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Parity-violating scalar trispectrum from helical primordial magnetic fields

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Observational evidence for cosmic magnetic fields has been accumulated over a wide range of scales, from galaxies and galaxy clusters to cosmic voids, yet their origin remains unsettled. In particular, magnetic fields in voids are difficult to account for solely by astrophysical mechanisms associated with structure formation, making primordial magnetic fields (PMFs) generated in the early universe a compelling candidate. In recent years, helical PMFs—realizable in magnetogenesis scenarios involving parity-violating couplings—have attracted considerable attention. Since magnetic helicity is a conserved quantity, helical fields can undergo an inverse cascade that increases their correlation length, potentially providing an origin for the large-scale magnetic fields observed today. Moreover, current observations have suggested that intergalactic magnetic fields may possess nonzero helicity, making helical PMFs a key target not only for elucidating cosmic magnetism but also for testing cosmological parity violation. In this talk, we focus on curvature perturbations sourced by the PMF anisotropic stress on superhorizon scales, the so-called passive mode. We derive an analytic expression for the trispectrum—the Fourier transform of the four-point correlation function—of the passive scalar mode, including parity-violating contributions sourced by primordial magnetic helicity. Assuming nearly scale-invariant PMF spectra, we evaluate the trispectrum analytically using the pole approximation, which isolates the dominant contributions from modes with wavenumbers near zero. By comparison with direct numerical integrations, we demonstrate that the pole approximation reproduces the qualitative behavior of the exact trispectrum. We then investigate the dependence of the trispectrum amplitude on the Fourier-space configuration by varying both the shape of the wavenumber tetrahedron and the ratio of the helical to non-helical components. Finally, we present an order-of-magnitude estimate of this ratio by relating our results to existing observational constraints on the CMB trispectrum. These results demonstrate that parity-violating signatures originating from primordial magnetic helicity can be imprinted on the cosmic microwave background (CMB) and large-scale structure (LSS) through higher-order correlation functions. Our findings highlight trispectrum-based analyses as a complementary avenue to conventional power-spectrum constraints for probing primordial magnetism.

Primary author: KAITO, Yura

Presenter: KAITO, Yura

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