**Special Report**

# BICEP2 Results: "[F]irst direct evidence of cosmic inflation"

Philip E. Gibbs*

## Abstract

At a presentation from the Harvard-Smithsonian, the BICEP2 team has announced that they have the "first direct evidence of cosmic inflation". As rumoured they have detected what they believe to be primordial gravitational waves with a ratio or tensor to scalar modes of r=0.2 (+0.07 -0.05) which is 5 sigma over the null hypothesis.

**Key Words:** BICEP2, Keck, B-modes, cosmic inflation, Big Bang, gravitational waves.

The Cosmic Microwave Background has been mapped out in exquisite detail by a series of space and Earth-based observatories including the European Planck mission which provided the best resolution all-sky survey of the CMB. So far Planck has only shown us the fluctuations of the scalar modes but it also looked at the polarisation of the background. Although it stopped working back in 2012 we are still waiting for those maps. Meanwhile some smaller scale results for the polarisation have already come in from land based observatories.

Microwave polarisation can be broken down into two modes using a Helmholtz decomposition which splits a vector field into a sum of two parts: The E-mode whose vector curl is zero and the B-mode whose divergence is zero. The E-mode in the CMB was first observed in 2002 by the DASI interferometer, but it is not particularly interesting. E-mode polarisation is generated by scattering from atoms before the radiation decoupled from matter but long after the period of inflation. Last summer the South Pole Telescope (SPT) found B-modes in the CMB for the first time, but these were known to be due to gravitational lensing of the radiation around massive galactic clusters. These can twist the E-mode polarisation to form B-modes so they are only slightly more interesting than the E-modes themselves. Really these lensing B-modes are not much better than a background that needs to be subtracted to see the more interesting B-modes that may be the signature of primordial gravitational waves.

The B-modes will have an anisotropy spectrum just as the scalar modes do and Planck may eventually provide us with a plot of this spectrum but as an initial result we are interested in the peak ratio of the tensor modes to the scalar modes which is given by a parameter known simply as $r$.

* Correspondence: Philip E. Gibbs, Ph.D., Independent Researcher, UK. E-Mail: philegibbs@gmail.com

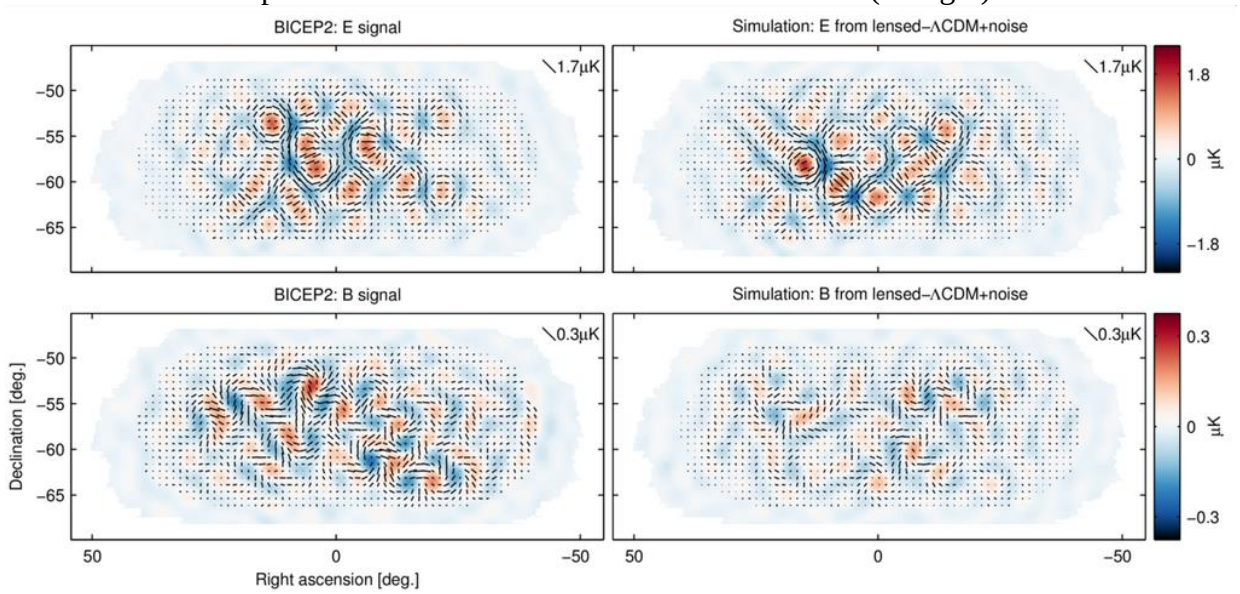
Note: This Special Report is based on http://blog.vixra.org/2014/03/15/primordial-gravitational-waves/ and http://blog.vixra.org/2014/03/17/first-direct-evidence-of-cosmic-inflation/

At a presentation from the Harvard-Smithsonian, the BICEP2 team has announced that they have the "first direct evidence of cosmic inflation". As rumoured they have detected what they believe to be primordial gravitational waves with a ratio or tensor to scalar modes of r=0.2 (+0.07 -0.05) which is 5 sigma over the null hypothesis. This is a game-changing result for inflationary cosmology and possibly for quantum gravity research because the result indicates that the scale of the inflation is only about a factor of 100 below the Planck scale. These results and the future follow ups that will no doubt be carried out could be the experimental test-bed for the leading edge of theoretical physics including string-theory.

Full paper is at http://bicepkeck.org/b2_respap_arxiv_v1.pdf and its Abstract reads:

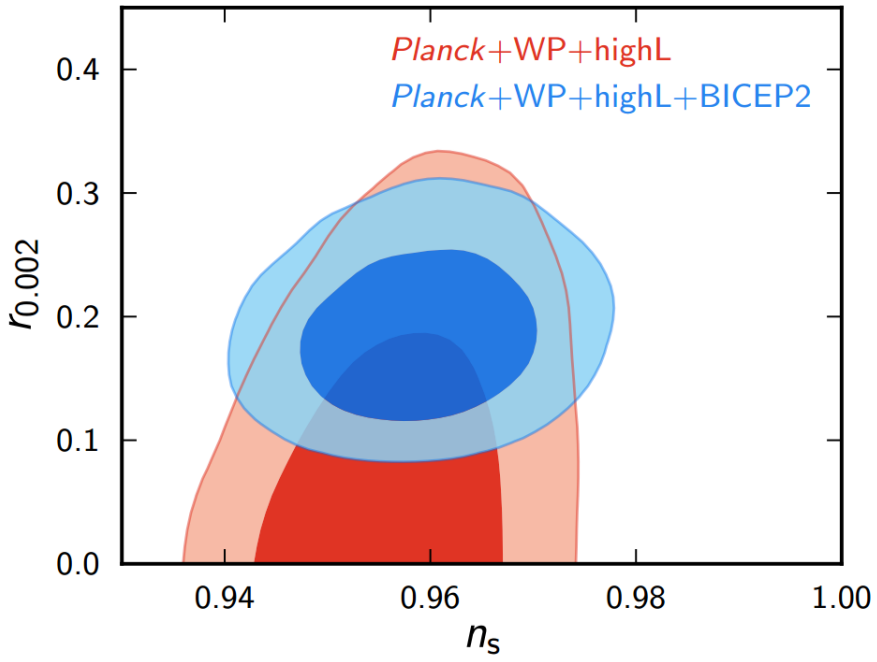
We report results from the BICEP2 experiment, a Cosmic Microwave Background (CMB) polarimeter specifically designed to search for the signal of inflationary gravitational waves in the $B$-mode power spectrum around $\ell \sim 80$. The telescope comprised a 26 cm aperture all-cold refracting optical system equipped with a focal plane of 512 antenna coupled transition edge sensor (TES) 150 GHz bolometers each with temperature sensitivity of $\approx 300\ \mu K_{CMB}\sqrt{s}$. BICEP2 observed from the South Pole for three seasons from 2010 to 2012. A low-foreground region of sky with an effective area of 380 square degrees was observed to a depth of 87 nK-degrees in Stokes $Q$ and $U$. In this paper we describe the observations, data reduction, maps, simulations and results. We find an excess of $B$-mode power over the base lensed-ΛCDM expectation in the range $30 < \ell < 150$, inconsistent with the null hypothesis at a significance of $> 5\sigma$. Through jackknife tests and simulations based on detailed calibration measurements we show that systematic contamination is much smaller than the observed excess. We also estimate potential foreground signals and find that available models predict these to be considerably smaller than the observed signal. These foreground models possess no significant cross-correlation with our maps. Additionally, cross-correlating BICEP2 against 100 GHz maps from the BICEP1 experiment, the excess signal is confirmed with $3\sigma$ significance and its spectral index is found to be consistent with that of the CMB, disfavoring synchrotron or dust at $2.3\sigma$ and $2.2\sigma$, respectively. The observed $B$-mode power spectrum is well-fit by a lensed-ΛCDM + tensor theoretical model with tensor/scalar ratio $r = 0.20^{+0.07}_{-0.05}$, with $r = 0$ disfavored at $7.0\sigma$. Subtracting the best available estimate for foreground dust modifies the likelihood slightly so that $r = 0$ is disfavored at $5.9\sigma$.

The images below show the actual signal from a small patch of the sky (on left) compared to a simulation based on predictions from inflation and cold dark matter (on right)




The signal is stronger than many theories predicted so it will have an immediate effect on the direction of theoretical research in quantum gravity and the first moments of the universe

http://www.youtube.com/watch?v=jq-OvV-XHdc.




The above graph is the money plot showing where we now stand in observational inflationary cosmology. Blue is the new result using BICEP2 compared to previous results from Planck and other sources. Note that Planck should release more polarisation measurements soon.
I should have spotted this video https://www.youtube.com/watch?v=ZlfIVEy_YOA sooner, very moving.

The most interesting thing now is going to see how theorists react to these results. They will have implications for inflationary cosmology (obviously), galaxy formation and quantum gravity. To get the ball rolling theorist Liam McAllister has a guest post on Lubos Motl's Blog with the quote "The tensor fluctuations write quantum gravity on the sky" exciting stuff!

## Reference

1. http://blog.vixra.org/2014/03/15/primordial-gravitational-waves/

2. http://blog.vixra.org/2014/03/17/first-direct-evidence-of-cosmic-inflation/