WHAT IS THE FATE OF THE UNIVERSE?

Hanging in the balance

By Elizabeth Quill ▪ Illustration by Nicolle Rager Fuller

The fate of the universe was supposed to be sealed by the turn of the millennium.

"I imagined we'd be walking around holding a sign saying 'the world is coming to an end' or 'the world is not coming to an end,'" recalls astrophysicist Saul Perlmutter.

But as Y2K soothsayers readied for impending doom, Perlmutter and his colleagues delivered a surprising discovery suggesting that the world's fate would stay in limbo long after the Times Square ball dropped and any leftover champagne went flat. More than a decade later, scientists are still vigorously debating what their finding means not only for the universe's future, but also for all of cosmology.

Perlmutter, of the University of California, Berkeley, led one of two teams that set out in the early 1990s to get a grip on the far future by studying distant supernovas. These stellar explosions serve as distance markers to help astronomers measure how fast the universe is expanding — a key factor in determining if and when it will meet its end. But after analyzing the data, both teams reported in 1998 that the universe's expansion isn't just cruising along — it is accelerating. Some mysterious force, now known as dark energy (see Page 24), is driving space apart, faster and faster.

A dark twist

Before dark energy's discovery, the forecast was surprisingly simple. If the gravitational pull of all the matter in the cosmos was strong enough to rein in expansion — like the Earth's pull on a rocket that can't quite reach escape velocity — the universe would eventually come crashing in on itself. That ending, dubbed the Big Crunch, would mirror the Big Bang that started the cosmic expansion in the first place. If, though, the universe's expansion escaped the claws of gravity, it would go on growing forever. Expansion would slow but never halt, and instead of ending, the universe would

In one end-time scenario, the entire universe — from galaxies down to atoms — would rip apart at its seams.

become a cold, dark, lonely place where life could not survive — a Big Freeze.

But dark energy gives the fleeing rocket some extra oomph, making end-time predictions quite a bit fuzzier.

"A crucial issue is how the dark energy will behave in time," says cosmologist Rocky Kolb of the University of Chicago. "Until we have some way to grapple with that, the fate of the universe hangs in the balance."

If the strength of dark energy's extra push remains forever unchanging, it could be the cosmological constant — a term Albert Einstein added to his equations for general relativity in 1917 and later dismissed as his "biggest blunder." In this case, something like the Big Freeze would play out. But if dark energy's strength decays over time, then a Big Crunch of sorts remains an option.

If instead dark energy grows stronger, exceeding the repulsive force of Einstein's cosmological constant, a more painful scenario awaits: "In a finite amount of time, dark energy gets infinitely dense," says cosmologist Max Tegmark of MIT. "First denser than our galaxy, and our galaxy flies apart. Then denser than Earth, and that flies apart. Then denser than atoms, and atoms fly apart. In a finite time, everything is ripped apart."

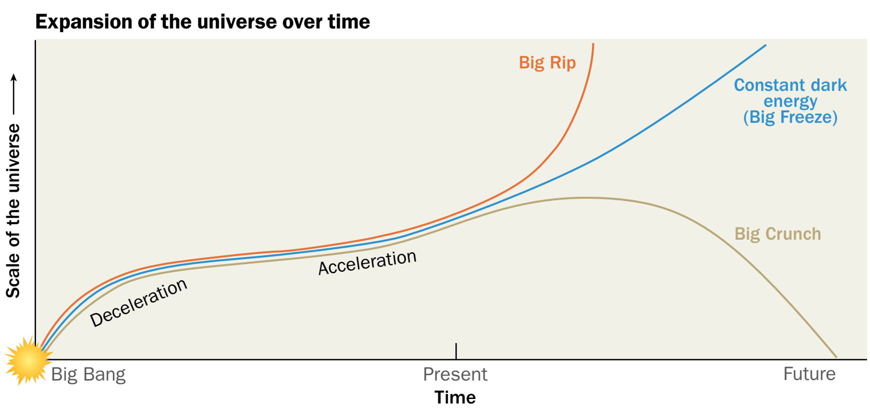
Figuring out whether the universe would end with this Big Rip, or a Freeze or Crunch, requires determining a property of dark energy called its equation of state. That quantity is the ratio of the pressure exerted by the dark energy to its density. The most recent findings, based on data that come from seven years of mapping the glowing radiation left over from the Big Bang, suggest that the equation of state is close to that expected for the cosmological constant, deviating by no more than 14 percent.

But over billions of years, even a much tinier deviation — undetectable with current instruments — could dramatically alter the universe's fate, especially if the dark energy's strength is not constant but can change over time.

"The million dollar question is an experimental question," Tegmark says. Scientists need better measurements to determine whether dark energy's equation of state is perfectly constant.

So some experimentalists are turning back to those very same stellar explosions that revealed dark energy's existence to begin with. A paper by Perlmutter and collaborators, appearing in 2009 in the *Astrophysical Journal*, describes an ongoing effort to compile the world's supernova datasets. Many scientists have their hopes set on a future observatory, WFIRST, which would look for the signal of dark energy in the appearance of distant galaxies and in the imprint of the cosmic equivalent of sound waves in the early universe. A proposed mission named Euclid, from the European Space Agency, and a camera mounted on a telescope in the Andes will further the efforts.

Cosmic Armageddon The discovery of dark energy made the fate of the universe much more difficult to forecast. Scientists typically talk about three possible endings (depicted below), depending on what this mysterious force actually is and how it behaves over time.



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Beyond the end

But others say that a theoretical breakthrough is necessary. Measuring the equation of state with enough precision, they argue, is impossible; a tiny deviation could always linger.

"We don't just want to measure a number," Kolb says. "We want to understand how this crucial piece of physics fits into the overall fabric of the theory of nature. And until we do that, I am not going to be comfortable with any explanation of dark energy."

Kolb thinks no current proposal adequately explains dark energy, thus no proposal decides among a Freeze, Crunch or Rip scenario.

Of course, the right theory might even predict that the universe meets its doom by some other, unknown means. One such possibility presents itself if the observable universe is just one of many bubble universes constantly being created and growing in some larger space. In this "multiverse" scenario, bubble universes can collide. If another bubble encroached on the bubble that people occupy, it would be bad news, says Anthony Aguirre of the University of California, Santa Cruz. "We would just be sitting around," he says, "and this other bubble would smash into us at the speed of light with some huge energy and we would die."

Beyond predicting another possible end, the multiverse ushers in a new way of thinking about what an "end" actually means. "We'd have to be living in a lucky (for cosmologists) or simple universe for the part that we see to be telling us about the whole thing," Aguirre says.

Imagining the death of the observable universe as the ultimate end may be just as naïve as imagining that the destruction of the Earth, for that matter, means the end of all life in the galaxy. There might be much more out there. Even if the bubble occupied by people bursts, other universes could live long and prosper. ■