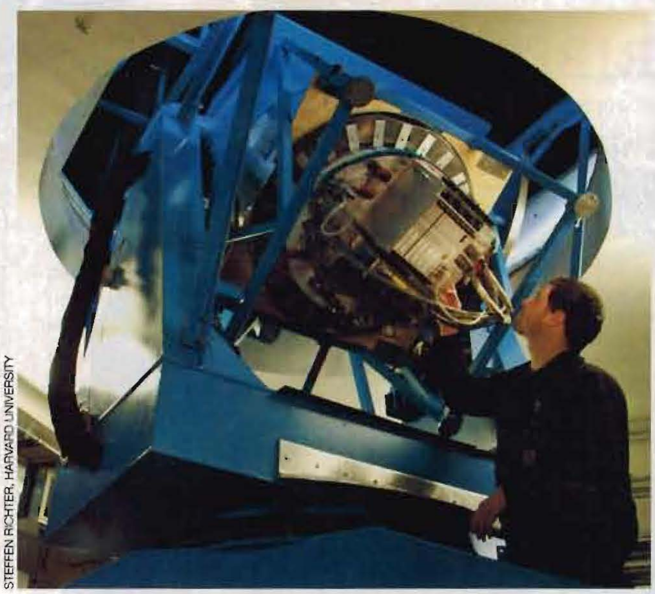
The Big Burp

Evidence of how the universe began in warp drive

Last March, on lucky St. Patrick's Day, a collaborative team of astronomers announced that they had found definitive evidence that our universe began, not with a bang, but with a sort of cosmic *burp*—a brief moment of superaccelerated expansion that transformed a subatomic smudge of energy into a cosmos capable of generating galaxies, stars, and planets. More than thirty years ago the MIT physicist Alan H. Guth had introduced the astounding idea, which has been avidly investigated and challenged, and the latest announcement may have verified it.

Guth trained in particle physics, with no plans for cosmology until the late 1970s. Then, in 1978, he and a fellow postdoc at Cornell University, Henry Tye, were analyzing theories on the unification of the forces of nature. Guth and Tye wondered whether unification in the very early universe might have given rise to magnetic monopoles: hypothetical particles that have only one magnetic pole, either north or south. Continuing to work together after Guth moved to another postdoc position at Stanford University, the two concluded that, indeed, so many monopoles would have been created in the standard conception of the Big Bang that, as Guth said, "we began to wonder why the universe was here at all. [The monopoles'] tremendous weight would have closed the universe back up eons ago." To explain why that didn't happen, they surmised that the early universe "supercooled" as it expanded, keeping the forces unified a bit longer as temperatures plunged, just as water can sometimes supercool and remain liquid below its freezing point under certain conditions. Supercooling would have curbed monopole production.



STEFFEN RICHTER, HARVARD UNIVERSITY

At the South Pole, the BICEP2 telescope, with a 10-inch aperture, collected data from 2010 to 2012 about the birth of our universe.

Things really got interesting when Guth decided one night to quickly check how such supercooling might have affected the expansion of the newly born universe. On December 6, 1979, around eleven o'clock, the young physicist sat down in his makeshift home office and began to work on a series of calculations that within a couple of hours covered four pages. The title at the top of the first page, recorded in small, precise black letters, proclaimed his ambitious intention: he was tackling nothing less than the EVOLUTION OF THE UNIVERSE.

CALTECH

Three receivers at the South Pole help astronomers measure the polarization of cosmic microwaves.

Guth was dealing with the arcane tools of his trade—concepts called "Higgs fields" and "false vacuum states." But, as Guth put down his pen around 1:00 A.M., the bottom line was undeniable. If his equations were valid, the universe did not just expand at the moment of its birth, it tore outward like a fanciful science-fiction spaceship in warp drive. Perhaps inspired by the double-digit rises in the cost of living at the time, Guth came up with an appropriate name for this brief period of hyperacceleration: he called it inflation.

Inflation began around 10^{-35} second into our birth, when the universe was less than a trillionth the size of a proton. Guth saw that the proposed supercooling endowed the universe with a tremendous potential energy, not unlike a rock precariously perched on the edge of a precipice. In this state, gravity, normally a force that draws things together, did a turnabout and became repulsive, causing space-time to balloon outward at a superaccelerated rate for an infinitesimal fraction of a second. But that was enough of a window for our subatomic speck of a cosmos to double in size 60 to 100 times over. Once inflation ended (when the universe was about the size of a marble or larger), its latent energy was converted into *all* the particles and radiation that surround us today. It was inflation's demise that actually put the *bang* into the

Big Bang, providing our cosmos with all its necessary building materials. As Guth likes to put it, "The universe is the ultimate free lunch." A lot came out of nearly nothing.

Inflation explained a longtime mystery: the uniformity of the universe from end to end. Caught in an unusual state of expansion, the growing cosmic seed was able to maintain a uniform density as space-time hyperaccelerated outward, so that our universe ended up looking pretty much the same in all directions. Guth was initially elated by this finding, until he discovered a fatal flaw in his scenario: at the end of his rip-roaring burst, he ended up with a chaotic collection of tiny "bubble universes," none looking like ours. But in the following years, other theorists, such as the Russian physicist Andrei D. Linde, now at Stanford, figured out ways to get one of Guth's many bubbles to balloon into a suitable cosmos.

Yet how do you obtain proof of such a fantastic event, one that occurred at the birth of time itself? If astronomers could peer back with their telescopes to the initial fireball, they wouldn't see anything at all. Much as the Sun's hot outer layers prevent us from gazing to its core, the universe at this time was a blurry soup of plasma, impossible for any optical, radio, or x-ray telescope to discern. The universe didn't become truly transparent until it was about 400,000 years old—when electrons settled down with protons and neutrons to form atoms, and the primordial photons were at last able to travel through the universe unimpeded. Stretched out by the universe's expansion, remnant radiation from the Big Bang now exists as a wash of microwaves bathing the entire universe. Detecting that "cosmic microwave background" tells us how the universe was doing several hundreds of thousands of years after the Big Bang, no earlier.

But clever theorists found a way around this. They predicted that quantum fluctuations, tiny jitters in the universe's initial seed, would have blown up to astronomical scales as the universe whizzed outward. And it was those perturbations that helped organize primordial matter into the clusters and galaxies we see today. Valuable support for that idea came when balloons and satellites—sent into space to measure the microwave background with exquisite precision—captured a signal related to temperature with just the pattern of fluctuations predicted by the inflationary models. But competing models for the early universe's behavior, which didn't involve inflation, offered similar predictions.

By the 1990s, a more powerful test for inflation was offered by theorists, who suggested that primordial gravity waves, generated during inflation, would engrave a unique signature upon the cosmic microwave background. A consequence of Einstein's general theory of relativity, gravity waves are actual ripples in the fabric of space-time, jiggles that alternately stretch and squeeze anything in their path. Searches for this gravity-wave signature were initiated by a number of groups, including a team led by John M. Kovac of the Harvard-Smithsonian Center for Astrophysics.


KOVAK LABORATORY, HARVARD UNIVERSITY

Researcher adjusts the Keck array, an instrument that will soon provide more support—or doubt—about gravity waves.

Kovac's group set up a special radio telescope on the icy terrain of the South Pole, notable for its thin, dry air, the best conditions for gathering celestial microwaves (other than in space). Starting in 2010, this detector collected the faint signal for three long years, as the effect being sought was very subtle. And finally, after months of careful data analysis, the astronomers found what they were looking for, announcing it to the world last March: gravity waves, as predicted, had imposed a slight swirling pattern on the remnant Big Bang radiation, which had become "polarized" (the electric fields oscillating back and forth in one preferred orientation). The gravity waves, as they rippled space-time, gave the light a little kick that caused its orientation to curl, a pattern that only inflationary gravity waves could imprint. In fact, the work by Kovac and his colleagues was a two-for-one. They not only made the case for inflation far stronger, but also provided the best evidence to date that gravity waves, first suggested by Einstein in 1916, are more than theoretical. Finally, a deep connection between quantum mechanics and general relativity has been established.

Of course, the race is now on to review this discovery. Some analyses suggest that cosmic dust might be responsible for the signal, so astronomers are awaiting more results from the Keck array, also at the South Pole [*see image above*]. Still, if verified, this is the sort of scientific finding that might prompt its discoverers to think about a Scandinavian vacation, when they pick up their Nobel prizes.

MARCIA BARTUSIAK is a professor of the practice in the MIT Graduate Program in Science Writing and the author of five books on astrophysics and the history of astronomy. Her latest, Biography of the Black Hole, *will be published next year.*