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The Uncreated Universe

> *Who are we? We find that we inhabit an insignificant planet of a humdrum star lost in a galaxy tucked away in some forgotten corner of a universe in which there are far more galaxies than people.*
>
> –Carl Sagan, 1983

The First Ten Microseconds

In an article in the *New York Times* on January 28, 2001, science reporter James Glanz wrote:

> Ask a philosopher, a theologian, an artist or a composer how close humanity is to understanding the mystery of cosmic creation, and you are liable to get an answer that is majestic, inspiring and extremely imprecise. Ask a physicist the same question and the answer will be much more cut-and-dried: about 10 millionths of a second.[1]

While he was not responding directly to Glanz, Richard Dawkins has tried to counter the common impression, to which Glanz may have further contributed, that science has removed all the beauty and mystery from life:

> The feeling of awed wonder that science can give us is one of the highest experiences of which the human psyche is capable. It is a deep aesthetic passion to rank with the finest that music and poetry can deliver. It is truly one of the things that make life worth living and it does so, if anything, more effectively if it convinces us that the time we have for living is quite finite.[2]

I do not think science has to make any apologies. It looks at the world and tells it like it is. And we all live longer, better lives because of this dispassionate view. Sure, it commands awe and provides inspiration. Still, I would rather be operated on by a surgeon who sees me as an assemblage of atoms than one who lovingly tries to manipulate what he or she imagines are my vital energy fields. Dawkins himself has been particularly eloquent in getting across the message that science does not paint a picture of a universe that always fulfills human wishes. Indeed, it paints a more wondrous sight that goes far beyond human fantasies and petty concerns.

Glanz was reporting on a new experiment about to commence operation at the Brookhaven National Laboratory on Long Island in New York. Gold nuclei moving near the speed of light were to be smashed against other gold nuclei, producing the enormous energy densities that, according to current cosmological theory, existed during a few microseconds after our universe began. This is made possible by the high electric charge of the gold nucleus and the enormous electric field that develops when two such nuclei come into near contact. Under these conditions, matter exists in a state called the *quark-gluon* plasma. In a more familiar plasma,[3] such as exists in the ionosphere of Earth's atmosphere, electrons are ripped from atoms leaving behind electrically charged nuclei and electrons. In the Brookhaven quark-gluon plasma, not only are the original gold atoms ripped apart, but so are their nuclei and the protons and neutrons inside these nuclei. What remains is a highly dense mixture of *quarks*—the constituents of nucleons—and *gluons*, the particles responsible for the force between quarks. Under normal conditions, quarks remain bound inside protons and neutrons. However, for a small fraction of a second, the Brookhaven experiment is designed to produce matter as it existed in the first ten microseconds.

The theory that describes the quark-gluon plasma is called *quantum chromodynamics* (QCD) and is part of the wider *standard model* of elementary particles and forces developed in the 1970s. This model proposes that a small number of elementary particles (quarks and *leptons*) comprise the basic units of matter while the forces between these particles result from the exchange of other elementary particles (*bosons*).[4] The Brookhaven experimenters will fill in further details and look for anomalies, but so far QCD and the standard model have passed every experimental test. The current expectation is that no new physics beyond the standard model will be discovered until the Large Hadron Collider (LHC), now being built in Geneva, Switzerland, at the European Organization for Nuclear Research (CERN) begins taking data around 2006. Of course, physicists will keep looking for new physics with existing technology.

While science continually uncovers new mysteries, it has removed much of what was once regarded as deeply mysterious. Although we certainly do not know the exact nature of every component of the universe, the basic principles of physics seem to apply out to the farthest horizon visible to us today.

With powerful telescopes and other instruments, we can observe and study galaxies billions of light-years distant. These galaxies look different from ours in several ways; for example, they have many more young stars. Even as I write this, the media are reporting the first results from the Chandra X-ray space telescope, which indicate far more high-energy radiation from distant galaxies, viewed as they were billions of years ago, than those closer by and "only" a million years or so from our own epoch. The data offer strong support for a universe that has evolved over time, one that is not the "firmament" implied by the Bible. Not only has life evolved, so has the universe itself.

However, while early and distant galaxies are structurally different from the ones nearer home, they exhibit the same basic physical processes. For example, the spectral lines of atomic hydrogen emitted by other galaxies, near and far, are identical to those observed in the Sun and in laboratories on Earth. They are just shifted to longer wavelengths or lower frequencies (the "red shift") by the Doppler effect that results from the high speeds at which the galaxies move away from us. (The Doppler shift is the familiar experience in which the sound of an ambulance siren is higher pitched as the ambulance rushes toward us, and then becomes lower pitched as it moves away). Similarly, the faster a galaxy is receding from us, the farther away it gets as time goes on. Thus, the most distant galaxies are those that are receding at the highest speeds. Another interesting recent discovery by the Chandra X-ray telescope provides evidence that giant black holes are likely sources of the distant X-rays that it has detected. These deep-space X-rays were predicted to exist by the same equations from Einstein's theory of general relativity that explain minute gravitational effects observed in our own solar system much closer to home.

In other words, while the detailed structure of the universe has evolved over billions of years, the basic laws of physics have not. They have apparently remained in force as far back in time as we have been able, so far, to peer. However, while we cannot look directly into the heart of the early universe, our existing knowledge can be used to infer the physical processes that took place within a tiny fraction of a second after the start of things—over ten billion years ago. This extrapolation beyond the observable is not as unreliable a procedure as you might think. While any such extrapolation can turn out to be wrong, science has a successful track record in applying its established theories to new situations.

For example, we were able to send men to the Moon and get them back by assuming that the same laws of physics applied on the Moon as on Earth. Indeed, this may have been Newton's greatest insight—that his laws of motion and gravity applied for the Moon falling around Earth and the apple falling off a tree. Theories of the early universe have been precisely tested in laboratory experiments that, like Brookhaven, mimic conditions at that time. We have no reason to think these theories should not apply, although we must make whatever observations and checks that are possible.

The standard model, when combined with equally conventional cosmological models, provides a picture of the early universe that is consistent with the very detailed measurements made in recent years on the cosmic microwave background. This radiation has long stopped interacting significantly with the other matter of the universe, cooling off (considerably) over billions of years as a result of the universe's expansion but remaining otherwise pristine in its structure. Observations of that structure have beautifully corroborated the cosmological picture developed over the last twenty years.

Evidence for the expansion of the universe was first found by Edwin Hubble in the 1920s with his observations of the red shift of galaxies. In fact, it was Hubble who first recognized that many (but not all) of the fuzzy "nebulae" he and other astronomers saw in the sky were not part of the Milky Way but were separate galaxies of stars in their own right. The detection of the cosmic microwave background by Arno Penzias and Robert Wilson in 1965 provided the first confirmation for the *big bang* model in which the universe is seen as the expanding remnant of an explosion of matter and energy that occurred 13 billion years ago.

A number of theoretical difficulties with the big bang led to the development, in the 1980s, of a supplementary model called *inflation*.[5] This model proposed that the currently observed, almost (but not quite) linear expansion was preceded by an exponential expansion during which the universe grew by many orders of magnitude in a time interval many orders of magnitude less than a second.

Although, as creationists will tell you, no physicist was present billions of years ago to observe inflation, the quantitative theory had measurable implications that could be tested. These tests were sufficiently stringent to have been capable of falsifying the inflationary theory of the early universe. As we will see, the theory of inflation has so far passed every test.[6]

Early observations indicated that the cosmic microwave background radiation was highly uniform, with the same temperature of 2.7 degrees Kelvin being measured in all directions. This uniformity was a puzzle and provided one of the original motivations for proposing inflation. In the linear big bang scenario, different parts of the sky would never have been in contact and thus unable to reach the equilibrium indicated by these regions having the same temperature. With exponential inflation, those regions were easily in original contact.

Still, while high uniformity is good for inflationary theory, too much uniformity is bad. Calculations with the inflationary model indicated that the observed temperature in different directions in space had to vary by about one part in one hundred thousand or else galaxies would never have formed. A greater observed uniformity would have implied that the matter to build galaxies was far too smoothly distributed to accumulate by gravity into localized objects, such as galaxy clusters, in the time since inflation ended.

As we learned in chapter 3, the precise quantitative variation from uniformity that inflationary theory required was verified in 1992 by the Cosmic Microwave Background Explorer (COBE) satellite. Recall that Christian physicist Hugh Ross called this the "discovery of the century" since it confirmed that the universe had a beginning and thus, in his mind, was created by a supernatural being.

Observations since 1992 have further substantiated the validity of inflationary big bang cosmology. At this writing, a remarkable new satellite observatory called the Microwave Anisotropy Probe (MAP) has just been launched that will measure the temperature to twenty millionths of a degree Kelvin in angular intervals of 0.23 degree on the celestial sphere.[7] This should lead to an even deeper understanding of the early moments of the big bang. Many of the details of the early universe, and questions such as the nature of the *dark matter* and *dark energy*, are very sensitive to the structure of the microwave background.

Was the Creation of the Universe a Miracle?

People have a hard time imagining how the universe can possibly have come about by anything other than a miracle, a violation of natural law. The intuition being expressed here is at least twofold/ First, it is widely believed that something cannot come from nothing, where that "something" refers to the substance of the universe—its matter and energy—and "nothing" can be interpreted in this context as a state of zero energy and mass. Second, it is also widely believed that the way in which the substance of the universe seems to be structured in an orderly fashion, rather than simply being randomly distributed, could not have happened except by design.

By the way, the universe is not as orderly as most people think. We live on a small pocket of order, Earth, and we see stars and galaxies in the sky that exhibit what seems to be a lot of structure. However, as we will see in more detail below, the visible matter of the universe is only about 0.5 percent of all the matter in the universe. Much of the rest, as best as we can tell, has little more structure than the cosmic microwave background, which we recall is smooth to one part in a hundred thousand.

Let us look at the physics questions implied by common intuition. If we hypothesize that the universe is an isolated or "closed" system, meaning nothing going in and nothing coming out, then both the first and second laws of thermodynamics would seem to have been violated when the universe, as we know it, came into existence. The first law is equivalent to matter-energy conservation, and a reasonable question is: Where did the current matter and energy of the universe come from?"

As best as we can tell from current observational data, the total kinetic energy of motion exactly balanced by the negative energy of gravity. As Stephen Hawking explains it:

> There are something like ten million million million million million million million million million million million million million million (1 with eighty zeroes after it) particles in the region of the universe that we can observe. Where did they all come from? The answer is that, in quantum theory, particles can be created out of energy in the form of particle/antiparticle pairs. But that just raises the question of where the energy came from. The answer is that the total energy of the universe is exactly zero. The matter in the universe is made out of positive energy. However, the matter is all attracting itself by gravity. Two pieces of matter that are close to each other have less energy than the same two pieces a long way apart, because you have to expend energy to separate them against the gravitational force that is pulling them together. Thus, in a sense, the gravitational field has negative energy. In the case of a universe that is approximately uniform in space, one can show that this negative gravitational energy exactly cancels the positive energy represented by the matter. So the total energy of the universe is zero.[8]

Actually, Hawking is referring only to the the total kinetic and potential energies. While these cancel, energy is still carried in the mass of particles. This is the rest energy given by Einstein's equation $E = mc^2$. However, in the inflationary scenario, the mass-energy of matter was produced during that rapid initial inflation. The field responsible for inflation has negative pressure, allowing the universe to do work on itself as it expands. This is allowed by the first law of thermodynamics. Some small amount of energy was required to trigger inflation, but was a fluctuation allowed by quantum mechanics.

In other words, NO energy from the outside was required to "create" the universe. What is more, this is also a prediction of inflationary cosmology, which we have seen has now been strongly supported by observations. Thus we can safely say, *No violation of energy conservation occurred if the universe grew out of an initial void of zero energy.*

Another common belief is that the formation of order by natural processes is impossible. This is the old argument from design, which was discussed in detail in chapter 3. Here it appears as the intuitive claim that the second law of thermodynamics requires that the universe begin in a state of low entropy (high order) and evolve toward a final state of ultimately maximum entropy (low order)—the so-called heat death of the universe. Creationists have asserted that even if local order can occur naturally, supernatural design is evident in the existence of the highest level of order, that is, lowest entropy, at the "creation."

This argument had great weight in the nineteenth century, when the universe was assumed to be the biblical firmament of fixed stars. However, we now know that the universe is expanding. As shown in appendix C, treating the universe as a sphere of radius R,[9]the entropy of the universe increases linearly with R. However, the maximum allowable entropy of the universe increases with the square of R. As shown in figure 6.1, this allows increasing room for order to form locally.

This can be easily understood from the following mundane example: Suppose, each day you empty your kitchen waste basket into your yard. Pretty soon the yard will have no room left for trash. So you buy up the surrounding property and start dumping there. As long as you keep that up, expanding your property perimeter, you can always make your house more orderly by simply dumping your rubbish (entropy) to the outside.

To make this more quantitative, and thus more precise, I once again need to get a bit technical. The formation of order on Earth is illustrated in figure 6.2. For each visible photon that Earth receives from the Sun, it emits twenty infrared photons back to the universe. This is simple energy conservation. Earth is in thermal equilibrium with a surface temperature of 300 degrees Kelvin, kept there by energy from the Sun.[10] The Sun is also in thermal equilibrium, with a surface temperature of 6,000 degrees Kelvin, maintained by nuclear processes at its core. Both the Sun and Earth radiate a spectrum of photon energies, but, on average, a photon emitted from the Sun is twenty times as energetic as one from Earth since its surface temperature is twenty times higher than Earth's.

Each photon can be regarded as one bit of entropy, using the units of entropy defined by Shannon (see chapter 4). In this process, the Sun loses one bit of entropy and Earth loses a net of nineteen bits. Thus the Sun becomes more orderly by one bit, Earth more orderly by nineteen bits, and the rest of the universe more disorderly by twenty bits. The local ordering of the Sun and Earth is made possible by the fact that the maximum entropy of the universe (in figure 6.1) is much greater than its actual total entropy, as described above, so the universe has increasing room to gain entropy as it expands.

A simple calculation shows that more than ample room exists for the formation of the order in all the galaxies in the universe. The photons emitted by the Earth are absorbed by the Cosmic Microwave Background (CMB), which currently has a temperature of 3 degrees Kelvin but is not in thermal equilibrium, cooling as the universe expands. Since Earth was formed, it has emitted about 10^{54} photons, thus increasing the entropy of the CMB by that amount. However, the CMB contains about 10^{87} photons. If we estimate ten planets for every star, 10^{11} stars for every galaxy, and 10^{11} galaxies in the visible universe, then the ordering of those planets has increased the entropy of the CMB by 10^{76}, or only one part in 10^{11} of its total entropy.[11]

We can also understand this process using the information-theory language discussed in chapter 4, where information was defined as the change in entropy in bits. In the Earth-Sun example, the Sun gains one bit of information for every photon lost, while Earth gains nineteen bits.

As long as the universe keeps expanding, and we now have good reason to think that this will go on forever, we always have a place to toss out our entropy as we organize ourselves locally. Whether we will always have sufficient energy to do this is another question I will not address here. For now, we have enough.

The universe is now expanding, and we have no evidence that it ever underwent a contracting phase. We can use our existing cosmological models to extrapolate back in time to when the universe was a sphere 10^{-35} meter in diameter, what is called the *Planck length*. The models suggest that at this time the universe was indistinguishable from a black hole of the same size (see appendix A). Since a black hole has maximum entropy for an object of its size, it follows that the universe had maximum entropy at this early moment. At that time, the universe was as disorderly as it could possibly have been. It was without order—without design. If a creator existed, any information he may have inserted into the universe prior to that time would have been lost. Thus,

No violation of the second law of thermodynamics was required to produce the universe.

In short, no miracle, no violation of any known principles of physics, need have occurred at the creation.[12] In fact, the data are just what would be expected for a universe that came into being without design or cause.

Fine-Tuned for You and Me

In chapter 3, I briefly mentioned the *fine-tuning* argument for the existence of purposeful design in the universe. We saw that this is another of the variations that have recently appeared on the ancient, already well refuted argument from design. The so-called anthropic coincidences are claimed as evidence for a universe that was created with humans in mind.

I have covered the fine-tuning claims extensively in two previous books, *The Unconscious Quantum* and *Timeless Reality*. Here, to avoid repetition, I will only summarize the points made there and concentrate on important new developments from cosmology that have provided a tentative answer to one particular "coincidence," which, until now, has been perhaps the most puzzling of all—at least to physicists.

Most of the anthropic coincidences bear on the manufacture of carbon and other heavy elements that occurs in stars and the time needed for life to evolve once these elements are released into space and coalesce into planets. In the entire periodic table of chemical elements, which one can find hanging on the wall of any chemistry classroom, only the first three lightest elements–-hydrogen, helium, and lithium–-were produced in the early universe. All the elements heavier than lithium, which are called "heavy elements" in an astronomical context, were manufactured in massive stars.

Over the billions of years of the lifetime of a star, hydrogen nuclear fusion provides its main source of energy. Once its hydrogen is used up, a star collapses and its internal pressure rapidly increases. A less massive star, like our Sun, eventually reaches a stable state called a *white dwarf*. A more massive star continues to collapse, and heavy elements are fabricated by nuclear processes in the intense heat that develops. At some point the immense pressure builds up to the point where the star explodes as a *supernova,* spraying its matter into interstellar space and leaving a *neutron star* behind. Planets composed of heavy elements can then assemble from this matter as it is drawn together by gravity.

It has long been known that the production of carbon in stars depends sensitively on certain parameters in nuclear reactions. If those parameters had been slightly different, sufficient carbon may not have been available for life as we know it.

Obviously, the parameters were such as to produce sufficient carbon for life as we know it; however, is carbon necessary for every conceivable from of life? Hugh Ross seems to think so:

> If you want physicists (or any other lifeforms), 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 reasonably assume that life must be carbon based.[13]

But, conceivably, boron would not be so rare with some other set of parameters determining the production of elements in the nuclear reactions inside of stars. And, why must life under every circumstance be based on amino acid chemistry? Ross and other theists seem to be blind to the possibility of forms of life other than those based on carbon, perhaps because of the religious doctrine that we were all made in the image of God.

From what we now know, "life" is the label we assign to a material structure that exhibits a certain set of qualities and characteristics when those structures have reached a high level of complexity. With the physical laws and constants of our universe, heavy-element chemistry—not necessarily carbon-based—may be the only available platform for life, although we can't be sure with only one form of life to study. In opening the possibility of alternative universes with different laws and constants, we can hardly even speculate on what other forms life might take. And, it is pure speculation to suggest that no form of life other than our own is possible under all circumstances.

About the best we can do with existing knowledge is consider what the universe might be like if it had the same basic physics equations but with different values of the "constants" that go into those equations. We can use those same equations to calculate various properties that the universe might have under those conditions.

If we limit ourselves to life based on chemistry, then one obvious property that a universe with life must possess is a long lifetime for stars to allow life to evolve from whatever elements may be present in the interstellar medium. In appendix B, I present the equation for the minimum lifetime of the heavier class of stars that end their lives as supernovae. (The Sun is not in this class, being less massive and longer-lived). Other than arbitrary constants that simply define the units one is using, this minimum lifetime depends on just three parameters: the strength of the electromagnetic force, α, the mass of the proton, m_p, and the mass of the electron, m_e. The relative strength of the gravitational force is reflected in the mass of the proton.

I find that long lifetime stars that could make life more likely will occur over a wide range of these parameters. For example, if we take the electron and proton masses to be equal to their values in our universe, an electromagnetic force strength having any value greater than its value in our universe will give a stellar lifetime of more than 680 million years. The strong interaction strength does not enter into this calculation. If we had an electron mass 100,000 time lower, the proton mass could be as much as 1,000 times lower to achieve the same minimum stellar lifetime. This is hardly fine tuning.

Of course, many more constants are needed to fill in the details of our universe. And our universe 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. The gross properties of our universe are determined by these four constants, and we can vary them to see what a universe might grossly look like with different values of these constants.

I have examined the distribution of stellar lifetimes for 100 simulated 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.[14] While a few are low, most are 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 stellar lifetime is not the only requirement for life, but it certainly is not an unusual property of universes.

I do not dispute that life *as we know it* would not exist if any one of several of the constants of physics were just slightly different. Additionally, I cannot prove that some other form of life is feasible with a different set of constants. But anyone who insists that our form of life is the only one conceivable is making a claim based on no evidence and no theory.

The Quintessence of Dust

While the topic is also somewhat technical, I think it is worthwhile to single out for additional discussion the one anthropic coincidence that is found to be the most puzzling and the most difficult to explain. It is one of the prime examples used by Ross and other theists when they promote the fine-tuning argument for the existence of God. This is what is known as the *cosmological-constant problem*.

When Einstein formulated general relativity around 1915, his equation for the curvature of space at a given point contained a constant term that was not constrained to any particular value. This was the *cosmological constant*. When positive in value, it provides for an effective gravitational repulsion. At first, Einstein included this term to balance the more familiar attractive gravitation to provide for the stable firmament of stars that was assumed at the time. When, a few years later, Hubble discovered that the universe was expanding, Einstein dropped this term from his equations, calling it his "greatest blunder." Actually, his greatest blunder was calling this a blunder.

The cosmological constant is often referred to as a "fudge factor," the implication being that it was something Einstein arbitrarily stuck into his equations to get an answer he wanted. This is somewhat misleading. The constant is required by those equations unless additional assumptions are made to rule it out. So, Occam's razor, which is a logical tool for determining the minimum requirements of an explanation, would require that the cosmological constant be included unless the data indicate otherwise. No fundamental basis in established physics has yet been found for taking the cosmological constant to be identically zero, although it is predicted to be zero by a principle called *supersymmetry* that many physicists think is a fundamental symmetry in nature. Until very recently, observational data indicated that the cosmological constant was very close to zero, and so this was what was assumed.

Cosmologists began to talk about a nonzero cosmological constant again in the 1980s, with the introduction of inflationary cosmology. An exponential expansion of the early universe was seen to follow from Einstein's equations in the absence of matter or radiation, with the curvature of space given by the cosmological constant.

More recently, unexpected evidence of the apparent current accelerating expansion of the universe has come from two independent studies of distant supernovae.[15] A nonzero cosmological constant has been considered as a possible explanation for this finding. Although this interpretation of the data is still preliminary at this writing, the universe today appears to be undergoing another round of inflation—much slower than the first.

Current observations indicate that the mass/energy of the universe is shared among its various components as shown in Table 5.1.[16]

Table 5.1. The Energy Budget of the Universe

Radiation	0.005 %
Ordinary visible matter	0.5 %
Ordinary nonluminous matter	3.5 %
Exotic dark matter	26 %
Even-more-exotic dark energy	70 %

Neither the dark matter nor the dark energy has yet been identified. The existence of dark matter has been known about for some time, detected indirectly by its gravitational effect on the behavior of visible bodies such as stars. In just the past few years, however, the data have become good enough to determine that the amount of dark matter is insufficient to flatten the universe.

A geometrically flat or Euclidean universe is required by the inflationary model, which we can easily see as follows: The universe expanded by many orders of magnitude during inflation. After inflation, the space within our visible horizon is like a tiny patch on the surface of a balloon that has been blown up to a huge size. That patch will be very flat.

With observations in the mid-1990s indicating insufficient dark matter to flatten the universe, it was beginning to appear that the inflationary model might be wrong. This proved a real puzzle for cosmologists because the independent data coming in on the cosmic microwave background was providing increased support for the flat universe predicted by inflation.

Inflationary cosmologists have been rescued by the observed accelerating expansion and the inferred dark energy, which seems to be just sufficient to give a flat universe. Yet another gap for God to act in may have been closed. Read on, and we might be able to close one more.

What could this new dark energy possibly be? One possibility is that it is the result of a residual cosmological constant left over from the end of inflation. However, the prospect of a nonzero cosmological constant leads to an enormous difficulty that was recognized well before these latest observational developments. The cosmological-constant term in Einstein's equation is equivalent to a field with negative pressure and positive, constant energy density. As the universe expands, the total energy contained in the cosmological term will increase. In the time since the end of inflation, during the almost-linear big-bang expansion, the cosmological energy would have increased by something like 120 orders of magnitude.

Currently, 13 billion years later, the dark energy is of the same order of magnitude as the other main components in table 5.1. This implies that it was "fine-tuned" at the end of inflation to be 120 orders of magnitude below what it is now. If, for example, the dark energy was just a hair larger at the end of inflation, that energy would be so great today that space would be highly curved, and the stars and planets could not exist.

This fact has not been lost on those theists, such as Ross, who see the hand of God in assuring that life, as we know it, could exist by fine-tuning the cosmological constant. However, recent theoretical work has offered a possible explanation for a nondivine solution to the cosmological-constant problem.

Several theoretical physicists have proposed models in which the dark energy is not the result of a cosmological constant at all but rather a dynamical energy field that does not have constant energy density. As a result, it evolves along with the other matter/energy fields of the universe and so need not be fine-tuned. The proposed field has been given the grand name of *quintessence,* after Aristotle's aether. In these models, the cosmological constant is exactly zero, as predicted from supersymmetry. Since zero multiplied by 10^{120} is still zero, we have no cosmological-constant problem in this case.

While the work on quintessence is highly preliminary and may not turn out to provide a viable explanation for the cosmological-constant problem, it is sufficiently interesting to mention at this juncture. If nothing else, it demonstrates that science is always at work trying to solve its puzzles. Furthermore, history shows that it has, so far, always succeeded in doing so within a materialistic framework. The assertion that God can be seen by virtue of his acts of cosmological-fine tuning, like intelligent design and all the earlier versions of the argument from design, is nothing more than yet another variation on the same old God-of-the-gaps argument. These rely on the faint hope that scientists will never be able to find an explanation for one or more of the puzzles that currently have them scratching their heads and will have to insert God into the remaining gaps.

Notes

1. James Glanz, "Bang, You're Alive! On the verge of Re-Creating Creation. Then What?" *New York Times Week in Review* January 28, 2001.

2. Richard Dawkins, *Unweaving the Rainbow: Science, Delusion and the Appetite for*

Wonder (Boston, New York: Houghton Mifflin Co., 1998), p. x.

3. The term plasma in physics refers to an ionized gas and is not to be confused with blood plasma.

4. For my narrative of the development and significance of these theories, see Victor J. Stenger, *Timeless Reality: Symmetry, Simplicity, and Multiple Universes* (Amherst, N.Y.: Prometheus Books, 2000).

5. While physicist Alan Guth is usually given the primary credit for the idea of inflation, A. Guth, "Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," *Physical Review* D23 (1981): 347-56, several other physicists had come up with it at about the same time: D. Kazanas, "Dynamics of the Universe and Spontaneous Symmetry Breaking," *Astrophysical Journal* 241 (1980): L59-63; Andre Linde, "A New Inflationary Universe Scenario: A Possible Solution of the Horizon, Flatness, Homogeneity, Isotropy, and Primordial Monopole Problems," *Physics Letters* 108B (1982): 389-92. Nevertheless, Guth's book, *The Inflationary Universe* (New York: Addison-Wesley, 1997), is a good place to learn about inflation.

6. Recently, an alternative to inflation has been proposed called "the ekpyrotic universe," Justin Khoury, Burt A. Ovrut, Paul J. Steinhardt, and Neil Turok, "The Ekpyrotic Universe: Colliding Branes and the Origin of the Hot Big Bang," *Physical Review* D64: 123522 (2001). While current data cannot distinguish between the two models, the authors propose that future measurements of the polarization of the cosmic microwave background and gravitational waves

should do so. We will have to wait and see. It should be noted that some of the existing observations that this new theory explains were built into its formulation, whereas in the case of the inflationary model, they were part of its predictions.

7. Charles L. Bennett, Gary F. Hinshaw, and Lyman Page, "A Cosmic Cartographer," *Scientific American* (January 2001): 44-45.

8. Stephen W. Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam, 1988), p. 129.

9. For general relativity purists, *R* here is the scale factor of the universe. Also, I should note that both Hawking and I have oversimplified the question of the total energy of the universe from the purist's standpoint. However, the basic conclusion that zero energy was required to produce the universe is unchanged by a more sophisticated analysis.

10. The radioactivity of Earth also contributes to its temperature. In fact, life, as we know it, would not be possible without this added heat. I am neglecting this here for simplicity's sake, since this does not change the conclusion.

11. Since the CMB is not in thermal equilibrium, the photons it receives from stars and planets can go to increasing its temperature (although, as I have shown, this is negligible) and does not have to be reabsorbed by stars and planets. The CMB photons that are absorbed by Earth do not appreciably increase the entropy of Earth.

12. For example, the universe has a zero value of linear momentum, angular momentum, electric charge, and any of the other quantities that physics says are conserved, that is, neither created nor destroyed in physical processes.

13. Hugh Ross, *The Creator and the Cosmos: How the Greatest Scientific Discoveries of the Century Reveal God* (Colorado Springs: Navpress, 1995), p. 133.

14. Victor J. Stenger, "Natural Explanations for the Anthropic Coincidences," *Philo* 3 (2000): 50-67.

15. A Reiss, *et al.* "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant," *Astronomical Journal* 116: 1009-38 (1998); S. Perlmutter, *et al.*, "Measurements of Omega and Lambda from 42 High-Redshift Supernovae," *Astrophysical Journal* 517: 565-86 (1999).

16. Jeremiah P. Ostriker and Pail J. Steinhardt, "The Quintessential Universe," *Scientific American* (January, 2001):46-53.