Christian tradition is not, and cannot possibly be, the God of self-outpouring love revealed in Christ. If God is the good creator of all, he is the savior of all, without fail, who brings to himself all he has made, including all rational wills, and only thus returns to himself in all that goes forth from him. Only thus can it be true that God made the world and saw that it was good; and only thus can we hope in the end to see that goodness, and also to see that he who made it is himself the Good as such.

CHAPTER 14

What Does Physical Cosmology Say about Creation from Nothing?

Adam D. Hincks, S.J.

Less than a hundred years ago, the Milky Way was the only known galaxy, and the universe was believed to be static. Today, we know that the universe emerged from a big bang, that it is 13.8 billion years old, and that the Milky Way is one of some hundreds of billions of observable galaxies. Physical cosmology, the branch of astrophysics that has uncovered these and many other facts about the universe on its largest scales of space and time, has made this rapid progress over the past few generations thanks to remarkable improvements in telescope technology coupled to a growing understanding of the relevant physics.

The successes of cosmology,[1] particularly its ability to study the universe in its infancy, have prompted speculation about what, if anything, it reveals about the need for a divine Creator. Some prominent cosmologists eschew such a need. Stephen Hawking, for example, made headlines a few years ago when he claimed that God is "not necessary" to explain the universe.[2] But the conversation between cosmology and theology contains other points of view, and there is a fair amount of academic literature on the subject.[3] In much of the discourse about cosmology vis-à-vis God, the issue of design is emphasized, and the question is whether it is "necessary," in some sense, to invoke an intelligent Creator to explain the makeup of our universe.

In this paper, however, my primary interest is how cosmology relates specifically to creation *ex nihilo* (CEN), or the doctrine that God is not merely a demiurge who imparts intelligibility to matter, but is also the being who makes possible the very conditions of order and intelligibility in the world. Focusing on this topic is fruitful because it provides a distinct perspective that focuses not on design but rather on the metaphysical framework that is common to physical cosmology and the doctrine of CEN.

After giving a brief overview of contemporary cosmology, I shall examine three topics that are often presumed to have some bearing on creation: first, the so-called multiverse theory, in which our observable universe is a minuscule patch of a much larger landscape that can look radically different elsewhere; second, the possibility of a cyclic universe in which the big bang is not the beginning of time; and third, the attempts in quantum cosmology to describe physically how a universe can come from "nothing." I shall take special care to distinguish between the elements that are empirically well-grounded and those that are speculative. What will emerge is that cosmology's real contribution to understanding CEN is not that it proves or disproves it or somehow probes its mechanics, but rather that cosmology can help elucidate and purify its metaphysical framework, particularly notions like matter, nothingness, space, and time.

A Brief History of Contemporary Cosmology

Contemporary cosmology has its origins in the 1920s when Edwin Hubble made a series of observations of galaxies using the powerful new 2.5-meter Hooker telescope in California. He discovered that, on average, all galaxies are moving away from each other.[4] This had, in fact, been independently predicted by Alexander Friedmann and by the physicist-priest Georges Lemaître upon studying Einstein's new theory of gravity, also known as the general theory of relativity. In 1931, Lemaître began proposing that this expanding universe had an explosive, temporal beginning starting with a 'primeval atom,' an idea that eventually became known as the big bang theory.[5]

There is a common misconception that the big bang was like a bomb explosion in which material was ejected outwards from a central point. However, in the expanding universe, space itself is stretching, and the material within space goes along for the ride. A better analogy than a bomb is an expanding rubber sheet. If you imagine that galaxies are points painted on the sheet, what is happening is not that the points are moving relative to the surface of the sheet, but rather that the sheet is stretching and the distance between the fixed points is increasing. Thus, the big bang did not occur at a single point in space, but rather everywhere.

This should make it clear that the question of what space is expanding "into" is nonsensical: expanding into something is already a spatial concept. On the other hand, the question of whether space is infinite or finite is cogent. In the latter case, the universe would have a topology such that if you traveled far enough in a straight line, you would end up where you started, just like on the surface of the earth. However, as far as we can see, there is no such wrapping of space. But this is just as far as we can see. Cosmologists commonly refer to the "observable universe," or the volume of space defined by the distance that light can travel in the age of the universe, or 13.8 billion years—a number we know to a precision of about 3 percent.[6] Beyond these 13.8 billion years,[7] we cannot say with empirical certainty whether space is finite or infinite.[8]

Though Hubble's measurements of receding galaxies were made in the 1920s, it took a few decades for the theory of the expanding universe to be fully convincing. Two other pieces of evidence emerged that helped make the case. First, the big bang theory makes specific predictions about the relative abundances of hydrogen and helium in the universe. These two elements were produced at different rates by the nuclear reactions that occurred soon after the big bang, and their observed relative abundance in the nearby universe is an impressive match to the predictions of nuclear physics.[9] Second, in the 1960s, researchers discovered a background signal of microwaves that is the same intensity everywhere in the sky.[10] It was soon realized that it is the glow of the universe soon after the big bang, at a time when the universe was still small, dense, and hot, and long before the gas had collapsed into stars or galaxies.[11] This microwave background radiation comes from almost 13.8 billion years ago and is the very earliest light that we have access to. By studying it, we learn about the conditions very early on and we are able to connect it to the structure of the local universe, thereby learning how the universe has evolved into its present form.

The basic history of the universe is as follows. In the first few seconds of the universe, everything was so hot and dense that even the simplest elements in the periodic table were not stable against the massive amount of radiation. Within the first few minutes, the universe cooled enough that hydrogen and helium nuclei began forming. About four hundred thousand years later it had cooled further, and the nuclei were able to join with electrons to form stable atoms, at which time the microwave background was produced. Slight overdensities in this neutral gas of hydrogen and helium slowly condensed and collapsed to form the first stars—when precisely this occurred is currently a popular area of research, but it would have been a few hundred million years after the big bang.[12] When the first stars came to the ends of their lives and were destroyed in supernovae, they produced the heavier elements such as oxygen, nitrogen, carbon, and so on. And as gravity continued its work of collapsing structure, galaxies consisting of billions of stars started taking shape.

There are still many open questions in cosmology—not least of which is the fact that only about 5 percent of the universe is made up of atomic matter, with the rest being so-called dark matter and dark energy, mysterious substances that are necessary for understanding how the universe evolved but about which we have virtually no theoretical understanding. But the area of research most relevant to this paper is the attempt to understand the conditions in the very early universe. Remarkably, we can describe the universe back to less than one second after the big bang, but there are still important questions about what occurred even earlier than this and about the big bang itself. It is these issues that we shall examine in depth.

MATTER AND THE MULTIVERSE

A major puzzle in cosmology is the fact that the early universe appears to have been very finely tuned. The cosmic microwave background glows at the same temperature everywhere, but any given region would never have been in causal contact with other regions in the universe in the simple big bang scenario. How, then, could everything have been the same temperature—precise to five decimal places—if there was no time for the temperature to even out on its own? Again, as far as we can measure, the curvature of the universe has always been completely flat: that is, it follows Euclidean geometry—angles in a triangle add up to one hundred eighty degrees and parallel lines never intersect—though there is no a priori reason why it shouldn't be curved negatively (like a saddle) or positively (like a sphere). Finally, there is the somewhat more technical problem that the universe seems devoid of magnetic monopoles, the magnetic equivalents of the electric charge, even though many theories of particle physics predict their existence.

The most popular way to explain these puzzles is via the theory of inflation, which proposes that almost immediately after the big bang, the universe underwent an extremely rapid but brief period of expansion. In figures, it would have grown by a factor 10^{25} in less than 10^{-32} seconds, equivalent to the nucleus of an atom growing to the size of the Solar System in less time than light would take to traverse the width of the aforesaid nucleus.[13] The numbers may sound incredible, but Alan Guth introduced inflation in 1980 after realizing that this simple mechanism explains the fine-tuning problems.[14] The volume that comprises our universe initially was in causal contact, and only after it inflated did different regions fall out of contact: this explains how the microwave background is the same temperature everywhere. The problem of flatness is solved because inflation can smooth out any initial curvature to the point where it is undetectable. The monopole problem is solved because any existing monopoles have been spread out so thin that one would reasonably expect them to be too rare to observe.

Inflation also explains the origin of large-scale structure in the universe. During inflation, quantum fluctuations produced tiny inhomogeneities in the density of the universe that later grew into galaxies under the influence of gravity. We can observe these initial perturbations in the cosmic microwave background, and even better, the distribution and properties of the perturbations are exactly what inflation would produce. Indeed, after the *Planck* satellite released its maps of the microwave background in 2013, Guth, together with colleagues David Kaiser and Yasunori Nomura, reported: "To date, every single one of these inflation-scale predictions has been confirmed to good precision."[15]

However, there is one further prediction that has not been observed. Inflation also produces gravity waves—that is, undulations in space itself. These too should in principle be observable in the microwave background, but their signature is extremely faint. Inflationary theory does not predict exactly how faint they should be, so if we are unlucky, the gravitational waves could be so small that we could never practically observe them. Nevertheless, there are several experiments currently underway designed to detect them, in hopes that they are large enough to be seen. In 2014, the BICEP2 collaboration claimed that they may have made a detection,[16] but subsequent analysis has shown that dust in our own galaxy is very likely responsible for the bulk of the signal,[17] so further observations are still needed.

In the absence of a detection of gravitational waves, inflation is not fully verified, but it remains the leading theory of the early universe. However, it solves the fine-tuning problems only by pushing them back further. To get the early-universe conditions that we observe, inflation needs to last the right amount of time and produce the right kind of expansion. As of yet there is no complete physical theory that naturally predicts the specific form of inflation that our universe requires, and therefore it remains an ad hoc prescription.

One paradigm often invoked to circumvent this difficulty is the so-called multiverse. This is a somewhat misleading moniker because the multiverse is not a collection of radically disconnected realities. Rather, the multiverse consists of a vast expanse of space in which different regions have strikingly different properties, and we live in a tiny patch that happens to be conducive to the formation of galaxies and planetary systems, and therefore to life as we know it.

The idea that there is an intimate link between the multiverse and inflation can be traced to Andrei Linde's work in 1983.[18] He proposed that after the big bang, the energy field responsible for inflation existed everywhere, but took on different, random values in different places. Our observable universe began by inflating in a patch that happened, by chance, to have a suitable value of the inflation field; different patches have undergone different types of inflation that could never lead to a stable universe suitable for life. Fittingly, Linde named his theory "chaotic inflation." One of its unexpected consequences is that most places never stop inflating. Our observable universe, then, is a tiny, safe haven that has stopped inflating amidst a (presumably) infinite landscape, most of which is perpetually expanding at exponential rates. Other "bubbles" that, like our universe, have stopped inflating, would be very sparsely sprinkled throughout.

The multiverse has the added attraction that it may explain other fine-tuning problems that are more or less independent of the puzzles that inflation was invoked to explain. If certain physical constants of nature, such as the strength of the electrical force or the mass of the proton, were altered even slightly, stars would never have formed and the structure of our universe would be so radically different that it would be inhospitable to life.[19] In a multiverse, however, one can postulate that in addition to the inflation field, the other constants of nature take on different values in different patches. Thus, some patches would not only have the right type of inflation to produce our universe, but also the right combination of other physical parameters.[20] Even better, this idea appears to align nicely with current research in theoretical physics. At the high energies of the early universe, the fundamental forces of nature were unified. As universe cooled, the forces split apart into the strong, weak, and electromagnetic forces, each with its own strength and parameters, but how exactly the split occurred would have been a random process varying from place to place. Hence, physical "constants" would vary from patch to patch. In some versions of string theory, which include gravity in this splitting, the number of possible resulting combinations of parameters exceeds the number of atoms in the observable universe. Many physicists view the multiverse as a natural partner or even corollary of this theoretical framework, which would make it more than simply an ad hoc mechanism to explain fine-tuning.

At least two serious criticisms that be leveled at the multiverse hypothesis. The first is based on recent searches for inflationary gravity waves that have made simple versions of chaotic inflation appear quite unlikely.[21] Some cosmologists have maintained confidence that improved theories consistent with observations will emerge.[22] Others, however, have argued that this amounts to adjusting arbitrary theoretical knobs to force ad hoc theories to match the data; they advocate abandoning chaotic inflation altogether.[23]

However, the more serious criticism is that the multiverse theory falls outside the domain of natural science. The multiverse is unobservable because, by definition, it extends beyond the observable universe. The most that can be done is to figure out how likely it is for a universe like ours to arise under the assumption that we live in a multiverse. This probabilistic exercise can then be interpreted as the predictive power of the theory—although nobody currently knows how to calculate such probabilities. But the fact remains that even a complete theory of the multiverse would not be empirically verifiable in any traditional sense. As George Ellis has argued, "The multiverse idea is provable neither by observation, nor as an implication of well established physics. It may be true, but it cannot be shown to be true."[24]

These criticisms notwithstanding, the multiverse concept is relevant to our discussion because it is often invoked as an argument against a Creator. According to Stephen Hawking and Leonard Mlodinow: "Many people through the ages have attributed to God the beauty and complexity of nature that in their time seemed to have no scientific explanation. But just as Darwin and Wallace explained how the apparently miraculous design of living forms could appear without intervention by a supreme being, the multiverse concept can explain the fine-tuning of physical law without the need for a benevolent creator who made the universe for our benefit."[25] Bernard Carr is even more pithy: "If you don't want God, you'd better have a multiverse."[26] The basic argument is that in the multiverse, there is no fine-tuning properly speaking but only random occurrences in an enormous ensemble of options: "In an eternally inflating universe, anything that can happen will happen: in fact, it will happen an infinite number of times."[27] Therefore, there is no Fine Tuner.[28]

However, if it were valid to argue that the multiverse is required if there is no Creator, this would not imply that if the multiverse is real that there is no God. There may even be good reasons to suppose that God would choose to create a multiverse because this makes nature more beautiful and elegant.[29] For instance, Don Page (a former doctoral student of Stephen Hawking) has argued that certain versions of the multiverse may actually have an overall simpler structure than certain versions of a single universe, implying a possible fittingness for the multiverse from the design point of view; he concludes, "God might indeed so love the multiverse."[30]

Despite the importance of understanding the relationship between providence, design, and randomness in nature, the central concern in this paper is CEN. In fact, it is very useful to turn our attention to this doctrine because it cuts across the issue of design in an important way. Namely, CEN is not primarily about how the intelligible structure of the world came to be as it is, but rather about the conditions for it to exist at all. In classical language, CEN does not first and foremost explain why the form of the universe is what it is, but insists that the matter which is actually informed must first be explained. Without matter, there can be no form: and all arguments about the relationship between the Creator and fine-tuning presume that there is matter.

It is essential to be aware that the modern use of the word "matter" is significantly different from the classical[31] meaning that CEN employs. In the modern sense, matter means "stuff": the collections of elementary particles that form atoms and molecules. These particles can be "created" and "annihilated." For instance, in a particle accelerator, colliding electrons and positrons annihilate each other and produce energy. And in a vacuum, particles continually pop in and out of existence on short time scales. Classically, however, matter is that which underlies change; it is the substrate that makes form, or intelligibility, possible in a thing. It is the component in stuff that allows it to be either this kind of stuff or that kind of stuff; it is potency, and as such is functionally related to form. Clearly, matter in the classical sense is a metaphysical concept, whereas in the modern sense it is a physical concept, and therefore the two senses of the word, while different, are not incompatible. This can be illustrated by considering a solid, which, as we all know, is composed of molecules. In classical language, the molecules stand as matter to the form of the solid. But if we were to consider the chemistry of the molecules, then the molecules would be forms of which the matter is atoms and atomic forces. Classically, the molecules are the matter when considering the form of the solid, but they are forms when considering their chemistry. On the other hand, in the modern sense of matter, the molecules are material regardless of which aspect of the solid we are considering.

Of course, one might question whether matter, in the classical sense (which I shall henceforth be careful to distinguish as such), is a useful or even a valid concept. I shall return to this point in the next section when I explore the place of contingency in cosmology. For now, however, I wish to establish that CEN is intimately connected to a basic insight that all form or intelligibility in the universe is contingent: that is, it all has underlying matter—classically speaking, of course—which, because it is the very potential for it to change, also means the intelligible structure is not at all necessary, but could very well be different. It is the matter that CEN explains. God is not just a Platonic demiurge that informs preexisting matter; rather, he is the Creator of matter and the author of the very existence of possibility itself. Once this is established, the role of the Creator in the actual informing of matter becomes a secondary question. The issue of fine-tuning is one example of this subsequent question; the multiverse presumes, by definition, that a landscape of possibility preexist. But that landscape, which is the matter of the multiverse (if the multiverse should actually exist) is precisely what CEN explains.

The foregoing is an excellent example of how the contingency of cosmological theories—of the multiverse on the possibility of a landscape of variable physical parameters, in this instance—is what is relevant to CEN. For if something is contingent, it is the result of a possibility, and where there is possibility there is matter, and CEN is the doctrine that form did not simply arise from some preexisting (classical) matter that is just there. If everything is to be explained, then the existence of matter cannot be taken for granted. For potentiality is by definition not actual, and as such does not explain its own existence.

The Cyclical Universe versus Inflation: Can We See the Beginning?

As early as inflation occurred, it still would not have been at the beginning of the universe. Space filled with energy must already exist for inflation to occur. Now, the big bang theory formally says that the universe began in an infinitely dense and energetic state—a "singularity," to use the technical word. In fact, there are a series of theorems that prove that Einstein's theory of gravity under some reasonable physical conditions *requires* that the universe begin with a singularity.[32] However, while it seems that the universe must have a beginning, it is a beginning that we cannot physically describe because it consists in something infinitely dense and hot; and, like philosophers, physicists have

trouble with actual infinities. As Hawking puts it, "Classical general relativity brings about its own downfall: it predicts that it can't predict the universe."[33]

The foregoing, however, is strictly true only under classical[34] physics. While classical gravity (i.e., general relativity) tells us how space expands, we need quantum mechanics to describe the matter and energy that occupy that space. And at very high energies—above what is called the "Planck scale"—we have no rigorous knowledge of how to use both theories together. Classical gravity becomes inadequate for describing the universe. Indeed, we know that a new, more fundamental theory is necessary. Therefore, any ideas about what the universe was like at or very soon after the big bang are still necessarily speculative.

One interesting idea that has emerged over the past fifteen years or so is a cyclic universe. A universe that continually dies and is reborn is an ancient concept, but what is novel about the contemporary theory, conceived by Paul Steinhardt and Neil Turok,[35] is that it finds some measure of success in explaining the same data that inflation considers, but with a profoundly different model. In the cyclic model, our three-dimensional universe is embedded in a four-dimensional space, or, in the language of string theory, our universe lives on a "brane" of the higher dimensional space. This brane has a partner brane with which it collides periodically. After a collision, the branes bounce apart, only to slowly be attracted to one another again in the future. It is the energy of the collision that produces the big bang within our three-dimensional universe—or rather, many successive big bangs—and it is the energy between the branes that creates the mysterious dark energy mentioned earlier. Between the big bangs, there are trillions of years of expansion and contraction driven by the dark energy. From the point of view of the higher-dimensional space, the universe grows from cycle to cycle, and its entropy, which determines the arrow of time, also continually increases. But in the three-dimensional world in which we live, and from which we cannot directly see the other dimensions, each cycle appears more or less the same.

The big bang from which we have issued is not the beginning of time in the cyclic model. There is also no singularity at the beginning of a cycle in the three-dimensional universe: everything remains finite and well behaved during the big bang—although there is a large question mark about whether the physics breaks down in the higher-dimensional universe when the two branes collide. This problem aside, however, the cyclic model naturally produces the initial conditions we observe in the universe without requiring inflation. Further, it can be distinguished from inflationary models by the fact that it creates no gravitational waves in the early universe. Hence, if primordial gravity waves are discovered, the cyclic model is ruled out.

It can be asked if the cyclic universe exists forever. The singularity theorems described above that require that the universe not extend infinitely into the past are still valid. However, the situation is subtle, because the enormous expansion of the previous cycle spreads matter out so much that it ends up extremely diluted. This means that the probability of finding a particle that did not originate in the most recent big bang or its predecessor, but in some earlier cycle, is essentially nil. Therefore, in practice there are no particles whose history actually extends back past one or two cycles. For this reason, Steinhardt and Turok "do not attribute any physical significance" to the fact that even the cyclic universe needs initial conditions, simply because those initial conditions get completely erased by all the cycles that have occurred since.[36]

It is significant, in fact, that this "erasing," or perhaps "forgetting," of initial conditions, is not unique to the cyclic model. Inflation too erases information that existed previously, simply by the fact that it stretches everything out so much and so violently. It seems to be a fairly generic feature of primordial cosmological theories that whatever the universe was like initially, its earliest evolution has been made inaccessible to later observers. In this context, Alex Vilenkin opines, "Quantum cosmology is not about to become an observational science. The dispute between different approaches will probably be resolved by theoretical considerations, not by observational data."[37]

Clearly, as with the multiverse conjecture, the nature of empirical science is at stake. The cyclic universe has the virtue that it does not predict gravity waves, and is thus empirically distinguishable from inflation. However, consider the scenario in which inflation did happen but produced gravity waves that are too small to detect. Not detecting gravity waves does not imply that the cyclic model is correct; it implies that we cannot distinguish between inflation with unobservably small gravity waves and the cyclic model with no gravity waves. It would then be unclear whether it is scientifically viable to prefer one or the other of the

cyclic or the inflationary models. Although they describe radically different cosmological histories, both would "save the appearances."

Confronted with a potential lack of discriminatory data, cosmologists are somewhat divided. On the one hand, some are comfortable making claims about the origin of the universe based purely on "theoretical considerations," to use Vilenkin's language from above. Guth, Kaiser, and Nomura, who advocate the multiverse paradigm, argue: "The successes that inflation has had in explaining the observed features of the universe give us motivation to explore the speculative ideas about the implications of inflation for questions far beyond what we can observe."[38] Along these lines, Stephen Weinberg is not alone when he muses, "Now we may be at a new turning point, a radical change in what we accept as a legitimate foundation for a physical theory."[39] On the other hand, this kind of logic has been (pejoratively) labelled "postmodern" and "a construct that lies outside of normal science."[40] And George Ellis contends: "It is a retrograde step towards the claim that we can establish the nature of the universe by pure thought without having to confirm our theories by observational or experimental tests. This abandons the key principle that has led to the extraordinary success of science."[41]

This debate is relevant to CEN because of its connection to the contingency I introduced earlier. It often seems at first blush that those who advocate a cosmology relying solely on theory extrapolated to that which is "far beyond what we can observe" are actually expressing a vague conviction that cosmology will eventually become an a priori science. That is, there sometimes appears to be a confidence that our physical theories will one day evince a metaphysical necessity that will make their extension beyond the boundaries of empirical access rigorously valid. If the doctrine of CEN is to be seriously called into question, it must be around this issue. For if cosmology turns out to be not an empirically a posteriori but rather a logically a priori science, then what appears to be contingency in our universe is merely due to our current ignorance. If scientific theory is strictly necessary in all its aspects, then there is no matter (in the classical sense I defined earlier) in the world; or to put it another way, if the world is governed in all its aspects by purely necessary laws, then there is no potentiality properly speaking. CEN claims that matter is created by God; but if there is no matter, there is no CEN.

However, when it comes down to it, I am not aware of any cosmologists that go so far as to propose an approach to cosmology as bald as that caricatured above. All the ideas about the early universe that I am presenting in this paper are ultimately motivated by observations; and everyone insists upon the importance of empirical data. A good example is provided by Hawking and Mlodinow, who, when discussing string theory as a candidate for a complete physical theory explaining everything about the universe, write, "Perhaps the true miracle is that abstract considerations of logic lead to a unique theory that predicts and describes a vast universe full of the amazing variety that we see." But they immediately stress that it must be confirmed by observation before it can be "successful,"[42] thereby effectively conceding that it will never be a purely necessary theory. Further, cosmologists in the so-called postmodern camp still tend to use words like "speculative" or "plausible" to qualify their descriptions, as we saw in the quote from Guth, Kaiser, and Normura above, for instance. It seems, therefore, that the main point of interest is demonstrating not the necessity of theories like the multiverse, but rather their possibility. Hence Lawrence Krauss expresses satisfaction simply in the fact that we can guess at what it *may* have been like: "Plausibility itself, in my view, is a tremendous step forward as we continue to marshal the courage to live meaningful lives in a universe that likely came into existence, and may fade out of existence, without purpose, and certainly without us at its centre."[43]

At the end of the day there does not seem to be any substantial challenge from cosmology to the radical contingency of being in the universe that is premised by CEN. In fact, it is striking just how much of our knowledge about cosmology could not have been predicted. As cataloged earlier in this paper, the last hundred years have seen a series of cosmological surprises: the expansion of the universe, the existence of dark matter and of dark energy and the apparent fine-tuning of initial conditions, to name a few of the more important. Such unexpected discoveries in of themselves are salient indicators of the thoroughgoing contingency I have been emphasizing.

It is important, therefore, to recognize cosmological conjectures, like the multiverse paradigm or the cyclic universe, for what they are. They may be interesting and even worth understanding as possibilities—perhaps even "plausible" possibilities, for what that is worth—but as long as they lack empirical consequences, I would agree with those who caution that they exit the realm of "normal science."[44] Bernard Lonergan has succinctly summarized the latter in a way I find very helpful: "Empirical science rests upon two distinct grounds. As insight grasping possibility, it is science. As verification selecting the possibilities that in fact are realised, it is empirical."[45] This second ground, which was the key advance of modern science over the Aristotelian approach, is what separates conjecture about the physical world from scientific knowledge about the physical world. The commitment to empiricism, which has led to such success in cosmology, entails a commitment to the presence of contingency in the world. In its very philosophical basis, then, cosmology as an empirical science remains open to the possibility of CEN.

Is *Ex Nihilo* a Scientific Category?

Our final topic to explore is the notion of *ex nihilo*, particularly because of claims that cosmology can explain how the universe comes "from nothing" without a divine Creator. Popular books such as Lawrence Krauss's *A Universe from Nothing* and Hawking and Mlodinow's *The Grand Design* are recent examples of this atheistic proposal.

Let me preface this section by mentioning that I take it as a matter of course that CEN is not primarily about the beginning of time. It teaches the radical dependence of the contingent being of the universe on God, whose existence is wholly actual and noncontingent. This dependence is clearly not limited to a t equals zero, as though the universe stopped being contingent at t greater than zero. Augustine is at pains to emphasize that although the creation of matter precedes its reception of intelligibility, it is not a temporal precedence, precisely because time is measured by change, which requires form.[46] Saint Thomas argues that the finite age of the universe cannot be demonstrated but is an article of faith;[47] he explains that creation is often associated with the beginning of time not because the beginning encompasses creation, but because time itself was part of creation.[48] What I wish to explore in this section, then, is not the beginning of time as a necessary condition for the possibility of CEN, but rather what *ex nihilo* means with respect to theories of physical cosmology.

The scientific idea that the universe can come from "nothing"—a term we shall certainly examine in due course—is motivated by attempts to circumvent the infinities of the big bang that I introduced in the last section. As I explained, there is currently no viable theory that properly combines quantum mechanics and gravity. Nevertheless, this has not prevented theorists from working on "quantum cosmology," or the introduction of quantum mechanics into the big bang theory in a provisional sort of way. Although it requires sweeping a fair bit of detail under the rug and then arguing that this does not make much difference, quantum cosmology provides what physicists call "toy models": theoretical constructs that we know to be inadequate, but that we hope provide insight into the real world.

One famous model, first proposed by Vilenkin,[49] is that the universe "tunneled" out of nothing. Quantum tunneling is a well-known phenomenon that has been experimentally observed: it means that a system can overcome an energy barrier that it could not do in classical physics. For example, in our sun, nuclear fusion occurs when hydrogen nuclei combine to form helium. Classically, the hydrogen nuclei in the sun are not energetic enough to collide because their mutually repulsive electrical charges are too strong. However, quantum mechanically, there is a probability that hydrogen nuclei will "tunnel" through the electric barrier and fuse to helium. It is one of the consequences of quantum mechanics' uncertainty principle: energy can be "borrowed" if it is "returned" in an appropriate amount of time. In the sun, the extra energy to overcome the repulsion between hydrogen nuclei is promptly returned by the larger amount of energy released when they fuse into helium. Another manifestation of tunneling is the fact that particles can spontaneously appear and disappear in a vacuum. It takes energy to create particles, which the vacuum does not possess, but the uncertainty principle allows two particles appear and annihilate with each other in a brief enough time. Hence particles can tunnel in and out of existence.

Vilenkin proposed that universes may spontaneously appear and disappear like particles, but unlike a pair of particles that appears in a vacuum already embedded in space and time, a spontaneous universe would appear together with its space and time from a state without space and time. According to the uncertainty principle, such a universe would have to quickly disappear. However, Vilenkin calculated that there is actually a nonzero probability for one of these ephemeral universes to tunnel into an inflating universe filled with energy, just like our universe, but only if the total net energy of the resulting universe is zero. This would occur if the positive energy contributed by matter and radiation is precisely canceled out by the negative gravitational energy that obtains when space has a certain geometric curvature. Because the final total energy is zero, no energy would be borrowed, and the universe could persist. Although our own universe appears to be geometrically flat to the best of our observational capabilities, it is possible that inflation stretched space so much that the curvature needed to make the energy zero is present but not detectable. Thus, it is argued that our universe could have emerged from nothing.

$p>0$

Another well-known quantum model is the "no-boundary" proposal of Hartle and Hawking.[50] They make use of the tight-knit relationship between space and time in general relativity. In extreme conditions, such as in black holes, the dimension that we ordinarily label as "time" actually behaves more like what we label "space." Hartle and Hawking argue that the beginning of the universe is best understood not in a geometry consisting of three spatial dimensions and one temporal dimension, such as we are accustomed to, but rather a geometry consisting of four spatial dimensions and no temporal dimension. The universe does "begin" at a point, but this point has no temporal label. "Before" and "after" do not exist, therefore, with reference to this point. Our three-dimensional space with a temporal dimension subsequently emerges from this atemporal four-dimensional space. Hawking and Mlodinow provide the following helpful analogy:

> Suppose the beginning of the universe was like the South Pole of the earth, with degrees of latitude playing the role of time. As one moves north, the circles of constant latitude, representing the size of the universe, would expand. The universe would start as a point at the South Pole, but the South Pole is much like any other point. To ask what happened before the beginning of the universe would become a meaningless question, because there is nothing south of the South Pole.[51]

The no-boundary proposal eliminates the problematic singularity at the beginning of time by reconceptualizing the origin of the universe in an atemporal manner. The universe still comes from nothing (in a sense), but it doesn't "come from" in a conventionally temporal way. On the other hand, whether the mathematical convenience of a spatial dimension switching to a temporal dimension is physically meaningful is not entirely clear.

Their speculative nature notwithstanding, the tunneling and the no-boundary proposals are appealing because the beginning of the universe is physically describable. Physics is not merely given a universe at some early but nonzero initial time before which physics can ask no questions; rather, the universe is intelligible through and through. As Hawking explains of the no-boundary proposal, "[The universe] would quite literally be created out of nothing: not just out of the vacuum but out of absolutely nothing at all because there is nothing outside the universe."[52] Part of what he is expressing here is that his theory, like other quantum cosmological models, includes all of space and time in its purview.

With this brief introduction to quantum cosmology complete, we can return to CEN. Much is made of how quantum cosmology demonstrates that the universe can be created from nothing without God. In their popular book *The Grand Design*, Hawking and Mlodinow conclude: "Spontaneous creation [i.e., as described by quantum cosmology] is the reason there is something rather than nothing, why the universe exists, why we exist. It is not necessary to invoke God to light the blue touch paper and set the universe going."[53] Similarly, in his best seller *A Universe from Nothing*, Lawrence Krauss maintains: "Just as Darwin, albeit reluctantly, removed the need for divine intervention in the evolution of the modern world . . . our current understanding of the universe, its past, and its future make it more plausible that 'something' can arise out of nothing without the need for any divine guidance."[54] In the book's afterword, Richard Dawkins enthusiastically responds: "Even the last remaining trump card of the theologian, 'Why is there something rather than nothing?' shrivels before your eyes as you read these pages."[55]

Of course, the meaning of "nothing" is crucial, and much of Krauss's book is devoted to exploring this question. Despite a fair amount of rambling (e.g., "By nothing, I do not mean nothing, but rather nothing"[56]), he settles on the notion of nothing as physical laws in the absence of space and time,[57] but also indicates there may be a "more fundamental nothingness" than this, by which he seems to mean a preexisting landscape of potential physical theories, such as is envisaged by the multiverse.[58]

Clearly none of these is the metaphysical nothing, or complete absence of being, that is meant by CEN. In the context of a universe tunneling from nothing, Vilenkin is refreshingly frank: "The state of 'nothing' cannot be identified with absolute nothingness. The tunnelling is described by the laws of quantum mechanics, and thus 'nothing' should be subjected to these laws. The laws of physics must have existed, even though there was no universe."[59]

To recast this in the classical language that I employed earlier, even a universe that tunnels from null space-time requires potentiality. And so again we find that matter, in the classical sense, is the crux of CEN in the cosmological context: The *ex nihilo* of CEN is the affirmation that God created even the potential for physical processes to occur in the universe—be it the universe tunneling from a vacuum, emerging from an atemporal state of four spatial dimensions, or entering into an endless cycle of big bangs.

Nonetheless, Krauss resists an exploration of the metaphysical meaning of nothing and of creation—an exercise he characterizes as "abstract and useless" in contrast to the "useful, operational efforts" of physics.[60] He accuses theology of obscurantism because it proposes views on the meaning of nothing "without providing any definition of the term based on empirical evidence."[61] This is highly revealing, because it shows that Krauss operates under a radical scientific reductionism. Being, for Krauss, can be known only through the empirical method. Hawking and Mlodinow are of the same mind. "Philosophy is dead," they claim, for "scientists have become the bearers of the torch of discovery in our quest for knowledge."[62]

This point of view is anticipated by Saint Thomas in the well-known question on "whether God exists": "It seems that everything we see in the world can be accounted for by other principles, supposing God did not exist. For all natural things can be reduced to one principle which is nature."[63] Clearly, the reductionist doctrine is inspired by the fundamental presupposition of the natural sciences that Thomas articulates here, physical cosmology included: the whole of the empirical world is understandable. There is, of course, nothing wrong with this. I for one think it is the most self-consistent position one can have about the physical world. It is therefore fitting for cosmologists not to be content with the notion that there was a time before which physics is impotent; it is very apt that cosmology attempt to explain the whole physical universe including its emergence from a physical nothingness. But as we have seen, a physical nothingness—the absence of space and time and perhaps even of fixed physical laws—is not an absence of potentiality. "Nature itself causes natural things as regards their form, but presupposes matter," as Saint Thomas puts it.[64] Nature is not necessary, but contingent, and as such does not explain itself.

Of course, the crucial question is whether the existence of such a contingent nature needs to be explained by CEN. On the atheistic view there could be contingent facts, such as a quantum wave-function for the universe, that "just are." Ultimately I think this leads to a profound incoherence, for it forces one to hold to the validity of causality and sufficient reason in some cases but not in others. Nevertheless, it is beyond the scope of this essay to defend this position rigorously. My main point is that it is not an issue answerable by physical cosmology. Cosmology as an empirical science presumes that the world is contingent. It cannot, therefore, be used to argue against CEN without destroying its own foundation—a foundation that nobody, including Krauss and Hawking, appears willing to completely abandon. To argue for or against CEN requires moving into the philosophical and theological domains.

WHAT DOES PHYSICAL COSMOLOGY SAY ABOUT CREATION FROM NOTHING?

In this paper, I have indicated some of the important boundaries between empirical results and speculative conjectures that are present in contemporary cosmology. I have explained that ideas like the multiverse or the spontaneous appearance of the universe are speculative, and in an important sense outside of the traditional domain of empirical science. Additionally, it seems to be a generic theoretical feature that we may never be able to make observations that bear directly on the very beginning of the universe: both the theory of inflation and the cyclic model indicate that information on the prior state of the universe has been erased from our view. The cosmological conjectures I have discussed are indications of what the universe in the totality of its history and extent might *possibly* be like.

Nevertheless, even if they are only possibilities, some cosmologists present scientific theories as alternatives to the theological notion of creation. I have argued throughout this paper that this will not do. The linchpin to my position is the fact that CEN is not merely an explanation for why the universe is as it is, but the claim that the very potential for the universe to be like anything at all must be created: in classical language, God creates matter prior (but not necessarily temporally prior) to the form. I have argued throughout that cosmological theories always presuppose (classical) matter. They do so because they are physical theories, ultimately connected to empirical method, and as such they are possibilities that may happen to be realized, not necessities that must be. Hence, contemporary cosmology actually operates in the same metaphysical framework as CEN, in which the being of the world is thoroughly contingent.

Cosmology will not, therefore, prove or disprove CEN as such, but it still does have something important to say on the subject. For as Lonergan has aptly put it, investigating metaphysical issues without reference to the empirical sciences "exposes the metaphysician to the ever recurrent danger of discoursing on quiddities without suspecting that quiddity means what is to be known through scientific understanding."[65] In the foregoing pages, we have seen important examples of how the science of physical cosmology makes more concrete some of the conceptual framework—the quiddities, so to speak—of CEN. We have seen three important instances of this.

First, cosmology provides insights into how to think of the matter (classically speaking) that CEN explains.[66] The matter of the multiverse is the potential for the inflationary field to take on different values in different places or for the physical parameters of string theory to take on different combinations. The matter of the cyclic universe is the underlying, higher-dimensional space in which the big bang process can occur. The matter of the no-boundary universe or the universe tunneling from a null space-time is an underlying quantum wave-function. These are all concrete (albeit speculative) ways to think about what the matter that is created *ex nihilo* might be like. A topic for further investigation would be how this relates to the classical notion of prime matter. Thus, one might try to determine whether cosmology can probe a fundamental level of intelligibility below which there is *only* matter.

Second, cosmology makes it clear that empty space and time do not constitute nothingness. CEN should not be conceived in a manner in which space and time are a neutral backdrop to the matter of the universe, but rather are part of the empirical world. Einstein's theory of general relativity, which undergirds modern cosmology and has passed every experimental test successfully attempted to date, has at its core the principle that the behavior of space and time is fundamentally connected to the behavior of matter (in the modern sense) and energy; it wholly displaces any Newtonian or Kantian concept of space and time as a priori to the empirical world. Thus, all cosmological theories have space and time as explicitly constitutive elements: the expanse of space containing the multiverse, for instance, or the evolution of branes in the higher dimensions of the cyclic universe. Further, quantum cosmologies, though only toy models, can at least explore the role of space and time in the physical origin of the universe.

Finally, to highlight the latter point in particular, there is an important lesson to be learned from the quantum cosmological attempts to paint a self-consistent picture of how the universe could have a temporal beginning without introducing manifest self-contradictions such as assuming that something happened "before" the beginning. Even if they be speculative, such attempts drive home the Thomistic point I mentioned earlier about time being part of creation. Time is not a supernatural clock that runs the universe from the outside, but is part and parcel with the universe. Hence, even if the universe has not existed forever, it has always existed, in the sense that "always" refers to all possible time, whether it be infinite or finite.[67] Cosmological theory can explore what that might be like physically. Along these lines, I feel that it would be worthwhile exploring with more philosophical rigor the claim of quantum cosmology to be able to describe the spontaneous appearance of the universe in an atemporal fashion. Terms like "spontaneous appearance" or "emergence" seem to denote a kind of change, of which time is normally considered the measure, so one may legitimately ask whether quantum cosmology inadvertently smuggles temporality back into the picture.

In sum, cosmology tells us something about creation not by pushing out theology as a discipline, but rather by elucidating just what the metaphysical terms it employs are like in the world we live in. It is probably not possible for physical cosmology alone to demonstrate that God created everything from nothing. But cosmology can help us to get straight what exactly we might mean by "nothing," and what exactly is included in "everything." True to the traditional metaphor, cosmology is a worthy handmaiden to the theology of creation.

Notes

1. Henceforth, "cosmology" will be used frequently as shorthand "physical cosmology."

2. E.g., Laura Roberts, "Stephen Hawking: God Was Not Needed to Create the Universe," *The Telegraph*, September 2, 2010, http://www.telegraph.co.uk/news/science/science-news/7976594/Stephen-Hawking-God-was-not-needed-to-create-the-Universe.html.

3. For an overview, see, e.g., Hans Halvorson and Helge Kragh, "Cosmology and Theology," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, 2013, http://plato.stanford.edu/archives/fall2013/entries/cosmology-theology/.

4. Edwin Hubble, "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae," *Proceedings of the National Academy of Sciences* 15, no. 3 (1929): 168–73.

5. Though Lemaître is credited as being the originator of the big bang theory, the history of the idea's development is complex. See. H. S. Kragh and D. Lambert, "The Context of Discovery: Lemaître and the Origin of the Primeval-Atom Universe," *Annals of Science* 64 (2007): 445–70.

6. P. A. R. Ade et al., "Planck 2015 Results. XIII. Cosmological Parameters," *Astronomy & Astrophysics* 594, id. A13 (2016), http://www.aanda.org/articles/aa/abs/2016/10/aa25830-15/aa25830-15.html.

7. An age of 13.8 billion years corresponds to a *distance* of about 46 billion light years. This is further than the 13.8 billion light years that one would naïvely infer from the age of the universe for technical reasons stemming from general relativity, but can be calculated very accurately.

8. Technically, this is not quite true. If the universe were finite but only slightly larger than the observable volume, there would be some observable effects (see, e.g., J. Levin, "Topology and the Cosmic Microwave Background," *Physics Reports* 365 [2002]: 290–92 [§4.4]); these have not been detected with current data, however.

9. R.H. Cyburt et al., "Big Bang Nucleosynthesis: 2015," *Reviews of Modern Physics* 88, id.015004 (2016).

10. A. A. Penzias and R. W. Wilson, "A Measurement of Excess Antenna Temperature at 4080 Mc/s.," *Astrophysical Journal* 142 (1965): 419–21.

11. R.H. Dicke et al., "Cosmic Black-Body Radiation," *Astrophysical Journal* 142 (1965): 414–19.

12. For a summary of current constraints on the epoch of the first stars, see L. Koopmans et al., "The Cosmic Dawn and Epoch of Reionisation with SKA," *Advancing Astrophysics with the Square Kilometre Array (AASKA14)* (2015): §2.2, https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215.

13. In response to popular presentations of inflation, many ask how the universe could expand faster than the speed of light if the latter is a universal "speed limit." The answer is that in fact during inflation nothing *does* travel faster than light. Just as with the expanding universe, objects are not traveling through space, but space itself is inflating. Hence the speed limit is not violated.

14. A. H. Guth, "Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," *Physical Review D* 23 (1981): 347–56.

15. A. H. Guth, D. I. Kaiser, and Y. Nomura, "Inflationary Paradigm after Planck 2013," *Physics Letters B* 733 (2014): 112.

16. P. A. R. Ade et al., "Detection of B-Mode Polarization at Degree Angular Scales by BICEP2," *Physical Review Letters* 112, id.241101 (2014), http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.241101.

17. P. A. R. Ade et al., "Joint Analysis of BICEP2/Keck Array and Planck Data," *Physical Review Letters* 114, id.101301 (2015), https://physics.aps.org/featured-article-pdf/10.1103/PhysRevLett.114.101301.

18. A. D. Linde, "Chaotic Inflating Universe," *Soviet Journal of Experimental and Theoretical Physics Letters* 38 (1983): 176.

19. B. J. Carr and M. J. Rees, "The Anthropic Principle and the Structure of the Physical World," *Nature* 278 (1979): 605–12; Robin Collins, "The Multiverse Hypothesis: A Theistic Perspective," in *Universe or Multiverse?*, ed. Bernard Carr (Cambridge: Cambridge University Press, 2007), 459–80.

20. Using the criterion that the laws of physics and cosmology must be able to generate a universe like ours, one that is hospitable to life, is usually referred to as *anthropic*. It is a term used with considerable looseness and involves a fair amount of philosophical subtlety that is not always fully acknowledged; for this reason, and because it is not necessary to introduce it for the purposes of my paper, I have chosen not to mention it explicitly except in this note.

21. Ade et al., "Joint Analysis of BICEP2/Keck Array and Planck Data."

22. E.g., Guth, Kaiser, and Nomura, "Inflationary Paradigm after Planck 2013."

23. E.g., Anna Ijjas, Paul J. Steinhardt, and Abraham Loeb, "Inflationary Schism," *Physics Letters B* 736 (2014): 142–46.

24. George Ellis, "Opposing the Multiverse," *Astronomy & Geophysics* 49, no. 2 (2008): §2.35.

25. S. Hawking and L. Mlodinow, *The Grand Design* (New York: Random House, 2010), 165.

26. Quoted in Tim Folger, "Science's Alternative to an Intelligent Creator: The Multiverse Theory," December 2008, http://discovermagazine.com/2008/dec/10-sciences-alternative-to-an-intelligent-creator.

27. A.H. Guth, "Inflation and Eternal Inflation," *Physics Reports* 333 (2000): 555–74.

28. Of course, this line of reasoning is not new: it is highly reminiscent, for example, of Epicurean philosophy, which also taught that there is an infinite number of worlds. See, e.g., Epicurus, *Letter to Herodotus* 45, 73.

29. See, e.g., Collins, "Multiverse Hypothesis: A Theistic Perspective."

30. D. N. Page, "Does God So Love the Multiverse?," in *Science and Religion in Dialogue*, ed. Melville Y. Stewart (Chichester: Blackwell, 2010), 380–95.

31. In physics, the word "classical" refers to prequantum theories or concepts. I do not, of course, intend that sense in this paper, but rather use it to refer to the classical period of philosophy which was the original context for CEN.

32. S. W. Hawking and R. Penrose, *The Nature of Space and Time*, Princeton Science Library (Princeton: Princeton University Press, 2000), ch. 1.

33. Hawking and Penrose, *Nature of Space and Time*, 75.

34. Here, of course, "classical" refers to prequantum theory, not to ancient philosophy.

35. P. J. Steinhardt and N. Turok, "A Cyclic Model of the Universe," *Science* 296 (2002): 1436–39; for a popular introduction to their theory, see Steinhardt and Turok, *Endless Universe: Beyond the Big Bang* (New York: Doubleday, 2007).

36. P. J. Steinhardt and N. Turok, "Cosmic Evolution in a Cyclic Universe," *Physical Review D* 65, no. 12 (2002): 8.4.

37. Alex Vilenkin, *Many Worlds in One: The Search for Other Universes* (New York: Hill and Wang, 2006), 193.

38. Guth, Kaiser, and Nomura, "Inflationary Paradigm after Planck 2013."

39. Steven Weinberg, "Living in the Multiverse," in Carr, *Universe or Multiverse?*, 30.

40. Ijjas, Steinhardt, and Loeb, "Inflationary Schism," 145.

41. Ellis, "Opposing the Multiverse," 2.35.

42. Hawking and Mlodinow, *Grand Design*, 181.

43. L.M. Krauss, *A Universe from Nothing: Why There Is Something Rather Than Nothing* (New York: Atria Books, 2012), 147.

44. This is not to claim that the multiverse or the cyclical universe *cannot* have empirical consequences. I simply point out that we currently lack solid empirical data, and I flag the possibility that we may never have them.

45. Bernard Lonergan, *Insight: A Study of Human Understanding* (Toronto: University of Toronto Press, 1992), 101.

46. Augustine, *Confessions* 12.29. As a point of interest, Alex Vilenkin, who developed the notion of the universe tunneling from nothing (see later in this essay), explicitly mentions in one of his scientific papers that Saint Augustine had basically solved the conundrum of what happened before the universe began. A. Vilenkin, "Quantum Origin of the Universe," *Nuclear Physics B* 252 (1985): 141.

47. Thomas Aquinas, *Summa Theologiae* (*ST*), trans. Fathers of the Dominican Province (New York: Benziger Bros., 1947), I.46.2. Thomas notes that because our knowledge of the world is abstracted from the here and now, there cannot be a scientific demonstration of its "newness." An interesting line of inquiry which I do not pursue in this paper is whether this claim is really valid in the light of our ability to see the universe at different times due to the finite speed of light.

48. *ST* I.46.2.

49. A. Vilenkin, "Creation of Universes from Nothing," *Physics Letters B* 117 (1982): 25–28.

50. J.B. Hartle and S.W. Hawking, "Wave Function of the Universe," *Physical Review D* 28 (1983): 2960–75.

51. Hawking and Mlodinow, *Grand Design*, 130.

52. Hawking and Penrose, *Nature of Space and Time*, 83.

53. Hawking and Mlodinow, *Grand Design*, 180.

54. Krauss, *Universe from Nothing*, 147.

55. Ibid., 191.

56. Ibid., 58.

57. Ibid., 170.

58. Ibid., 174, Supplementary Q&A #1.

59. Vilenkin, *Many Worlds in One*, 181.

60. Krauss, *A Universe from Nothing*, xv.

61. Ibid., xvi.

62. Hawking and Mlodinow, *Grand Design*, 5; cf. also 34.

63. *ST* I.2.3.

64. *ST* I.45.2.

65. Lonergan, *Insight*, 533.

66. Matter, of course, is not a quiddity, but it is known when potentiality is realized in form. And the latter can be studied by the natural sciences.

67. I cannot recall for certain, but to give credit where it is due, I believe I received this insight into the meaning of "always" from a colloquium delivered by Roger Penrose to the Princeton Physics Department sometime between 2004 and 2009. Unfortunately, I have not been able to find the date.