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Viewpoint

Matter Adds Twist to Cosmic Microwave Background

Eiichiro Komatsu
Max Planck Institute for Astrophysics, Karl-Schwarzschild-Strasse 1, 85741 Garching, Germany

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A microwave telescope at the South Pole has for the first time captured a particular polarization signal in the cosmic microwave background that arises from gravitational lensing by intervening matter.

Subject Areas: **Cosmology**

A Viewpoint on:
Detection of B -Mode Polarization in the Cosmic Microwave Background with Data from the South Pole Telescope
D. Hanson et al. (SPTpol Collaboration)
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The cosmic microwave background (CMB) is the oldest discernible light in the Universe. It provides us with a photograph of an infant Universe—the Universe 13.7 billion years ago. But this ancient snapshot has been slightly distorted by intervening matter. As CMB light rays propagated through the Universe to us, they encountered countless lumps of matter that slightly deflected their direction by the effect called "gravitational lensing." Some aspects of this lensing have been observed before, but now a team of astronomers using the 10-meter South Pole Telescope (SPT) have detected for the first time a subtle twisting in the polarization of the CMB due to gravitational lensing. The achievement, described in *Physical Review Letters*[1], could lead to a map of the distribution of matter in the Universe, including the invisible dark matter.

The CMB is often called the "afterglow of the big bang" because it originated from the hot ionized plasma that filled the early Universe. Primordial density fluctuations in this plasma were recorded in the hot and cold spots that have been observed in the CMB. The fluctuations also left their mark in the polarization of the light. The last interaction that CMB photons had with the plasma was elastic (Thomson) scattering, and this would have imprinted a particular polarization pattern. The physics of Thomson scattering tells us that if we look at a ring of light around a hot or cold spot in the CMB, the light will be polarized along radial or tangential lines, respectively (see Fig. 1). However, as the CMB light propagates through a lumpy Universe, gravitational lensing slightly distorts these radial/tangential patterns, creating patterns that look more like vortices [2]. Cosmologists use an analogy with the spatial properties of electromagnetic fields and call the tangential/radial patterns "electric" or E-mode polarization, and the vortices "magnetic" or B-mode polarization. The E-mode polarization dominates, with only about 6% of this polarization converted to B mode through gravitational lensing. The DASI Collaboration was the first to detect the primeval E-mode polarization in 2002 [3]. Subsequent experiments, including NASA's Wilkinson Microwave Anisotropy Probe [4] and European Space Agency's (ESA) Planck satellite [5], have measured E-mode polarization with increasing precision. However, B-mode polarization has until now remained undetected.

The SPT Collaboration (Hanson *et al.*) has managed to extract the faint signal of B-mode polarization in the CMB using 1176 and 360 polarization-sensitive bolometers working at 2- and 3-millimeter wavelengths, respectively. To reduce contamination due to instrumental polarization and various systematics, they compared their B-mode polarization signal with a prediction of the lensing effect based on galaxy counts. Galaxies form in dense regions so they can tell us where the matter density is high, but they only give part of the story since 80% of the matter in the Universe is invisible dark matter. Astronomers therefore require complicated models to convert galaxy observations into a total matter distribution over the sky. The SPT Collaboration focuses on a particular class of galaxies, which contain a lot of warm dust grains emitting light at submillimeter wavelengths. In previous work, the researchers used images from ESA's Herschel satellite to identify these dusty galaxies and then showed that they could estimate the total matter along a line of sight using the galaxy data [6]. They now use this "matter map" to predict the amount of gravitational lensing and its effect on the E-mode polarization that they measure. This process yields a map of B-mode polarization that would be expected based on

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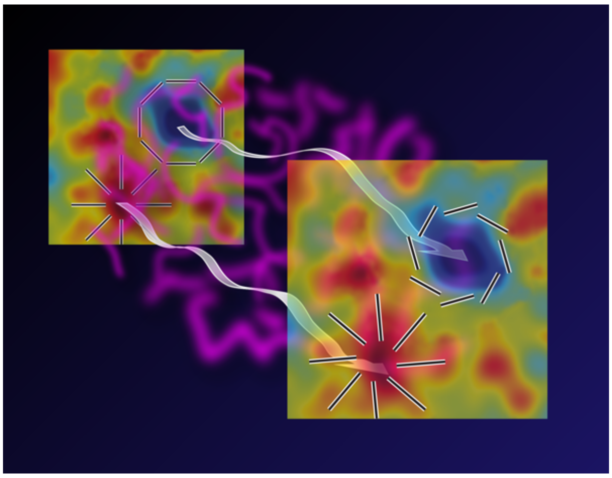

FIG. 1: When the cosmic microwave background (CMB) originated 13.7 billion years ago (represented by the map on the left), it was polarized with radial and tangential patterns around hot (red) and cold (blue) regions, respectively. This E-mode polarization has been previously observed in CMB measurements. However, gravitational lensing from intervening matter (purple) causes a slight twist in the primeval pattern (shown in the map on the right). This B-mode polarization has been detected for the first time by the SPT Collaboration. (APS/Alan Stonebraker)

the galaxy counts. When the Collaboration cross correlated the predicted and measured B-mode polarization maps, they detected a high level of correlation between these two maps at the statistical significance of nearly eight standard deviations.

The advantage of B-mode polarization over the traditional method of counting galaxies is that it provides us with a high-fidelity map of the total matter, including dark matter, rather than an indirect estimate based only upon the visible matter such as galaxies. The B-mode maps can complement other methods of detecting dark matter, which tend to measure the amount of matter in a particular galaxy cluster or along particular lines of sight. The SPT Collaboration has thus opened up a new window into the era in which we can finally "see" dark matter filling the intergalactic space via gravitational lensing. With this new method, cosmologists are hoping to measure, among other things, the mass of neutrinos [7]. Since neutrinos have very small masses (about 10 billion times smaller than the proton mass), they are generally moving too fast to be held in the gravitational potentials of galaxy clusters. They therefore spread out more uniformly, leading to a smoother matter distribution that produces less gravitational lensing, and therefore less B-mode polarization, than might normally be predicted. Full-sky measurements of B-mode polarization could characterize the level of smoothing and thereby estimate the neutrino mass.

What is next? Gravitational lensing is not the only mechanism to produce B-mode polarization. Primeval ripples in space, called gravitational waves, could have been produced during the earliest moment in the Universe [8], and they can also produce B-mode polarization in the CMB [9]. Gravitational-wave-induced B modes can be distinguished from lensing-induced B modes in that the former should fluctuate on much larger angular scales than the latter. Detection of B-mode polarization from the primeval gravitational waves is thought to provide definitive evidence for the cosmic inflation paradigm, which states that the early Universe underwent a period of rapid, accelerating expansion right after its birth and that the structures we see in the Universe such as stars, galaxies, and ourselves originate from quantum fluctuations produced during this inflation. B-mode polarization thus offers a clue to the fundamental question about the origin of our own Universe. The detection of nonprimeval, lensing-induced B-mode polarization by the SPT Collaboration is a significant step toward the ultimate detection of signatures of the primeval gravitational waves from inflation.

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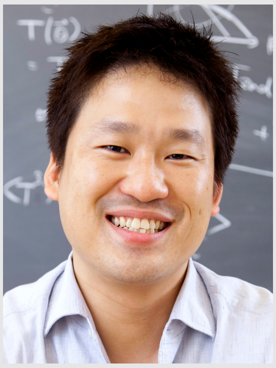
About the Author

Eiichiro Komatsu



Eiichiro Komatsu is a cosmologist who enjoys both theoretical and observational work. He has been Director of the Physical Cosmology division at the Max Planck Institute for Astrophysics in Garching, Germany, since 2012. Prior to this he was a professor in the Department of Astronomy and Director of Texas Cosmology Center at the University of Texas at Austin. He obtained his Ph.D. from Tohoku University in Sendai, Japan, in 2001. In recent years he has been trying to find ways to prove that the Universe underwent a period of quasi-exponential, accelerated expansion called "inflation" before the big bang, and to understand why and how the expansion of the current Universe is also accelerating.

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