BY MARCIA BARTUSIAK

BEFORE THE BIG BANG: THE BIG FOAM

In answer to the question of why it happened, I offer the modest proposal that our Universe is simply one of those things which happen from time to time.

—Edward P. Tryon

According to legend, the seventeenth-century Irish theologian James Ussher was faced with cosmology's greatest enigma. When Bishop Ussher, an authority on biblical chronology, solemnly announced to his fellow churchmen that God began to forge the heavens and the earth at 2:30 in the afternoon on Sunday, October 23, in the year 4004 B.C., one brave soul is alleged to have asked, "And pray, Holy Father, what was God doing *before* he created the universe?" To which Ussher thunderously replied, "Creating hell for those who ask questions such as that!"

Today this mystery remains just as hellish. Each advance that we have witnessed in cosmology these last few decades has increased our understanding of how the cosmos acted at earlier and earlier epochs. When theorists view the expansion of our universe backward in time—like a motion picture in reverse—every bit of mass-energy ends up packed into an infinitesimal speck. It was this infinitely condensed speck that supposedly exploded, some 15 billion years ago, in a primordial Big Bang, causing space to expand and matter to condense into the stars and planets of our present universe.

This widely accepted scenario, however, leads to questions as bothersome as the one posed by Ussher's follower: How did that primordial egg of seemingly infinite density and infinite temperature get there in the first place, and why did it explode? In other words, how do you get *something* out of *nothing* without invoking divine intervention?

For many years this problem was handily sidestepped by the suggestion that our universe oscillates. In this model, the expansion that our cosmos is now experiencing is merely one in an endless sequence of expansions and

contractions. This puts the question of our origins in the infinite past, where science doesn't have to worry much about it. What preceded the Big Bang was a never-ending cycle of birth, death, and rebirth. The relentless pull of gravity gradually halts each expansion and draws the galaxies inward until they reform that primeval fireball from which they emerged. And then, like a bouncing ball, the universe rebounds into another burst of expansion, forming a new generation of galaxies, stars, and planets. Yet many theorists are convinced that a cyclic universe, if it exists at all, will always run down, much the way the bounce of a ball eventually peters out. Except that in this case each bounce, strangely enough, takes longer and expands farther than the last one, which means that only a limited number of cycles could have preceded our present bounce. No longer would the universe have an infinite past, and this conclusion thrusts the problem of our beginnings back into the spotlight.

Some Big Bang cosmologists simply ignore the perplexity by declaring that any comments on the conditions that might have existed prior to the explosion will remain outside the domain of physical science. Stephen Hawking summed up this viewpoint by noting that "time ceases to be well defined in the very early universe just as the direction 'north' ceases to be well defined at the North Pole of the Earth. Asking what happens before the Big Bang is like asking for a point one kilometer north of the North Pole." But Hawking himself, a physicist who holds the Lucasian Chair of Mathematics at Cambridge University in England, as Newton did, is far from discouraged by the conundrum. He has also stated that "the initial conditions of the universe are as suitable a subject for scientific study and theory as are the local physical laws. We shall not have a complete theory until we can do more than merely say that 'things are as they are because they were as they were.'"

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Physicist Edward Tryon of Hunter College in New York City believes part of the problem has been psychological. "The universe overwhelms one's psyche with its size, and that poses a psychological barrier to people trying to ask, 'How could the universe have emerged following known physical laws?'"

But in recent years these walls have begun to crumble. A few theorists are daring to wrestle with that once unthinkable question: What was happening at "time zero"? Their musings are not vague speculations hashed out over coffee in a physics-department lounge, but rigorous mathematical treatises that adhere to the laws of particle physics, quantum mechanics, and Einstein's theories of relativity. The titles of the scientific papers display a certain boldness. One enigmatically suggests the "Creation of Universes from Nothing."

Many of these venturesome physicists admit that the details of their models may appear charmingly quaint in coming years as the laws governing the actions of highly energetic subatomic particles are better understood. But their intriguing (some would say disturbing) conclusions may not change: Our cosmos may be only one of many universes bubbling out of a yet-to-be-defined dimension. Each appears as a sudden *poof* out of the void. It is a vision of genesis that is sure to knock out some of our philosophical underpinnings, wrenching askew our place in the cosmos.

Tryon planted the seed for these contemplations in the late 1960s when, as an eager young assistant professor at Columbia University, he attended a talk by a prominent British cosmologist: "I was sitting off to the right side of the room hazily listening when, during a pause in the lecture, I suddenly blurted out, 'Maybe the universe is a vacuum fluctuation.'" By which he meant an instantaneous blip out of nothingness. "But I was crestfallen," he recalls, "when everyone in the room burst into laughter. With three Nobel laureates in the audience, I wasn't about to tell them I wasn't joking. I mean, who was I to tell them where the universe came from?"

But the idea came back to haunt him a few years later as he was preparing a popular article on cosmology. He was captivated by the fact that astronomy cannot yet determine with absolute certainty whether our universe is open or closed, that is, whether it will expand indefinitely (open) or eventually collapse in on itself (closed). This depends on the amount of matter in the cosmos.

It was Einstein who first taught cosmologists about the intimate relationship between matter, gravity, and the curvature of space-time: Matter causes space to warp and bend. If there's not enough celestial matter to exert the gravitational muscle needed to halt the expansion of space-time, then our universe will expand for all eternity. With too little mass, space never closes back upon itself. Instead, a mass-poor space curves out like a saddle whose edges go off to infinity, fated never to meet.

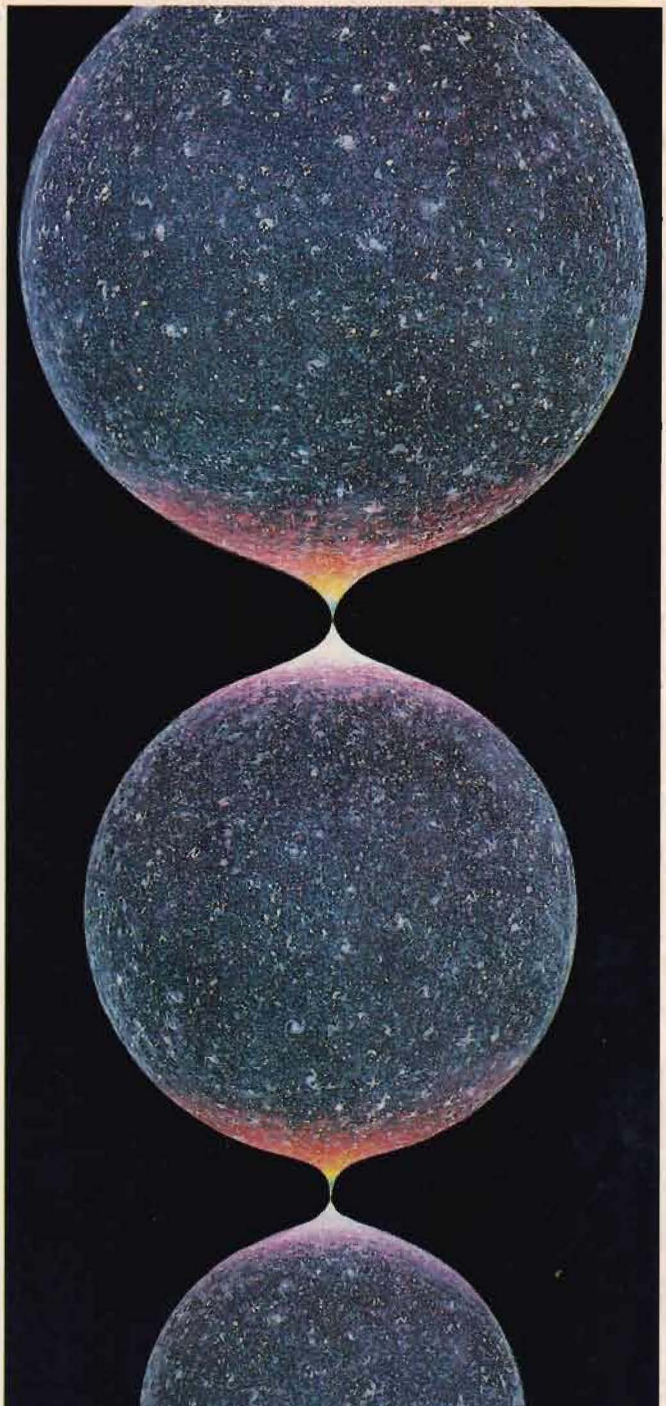
On the other hand, a higher density would provide enough gravity to lasso the speeding galaxies—slowing them down at first, then drawing them inward until space-time curls back up in a "Big Crunch." In a closed universe, space-time would encompass a finite volume and yet have no boundaries. The two-dimensional analogy would be the surface of a sphere, like our earth. A space voyager who traveled a straight-line course long enough through a closed universe would eventually return to the starting point (not unlike completing a round-the-world cruise).

Adding up all the luminous and gravitating mass thus far measured in the universe takes the cosmos to about one tenth of "critical density," the notable juncture between open and closed. Theorists suspect that there is ten times more matter around, bringing the cosmos right to the dividing line.

Tryon speculated on what might have placed the universe in this precarious near-equilibrium. "We learned from Einstein in his famous equation $E = mc^2$ that matter is a form of energy, and our universe contains an enormous amount of matter," he points out. "But there is also another form of energy important to cosmology that acts, in some sense, in opposition to this mass-energy. Namely, gravitational potential energy." Akin to the energy a boulder possesses when it's perched on a hillside, about to fall, this is the energy that each star, planet, and wisp of gas possesses by virtue of its gravitational attraction to every other bit of mass in the heavens. One could think of this as the supply of energy needed to push the galaxies infinitely far apart; hence it is regarded as a negative energy on the ledger books of the universe.

Maybe the enormous amount of *positive* mass-energy in the universe, Tryon surmised, is perfectly balanced with the *negative* gravitational potential energy present. In a universe brought to the brink of closure, as ours might be, these energies would cancel each other out in a stalemated tug-of-war. This suggests that the total energy of our universe is actually zero! "If this be the case," Tryon wrote in 1973, "then our Universe could have appeared from nowhere without violating any conservation laws"—the laws that dictate that certain quantities in the universe, such as matter and energy, must always be preserved or in balance.

Tryon says he was immediately intrigued by this concept because "it had a cold, precise, impersonal beauty about it." The idea of a zero-energy universe does mesh nicely with other conservation laws in our cosmos. For every positively charged particle floating in space, for example, there seems to be a negatively charged particle



ILLUSTRATIONS BY DAVID EGGE

By some accounts, our universe is in an endless cycle of expansion and collapse. But the cycle may be waning. Paradoxically, each decreasingly energetic "bang" causes a *greater* expansion of the universe (bottom to top).

around to neutralize it, resulting in a net electric charge of zero. And for every galaxy receding from us in the northern hemisphere of the cosmos, there's a corresponding galaxy racing away in the southern sector, adding up to a net momentum of zero. "If," muses Tryon, "you're considering energy, momentum, or electric charge, the universe indeed adds up to zero. But if you're interested in theater, art, or fishing, then you might conclude, 'How interesting nothing can be.' Human existence seems to meander in and around these cold, valueless quantities."

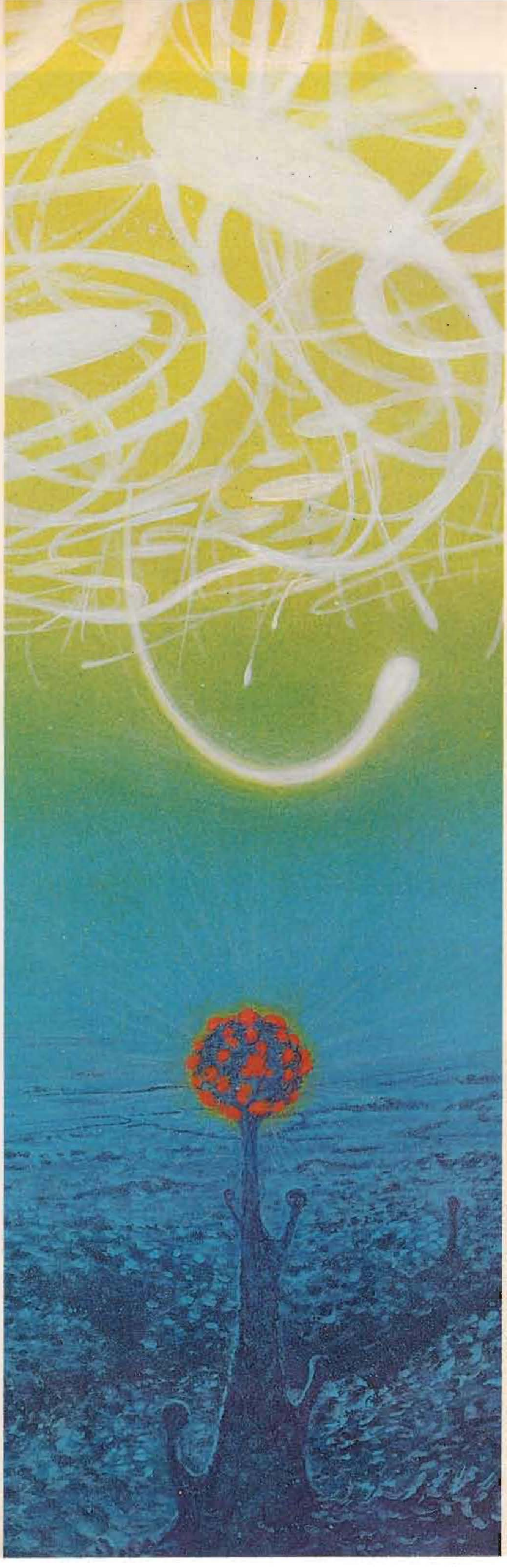
What we have not yet considered is how this cosmic teeter-totter originated. Cars and houses never pop out of thin air. Why should a dense kernel of matter and radiant energy that gives birth to an entire universe suddenly materialize? To answer that, we must turn to quantum field theory, the bizarre set of rules that governs the submicroscopic world of elementary particles.

In the first few decades of this century, scientists came to realize that atomic particles behave with less predictability than such ordinary objects as cars or pencils. Nature at this level operates not like a methodical machine, but like a game of probability. The words *always* and *never*, used so freely in describing processes in the macroscopic world, were replaced with *usually* and *seldom*. Nothing could be counted on or ruled out.

Quantum mechanics' equations of probability even predict that atomic particles can turn up in places where classical laws declare they cannot be. Take radioactivity: By all the laws of nineteenth-century physics, there just isn't enough energy around for a proton or neutron to break free from a nucleus's grip. Yet, the *click, click, click* of a Geiger counter stationed near a piece of uranium instructs us that some particles obviously do escape from time to time. Even in the strange world of modern physics this is quite an amazing feat—as if you had a car locked in a garage and suddenly found that it could tunnel through the garage door to the driveway.

By 1927 German physicist Werner Heisenberg keenly grasped that the probabilistic nature of the laws of quantum mechanics places subtle limitations on how much we can ever know about an atomic system. One might expect the state of an atom to be characterized completely by the position and velocity of its constituent particles, as well as by its energy. But Heisenberg declared that these quantities would always remain uncertain to some degree. Appropriately enough, this limitation came to be known as Heisenberg's uncertainty principle. Einstein himself railed against it and announced that he would "never believe that God plays dice with the world."

Eventually, though, Heisenberg's uncertainty principle would affect scientists' thoughts about the most sacred law of physics: conservation of matter and energy. In our workaday world, matter and energy can be neither created nor destroyed. Gasoline never materializes in our gas tanks (unfortunately), and when you burn one gallon of the fuel, you end up with exactly one gallon's worth of power and residue. But on the atomic scale, there's a loophole in that law. That tiny degree of uncertainty that Heisenberg told us would always exist at submicroscopic levels allows for minor fluctuations in the energy of a system over very brief moments of time.



For instance, within one billionth of a trillionth of a second, an electron and its antimatter twin, a positron, can emerge out of nothingness without warning, come back together again, and then vanish. This is more than mere speculation; the effects of these spontaneous acts of creation and annihilation have been measured in the laboratory. Physicists cannot explain exactly how this happens; they know only that it's one possible outcome as nature keeps throwing down its dice. Conservation laws do not forbid it, and quantum mechanical uncertainties make it inevitable. As Nobel laureate Murray Gell-Mann once remarked (paraphrasing a statement in T. H. White's *The Once and Future King*), "Everything that is not forbidden is compulsory."

Such goings-on at the subatomic level have given physicists a new perspective in their understanding of empty space. To physicist Heinz Pagels of Rockefeller University, the vacuum comes to resemble the surface of the sea: "Imagine that you're flying over the ocean in a jet plane. From that vantage point, the sea looks perfectly smooth and empty. But you know, when you get down close to it in a small boat, that huge waves are fluctuating all over the place. Well, that's the way

Before the beginning, there may have been a foam of space-time bubbles—forever appearing and vanishing. Rarely, a bubble persists and becomes a universe. Each is tinier than an electron (shown as the bright streaks at the top).

it is with empty space. Over large distances—the scales that we experience as human beings—space appears completely empty. But if you were able to probe it very closely, you'd find *all* the quantum particles in existence going in and out of nothingness."

Physicists refer to these ephemeral particles as vacuum fluctuations. This concept seems to defy common sense yet is perfectly valid within the framework of quantum mechanics. "No point is more central than this," physicist John A. Wheeler has written, "that empty space is not empty. It is the seat of the most violent physics."

And that was the key to Tryon's 1973 version of the Big Bang. According to Heisenberg's uncertainty principle, energy and time are related in an inversely proportional way. The smaller the amount of energy being asked to spontaneously pop into existence, the longer the period of time it can stick around. Tryon took this to the extreme: "I thought that, if the universe actually has zero energy, then maybe it's a vacuum fluctuation of some larger space in which our universe is embedded, a vacuum fluctuation that has persisted for billions of years. I was saying that there was a minuscule probability for 10^{87} particles and photons to spontaneously arise out of the vacuum in one shot." Pundits have remarked that this turns Einstein's famous statement around a full 180 degrees. Now, it is dice that are playing God with the universe!

Tryon was the first to agree that his conjecture was besieged by problems. Most important, it didn't explain in any natural way why the early universe was so hot or why it ended up so big. "It's more likely that a smaller universe would have been created," says Tryon. "Our universe is not only large, it's larger than it needs to be for us to have evolved and found ourselves observing it."

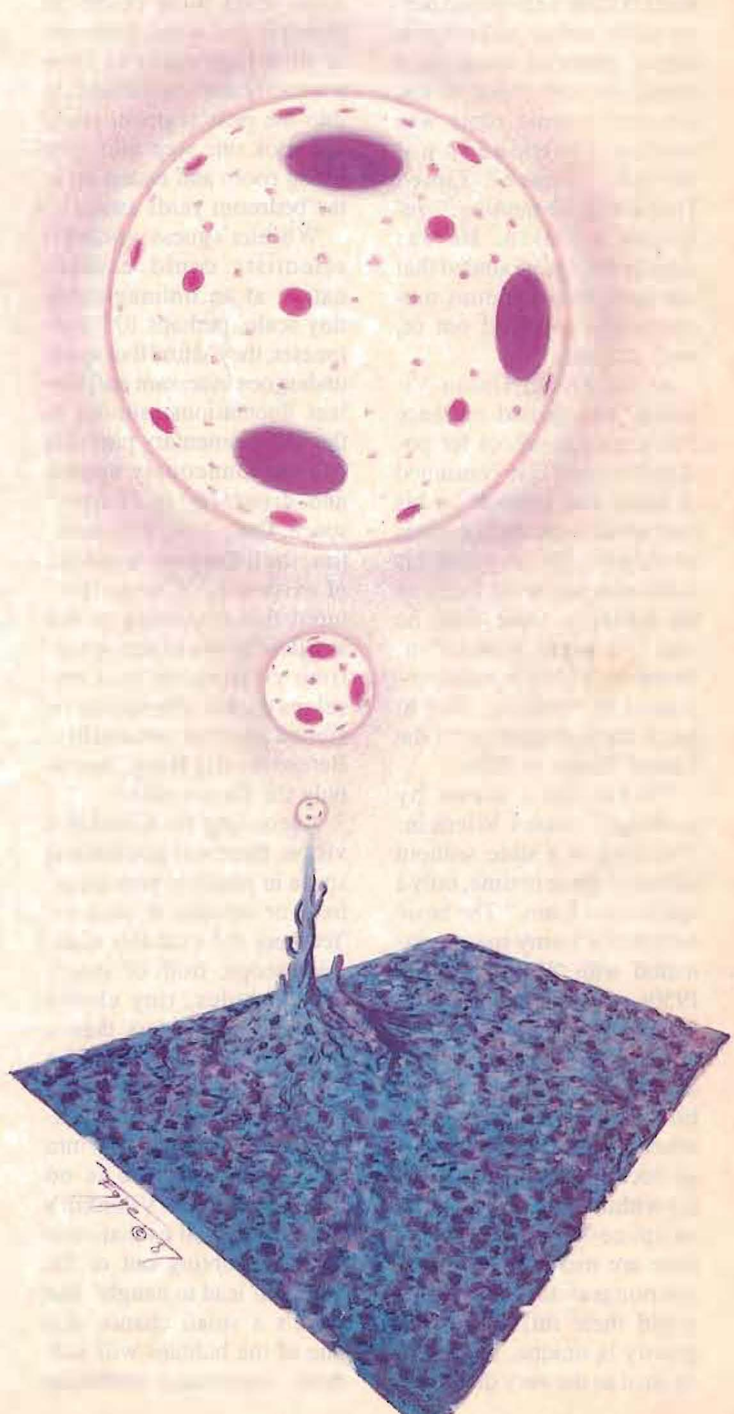
At this point Tryon was offering up only an idea, not a detailed model of the universe's creation. In the next few years others attempted to solve this puzzle with their own creation scenarios.

Late one night in December 1979 Alan Guth, then a postdoctoral fellow at the Stanford Linear Accelerator Laboratory in California, decided to investigate how the latest particle-physics theories affected the evolution of the early universe. His calculations revealed that our universe may have begun not with a bang but with a sort of *burp*—an infinitesimal moment of superaccelerated motion. The universe did not just expand over this interval, it tore outward like a fanciful science fiction spaceship in warp drive. Perhaps inspired by the double-digit rises in the cost of living, Guth soon came up with a name for this period of hyperacceleration—he called it inflation.

Guth's scenario begins 10^{-35} second into the birth, when the universe as we know it was only the size of a proton and starting to cool below 10^{27} degrees. At that stage, over the next 10^{-32} second, our observable cosmos inflated, doubling its size 100 times until it was the size of a softball or maybe even larger.

More important, at the sudden end of this frenzied spurt, the universe released an awesome cascade of extremely hot matter—in fact, *all* the particles and radiation that surround us today. It was inflation's demise that actually provided our cosmos with all its necessary building materials. As Guth, now at MIT, puts it, "our universe is the ultimate free lunch." Whatever mass-energy was contained in the original, pre-inflationary seed—which Guth figures could have been as little as 20 pounds—was simply overwhelmed by the fiery flood tide.

Inflation became the answer to a universe-creator's prayer. "Alan Guth taught us



The sequence of events producing our universe might have begun as a bubble rose from the space-time foam and expanded rapidly, creating time and matter where there was none before.

how to make something big out of something very little," says Tufts University physicist Alexander Vilenkin. Now the quest for our origins was couched in new terms: how to bring into existence that amazing preinflationary bubble just bursting with energy and ready to inflate.

But many theorists still needed their embryonic universes to emerge within some empty, primeval space. In a sense, the discovery of our ultimate cosmic roots was merely postponed, not solved. "Space? Time? That's still *something*," responds Vilenkin. He has more boldly propounded that our universe quantum mechanically appeared out of, well, nothing.

In the Soviet Union Vilenkin was denied entrance into graduate school for political reasons. He continued to study and publish on his own while working at a series of odd jobs. On one paper, his affiliation was even listed as the Kharkov State Zoo; he was the night watchman. However, Vilenkin's contemplation of "nothing" had to await his immigration to the United States in 1976.

"What do I mean by *nothing*?" muses Vilenkin. "Nothing is a state without classical space or time, only a space-time foam." The basic notion of a foamy space originated with Wheeler in the 1950s when he attempted to join quantum mechanics with the law that currently best describes gravity for us, Einstein's general theory of relativity. Other forces, such as electromagnetism, always act within the fixed backdrop of space-time. Space and time are mere spectators as the nongravitational forces wield their influence. But gravity is unique, since it is defined as the very distortion of space-time. To have gravity obey the laws of quantum mechanics means that at some level there could be points in space and moments in time that cease to flow smoothly and continuously into the next segment (as if you took one step into your living room and ended up in the bedroom yards away).

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Wheeler's guess was that if scientists could explore nature at an unimaginably tiny scale, perhaps 10^{-33} centimeter, they'd find that space undergoes incessant and violent fluctuations, similar to the way elementary particles can spontaneously appear and disappear in "empty" space. Only now, it is space-time itself that pops in and out of existence. Wheeler pictured this occurring at the smallest levels of the space-time continuum that envelops us, but Vilenkin envisioned another possibility: Before the Big Bang, maybe only the foam existed.

According to Vilenkin's vision, there was no classical space in which to park a star, tree, or subatomic particle. Yet there did exist this ultramicroscopic froth of space-time bubbles, tiny closed universes (each less than a trillionth of a trillionth of a millimeter across) perpetually growing, collapsing, then disappearing into nothingness. There is no past, no future. Vilenkin's calculations tell us that most of this bubbling out of the void will lead to naught. But there's a small chance that one of the bubbles will suddenly materialize exhibiting all the properties of Guth's inflationary system, moving explosively outward to release its latent energy. Not only a universe but time itself is born. This answers the question of why there is something instead of nothing. Nothing is unstable.

It is even possible in this scheme for bubbles to form with differing energies, some leading to universes like ours, some not. We were quite lucky. Like the baby bear's porridge in the story of Goldilocks, our universe seems to have turned out "just right," at least good enough for matter to have clumped into galaxies that produced stars that formed planets that generated biological creatures that could ask such questions of the cosmos.

According to a few audacious physicists, our good fortune could be proof that a whole family of sister universes exists. They're disturbed by the fact that our own cosmos would be turned topsy-turvy if certain physical constants were shifted by the tiniest amount. Reduce the strong nuclear force by a few percent, for example, and atoms more complicated than hydrogen would fly apart, making the formation of habitable planets an impossibility. A minute change in the strength of the force of gravity or electromagnetism would alter a star's ability to fuse atoms within the thermonuclear engine at its core, causing the star to either radiate too feebly or burn too quickly for living organisms to evolve nearby. Is it sheer coincidence that nature's basic parameters settled into a range that worked out to our benefit, or is it something more? Some scientists contend this incredible fine-tuning makes more sense if the physical constants were just one assortment of a multitude of possibilities randomly set at the moment of creation. We seem to have won in this cosmic game of Russian roulette; other universes may not have been so favored, ending up starless and lifeless. According to this "anthropic principle," as the controversial notion is sometimes labeled, the physical constants must be the way they are or we wouldn't be around to measure them at all. Our own existence sets constraints on the universe we observe.

At first glance, there seems to be no way to prove directly that we're just a minor bit of flotsam floating within a megauniverse filled with disconnected cosmoses. Each photon, cosmic ray, and galaxy in our universe is forever trapped within the confines of a space-time cocoon, cut off from any opportunity to retrieve a sample of some extra-extraterrestrial material. Yet, an observational test does exist, although it's a long shot. The possibility hinges on a model of creation fashioned by Princeton astrophysicist J. Richard Gott (an ironic surname; it's the German word for "god").

Gott compares his work to writing a mystery novel backward. "Particle physicists are trying to write this novel from the first page, hoping it will lead to the proper ending," he says. "But, being an astronomer, I know how it turns out on the last page. So what I do is ask, 'What kind of creation do we need to produce the universe as it looks today?'"

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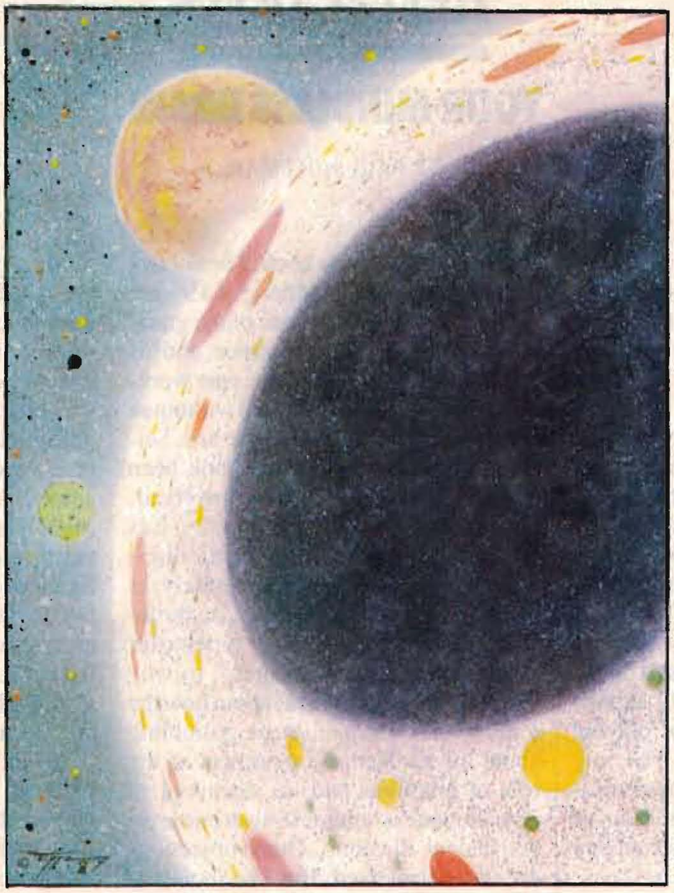
Gott takes Guth's inflationary-universe idea one step further. He suggests that our normal-looking universe resides in a larger superspace that has been inflating for an indescribably long time and will continue to swell outward for all eternity. In a sense, the inflation Guth says the universe experienced during the Big Bang was a peek into this bizarre, ever-expanding otherworld.

This superspace is ferociously hot (possibly as high as 10^{31} degrees), exceedingly dense (up to 10^{93} grams of mass-energy in every thimbleful), and markedly unstable. What it wants to do more than anything else is to form bubbles of lower density, much the way bubbles of steam start forming in a pot of boiling water. An observer inside any of these bubbles would see first a moment of inflation, then the formation of ordinary matter.



In a close–up, nascent universes are seen as cool, dark oases on an expanding hot, dense "superspace." In the background, the ethereal space-time foam.

Astronomers look back on it all today and call it the Big Bang. Meanwhile, in between the bubbles, there's more and more of this peculiar space getting bigger and bigger and bigger—roomy enough to contain an infinite number of bubble universes. As writer Arthur C. Clarke once prophetically penned, "Many and strange are the universes that drift like bubbles in the foam upon the River of Time."

This is where the observational test enters: Gott's frothy vision has the potential to turn deadly. The Princeton astrophysicist and his colleague Thomas Statler have determined that there might be discomforting side effects to a megauniverse filled with a bevy of cosmos-size bubbles. "Since the bubbles are generated randomly in this space, some of them will eventually form next to our bubble and hit it," says Gott.

The supracelestial bump could conceivably create an opening between the two universes, starting as a pinpoint but soon growing larger and larger. It might be quite a bright spot in the sky. An opening that began to grow billions of years ago would now stretch half a degree across the sky, about the size of the moon. Nothing like that has been sighted so far, but this is an event astronomers may not want to detect. Particles spewing into our universe through this interspatial portal could be energized up to a trillion trillion electron volts, as potent as the Big Bang itself! In which case, every solar system, galaxy, and supercluster would soon be vaporized. It would prove that Gott was right, but then no one would be around to congratulate him.

Of course, it need not be that dramatic. The momentous meeting might be noticed only as a slight glitch in the microwave background of our universe. This neighborly knock at our space-time door could take place tomorrow, but Gott and Statler's theory currently predicts a very low rate of bubble formation. The collision might not occur for another 10^{500} years.

There is a risk in writing about astonomy's frontier, because its borders can never be clearly delineated. The boundaries expand, ever so subtly, daily: New planetary systems are discovered; new theories are expounded; new glitches appear in telescopic detectors, awaiting an explanation. A gravity-wave telescope, watching for undulations in the very fabric of space-time, could very well register some blips that would alter our cosmic perspective once again.

Scientific models, perhaps like rules, are meant to be broken (or at least amended). "We advance," muses University of Maryland astronomer Leo Blitz, "because we doubt what has come before." The idea of a cosmos endowed with Aristotelian perfection was no longer viable after Galileo inspected the heavens with the telescope. A few centuries later, the mere notion of neutron stars and black holes completely disrupted the more modest view of stellar evolution held by Arthur Eddington, who in 1935 stated that there should be a law of nature to prevent stars from behaving in such absurd ways. Some current hypotheses are just as vulnerable.

That unresolved mysteries exist, however, cannot in any way diminish the many accomplishments that have already been made. A small planet in the outer reaches of a galaxy may seem insignificant when balanced against the immensity of the heavens. But more awe-inspiring is the ability of men and women to investigate mere spots of light shimmering in the nighttime sky, and from their examinations arrive at such a magnificent description of creation. "In the last analysis," it was noted in 1948 during the opening ceremonies for the famous Hale telescope in California, "the mind which encompasses the universe is more marvelous than the universe which encompasses the mind." ☐