Astron. Astrophys. 275, L21–L24 (1993)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

A strong dependence of the narrow C IV absorption line density on the quasar emission redshift*

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Received March 25, accepted May 28, 1993

Abstract. The motivation for our work was to search for indications of gravitational lensing in samples of narrow metal absorption line systems observed in quasar spectra. We here discuss statistical properties of highly displaced CIV systems, taken from the line lists of five surveys found in the literature. In the combined sample, the number of systems per unit redshift range is strongly dependent on the quasar emission redshift z_e; most significant is a "break" at $z_e \simeq 2.8$. The only plausible explanation is a strong selection effect varying with z_e; for $z_e \gtrsim 2.8$, most quasars are selected with respect to the detection of Ly α emission in objective prism surveys. The negative redshift evolution of the absorbers, being present for absorption redshifts $z_a \gtrsim 1.8$, is possibly nothing but a reflection of this selection effect. We conclude that our result makes the *association hypothesis* for at least a large fraction of the absorbers more probable. Due to the non-uniformity of the yet observed quasar samples, it is not possible to test as to whether an amplification bias by gravitational lensing contributes to the z_e-dependence of the absorption line density.

Key words: Quasars: absorption lines

1. Introduction

This article deals with the narrow metal absorption lines found in the optical spectra of most medium- to high-redshift quasars. The narrow metal lines are usually considered to be a class of absorption features distinct from both the Ly α-forest lines and the broad absorption lines (BAL). The latter ones originate very probably in gas ejected by the quasar, whereas most investigators assume that the other two classes are cosmologically intervening (see § 2). Due to the initially unknown z_a, the type of ions causing a certain narrow metal line can only be determined if the line belongs to an *absorption system* of two or more lines having specific wavelength ratios. Most frequently identified are the doublets MgII 2796,2803 and CIV 1548,1551. Sometimes a system can also be defined on the basis of other lines alone; however, by rule of thumb, one of these doublets is then found, too, if it is located in a useful region of the actual quasar spectrum beyond the Ly α forest. Therefore one has only to distinguish between the "MgII-systems", generally found at $0.3 \lesssim z_a \lesssim 1.5$, and the "CIV-systems", found at $1.3 \lesssim z_a \lesssim 3.5$, respectively limited through the wavelength coverage of typical spectra. We concentrate here on the latter ones which can only be searched for between the broad Ly α (+NV) and CIV emission lines if one is interested in line samples, S_o, complete with respect to a lower limit in the *observed* equivalent width W_o. This spectral range corresponds to a redshift interval $[z_{a,min};z_e]$ of width $\Delta z_{a,tot} \simeq 0.22(1+z_e)$ as well as to a range in velocities, $0.0 \lesssim \beta \lesssim 0.2$ (in units of c), of the systems with respect to the quasar. There is an excess of systems with $\beta c \lesssim 5000\,\mathrm{km\,s^{-1}} = \beta_0 c$. It is usually brought into connection with the (super-)clusters surrounding the quasars; such systems are obviously not cosmologically intervening. In the following, we exclude all systems with $\beta \leq \beta_0$, leaving only the *highly displaced systems*. Consequently, we restrict the considered redshift interval $[z_{a,min}; z_{a,max}]$ in each spectrum to this highly displaced range of width $\Delta z_a \simeq 0.20(1+z_e)$.

When studying the physical nature of the absorption systems by a statistical analysis of a line sample, completeness with respect to the *rest-frame* equivalent width W_r is reasonable to require. Such a sample, S_r, can easily be extracted from a sample S_o since $W_o = (1+z_a)W_r$. For our analyses, we use the line lists of five published CIV-absorption surveys (Young et al. 1982, hereafter YSB; Foltz et al. 1986, FWP; Sargent et al. 1988, SBS; Steidel 1990, S90; Barthel et al. 1990, BTT). The corresponding samples S_r are listed in separate tables in each of these publications. We give an overview in Table 1.

2. Physical origin of the absorbers

Until the end of the '70s, there was a continuous, mainly bipolar controversy about the physical origin of the narrow metal lines (e.g. Perry et al. 1978; Weyman et al. 1981, hereafter WCS): **H1**, the "intervening hypothesis", states that the systems originate in gas clouds (of e.g. galaxies) located at the cosmological distances which are indicated by z_a; whereas **H2**, the "association hypothesis", assumes an origin in the vicinity of the quasar, e.g. ejected gas. The truth, however, lies probably in a certain combination of H1 and H2, since it is well known that there exist some quasars lying behind galaxies which contain gas *and* that quasars are able to eject matter with a β-value of at least ≈ 0.1 (BAL quasars). In their 1981 review, WCS did "sense ... a fairly strong shift in opinion" towards H1; they did not want to judge, however, "whether this represents a real gain in understanding or merely an exchange

*dedicated to G. Burbidge who never ceased in demanding a second thought on accepted quasar properties

Table 1. Samples of CIV-absorption line systems. SR: spectral resolution; $W_{\rm r,lim}$: limiting value above which the sample is complete; $\sum_i \Delta z_{\rm a}(i)$: summed up range in redshift space in which systems could be found that fulfill the selection criteria; $n_{\rm a}$: number of (highly displaced) systems that can be used for a combined sample with $W_{\rm r,lim} = 0.3$ Å. Quasars included in more than one survey are listed only once

Ref.	SR (Å)	$n_{\rm qso}$	$z_{\rm e}$	$W_{\rm r,lim}$ (Å)	$\sum_i \Delta z_{\rm a}(i)$	$n_{\rm a}$ (>0.3Å)
YSB	2.5	16	1.4–2.7	0.3	8.3	11
FWP	1.0	27	1.4–1.9	0.3	10.1	10
SBS	0.8/1.5	55	1.8–3.6	0.15	33.5	67
S90	1.0	11	3.1–4.1	0.15	9.3	6
BTT	5.0	17	1.6–3.8	0.3	9.4	11
Total	—	126	1.4–4.1	—	70.6	105

of prejudices associated with a change of reviewers". The intervening model seems to have been accepted since that time and only few investigators (see, e.g., Turnshek and discussions in Blades et al., 1988, for examples found in a single publication) tried to follow H2. There are many indications for H1 representing the more plausible explanation for most of the highly displaced systems (e.g. Sargent 1988); however, there is indeed ***no strict physical proof*** to rule out that a significant fraction of the CIV absorbers is directly associated with the quasars. In § 3 and 4, we postulate H1 as a working hypothesis.

3. Bias effects

If the narrow metal absorption line systems were associated with the quasars (H2) their number could well depend on other quasar properties. In this case selection effects might be very important for the statistics of absorption lines. However, assuming H1 the probability of finding an absorption systems at a redshift $z_{\rm a}$ should be the same for quasars out of any *complete sample* at redshift $z_{\rm e} > z_{\rm a}$. The only effect that can influence the statistics is introduced by observing ***flux limited quasar samples***. The motivation for our work was to search for indications of an ***amplification bias*** (e.g. Borgeest et al. 1991, "magnification bias" is used synonymously) by gravitational lensing. The quasars selected for CIV absorption line surveys belong in general to the most luminous ones. It is well known that many highly luminous quasars (HLQs) are affected by gravitational lensing (e.g. Surdej et al. 1993). The quasar luminosity function is very steep at its bright end so that a relatively high percentage of HLQs entered this class through amplification by lensing. Lensing objects are galaxies or clusters of galaxies. If now these galaxies cause absorption in the quasar spectra one may argue that the HLQs should show an enhanced number of absorption lines compared to fainter quasars which, however, have until now not been observed at comparable spectral resolution. The lines-of-sight to HLQs might therefore represent biased directions for cosmological studies (cf. Thomas & Webster 1990). Radio selected high redshift quasars are even subject to a double bias (Borgeest et al. 1991), the first due to the radio flux limit in the original survey, the second due to the optical flux selection of the absorption line survey. Possibly, there is an opposite bias, a "de-amplification bias", which may sometimes even overwhelm the lensing bias in the optical: If a significant fraction of the sky is covered by dust associated with absorption systems (cf. Ostriker 1988) the HLQs would appear predominantly in dust-free regions and would, therefore, show less absorption lines. The importance of bias effects can be tested by looking for a correlation between the number density (in redshift space) of the absorption systems and the quasar luminosity. SBS plotted the number of systems versus M_V – with a negative result. However, SBS would have found a result similar to that found by us (see § 4.2) if they had plotted number densities instead of pure numbers. Another possibility, which we follow in the next section, is to look for a correlation between the absorption line density and the emission redshift $z_{\rm e}$: (i) statistically, $z_{\rm e}$ is correlated with the luminosity; (ii) the optical fluxes of the quasars treated in this letter have not been measured uniformly; $z_{\rm e}$ is therefore a much better defined observable than the luminosity; (iii) with increasing $z_{\rm e}$ the probability of a galaxy with $z_{\rm a,min} < z_{\rm gal} < z_{\rm a,max}$ to lie in front of a quasar increases so that bias effects become stronger.

4. Statistical analysis

It is somewhat problematic to combine data obtained under different spectral resolution (SR, Table 1) since some systems tend to split into sub-systems in higher resolution spectra. The number of systems found does therefore weakly depend on SR. We have not corrected for this effect because the quasars included in more than one survey show only marginal differences. In addition, it is easily seen that the effect works in opposite directions depending on $W_{\rm r}$ of the unresolved line. Note that we did not restrict the combined sample, as described by SBS, to create a "Poisson sample".

4.1. Number densities in the $z_{\rm e}\times z_{\rm a}$-plane

In Fig. 1*a*, we have plotted the locations of the absorption systems two-dimensionally, in the $z_{\rm e}\times z_{\rm a}$-plane. Each spectrum obtained during the surveys is represented by a vertical line, indicating the range $\Delta z_{\rm a}(i)$ in which the completeness criteria are fulfilled; each absorption system is marked by a dot. This presentation gives a nice overall view of the whole data set. Systems were only found in intervals $[z_{\rm a,min}; z_{\rm a,max}]$ of widths $\Delta z_{\rm a} = 0.20(1+z_{\rm e})$, between the CIV- and Ly α emission lines. In the $z_{\rm e}$-direction the width of the window $[z_{\rm e,min}; z_{\rm e,max}]$ is $\Delta z_{\rm e} = 0.26(1+z_{\rm a})$. Let us now assume an idealized quasi-continuous distribution of absorption systems. With $\partial^2 N(z_{\rm a}, z_{\rm e})$ being the number of systems in the small area $\partial z_{\rm a} \partial z_{\rm e}$ and $n_{\rm qso}$ the number of spectra that contribute spectral information to this area, we can define the surface number density

$$\mathcal{N}_{\rm a,e}(z_{\rm a}, z_{\rm e}) = \frac{1}{n_{\rm qso}(z_{\rm a}, z_{\rm e})} \frac{\partial^2 N(z_{\rm a}, z_{\rm e})}{\partial z_{\rm a} \partial z_{\rm e}} \,. \tag{1}$$

Linear densities in the $z_{\rm a}$- and $z_{\rm e}$-direction, respectively, are obtained by projection:

$$\mathcal{N}_{\rm a}(z_{\rm a}) = \int_{z_{\rm e,min}}^{z_{\rm e,max}} \mathcal{N}_{\rm a,e} \, {\rm d}z_{\rm e} \,, \qquad \mathcal{N}_{\rm e}(z_{\rm e}) = \int_{z_{\rm a,min}}^{z_{\rm a,max}} \mathcal{N}_{\rm a,e} \, {\rm d}z_{\rm a} \,. \tag{2}$$

Usually $\mathcal{N}_{\rm a}$ is described by a power law, $\mathcal{N}_{\rm a} \propto (1+z_{\rm a})^\gamma$, e.g. SBS and S90 found $\gamma \lesssim -1$. Assuming that all absorption systems are cosmologically intervening (H1) and that bias effects can be ignored, γ indicates the cosmological evolution of the absorbers. The surface density $\mathcal{N}_{\rm a,e}$ would then only reflect the distribution of $\mathcal{N}_{\rm a}$, i.e.

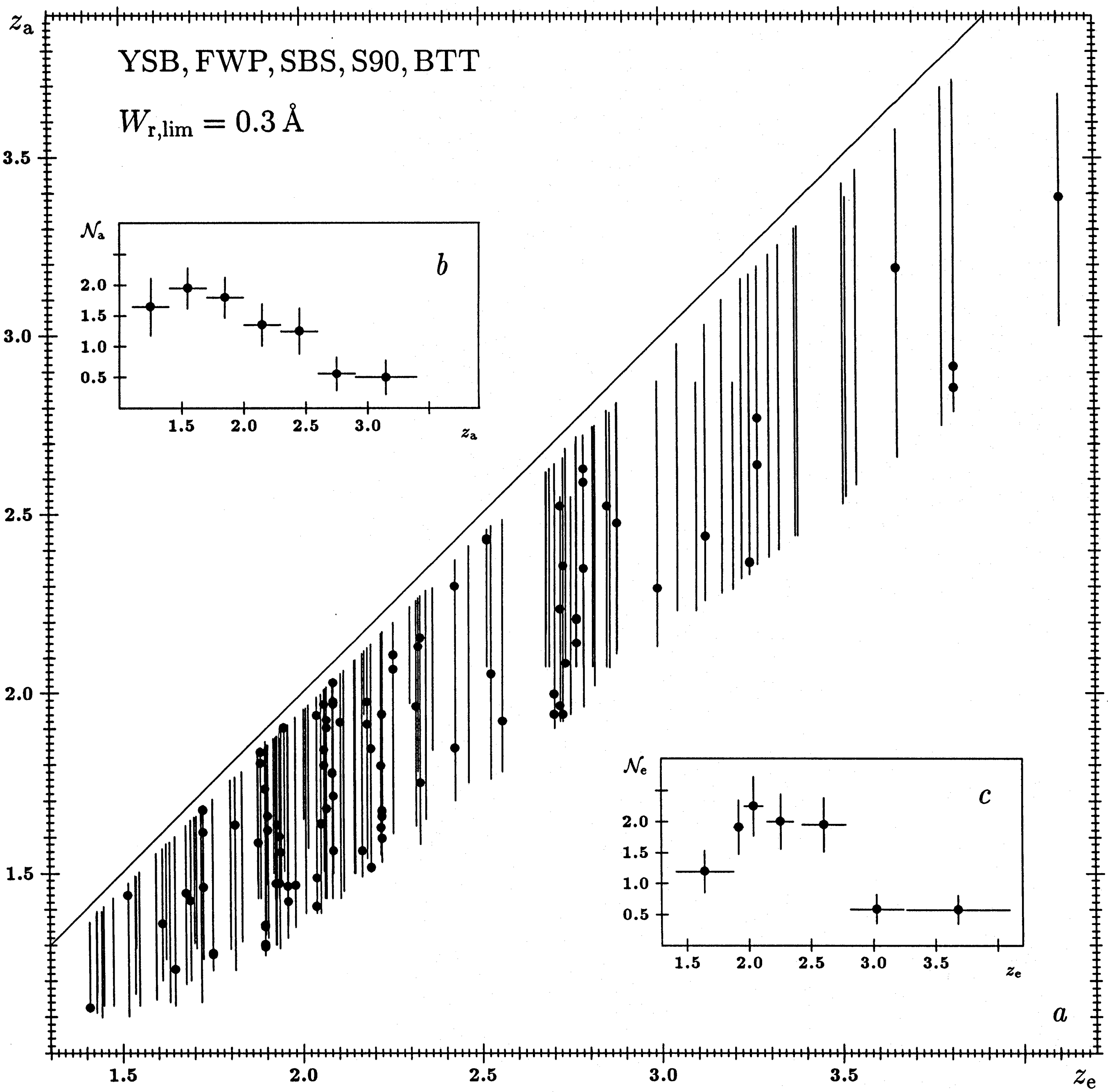

Fig. 1. *a:* Plot of all 126 spectra, including 105 highly displaced systems indicated by dots. Vertical lines represent the spectral regions fulfilling the completeness criteria. The location of the broad CIV emission line is indicated by a straight line. *b:* Number density $\mathcal{N}_a$; for the vertical error bars, we assumed Poisson statistics. *c:* Number density $\mathcal{N}_e$; due to the non-uniform z_e-distribution of the spectra, we have here chosen bins containing roughly the same co-added path length $\sum_i \Delta z_a(i) \simeq 10$

$$\mathcal{N}_{a,e}(z_a, z_e) = \mathcal{N}_a(z_a)/\Delta z_a(z_e)\,. \tag{3}$$

Under these assumptions, the systems have in the z_e-direction an *expected distribution*

$$\mathcal{N}_e^\star(z_e) \simeq \frac{1}{0.20(1+z_e)} \int_{z_{a,\min}}^{z_{a,\max}} \mathcal{N}_a(z_a)\,\mathrm{d}z_a\,, \tag{4}$$

which should be statistically equivalent to $\mathcal{N}_e$ for any quasar sample. If, e.g., $\mathcal{N}_a$ is given by a power law it is easily seen that Eq. (4) yields the same power law for $\mathcal{N}_e^\star$. A significant difference between $\mathcal{N}_e^\star$ and $\mathcal{N}_e$ gives a hint on bias effects in the sample.

4.2. The actual sample

In Figs. 1*b*,*c*, we show $\mathcal{N}_a$ and $\mathcal{N}_e$, respectively, for the combined sample. The distribution $\mathcal{N}_a$ is fairly smooth and consistent with a monotonically decreasing function, e.g. a power law with negative γ. In contrast, $\mathcal{N}_e$ shows a "break" at $z_e \simeq 2.8$ which is about as significant in the survey carried out by SBS and S90 (also for $W_{r,\rm lim} = 0.15$ Å). As noted above, we expect from the smooth distribution of $\mathcal{N}_a$ that $\mathcal{N}_e$ is smoothly distributed, too. The break in $\mathcal{N}_e$ contradicts the assumptions made. Note, however, that Figs. 1*b, c* are only used for illustration because the shapes of both distributions depend on the binning. To carry out a quantitative statistical test, we have calculated the cumulative distribution functions, corresponding to both $\mathcal{N}_e$ and $\mathcal{N}_e^\star$, from the distribution $\mathcal{N}_{a,e}$ derived from Fig. 1. We have then performed a Kolmogorov-Smirnov test with the result that one may reject the hypothesis that both distributions are drawn from the same parent distribution with a confidence above 97%. Thus we have to *conclude that the assumption that all systems are cosmologically intervening and that bias effects can be ignored is wrong.* Additional significance for this conclusion comes from the fact that the limiting redshift value, $z_e \simeq 2.8$, does roughly correspond to a discontinuity in the z_e-distribution of the quasars seen in Fig. 1. The discontinuity results from a selection effect: most quasars with $z_e \gtrsim 2.8$ have been discovered in optical surveys using the detection of broad emission lines as the criterium (e.g. indicated by "O" in Hewitt & Burbidge, 1989). At lower z_e about all quasars are selected with respect to radio flux or optical colour.

Above, we have assumed that $\mathcal{N}_a(z_a)$ is the basic relation. Changing the point of view, we suppose now that $\mathcal{N}_a$ is only a reflection of $\mathcal{N}_e(z_e)$, i.e. the expected distribution

$$\mathcal{N}_a^\star(z_a) \simeq \frac{1}{0.26(1+z_a)} \int_{z_{e,\rm min}}^{z_{e,\rm max}} \mathcal{N}_e(z_e)\,\mathrm{d}z_e \qquad (5)$$

should be statistically equivalent to $\mathcal{N}_a$. Interestingly, a Kolmogorov-Smirnov test shows indeed that $\mathcal{N}_a^\star$ and $\mathcal{N}_a$ are consistent with being drawn from the same parent distribution.

5. Discussion

The results obtained above are consistent with no redshift evolution of the absorber density being present for $z_a \gtrsim 1.8$. A break in the distribution function $\mathcal{N}_e(z_e)$ at $z_e \simeq 2.8$ is the most significant feature in the two-dimensional distribution of absorbers in the $z_e \times z_a$-plane. This break is probably due to the selection of quasars in the original surveys; most quasars with $z_e \gtrsim 2.8$ have been discovered in optical surveys using the detection of the Ly α emission line as the criterium. The break can most easily be understood in terms of the association hypothesis (H2); i.e. high redshift quasars with strong Ly α emission lines show less gas in the direction of the sight line.

When assuming the intervening hypothesis (H1) for all narrow CIV absorption systems, the break in $\mathcal{N}_e$ can only be caused by a bias effect; i.e. high redshift, strong Ly α emission line quasars appear predominantly in directions with less foreground galaxies than high redshift quasars selected with respect to other criteria. The strength of the amplification bias depends crucially on the exponent in the luminosity function of the quasars under consideration. If the luminosity function of strong Ly α emission line quasars would be less steep than that of other quasars, the latter ones could well show an enhanced average number of foreground galaxies. Note the additional effect of a double bias for radio selected quasars.

A strong amplification bias by gravitational lensing can only be present if most systems are associated with very massive foreground galaxies. But anyway there is a severe problem in assuming lensing as a reason for a strong bias effect, since the lenses have to be at the redshifts z_a of the absorbers which are all relatively high. The most effective lenses would, however, be expected at $z_a < 1$.

Up to now, there is no evidence for a significant amount of dust being associated with ordinary metal absorption systems. However, the possibility of a de-amplification bias should not be excluded in principle. In this case the (apparently) most luminous quasars have been found in directions with less dust than average.

Since most of the used samples are badly defined with respect to observed quasar parameters, except z_e, it seems neither possible at present to use statistical properties for discriminating between the intervening and the association hypothesis nor to determine the physical origin of the selection effect discussed above. At least it seems clear that the effect is too strong to be a result of an amplification bias by gravitational lensing alone.

Acknowledgements. We are indebted to J. Bergeron, P. Boissé, P. King, S. Refsdal, L. Wisotzki and the referee J. Surdej for very helpful comments. We thank J. v. Linde for repeatedly calling attention to the possible importance of extinction

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