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Damped Lyman-α Absorbers bias: measurement and evolution

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Abstract

We present an update on the measurement of the Damped Lyman-α Absorbers (DLAs) bias from the cross-correlation of DLA and the Lyman-α forest ([11]). We also use an upgraded method to deal with the broadband function problems. In our analysis, we use of the final Data Release of BOSS. We find the bias of the DLA to be $b_d = 1.90 \pm 0.11$. With the improved statistics, we explore the evolution of the DLA bias with column density and redshift. We find no clear evidence of any evolution in neither of them. This means that the dark matter halos hosting the DLA are essentially the same independently of the properties of the DLA.

1 Introduction

Damped Lyman-α Absorbers (DLAs) are defined as absorption systems with neutral hydrogen column density $N_{HI} \geq 2\times10^{20}\text{cm}^{-2}$ [21]. Being large clouds of gas, DLAs are bound to follow the gravitational potential of matter halos. Thus, they are tracers of the underlying dark matter distribution. This means that we can measure the DLA bias by measuring the cross-correlation between DLAs and the Lyman-α forest. Previous attempts to measure the DLA bias gave values of $1.3 < b_d < 4$ ([5]) and of $b_d = 2.17 \pm 0.20$ ([11]). The former derived this value from measuring the cross-correlation with luminous Lyman break galaxies, using a very small sample of only 11 DLAs in their spectra. The later used the cross-correlation with the Lyman-α forest using data from BOSS ([6]) in the SDSS-III Collaboration ([8]). Their sample contained a total of 7458 DLAs and provided the first measurement of the DLA bias.

While being able to measure for the first time the bias of the DLAs, [11] used only part of both the DLAs and the Lyman-α forest observations from BOSS (the survey hadn't finished collecting data by the time their results were published). Using the entire sample we can decrease those errorbars and we can even explore the dependence of the bias factor with the DLA properties. This is interesting because there are hints that the evolution of DLA properties, in particular the metallicity, are not constant with either redshift or column density.

We start by describing the datasets used to derive the DLA bias in Section 2. We use an improved estimator for the cross-correlation than [11], briefly described in Section 3. Section 4 explain the model used to extract the DLA bias. Finally, we present our results and conclusions in Section 5. Note that throughout this paper we use the cosmology from [17], i.e., a flat LCDM cosmology with $\Omega_m = 0.3183$, $\Omega_b = 0.0490$, $h = 0.6704$, $n_s = 0.9619$, and $\sigma_8 = 0.8347$.

2 Data

The Data Release 12 (DR12) of theSDSS-III Collaboration ([9, 23, 10, 8, 2, 19]) contains the final sample of BOSS ([6]). The quasar target selection used in BOSS is summarized in [18], and combines different targeting methods described in [22, 13, 3].

For the DLA sample we use the DR12 extension of the DLA catalogue from [15]. This sample contains a total of 34050 DLA with column density $N_{HI} \geq 10^{20}\mathrm{cm}^{-2}$. Even though the strict definition of DLA requires its column density to be at least $2 \times 10^{20}\mathrm{cm}^{-2}$, we are considering the threshold to be a factor of two lower because systems with column density down to $10^{20}\mathrm{cm}^{-2}$ are robustly identified and are not expected to sharply change their nature. Note that when we refer to DLA we also include these systems.

We apply several cuts in order to increase the purity of the catalogue. Keep in mind that any object included in the catalogue which is not a DLA will decrease the measured bias of the DLAs. On the other hand, completeness is not as important: eliminating a fraction of the real DLAs will only result in a increase on the errors of the cross-correlation without modifying it systematically. The cuts applied here are similar to those in [11] but we exclude all those DLAs found bluewards of the Lyman-β line.

We separate the total dataset in bins according to the redshift value of the DLAs and according to its column density. The cuts in column density are applied to DLAs in such a way that the resulting sub-sambles have similar number of DLAs. The cuts in redshift are applied to the DLAs in such a way that the resulting signal-to-noise in the cross-correlation measured in the different sub-samples are similar. Because the Lyman-α forest data available for cross-correlation is much more sparse at high redshift in BOSS, the third bin in redshift has to be made wider if the signal-to-noise is to be similar amongst the different subsamples. We label the redshift sub-samples Z1, Z2, and Z3, and the column density sub-samples N1, N2, and N3.

For the Lyman-α sample we use the DR12 Lyman-α spectra computed as in [4] (N. Busca, private communication). This corresponds to a total of 157922 spectra containing over 27 million Lyman-α pixels. In particular we use their *analysis pixels* that are the flux average over three adjacent pipeline pixels. Throughout the rest of this paper, *pixel* refers to analysis pixels unless otherwise stated. The effective width of these pixels is 210 $\mathrm{km\,s^{-1}}$. For the quasar continuum fit their method 1 was used.

3 Method

The method here differs from the previous measurement ([11]). There, they used a very simple estimator,

$$\xi^A = \frac{\sum_{i\in A} w_i \delta_i}{\sum_{i\in A} w_i} \ , \tag{1}$$

where the sum is over all the pixels located at a separation from a DLA that is within a bin A of $\mathbf{r}$. Then they performed a MTC to compensate for the effects on the quasar continuum estimation.

Here we present a different approach. The goal is to compute things in such a way that the MTC correction is no longer necessary. The hypothesis is that the measured Lyman-α transmission fluctuation, $\delta^{(m)}$, differs from the true Lyman-α transmission fluctuation, $\delta^{(t)}$ according to

$$\delta_i^{(m)} = \delta_i^{(t)} + a + b\lambda_i \ , \tag{2}$$

where a and b are small unknown functions that depend on the δ field in a complicated way, and λ is either the wavelength or the logarithm of the wavelength (whichever is used in the computation of the δ field). Here we assume that a, b are constant within a given forest.

Since it is impossible for us to know the values of a and b, it is necessary for us to find a projector, P, that allow us to *get rid* of these parameters. Namely,

$$P\delta^{(m)} = P\delta^{(v)} \ . \tag{3}$$

Details about the motivation and derivation of this projector are given in [16].

Within this new formalism the cross-correlation in bin A is then computed as:

$$\xi^A = \frac{\sum_{q,f}\sum_{i\in f}\Theta_{iq}^A w_i \sum_{j\in f} P_{ij}\delta_j}{\sum_{q,f}\sum_{i\in f}\Theta_{iq}^A w_i} \ , \tag{4}$$

where the indexes q and f run over quasars and forests respectively, the indexes i, j, and k, run over pixels in a particular forest, and Θ_{qi}^A is 1 if the quasar-pixel pair is in bin A and 0 otherwise.

The covariance of the cross-correlation for two bins A and B is equal to

$$C^{AB} \equiv \left\langle \xi^A \xi^B \right\rangle - \left\langle \xi^A \right\rangle \left\langle \xi^B \right\rangle = \frac{1}{S^{AB}} \sum_{qf}\sum_{i\in f}\sum_{q'f'}\sum_{i'\in f'} \Theta_{iq}^A \Theta_{i'q'}^B w_i w_{i'} \xi_{ii'} \ , \tag{5}$$

where $\xi_{ii'}$ is the correlation of the measured values of δ in pixels i and i', and the normalization factor is

$$S^{AB} = \sum_{qf}\sum_{i\in f}\Theta_{iq}^A w_i \sum_{q'f'}\sum_{i'\in f'}\Theta_{i'q'}^B w_{i'} \ . \tag{6}$$

Note that the correlation $\xi_{ii'}$, with two subindexes for the two correlated pixels, should not be confused with the cross-correlation estimator ξ^A, which is a different matrix with index referring to bins in (π, σ).

4 Model

In Fourier space, linear theory predicts that redshift space distortions of a biased tracer enhance the amplitudes of each Fourier mode by a factor $b\left(1+\beta\mu_k^2\right)$, where b is the bias factor of the tracer, β its redshift space distortion parameter, and μ_k the cosine of the angle between the Fourier mode and the line of sight. For the DLA-Lyman-α cross-correlation, the associated power spectrum is then equal to

$$P_{d\alpha}\left(\vec{k}, z\right) = b_d\left(1+\beta_d\mu_k^2\right) b_\alpha\left(1+\beta_\alpha\mu_k^2\right) P_L\left(k, z\right) \;, \tag{7}$$

where the subscript d stands for DLA, the subscript α for Lyman-α, and $P_L\left(k, z\right)$ is the linear matter power spectrum. Note that in this model we do not include neither a broadband function as done in previous studies with BOSS data (e.g. [12, 7, 1]) nor the MTC correction used in [11].The correction is already implemented in the projection of the δ field.

We fix $\beta_\alpha = 1.39$ and $b_\alpha\left(1+\beta_\alpha\right) = -0.374$ at reference redshift $z_{\rm ref} = 2.3$ from [1]. Also, we fix $\beta_d b_d = f\left(\Omega\right) = 0.968897$. To account for the fact that the mean redshift of different bins are not exactly at $z_{\rm ref}$, we assume the bias factor of the Lyman-α forest to evolve with redshift as $\left(1+z\right)^{2.9}$, as suggested in [14], and the redshift space distortion parameter for the Lyman-α forest to be constant with redshift. The bias factor of the DLAs is assumed to be constant in redshift as far as the fitting is concerned.

5 Results and Conclusions

The results for the overall sample are shown in a contour plot in Fig. 1. Note that the contour plot is showing smoothed contours. Our fit gives $b_d = 1.90 \pm 0.11$ at $z_{\rm ref} = 2.3$. Note that only bins with $r = \left(\pi^2+\sigma^2\right)^{1/2} \geq 10\,h^{-1}$Mpc and $r \leq 90\,h^{-1}$Mpc are considered for the fit, and that a single set of parameters was used to fit the data in all bins.

The value we obtain for the DLA bias, $b_d = 1.90 \pm 0.11$ is somewhat lower to that reported by [11], $b_d = 2.17 \pm 0.20$ for $\beta_\alpha = 1$. This corresponds to $b_d = 2.33 \pm 0.22$ for $\beta_\alpha = 1.39$ (see their section 4.7). Part of the discrepancy we see here is not a real discrepancy but it arises because we use different Lyman-α forest parameters and different fiducial cosmologies. The corrected value for the DLA bias from [11] is then $b_d = 2.09 \pm 0.19$, where we have assumed the relative error to be conserved. This value is still higher than our measurement, but is consistent with it being a statistical fluctuation. What is more, if we repeat our analysis using only DR9 quasars we recover $b_d = 2.09 \pm 0.16$ which is equivalent to the measurement reported in [11]. The difference in the measured errors lies on the fact that [11] uses a model to compute the covariance matrix and here we compute it directly from the data.

The dependence of the DLA bias with the DLA redshift is analysed by comparing the DLA-Lyman-α cross-correlation of samples Z1, Z2, and Z3. Left panel in Figure 2 show the

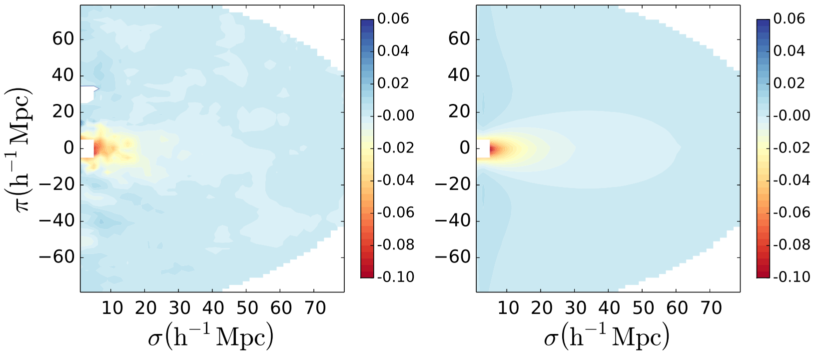

Figure 1: Contour plot of the measured DLA-Lyman-α cross-correlation (left) and our best-fit theoretical model considering bins with $10\,h^{-1}\mathrm{Mpc} < r = \left(\pi^2 + \sigma^2\right)^{1/2} < 90\,h^{-1}\mathrm{Mpc}$ (right).

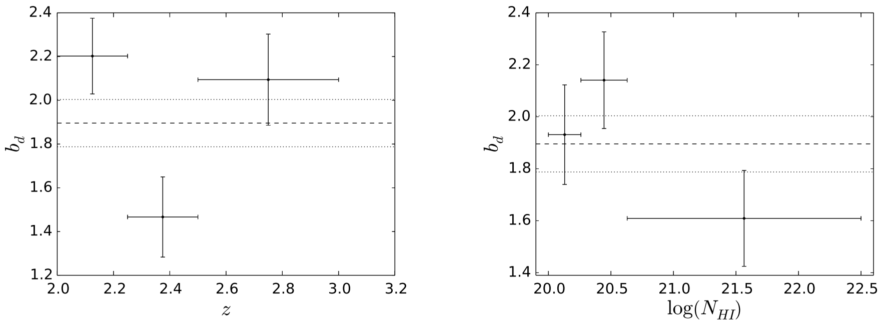

Figure 2: Bias of the DLA against z (left) and $\log(N_{HI})$ (right) obtained by fitting samples Z1, Z2, and Z3, and N1, N2, and N3 respectively. Dashed lines indicate the value obtained by fitting sample A. Dotted lines indicate the 1σ region.

measured dependence of the DLA bias with the DLA redshift. Similarly, to estimate the dependence of the DLA bias with the DLA column density, we compute the DLA-Lyman-α cross-correlations for sub-samples in column density, samples N1, N2, and N3. Right panel in Figure 2 shows the measured dependence of the DLA bias with the DLA column density. Our results indicate that there is no evolution of the DLA bias neither with redshift nor the DLA colomn density.

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