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Boosting HI-Galaxy Cross-Clustering Signal through Higher-Order Cross-Correlations

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After reionization, neutral hydrogen (HI) traces the large-scale structure (LSS) of the Universe, enabling HI intensity mapping (IM) to capture the LSS in 3D and constrain key cosmological parameters. We present a new framework utilizing higher-order cross-correlations to study HI clustering around galaxies, tested using real-space data from the IllustrisTNG300 simulation. This approach computes the joint distributions of ⊠-nearest neighbor (⊠NN) optical galaxies and the HI brightness temperature field smoothed at relevant scales (the ⊠NN-field framework), providing sensitivity to all higher-order cross-correlations, unlike two-point statistics. To simulate HI data from actual surveys, we add random thermal noise and apply a simple foreground cleaning model, filtering out Fourier modes of the brightness temperature field with $k_{\parallel} < {}_{\mathrm{min},\parallel}$. Under current levels of thermal noise and foreground cleaning, typical of a Canadian Hydrogen Intensity Mapping Experiment (CHIME)-like survey, the HI-galaxy cross-correlation signal in our simulations, using the ⊠NN-field framework, is detectable at > 30σ across $= [3, 12]\, h^{-1}\mathrm{Mpc}$. In contrast, the detectability of the standard two-point correlation function (2PCF) over the same scales depends strongly on the foreground filter: a sharp ⊠ filter can spuriously boost detection to 8σ due to position-space ringing, whereas a less sharp filter yields no detection. Nonetheless, we conclude that ⊠NN-field cross-correlations are robustly detectable across a broad range of foreground filtering and thermal noise conditions, suggesting their potential for enhanced constraining power over 2PCFs.

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