Commentary: BICEP2’s *B* modes: Big Bang or dust?

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Physics Today **67** (12), 8–10 (2014);
https://doi.org/10.1063/PT.3.2598

Commentary

BICEP2's *B* modes: Big Bang or dust?

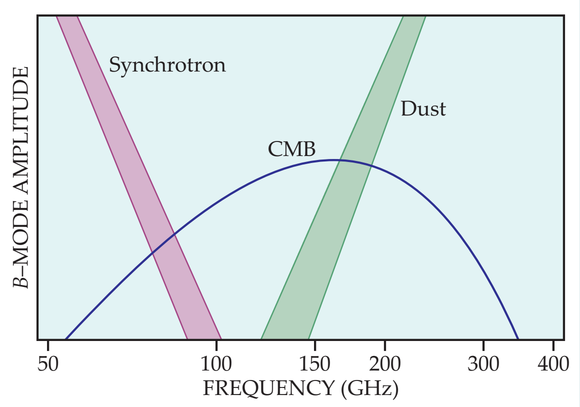
In March 2014 a team of scientists analyzing data from the BICEP2 telescope at the South Pole found *B*-mode polarization—a specific imprint in the cosmic microwave background (CMB) that could have been created by the gravitational waves resulting from cosmic inflation. (See PHYSICS TODAY, May 2014, page 11.) The scientific paper describing the results was published in June.[1] Inflation is a stupendously rapid expansion that the universe is thought to have undergone within the first 10^{-36} seconds after the Big Bang. During the expansion, quantum fluctuations in the gravitational field grew in size, eventually turning into long-wavelength gravitational waves that stretched space in one transverse direction and compressed it in the perpendicular one.

As a consequence of the orthogonal stretchings and compressions of space, the CMB is expected to have become polarized—that is, having a larger amplitude in one direction than in the perpendicular direction. The important point is that the polarization induced by gravitational waves exhibits a distinct twisting pattern, known as a *B* mode, that distinguishes it from the polarization produced by, for example, density fluctuations,[2] known as *E* modes, which exhibit a circular or radial pattern.

The above description explains why the BICEP2 team's announcement, if confirmed, will mark one of the most dramatic discoveries in decades. Not only would it confirm a process that occurred when the universe was about 10^{-36} seconds old, it would also be the first detection of the direct effect of gravitational waves and a clear indication that the gravitational field obeys the laws of quantum mechanics.

Extraordinary claims require extraordinary scrutiny, and a few scientists were quick to point out that dust particles in our own Milky Way galaxy could, in principle, produce a polarization signal similar to the one observed by the BICEP2 team.[3] Although little is known about the precise polarization pattern produced by dust, any generic polarization pattern is expected to have roughly equal contributions of *E* modes and *B* modes. For the dust polarization to be entirely free of *B* modes would require special circumstances.

As shown in the figure, though, the CMB and dust contributions to the *B*-mode maps can be distinguished by their frequency dependences. Whereas the CMB has a blackbody spectrum that peaks near a frequency ν of 160 GHz, the thermal-emission spectrum of dust rises roughly as the power law $\nu^{1.6}$ over the frequencies at which CMB measurements are made. Also, at relatively low frequencies, synchrotron radiation from electrons spiraling in the galactic magnetic field makes a significant contribution to the *B* modes imprinted on the CMB.



Sources of *B*-mode polarization as a function of frequency. The *B*-mode spectrum of the cosmic microwave background (CMB) is a blackbody function with a temperature of 2.73 K, while models of synchrotron and dust emission from our galaxy predict steeply falling and rising spectra, respectively, over the frequencies at which CMB measurements are made. The amplitudes of all three contributions can be determined through measurements at three or more frequencies. Measurements at 22 GHz from the *Wilkinson Microwave Anisotropy Probe* indicate that the synchrotron contribution, while significant at the lowest frequencies, is relatively small at BICEP2's 150 GHz. On the other hand, extrapolation of *Planck* *B*-mode measurements at 353 GHz indicate that the dust contribution at 150 GHz may be appreciable in the region of the sky that BICEP2 surveyed.

In an effort to distinguish CMB from dust, the BICEP2 team correlated its 150-GHz map with a lower signal-to-noise map at 100 GHz. If their 150-GHz signal were due entirely to dust, that correlation would be far weaker than if it were entirely CMB. The amplitude of that correlation favors CMB over dust, but at a level of only 1.6 standard deviations.

The researchers then used a correlation analysis to look for similarities between the spatial distribution of their *B* modes on the sky and those expected from models of the dust distribution in our galaxy. That analysis showed no correlation. The amplitude of their signal was, moreover, larger than that expected from only dust. The models, however, were based solely on measurements of the spatial distribution of dust on the sky, and the polarization orientation and amplitude were largely a matter of guesswork.

In September 2014 the *Planck* satellite team released its results on polarized dust emission at intermediate and high galactic latitudes,[4] and at face value those results are not encouraging for attributing the BICEP2 signal to cosmic inflation. The new *Planck* data suggest that the contribution of dust to the *B*-mode polarization may be larger than that assumed in the dust models used by BICEP2. More precisely, the *Planck* researchers extrapolated the *B*-mode amplitude they measured at 353 GHz on the BICEP2 patch of sky down to the 150-GHz frequency of BICEP2 and found that polarization by Milky Way dust might explain the signal detected by BICEP2.

The *Planck* team was careful to note, though, that because of uncertainties in the extrapolation and statistical errors, its results do not rule out the possibility that the *B*-mode spectrum measured by BICEP2 contains a component produced by inflation. A far better way to distinguish CMB from dust will be to correlate the *Planck* 353-GHz maps with the BICEP2 150-GHz maps. If the BICEP2 signal is due entirely or largely to dust, the spatial distribution of that signal should resemble the spatial distribution of the 353-GHz map. The BICEP2 and *Planck* teams are now working together to perform that correlation analysis, and they are also including new data from the Keck Array in the South Pole at 100 GHz and 150 GHz.

Several other experiments will also expand the observed frequency range and make measurements on different and broader regions of the sky. In particular, the Cosmology Large Angular Scale Surveyor experiment, scheduled to be deployed next year, will observe at 40, 90, 150, and 220 GHz and will separate polarization components in situ.[5] If there are indeed detectable cosmic *B* modes, they should be seen with similar amplitudes by those other experiments, not only on the BICEP2 patch of sky but everywhere else as well. Furthermore, a true inflationary gravitational-wave signal should exhibit additional hallmarks, such as a characteristic angular power spectrum and statistics.

Overall, the *B*-modes story demonstrates how progress in science is truly achieved. Rather than through a direct march to the truth, science advances in a zigzag path that involves many false starts, detours, and blind alleys. Crucially, the scientific method requires that theories should make falsifiable predictions that can be tested through subsequent experiments or observations. Science therefore allows for self-corrections. Still, there may be some lessons to be learned here about the importance of communicating exciting and promising new scientific results to the public in a way that stresses the process, the uncertainties involved in measurements and interpretation of data, and their possible implications.

References

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Letters

Diverse suggestions for improving physics teaching

The photograph in figure 1 of "Psychological insights for improved physics teaching" by Lauren Aguilar, Greg Walton, and Carl Wieman (PHYSICS TODAY, May 2014, page 43) showed a physics lecture with an audience that appeared to be almost all white males. The caption suggested that most readers might not see what a woman or member of a minority group would see in that audience. I can attest to what one female high school student saw in a strikingly similar situation.

About 20 years ago, I was conducting an on-reservation summer program for Native American students, which ended with a class visit to an off-reservation college. The engineering school had offered a tour, which the dean conducted himself. He showed us an engineering lab with about a dozen people working diligently, mentioned the investment in equipment that allowed such research, and asked if there were any questions.

One of the female students in my class raised her hand and asked, "Why aren't there any women in there?" Her question brought the dean up short, but he handled it honestly, confessing that she had seen something important that he had not and that he was embarrassed and chagrined. So the question "Is there anyone like me here?" in the photo's caption certainly does get asked.

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■ **The authors of** "Psychological insights for improved physics teaching" made some good points, but I think an equally important factor affecting classroom success is the image of scientists in popular culture. Scientists are generally shown as either antisocial eccentrics or brilliant adventurers. Who wouldn't like to lead the life of Indiana Jones, an exceptional archaeologist who somehow, in his exciting and adventurous life, took time out to do the dull work of actually studying his subject?

According to the popular stereotype, successful scientists are so bright that everything comes easily to them. The assumed corollary is damning: A student who doesn't understand something immediately will never be successful as a scientist.

Even the brilliant Richard Feynman, though, had to work hard in his field. Unfortunately, he never stressed that fact in his own books. I guess his editor felt that describing in detail all the time he spent on his work would make his books too dull for popular reading.

Although Indiana Jones is a purely fictional character, his image can still have a strong effect on young people. The message that science is easy (for geniuses) and exciting can be found everywhere, including in science-oriented television programs like *NOVA* and *Cosmos*, where only the results of learning are discussed, but never the hard work.

Perhaps it is time to show that real academic work is necessary and that one doesn't have to be a genius to be successful. A reasonable level of intelligence together with a willingness to work hard can lead to a satisfying career even if it doesn't lead to the Nobel Prize or a popular television program.

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■ **The insights** by Lauren Aguilar, Greg Walton, and Carl Wieman on how students perceive their classroom experience and on suggested interventions for improving physics teaching are indeed helpful in elementary and perhaps middle schools. By the time students reach high school and college levels, however, it is too late. Many stu-