

# Alan Guth on new insights into the 'Big Bang'

March 20 2014, by Steve Bradt

---



Alan Guth. PHOTO: RICK FRIEDMAN

Earlier this week, scientists announced that a telescope observing faint echoes of the so-called "Big Bang" had found evidence of the universe's nearly instantaneous expansion from a mere dot into a dense ball containing more than 10<sup>90</sup> particles. This discovery, using the BICEP2 telescope at the South Pole, provides the first strong evidence of "cosmic inflation" at the birth of our universe, when it expanded billions of times

over.

The theory of cosmic inflation was first proposed in 1980 by Alan Guth, now the Victor F. Weisskopf Professor of Physics at MIT. Inflation has become a cornerstone of Big Bang cosmology, but until now it had remained a theory without experimental support.

Guth discussed the significance of the new [BICEP2 results](#) with MIT News.

## **Q: Can you explain the theory of cosmic inflation that you first put forth in 1980?**

A: I usually describe inflation as a theory of the "bang" of the Big Bang: It describes the propulsion mechanism that drove the universe into the period of tremendous expansion that we call the Big Bang. In its original form, the Big Bang theory never was a theory of the bang. It said nothing about what banged, why it banged, or what happened before it banged.

The original Big Bang theory was really a theory of the aftermath of the bang. The universe was already hot and dense, and already expanding at a fantastic rate. The theory described how the universe was cooled by the expansion, and how the expansion was slowed by the attractive force of gravity.

Inflation proposes that the expansion of the universe was driven by a repulsive form of gravity. According to Newton, gravity is a purely attractive force, but this changed with Einstein and the discovery of general relativity. General relativity describes gravity as a distortion of spacetime, and allows for the possibility of repulsive gravity.

Modern particle theories strongly suggest that at very high energies,

there should exist forms of matter that create repulsive gravity. Inflation, in turn, proposes that at least a very small patch of the [early universe](#) was filled with this repulsive-gravity material. The initial patch could have been incredibly small, perhaps as small as  $10^{-24}$  centimeter, about 100 billion times smaller than a single proton. The small patch would then start to exponentially expand under the influence of the repulsive gravity, doubling in size approximately every  $10^{-37}$  second. To successfully describe our visible universe, the region would need to undergo at least 80 doublings, increasing its size to about 1 centimeter. It could have undergone significantly more doublings, but at least this number is needed.

During the period of exponential expansion, any ordinary material would thin out, with the density diminishing to almost nothing. The behavior in this case, however, is very different: The repulsive-gravity material actually maintains a constant density as it expands, no matter how much it expands! While this appears to be a blatant violation of the principle of the conservation of energy, it is actually perfectly consistent.

This loophole hinges on a peculiar feature of gravity: The energy of a [gravitational field](#) is negative. As the patch expands at constant density, more and more energy, in the form of matter, is created. But at the same time, more and more negative energy appears in the form of the gravitational field that is filling the region. The total energy remains constant, as it must, and therefore remains very small.

It is possible that the total energy of the entire universe is exactly zero, with the positive energy of matter completely canceled by the negative energy of gravity. I often say that the universe is the ultimate free lunch, since it actually requires no energy to produce a universe.

At some point the inflation ends because the repulsive-gravity material becomes metastable. The repulsive-gravity material decays into ordinary

particles, producing a very hot soup of particles that form the starting point of the conventional Big Bang. At this point the repulsive gravity turns off, but the region continues to expand in a coasting pattern for billions of years to come. Thus, inflation is a prequel to the era that cosmologists call the Big Bang, although it of course occurred after the origin of the universe, which is often also called the Big Bang.

**Q: What is the new result announced this week, and how does it provide critical support for your theory?**

A: The stretching effect caused by the fantastic expansion of inflation tends to smooth things out—which is great for cosmology, because an ordinary explosion would presumably have left the universe very splotchy and irregular. The early universe, as we can see from the afterglow of the [cosmic microwave background](#) (CMB) radiation, was incredibly uniform, with a mass density that was constant to about one part in 100,000.

The tiny nonuniformities that did exist were then amplified by gravity: In places where the mass density was slightly higher than average, a stronger-than-average gravitational field was created, which pulled in still more matter, creating a yet stronger gravitational field. But to have structure form at all, there needed to be small nonuniformities at the end of inflation.

In inflationary models, these nonuniformities—which later produce stars, galaxies, and all the structure of the universe—are attributed to quantum theory. Quantum field theory implies that, on very short distance scales, everything is in a state of constant agitation. If we observed empty space with a hypothetical, and powerful, magnifying glass, we would see the electric and magnetic fields undergoing wild oscillations, with even electrons and positrons popping out of the

vacuum and then rapidly disappearing. The effect of inflation, with its fantastic expansion, is to stretch these quantum fluctuations to macroscopic proportions.

The temperature nonuniformities in the cosmic microwave background were first measured in 1992 by the COBE satellite, and have since been measured with greater and greater precision by a long and spectacular series of ground-based, balloon-based, and satellite experiments. They have agreed very well with the predictions of inflation. These results, however, have not generally been seen as proof of inflation, in part because it is not clear that inflation is the only possible way that these fluctuations could have been produced.

The stretching effect of inflation, however, also acts on the geometry of space itself, which according to [general relativity](#) is flexible. Space can be compressed, stretched, or even twisted. The geometry of space also fluctuates on small scales, due to the physics of quantum theory, and inflation also stretches these fluctuations, producing [gravity waves](#) in the early universe.

The new result, by John Kovac and the BICEP2 collaboration, is a measurement of these gravity waves, at a very high level of confidence. They do not see the gravity waves directly, but instead they have constructed a very detailed map of the polarization of the CMB in a patch of the sky. They have observed a swirling pattern in the polarization (called "B modes") that can be created only by gravity waves in the early universe, or by the gravitational lensing effect of matter in the late universe.

But the primordial gravity waves can be separated, because they tend to be on larger angular scales, so the BICEP2 team has decisively isolated their contribution. This is the first time that even a hint of these primordial gravity waves has been detected, and it is also the first time

that any quantum properties of gravity have been directly observed.

**Q: How would you describe the significance of these new findings, and your reaction to them?**

A: The significance of these new findings is enormous. First of all, they help tremendously in confirming the picture of inflation. As far as we know, there is nothing other than inflation that can produce these gravity waves. Second, it tells us a lot about the details of inflation that we did not already know. In particular, it determines the energy density of the universe at the time of inflation, which is something that previously had a wide range of possibilities.

By determining the energy density of the universe at the time of inflation, the new result also tells us a lot about which detailed versions of inflation are still viable, and which are no longer viable. The current result is not by itself conclusive, but it points in the direction of the very simplest inflationary models that can be constructed.

Finally, and perhaps most importantly, the new result is not the final story, but is more like the opening of a new window. Now that these B modes have been found, the BICEP2 collaboration and many other groups will continue to study them. They provide a new tool to study the behavior of the early universe, including the process of [inflation](#).

When I (and others) started working on the effect of quantum fluctuations in the early 1980s, I never thought that anybody would ever be able to measure these effects. To me it was really just a game, to see if my colleagues and I could agree on what the fluctuations would theoretically look like. So I am just astounded by the progress that astronomers have made in measuring these minute effects, and particularly by the new result of the BICEP2 team. Like all experimental

results, we should wait for it to be confirmed by other groups before taking it as truth, but the group seems to have been very careful, and the result is very clean, so I think it is very likely that it will hold up.

*This story is republished courtesy of MIT News ([web.mit.edu/newsoffice/](http://web.mit.edu/newsoffice/)), a popular site that covers news about MIT research, innovation and teaching.*

Provided by Massachusetts Institute of Technology

Citation: Alan Guth on new insights into the 'Big Bang' (2014, March 20) retrieved 20 March 2024 from <https://phys.org/news/2014-03-alan-guth-insights-big.html>

<p>This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.</p>
--