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Cross-correlation of Mg II absorption and galaxies in BOSS

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Abstract

We measure the cross-correlation of Mg II absorption and massive galaxies, using the Data Release (DR)11 main galaxy sample of the Baryon Oscillation Spectroscopic Survey (BOSS) of Sloan Digital Sky Survey III (SDSS-III; CMASS galaxies), and the DR7 quasar spectra of SDSS-II. The cross-correlation is measured in a blind analysis by stacking quasar absorption spectra shifted to the redshift of galaxies within a certain line-of-sight separation. The absorption spectra are obtained after dividing the quasar spectra by a quasar continuum model. Two models are presented and compared. We show that special care needs to be taken to use an unbiased continuum estimator in this type of analysis. Otherwise systematic errors are likely to be introduced in the mean stacked MgII equivalent width.

We find that at large impact parameter the measured cross-correlation follows the galaxy correlation function, although measurement errors are large. We derive the bias factor of Mg II absorbers, finding $b_{\rm MgII} = 2.33 \pm 0.19$, where the error accounts only for the statistical uncertainties in measuring the mean equivalent width. We discuss the modeling uncertainties that may cause the bias factor to be larger than that found in the literature, but if correct it suggests that the Mg II absorbers at redshift $z \simeq 0.5$ are spatially distributed on large scales similarly to the CMASS galaxies in BOSS.

1 Introduction

Magnesium is amongst the most abundant of the heavy elements. The Mg II doublet, at rest-frame wavelengths $\lambda = 2796.3543$ Å and 2803.5315 Å, presents a large oscillator strength and is easily observable from ground-based telescopes at $z > 0.3$. Thus, the Mg II doublet absorption line has been widely studied in the literature (see e.g [2], [3], [10], [11], [16]).

An association of Mg II absorption systems with galactic halos was established in [13], [1], and [21]. Mg II absorption with rest-frame equivalent width $W > 0.3$ Å is nearly always observed at impact parameters $r_p \leq 50(L_{\rm K}/L^*_{\rm K})^{0.15}$ kpc of a galaxy K-band luminosity L_K, and becomes rapidly weaker at larger radii for all the considered galaxy types ([22]). This leads to a simple model of halos that are close to spherical and is consistent with the fast declined of the mean Mg II equivalent width, $\overline{W} \propto r_{\rm p}^{-1.5}$, shown in more recent studies ([6], [7]).

The association with galaxies implies a large-scale cross-correlation of these objects. At small scales, the cross-correlation will be dominated by the actual association of an absorbing cloud with a galaxy. At large scales, however, the dominant effect will be the absorbing cloud being associated with a different galaxy that may be a satellite of the first, or simply an unrelated galaxy that is spatially correlated with the first. At intermediate scales there will be a mixture of both effects that is impossible to cleanly separate.

The typical approach in measuring the large-scale Mg II-galaxy cross-correlation is to compute it from a catalog of Mg II absorbers and was first measured using the photometric catalog of Luminous Red Galaxies in SDSS ([23]) and the set of individually detected Mg II absorbers in the spectra of SDSS quasars by [4], [5], [14], [9] and [15]. Using slightly different samples, a bias factor for the Mg II absorbers of $b_{\rm Mg} = 1.10 \pm 0.24$ was obtained by [15], and $b_{\rm Mg} = 1.36 \pm 0.38$ was derived in [9].

This approach, however, requires extensive use of simulations, because the number of absorbers will be enhanced in the regions with higher signal-to-noise spectra, owing to variable observing conditions. Here, we present a different approach. We perform a blind analysis in the sense that we do not try to detect the Mg II absorption. Instead, we use a stacking method the measure the average absorption around a galaxy as a function of the impact parameter and redshift separation. The data and the method used are described in Section 2, and the results and conclusions are presented in Section 3. Throughout this paper we use the ΛCDM model with $H_0 = 68\,{\rm km\,s^{-1}\,Mpc^{-1}}$ and $\Omega_m = 0.3$.

2 Data & Method

2.1 Background and foreground samples

As background and foreground samples we use the quasar catalog of [20] from the 7$^{\rm th}$ Data Release of the SDSS-II Collaboration and the CMASS catalog from the 11$^{\rm th}$ Data Release of the SDSS-III Collaboration respectively. After applying some cuts described in [19] we end up having 105,783 quasars as background sample and 895,472 galaxies as foreground sample.

2.2 Stacking procedure

To compute the stacked absorption profiles of the MgII doublet the following steps are required. Each quasar spectrum is shifted to the redshift of the galaxy that it is paired with to obtain the cross-correlation, and divided by a continuum model (obtained from the mean quasar continuum) to obtain an absorption spectrum. Finally, these absorption spectra are stacked at each impact parameter bin, to obtain the mean absorption profile around the average CMASS galaxy.

We have developed a special method that recovers the mean equivalent width of all lines, whether or not they are detected in individual spectra, and we have shown that other methods that are often used to set the continuum suffer from a bias due to the effect of undetected absorption lines on the continuum determination ([19]).

The results of the stacked absorption profiles, $\delta\tau_{\rm e}\,(r_{\rm p}, v)$, are obtained for a total of 17 impact parameter intervals, measured in proper units at the redshift of the galaxy. The first interval is for $r_{\rm p} < 50\,{\rm kpc}$, and the other 16 intervals are $2^{(i-1)/2} < (r_p/50\,{\rm kpc}) < 2^{i/2}$, for $i = 1$ to 16, up to a maximum impact parameter of 12.8 Mpc.

2.3 Model

Our stacked spectra measure the mean excess of the effective optical depth as function of impact parameter $r_{\rm p}$ and velocity separation from a galaxy. The integrated absorption from these spectra,

$$W_{\rm e}\,(r_{\rm p}) = \frac{\lambda_{\rm MgII}}{c} \int \delta\tau_{\rm e}\,(r_{\rm p}, v)\,{\rm d}v \ , \tag{1}$$

is related to the projected cross-correlation.

The cross-correlation of Mg II absorption systems and galaxies clearly reflects properties of the spatial distribution of these two objects. In the limit of large-scales, when the fluctuations are in the linear regime, these two population of objects are tracers of the large-scale mass perturbations. This means that the cross-correlation is equal to the correlation function of the mass times a bias factor for each of the species ([12], [8]). Here, we assume that the cross-correlation of the Mg II systems and CMASS galaxies is the same as the CMASS galaxies auto-correlation times the ratio of biases, $b_{\rm Mg}/b_{\rm g}$, of the two types of objects. In other words, we assume that the linear relation can be extended to the non-linear regime as far as the ratio of the cross-correlation to the auto-correlation is concerned.

This assumption can be justified from observations of the correlations of galaxies of different luminosity. [24] measured the projected correlation of the galaxies in the DR7 catalog in different luminosity ranges. To a good approximation and in the impact parameter range of our interest, the result is a fixed shape times the variable bias factor (see, e.g., their figure 6). This shape does vary slightly with the luminosity, but the most important variation is determined by the bias factor. Hence, our assumption can only be considered a first approximation that will need to be tested in the future, but it allows us to obtain a bias factor for the Mg II absorption systems assuming that they behave in a similar way as the CMASS galaxies.

Under this assumption the following relation holds:

$$W_{\rm e}(r_{\rm p}) = \frac{\lambda_{\rm MgII}}{c} \frac{\tau_{\rm e0}\, H(z)}{1+z} \frac{b_{\rm Mg}}{b_{\rm g}}\, w_{\rm gg}(r_{\rm p}) \ , \tag{2}$$

where $w_{\rm gg}(r_{\rm p})$ is the projected galaxy correlation function, $b_{\rm g}$ and $b_{\rm Mg}$ are the galaxy bias factor and the mean bias factor of Mg II absorption systems respectively, and $\tau_{\rm e0}$ is the average absorption from the population of MgII absorbers. We have used ${\rm d}v = H(z)/(1+z)\,{\rm d}x$, where ${\rm d}x$ is the comoving space coordinate that is integrated to obtain the projected galaxy

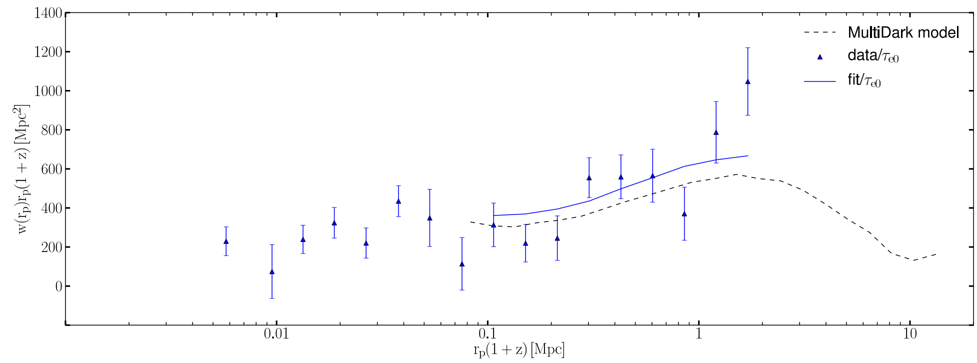

Figure 1: Projected correlation functions multiplied by the comoving impact parameter as a function of the comoving impact parameter $r_{\rm p}(1+z)$. Blue triangles are the mean equivalent width $W_{\rm e}(r_{\rm p})$ times the factor $(1+z)/H(z)/\tau_{\rm e0}$ times $r_{\rm p}(1+z)$. The thick solid black line is the MultiDark model prediction described in [18]. The solid blue line is the fit to $W_{\rm e}$ for the mean subtraction and the variable smoothing methods respectively. The ratio of the each of these lines with the thick solid black line is the ratio of bias factors, $b_{\rm Mg}/b_{\rm g}$.

correlation function, and z is the mean redshift of the galaxies and associated Mg II absorption systems.

3 Results & Conclusions

To derive the bias factor of the Mg II absorption systems we use [18] prediction for the galaxy correlation function based on assigning galaxies to halos and subhalos in their MultiDark simulation. It is shown as a black thick line in Fig. 1. They obtain a galaxy bias of $b_{\rm g} = 2.0 \pm 0.07$. We also use $\tau_{\rm e0} = 5.0 \times 10^{-4}$. This value is derived from [17] and is subject to uncertainties owing to the redshift evolution and the accuracy of the fit to the equivalent width distribution.

The results we obtain for the Mg II absorption bias factor is

$$b_{\rm Mg\,mean\,subtraction} = 2.33 \pm 0.19 \ , \tag{3}$$

and is shown in Fig. 1.

Our measurement for the Mg II bias factor is discrepant from the previously reported values by [9] of $b_{\rm Mg} = 1.36 \pm 0.38$, and by [14] of $b_{\rm Mg} = 1.10 \pm 0.24$. Our result is closer to the bias factor measured for the galaxies, implying that most of the Mg II systems are associated to massive galaxies like the CMASS ones or even more massive.

There are several arguments to explain the observed discrepancy. One possible reason is the degeneracy between $\tau e0$ and $b_{\rm Mg}$. We can only recover the Mg II bias once $\tau_{\rm e0}$ is fixed to a specific value. This means that an underestimation of $\tau_{\rm e0}$ will result in an overestimation of $b_{\rm Mg}$. Another possible explanation may be that there is a real difference, because our measurement includes a contribution from weak Mg II absorption systems which may be more strongly clustered than strong absorbers. Both [14] and [9] found hints that it was indeed the case, although this result was not statistically significant. More accurate measurements and better modeling will be necessary to clarify this question. Yet another possible explanation is our use of a limited velocity range for evaluating the projected cross-correlation of MgII absorption and galaxies. We note that the point at largest impact parameter pushes the bias to a higher value. This point might be too high because linear redshift distortions have increased the density of MgII absorbers in the interval used for integration, and decreased them in the interval used for continuum fitting. The projected cross-correlation should not be affected by these redshift distortions when it is computed by integrating over the whole line of sight, but at the largest impact parameters our integrating intervals are probably not large enough.

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