一、請以清楚易懂的文字向一般民眾解說以下四個詞彙(每則不超過 250 字)：

(1)全球暖化(global warming)。(10 分)

(2)基因(gene)。(10 分)

(3)希格斯粒子(Higgs particle)。(10 分)

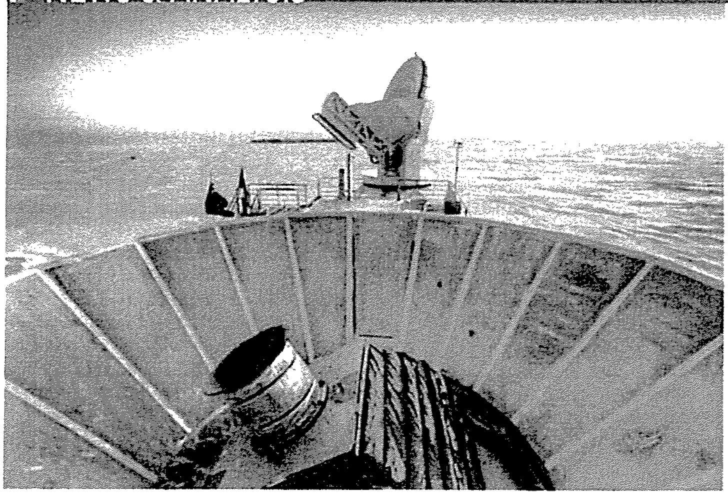
(4)禽流感(avian influenza or bird flu)。(10 分)

二、科學期刊 *Science* Magazine 在 2014 年 3 月、5 月、9 月對於 BICEP 實驗團隊的發現刊登了相關報導(請見文章一、二、三)。請依據 *Science* 這三篇文章的內容，撰寫一篇約 800 字的中文報導，向一般民眾解說這個相當受到矚目的科學事件。(60 分)

見背面

文章一

NEWS & ANALYSIS



**Long, cold stare.** From its South Pole perch, BICEP2 (foreground) peers at the sky.

COSMOLOGY

# First Wrinkles in Spacetime Confirm Cosmic Inflation

Few cosmologists were surprised on Monday, when observers announced that they had spotted traces of gravitational waves—undulations in the fabric of space and time—rippling through the infant universe. Rumors of the discovery had circulated for days. Yet, the observation electrified scientists the world over. That's because, if it holds up, it clinches the idea that in its first sliver of a second, the cosmos expanded like a gargantuan balloon in a faster-than-light growth spurt known as inflation—a wild idea proposed more than 30 years ago. It also shows for the first time that gravity must follow the same rules of quantum mechanics that other forces such as electromagnetism do. Forging a quantum theory of gravity may be the grandest goal in theoretical physics.

Some cosmologists say the discovery is the biggest in their lives. "Never has the boundary of human understanding been pushed back so far," says Max Tegmark of the Massachusetts Institute of Technology (MIT) in Cambridge, who was not involved in the work. Researchers had good evidence of how the first atomic nuclei formed a second after the big bang. But now they have probed the first $10^{-32}$ seconds, says Marc Kamionkowski, a cosmologist at Johns Hopkins University in Baltimore, Maryland. "It's not every day that you wake up and find out what happened one trillionth of a trillionth of a trillionth of a second after the big bang."

The discovery comes from a study of the big bang's afterglow, the cosmic microwave background (CMB). Cosmologists with the Background Imaging of Cosmic Extragalactic Polarization (BICEP), a small but sophisticated telescope at the South Pole, mapped how the arrowlike polarization of those microwaves varies from place to place across the sky. In data taken from January 2010 to December 2012, they found faint pinwheel-like swirls called B modes. "We believe that gravitational waves could be the only way to introduce this B-mode pattern," says John Kovac, a cosmologist at Harvard University and one of the four principal investigators of BICEP. The results were announced in a talk at the Harvard-Smithsonian Center for Astrophysics in Cambridge.

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>
> —MARC KAMIONKOWSKI, JOHNS HOPKINS UNIVERSITY

Many cosmologists also consider B modes the smoking gun for inflation. According to the standard model of cosmology, when the universe sprang into existence it contained one thing: a quantum field, similar to an electric field, made up of particles called inflatons. That field blew up spacetime so that within $10^{-32}$ seconds the cosmos doubled and redoubled its size 60 times. In the process, it pulled itself "flat" like a bed sheet snapping taut and evened out in temperature. Inflation stopped as the inflatons decayed into other particles, ultimately including photons, electrons, and quarks. That inflationary scenario was invented in 1980 by Alan Guth, a cosmologist at MIT.

The inflaton field roiled with tiny quantum fluctuations. Inflation magnified those fluctuations to enormous size, seeding variations in the density of energy and matter that eventually grew into galaxies. The fluctuations also created part-in-100,000 variations in the temperature of the CMB across the sky. By measuring the statistical distribution of hot and cold spots of different sizes, researchers have determined the content of the universe in terms of ordinary matter, mysterious dark matter whose gravity binds the galaxies, and weird space-stretching dark energy (*Science*, 29 March 2013, p. 1513).

That much of the evolution of the universe has been traced, and it all appears to be consistent with the idea of inflation. But with the new results, researchers have gone a big step further and tested a particular prediction of inflation. Thanks to quantum mechanics, not only did the stuff inside the infant universe fluctuate—so did spacetime itself. Or so it must have if spacetime and gravity are quantum mechanical. Inflation stretched that jittering into gravitational waves billions of light-years in wavelength that left their own imprint on the CMB. Whereas the density variations caused a simple sloshing of matter and energy from more dense spots to the less dense ones, gravitational waves stirred up a more complex twisting motion called "tensor modes." Only that type of motion can give rise to B modes, says Uros Seljak, a cosmologist at the University of California, Berkeley.

Spotting those modes wasn't easy.

CREDIT: STEFFEN RICHTER/HARVARD UNIVERSITY





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The B modes are only 1% as strong as the already-faint temperature variations. To see them, the BICEP team deployed BICEP2, a 26-centimeter telescope with 500 exquisitely sensitive microwave detectors called bolometers, each cooled to within a fraction of a degree of absolute zero. Researchers got a little help from nature, as the B-mode signal appears about 20 times stronger than many cosmologists had expected.

BICEP scooped a gaggle of other experiments, including the European Space Agency's Planck spacecraft, which took data from 2009 until last year and is expected to present polarization data soon. Ironically, Kovac says, BICEP owes its success in part to detectors made by Jamie Bock and colleagues at the California Institute of Technology in Pasadena, who also developed detectors for Planck. Suzanne Staggs, a cosmologist at Princeton University who works on the Atacama B-mode Search in Chile, says she was shocked when she heard of BICEP's success. "The more I think about this, the more excited I am because the signal is so big," she says.

In particular, the big signal suggests that cosmologists may soon be able to test the idea of inflation in earnest. If nothing else, many researchers say, it should silence doubters of the faster-than-light stretching. That's because alternative theories do not produce B modes, says Scott Dodelson, a cosmologist at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. "All of the alternatives that have been proposed are dead," he says. "This is a done deal."

Now cosmologists hope to probe the characteristics of the inflaton field—particularly how the field interacted with itself to give itself energy. Cosmologists think of the field like a marble on a hillside, with height denoting the field's energy and horizontal position denoting its amplitude. The field started somewhere up on the hill and rolled down toward zero energy and amplitude. BICEP's result reveals the marble's initial height, Dodelson says, which is equivalent to the energy density of the universe during inflation—3 trillion times any energy achieved with a particle accelerator. Cosmologists' next big goal is to determine the shape of the energy landscape, or "potential."

Many cosmologists say that the signal strength reported by BICEP jibes nicely with a model of that landscape proposed in 1982 by Andrei Linde of Stanford University in California, which is a parabola. "Suddenly this very simple model works very well," says MIT's Tegmark.

A few cosmologists remain inflation holdouts, however. Paul Steinhardt of Princeton University has called inflation "contrived" and says the BICEP results just make it worse. BICEP's B-mode signal implies that the tensor churning in the early universe is twice as strong as the upper limit inferred from Planck's temperature measurements, he says. To make those two observations mesh, the spectrum of shorter and longer quantum fluctuations in the infant universe must have been a lot more complicated than standard theory assumes, he argues: "That's not good for inflation."

Steinhardt acknowledges that the discovery rules out his own noninflationary models—in which big bangs occur over and over again within a much older spacetime. But when the dust settles, he predicts, theorists may still find themselves searching for an alternative to inflation.

Only more observations can settle the issue, scientists say. First off, researchers need to confirm the BICEP result, which may happen fairly quickly if the signal is as large as reported. Beyond that, to trace the inflaton's energy landscape, observers must measure the statistical distribution of the swirling B modes in exactly the same way they measured the statistical distribution of the hot and cold spots. Researchers break the hot and cold spots down into overlapping spots of bigger and smaller sizes on the sky, and the spectrum of different size spots encodes the recipe for the universe.

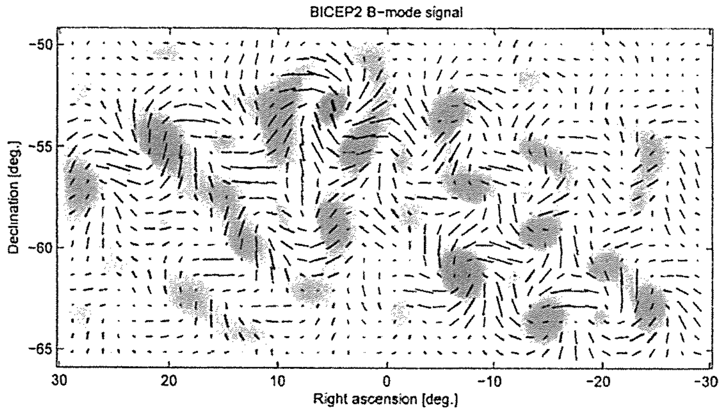
In much the same way, the spectrum of larger and smaller B modes should reveal the shape of the inflaton potential, says Berkeley's Seljak. The BICEP team has measured the modes in a patch of sky measuring 15° by 60° and has observed B modes that make pinwheels about a degree wide. Primordial gravitational waves should also produce B modes stretching about 10° across. Spotting those bigger B modes would most likely require another more sensitive spacecraft, which, like Planck, could map the whole sky. "The community will probably make the case for another satellite mission to measure polarization," Seljak says. "That's where I expect we will go."

Perhaps most tantalizing, such a mission might finally enable physicists to test theories that attempt to meld quantum mechanics and Einstein's general theory of relativity, which says that gravity arises when mass and energy bend spacetime. The BICEP result proves that gravity must be quantum mechanical, says Fermilab's Dodelson, as B modes originate from quantum fluctuations in spacetime itself.

Moreover, Dodelson says, theories of quantum gravity, such as string theory, predict modifications to the shape of the inflaton energy landscape. So if that landscape can be measured precisely, he suggests, physicists might finally put string theory—long mocked as an untestable "theory of anything"—to a concrete test.

Even if that dream doesn't come true, the observation of primordial gravitational waves has shaken up cosmology almost as much as the waves did the fledging universe.

**–ADRIAN CHO AND YUDHIJIT BHATTACHARJEE**




**Twisted.** Pinwheel-like swirls in BICEP's polarization map of the microwave background are the prized B modes.





見背面

文章二



COSMOLOGY

# Blockbuster claim could collapse in a cloud of dust

## Smoking-gun evidence for cosmic inflation may actually be radiation from within our galaxy

*By* **Adrian Cho**

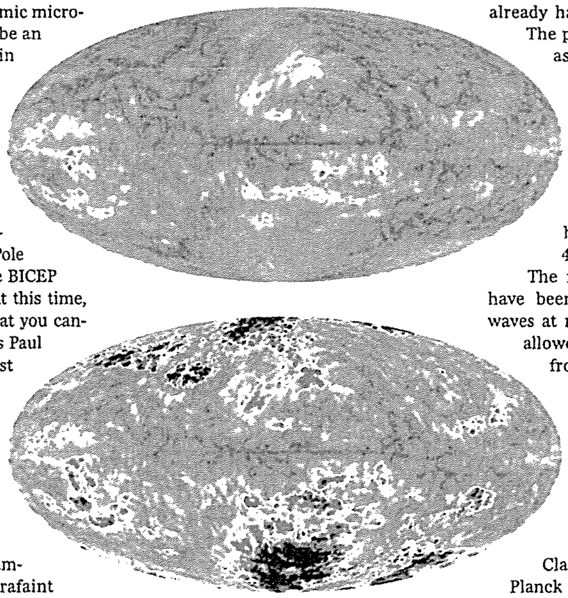
Perhaps it was too good to be true. Two months ago, a team of cosmologists reported that it had spotted the first direct evidence that the newborn universe underwent a mind-boggling exponential growth spurt known as inflation (*Science*, 21 March, p. 1296). But last week a new analysis suggested the signal, a subtle pattern in the afterglow of the big bang, or cosmic microwave background (CMB), could be an artifact produced by dust within our own galaxy.

"We're certainly not retracting our result," says John Kovac, a cosmologist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, and co-leader of the team, which used a specialized telescope at the South Pole known as BICEP2. Others say the BICEP team has already lost its case. "At this time, I think the fair thing to say is that you cannot claim detection—period," says Paul Steinhardt, a theoretical physicist at Princeton University.

From 2010 through 2012, BICEP2 peered at a small patch of the CMB to measure the polarization of the microwaves as it varies from point to point. On 17 March, BICEP researchers announced at a press conference in Cambridge that they had spotted ultrafaint pinwheel-like swirls in the sky. Those swirls, or B modes, are most likely traces of gravitational waves rippling through space and time during the $10^{-32}$ seconds that inflation lasted, the BICEP team says, and they fulfill a key prediction of the theory of inflation. Many cosmologists hailed the detection as a "smoking gun" for that theory.

But dust within our galaxy can also emit microwaves that mimic the signal. Much or all of the BICEP signal could come from that dust, says Raphael Flauger, a theoretical physicist at the Institute for Advanced Study in Princeton, New Jersey, who performed the new analysis. He presented it at Princeton University on 15 May.

BICEP researchers estimated that "galactic foreground" was negligible. They modeled it several ways, as they report in the paper announcing their claim, which has been submitted to a journal that Kovac declined to name. The most sophisticated model relied on a map of the foreground generated by the European Space Agency's spacecraft Planck, which mapped the CMB across the entire sky from 2009 until last year. Because Planck has not yet released that data, researchers scanned the map from a slide presented at a talk.



A reconstruction of the contaminated foreground map BICEP used (*top*) and the corrected map.

The BICEP team apparently assumed the map shows radiation only from dust inside our own galaxy. In reality, it may also contain an unpolarized haze from other galaxies, which would make the microwaves from within the galaxy look less polarized than they are. So using the map could have led the researchers to underestimate the galactic foreground and overestimate the CMB signal.

To test that idea, Flauger used other Planck data—also scraped from a talk—to correct the map BICEP used (see figure). The foreground appears stronger in the corrected map and could account for the entire BICEP signal, he reported.

BICEP's Kovac says his team always made it clear that they couldn't be sure how much of their signal really comes from the CMB. And he won't put a number on it. "The six models of polarized dust that we use are all quite uncertain," he says, "so the statements that we make about the interpretation are necessarily more qualitative."

Flauger stresses that he hasn't proved that BICEP's signal is spurious. "I'm still hoping that after all I've done there is a signal there," he says. However, the claim already has a couple of strikes against it. The polarization signal is twice as big as an upper limit Planck researchers set indirectly by measuring temperature variations in the CMB. Making the two results jibe would be difficult, researchers say. The size of the signal also causes headaches for theorists trying to explain how inflation happened (*Science*, 4 April, p. 19).

The flap over the BICEP signal may have been predictable. Sampling microwaves at multiple frequencies would have allowed BICEP2 to separate foreground from CMB by itself. But the telescope was designed to maximize overall sensitivity and tracked only one frequency. "All the other experiments that I know of use multiple frequencies," says Charles Bennett of Johns Hopkins University in Baltimore, Maryland.

Clarity may come in October, when Planck researchers plan to release their polarization data. If Planck shows that the foreground is small and the BICEP signal is real, then the BICEP team should still get credit for the discovery, says Marc Kamionkowski, a cosmologist at Johns Hopkins. But David Spergel, a cosmologist at Princeton, says that in that case, the Planck team alone should get the credit.

If Planck shoots down the result, the credibility of science may suffer, Bennett says: "You talk about something like climate change and the public says, 'Yeah, but you guys say you found something and then you take it back all the time.' " ■

PHOTOS RAPHAEL FLAUGER





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文章三

IN DEPTH

# *Evidence for cosmic inflation wanes*

## The biggest result in cosmology in a decade fades into dust

Planck produced a map of polarized microwaves from galactic dust (*below*) in which red means more emissions and blue means less.

*By* **Adrian Cho**

A beleaguered claim that appeared to reveal the workings of the big bang may instead say more about how science is done in an age of incessant news coverage.

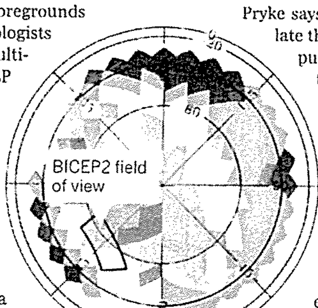
In March, researchers working with a specialized telescope at the South Pole, known as BICEP2, reported extremely faint pinwheel-like swirls in the afterglow of the big bang—the so-called cosmic microwave background (CMB). They claimed they had found traces of gravitational waves rippling through the infant universe—direct evidence that the newborn cosmos had undergone a bizarre exponential growth spurt known as inflation (*Science*, 21 March, p. 1296). But the supposed signal might have been emitted by warm dust within our own galaxy, others argued (*Science*, 23 May, p. 790). Now, data from the European Space Agency's Planck spacecraft show that dust accounts for some, and possibly all, of the BICEP signal.

"We've gone from 'They can't prove that it isn't dust' to 'It's probably dust,'" says David Spergel, a cosmologist at Princeton University who is not a member of the BICEP team. But George Efstathiou, a cosmologist at the University of Cambridge in the United Kingdom and a member of the Planck team, cautions that the new data do not prove that the BICEP signal was entirely spurious.

In fact, to keep people from jumping to that conclusion, the Planck team decided not to issue a press release when it posted its paper to the arXiv preprint server and submitted it to *Astronomy & Astrophysics*, Efstathiou says. "It's very tricky stuff," he says, "so we were anxious that it not go into the press as 'Planck says that BICEP is wrong' because it doesn't."

The new data do show that the BICEP team underestimated the "galactic foreground" radiation. BICEP2—short for Background Imaging of Cosmic Extragalactic Polarization 2—took data from 2010 to 2012, aiming to map the polarization of the primordial microwaves in a small patch of sky. To maximize the instrument's sensitivity, researchers designed it to detect microwaves of only one frequency, 150 gigahertz (GHz).

But the push to improve sensitivity came at a cost. To distinguish radiation from dust and other galactic foregrounds from the CMB, cosmologists generally take data at multiple frequencies. So BICEP researchers had to rely on other groups' estimates of the dust foreground in their field of view—including preliminary numbers presented in a talk by Planck researchers.




Now researchers with Planck, which took data from 2009 to 2013, have mapped dust emissions across the entire sky and have shown that dust could account for some or all of the BICEP signal. The map shows dust emissions at a frequency of 353 GHz; to estimate emissions at BICEP's frequency of 150 GHz, Planck researchers extrapolated using the average spectrum for dust emissions. But that extrapolation is "solid," Spergel says.

The presence of dust "can only diminish" the BICEP signal, acknowledges Clement Pryke, a cosmologist at the University of Minnesota, Twin Cities, and a co-principal investigator for the BICEP team. "I'm not going to say 'Goddamn it, there's a cosmological signal there,'" Prkye says. "I'm not going to say there isn't, either." The BICEP and Planck teams are working on a joint analysis that should provide a more definitive answer, perhaps by year's end, he says.

Some researchers say the BICEP team made its result seem much stronger than it was by announcing it in a press conference and a press release that proclaimed the "first direct evidence of cosmic inflation." "It's a very bold gamble that's been taken," Princeton cosmologist William Jones said at the time. But BICEP researchers felt pressure from the media to stake a definite claim, Pryke says: "They're trying to translate this into something that the public can understand, and they want a yes or no."

Charles Bennett, a cosmologist at Johns Hopkins University in Baltimore, Maryland, says his impression is that BICEP researchers thought they'd nailed the discovery. "They just got overenthusiastic," he says, "but it's tough to know when you really have something." BICEP researchers might have done better to simply post their preprint as the Planck team has done, Bennett says. "If the result held up, they would have gotten credit anyway," he says.

The new Planck results have sobering implications, Bennett says. They suggest the sky is relatively dusty and that extracting evidence of primordial gravitational waves may take years and multiple experiments, he says. Max Tegmark, a cosmologist at the Massachusetts Institute of Technology in Cambridge, is more optimistic. "There are places in the sky that seem to be twice as clean" as BICEP's field of view, he says. "So people are going to look there." ■







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