

R. PAPER



## Big Bang blunder bursts the multiverse bubble

Premature hype over gravitational waves highlights gaping holes in models for the origins and evolution of the Universe, argues Paul Steinhardt.

When a team of cosmologists announced at a press conference in March that they had detected gravitational waves generated in the first instants after the Big Bang, the origins of the Universe were once again major news. The reported discovery created a worldwide sensation in the scientific community, the media and the public at large (see *Nature* 507, 281–283; 2014).

According to the team at the BICEP2 South Pole telescope, the detection is at the 5–7 sigma level, so there is less than one chance in two million of it being a random occurrence. The results were hailed as proof of the Big Bang inflationary theory and its progeny, the multiverse. Nobel prizes were predicted and scores of theoretical models spawned. The announcement also influenced decisions about academic appointments and the rejections of papers and grants. It even had a role in governmental planning of large-scale projects.

The BICEP2 team identified a twisty (B-mode) pattern in its maps of polarization of the cosmic microwave background, concluding that this was a detection of primordial gravitational waves. Now, serious flaws in the analysis have been revealed that transform the sure detection into no detection. The search for gravitational waves must begin anew. The problem is that other effects, including light scattering from dust and the synchrotron radiation generated by electrons moving around galactic magnetic fields within our own Galaxy, can also produce these twists.

The BICEP2 instrument detects radiation at only one frequency, so cannot distinguish the cosmic contribution from other sources. To do so, the BICEP2 team used measurements of galactic dust collected by the Wilkinson Microwave Anisotropy Probe and Planck satellites, each of which operates over a range of other frequencies. When the BICEP2 team did its analysis, the Planck dust map had not yet been published, so the team extracted data from a preliminary map that had been presented several months earlier. Now a careful reanalysis by scientists at Princeton University and the Institute for Advanced Study, also in Princeton, has concluded that the BICEP2 B-mode pattern could be the result mostly or entirely of foreground effects without any contribution from gravitational waves. Other dust models considered by the BICEP2 team do not change this negative conclusion, the Princeton team showed (R. Flauger, J. C. Hill and D. N. Spergel, preprint at <http://arxiv.org/abs/1405.7351>; 2014).

The sudden reversal should make the scientific community contemplate the implications for the future of cosmology experimentation and theory. The search for gravitational waves is not stymied. At least eight experiments, including BICEP3, the Keck Array and Planck, are already aiming at the same goal.

This time, the teams can be assured that the

world will be paying close attention. This time, acceptance will require measurements over a range of frequencies to discriminate from foreground effects, as well as tests to rule out other sources of confusion. And this time, the announcements should be made after submission to journals and vetting by expert referees. If there must be a press conference, hopefully the scientific community and the media will demand that it is accompanied by a complete set of documents, including details of the systematic analysis and sufficient data to enable objective verification.

The BICEP2 incident has also revealed a truth about inflationary theory. The common view is that it is a highly predictive theory. If that was the case and the detection of gravitational waves was the ‘smoking gun’ proof of inflation, one would think that non-detection means that the theory fails. Such is the nature of normal science.

Yet some proponents of inflation who celebrated the BICEP2 announcement already insist that the theory is equally valid whether or not gravitational waves are detected. How is this possible?

The answer given by proponents is alarming: the inflationary paradigm is so flexible that it is immune to experimental and observational tests. First, inflation is driven by a hypothetical scalar field, the inflaton, which has properties that can be adjusted to produce effectively any outcome. Second, inflation does not end with a universe with uniform properties, but almost inevitably leads to a multiverse with an infinite number of bubbles, in which the cosmic and physical properties vary from bubble to bubble. The part of the multiverse that we observe corresponds to a piece

of just one such bubble. Scanning over all possible bubbles in the multiverse, everything that can physically happen does happen an infinite number of times. No experiment can rule out a theory that allows for all possible outcomes. Hence, the paradigm of inflation is unfalsifiable.

This may seem confusing given the hundreds of theoretical papers on the predictions of this or that inflationary model. What these papers typically fail to acknowledge is that they ignore the multiverse and that, even with this unjustified choice, there exists a spectrum of other models which produce all manner of diverse cosmological outcomes. Taking this into account, it is clear that the inflationary paradigm is fundamentally untestable, and hence scientifically meaningless.

Cosmology is an extraordinary science at an extraordinary time. Advances, including the search for gravitational waves, will continue to be made and it will be exciting to see what is discovered in the coming years. With these future results in hand, the challenge for theorists will be to identify a truly explanatory and predictive scientific paradigm describing the origin, evolution and future of the Universe. ■

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