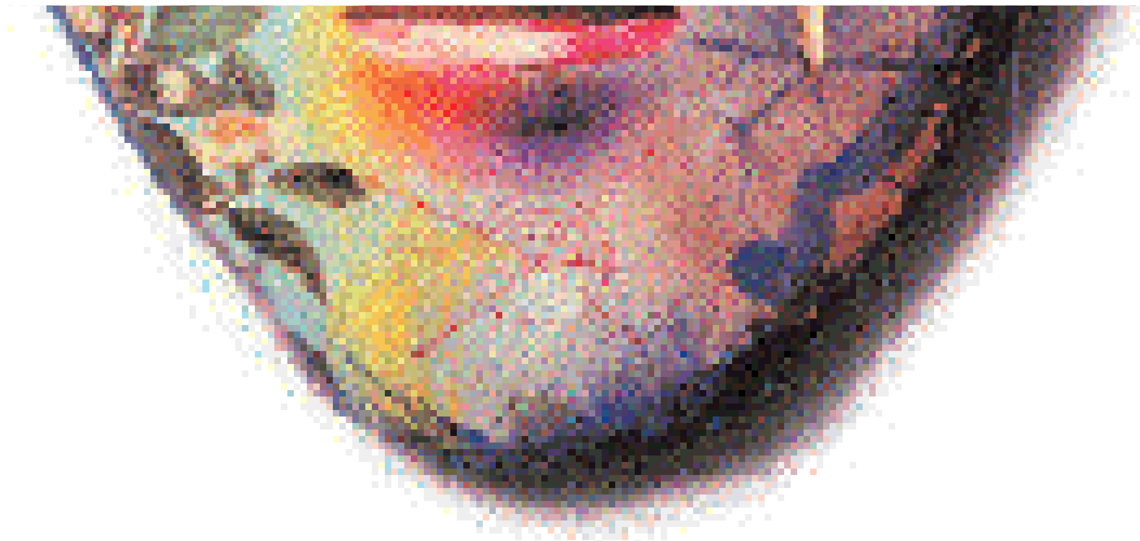
THE SCIENCES

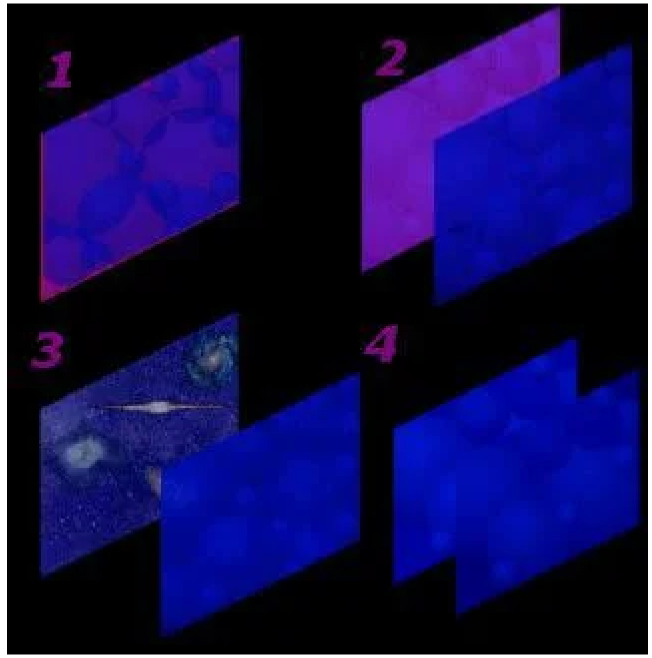
A Recycled Universe

Crashing branes and cosmic acceleration may power an infinite cycle in which our universe is but a phase

By George Musser, JR Minkel on February 11, 2002



Credit: J. W. Stewart



Images: after animation by Paul Steinhardt

A UNIVERSAL CYCLE of birth and rebirth occurs every trillion years or so, according to one new cosmology. Big bangs result when two 10-dimensional "branes" collide *(1)* and expand *(2)* and then collide again *(4)*. In this scenario, our universe *(3)* marks just one phase in this infinite cycle.

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Some questions are disquieting because they can be answered in only one of two equally mind-boggling ways. For instance, are we the sole intelligent beings in the universe, or will

we find others? Another discomforting doozy is this: did the universe begin at some remote time in the past, or was it always here?

The big bang clearly marks some kind of first. That fearsome flash of energy and expansion of space set in motion everything our eyes and telescopes can see today. But on its own, the big bang theory would leave us in a curved universe where matter and energy aren't well mixed. In fact, we now know that spacetime is flat and that galaxies and radiation are evenly distributed throughout. To shore up the big bang theory, cosmologists proposed that the universe began with a burst of exponential expansion from a single uniform patch of space, whose stamp remains on the cosmos to this day. Such inflationary cosmologies have worked so well they've crowded out all the competition.

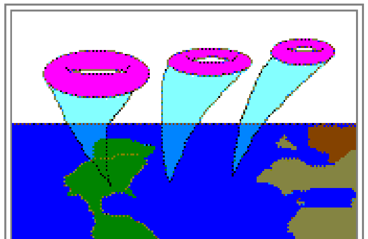
During this past year, however, one group of researchers has started to challenge that idea's preeminence, though the field of cosmology has yet to be completely taken with the new approach. Drawing on some cutting-edge but unproved notions in particle physics, the challengers interpret the big bang as a violent clash between higher-dimensional objects. In the latest installment to the saga, the authors of this interpretation have found a way to turn that single clash into a never-ending struggle that rears its fiery head every trillion years or so, making our universe just one phase in an infinite cycle of birth and rebirth.

Such cyclic ideas are not new. In the 1930s, the late Richard Tolman of the California Institute of Technology wondered what would happen if a closed universein which all matter and energy are ultimately compacted in a big crunchwere to survive its closure and burst forth again. Unfortunately, as Tolman realized, the universe would gather entropy during each new cycle; to compensate, it would have to grow every time like a runaway snowball. And just as a snowball has to begin at some point in time, so, too, would such a snowball. And just as a snowball has to begin at some point in time, so, too, would such a universe.

Then in the 1960s, physicists proved that a big crunch, too, must culminate in a singularitya point stuffed with infinite matter and heatwhere general relativity breaks down. The laws of physics are thus up for grabs. "The idea of a cyclic universe has been around for a long time," says Andreas Albrecht of the University of California at Davis, a co-inventor of inflation, "and it has always been plagued by a fundamental problem: what physics causes the collapsing universe to bounce back into the expanding phase?"

String-ularity

One potential way of getting around that problem is by supposing that elementary particles such as electrons, photons and quarks are really just manifestations of tiny strings of energy jiggling in higher dimensions. The thing is, such a string theory requires the universe to have at least 10 dimensions, as opposed to the usual three in space and one in time that we perceive. "In string theory you learn one thingyou are in higher dimensions," says string theorist Burt Ovrut of the University of Pennsylvania. "Then the question is, where does our real world come from? That's a damn good question."



FIRST STRING. String theory has spawned more than one attempt to do away with the big bang singularity.

Paving the way for an answer in 1995 were Petr Horava, then at Princeton University, and Ed Witten of Princeton's Institute for Advanced Studies, who showed that strings could also exist in a more fundamental, 11-dimensional theory. They collapsed one of these dimensions mathematically into a minuscule line, yielding an 11-dimensional spacetime, flanked on either side by two 10-dimensional membranes, or branes, colorfully dubbed "end of the world" branes. One brane would have physical laws like our own universe. From there, Ovrut and colleagues reasoned that six of those 10 dimensions could be made extremely small, effectively hiding them from everyday view and leaving the traditional four dimensions of space and time.

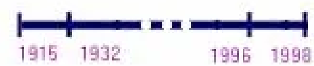
Early in 2001, cosmologists Justin Khoury and Paul Steinhardt of Princeton, another inflationary pioneer, Neil Turok of the University of Cambridge, and Ovrut put their branes to work on the big bang. By turning back the clock in string theory, they found that as our universal brane passed through its starting singularity in reverse, it went suddenly from a state of intense but finite heat and density to one that was cold, flat and mostly empty. In the process, it shed another kind of brane into the 11-dimensional gap. Run forward in time, the big bang appeared as nothing more than two branes smacking into each other like cymbals. They christened this process the ekpyrotic model, after the ancient Greek "conflagration" cosmology wherein the universe is born in and evolves from a fiery explosion.

Without a better understanding of the singularity in string theory, however, the group could not study what would happen as our brane expands after the collision; the model only provided for a contracting universe. Then later last year, the group discovered in collaboration with Nathan Seiberg of the Institute for Advanced Study that the singularity could be interpreted as a collision between the two "end of the world" branes, in which only the gap dimension separating them shrinks down to zero for an instant. "So what looks sort of disastrously singular, when you describe it as a brane collision, is not very singular at all," Turok explains. This scenario remains a conjecture, Seiberg notes, but is mathematically identical to the description of the big bang singularity in general relativity.

The ekpyrotic model had seemed a little contrived up to this point, notes Alan Guth of the Massachusetts Institute of Technology, another author of inflation. The pre-bang universe had to be dark, flat and infinite, seemingly by fiat. But why should it have begun in such a state? The answer, according to the latest work from Steinhardt and Turok, has to do with dark energy, the force that is driving the galaxies apart at ever-increasing speeds.

Drained Branes

As the universe accelerates, it will become harder for light to travel between distant corners of space. Over time, galaxies will become isolated from their neighbors; stars will wink out; black holes will evaporate quantum mechanically into radiation; even that radiation will be diluted in a sea of space. The universe could end up much as the ekpyrotic model suggests it should appear before the big bang.



MODERN COSMOLOGY is a relatively new invention.

Steinhardt and Turok accordingly have proposed that the dark energy, combined with the milder singularity of the ekpyrotic model, provides a tidy way of setting up a cyclic universe. Our brane and its counterpart would bounce off each other as usual, but instead of going their separate ways, they would smack each other again and again as if connected by a spring. This attractive force between branes would in fact be a special case of the kind of force that inflationary cosmologies posit to explain the early universe's blowup.

The branes' oscillating motion would work to pump space into our universe like a bellows, explaining the acceleration that we see today. So "when you ask why is the universe the way it is," Turok explains, "well, it's because it has to be that way in order to repeat the next time around." And because each brane is already infinitely large and flat, there would be no first cycle to worry about.

The model is intriguing in drawing the ultimate link between early inflation and the current acceleration of the universe, Albrecht remarks, but "the case would be a lot more compelling if they were able to really show that a cyclic universe is possible." Guth is also unmoved. He explains that although he awaits the day when cosmology merges with string theory, he expects inflation to be that cosmology. In general, not all physicists are convinced that colliding branes can generate the small fluctuations in matter and energy density that inflation neatly resolves. Such minute variations in these quantities are required to explain the way in which stars and galaxies clump together and the detailed properties of the cosmic microwave background radiation.

In the ekpyrotic model, the necessary fluctuations are supposed to arise as the branes ripple quantum mechanically, so that different areas would strike one another and take off expanding first. The ekpyrotic camp is convinced these ripples can generate the exact variations we see today. "I think it's surprising how well this model works in terms of reproducing everything we see and yet being so different," Steinhardt remarks. "That's quite shocking and, I think, important, because we thought we were converging toward something that was a unique cosmic story."

But the singularity remains as another hurdle. Despite the recent advance, no one is certain whether features such as brane ripples could actually pass unmolested from big crunch to bang. "What happens at the singularity?" Seiberg ponders. "This is a big open question." So although the singularity in string theory may be, as Turok says, the "mildest possible" one, it is still a wild card.

The dealing isn't done, however, making it too soon to say if colliding branes will hold or fold. Perhaps it will attract new players with even more imaginative ideas. "I happen to think the cyclic model is a real intriguing one," Steinhardt says. "It has a lot of new ingredients that people haven't had a chance to play with. When they play they might find other interesting things that we missed." Or not.

ABOUT THE AUTHOR(S)

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George Musser is a contributing editor for *Scientific American*, author of *The Complete Idiot's Guide to String Theory* (Alpha, 2008) and of *Spooky Action at a Distance* (Farrar, Straus and Giroux, 2015). This article won the 2011 Science Communication Award from the American Institute of Physics.

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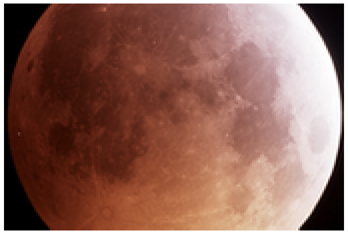

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