COSMOLOGY

DOES THE MULTIVERSE REALLY EXIST?

Proof of parallel universes radically different from our own may still lie beyond the domain of science

By George F. R. Ellis

IN THE PAST DECADE AN EXTRAORDINARY CLAIM HAS CAPTIVATED COSMOLOGISTS: THAT THE EXPANDING universe we see around us is not the only one; that billions of other universes are out there, too. There is not one universe—there is a multiverse. In *Scientific American* articles and books such as Brian Greene's latest, *The Hidden Reality,* leading scientists have spoken of a super-Copernican revolution. In this view, not only is our planet one among many, but even our entire universe is insignificant on the cosmic scale of things. It is just one of countless universes, each doing its own thing.

The word "multiverse" has different meanings. Astronomers are able to see out to a distance of about 42 billion light-years, our cosmic visual horizon. We have no reason to suspect the universe stops there. Beyond it could be many—even infinitely many—domains much like the one we see. Each has a different initial distribution of matter, but the same laws of physics operate in all. Nearly all cosmologists today (including me) accept this type of multiverse, which Max Tegmark calls "level 1." Yet some go further. They suggest completely different kinds of universes, with different physics, different histories, maybe different numbers of spatial dimensions. Most will be sterile, although some will be teeming with life. A chief proponent of this "level 2"

Photograph by Levi Brown

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IN BRIEF

The notion of parallel universes leapt out of the pages of fiction into scientific journals in the 1990s. Many scientists claim that megamillions of other universes, each with its own laws of physics, lie out there, beyond our visual horizon. They are collectively known as the multiverse.

The trouble is that no possible astronomical observations can ever see those other universes. The arguments are indirect at best. And even if the multiverse exists, it leaves the deep mysteries of nature unexplained.

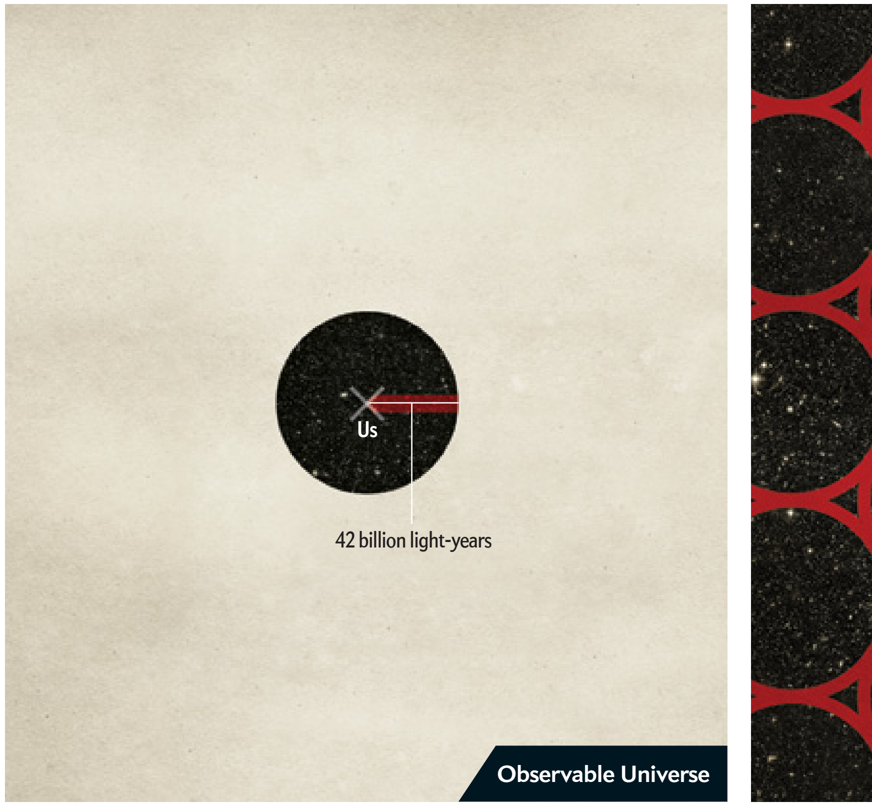
THE PERILS OF EXTRAPOLATION

What Lies Beyond?

When astronomers peer into the universe, they see out to a distance of about 42 billion light-years, our cosmic horizon, which represents how far light has been able to travel since the big bang (as well as how much the universe has expanded in size since then). Assuming that space does not just stop there and may well be infinitely big, cosmologists make educated guesses as to what the rest of it looks like.

Level 1 Multiverse: Plausible The most straightforward assumption is that our volume of space is a representative sample of the whole. Distant alien beings see different volumes, but all of these look basically alike, apart from random variations in the distribution of matter. Together these regions, seen and unseen, form a basic type of multiverse.

Level 2 Multiverse: Questionable Many cosmologists go further and speculate that, sufficiently far away, things look quite different from what we see. Our environs may be one of many bubbles floating in an otherwise empty background. The laws of physics would differ from bubble to bubble, leading to an almost inconceivable variety of outcomes. Those other bubbles may be impossible to observe even in principle. The author and other skeptics feel dubious about this type of multiverse.



multiverse is Alexander Vilenkin, who paints a dramatic picture of an infinite set of universes with an infinite number of galaxies, an infinite number of planets and an infinite number of people with your name who are reading this article.

Similar claims have been made since antiquity by many cultures. What is new is the assertion that the multiverse is a scientific theory, with all that implies about being mathematically rigorous and experimentally testable. I am skeptical about this claim. I do not believe the existence of those other universes has been proved—or ever could be. Proponents of the multiverse, as well as greatly enlarging our conception of physical reality, are implicitly redefining what is meant by "science."

OVER THE HORIZON

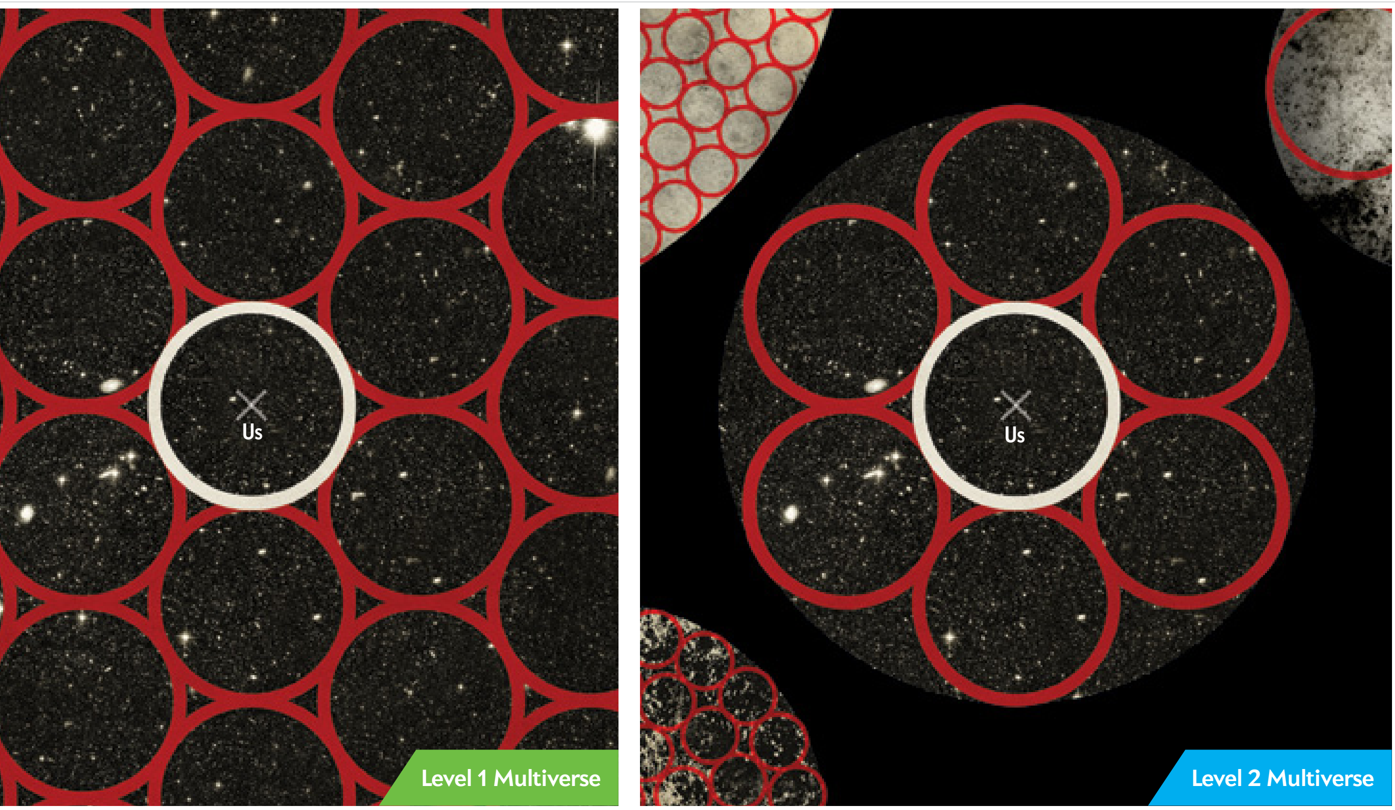
THOSE WHO SUBSCRIBE to a broad conception of the multiverse have various proposals as to how such a proliferation of universes might arise and where they would all reside. They might be sitting in regions of space far beyond our own, as envisaged by the chaotic inflation model of Alan H. Guth, Andrei Linde and others [see "The Self-Reproducing Inflationary Universe," by Andrei Linde; SCIENTIFIC AMERICAN, November 1994]. They might exist at different epochs of time, as proposed in the cyclic universe model of Paul J. Steinhardt and Neil Turok [see "The Myth of the Beginning of Time," by Gabriele Veneziano; SCIENTIFIC AMERICAN, May 2004]. They might exist in the same space we do but in a different branch of the quantum wave function, as advocated by David Deutsch [see "The Quantum Physics of Time Travel," by David Deutsch and Michael Lockwood; SCIENTIFIC AMERICAN, March 1994]. They might not have a location, being completely disconnected from our spacetime, as suggested by Tegmark and Dennis Sciama [see "Parallel Universes," by Max Tegmark; SCIENTIFIC AMERICAN, May 2003].

Of these options, the most widely accepted is that of chaotic inflation, and I will concentrate on it; however, most of my remarks apply to all the other proposals as well. The idea is that space at large is an eternally expanding void, within which quantum effects continually spawn new universes like a child blowing bubbles. The concept of inflation goes back to the 1980s, and physicists have elaborated on it based on their most comprehensive theory of nature: string theory. String theory allows bubbles to look very different from one another. In effect, each begins life not only with a random distribution of matter but also with random types of matter. Our universe contains particles such as electrons and quarks interacting through forces such as electromagnetism; other universes may have very different types of particles and forces—which is to say, different local laws of physics. The full set of allowed local laws is known as the landscape. In some interpretations of string theory, the landscape is immense, ensuring a tremendous diversity of universes.

Many physicists who talk about the multiverse, especially advocates of the string landscape, do not care much about parallel universes per se. For them, objections to the multiverse as a concept are unimportant. Their theories live or die based on internal consistency and, one hopes, eventual laboratory testing. They assume a multiverse context for their theories without worrying about how it comes to be—which is what concerns cosmologists.

For a cosmologist, the basic problem with all multiverse proposals is the presence of a cosmic visual horizon. The horizon is the limit to how far away we can see, because signals traveling toward us at the speed of light (which is finite) have not had time

Illustrations by Chad Hagen



since the beginning of the universe to reach us from farther out. All the parallel universes lie outside our horizon and remain beyond our capacity to see, now or ever, no matter how technology evolves. In fact, they are too far away to have had any influence on our universe whatsoever. That is why none of the claims made by multiverse enthusiasts can be directly substantiated.

The proponents are telling us we can state in broad terms what happens 1,000 times as far as our cosmic horizon, 10^{100} times, $10^{1,000,000}$ times, an infinity—all from data we obtain within the horizon. It is an extrapolation of an extraordinary kind. Maybe the universe closes up on a very large scale, and there is no infinity out there. Maybe all the matter in the universe ends somewhere, and there is empty space forever after. Maybe space and time come to an end at a singularity that bounds the universe. We just do not know what actually happens, for we have no information about these regions and never will.

SEVEN QUESTIONABLE ARGUMENTS

MOST MULTIVERSE PROPONENTS are careful scientists who are quite aware of this problem but think we can still make educated guesses about what is going on out there. Their arguments fall into seven broad types, each of which runs into trouble.

Space has no end. Few dispute that space extends beyond our cosmic horizon and that many other domains lie beyond what we see. If this limited type of multiverse exists, we can extrapolate what we see to domains beyond the horizon, with more and more uncertainty as regards the farther-out regions. It is then easy to imagine more elaborate types of variation, including alternative physics occurring out where we cannot see. But the trouble with this type of extrapolation, from the known to the unknown, is that no one can prove you wrong. How can scientists decide whether their picture of an unobservable region of spacetime is a reasonable or an unreasonable extrapolation of what we see? Might other universes have different initial distributions of matter, or might they also have different values of fundamental physical constants, such as those that set the strength of nuclear forces? You could get either, depending on what you assume.

Known physics predicts other domains. Proposed unified theories predict entities such as scalar fields, a hypothesized relative of other space-filling fields such as the magnetic field. Such fields should drive cosmic inflation and create universes ad infinitum. These theories are well grounded theoretically, but the nature of the hypothesized fields is unknown, and experimentalists have yet to demonstrate their existence, let alone measure their supposed properties. Crucially, physicists have not substantiated that the dynamics of these fields would cause different laws of physics to operate in different bubble universes.

The theory that predicts an infinity of universes passes a key observational test. The cosmic microwave background radiation reveals what the universe looked like at the end of its hot early expansion era. Patterns in it suggest that our universe really did undergo a period of inflation. But not all types of inflation go on forever and create an infinite number of bubble universes. Observations do not single out the required type of inflation from other types. Some cosmologists such as Steinhardt even argue that eternal inflation would have led to different patterns in the background radiation than we see [see "The Inflation Debate," by Paul J. Steinhardt; SCIENTIFIC AMERICAN, April]. Linde and others disagree. Who is right? It all depends on what you assume about the physics of the inflationary field.

Fundamental constants are finely tuned for life. A remarkable fact about our universe is that physical constants have just the right values needed to allow for complex structures, including living things. Steven Weinberg, Martin Rees, Leonard Susskind and others contend that an exotic multiverse provides a tidy explanation for this apparent coincidence: if all possible values occur in a large enough collection of universes, then viable ones for life will surely be found somewhere. This reasoning has been applied, in particular, to explaining the density of the dark energy that is speeding up the expansion of the universe today. I agree that the multiverse is a possible valid explanation for the value of this density; arguably, it is the only scientifically based option we have right now. But we have no hope of testing it observationally. Additionally, most analyses of the issue assume the basic equations of physics are the same everywhere, with only the constants differing—but if one takes the multiverse seriously, this need not be so [see "Looking for Life in the Multiverse," by Alejandro Jenkins and Gilad Perez; Scientific American, January 2010].

Fundamental constants match multiverse predictions. This argument refines the previous one by suggesting that the universe is no more finely tuned for life than it strictly needs to be. Proponents have assessed the probabilities of various values of the dark energy density. The higher the value is, the more probable it is, but the more hostile the universe would be to life. The value we observe should be just on the borderline of uninhabitability, and it does appear to be so [*see illustration at right*]. Where the argument stumbles is that we cannot apply a probability argument if there is no multiverse to apply the concept of probability to. This argument thus assumes the desired outcome before it starts; it simply is not applicable if there is only one physically existing universe. Probability is a probe of the consistency of the multiverse proposal, not a proof of its existence.

String theory predicts a diversity of universes. String theory has moved from being a theory that explains everything to a theory where almost anything is possible. In its current form, it predicts that many essential properties of our universe are pure happenstance. If the universe is one of a kind, those properties seem inexplicable. How can we understand, for example, the fact that physics has precisely those highly constrained properties that allow life to exist? If the universe is one of many, those properties make perfect sense. Nothing singled them out; they are simply the ones that arose in our region of space. Had we lived elsewhere, we would have observed different properties, if we could indeed exist there (life would be impossible in most places). But string theory is not a tried-and-tested theory; it is not even a complete theory. If we had proof that string theory is correct, its theoretical predictions could be a legitimate, experimentally based argument for a multiverse. We do not have such proof.

All that can happen, happens. In seeking to explain why nature obeys certain laws and not others, some physicists and philosophers have speculated that nature never made any such choice: all conceivable laws apply somewhere. The idea is inspired in part by quantum mechanics, which, as Murray Gell-Mann memorably put it, holds that everything not forbidden is compulsory. A particle takes all the paths it can, and what we see is the weighted average of all those possibilities. Perhaps the same is true of the entire universe, implying a multiverse. But astronomers have not the slightest chance of observing this multiplicity of possibilities. Indeed, we cannot even know what the possibilities are. We can only make sense of this proposal in the face of some unverifiable organizing principle or framework that decides what is allowed and what is not—for example, that all possible mathematical structures must be realized in some physical domain (as proposed by Tegmark). But we have no idea what kinds of existence this principle entails, apart from the fact that it must, of necessity, include the world we see around us. And we have no way whatsoever to verify the existence or nature of any such organizing principle. It is in some ways an attractive proposition, but its proposed application to reality is pure speculation.

ABSENCE OF EVIDENCE

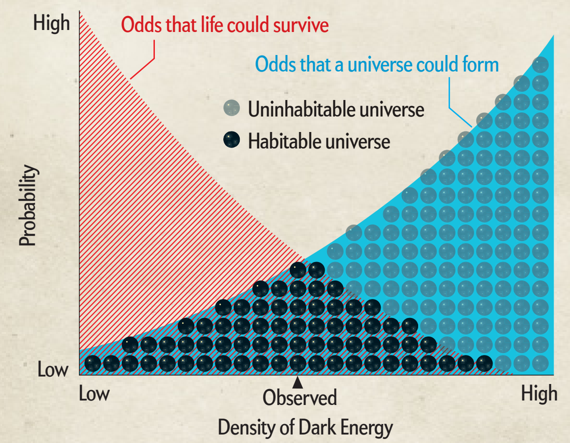
Although the theoretical arguments fall short, cosmologists have also suggested various empirical tests for parallel universes. The cosmic microwave background radiation might bear some traces of other bubble universes if, for example, our universe has ever collided with another bubble of the kind implied by the chaotic inflation scenario. The background radiation might also contain remnants of universes that existed before the big bang in an endless cycle of universes. These are indeed ways one might get real evidence of other universes. Some cosmologists have even claimed to see such remnants. The observational claims are strongly disputed, however, and many of the hypothetically possible multiverses would not lead to such evidence. So observers can test only some specific classes of multiverse models in this way.

A second observational test is to look for variations in one or

DARK ENERGY AND THE MULTIVERSE

Does the Glove Fit?

As evidence for a multiverse, proponents often cite the density of the dark energy that dominates our universe. The process of eternal inflation endows each universe in a multiverse with a random density of dark energy. Relatively few universes have zero or a low value; most have higher values (*blue area*). But too much dark energy tears apart the complex structures needed to sustain life (*red area*). So most habitable universes should have a middling density of dark energy (*peak of overlap region*)—and, lo and behold, our universe does. Multiverse skeptics, though, say this reasoning is circular: it holds only if you assume the multiverse to begin with. It is a consistency test, not a proof.



Graphic by Jen Christiansen

more fundamental constants, which would corroborate the premise that the laws of physics are not so immutable after all. Some astronomers claim to have found such variations [see "Inconstant Constants," by John D. Barrow and John K. Webb; Scientific American, June 2005]. Most, though, consider the evidence dubious.

A third test is to measure the shape of the observable universe: Is it spherical (positively curved), hyperbolic (negatively curved) or "flat" (uncurved)? Multiverse scenarios generally predict that the universe is not spherical, because a sphere closes up on itself, allowing for only a finite volume. Unfortunately, this test is not a clean one. The universe beyond our horizon could have a different shape from that in the observed part; what is more, not all multiverse theories rule out a spherical geometry.

A better test is the topology of the universe: Does it wrap around like a doughnut or pretzel? If so, it would be finite in size, which would definitely disprove most versions of inflation and, in particular, multiverse scenarios based on chaotic inflation. Such a shape would produce recurring patterns in the sky, such as giant circles in the cosmic microwave background radiation [see "Is Space Finite?" by Jean-Pierre Luminet, Glenn D. Starkman and Jeffrey R. Weeks; Scientific American, April 1999]. Observers have looked for and failed to find any such patterns. But this null result cannot be taken as a point in favor of the multiverse.

Finally, physicists might hope to prove or disprove some of the theories that predict a multiverse. They might find observational evidence against chaotic versions of inflation or discover a mathematical or empirical inconsistency that forces them to abandon the landscape of string theory. That scenario would undermine much of the motivation for supporting the multiverse idea, although it would not rule the concept out altogether.

TOO MUCH WIGGLE ROOM

All in all, the case for the multiverse is inconclusive. The basic reason is the extreme flexibility of the proposal: it is more a concept than a well-defined theory. Most proposals involve a patchwork of different ideas rather than a coherent whole. The basic mechanism for eternal inflation does not itself cause physics to be different in each domain in a multiverse; for that, it needs to be coupled to another speculative theory. Although they can be fitted together, there is nothing inevitable about it.

The key step in justifying a multiverse is extrapolation from the known to the unknown, from the testable to the untestable. You get different answers depending on what you choose to extrapolate. Because theories involving a multiverse can explain almost anything whatsoever, any observation can be accommodated by some multiverse variant. The various "proofs," in effect, propose that we should accept a theoretical explanation instead of insisting on observational testing. But such testing has, up until now, been the central requirement of the scientific endeavor, and we abandon it at our peril. If we weaken the requirement of solid data, we weaken the core reason for the success of science over the past centuries.

Now, it is true that a satisfactory unifying explanation of some range of phenomena carries greater weight than a hodgepodge of separate arguments for the same phenomena. If the unifying explanation assumes the existence of unobservable entities such as parallel universes, we might well feel compelled to accept those entities. But a key issue here is how many unverifiable entities are needed. Specifically, are we hypothesizing more or fewer entities than the number of phenomena to be explained? In the case of the multiverse, we are supposing the existence of a huge number—perhaps even an infinity—of unobservable entities to explain just one existing universe. It hardly fits 14th-century English philosopher William of Ockham's stricture that "entities must not be multiplied beyond necessity."

Proponents of the multiverse make one final argument: that there are no good alternatives. As distasteful as scientists might find the proliferation of parallel worlds, if it is the best explanation, we would be driven to accept it; conversely, if we are to give up the multiverse, we need a viable alternative. This exploration of alternatives depends on what kind of explanation we are prepared to accept. Physicists' hope has always been that the laws of nature are inevitable—that things are the way they are because there is no other way they might have been—but we have been unable to show this is true. Other options exist, too. The universe might be pure happenstance—it just turned out that way. Or things might in some sense be meant to be the way they are—purpose or intent somehow underlies existence. Science cannot determine which is the case, because these are metaphysical issues.

Scientists proposed the multiverse as a way of resolving deep issues about the nature of existence, but the proposal leaves the ultimate issues unresolved. All the same issues that arise in relation to the universe arise again in relation to the multiverse. If the multiverse exists, did it come into existence through necessity, chance or purpose? That is a metaphysical question that no physical theory can answer for either the universe or the multiverse.

To make progress, we need to keep to the idea that empirical testing is the core of science. We need some kind of causal contact with whatever entities we propose; otherwise, there are no limits. The link can be a bit indirect. If an entity is unobservable but absolutely essential for properties of other entities that are indeed verified, it can be taken as verified. But then the onus of proving it is absolutely essential to the web of explanation. The challenge I pose to multiverse proponents is: Can you prove that unseeable parallel universes are vital to explain the world we do see? And is the link essential and inescapable?

As skeptical as I am, I think the contemplation of the multiverse is an excellent opportunity to reflect on the nature of science and on the ultimate nature of existence: why we are here. It leads to new and interesting insights and so is a productive research program. In looking at this concept, we need an open mind, though not too open. It is a delicate path to tread. Parallel universes may or may not exist; the case is unproved. We are going to have to live with that uncertainty. Nothing is wrong with scientifically based philosophical speculation, which is what multiverse proposals are. But we should name it for what it is. SA

MORE TO EXPLORE

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