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A modified lognormal approximation of the Lyman-α forest: comparison with full hydrodynamic simulations

Observations of the Lyman-α forest in distant quasar spectra with upcoming surveys are expected to provide significantly larger and higher-quality datasets. To interpret these datasets, it is imperative to develop efficient simulations. One such approach is based on the assumption that baryonic densities in the intergalactic medium (IGM) follow a lognormal distribution. We develop and end-to-end MCMC technique using the mean and power spectrum of the transmitted flux, to assess the robustness of the lognormal model of the Lyman-α forest in recovering the parameters characterizing IGM state, namely, the mean-density IGM temperature (T_0), the slope of the temperature-density relation (γ), and the hydrogen photoionization rate (Γ_{12}), by comparing with high-resolution Sherwood SPH simulations across the redshift range $2 \leq z \leq 2.7$. We find that the usual lognormal distribution of IGM densities cannot recover the parameters of the SPH simulations. This limitation arises from the fact that the SPH baryonic density distribution cannot be described by a simple lognormal form. To address this, we extend the model by scaling the linear density contrast by a parameter ν. While the resulting baryonic density is still lognormal, the additional parameter gives us extra freedom in setting the variance of density fluctuations. With this extension, values of T_0 and γ implied in the SPH simulations are recovered at $\sim 1-\sigma$ (
$lesssim$ 10\%) of the median (best-fit) values for most redshifts bins. However, this extended lognormal model cannot recover Γ_{12} reliably, with the best-fit value discrepant by
$gtrsim 3-\sigma$ for $z > 2.2$. Despite this limitation in the recovery of Γ_{12}, whose origins we explain, we argue that the model remains useful for constraining cosmological and dark matter parameters.

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