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Characterization of Lyman Alpha Spectra and Predictions of Structure Formation Models: A Flux Statistics Approach

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In gravitational instability models, Lyα absorption arises from a continuous fluctuating medium, so that spectra provide a non-linear one-dimensional "map" of the underlying density field. We characterise this continuous absorption using statistical measures applied to the distribution of absorbed flux. We describe two simple members of a family of statistics which we apply to simulated spectra in order to show their sensitivity as probes of cosmological parameters (H_0, Ω, the initial power spectrum of matter fluctuations) and the physical state of the IGM. We make use of SPH simulation results to test the flux statistics, as well as presenting a preliminary application to Keck HIRES data.

1 Introduction

Hydrodynamical simulations are now providing us with the detailed predictions of structure formation models for what should be seen in quasar absorption spectra[1,2,3]. If we accept the same picture of formation of structure by gravitional instability that is believed to be responsible for the observed galaxy distribution, then in the same sense that galaxy redshift surveys can provide important cosmological constraints, there is a wealth of information to be extracted from the Lyα forest.

We analyse TreeSPH[4] hydrodynamic simulations of three CDM-based cosmological models : SCDM and CCDM have $\Omega_0 = 1$, $h = 0.5$ and $\sigma_8 = 0.7$, $\sigma_8 = 1.2$ respectively, OCDM has $\Omega_0 = 0.4, \Omega_\Lambda = 0, h = 0.65, \sigma_8 = 0.75$. For all, $\Omega_b h^2 = 0.05$ and a photoionizing UV background is included. Details of the simulations are given in [5]. In the models, Lyα absorption arises from a continuous fluctuating medium, the optical depth to absorption, τ, being correlated with the underlying density, which is shown in Figure 1. The empirically measured relationship, $\tau \propto \rho_b^{1.6}$ can be predicted from the interplay

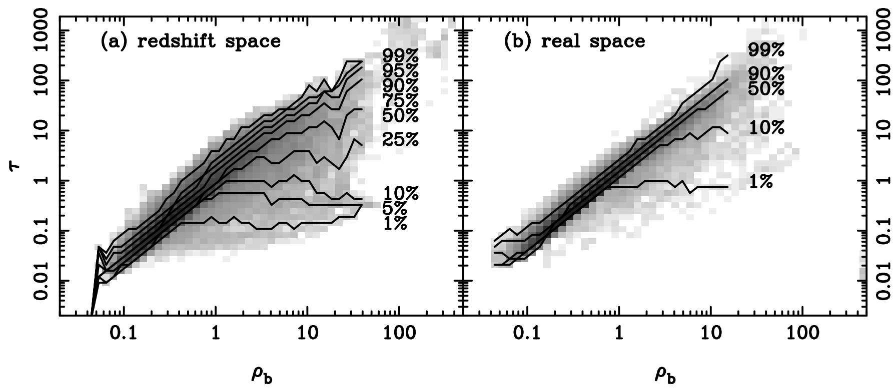

Figure 1: The joint distribution of optical depth and ρ_b (in units of the mean baryon density) for the SCDM model at $z = 3.0$. Panel (a) is in redshift space and in panel (b) peculiar velocities were set to zero. The logarithmic grey scale shows the fraction of pixels in each (ρ_b, τ) bin. Lines show the percentile distribution of $\tau_{\rm HI}$ in each bin of ρ_b

between photoionization heating and adiabatic cooling[5,6]. The scatter in 1(a) is mainly due to the effects of peculiar velocities (set to zero in 1(b)).

2 Flux statistics

We apply two sets of statistics to the simulated spectra as well as to a Keck spectrum of Q1422+231 (observations described in [7], $\overline{z}$ of absorption = 3.2):

(1) The fraction of each spectrum (FF, or filling factor) above a given threshold in flux decrement (D=$1 - e^{-\tau}$). The dotted lines in Figure 2(a) show the results at two different redshifts in the SCDM model. The expansion of the Universe, which results in a lower mean density of neutral hydrogen is the main factor driving the dramatic evolution in the shape of the curve and the mean optical depth. All three models fit the observations reasonably well (see also [8]) , once the strength of the UV background has been adjusted to yield the correct mean amount of absorption, with CCDM giving the best fit.

(2) N, the mean number of times per unit length a spectrum crosses a given threshold in D. We plot N against against FF instead of D (Figure 2(b)) so that the two panels give us entirely independent information. When plotted in this fashion, N is member of a family of statistics such as the distribution of distances between downcrossings and upcrossings ("size of absorbers") which is unaffected by variations in Ω_b and the UV background. N is sensitive to the length scale and therefore H_0, as well as the power spectrum of fluctuations and the temperature of the IGM (thermal broadening results in less crossings).

In Figure 2(b) we see that the three cosmological models have a smaller N

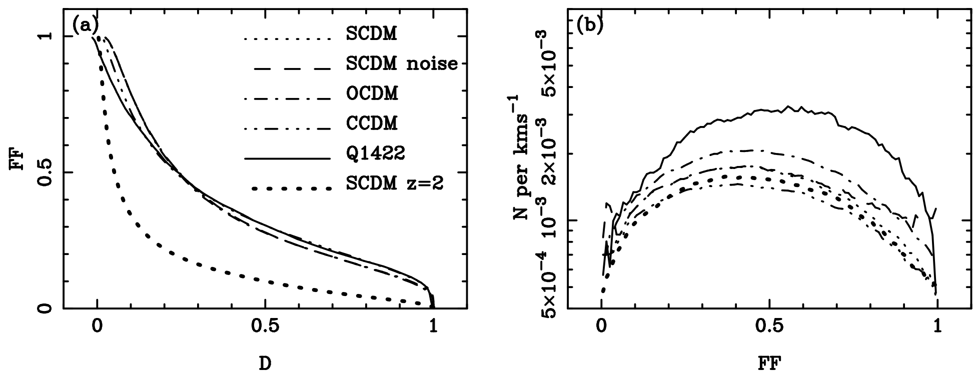

Figure 2: (a) Filling factor, FF vs flux decrement, D for 3 different models (see text) at z=3, as well as SCDM with noise, SCDM at z=2 , and a Keck spectrum of Q1422+231. (b) Number of crossings, N, per kms^{-1} vs FF. A 20 kms^{-1} tophat filter was applied to all the spectra before calculating the statistics for both panels.

than the Keck spectrum of Q1422+231, the difference being worse at high FF (low D). Adding simulated Keck noise to the SCDM model does not resolve the discrepancy. There is genuinely more structure in the QSO spectrum than in low density regions of the simulations, . At the moment it is uncertain whether this discrepancy reflects a failure of these cosmological models (e.g. they have the wrong power spectrum on these scales) or a failure of the simulations to resolve the smallest scale features in the fluctuating intergalactic medium.

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