When Worlds Collide

Are we in danger of a fatal crash with another universe? Jaume Garriga, Alan Guth, and Alex Vilenkin calculate the odds.

by **KATE BECKER**

Collaboration: Jaume Garriga, Alan Guth & Alex Vilenkin August 1, 2008

It started with the end of the world.

An ABC News reporter researching a story on "global threats to humanity" emailed cosmologist Alan Guth at MIT with an unusual interview request. She had heard of a theory in which our universe is just one of many "bubble universes." What would happen, she wondered, if two of these alleged bubble universes were to collide? Would they both be destroyed? Would it be the end of the world? And could Guth chat about it in time for her to make her deadline?

That was in 2006. The interview, as it happens, never aired. But her question inspired Guth and his colleague Alexander Vilenkin, director of the Institute of Cosmology at Tufts University, Massachusetts, to take a serious look at the physics of bubble universe collisions.

MANY WORLDS, MANY MINDS
Alex Vilenkin (left) and Alan Guth (right)
(Credit: *Inna Vilenkin*)

With help from physicist Jaume Garriga, of the University of Barcelona, Spain they have begun to calculate the chances of such a collision—and the results have surprised them all.

Cosmic Cacophony

The notion that our universe might really be part of a "multiverse" containing many bubble universes springs from the theory of inflation, first proposed by Guth in the 1980s. Inflation describes an early burst of cosmic expansion that stretched space in the moments after the Big Bang, and has now been embraced as a familiar milestone in our universe's history.

For decades, physicists have theorized that this process could take place in different regions, at different times. Multiple bubble universes could exist, possibly endowed with different physical constants. Each would be born from its own Big Bang—just one of many in a cosmological cacophony.

Although inflation ends locally within each bubble, it continues in the ever-expanding domain outside the bubbles. So, as these new bubbles snap to life, they are hurled apart. They are sufficiently distant from each other that—short of a collision—they have never been able to communicate. And because the space between them is stretching at breakneck speed, they never will.

> Alan is very systematic.
> I like shortcuts.
> \- *Alex Vilenkin*

Today, researchers like Vilenkin, Garriga and Guth are continuing to interpret some of inflation's wilder predictions, such as this eternally reproducing multiverse. Sparked by the reporter's question, these three researchers came together in the summer of 2006 to discuss what happens to a bubble universe over time.

"As this bubble expands, it hits other bubbles. Eventually, it hits infinitely many," says Vilenkin. If such a collision sends destruction screaming through the walls of both bubbles—as Vilenkin and Guth suspect—it's a wonder that our universe is still around.

To probe this paradox, they sought to calculate how often bubbles should collide. At first glance, one might assume that a collision results in immediate destruction. But, in fact, a bubble-on-bubble collision doesn't instantaneously pop both bubbles. A person living inside a bubble, but far removed from the impact site, might never know that cosmic havoc lurked beyond their vision. The

THE BUBBLE NEBULA EXPANDS WITHIN OUR UNIVERSE
How would an expanding universe appear in the multiverse?
(Credit: *Donald Walter and NASA*)

team realized that they had to consider the likelihood that an observer living inside the bubble would actually register the collision.

Quantum Peach Fuzz

Though Garriga, Guth, and Vilenkin had not worked as a threesome before taking on this question, they had a long history of pairing up. Vilenkin first encountered Garriga "ages ago," he says (that is, in the 1980s) while visiting Garriga's thesis advisor in Spain.

> To the surprise of both of us, he did it!
> - *Alan Guth on Jaume Garriga*

The following year, armed with a Fulbright fellowship, Garriga came to Tufts to work directly with Vilenkin. Together, they studied the layer of quantum mechanical peach-fuzz that makes these bubbles slightly-less-than-perfect spheres. Since then, they have authored more than a dozen papers together, with Garriga spending many summers in Boston and Vilenkin making frequent trips to Barcelona.

Vilenkin and Guth, on the other hand, are both based in Massachusetts and need only cross city lines to meet face to face. They have taken advantage of their physical proximity to team up against the toughest riddles is cosmology, and today they organize a seminar series shared by Tufts, MIT, and the Harvard Smithsonian Center for Astrophysics.

Their styles complement each other: "Alan is very systematic," says Vilenkin, but "I like shortcuts." So when they began digging into the problem of bubble collision, Vilenkin jumped right in and tried to get at the solution as fast as he could. To simplify the analysis, he started out with a classic simplification: He imagined what would happen to an observer situated smack in the center of the bubble.

Nothing Special?

That simplifying move may seem presumptuous. After all, intuition might suggest that exactly where an observer is located within the bubble would have a big influence on how likely they are to be aware of a collision. Gut-logic suggests that observers living on the edge of the bubble should be most at risk.

But to cosmologists, the decision to focus on a centrally-situated observer seems reasonable because they believe that the universe is *homogeneous* and *isotropic*—that is, it has no special directions and no special places. The universe looks basically the same whether you gaze north, south, east or west, and this remains true no matter where you're standing. Sure, the particulars may vary—the constellations mark the sky with telltale patterns, for instance, and the Milky Way itself splits the sky like a compass needle—but on larger scales, the sky retains the same character regardless of direction.

Within the universe, you cannot pick out a true physical center, so the team believed that adopting one arbitrarily for the sake of mathematical clarity would not cause problems. Indeed, explains Garriga, the process of bubble formation has a "certain symmetry" that supports the assumption that there is no special location in the bubble.

But as the trio proceeded with the analysis, they "discovered contradictions," says Guth.

Something was amiss, and Guth suspected it was the innocent-seeming assumption that put the observer at the center of the bubble. There still remained a niggling doubt over the dissonance between the mathematical model they had created and the gut-feeling that location was important. Vilenkin began to despair: "I thought this was a waste of time!"

Location, location, location

Despite their doubts, they followed the trail and outlined a calculation on the blackboard that would address whether location matters, once and for all. But the calculation was so onerous that neither Guth nor Vilenkin—no slouches when it comes to besting the beastliest equations—wanted to take it on.

JAUME GARRIGA
University of Barcelona

That's where Garriga stepped in. He was spending two weeks visiting Vilenkin at Tufts, and was not as intimidated by the calculation. "It dawned on me that the calculation was quite simple," he recalls, "and unlike Alan or Alex, I had plenty of time in my hands to complete it."

Vilenkin and Guth met Garriga's "quite simple" calculation with amazement: "To the surprise of both of us, he did it!" recalls Guth.

Not only had Garriga done the calculation, he had discovered a result in direct contradiction to the dictate of isotropy: It *did* matter where the observer was. Observers on the edge of the bubble were more likely to be smacked by a collision than were observers living in the bubble's protected center.

> Working with friends is always fun. It helps to have multiple minds engaging.
>
> - *Alan Guth*

It may stun physicists, but it was "just like what a first grader would have expected," says Vilenkin. It would have been unsurprising "except for the mathematical fact" of isotropy, he adds. In fact, the result wasn't just a challenge to isotropy—it was a challenge to the idea that inflation causes a universe to "forget" the precise circumstances of its birth.

Lasting Impression

Guth and Vilenkin explain the result this way. Einstein, in his theory of special relativity, pointed out that two events that occur simultaneously when viewed by one person will not appear simultaneous to another person speeding past the first.

In the case of bubble collisions, we can imagine that one particular group of observers perceives inflation as starting everywhere in the universe at once. "Once inflation begins, bubbles start popping out, and since inflation started everywhere at once, the expanding bubbles will be hitting the observer at the same rate from all directions," explains Vilenkin.

But for an observer who is speeding by on "some kind of a super-spacecraft," inflation no longer starts simultaneously everywhere, says Guth. This observer will always see more bubbles cropping up in the direction she's headed than in the direction she's leaving behind.

All of which means that there is a special set of conditions—marked out by a particular way in which the observer is moving—that is inextricably tied to the onset of inflation. "Of all possible velocities of an observer, there is only one that gives an isotropic distribution of bubbles, and it is the velocity that corresponds to a simultaneous start of inflation," says Vilenkin.

Shocking discovery

Cosmologists have always believed that any indication or memory of these uneven initial universe conditions would have long been diluted away by inflation. "The expectation was that this memory will rapidly fade as inflation progresses, and our 'shocking' discovery was that it persists," says Vilenkin.

"At first I was totally surprised, then a day or two later I believed the conclusion, and by now I wonder how anyone could have thought otherwise," says physicist Leonard Susskind of Stanford University, California. But the analysis is more than simply elegant or surprising. "It suggests that it may be possible, at least in principle, to look back and detect fossil evidence of the anisotropy or inhomogeneity," Susskind adds.

"The way that Garriga, Guth and Vilenkin worked it out logically and in detail brings the issue into clear view," agrees Anthony Aguirre, a theoretical cosmologist at the University of California, Santa Cruz. "It lays a foundation for further work exploring the fascinating set of questions that arise from this new perspective on the inflationary multiverse."

The trio believes that this insight might never have come about had they been working solo. "If it was just me, I would have written a paper saying the symmetry was there" and missed the most startling conclusion of the paper, says Vilenkin.

While Vilenkin is grateful for Guth and Garriga's technical discipline, Guth appreciates that Vilenkin follows his instincts: "Alex puts his fingers on the important problems," he explains.

Vilenkin also balances out some of Guth's eccentricities. As Arvind Borde, of Long Island University, New York, who has worked with both, attests: "Both of them have the ability to cut to the essentials of a question." As far as *physical* organization goes, though, Borde thinks Vilenkin takes the prize. "Alan, after all, famously won the Boston Globe's messiest office competition," Borde says.

"Working with friends is lots of fun," adds Guth. "It helps to have multiple minds engaging" these concepts.

About to pop?

So, back to the reporter's question: If bubble collisions are happening all the time, and if they are indeed destructive, why are we still here?

Two years on, Garriga, Guth, and Vilenkin still don't have a precise answer to the question of whether a bubble collision is a likely instrument of the apocalypse. But they present cause for optimism. Parts of the universe that haven't been struck by a bubble yet are probably very distant from collision sites, and therefore are unlikely to meet another bubble in the future. Over time, collisions may have carved wedges out of our bubble, but Earth and its neighborhood are most likely in a cosmic safe zone.

If we've survived until now, their analysis goes, the future looks bright. So far, so good…

IS OUR BUBBLE ABOUT TO BURST?
(Credit: *Ken Crawford*)