Discovering Primordial Cosmic Protostructures With a Novel Multi-Scale Infrared Background Inverse Tomographer (IBIT)

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Recent observations have revealed unexpected galaxy populations at cosmic noon and “ultra-large-scale structures” in the local universe that challenge standard mass assembly models. To investigate how such discrepancies arise, it is necessary to map and characterize the cosmic web of the early universe. However, conventional imaging surveys are limited at high redshifts due to the faintness and sparsity of sources. This work introduces a novel approach to reconstruct early-universe large-scale structure (LSS) by decomposing the Cosmic Infrared Background (CIB)–the integrated infrared emission from all cosmic history–using a custom-built Infrared Background Inverse Tomographer (IBIT). IBIT is an adversarially-trained neural architecture that takes as input far-infrared CIB maps and a low-redshift LSS prior, and outputs 3D reconstructions of early-universe LSS. Trained on 10^3 synthetic universes generated in this study, the model demonstrates superior performance relative to JWST-like simulated observations at $z = 4$ (? 1.7 Gyr after the Big Bang). Applied to empirical data from the COSMOS field, IBIT resolves early LSS with unprecedented fidelity and identifies large-scale features indicative of the first stages of mass assembly. These predictions are consistent with s8 constraints from cosmic microwave background analyses and show significant spatial correlation with observed protocluster overdensities in the field. IBIT represents the first method capable of data-driven, high-redshift LSS mapping from diffuse background light, and offers a promising avenue for resolving key tensions in ?CDM and galaxy evolution theory by enabling statistically complete surveys of structure formation in the early universe.

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