthquake being caused by Poseidon striking the ground with his trident, Thales suggested it was the result of Earth resting unstably on water.

Of course this explanation of earthquakes was wrong, as are many scientific ideas. But the scientific method of observation and hypothesis testing, and a ready willingness to replace old models with better ones, is the key to the success of science. Indeed, ancient Greek science and philosophy, starting with Thales, was notable for the way disciples built upon the teachings of their masters but also did not hesitate to disagree with them. Science never developed in those societies, such as China, where dissent resulted in the loss of the part of your body above your shoulders.

We would be a thousand years further along in the scientific quest had it not been interrupted when, in the fourth century of the Common Era, the Catholic Church assumed control of the Roman Empire and plunged Europe into the Dark Ages. Only with the Renaissance, when free thought once again became possible, did a new science develop that led to the modern world.

Pigliucci never discusses my central and unique argument in *God: The Failed Hypothesis*, which is that not only can we treat God as a scientific hypothesis, we can conclude from the data that the hypothesis that the God most people worship actually exists has been falsified. Since this is a far stronger statement than that made by Dawkins or any of the other new atheists, I will address it in detail.

First, I do not address the existence of every possible god, such as a deist or pantheist god, but only a personal God who is claimed to have created the vast universe and to reign over it all while at the same time playing a dominant role in every event, guiding every leaf that falls to the ground, listening to every human thought, and answering our prayers.

Since there are very possibly trillions upon trillions of other sentient life forms in the universe, God also must listen to their thoughts and control events on their planets as well. Assuming all these sentient beings are in need of redeeming, then it follows that Jesus must be dying on the cross every nanosecond or so across the universe.

Now, a Christian apologist might say God is infinite and fully capable of redeeming all the sentient beings in his creation. Certainly that is true, if such a God exists. But it is inconsistent with the deeply entrenched Christian tradition that humanity is a special creation of God, existing on a higher metaphysical plane than all other living creatures. This is a view that has been expressed by both evangelicals (Van Bebber 2014) and the director of the Vatican Observatory (Catholic News Agency 2008), who both say Jesus only visited Earth.

Second, I use the word “proof” to refer to scientific proof rather than deductive logical or mathematical proof. Scientific proof does not provide absolute certainty, but is more like the proof “beyond a reasonable doubt” that is applied in criminal courts in the United States. I dispute the common assertion that you cannot prove or disprove the existence of God. You can, if you mean scientific proof. If Pigliucci were to use the scientific definition of proof rather than the deductive one, he could remove the hyphen from a-unicornist since surely he believes beyond a reasonable doubt that there are no unicorns. And, while he is at it, he can take the hyphen out of a-theist, too.

Third, the hypothesis I am testing is not what Pigliucci seems to think Dawkins and I are doing, namely asking for some kind of physical evidence for the nature of a supernatural being. Rather we are asking for tangible evidence — *scientific* evidence—that a God who plays an important role in the universe exists. If such a God exists, then his actions should leave some observable effects in the real world, effects that should be at least as obvious as the footprints in the snow of passing wildlife that I see in the field behind my house. I rarely actually see those animals, but I know they exist. God has left no footprints on the snows of time.

I go further than the other new atheists, who simply say there is no evidence for God. I assert that we can now scientifically prove beyond a reasonable doubt that the God worshipped by most believers does not exist. In the following I present a summary of evidence that should be there but is not.

The Absent Evidence

1. Cosmology should have evidence for a God who miraculously and supernaturally created the universe. It has none. No violations of physical law were required to produce the universe, its laws, or its existence rather than nonexistence. Furthermore, current cosmological theories strongly suggest that our universe is just one of an unlimited number of other universes in a "multiverse" that always existed, in which case there never was a creation (Linde 1986, 1994; Vilenkin 2006).
2. If God is responsible for the complex structure of the world, especially living things, we should see evidence for it in nature. We do not. Complex systems are observed to evolve from simpler ones and show none of the expected signs of design. Indeed, the

universe looks as it should look in the absence of design. What is more, well established cosmological knowledge indicates that the universe began with maximum entropy, that is, total chaos with the absence of structure. Thus the universe bears no imprint of a creator.

3. We should see evidence for a God who has given humans immortal souls. We do not. All the empirical facts indicate that purely physical processes determine human memories, thoughts, and personalities. No nonphysical or immaterial powers of the mind can be found. No evidence exists for an afterlife.
4. We should be able to verify that a personal God interacts with humans by means of revelation as recorded in scriptures. We cannot. Miraculous interventions that are claimed in scriptures are contradicted by the lack of independent evidence that these miraculous events took place. In fact, physical (archeological) evidence now convincingly demonstrates that some of the most important biblical narratives, such as the Exodus, the conquests of Joshua, and the magnificent, unified empire of David and Solomon never occurred.
5. With billions of prayers being solicited every year, by now there should be some evidence for prayers being answered. There isn't any. Careful scientific studies of the medical efficacy of prayer by several highly reputable research institutions have found none (Aviles 2001, Benson 2007, Sloan 2002).

6. If humanity is made in God's image and is the reason he created the heavens and Earth, then the universe should be congenial to human life. It is not. Humans did not appear until the universe was already 13.8 billion years old. Furthermore, we are confined to a tiny speck of dust in a vast cosmos and unable to survive anywhere else within reach.
7. If God communicates directly with humans during religious experiences, then we should be able to verify that fact. We cannot. No claimed revelation has ever contained information that could not have been already in the head of the person making the claim.
8. If God is the source of morality and values then there should be evidence that revelations and religion are the source of a superior and unchanging morality and ethics. But history and anthropology show that morality and ethics have grown from social contact and the need to live in harmony. The moral pronouncements of religion have more often been an obstacle to improvement and even devout believers pick and choose for themselves what is good and what is bad. Hardly anyone accepts what were once religious teachings on the divine right of kings, the oppression of women, the conquest of infidels, slavery, the virtue of not bathing. Most Catholics now reject the Church's teachings on contraception as they earlier rejected it's teaching on sin as the cause of disease. Nonbelievers behave no less

morally and, as some surveys indicate, arguably more morally than believers.

I will grant that Pigliucci is justifiably miffed by the statements made by a number of scientists that question the value of philosophy. Scientists as a whole are a hard-headed lot and can be skeptical, if not downright dismissive, of thinking that they see as vague and muddled – which, it is fair to say, is true of much of what passes for philosophy. But anti-philosophy statements are not unique to the new atheist movement, and it is disingenuous to link this viewpoint with New Atheism. And of course the best philosophers over the ages have been highly intelligent and clear-thinking. I personally have benefited greatly from my reading of philosophy and interactions with philosophers, such as Larry Laudan and Daniel Dennett, who, I have found, often know more about the nature of science than those scientists that criticize them.

I do not think New Atheism is at war with philosophy. Nor are its principles in conflict with philosophy. Theology is another matter. The principles of New Atheism, as I see them to have been elucidated in the new atheist literature, are:

1. We should seek the “end of faith” because it is at best worthless and at worst harmful to believe without evidence, and downright dangerous to believe despite the evidence.
2. Religious claims – whether about the world or about human morality and ethics—should be studied scientifically and not be given a free pass from criticism.

3. Religion should be studied scientifically and not be given a free pass from criticism.

4. Religion "poisons everything."
5. There not only is no evidence for God, there is ample evidence against the existence of a God, such as the Judaic-Christian-Islamic God, who plays and important role in the universe and in human life.
6. Yet, the situation is not hopeless. Surveys indicate that the tide is turning

   against theism, especially among the young who are the future.

As long as believers continue to promote a faith that claims divine revelation as a source of knowledge, they encourage the extreme elements of that faith to commit any horrific act, convinced they are carrying out the will of God.

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Does science make belief in God obsolete?

Victor J. Stenger

Yes.

Once upon a time there were a number of strong scientific arguments for the existence of God. One of the oldest and most prevalent is the argument from design. Most people look at the complexity of the world and cannot conceive of how it could have come about except by the action of a being or force of great power and intelligence.

The design argument received perhaps its most brilliant exposition in the work of the Anglican archdeacon William Paley. In his *Natural Theology or Evidences of the Existence and Attributes of the Deity Collected from the Appearance of Nature*, first published in 1802, Paley wrote about finding both a stone and a watch while crossing a heath. Though the stone would be regarded as a simple part of nature, no one would question that the watch is an artifact, designed for the purpose of telling time. Paley then proposed that objects of nature, such as the human eye, give every indication of being similar contrivances.

When Charles Darwin entered Cambridge in 1827 he was assigned to the same rooms in Christ's College occupied by William Paley seventy years earlier. By that time the syllabus included the study of Paley's works and Darwin was deeply impressed. He remarked that Paley's work, "gave me as much delight as did Euclid."

Yet Darwin ultimately discovered the answer to Paley and showed how complex systems can evolve naturally from simpler ones without design or plan. The mechanism he proposed in 1859 in *The Origin of Species (*inferred independently by Alfred Russel Wallace) was natural selection, by which organisms accumulate changes that enable them to survive and have progeny that maintain those features.

But, as Darwin recognized, a serious objection to evolution existed based on the known physics of the time. Calculations by the great physicist William Thomson (Lord Kelvin) estimated ages for the sun that were far too short for natural selection to operate.

However, at the time, nuclear energy was unknown. When this new form of energy was discovered early in the twentieth century, physicists estimated that the energy released by nuclear reactions would allow the sun and other stars to last billions of years as stable energy sources.

Prior to the twentieth century, the simple fact that the universe contains matter also provided strong evidence for a creation. At the time it was believed that matter was conserved, and so the matter of the universe had to come from somewhere. In 1905 Einstein showed that matter could be created from energy. But where did that energy come from?

This remained unanswered for almost another century until accurate observations with telescopes determined that an exact balance exists between the positive energy of matter and the negative energy of gravity. So, no energy was required to produce the universe. The universe could have come from nothing.

Independent scientific support for a creation was also provided by a basic principle of physics called the *second law of thermodynamics,* which asserts that the total disorder or entropy of the universe must increase with time. The universe is growing more disorderly with time. Since it now has order, it would seem to follow that at some point in the past, even greater order must have been imparted from the outside.

But in 1929, astronomer Edwin Hubble reported that the galaxies were moving away from one another at speeds approximately proportional to their distance, indicating that the universe was expanding. This provided the earliest evidence for the Big Bang. An expanding universe could have started with low entropy and still have formed localized order consistent with the second law.

(continued)

Extrapolating what we know from modern cosmology back to the earliest definable moment, we find that the universe began in a state of maximum disorder. It contained the maximum entropy for the tiny region of space, equivalent to zero information. Thus, even if the universe were created, it retains no memory of that creation or of the intentions of any possible creator. The only creator that seems possible is the one Einstein abhorred—the God who plays dice with the universe.

Now, such a God could still exist and play a role in the universe once the universe exploded out of chaos. We no longer have total disorder; but disorder still dominates the universe. Most of the matter of the universe moves around randomly. Only 0.1 percent, the part contained in visible parts of galaxies, has any significant structure.

If he is to have any control over events so that some ultimate plan is realized, God has to poke his finger into the works amidst all this chaos. Yet there is no evidence that God pokes his finger in anyplace. The universe and life look to science just as they should look if they were not created or designed. And humanity, occupying a tiny speck of dust in a vast cosmos for a tiny fraction of the life of that cosmos, hardly looks special.

The universe visible to us contains a hundred billion galaxies, each with a hundred billion stars. But by far the greatest portion of the universe that expanded exponentially from the original chaos, at least fifty orders of magnitude more, lies far beyond our horizon. The universe we see with our most powerful telescopes is but a grain of sand in the Sahara. Yet we are supposed to think that a supreme being exists who follows the path of every particle, while listening to every human thought and guiding his favorite football teams to victory. Science has not only made belief in God obsolete. It has made it incoherent.

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