Editorial

How Certain Are the BICEP2 Findings?

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Abstract

In this essay, I will give my view on how much we can believe the BICEP2 results and the conclusions that could be drawn from them. This actually breaks down into a whole sequence of questions. Has BICEP2 really seen cosmological B-modes? Were these B-modes formed by primordial gravitational waves? If so does this confirm inflation? Does it tell us anything more specific about inflation? Does it support the multiverse?

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

Now that the excitement over the BICEP2 results has abated a little it is a good time to look at just how much we can believe the BICEP2 results and the conclusions that could be drawn from them. This actually breaks down into a whole sequence of questions. Has BICEP2 really seen cosmological B-modes? Were these B-modes formed by primordial gravitational waves? If so does this confirm inflation? Does it tell us anything more specific about inflation? Does it support the multiverse?

There have already been some words of caution pushed around. On the blogosphere, this is most notable from Matt Strassler, Peter Coles, Neil Turoc and Ted Bunn. I endorse their point of view and I think it is fair to say that every scientist we have heard from has expressed an appropriate degree of caution. But because of their natural excitement it is easy for onlookers to miss this. There is a danger that soon Planck or another experiment will publish a contradictory result that seems to rule out B-modes at the level BICEP2 has claimed and then the news headlines will be that scientists were wrong again. This would be unfair. It is important to understand that the results are preliminary but there is no need to wait for confirmation before thinking about what the implications will be on the assumption that they are confirmed.

If anyone was not able to see much of the press conference on Monday due to the web overload, a video recording is available. Here is a direct link . There was also a live streamed colloquium from Stanford yesterday evening that was very watchable and informative. I don't know if a recording will be made available. Many questions were raised at these events about the reliability of the experiment and its implications. Even the question about the multiverse has come up several times. More about that will be said later.
So let's look at some of the important questions in a little more detail.

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Note: This Editorial is based on http://blog.vixra.org/2014/03/20/how-certain-are-the-bicep2-findings/

Has BICEP2 really seen cosmological B-modes?

Everybody agrees that the BICEP2 team know their stuff and have been very professional in their approach to evaluating their results. They have performed many consistency checks on their data. In particular, they have played the game of partitioning their data into two according to a variety of criteria and then examining each half independently. This is a standard technique for identifying systematic errors and every test was passed. They have expressed high confidence that their observation really shows B-mode polarisation in the cosmic microwave background, but everyone is subject to the human failings of cognitive bias so this alone is not enough.

Their positive cross-correlations between the BICEP1, BICEP2 and Keck are another good indication that the results are not instrument error but there are common elements of the analysis that could still be wrong. For example, there was much made at the colloquium of a numerical analysis method devised by one of the team members that greatly improved their ability to extract the signal. The B-mode data is less than 20% of the strength of the E-mode signal from which it must be separated so you have to be careful that there is no systematic error (leakage) in this process. The BICEP2 team knows this as well as anyone and has used data simulations to confirm that the method works. I have no reason to doubt that this is a good check but it would be wise to see if other independent teams can replicate the same B-mode pattern independently. There was also some talk about doing a correlation-check with data from the South Pole Telescope. These correlation checks are valid confirmations even though BICEP1 and SPT do not have sufficient sensitivity on their own but they are not anything like as good as another team independently producing a B-mode signal that shows the same bumps.

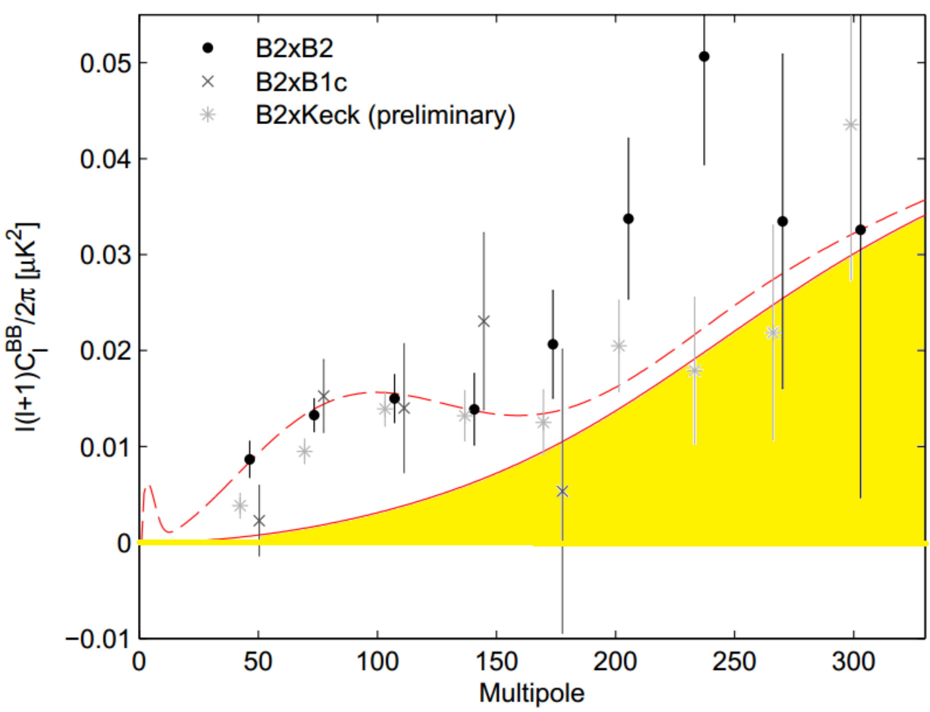
It is worth trying to put a confidence level on how good you think the result is. I don't do bets but I can consider a thought experiment in which Hawking is forcing me to make a bet under threat of running me down at high speed on his wheelchair. That would makes me to imagine what are the breakeven odds I would accept, as a way to evaluate my Bayesian estimate for the probability, that BICEP2 have indeed seen cosmological B-modes. I would put this figure at about 80% for now and I consider that to be a good level of confidence at this early stage. This will change dramatically either up or down when other completely independent results either confirm or refute the BICEP2 results.

There was an interesting exchange during the discussion at the end of Yesterday's colloquium when someone asked "How could Planck have missed this?" It was pointed out that Planck has a very broad mission compared to BICEP2 whose only goal was to find the B-modes. Someone from Planck then stated quite pointedly that they had not yet published anything that would justify the claim that they had missed this signal. Very interesting! There is a further long list of other experiments that have the capability to look for B-modes too, so soon we should know the answer to this particular question with a much better level of confidence.

Were these B-modes formed by primordial gravitational waves?

So, if we now assume that the observations of B-modes are good, we can ask about how certain we can be that these are a signature of primordial gravitational waves. At the Colloquium we heard from Uros Seljak who was the first cosmologist to realize in 1996 that B-mode CMB polarisation could be used as a signal for these gravitational waves. He was followed shortly after by Marc Kamionkowski, Arthur Kosowsky, and Albert Stebbins. See this report from Berkeley for the details of the story. If I were in a position to make nominations for the Nobel prize for the observational side of this discovery, I would want to include Seljak along with people from BICEP2 but past awards indicate that the phenomenologists who take these crucial steps usually fail to be recognised at this level because they fall between the two stones marking the original theoretical insight and the final experimental discovery, too bad.

I noticed that several theorists claimed that the B-modes can only be produced by gravitational waves. I think we need to be cautious about this claim. The well-known additional source of B-modes is gravitational lensing from background galaxy clusters. Fortunately, this effect can be accurately modelled because we can observe the galaxies and we know very well now how much dark matter is clumped around them. The power spectrum plot from BICEP2 compares their signal with the lensing background. Here is the plot with the lensing background filled in yellow to show clearly how the signal stands out above the lensing. Simply put the gravitational wave spectrum is seen a higher angular scales than the lensing so it is clearly separated.



Could something other than lensing or gravitational waves produce B-modes? One thought that came to my mind was the magnetic fields can also twist the polarisation of radiation as first shown by Michael Faraday. None of the theorists have discussed this possibility so I was at first willing to accept that you need tensor modes rather than vector fields to produce the B-modes, but then I found this presentation by Levon Pogosian that seems to say otherwise. Traditionally, magnetic fields have been discounted in cosmological models but in recent years some have found reason to be more open to their importance. I have no idea if this is a viable alternative source for the B-modes but until I hear a plausible direct refutation I am keeping this open in my mind. The good news is that new radio telescopes such as SKA and LOFAR should be able to detect signals from cosmic magnetic fields so I think this is a question that can be settled.

Other sources of the B-modes such as galactic dust and synchrotron radiation were considered by the BICEP2 team but were only discounted at 97% confidence. This is not a high confidence level for such an important result. The significance of an observation is only valid when all possible backgrounds are accounted for so the 5 to 7 sigma claims are questionable here. We have seen many observations in particle physics and cosmology at 2 to 3 sigma fade away as new data arrived. As outsiders who could hear such results from hundreds of experiments that are taking place we should not discount the "look elsewhere effect" that this implies.

The only other possibility I can think of as an alternative explanation for B-modes would be if cosmic structure had formed in dark matter before the moment of last scattering when the CMB decoupled from the visible matter. This is not the accepted view in cosmology but since the surprisingly early formation of galaxies after that time has not been explained I will not discount it. Ironically, there is an improved chance of something like this happening if the primordial gravitational waves are present and that weakens the doubt that this alternative casts. Finally, we should perhaps allow for the more remote possibility that something else we have not thought of can produce these B-modes.

So with Hawking on my heels how would I rate my confidence that B-modes are signatures of gravitational waves. Again, I think I would have to put it at about the 80% level which is pretty good confidence. This figure is harder to improve than the certainty in the BICEP2 experiment itself but future measurements of cosmic magnetic fields would make a significance difference.

Assuming primordial gravitational waves have been observed, did inflation happen?

Primordial gravitational waves have been described as a "smoking gun" for inflation. That would of course be the starter gun that set the universe off rather than a murder weapon, I hope. However, most versions of inflation theory that had risen in popularity before these results had been announced predicted very small values of r. Very few can come close to accounting for r=0.2 or even r=0.1 if we take the lower side of the error range. There are some models that might, such as the axion monodromy inflation and even Linde's chaotic inflation that had been all but abandoned until now. Indeed, you could make the case that it would have been a better signal for inflation if primordial gravitational waves had been ruled out at this amplitude because most inflation models predict that. In a different sense it is a good thing that so many inflation models would be discounted by BICEP2 if it stands because it concentrates inflation theorists in a new direction, but the harsh fact remains that they do not yet have a fully viable theory for inflation. Scaling invariance in the CMB has already been a good result for inflation but there may be other theories that explain it (e.g. gravitational waves from other phase transitions have been cited as an alternative).

The simple truth is that we know so little about the earliest origins of the universe that we cannot honestly place very high confidence on the claim that primordial gravitational waves are a sure fire signature of inflation. Nevertheless, I will once again place an my confidence level at 80% in inflation if the primordial gravitational waves are well confirmed.

What would it take to improve this figure? I would like to see a fully viable theory of the inflation mechanism with an uncontrived prediction (or retrodiction) of the power spectrum of gravitational waves. When this power spectrum is known to better precision (and that should now converge rapidly over the next few years) and it agrees nicely with the model, we can then be very happy with the result.

So has inflation been confirmed as a Nobel worthy theory?

Not yet. The problem is that there are at least these three major levels of uncertainty. For each one I give a good confidence level of 80%, but 80% cubed is only about 50%

When Sean Carroll asked us three years ago if we thought inflation happened, I put my assessment at only 40% likely. This had probably increased to about 60% in the intervening years because of Planck results, but I am still open-minded either way. I should make it clear that I do have a high level of confidence in the big bang theory itself but the inflation part cannot be considered settled until we have both a good theory and a solid observational confirmation. I do appreciate its strength in resolving cosmological problems and its successful prediction of CMB fluctuations but I want to see more.

The BICEP2 result does not yet change my mind very much, but the good news is that there is now hope that further confirmation will make a huge difference. More detailed measurements of the B-modes have the potential to tell us in great detail how the process of inflation started, progressed and ended. Just when we thought our understanding of physics was hitting a brick wall we get this gift of an observation that promises to completely revolutionize our understanding once again.

Does BICEP2 support the multiverse?

This question was asked twice at the press conference (44 minutes and 53 minutes into the video recording) John Novak was quick to interject that as an experimentalist he is firmly opposed to theories that have no observational consequences. The theorists in the room countered that by pointing out that people doubted inflation initially because they did not believe it could make testable predictions (this was all said with a lot of laughter). Linde and Guth were then consulted and they said that it is hard to develop models of inflation that do not lead to the multiverse (such as eternal inflation). There are certainly many other theorists who would have provided a very different view if they had been there.

My personal view does not count for much but I have always discounted eternal inflation because it is a conclusion that is situated at the end of a long combination of speculative and unconfirmed ideas. It also does not fit with my favourite philosophical position but nobody else should care about that and anyone needs to be ready to update their philosophy if experiment requires. On the other hand I do find that the multiverse is a fitting explanation for small levels of fine-tuning and it follows naturally from what quantum gravity seems to be trying to tell us about the landscape of the vaccum (in string theory and alternatives) I just see the multiverse as the range of logically possible solutions of the physics rather than something that is actually realised.

Now if the results from BICEP2 are confirmed and improved leading to a solid theory of inflation and that theory tells us in a convincing way that the multiverse must be out there, then things will be very different. Most of the levels of speculation I was concerned about would then have turned into solidly confirmed science. It is hard even then to see how a directly observable prediction could be made using the multiverse although that is not something we can completely discount and if the theory is complete and convincing enough it may even not be necessary.
I am sure there will be more opinions than physicists with an opinion on this subject, but that for what it is worth is mine.

Reference

1. http://blog.vixra.org/2014/03/20/how-certain-are-the-bicep2-findings/