Photons' journeys across the universe help unravel cosmological mysteries

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Polarization maps illustrating the rotation of photon polarization. Credit: Liang Dai. ©2014 American Physical Society

(Phys.org) —The faint background glow that exists throughout the Universe, called the Cosmic Microwave Background (CMB), is made of photons that have been scattering since the universe was just 400,000 years old. Now in a new paper, physicist Liang Dai at Johns Hopkins University in Baltimore, Maryland, has shown that the polarization of these photons is rotated as they travel by things such as gravity waves and cosmic matter flows. By accounting for this rotation effect when observing the CMB photons, scientists may be able to investigate parts of the Universe that might otherwise remain unknown.

"The CMB is like a cosmic back light," Dai told *Phys.org*. "When the CMB photons finally reach us today, they have traversed vast cosmic space, and are distorted by whatever lies in between. It is of great significance to study/measure these distortions (to both temperature and polarization) because we then learn about the distribution and evolution of the 'stuff' in between, and hence understand the more recent Universe."

This 'stuff' that distorts the CMB photons on their journey includes the large-scale structure of matter in the Universe, as well as less visible stuff, such as primordial gravity waves and vortical cosmic matter flows (for example, the circular collective movement of galaxies).

"Gravity waves will tell us a lot about the very beginning of Universe, and vortical flows reveal a lot about the structure formation in the Universe," Dai said.

Dai's theoretical results show that this 'stuff'—gravity waves and vortical flows—distorts the polarization anisotropies of the CMB. The previous calculation of this effect was incomplete, but Dai's work provides a complete and correct calculation of the polarization rotation effect.

"When a photon travels in some direction, it oscillates in a plane perpendicular to that direction," Dai explained. "However, there are still two independent planes in which it can oscillate (we call them two transverse directions), and the photon's polarization state is about in which plane oscillation happens.

"Suppose there is a distant source emitting photons polarized in one transverse direction. In flat space, the receiver will see exactly the polarized direction as it is at emission. But in a Universe filled with all kinds of 'stuff,' spacetime is slightly curved, so the receiver is going to see a slightly different polarized direction from that at emission. If one knows the original polarized direction, then one can measure this effect by seeing how the observed polarized direction differs from the original direction. Sometimes, we don't know the original direction, but we still know the probabilistic distribution of original polarized direction. In that case, we can still determine in a statistical way whether the polarization plane has changed during the photon's propagation."

The effects are not only limited to CMB photons, but could also apply to photons coming from other sources, such as radio emissions and quasars.

"Like the CMB, 21-cm radio emissions are just another backlight that illuminates what is 'in between'; the difference is that they are electromagnetic signals of different frequency and that they originate from places of lower redshift. But they can also be polarized due to scattering. In this sense, the same results can be applied to that case as well.

"Unlike the CMB and 21-cm emissions, quasars are point-like back-lights," he continued. "Sometimes, a single quasar appears in multiple images on the sky because it happens to be behind, e.g., a galaxy cluster. We call this situation strong lensing. The results of my paper imply that light from two distinct images of the same quasar will have slightly different polarizations because lights from both images follow different paths in spacetime. Although this is a second-order effect, it might be possible to measure this difference by interference techniques. Of course, in this situation the backlight reveals foreground structures instead of gravity waves."

In the future, Dai plans to investigate exactly how gravity waves distort and deflect photons traveling in the distant Universe.

"There have been many studies on the geometrical effect of gravity waves, i.e., how they deflect light paths from distant sources," he said. "Although this effect might eventually help in identifying gravity waves in the Universe, it is observationally very challenging; the effect is tiny because gravity wave amplitude decreases as the Universe expands as a whole.

"The dynamical effect of gravity waves, on the other hand, has not been quite studied and understood. The dynamical effect is basically how gravity waves distort the motion of matter particles (not light), and hence affect the physical distribution of matter, not just the apparent distribution. Compared to the geometrical effect, the dynamical effect can take place at even earlier time, and can be more significant. Next I am very interested in studying this aspect of gravity waves, continuing the search for gravity waves in the Universe."

More information: Liang Dai, et al. "Rotation of the Cosmic Microwave Background Polarization from Weak Gravitational Lensing." *PRL* 112, 041303 (2014). DOI: 10.1103/PhysRevLett.112.041303