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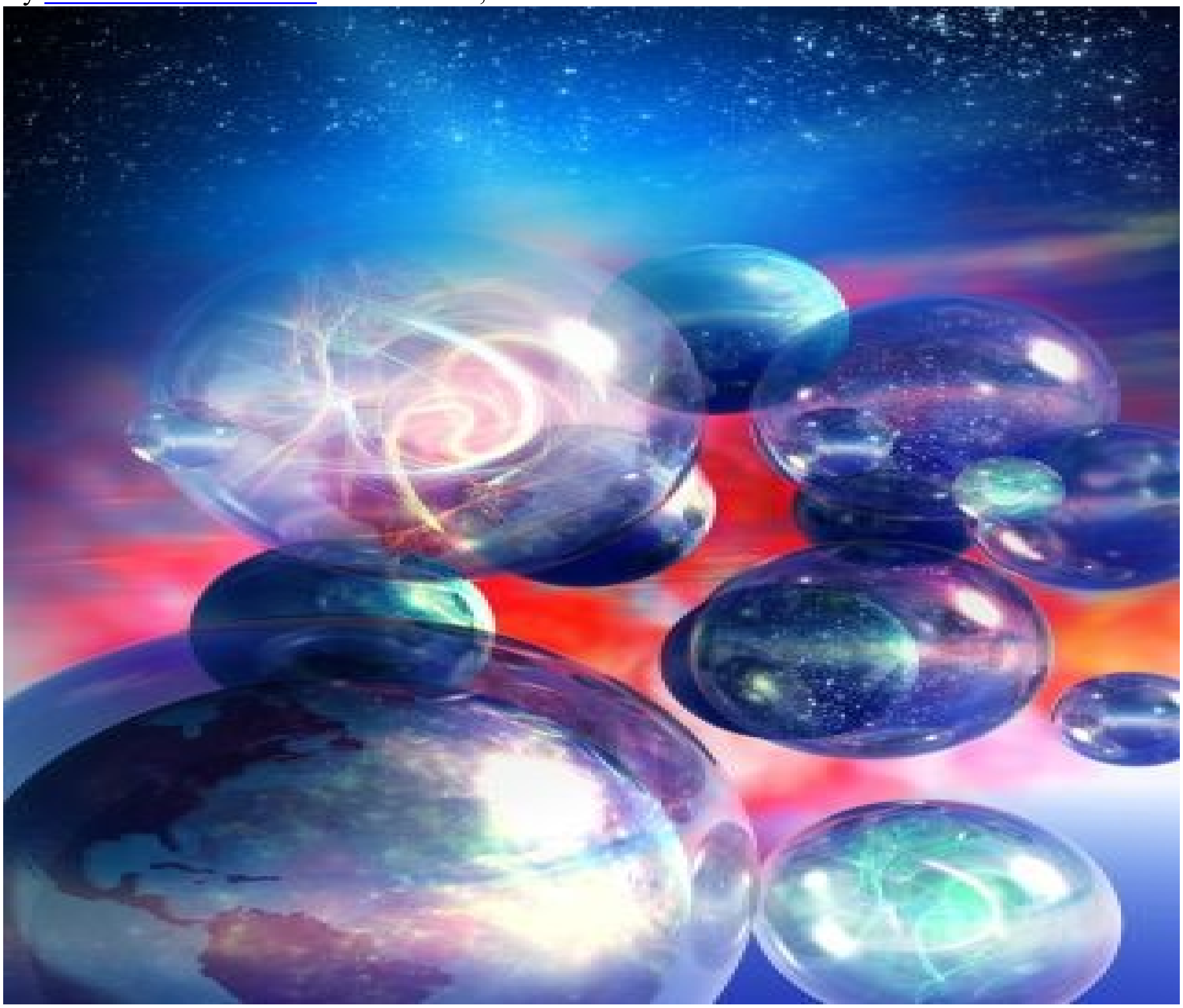
Confronting the Multiverse: What 'Infinite Universes' Would Mean

By Robert Lawrence Kuhn December 23, 2015



Our universe may be one of many, physicists say.
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Robert Lawrence Kuhn is the creator, writer and host of "Closer to Truth," a public television series and online resource that features the world's leading thinkers exploring humanity's deepest questions. Kuhn is co-editor, with John Leslie, of "The Mystery of Existence: Why Is There Anything at All?" (Wiley-Blackwell, 2013). This article is based on a "Closer to Truth" *episode produced and directed by Peter Getzels and streamed at www.closertotruth.com. Kuhn contributed this article to Space.com's* Expert Voices: Op-Ed & Insights.

Since childhood, I've obsessed about existence. What is existence? What's the extent of existence? What's the purpose of existence? Now, six decades on, having explored many things, I'm no surer (and feeling no smarter), but I continue my pursuit.

What's the largest, surest fact about existence that I can know with confidence? For me, it's the vastness of the cosmos. The universe is huge, but it is only with recent discoveries that we can realize how inconceivably immense the universe, or multiple universes, may actually be.

It's now one of humanity's ultimate questions — and until relatively recently, we didn't know enough to even ask it. How many universes exist?

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The multiverse

If we define "universe" as "all there is" or "all that exists," then obviously, by definition, there can be only one universe.

But if we define "universe" as "all we can ever see" (no matter how large our telescopes) or "space-time regions that expand together," then many universes may indeed exist. There is nothing in science more awesome, more majestic. To discern the nature of ultimate reality, one must begin with the challenge of multiple universes.

So what is a "multiverse"?

As physicist and Nobel laureate Steven Weinberg told me on "Closer to Truth" (the source of all following interviews), "The word 'universe,' I suppose, should properly mean the whole thing — everything. But when we think of 'universe,' we sometimes use the word to mean just our Big Bang, the things we can see out to almost 14 billion light-years in all directions. And in this manner, it's reasonable to question: Is our universe unique? Are there multiple Big Bangs? Could there be multiple Big Bangs in different senses?" [What Triggered the Big Bang? It's Complicated (Op-Ed)]

Steven Weinberg - How many universes exist?

"We started calling it a 'multiverse,'" meaning the entire ensemble of innumerable regions of disconnected space-time, said Andrei Linde, the Russian-American physicist now at Stanford. He developed the theory of "eternal chaotic inflation," which generates ever-increasing numbers of universes without end. Scientists created the neologism "multiverse," Linde continued, "because we found that what we had called 'the universe' can be divided into extremely large

Andrei Linde - How many universes exist?

regions, which may have different laws of physics. And one part may be suitable for life, and other parts unsuitable."

Linde portrays "universes" as painted balloons or bubbles on canvas, "squeezing off" from one another via eternal chaotic inflation. Each of his bubbles is a separate universe, each with different laws of physics. The whole collection of universes, the multiverse, is incomprehensibly vast — and growing ever more so.

Is such a multiverse merely speculation? Certainly it is not as widely accepted by scientists as quantum physics or the Standard Model of particle physics. But it is motivated by real science, and it does follow from the equations of cosmology that optimally explain the origin and structure of our universe. In fact, in some of Linde's mathematical models, cosmic inflation must be expanding eternally and chaotically.

Cosmic inflation

Eternal chaotic inflation, which generates multiple universes, builds from the theory of cosmic inflation, originated by physicist Alan Guth at the Massachusetts Institute of Technology. He formulated cosmic inflation to solve several deep problems in the cosmology of our universe — for example, why was the early universe extremely (and strangely) homogeneous, even though separated regions were causally disconnected? (Regions could not cause effects with others because the distances were too great and the elapsed time was too short, even though information was being exchanged at the speed of light, what theorists call the "horizon problem".)

Alan Guth - How do you make a cosmos?

On an episode of Closer To Truth, Guth described inflation this way: "Our universe began with a startlingly brief period of enormous, exponential expansion driven by a peculiar state of matter, called a 'false vacuum,' that actually creates a gravitational repulsion." (Guth's "startling brief period" is indeed startlingly brief — from 10^{-36} seconds after T0, the origin of the universe, to about 10^{-32} seconds.)

According to quantum field theory, the word "vacuum" indicates a sector of space that has local-minimum energy, but not the lowest possible energy, and the word "false" is used to mean ultimately unstable, though the vacuum can remain stable for a very long time. The significance is that a "false vacuum" can "tunnel" into a lower energy state, releasing or "creating" enormous energy.

In this inflationary scenario, Guth said, the exponential expansion ends, because the false vacuum that's driving the repulsive gravity is unstable, and so it decays, much like radioactive elements decay.

The end of that initial inflation, after space expanded exponentially in this fleeting fraction of a second, becomes the traditional Big Bang, in which the vast energy that was locked up in the false vacuum is released and converted into the energy and matter of the early universe. This energy is what produces an unimaginably hot, uniform soup of plasmic particles, which is the starting point in traditional Big Bang theory.

But according to the model of cosmic inflation, while the decay of the false vacuum triggered the Big Bang in one part of expanding space, that decay did not happen in all of expanding space — because not all of expanding space decays at the same time. Those varying rates of decay provide the special key that enables multiple universes to be generated without end.

Here's why: Sectors of false-vacuum space that do not decay go on expanding exponentially, stretching space even faster than the parts of false-vacuum space that do decay — and because this false-vacuum, still-expanding space is "metastable," parts of it will eventually decay (over very long periods of time).

Each decay generates a single so-called "pocket universe," which is Guth's term for a connected region of space-time. Because the rate of expansions is much faster than the rate of decays, new regions are created — with potentials for new decays, and hence potentials for new pocket universes.

That all works because the negative gravitational pressure of the false vacuum (in the sectors of space that do not decay) continues to create a repulsive gravitational field, which is the driving force behind inflation's exponential expansion of space. This creates more opportunities for local decays, which in turn generate pocket universes literally ad infinitum. Once again, it is because the rate of expansions of false-vacuum space, which stretches space, exceeds the rate of decays of false-vacuum space, which generates Big Bangs, that the process of generating multiple universes never stops.

Alex Vilenkin, a cosmologist at Tufts University in Massachusetts, explained that because "the space between these bubble or pocket universes is expanding very fast, room is being made for new bubbles to form, so there will be an unlimited number of pocket universes formed in the course of inflation."

If this picture is right, Guth said, "we see no end to it."

Pocket universes and quantum tunnels

To get our bearings in understanding how a multiverse could be generated, let's begin with the theory of cosmic inflation, which explains the origin and structure of our universe. Then, because cosmic inflation does not end everywhere at the same time, this leads to the theory of eternal chaotic inflation, which generates multiple pocket universes continuously and without end.

It is easy to forget that each of these new pocket universes is vastly larger than our observable universe (see next section). But these new universes are not superstrange, since they all exist within the same space-time framework that we know in our universe — though they erupt far beyond what we can see in our observable universe. What's more, once these new pocket universes are born, they are totally and forever disconnected from every other universe (including ours).

But how to commence cosmic inflation? Some physical material, however minuscule, is required. So from where does this primordial matter come?

Vilenkin said that the answer is “quantum tunneling.” He told me, "Quantum tunneling can create a universe 'from nothing' [because] in quantum mechanics things that are classically forbidden by energy barriers can happen by tunneling through energy barriers. So a universe of zero size — that is, no universe at all — can originate spontaneously by 'tunneling through' an energy barrier and then expanding by inflation." (Of course, the existence of the laws of quantum mechanics does not constitute "nothing" — but that's a story for another time.)

A similar conundrum is that cosmic inflation seems to create energy "out of nothing," which would violate the law of conservation of energy (a physical "no-no"). In fact, the net energy of the universe is zero, because the positive energy of all the matter that is created is balanced by the negative energy of the gravitation. Guth calls it the "ultimate free lunch."

What's the evidence for these theories of cosmic inflation, eternal chaotic inflation and multiple universes? It's challenging, to say the least, considering that cosmic inflation began and ended within the tiniest fraction of the first second of our universe's existence. And, eternal chaotic inflation, by definition, cannot be seen, as other universes, arguably generated by eternal chaotic inflation, are disconnected permanently from our universe.

Yet lines of corroborating evidence (beyond the elegance of the equations) have convinced many cosmologists to such a degree that cosmic inflation and eternal chaotic inflation have become, in essence, the "standard model" of cosmology. As for cosmic inflation, it seems to solve, at the same time, several, separate enigmas in the origin and structure of the universe (including the horizon problem I mentioned earlier). Moreover, cosmic inflation makes interesting predictions, especially about the cosmic microwave background (CMB) radiation, a remnant of the Big Bang — predictions that have been confirmed and reconfirmed by increasingly precise data from satellites.

As for eternal chaotic inflation, it seems to be the unavoidable consequences of the mathematics of cosmic inflation: Once cosmic inflation starts, it seems impossible to stop. However, while there have been tantalizing hints of possible corroborating data, none is convincing (yet?).

Cosmic inflation revolutionized cosmology, and if ultimately confirmed — a demanding task — it may come to be recognized as one of humanity's most fundamental realizations.

How big is the multiverse?

One great question of existence is simply, how big is it? By "it" I mean everything that exists. All there is. What are the physical dimensions of all-there-is?

A place to start is the size of the universe in which we find ourselves. According to one of Guth's models, our pocket universe may be at least 10^23 times larger than our observable universe (because, in order to work, inflation requires at least 100 doublings of the size of the universe, 2^100 = roughly 10^30). This means that the pocket universe we call home would be 100 billion trillion times larger than everything we can see with our largest telescopes. (Models, no surprise, do jump around.)

Thus the vast expanse of our visible universe, Guth said, is but an insignificant speck within just our own inflating pocket universe. And this universe itself is only one pocket universe among an innumerable or even an infinite number of other pocket universes.

When I first realized how cosmic inflation majestically swells the size of the multiverse, how unutterably vast is the totality of the cosmos, it was unnerving. I can still feel the shock. It happened in the late 1990s when I was preparing for my first "Closer to Truth" interview with Andrei Linde.

In reading Linde's papers on eternal chaotic inflation (the parts I could understand), I kept coming across extremely large numbers that he was using to express the size of the universe — but often I did not see any units of measurement associated with those numbers. I was perplexed: Size always needs units, I thought.

I did understand that many of the large numbers were relative to the size of our current universe. But how big is our current universe? Limited by the speed of light traveling since the Big Bang, we cannot see it all. I craved units with all the numbers so I could get a sense of the actual size of Linde's multiverse vision (in the different models).

Was Linde talking about centimeters or kilometers? Or for that matter, about nanometers (10^-9 meters) or kiloparsecs (3,262 light-years)? It seemed impossible to describe absolute size with just a number, no units. Why was Linde frustrating me by not using units?

Suddenly, it hit me. Units don't matter! This sounds counterintuitive: How could the difference between nanometers and kiloparsecs not matter? It gets worse. Compare the smallest and largest known sizes: the Planck length, which is ~10^-35 m (a proton is about 100 million trillion times larger than the Planck length), and the diameter of the visible universe, which is ~10^27 m. The difference between these smallest and largest potential units of measure is ~10^62 orders of magnitude — but even this gigantic range shrinks to essentially zero when compared with Linde's numbers.

Here's what Linde told me: "If we're talking about the simplest models of inflation, the size of the universe is expected to be at least several orders of magnitude greater than what we see now. But it is very difficult to explain why would it be only several orders of magnitude greater than what we see now. In the past I used the estimate 10^10^12 (10 raised to the power of 10 raised to the power of 12), but if it is a self-reproducing, eternally inflating universe, then it is, most likely, simply infinite." (Linde stressed that "any estimates are very crude and model-dependent.")

Let's take Linde's noninfinite number, 10^10^12. As 10^12 is 1,000,000,000,000, or 1 trillion, the expression is 10^1,000,000,000,000. This number means one trillion orders of magnitude, one trillion consecutive multiplications by 10.

In comparison, even the vast expanse between the Planck length and the diameter of the entire visible universe — 62 orders of magnitude — becomes meaningless! It's not the difference between 62 and 1 trillion (which itself is obviously huge). It's the difference between 62 and 1 trillion orders of magnitude, the difference between multiplying by ten 62 times and multiplying by ten 1 trillion times. That is, this is a difference in sequential multiplications of 10 of 999,999,999,938.

This is why Linde's number for the size of an eternally chaotic inflating universe needs no units of measure. Units would add nothing to its meaning. The size of the cosmos is too vast.

Multiple types of multiverses

Most scientists support cosmic inflation because it can account for the origin and structure of our cosmos and explain several profound problems. Sir Martin Rees, the U.K.'s Astronomer Royal, calls the multiverse "speculative science, not just metaphysics." He said he's confident there is far more to physical reality than the vast domain that we see through our telescopes, and he would be amazed, he said, "if the universe didn't extend thousands of times beyond what we can see."

Martin Rees - How many universes exist?

But there are unanswered questions, and Rees raised two critical ones: "First, is our Big Bang the only one? And, second, if there are many Big Bangs, are they all governed by the same laws of physics?"

The "fascinating option," said Rees, is that different physical laws govern the other universes — "space may be different, gravity may be different, atoms may be different. This would mean that reality would consist of all these universes, governed by different laws, and only some tiny subset of them would be governed by laws that would allow complexity to evolve. Most universes would be sterile because, for example, gravity would be too strong to allow complex structures, or atoms would not be stable."

If, indeed, many Big Bangs generate an immense variety of physical laws, then, Rees said, only science fiction can describe all that might happen.

"These inflationary bubble or pocket universes expand at speeds approaching the speed of light," Vilenkin noted. "So we cannot possibly travel to other universes. For practical purposes, each of these inflationary bubble universes is a separate, self-contained unit — and they can in principle have different physical properties."

How could different laws in different universes be generated? Leonard Susskind, a physicist at Stanford University in California and one of the originators of string theory, gives one answer:

Multiple universes (the innumerable pocket universes) are populated by possible laws of physics emerging from possible structures of string theory. This theory postulates that reality at its most fundamental level consists of miniscule, one-dimensional "strings," whose size is nearly the smallest possible Planck length, ~10^-35- m, or 100 million trillion times smaller than a proton. Their vibrations in multiple dimensions of space-time (10, 11 or 26 dimensions, depending on the specific string theory) give rise to all the laws of physics, the theory says. String theory seems almost impossible to test experimentally, but the elegance and the beauty of its explanatory powers convince its adherents.

"What string theory brings is something about the number of possibilities," Susskind said. "But its numbers are far, far larger than the number of atoms in the universe — the number 10 to the 500 [10^500] gets bandied about. This does not mean 10^500 different pocket universes, but 10^500 different types of them in a string theory 'landscape' — each one being repeated over and over again [in different instances of the type]. So, on the one hand, string theory gives you the analog of the different number of ways of re-arranging a DNA molecule. What cosmic inflation theory gives you, on the other hand, is how do you bring these different [pocket] universes into existence?"

"That's why a multiverse of innumerable bubble or pocket universes can have a very wide variety of physical properties," Vilenkin said. "A property of inflation is that it will explore the whole landscape of these possibilities, or 'vacua,' because quantum mechanics allows tunneling through energy barriers to other minima. Moreover, quantum mechanics tells us that if a transition between two minima is not absolutely forbidden by some law, then it must inevitably happen. This means that all possible transitions between all possible states must happen."

It's a neat picture. String theory would provide the landscape of all permitted laws of physics, and cosmic inflation would provide the mechanism to generate actual universes to populate that landscape. This would mean that for each pocket universe, string theory would provide a particular set of physical laws. The smallest structures would determine the largest structures.

Levels of the multiverse

Max Tegmark, a cosmologist at MIT, goes further. He envisions four kinds of multiverses that may exist, labeling them "Levels":

- **Level I**: Space in our universe goes on far beyond that which we can see, and perhaps goes on forever — which would mean that infinitely many other regions exist in our own pocket universe, regions like our observable universe, where the laws of physics are the same.

- **Level II**: Infinitely many other regions exist in the same space-time as that of our universe, but they are disconnected permanently from our own pocket universe, and within each of them the laws of physics are different (described by Linde's eternal chaotic inflation and potentially the string theory landscape).

- **Level III**: A kind of space different from the space-time of our universe exists (called "Hilbert space," which is infinite-dimensional and abstract), where the laws of quantum mechanics generate multiple universes via innumerable branchings. (This is based on taking seriously the quantum wave function, which is a probability amplitude of the quantum state of the system.) The universe branches into different whole-world realities with every tick of time, whether at every Planck time, which is 10^-43 seconds (the time it takes a photon, traveling at the speed of light, to travel one Planck length, 10^-35 m), or at every instant of time when an observation is made. These other whole worlds would not be far away in terms of our kind of space — so in a sense they are right here — but branched out immensely into this different kind of (Hilbert) space. (This is the "many-worlds" interpretation of quantum mechanics, devised by the then relatively unknown physicist Hugh Everett in 1957 and now enjoying new respectability.)

- **Level IV**: Tegmark makes the extraordinary claim that every consistent system of mathematics describes some kind of existing world or universe. "It would seem odd if there were some basic asymmetry built into math," he told me, "such that some equations would be allowed to describe a physical universe and others would not. So my guess is that every mathematical structure which mathematicians can study is on the same footing and describes some kind of physical universe. I think that the reason that nature is so well-described by math is because in a very deep sense, nature really is math."

All of these universes are immense beyond the imagination, but are any truly infinite in the literal meaning of the term, going on without end or limit?

As Linde told me recently, "This is subtle. Suppose a bubble of a new vacuum is created in an eternally expanding universe — a standard picture in eternal chaotic inflation and the string theory landscape (Level II). Then, from the outside, each such bubble looks like a finite bubble that grows infinitely in time. But from the inside, it looks like an infinite open universe. Of course, 'looks like' means that someone is looking, but nobody can see an infinite universe."

Tegmark's Level I is accepted by almost all cosmologists (i.e., space in our universe extends far beyond that which we can see with our best telescopes); his Level II has become the "standard model" of cosmology (i.e., the cosmic inflation of Guth leads to the eternal chaotic inflation of Linde, generating disconnected pocket universes continuously and forever); his Level III is speculative and controversial (i.e., quantum branching); and his Level IV, while idiosyncratic, seeks deep truths of existence (i.e., reality is mathematics).

All this shows how far and how fast our knowledge of the cosmos has expanded: Generating multiple universes by eternal chaotic inflation, a theory developed in the last four decades, is now the standard model of cosmology.

I asked Steven Weinberg, a founder of the Standard Model of particle physics now at the University of Texas at Austin, about other kinds of multiple universes. "There's another possibility, which is fairly simple to imagine," he said. "Our Big Bang is one episode and may be followed [and/or may have been preceded] by a series of other bangs, and our universe will make a transition into a different kind of expanding universe so that we are just living through a particular age.

"There are still other possibilities, which are more recondite," Weinberg continued. "Quantum mechanics can be applied to the whole shebang. Because the fundamental quanta in quantum mechanics is not the individual particle or billiard ball but is something called the 'wave function,' which describes all possibilities, it may be that the universe, the comprehensive universe, the whole thing, is some kind of quantum mechanical superposition of different possibilities." (This is Tegmark's Level III.)

"Then, there are even more exotic possibilities," Weinberg added. "The philosopher Robert Nozick introduced the so-called 'principle of fecundity,' according to which everything imaginable exists some place — not in our same space-time but entirely separate." Weinberg noted that the principle of fecundity undermines (or trivializes) the question of why things are the way they are (i.e., why "this way" rather than "that way"), because whatever is possible must and does exist (somewhere). (The philosopher David Lewis proposed a similar theory of "modal realism" in which all possible worlds, astonishingly, are actual worlds.)

But to achieve such immensity and diversity, wouldn't there still have to be, at a deeper level, some rock-bottom, fundamental "universe-generating laws" to create all the multiple universes in the first place, each of which has its own different laws? Where is bedrock reality?

Dissenting voices

Not every cosmologist is a full convert to the multiverse. As cosmologist George Ellis told me, "I don't like the word 'multiverse.' I like the idea 'universe.'" He said he prefers to talk about "one universe with many different expanding domains," because to him, the "universe," by definition, is every physical thing that exists. Moreover, he stresses the basic problem of other domains of space-time. "Because we cannot see them," he said, "we can't prove anything about them.

"Now there is an alternative picture, which is actually rather nice," he said (with a twinkle). "Maybe this multiverse picture is wrong. Maybe we are seeing the same patch of space-time over and over again. Einstein's theory [of general relativity] allows this to happen because space-time not only is curved, but also it can have a different connectivity structure. So maybe we can go for several hundred million light-years [in one direction] and then suddenly we return from that side [to where we started from], just like Pac-Man did in those early computer games.

"In that case," Ellis concluded, "there actually would be many fewer galaxies than we appear to see. We would be seeing many images, maybe hundreds of images, of the same galaxy." This is what Ellis calls his "small universe" theory, which he finds "philosophically attractive." He said, "It could be the case," but admitted, "it probably isn't."

Physicist Paul Davies, director of the Beyond Center for Fundamental Concepts in Science at Arizona State University, said he gives "two cheers [not the full three] for the multiverse," because "although there are good reasons for supposing that what we see may not be all that exists, the hypothesis falls far short of being a complete theory of existence." A multiverse, Davies said, is often presented as solving the mysteries of existence by assuming that if there are an infinite number of universes, then "everything is out there somewhere, so that's the end of the story.

"That is simply not true," Davies said, because to get a multiverse, you need a universe-generating mechanism, "something that's going to make all those Big Bangs go bang. You're going to need some laws of physics. All theories of the multiverse assume quantum physics to provide the element of spontaneity, to make the bangs happen. They assume pre-existing space and time. They assume the normal notion of causality, a whole host of pre-existing conditions." Davies said there are about "10 different basic assumptions" of physical laws that are required "to get the multiverse theory to work."

Davies then made his deep point. "OK, where did those laws all come from? What about those meta-laws that generate all the universes in the first place? Where did they come from? Then what about the laws or meta-laws that impose diverse local laws upon each individual universe? How do they work? What is the distribution mechanism?" Davies argues that the only thing the multiverse theory does is shift the problem of existence up from the level of one universe to the level of multiple universes. "But you haven't explained it," Davies asserted.

Davies dismissed the idea that "any universe you like is out there somewhere. I think such an idea is just ridiculous and it explains nothing. Having all possible universes is not an explanation, because by invoking everything, you explain nothing."

Davies' critique of the multiverse goes deeper. To explain the universe, he rejects "outside explanations," he said.

"I suppose, for me, the main problem [with a multiverse] is that what we're trying to do is explain why the universe is as it is by appealing to something outside of it," Davies told me. "In this case, an infinite number of multiple universes outside of our universe is used as the explanation for our universe."

Then Davies makes his damning comparison. "To me, multiverse explanations are no better than traditional religion, which appeals to an unseen, unexplained God — a God that is outside of the universe — to explain the universe. In fact, I think both explanations — multiverse and God — are pretty much equivalent." To Davies, this equivalence is not a compliment.

Davies said he appreciates all the motivations and mathematics that drive inflation theory, along with the multiple universes that seem the compulsory consequences. But still, he said, he feels that an infinite number of universes does not make sense. Something's amiss.

Seven kinds of multiple universes

What's my take? Long out of childhood, but still feeling childlike in the presence of a multiverse, I try to assess the possibilities. I like to categorize things, to discern scope and breadth. Here are seven possible mechanisms that could generate multiple universes.

1. Different spatial regions of our ordinary space-time could exist in our own pocket universe, yet so far away that even the light of their stars, traveling at the speed of light, will never have sufficient time to reach us (generated by cosmic inflation).
2. Different temporal periods of our ordinary space-time could exist in our own pocket universe, such that multiple universes arise in sequence, not in parallel (generated by cycles of universal expansion and contraction, Big Bangs and big crunches).
3. Different domains of our ordinary space-time could "squeeze off" to become other pocket universes, separated forever from our universe (each new universe generated by eternal chaotic inflation and perhaps characterized by string theory).
4. Different dimensions of space and time could exist, where in higher dimensions, entirely independent realities may exist. These different dimensions may be in some sense very close, but with respect to information flow and communications, forever apart.
5. Different universal histories could be created via the wave function (and strangeness) of quantum mechanics, where at each fleeting instant (such as every moment of Planck time or flash of observation), all reality splits into many worlds (generated by taking the wave function as objective reality).
6. Whatever can be expressed by consistent mathematical systems can in fact exist in some kind of reality (Tegmark's Level IV).
7. The principle of fecundity or modal realism might operate: All possibilities of any kind, whether imagined or unimagined, do really exist. Somewhere (Nozick, Lewis).

What's more, these seven mechanisms for generating multiple universes are not mutually exclusive. Several, or even all of them, could be true — and they could nest in various ways, one within others, others within one.

Do all things exist?

In a multiverse, one cannot avoid infinity, and infinity does strange things. There are two types of possible infinities in a multiverse: Type I: A single universe may be infinite in size (e.g., in our universe, if space and galaxies would continue forever without end or closure), or Type II: All the separate universes in a multiverse can be infinite in number (irrespective of whether any or all of the universes are infinite in size themselves).

The consequences of either infinity become bizarre. First of all, even Tegmark's Level I multiverse, assuming it's infinite, must contain everything that's physically possible. This means, for example, that every "Star Wars" scenario really exists out there, including those that didn't make it into the films and even all those the writers didn't think of!

Similarly, as long as there is sufficient space for unending random shufflings of particles (and a universe of infinite size certainly has sufficient space), there would have to be a sector of space out there identical to our sector of space, with persons identical to you and to me. Tegmark estimates that our closest identical copy is 10^10^28 m away.

I'm not so impressed even by this bizarre proposition. There would also have to be a sector of space identical to our sector of space except for, say, one hair on the head of one person, which is skewed 1 nanometer to the right. And another sector of space in which all else is the same except for that same hair, which is now skewed 2 nanometers to the left. Then all the hairs on all the people, skewed this way and that way. And then all the things in whole sectors of space, arranged in every possible combination and permutation. There would be innumerable minute differences and innumerable large differences, with every one a separate sector of space — all enabled because the one infinite universe with infinite sectors of space goes on forever. Obviously, on this vision, randomized particles in the overwhelming majority of vast sectors of space yield nothing much at all.

To be clear, a truly infinite universe means that anything that is not impossible (no matter how obscure) will happen, must happen and must happen, weirdly, an infinite number of times. An infinite universe goes on forever, not only generating uncountable variations, but also requiring *each* of the uncountable variations to occur an infinite number of times. That's the strange nature of a true infinity.

I agree with Davies: Something is amiss.

Does a multiverse undermine God? Or enrich God?

If multiple universes are real, and especially if a true infinite number of universes really exist, then our worldview changes. Everything changes. Whatever you believe — even about God (that God exists? that God doesn't exist?) — nothing remains the same. If only the material world exists, then the material world becomes inconceivably larger. If an infinite God exists, then God's infinity becomes expressed by science and enriched with new meaning.

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But would the real existence of a multiverse undermine arguments for the real existence of God (by undercutting the modern "argument from design" based on the "fine-tuning" of our universe)? How would God, if there is a God, relate to a multiverse? If one believes in God, or wonders whether to believe in God, this issue cries out to be addressed. Why would God, if there is a God, create multiple universes? Why would God create *infinite* multiple universes? Could a multiverse elucidate what God, if there is a God, would be like? And if God does not exist, then what? Does a multiverse have meaning? (All this I shall consider in a future essay.)

If, from this essay I seem rational, coolheaded and self-assured about multiple universes, then I have been unintentionally deceptive. I am intimidated by the ineffable endlessness of an overarching, overwhelming multiverse. I shrink before the terrifying vision of the 17th century philosopher Blaise Pascal: "The eternal silence of these infinite spaces frightens me."

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