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A New View of Our Universe: Only One of Many

By DENNIS OVERBYE

Astronomers have gazed out at the universe for centuries, asking why it is the way it is. But lately a growing number of them are dreaming of universes that never were and asking, why not?

Why, they ask, do we live in 3 dimensions of space and not 2, 10 or 25? Why is a light ray so fast and a whisper so slow? Why are atoms so tiny and stars so big? Why is the universe so old? Does it have to be that way, or are there places, other universes, where things are different?

Once upon a time (only a century ago), a few billion stars and gas clouds smeared along the Milky Way were thought to encompass all of existence, and the notion of understanding it was daunting — and hubristic — enough. Now astronomers know that galaxies are scattered like dust across the cosmos. And understanding them might require recourse to an even broader canvas, what they sometimes call a "multiverse."

For some cosmologists, that means universes sprouting from one another in an endless geometric progression, like mushrooms upon mushrooms upon mushrooms, or baby universes hatched inside black holes. Others imagine island universes floating and even colliding in a fifth dimension.

For example, Dr. Max Tegmark, a University of Pennsylvania cosmologist, has posited at least four different levels of universes, ranging from the familiar (impossibly distant zones of our own universe) to the strange (space-times in which the fundamental laws of physics are different).

Dr. Martin Rees, a University of Cambridge cosmologist and the Astronomer Royal, said contemplating these alternate universes could help scientists distinguish which features of our own universe are fundamental and necessary and which are accidents of cosmic history. "It's all science, but science for the 21st century, to seek the answers to these questions," Dr. Rees said, adding that he is often accused of believing in other universes.

"I don't believe," he said, "but I think it's part of science to find out."

Some cosmologists now say the realm we call the observable universe — roughly 14 billion light-years deep of galaxies and stars — could be only a small patch of a vast bubble or "pocket" in a much vaster ensemble bred endlessly in a chain of big bangs.

The idea, they say, is a natural extension of the theory of inflation, introduced by Dr. Alan Guth, now at the Massachusetts Institute of Technology, in 1980. That theory asserts that when the universe was less than a trillionth of a trillionth of a second old it underwent a brief hyperexplosive growth spurt fueled by an antigravitational force embedded in space itself, a possibility suggested by theories of modern particle physics.

Because inflation can grow a whole universe from about an ounce of primordial stuff, Dr. Guth likes to refer to the universe as "the ultimate free lunch." But Dr. Guth and various other theorists

— including Dr. Andrei Linde of Stanford, Dr. Alexander Vilenkin of Tufts and Dr. Paul Steinhardt of Princeton — have suggested that it may be an endless one as well. Once inflation starts anywhere, it will keep happening over and over again, they say, spawning a chain of universes, bubbles within bubbles, in a scheme that Dr. Linde called "eternal inflation."

"Once you've discovered it's easy to make a universe out of an ounce of vacuum, why not make a bunch of them?" asked Dr. Craig Hogan, a cosmologist at the University of Washington.
In fact, Dr. Guth said, "Inflation pretty much forces the idea of multiple universes upon us."
Moreover, there is no reason to expect that these universes will be identical. Even within our own bubble, tiny random nonuniformities in the primordial raw material would cause the cosmos to look different from place to place. If the universe is big enough, Dr. Tegmark and others say, everything that can happen will happen, so that if we could look out far enough we would eventually discover an exact replica of ourselves.

Moreover, cosmologists say, the laws of physics themselves, as experienced by creatures like ourselves, confined to four dimensions and the energy scales of ordinary life, could evolve differently in different bubble universes.

"Geography is a now a much more interesting subject than you thought," Dr. John Barrow, a physicist at the University of Cambridge, observed.

Inflation has gained much credit with cosmologists, despite its strangeness, Dr. Guth noted, because it plays a vital role in calculations of the Big Bang that have been vindicated by the detection of the radio waves it produced. The prediction of other universes must therefore be taken seriously, he said.

Lucky Numbers
Adjusting the Dials of Nature's Console

The prospect of this plethora of universes has brought new attention to a philosophical debate that has lurked on the edges of science for the last few decades, a debate over the role of life in the universe and whether its physical laws are unique — or, as Einstein once put it, "whether God had any choice."

Sprinkled through the Standard Model, the suite of equations that describe all natural phenomena, are various mysterious constants, like the speed of light or the masses of the elementary particles, whose value is not specified by any theory now known.

In effect, the knobs on nature's console have been set to these numbers. Scientists can imagine twiddling them, but it turns out that nature is surprisingly finicky, they say, and only a narrow range of settings is suitable for the evolution of complexity or Life as We Know It.

For example, much of the carbon and oxygen needed for life is produced by the fusion of helium atoms in stars called red giants.

But a change of only half a percent in the strength of the so-called strong force that governs nuclear structure would be enough to prevent those reactions from occurring, according to recent work by Dr. Heinz Oberhummer of Vienna University of Technology. The result would be a dearth of the raw materials of biology, he said.

Similarly, a number known as the fine structure constant characterizes the strength of electromagnetic forces. If it were a little larger, astronomers say, stars could not burn, and if it were only a little smaller, molecules would never form.
So is this a lucky universe, or what?

In 1974, Dr. Brandon Carter, a theoretical physicist then at Cambridge, now at the Paris Observatory in Meudon, pointed out that these coincidences were not just luck, but were rather necessary preconditions for us to be looking at the universe.

After all, we are hardly likely to discover laws that are incompatible with our own existence. That insight is the basis of what Dr. Carter called the anthropic principle, an idea that means many things to many scientists. Expressed most emphatically, it declares that the universe is somehow designed for life. Or as the physicist Freeman Dyson once put it, "The universe in some sense must have known that we were coming."

This notion horrifies some physicists, who feel it is their mission to find a mathematical explanation of nature that leaves nothing to chance or "the whim of the Creator," in Einstein's phrase.

"It touches on philosophical issues that scientists oftentimes skirt," said Dr. John Schwarz, a physicist and string theorist at the California Institute of Technology. "There should be mathematical ways of understanding how nature works."

Dr. Steven Weinberg, the University of Texas physicist and Nobel laureate, referred to this so-called "strong" version of the anthropic principle as "little more than mystical mumbo jumbo" in a recent article in The New York Review of Books.

Sorting Universes
Finding a Home for the 'A-Word'

Nevertheless, the "A-word" is popping up more and more lately, at conferences and in the scientific literature, often to the groans of particle physicists. The reason is the multiverse.
"It is possible that as theoretical physics develops, that it will present us with multiple universes," Dr. Weinberg said.

If different laws or physical constants prevail in other bubble universes, the conditions may not allow the existence of life or intelligence, he explained.

In that case the anthropic principle loses its mysticism and simply becomes a prescription for deciding which bubbles are capable of supporting life.

But many string theorists still resent the principle as an abridgment on their ambitions. The result has been a spirited debate about what physicists can expect from their theories.

"They have the pious hope that string theory will uniquely determine all the constants of nature," said Dr. Barrow, who wrote the 1984 book "The Cosmological Anthropic Principle" with Dr. Frank Tipler, a Tulane University physicist. The book argued that once life emerges in the universe it will never die.

In a recent paper titled "The Beginning of the End of the Anthropic Principle," three physicists — Dr. Gordon Kane of the University of Michigan, and Dr. Malcolm Perry and Dr. Anna Zytkow, both of Cambridge — argued that a unified theory of physics, as string theory purports to be, when finally formulated, would specify most of the constants of nature or specify relationships between them, leaving little room for anthropic arguments.

"The anthropic principle isn't as anthropic as people wanted," Dr. Kane said in an interview. But in a rejoinder titled "Why the Universe Is Just So," Dr. Hogan of Washington argued that physics was replete with messy processes like quantum effects, which leave some aspects of reality and the laws of physics to chance. According to string theory, he pointed out, the laws of physics that we mortals experience are low-energy, 4-dimensional shadows, of sorts, of a 10- or 11-dimensional universe. As a result, the so-called "fundamental constants" could look different in different bubbles.

Dr. Hogan admitted that this undermined some of the traditional aspirations of physics, writing, "at least some properties of the world might not have an elegant mathematical explanation, and we can try to guess which ones these are."

Even string theorists like Dr. Kane admit that, in the absence of a final form of the theory, they have no idea how many solutions there may be — one, many or even an infinite number — to the "final" string equations. Each one would correspond to a different condition of space-time, with a different set of physical constants.

"Any set that allows life to happen will have life," he said.

Dark Energies
When the Numbers Just Don't Add Up

But even some of the most hard-core physicists, including Dr. Weinberg, suggest they may have to resort to the anthropic principle to explain one of the deepest mysteries looming like a headache over science: the discovery that the expansion of the universe seems to be speeding up, perhaps in a kind of low-energy reprise of an inflation episode 14 billion years ago.

Cosmologists suspect a repulsion or antigravity associated with space itself is propelling this motion. This force, known as the cosmological constant, was first proposed by Einstein back in 1917, and has been a problem ever since — "a veritable crisis," Dr. Weinberg has called it. According to astronomical observations, otherwise undetectable energy — "dark energy" — accounts for about two-thirds of the mass-energy of the universe today, outweighing matter by two to one. But according to modern quantum physics, empty space should be seething with energy that would outweigh matter in the universe by far, far more, by a factor of at least 10^{60}. This mismatch has been called the worst discrepancy in the history of physics.

But that mismatch is crucial for life, as Dr. Weinberg first pointed out in 1987. At the time there was no evidence for a cosmological constant and many physicists presumed that its magnitude was in fact zero.

In his paper, Dr. Weinberg used so-called anthropic reasoning to pin the value of any cosmological constant to between about one-tenth and a few times the density of matter in the universe. If it were any larger, he said, the universe would blow apart before galaxies had a chance to form, leaving no cradle for the stellar evolution of elements necessary for life or other complicated structures.

The measured value of the constant is about what would be expected from anthropic arguments, Dr. Weinberg said, adding that nobody knows enough about physics yet to tell whether there are other universes with other constants. He called the anthropic principle "a sensible approach" to the cosmological constant problem.

"We may wind up using the anthropic principle to satisfy our sense of wonder about about why things are the way they are," Dr. Weinberg said.

Beyond the Dark
Searching for Proof From Better Theories

For Dr. Rees, the Astronomer Royal, it is not necessary to observe other universes to gain some confidence that they may exist. One thing that will help, he explained, is a more precise theory of how the cosmological constant may vary and how it will affect life in the universe. We should live in a statistically typical example of the range of universes compatible with life, he explained. For example, if the cosmological constant was, say, 10 percent of the maximum value consistent with life, that would be acceptable, he said.

"If it was a millionth, that would raise eyebrows."

Another confidence builder would be more support for the theory of inflation, either in the form of evidence from particle physics theory or measurements of the cosmic Big Bang radiation that gave a more detailed model of what theoretically happened during that first trillionth of a trillionth of a second.

"If we had a theory then we would know whether there were many big bangs or one, and then we would know if the features we see are fixed laws of the universe or bylaws for which we can never have an explanation," Dr. Rees said.

In a talk last month at a cosmology conference in Chicago, Dr. Joseph Polchinski, from the Institute for Theoretical Physics at the University of California in Santa Barbara, speculated that the there could be 10^{60} different solutions to the basic string equations, thus making it more likely that at least one universe would have a friendly cosmological constant.

Reminded that he had once joked about retiring if a cosmological constant was discovered, on the ground that the dreaded anthropic principle would be the only explanation, he was at first at a loss for words.

Later he said he hoped the range of solutions and possible universes permitted by string theory could be narrowed by astronomical observations and new theoretical techniques to the point where the anthropic principle could be counted out as an explanation.

"Life is still good," he said.

But Dr. Hogan said that multiple universes would have to be taken seriously if they came out of equations that science had faith in.

"You have to be open-minded," he said. "You can't impose conditions."

"It's the most scientific attitude," he added.