Cosmos from nothing? Questions at the edge of science

by Karl W. Giberson in the June 10, 2015 issue

Planetary nebulas, such as NGC 5189, represent the final stage in the life of a medium-sized star like the sun. The dying star comsumes the last of its core fuel and expels a large portion of its outer envelope into space. (Photo courtesy of NASA, ESA, and the Hubble Heritage Team [STScI/AURA].)

Freshman astronomy books typically include a timeline outlining the major events of the universe over the past 13.7 billion years, from the appearance of our universe to the present. Most timelines put a question mark at the very beginning to reflect the incomplete state of our knowledge about how the universe got started. We don't know what lit the spark that launched the grand adventure of our universe, despite millennia of wondering and decades of intriguing progress.

Remarkably, we know a lot about what happened a fraction of a second after the Big Bang. We have robust theories that have been tested in laboratories like that of the European Organization for Nuclear Research, where the early moments of the universe are simulated in high-energy experiments.

One thing we do know now about that mysterious beginning is that it proceeded according to a precise set of rules. We don't know whether these rules preexist our universe. We just know that they are there "in the beginning" and that they constrain what can and cannot happen.

These rules are surprisingly simple. One states that a negatively charged particle like an electron can exist only if there is a positively charged particle to balance it, so the total charge is always zero. Another rule states that all particles must have charge of -1, 0, or +1.

Quarks, however, are particles with a fractional charge of -2/3, -1/3, +1/3, or +2/3, but according to another rule of the universe quarks must assemble themselves into larger, composite particles, like protons or neutrons, that have a charge of either 0 or 1. (A proton is composed of two quarks with charges of +2/3 plus one quark with a charge of -1/3, for a net charge of 1.) The simplicity of these rules is mind-boggling.

Another rule says that charged particles will attract or repel each other. Negatively charged electrons will be attracted toward and then drawn into orbit around positively charged protons. And the nature of those orbits is specified in advance by the laws of quantum mechanics. We call these combinations hydrogen. So before there were any electrons or protons there were rules on how they would have to behave if they were to come into existence.

These rules—what we now call the laws of physics—are the DNA that controls the growth of the universe; with a different DNA, we'd get a different universe. The history of the universe is the story of complexity growing from simplicity, not unlike the growth of an organism. And the universe at that earliest moment of the Big Bang was astonishingly simple.

Everything that happened from that moment 13.7 billion years ago until now was an expression of just four kinds of interactions: gravitational, electromagnetic, strong nuclear (which binds quarks together and enables nuclear fusion), and weak nuclear (which produces radioactivity). Every event in the long history of the universe, from the formation of the first atom, to the explosion of a distant star, to the recollection of a childhood memory, to the purr of a cat, was and is controlled by these four interactions and the simple rules they are constrained to obey.

Physical objects fall into just two categories: quarks and leptons. Every physical object that has ever appeared in the universe, from the first atom billions of years ago to the latest iPhone on an assembly line in China, is made from quarks and leptons. The universe's quality control is so exceptional that every electron that has ever appeared is absolutely identical. The quarks appeared and were gathered into protons and neutrons. Electrons dropped into orbit around the protons. The early universe was full of electrically neutral hydrogen atoms. The charged particles were too numerous to count, but the total charge ended up being perfectly balanced so the universe has no net charge.

Because of gravity, hydrogen atoms gathered into steadily growing balls, randomly distributed across the expanse of the expanding universe. The balls grew ever larger until they ignited. Like a drawn-out but spectacular fireworks display, great balls of hydrogen turned into stars as a darkened cosmos experienced its first sunrise.

Gravitational forces within these huge new stars crushed the hydrogen atoms like eggs under a steamroller, fusing them into helium atoms. A helium and a hydrogen atom were crushed into a lithium atom. Two helium atoms were crushed into beryllium. A beryllium and a helium combined into a carbon, a nitrogen, an oxygen, and a neon, and so on, filling up the periodic table of the elements as the chemistry of the universe grew ever more interesting and diverse.

After shining for billions of years, certain large stars exploded, going out with the biggest of bangs. The force of a billion atomic bombs filled massive regions of space with the elements created inside them. Gravity is always and everywhere at work, and it gathered the debris from the exploded stars back into balls again; a large chunk at the center of the cloud became a second-generation star. Some debris ended up orbiting about the new star. These smaller balls had a rich roster of elements since they formed from a star that had converted much of its hydrogen into other elements.

Some of these smaller balls possessed an unusual molecular combination of hydrogen and oxygen. In most parts of the universe, this molecule is in the form of a solid. In others it is a gas. But on certain balls—we call them planets—that are exactly the right distance from a star, the molecule is liquid—a precious, rare liquid called water. Planets with water can harbor life. It takes roughly 10 billion years for the universe to produce a planet with water on it—the first stage in the preparation for life.

This is the cosmic part of our story—the part that features physics and chemistry. The biological part begins on Earth about 3.5 billion years ago, when the universe was about 10 billion years old. And now here we are, recent arrivals in a universe that seemed headed in our direction.

We cannot but marvel at the layered process by which each stage in the long history of our universe builds on the prior history. Each stage was both the completion of what has gone before and the anticipation of what was soon to come. Freeman Dyson, one the greatest scientists of the 20th century, a man with no conventional religious beliefs, puts it like this:

> The more I examine the universe and study the details of its architecture, the more evidence I find that the universe in some sense must have known that we were coming. There are some striking examples in the laws of nuclear physics of numerical accidents that seem to conspire to make the universe habitable.

The narrative of the universe is provocative on its own terms, but when we look closely at this history it becomes even more remarkable. We now understand that the details in the original blueprint for our universe had to be specified very precisely for the history to unfold as described above.

If, for example, gravity were a bit stronger or weaker we would never get stars, or we would get stars that don't shine long enough for life to evolve on planets orbiting around them. If the electrical force, the charge of the electron, or the mass of the proton were altered, there would never be a planet with water on it. So precisely do these details have to be specified that many people speak of the universe being "fine-tuned." The agnostic astronomer Fred Hoyle wrote in *The Intelligent Universe*, "A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology. . . . The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question."

A superintellect, of course, is not something that science is prepared to consider, after centuries of being burned by "explanations" for natural phenomena that invoked God. Science has produced a theory of the cosmos that avoids reference to a superintellect, however: it is the theory of the *multiverse*. This theory posits that our universe is embedded in an infinitely large ensemble of universes built from random blueprints. These random blueprints encompass all possible universes, so some of them are bound to look like ours. Our remarkable universe is just the lucky one among stillborn trillions incapable of hosting life. In *The Hidden Reality: Parallel Universes and the Deep Laws of the Cosmos*, cosmologist Brian Greene identifies no less than nine independent ways to produce an infinity of alternate worlds, any one of which can produce a universe like ours without a superintellect monkeying with the physics.

A scientific drawback to these theories is that none of these posited realities have any empirical connection to our reality—at least at the present time. On the other hand, they do arise naturally from theories in mathematical physics—although, with so many variations on how to produce them, we have to wonder if they are simply artifacts of the mathematics.

In an article in *Scientific American* defending the multiverse as a "solid scientific idea," cosmologists Alexander Vilenkin and Max Tegmark admit that the theory of the multiverse has no empirical foundation, but they defend it, arguing that it "explains the long-standing mystery of why the constants of nature appear to be fine-tuned for the emergence of life." They note that in some rare universes "by pure chance, the constants happen to be just right for life to evolve." We live, as I stated above, in one of these happy cosmic accidents.

Meanwhile, other cosmologists worry that discussions of the multiverse are injecting nonscientific metaphysical speculations into science. The boundaries of science are being pushed outward in the wrong direction. Mathematical results that traditionally were discarded as unrelated to the real world are now being treated as real. In an op-ed in *Nature*—considered the world's leading science magazine—senior cosmologists George Ellis and Joe Silk describe this "worrying turn":

> Faced with difficulties in applying fundamental theories to the observed Universe, some researchers called for a change in how theoretical physics is done. They began to argue—explicitly—that if a theory is sufficiently elegant and explanatory, it need not be tested experimentally, breaking with centuries of philosophical tradition of defining scientific knowledge as empirical. We disagree.

Ellis and Silk note that the mathematical theories that undergird the multiverse—such as string theory—have not been confirmed. Such theories pose profound challenges to the methods of science.

This battle for the heart and soul of physics is opening up at a time when scientific results—in topics from climate change to the theory of evolution—are being questioned by some politicians and religious fundamentalists. Potential damage to public confidence in science and to the nature of fundamental physics needs to be contained by deeper dialogue between scientists and philosophers.

It's clear by now that these scientific questions have deep theological overtones. At the edge of science, seemingly straddling the border of theology, are questions about the origins of the universe and the blueprint behind it: Is that blueprint created? Is it eternal? Does it exist in the mind of God? And how is the blueprint brought to life? Is there an undiscovered spark that summons a universe out of the blueprint? It is one thing to have rules about what can happen, but quite another to have things actually happening according to these rules. And finally: Are these questions to be answered inside science or outside it?

In his best-selling book *A Brief History of Time*, Stephen Hawking spotlights this mystery. The long-sought but elusive "theory of everything," he notes, is ultimately "just a set of rules and equations," despite the grandeur of its title. It is not a living, breathing, pulsating universe. "What is it that breathes fire into the equations," he asks, "and makes a universe for them to describe?" No matter how complete the model of our universe described by the blueprint, says Hawking, it will not answer the central question of "why there should be a universe for the model to describe. Why does the universe go to all the bother of existing?"

Hawking's question oozes metaphysical and theological significance. But again, some scientists insist that science has no business moving into territory occupied by theologians and philosophers. After all, has not science purchased its considerable success by avoiding theological speculations like, Why does the universe exist?

Cosmologist and popular science writer Lawrence Krauss, author of *A Universe from Nothing: Why There Is Something Rather than Nothing*, denies the existence of any territory off limits to science. He argues that "religion and theology have been at best irrelevant" to discussions of the origin of the universe and that they only "muddy the waters" of science. In thinking about origins, theologies focus on "questions of nothingness without providing any definition of the term based on empirical evidence." In an op-ed in the *Los Angeles Times*, he stated that the cosmic blueprint described above allows us to "understand how it is possible that the entire universe, matter, radiation and even space itself could arise spontaneously out of nothing, without explicit divine intervention."

Krauss is taking aim here at the Christian doctrine of creation ex nihilo, creation out of nothing. Creation ex nihilo by God is the traditional Christian answer to what to put at the beginning of the cosmic timeline. Before there was something there was God.

Historically, the discussion of creation ex nihilo was driven by concerns about the freedom of God in the act of creating. Did God create by imposing order upon a preexisting world? (This what the Genesis account actually seems to suggest.) Were God's intentions thus *constrained* by the properties of things that already existed, so that God may not have been completely free to create the world God wanted?

This view was popular in Greek philosophy and even in the early church, but by the fourth century the notion that something other than God was eternal had become offensive. God must have created freely, constrained by no preexisting matter, rules, laws, patterns, or beings. Otherwise creation could not have been the perfect realization of God's intentions.

But cosmology—like Darwinian evolution before it—has complicated this picture with its narrative of a creation that emerges in a sequence of events rather than all at once. We must keep in mind that the doctrine of creation ex nihilo emerged at a time when the cosmos was thought to have appeared fully functional all at once or over the course of six days, brought into existence by processes no longer operating. Now we understand that any creation that includes humans takes place over billions of years and that such creative processes can be studied by science.

Furthermore, the rules and laws that appear in the beginning—the cosmic blueprint—determine the kind of universe that can appear and how it can behave. Before there are any people—or any molecules—there are great constraints on what can and cannot emerge. These constraints raise questions about the plausibility of creation ex nihilo.

In *The Anthropic Cosmological Principle*, John Barrow and Frank Tipler show how the laws of physics constrain life forms. Animals on land have to be able to stand up, expel heat generated deep inside their bodies by their metabolism, and so on. They thus cannot be arbitrarily large. The largest possible land animal turns out to be roughly the size of the 26-meter 60-ton dinosaur known as *dreadnoughtus schrani*. Animals in the water have an easier time of it, since their buoyancy fights gravity for them. The great whales are about three times larger than the largest land animal and approximately the maximum size that the laws of physics permit for a water animal.

The laws of physics thus prohibit God from creating a million-ton land animal, even if God wanted to. They also prohibit God from creating stars the size of Jupiter or stars that can support life (a star is too hot to have liquid water). The universe that emerges out of the cosmic blueprint cannot have been created ex nihilo, without any constraints, even if we could somehow explain how fire was breathed into the equations.

So where do we find the elusive *nihilo*? Is there any point in the history or prehistory of the universe of which we can say, “Now *this* is nothing”?

Krauss, adhering to the scientific line, insists that a definition of nothing must be “based on empirical evidence.” I find it hard to imagine what this could mean, however, or that it is even a meaningful statement. Anything that can be defined or even described with empirical evidence cannot be “nothing.” What, for example, are the empirical properties of nonbeing? The moment something makes any connection to the empirical world it ceases to be nothing. Even to say, for example, that nothing cannot contain any energy is to posit something in some place in which the energy can be measured to be zero.

In cosmology what appears to have come from nothing (or perhaps *nowhere* would be a better term) is the cosmic blueprint for the universe. If we were to sequence the critical cosmic events, we would say, “First there was nothing; then there was a blueprint; and then the universe described by this blueprint appeared.” Krauss’s version of this states that “first there was a blueprint, which I will call *nothing*, and then the universe appeared out of this nothing.” That’s a linguistic trick, not a scientific statement.

We live in a remarkable universe at a remarkable time when it is possible to ask the sorts of questions being considered by Krauss, Tegmark, Ellis, and other cosmologists. If cosmic history had been different and we emerged at some far future time when the universe was dramatically older and larger, we could never have asked these questions. The evidence that confirmed the Big Bang, for example—the “cosmic background radiation”—will gradually dissipate until it can no longer be detected. Knowledge of it—the essential confirmation of the central idea in cosmology—will be known only from ancient texts.

Mathematical physicist turned Anglican priest John Polkinghorne draws a familiar theological conclusion from the above discussion: “Maybe there is only one universe, and it is the way it is because it is not any old world," he says. "It is a creation that is endowed by its Creator with precisely the finely tuned laws and circumstances which have enabled it to have a fruitful history." God created the cosmic blueprint, breathed the fire into it that started the universe, and now here we are.

Polkinghorne's claim in some ways recalls Isaac Newton's declaration in 1687—when all scientists were religious believers—that God must have designed the solar system, since the pattern of planetary motion was so regular: "It is not to be conceived that mere mechanical causes could give birth to so many regular motions. . . . This most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful Being."

A century later, however, Pierre-Simon Laplace discovered that "mere mechanical causes *could* give birth to so many regular motions." He explained, in a way still generally accepted, that our solar system originated in such a way as to produce the remarkable features that Newton said could only be arranged by God. With Laplace, science started tackling questions related to origins and not just the operations of the universe.

Polkinghorne's claim might then be considered just another "god of the gaps" assertion—explanations always in danger of being superseded by future scientific discovery.

But perhaps Polkinghorne is making a statement about the boundaries of scientific explanation, rather than gaps within such explanation. Are scientific explanations truly capable of explaining everything, encountering no boundary anywhere? Is science the only "way of knowing" about reality? Is the question, Why is there something rather than nothing? a *scientific* question?

To explain the universe, cosmologists have been forced to extend the boundaries of science into uncharted and controversial territory. Redefining nothing so it can be explained as Krauss has done is itself an explanation ex nihilo that dispels no mystery, satisfies no curiosity, answers no question.

These questions may not have answers at this point in the history of the universe. Surely there has to be a boundary to our knowledge, and not every question that can be posed can be answered. It is quite remarkable, however, that we have made it to the edge of the universe and the beginning of time. Now that we are there, we discover that scientists and theologians are asking identical questions and even talking to each other.