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Revisiting the incidence of Mg II absorbers along the blazar sightlines

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Abstract: It is believed that the cool gas clouds traced by Mg II absorption, within a velocity offset of 5000 km/s from the background quasar, are associated with the quasar itself, whereas the absorbers seen at larger velocity offsets towards us are intervening systems and hence their existence is completely independent of the background quasar. Recent evidence by Bergeron et al. 2011 (hereafter BBM), however, seriously questions this canonical view, by showing that the number density of intervening Mg II absorbers along the sightlines towards 45 blazars is, on average, $\sim$ 2 times the expectation based on the Mg II absorption systems seen on the sightlines to normal QSOs. Given the serious implications of this finding, it becomes important to revisit this issue by enlarging the source sample and subjecting it to an independent analysis. Here, we first report our results based on a re-analysis of the spectroscopic data for the BBM sample; this has reproduced their factor 2 excess in dN/dz along blazar sightlines, vis-a-vis the normal QSOs. Next, we assemble a 6 times larger sample of blazar sightlines, albeit with lower SNR. Using this enlarged sample together with the BBM sample, our analysis shows that the dN/dz of Mg II absorbers statistically matches that known for normal QSO sightlines.

1 Introduction

The analysis of quasar absorption-line systems has emerged as a powerful tool for investigating the physical conditions of the gaseous medium of intervening galaxies, particularly when they lie at extremely large distances and are hence too faint for direct imaging/spectroscopy even with the largest telescopes. It is widely held that the cool gas clouds (e.g., Mg II absorption systems) with velocities $\beta c \leq 5000$ km/s relative to the background quasar are gravitationally bound to the quasar itself ('associated systems'), whereas absorbers showing larger velocity offsets towards us are 'intervening systems' whose existence therefore should be completely independent of the background quasar. Recent evidence, however, appears to question this canonical view and suggests instead that even associated systems can have significantly relativistic speeds relative to the quasar (e.g., during the quasar phase of powerful jet activity and/or high speed accretion-disk outflow, BBM). A possible

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evidence for this would be if the incidence rate, dN/dz, close to the blazar (i.e. low velocity offset) will be higher due to the inclusion of absorption as a consequence of high speed jet driven outflows, as compared to normal QSOs (i.e without jet).

Indeed, this expectation is echoed in the unexpected finding of BBM that, on average, dN/dz of Mg II absorption systems for strong absorbers (having rest frame equivalent width of the $\lambda2796$ line (w_r) > 1 Å) towards blazars is ~ 2 times (at 3σ confidence) the value known for sightlines to normal quasars (QSOs). Recently, Joshi et al. (2013) probed this by using a large set of redshift-matched sightlines of 3975 core-dominated (CDQs) and 1583 lobe-dominated (LDQs) quasars, but they found only a mild (9% at 1.5σ significance) excess of dN/dz for CDQ sightlines. On the other hand, the excess seen by them for the CDQs in the $dN/d\beta$ distribution (with $\beta = v/c$) has a much higher significance (3.75σ) for $\beta < 0.1$. Similarly, Chand et al. (2012) have analyzed the existing high-resolution spectra of about 115 FSRQs (CDQs, non-blazar type) and they, too, did not find any excess as remarkable as that reported by BBM for blazars. They reconcile the results for CDQs and blazars by invoking the jet orientation scenario which lies at the heart of the Unified Scheme for powerful extragalactic radio sources. In their explanation, since CDQs are probably less closely aligned to the line-of-sight, any gas clouds accelerated outward by their powerful jets are unlikely to appear in the foreground of the quasar nucleus and hence escape detection in absorption against the quasar. On the other hand, it should also be appreciated that the BBM result rests on just 45 blazars, due to which small number statistics could be at work. It is relevant to recall that the 4-fold excess of dN/dz along the sightlines to gamma ray burst (GRB) sources, which was inferred by Prochter et al. (2006) using just 14 GRB sightlines, has recently been pronounced as a possible statistical fluke, on the basis of a 3 times larger sample (Cucchiara et al. 2013). Given the potentially deep ramifications of the BBM result, it seems worthwhile to revisit their finding of excess dN/dz towards blazars, by enlarging the blazar sample size and subjecting it to an independent analysis, as we present here.

2 The Enlarged Blazar Sample and Data Reduction

The blazar sample employed in our analysis is an amalgamation of the blazar compilations from 3 catalogs namely; ROMA-BZCAT (Massaro et al. 2009) , Véron-Cetty et al. (2010) , and Padovani et al. (1995). From the ROMA-BZCAT, we have taken sources with BZB classification (i.e., confirmed BL Lac). From the Véron-Cetty et al. (2010) catalog we included sources classified either as 'BL' (i.e., confirmed BL Lac), or 'HP' (a confirmed high polarization quasar, i.e., a blazar). The third catalog we have used is that of Padovani et al. (1995). Merging these 3 sets resulted in a final 'parent sample' of 1352 confirmed blazars . We then applied two main filters: (i) a median SNR of the whole spectrum is more than 5 so that false detection of Mg II lines due to noisy spectrum can be minimized; (ii) a blazar redshift must satisfy the condition that a minimum 10 Å wide observational coverage of the spectral range between the Lyα and Mg II emission lines is available, so that its spectrum is useful for the search of at least one Mg II doublet (given the 7.1 ± 0.25 Å spacing between the members of the Mg II doublets in the rest frame). From the application of these two selection filters to an extensive archival search for spectra (e.g,. from SDSS, ESO & Keck archives), we finally assembled a sample of 251 blazars whose details will be presented elsewhere (Mishra et al. in prep).
In addition, we have made use of the BBM blazar sample. The parent sample employed in their analysis contains of 45 blazars, out of which observation of 42 blazars had been carried out using the FOcal Reducer and low-dispersion Spectrograph (FORS1) at the ESO-VLT telescope under the program ID 080:A-0276, 081:A-0193. The raw data used in the BBM analysis for the remaining 3 northern sky BL Lacs were not accessible and hence could not be included in the present work. Details of our data reduction procedure will be reported in Mishra et al. (2017, in preparation). In brief, we

have used the ESO pipeline FORS-kit-5-1-4[1] for reducing the FORS data used in the BBM sample. The (lower dispersion) spectral data for the remaining sources were reduced using the standard IRAF tasks. For post-processing of the individual exposures, and combining them to generate the final normalized spectra and search for the Mg II feature, we followed the standard procedure outlined in Chand et al. (2012).

3 Computation of dN/dz

In assessing the absorption properties for a given spectrum, a proper evaluation of noise plays a vital role, as it defines the detection limit of equivalent width (EW$_{det}$) such that only those spectral regions which have EW$_{det}$ less than the equivalent width threshold (EW$_{th}$) can be included in the dN/dz analysis. To find such usable spectral regions we employed a matched-filter technique devised by Zhu et al. (2013) for generating the noise spectrum and to calculate the EW$_{det}(z_j)$ at a given pixel corresponding to the Mg II absorption redshift z$_j$ in the spectrum. The incidence rate of Mg II absorbers, is defined as $\frac{dN}{dz} = N_{obs}/\Delta z$; where N_{obs} is the total number of Mg II absorbers within the entire included redshift path within the spectrum, Δz; where the total redshift path, Δz, is defined as:

$$\Delta z = \int_0^\infty g(EW_{det}, z_j)dz \tag{1}$$

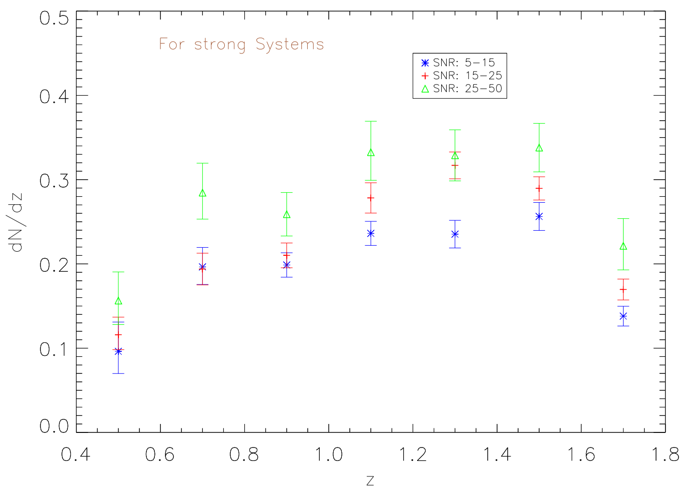
g$(EW_{det}, z_j) = 1$ if EW$_{th}$ (= 0.3 Å for weak and = 1 Å for strong systems) is more than 3× (EW_{det}, z_j) (for 3σ confidence) and g$(EW_{det}, z_j) = 0$ otherwise. Table 1 lists the computed value of Δz for our samples. The errors in the computed values of dN/dz were estimated assuming Poisson low number statistics for $N_{obs} < 50$, within a limit of 1σ confidence level of a Gaussian distribution, employing a table given by Gehrels et al. (1986).

4 Result and Conclusion

In order to probe the BBM claim of excess of Mg II absorbers towards blazars in comparison to normal QSOs, we revisited the issue by an independent re-analysis of the spectral data for the BBM sample. As seen from Table 1, our results are in good agreement with BBM. However, it is also evident from Table 1 that our enlarged sample shows no significant excess of Mg II clouds along the blazar sightlines, as compared to the QSO ones. A key difference between the BBM sample and the present enlarged sample is that the spectra in the former have high SNR (35-250) while our sample mostly consists of SDSS spectra for which the SNR is modest (5-30). As per the definition of a good redshift path (e.g, see Eq. 1), the choice of a threshold SNR is not expected to distort the derived (normalised) value of dN/dz for a given sample. Nevertheless, one may wish to check if samples with distinctly lower SNR spectral data suffer from some unknown bias(es), as compared to high SNR samples. Hence, we compared the Mg II absorption-line incidence rate using subsets of QSO spectral regions falling in different SNR bins of their spectra (where SNR here is derived by taking its median value in the continuum region of the good redshift path in a given redshift bin; Fig. 1).

For this we used the recent catalog[2] by Raghunathan et al. (2016), based on the SDSS-DR12. Absorption line data, such as the number of Mg II absorbers, absorption redshifts, equivalent widths and corresponding errors were taken from that catalog, while the redshift path was calculated by us following Zhu et al. (2013) (details will be presented in Mishra et al. 2017, in preparation). We plotted dN/dz vs z for the Mg II absorbers for 3 SNR bins (refer to the left panel in Fig. 1 to figure out if SNR affects the dN/dz). Unexpectedly, it turns out that the dN/dz vs z curve (left panel in Fig. 1)

[1]http://www.eso.org/sci/software/cpl/esorex.html
[2]http://srini.ph.unimelb.edu.au/mgii.php



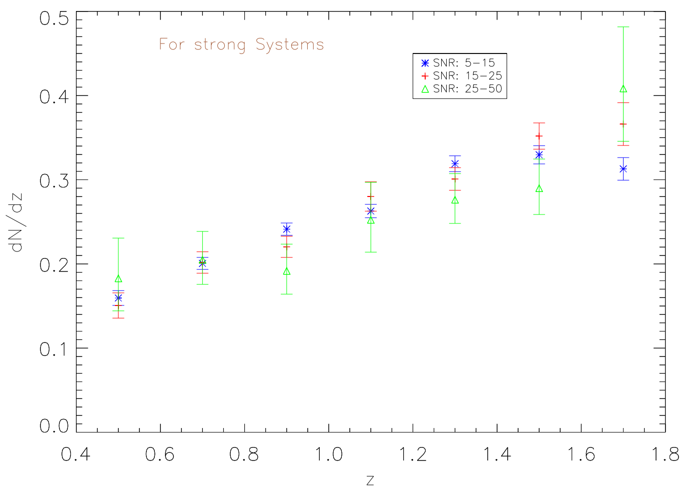


Figure 1: *Top:* Evolution of dN/dz vs z of Mg II absorbers with $EW_{rest} > 1$ Å based on the SDSS-DR12 catalog of Mg II absorption lines by Raghunathan et al. (2016) is plotted for three different SNR bins of continuum regions viz: 5-15 (blue, asterisk), 15-25 (red, plus) and 25-50 (green, triangle). *Bottom:* same as left but using the SDSS-DR7 catalog of Mg II absorption lines by Zhu et al. (2013).

based on significantly higher SNR spectra exhibits a higher incidence rate compared to that derived using the sightlines belonging to low SNR regions, as dN/dz is expected to be SNR independent by the definition of a good redshift path (details will be presented in Mishra et al.2017). To check whether this counter-intuitive dN/dz dependence on the SNR of the continuum regions in the spectra is related to some unknown systematics in the SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS) spectra, we extended this analysis to the SDSS-DR7 QSO sample, which has been searched for Mg II systems by Zhu et al. (2013). The results are shown in the right panel of Fig. 1, where no clear dependence on SNR is evident, contrary to our finding based on the Mg II catalog derived from BOSS-DR12 (left panel of Fig. 1), hence we caution about the use of statistical results based on the later catalog for such analysis, which needs further detailed investigations. We thus conclude that (i) our independent analysis of the blazar sample used by BBM has reproduced the factor two excess in dN/dz along the blazar sightlines vis-a-vis QSO sightlines, as claimed by BBM, and (ii) by enlarging the blazar sample size by ~ 6 times (though with a lower SNR), and combining it with the BBM sample, we arrive at a dN/dz estimate which is in statistical agreement with the dN/dz found for QSO sightlines. A satisfactory resolution of this apparent discrepancy would need systematic accumulation of high SNR spectra for larger samples of blazars, which we plan to undertake with the recently commissioned ARIES 3.6-m Devasthal Optical telescope (DOT).

Table 1: Comparison of the Mg II absorption systems towards blazars.

Sample Type	Weak absorption systems (0.3 Å $\leq w_r < 1.0$)				Strong absorption systems ($w_r \geq 1.0$ Å)			
	N	Δz	$\frac{dN}{dz}$	$\left(\frac{dN/dz}{(dN/dz)_{QSO}}\right)$	N	Δz	$\frac{dN}{dz}$	$\left(\frac{dN/dz}{(dN/dz)_{QSO}}\right)$
BBM Sample	18	27.70	$0.65^{0.19}_{0.15}$	$^{*}1.51^{0.45}_{0.35}$	12	29.87	$0.40^{0.15}_{0.11}$	$^{*}2.06^{0.78}_{0.59}$
Sample I $^{\beta}$	25	51.00	$0.49^{0.12}_{0.10}$	$1.14^{0.28}_{0.23}$	20	98.75	$0.20^{0.06}_{0.04}$	$1.09^{0.30}_{0.24}$
Sample II$^{\kappa}$	19	33.84	$0.56^{0.16}_{0.13}$	$1.30^{0.37}_{0.29}$	13	61.20	$0.21^{0.08}_{0.06}$	$1.11^{0.40}_{0.31}$

* BBM found an excess factor of $1.7^{0.5}_{0.4}$ for weak and $2.2^{0.8}_{0.6}$ for strong absorption systems
$^{\beta}$ Enlarged Sample of blazars (sources with only an upper limit on z_{emi} are also included)
$^{\kappa}$ sample of blazars with known emission line redshifts

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