POLARBEAR seeks cosmic answers in microwave polarization

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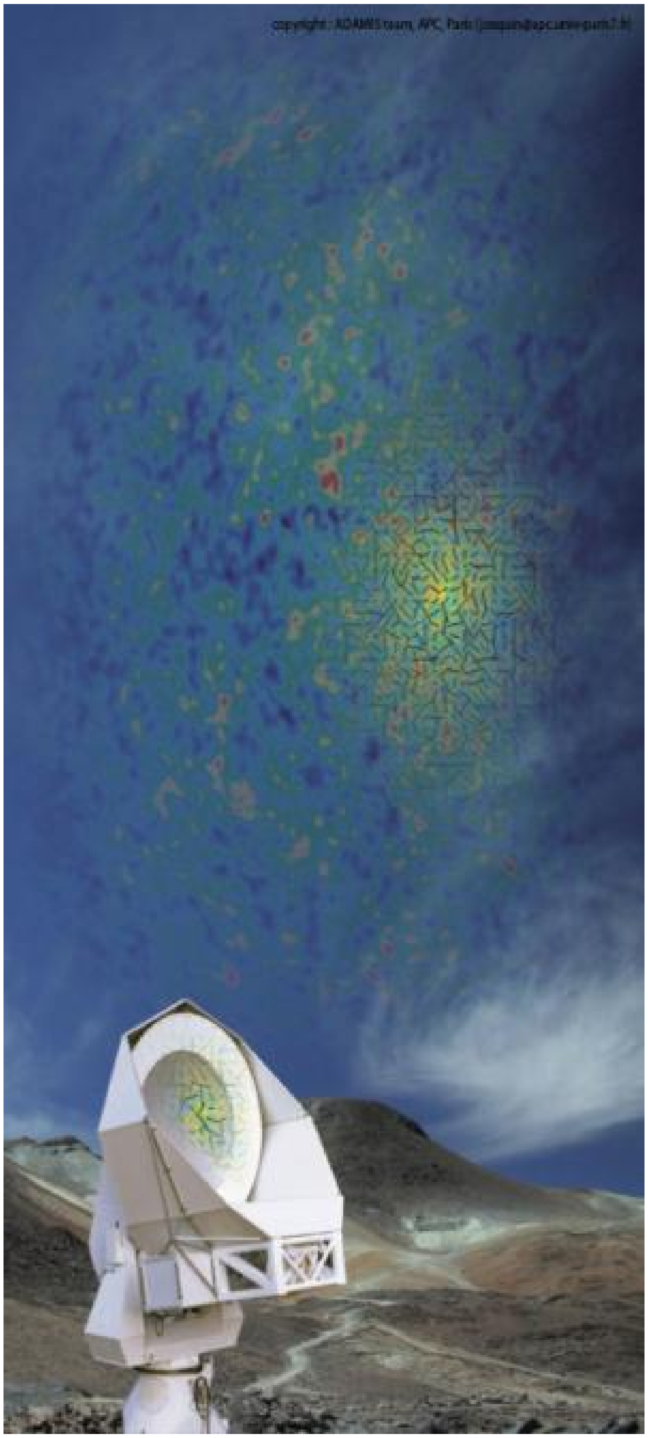


The Huan Tran Telescope in the Atacama Desert of Chile. The POLARBEAR microwave bolometers are mounted on the telescope to study the polarization of light from a period 380,000 years after the Big Bang. Credit: POLARBEAR consortium

An international team of physicists has measured a subtle characteristic in the polarization of the cosmic microwave background radiation that will allow them to map the large-scale structure of the universe, determine the masses of neutrinos and perhaps uncover some of the mysteries of dark matter and dark energy.

In a paper published this week in the *Astrophysical Journal*, the POLARBEAR consortium, led by University of California, Berkeley, physicist Adrian Lee, describes the first successful isolation of a "B-mode" produced by gravitational lensing in the polarization of the cosmic microwave background radiation.

Polarization is the orientation of the microwave's electric field, which can be twisted into a "B-mode" pattern as the light passes through the gravitational fields of massive objects, such as clusters of galaxies.

"We made the first demonstration that you can isolate a pure gravitational lensing B-mode on the sky," said Lee, POLARBEAR principal investigator, UC Berkeley professor of physics and faculty scientist at Lawrence Berkeley National Laboratory (LBNL). "Also, we have shown you can measure the basic signal that will enable very sensitive searches for neutrino mass and the evolution of dark energy."

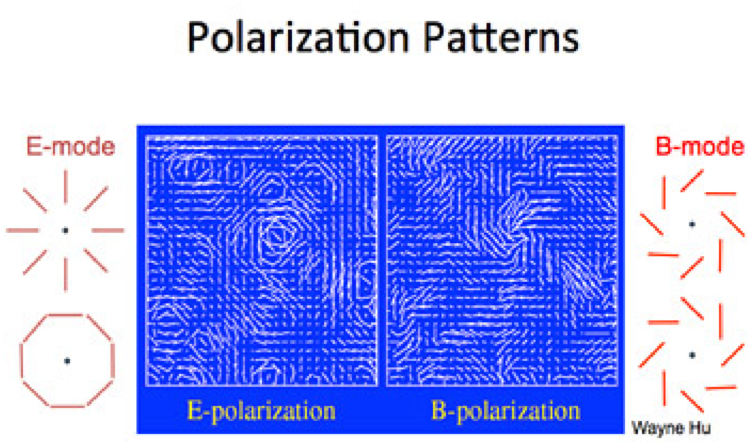
The POLARBEAR team, which uses microwave detectors mounted on the Huan Tran Telescope in Chile's Atacama Desert, consists of more than 70 researchers from around the world. They submitted their new paper to the journal one week before the surprising March 17 announcement by a rival group, the BICEP2 (Background Imaging of Cosmic Extragalactic Polarization) experiment, that they had found the holy grail of microwave background research. That team reported finding the signature of cosmic inflation – a rapid ballooning of the universe when it was a fraction of a fraction of a second old – in the polarization pattern of the microwave background radiation.

Subsequent observations, such as those announced last month by the Planck satellite, have since thrown cold water on the BICEP2 results, suggesting that they did not detect what they claimed to detect.

While POLARBEAR may eventually confirm or refute the BICEP2 results, so far it has focused on interpreting the polarization pattern of the microwave background to map the distribution of matter back in time to the universe's inflationary period, 380,000 years after the Big Bang.

POLARBEAR's approach, which is different from that used by BICEP2, may allow the group to determine when dark energy, the mysterious force accelerating the expansion of the universe, began to dominate and overwhelm gravity, which throughout most of cosmic history slowed the expansion.

Early universe was a high-energy laboratory



Microwave radiation left over from the Big Bang 13.8 billion years ago is polarized, like most light. An E-mode polarization pattern is symmetric, reflecting the physical conditions where it was emitted. A B-mode polarization pattern indicates that the light has been twisted by interactions with massive objects it passed on its way to Earth, allowing astronomers to map the matter in the universe.

The POLARBEAR team is measuring the polarization of light that dates from an era 380,000 years after the Big Bang, "when the early universe was a high-energy laboratory, a lot hotter and denser than now, with an energy density a trillion times higher than what they are producing at the CERN collider," Lee said. The Large Hadron Collider near Geneva is trying to simulate that early era by slamming together beams of protons to create a hot dense soup from which researchers hope new particles will emerge, such as the newly discovered Higgs boson. But observing the early universe, as the POLARBEAR group does may also yield evidence that new physics and new particles exist at ultra-high energies.

The team uses these primordial photon's light to probe large-scale gravitational structures in the universe, such as clusters or walls of galaxies that have grown from what initially were tiny fluctuations in the density of the universe. These structures bend the trajectories of microwave background photons through gravitational lensing, distorting its polarization and converting E-modes into B-modes. POLARBEAR images the lensing-generated B-modes to shed light on the intervening universe.

BICEP2 and POLARBEAR both were designed to measure the pattern of B-mode polarization, that is, the angle of polarization at each point in an area of sky. BICEP2, based at the South Pole, can only measure variation over large angular scales, which is where theorists predicted they would find the signature of gravitational waves created during the universe's infancy. Gravitational waves could only have been created by a brief and very rapid expansion, or inflation, of the universe 10-34 seconds after the Big Bang.

In contrast, POLARBEAR was designed to measure the polarization at both large and small angular scales. Since first taking data in 2012, the team focused on small angular scales, and their new paper shows that they can measure B-mode polarization and use it to reconstruct the total mass lying along the line of sight of each photon.

Last kiss

The polarization of the microwave background records minute density differences from that early era. After the Big Bang, 13.8 billion years ago, the universe was so hot and dense that light bounced endlessly from one particle to another, scattering from and ionizing any atoms that formed. Only when the universe was 380,000 years old was it sufficiently cool to allow an electron and a proton to form a stable hydrogen atom without being immediately broken apart. Suddenly, all the light particles – called photons – were set free.

"The photons go from bouncing around like balls in a pinball machine to flying straight and basically allowing us to take a picture of the universe from only 380,000 years after the Big Bang," Lee said. "The universe was a lot simpler then: mainly hydrogen plasma and dark matter."

These photons, which, today, have cooled to a mere 3 degrees Kelvin above absolute zero, still retain information about their last interaction with matter. Specifically, the flow of matter due to density fluctuations where the photon last scattered gave that photon a certain polarization (called E-mode polarization).

"Think of it like this: the photons are bouncing off the electrons, and there is basically a last kiss, they touch the last electron and then they go for 14 billion years until they get to telescopes on the ground," Lee said. "That last kiss is polarizing."

While E-mode polarization contains some information, B-mode polarization contains more, because photons carry this only if matter around the last point of scattering was unevenly or asymmetrically distributed. Specifically, the gravitational waves created during inflation squeezed space and imparted a B-mode polarization that BICEP2 may have detected. POLARBEAR, on the other hand, has detected B-modes that are produced by distortion of the E-modes by gravitational lensing.

While many scientists suspected that the gravitational-wave B-mode polarization might be too faint to detect easily, the BICEP2 team, led by astronomers at Harvard University's Center for Astrophysics, reported a large signal that fit predictions of gravitational waves. Current doubt about this result centers on whether or not they took into account the emission of dust from the galaxy that would alter the polarization pattern.

In addition, BICEP2's ability to measure inflation at smaller angular scales is contaminated by the gravitational lensing B-mode signal.

"POLARBEAR's strong suit is that it also has high angular resolution where we can image this lensing and subtract it out of the inflationary signal to clean it up," Lee said.

Two other papers describing related results from POLARBEAR were accepted in the spring by Physical Review Letters.

One of those papers is about correlating E-mode polarization with B-mode polarization, which "is the most sensitive channel to cosmology; that's how you can measure neutrino masses, how you might look for early behavior of dark energy," Lee said.

More information: — A Measurement of the Cosmic Microwave Background B-Mode Polarization Power Spectrum at Sub-Degree Scales

with POLARBEAR (*Astrophysical Journal*)
— Detection of B-modes by cross correlation with IR galaxy maps (*Physical Review Letters*)
— First CMB-only detection of polarized gravitational lensing in the CMB (*Physical Review Letters*)

Provided by University of California - Berkeley