

# Multiverse gets real with glimpse of big bang ripples

17:39 18 March 2014 by [Lisa Grossman](#)  
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Wave hello to the multiverse? Ripples in the very fabric of the cosmos, [unveiled this week](#), are allowing us to peer further back in time than anyone thought possible, showing us what was happening in the first slivers of a second after the big bang.

The discovery of these primordial waves could solidify the idea that our young universe went through a rapid growth spurt called inflation. And that theory is linked to the idea that the universe is constantly giving birth to smaller "pocket" universes within an ever-expanding [multiverse](#).

The waves in question are called gravitational waves, and they appear in Einstein's highly successful theory of [general relativity](#) (see "[A surfer's guide to gravitational waves](#)"). On 17 March, scientists working with the [BICEP2 telescope](#) in Antarctica announced the first indirect detection of primordial gravitational waves. This version of the ripples was predicted to be visible in maps of the [cosmic microwave background](#) (CMB), the earliest light emitted in the universe, roughly 380,000 years after the big bang.

## Repulsive gravity

The BICEP2 team had spent three years analysing CMB data, looking for a distinctive curling pattern called B-mode polarisation. These swirls indicate that the light of the CMB has been twisted, or polarised, into specific curling alignments. In two [papers published online](#) on the BICEP project website, the team said they have high confidence the B-mode pattern is there, and that they can rule out alternative explanations such as dust in our own galaxy, distortions caused by the gravity of other galaxies and errors introduced by the telescope itself. That suggests the swirls could have been left only by the very first gravitational waves being stretched out by inflation.

"If confirmed, this result would constitute the most important breakthrough in cosmology over the past 15 years. It will open a new window into the beginning of our universe and have fundamental implications for extensions of the standard model of physics," says [Avi Loeb](#) at Harvard University. "If it is real, the signal will likely lead to a Nobel prize."

And for some theorists, simply proving that inflation happened at all would be a sign of the multiverse.

"If inflation is there, the multiverse is there," said [Andrei Linde](#) of Stanford University in California, who is not on the BICEP2 team and is one of the originators of inflationary theory. "Each observation that brings better credence to inflation brings us closer to establishing that the multiverse is real." (Watch [video of Linde being surprised with the news](#) that primordial gravitational waves have been detected.)

The simplest models of inflation, which the BICEP2 results seem to support, require a particle called an inflaton to push space-time apart at high speed.

"Inflation depends on a kind of material that turns gravity on its head and causes it to be repulsive," says [Alan Guth](#) at the Massachusetts Institute of Technology, another author of inflationary theory. Theory says the inflaton particle decays over time like a radioactive element, so for inflation to work, these hypothetical particles would need to last longer than the period of inflation itself. Afterwards, inflatons would continue to drive inflation in whatever pockets of the universe they inhabit, repeatedly blowing new universes into existence that then rapidly inflate before settling down. This "eternal inflation" produces infinite pocket universes to create a multiverse.

## Quantum harmony

For now, physicists don't know how they might observe the multiverse and confirm that it exists. "But when the idea of inflation was proposed 30 years ago, it was a figment of theoretical imagination," says [Marc Kamionkowski](#) at Johns Hopkins University in Baltimore, Maryland. "What I'm hoping is that with these results, other theorists out there will start to think deeply about the multiverse, so that 20 years from now we can have a press conference saying we've found evidence of it."

In the meantime, studying the properties of the swirls in the CMB might reveal details of what the cosmos was like just after its birth. The power and frequency of the waves seen by BICEP2 show that they were rippling through a particle soup with an energy of about  $10^{16}$  gigaelectronvolts, or 10 trillion times the peak energy expected at the Large Hadron Collider. At such high energies, physicists expect that three of the four fundamental forces in physics – the strong, weak and electromagnetic forces – would be merged into one.

The detection is also the first whiff of [quantum gravity](#), one of the thorniest puzzles in modern physics. Right now, theories of quantum mechanics can explain the behaviour of elementary particles and those three fundamental forces, but the equations fall apart when the fourth force, gravity, is added to the mix. Seeing gravitational waves in the CMB means that gravity is probably linked to a particle called the graviton, which in turn is governed by quantum mechanics. Finding these primordial waves won't tell us how quantum mechanics and gravity are unified, says Kamionkowski. "But it does tell us that gravity obeys quantum laws."

"For the first time, we're directly testing an aspect of quantum gravity," says [Frank Wilczek](#) at MIT. "We're seeing gravitons imprinted on the sky."

## Waiting for Planck

Given the huge potential of these results, scientists will be eagerly anticipating polarisation maps from projects such as the POLARBEAR experiment in Chile or the South Pole Telescope. The next full-sky CMB maps from the Planck space telescope are also expected to include polarisation data. Seeing a similar signal from one or more of these experiments would shore up the BICEP2 findings and make a firm case for inflation and boost hints of the multiverse and quantum gravity.

One possible wrinkle is that previous temperature maps of the CMB suggested that the signal from primordial gravitational waves should be much weaker than what BICEP2 is seeing. Those results [set theorists bickering about whether inflation really happened](#) and whether it could create a multiverse. Several physicists suggested that we scrap the idea entirely for a new model of cosmic birth.

Taken alone, the BICEP2 results give a strong-enough signal to clinch inflation and put the multiverse back in the game. But the tension with previous maps is worrying, says [Paul Steinhardt](#) at Princeton University, who helped to develop the original theory of inflation but has since grown sceptical of it.

"If you look at the best-fit models with the new data added, they're bizarre," Steinhardt says. "If it remains like that, it requires adding extra fields, extra parameters, and you get really rather ugly-looking models."

Forthcoming data from Planck should help resolve the issue, and we may not have long to wait. [Olivier Doré](#) at the California Institute of Technology is a member of the Planck collaboration. He says that the BICEP2 results are strong and that his group should soon be adding their data to the inflation debate: "Planck in particular will have something to say about it as soon as we publish our polarisation result in October 2014."

## A surfer's guide to gravitational waves

HEY Einstein, surf's up! Researchers from the BICEP2 telescope in Antarctica [have announced the detection of primordial gravitational waves](#), ripples in space-time predicted by the iconic physicist.

The discovery should help us piece together the exact sequence of events in our universe's birth, as well as a collection of other cosmic puzzles (see main story). But what exactly is a ripple in space-time?

## Cosmic crashes

Albert Einstein compared the universe's shape to a single fabric, hewn from space and time. According to his theory of [general relativity](#), the force of gravity is the result of curvature in space-time: [gravitational waves are ripples in it](#). The ripples are produced by accelerating objects, such as two massive stars spinning around each other.

[Colliding black holes](#) and stars create modern-day gravitational waves. Cosmologists also believe the big bang itself produced primordial waves that still reverberate through space-time. It is these ripples, [dating back to a fraction of a second after the birth of the universe](#), that the BICEP2 researchers have detected. But they are not the first people to show indirect signals of gravitational waves.

In 1974, astronomers Russell Hulse and Joseph Taylor detected a binary pulsar, a pair of dead stars emitting pulses of radio waves. Hulse and Taylor realised that the two pulsars were losing energy and slowly spiralling towards each other in a way that is consistent with Einstein's equations of general relativity: the missing energy is thought to be emitted as gravitational waves. The finding [earned the pair the Nobel prize for physics in 1993](#).

But with only indirect signs of modern and primordial waves, physicists still hope to surf a passing gravitational wave, which would amount to the first direct detection. Experiments like [LIGO](#), which is spread over two sites in Washington state and Louisiana in the US, and VIRGO, in Cascina, Italy, look for high-frequency waves caused by modern-day black hole mergers or exploding stars. These should cause slight but measurable disturbances on Earth.

Detectors in space, meanwhile, can find lower frequency waves – next year the European Space Agency plans to launch [LISA Pathfinder](#), a test mission that will lead to a trio of spacecraft in 2034 intended to hunt for gravitational waves emitted by black holes. **Jacob Aron**