THE NATURE OF ASSOCIATED ABSORPTION IN RADIO-LOUD QUASARS

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ABSTRACT

We have found eight quasars with associated Mg II absorption in a spectroscopic survey of 56 faint, steep-radio-spectrum quasars. Several of these quasars have the unusual properties of having very red rest-frame colors and/or high optical polarization. In contrast, quasars selected by the presence of associated C IV absorption show neither of these characteristics, although in both cases the absorption is correlated with steep radio spectral index. We discuss possible origins for associated absorption, including cluster galaxies, intracluster material, and material intrinsic to the quasar. We propose a model of intrinsic absorption in which there is a dusty disk of moderate optical depth surrounding the nucleus, and the absorption arises in outflowing equatorial material. We also discuss the parallel between the properties of these quasars and those of broad absorption line quasars.

Subject headings: quasars: absorption lines

1. INTRODUCTION

The nature of the narrow associated absorption lines seen in radio-loud quasars has been a mystery since Weymann et al. (1979) first noticed an excess of C IV absorbers with $z_{abs} \approx z_{em}$. An apparently unrelated question is the nature of quasars with anomalously red colors ($\alpha_{opt} > 2.5$, cf. $\alpha_{opt} \sim 0.7$ for normal quasars) (Bregman et al. 1985; Smith & Spinrad 1980; Rieke, Lebofsky, & Kinman 1979). Intervening dust and an intrinsically steep spectrum have both been proposed as explanations. Dust explains the red colors and faintness of the quasars. The absence of 2200 Å dust absorption (Smith and Spinrad 1980) requires the dust to be unlike Milky Way dust. An intrinsically red spectrum could work but has as yet no convincing physical explanation.

We have now discovered new clues which link, and may help resolve, both these questions as well as place these objects within the broader context of the "unified models" (e.g. Antonucci 1993). In a spectroscopic survey of steep-spectrum radio quasars [1] we found evidence for a statistical excess of narrow associated Mg II absorbers (Aldcroft, Bechtold,& Elvis 1994) (ABE), unlike optically-selected samples (Steidel & Sargent 1992 (SS); Sargent, Steidel, & Boksenberg 1988; Lanzetta, Turnshek, & Wolfe 1987). More importantly, the absorbed quasars in our sample have unusual properties: three of them, 3C 68.1, 3C 212, and 3C 422, are very red, and two of these have high optical polarization. To investigate these characteristics further we compiled relevant data for the ABE sample, as well as for the Mg II absorbers in SS, and the associated C IV absorbers of Anderson et al. (1987) (AWFC). In this Letter we describe the statistical properties of the data and discuss possible interpretations of associated absorption.

2. SAMPLE OF ASSOCIATED ABSORBERS

ABE observed a total of 56 quasars, and for 46 of these the Mg II emission peak was within our spectral coverage. The sample was selected from the Veron-Cetty & Veron (1989) QSO catalog by radio flux ($S_{2.7} \geq 1$ Jy), radio spectral index ($\alpha_r \geq 0.4$), visual magnitude ($m_V \leq 19.5$), redshift ($z \geq 0.5$), and declination ($\delta \geq -30°$). The details of the sample selection are given in Aldcroft, Elvis, & Bechtold (1993), and the observations, data reduction, and absorption line detection are discussed in ABE. The statistically complete line extraction in our spectra yielded six associated Mg II absorbers. Our spectra have

[1] Throughout this paper "steep-spectrum" and "flat-spectrum" refer to the *radio* spectrum in the 1.4 – 5 GHz range. Quasars with steep *UV-optical* spectra are called "red".

an median 5-σ rest equivalent width detection limit of 0.55 Å with a range from 0.2 Å to 1.5 Å. The six absorbers have apparent ejection velocities relative to the quasar in the range $-1000 < v_e < 6000$ km sec^{-1}. The next closest velocity is $v_e = 12000$ km sec^{-1}.

In addition, two quasars in our sample, 3C 196 and 3C 205, have associated absorption lines listed in the catalog of Junkkarinen, Hewitt, & Burbidge (1991). In 3C 196, our spectrum does not cover the Mg II emission line, and in 3C 205 the absorption doublet is present in our spectrum at low significance, but with an equivalent width only half that given by Barthel, Tytler, & Thomson (1990). This variability is plausible if the absorption is intrinsic to the quasar. These two systems are not used in our estimate of statistical excess, but since they are in our original list of 56 steep-radio-spectrum quasars, they are included for study of the properties of associated absorption line quasars (AALQs). Any bias which is introduced in color, spectral index, polarization, or absolute magnitude will be minimal.

The detailed properties of the eight AALQs in ABE are given in Table 1. This table lists the quasar name, emission redshift, absolute magnitude, apparent ejection velocity, rest frame B-V, radio spectral index, lobe-dominance (LD=S_{lobes}/S_{total}), Mg II(λ2796) rest EW and FWHM, Mg I(λ2853) rest EW, and range of optical polarization strengths and position angles with respect to the radio axis. The *emitted* frame B and V magnitudes were calculated following Cristiani & Vio (1990), with an additional correction to account for the optical spectral index. Reddening by our galaxy is small in all cases and no correction has been made for this or internal reddening. We also compiled the same data for the sample of SS, which contains no excess absorption, and the objects in AWFC, in which 10 out of 12 steep-spectrum quasars show associated C IV absorption.

3. SAMPLE PROPERTIES

We find that the quasars with associated Mg II show a cluster of properties: (1) Probable statistical excess; (2) Steep radio spectra, implying lobe-dominance, and a wide range of absolute magnitudes; (3) Occurence of very red rest-frame B-V colors; (4) Occurence of high optical polarization. These characteristics are summarized in Table 2, and the details are as follows:

Statistical excess – In the 46 quasars we observed, we expect ~ 0.18 absorbers in each 1000 km sec^{-1} interval, based on the redshift and equivalent width distribution of Mg II absorbers from SS. For the velocity ranges $|v_e| < 3000, 5000,$ and 7000 km sec^{-1}, our sample thus contains excess absorbers at 97 %, 89%, and 95% confidence, respectively. The interval $|v_e| < 3000$ km sec^{-1} is most relevant if considering a cluster origin for the absorption, while

higher velocities could be appropriate if the material is intrinsic to the quasar. Previous Mg II surveys have found no suggestion of an excess, with the best statistics coming from SS, who observed 78 Mg II emission peaks to a limiting rest equivalent width of 0.3 Å.
Radio spectral index and absolute V magnitude – In Figure 1 we plot the absolute magnitude versus spectral index for ABE and the radio-loud quasars in SS, with AALQs marked by an open circle. The plot suggests that for our sample (crosses) the absorbed quasars have steeper spectra than non-absorbed quasars. The Komolgorov-Smirnov probability that the absorbed and non-absorbed quasars in our sample are drawn from the same population is 3% The AALQs in SS (dots) show that steep spectral index is not a strict rule. Figure 1 also shows that there is no apparent correlation between absorption and absolute magnitude.
Color – In Figure 2 we have plotted histograms of the number of quasars in ABE versus rest-frame B-V color, with the AALQs shown as filled squares. This shows the striking feature that there are three very red quasars in ABE, *all* of which show associated Mg II absorption, as indicated by the filled black squares. In addition, four of the eight objects with B−V> 0.4 are AALQs. In contrast, the colors of the AALQs in SS are consistent with the parent distribution of colors.
Optical polarization – The incidence of high polarization ($P \gtrsim 3\%$) amongst radio-loud quasars was found by Moore & Stockman (1984) to be 8% for $\alpha_r \geq 0.4$, and only 4% for $\alpha_r \geq 0.6$. That our sample (selected by $\alpha \geq 0.4$), should have 25% high-polarization quasars (HPQs) (seven definite and one possible, out of 28 quasars with polarization measurements. Even more remarkable is that if we restrict the sample to lobe-dominated quasars, then there are three definite HPQs, *all of which have associated Mg II absorption.* The polarization measurements available in the literature for the AALQs (Table 1) suggest less variability in these HPQs than in typical core-dominated HPQs, although more observations are needed.

Since the angle between the polarization axis and the radio jet axis is crucial for interpretation in lobe-dominated sources (most models predict that they are either parallel or perpendicular), it is important to notice that in both 3C 68.1 and 3C 212 the axes are about 50 – 60° apart. In the possible HPQ 3C 422 the optical and radio axes are nearly parallel, but this source is core dominated (at VLA scales) and a synchrotron origin for the polarization cannot currently be ruled out.

AALQs selected by C IV absorption have the following properties:

Statistical excess – Samples which contain many steep-spectrum quasars contain an excess (AWFC; Foltz et al. 1986; and Weymann et al. 1979), whereas optically selected samples such as Young, Sargent, & Boksenberg (1982) and Sargent, Boksenberg, & Steidel (1988) contain no such excess. Foltz et al. (1988) found associated C IV absorption, with rest equivalent width ≥ 0.5 Å, in 18 out of 27 quasars with $\alpha_r \geq 0.4$.

Radio spectral index and absolute V magnitude – In a sample containing 88 quasars with a wide range of spectral index, Foltz et al. (1988) showed that strong associated absorption is correlated with steep spectral index ($\alpha_r > 0.6$). Unlike Mg II however, there are also many weaker C IV absorbers with $0.6 < \alpha_R < 0.0$. Within the range of absolute magnitudes which were well-sampled ($-27 \lesssim M_V \lesssim -24.5$), there is no apparent correlation of associated absorption with absolute magnitude.

Color – In contrast to the extreme colors in our sample, the color distribution of the C IV absorbed quasars in AWFC shows no large deviations from the mean, although they are on average 0.1 mag redder than those in ABE or SS.

Optical polarization – Polarimetric data are available for the three absorbed quasars in AWFC, and none have high polarization. More data are needed to draw any conclusions.

4. DISCUSSION

The important qualitative results of Sections 2 and 3 are the following: (1) Associated Mg II and C IV absorption in radio loud quasars is correlated with spectral index. Mg II AALQs primarily have $\alpha_r > 0.6$; C IV AALQs are most common for $\alpha_r > 0.6$, but some have α_r as small as 0.0. (2) Most Mg II absorbers are lobe-dominated at VLA scales. The spectral index distribution of C IV absorbers indicates a mixture of lobe-dominated and core-dominated quasars. (3) There is no apparent correlation of associated absorption with absolute magnitude. (4) Some Mg II AALQs are very red. C IV AALQs show no extreme colors. (5) Some Mg II AALQs have high optical polarization, with possibly low variability. In C IV AALQs the data are inconclusive.

Possible origins for the absorbing material include:

Cluster galaxies – In most individual cases this interpretation is consistent with the data, and is supported by evidence that clusters associated with quasars are more common at $z \gtrsim 0.5$ (Yee & Ellingson 1993; Dressler et al. 1993; Bahcall & Chokshi 1992). The red colors and high polarizations could result from transmission through dust in high column density foreground galaxies (Fall & Pei 1993 and references therein). At low redshifts ($0.15 < z < 0.65$) Ellingson et al. (1994) found an excess of galaxies near the line of sight of quasars with associated C IV. Interestingly, they found no associated Mg II in these quasars, despite the presence of galaxies very near the line-of-sight, suggesting an "Mg II proximity effect." It is implausible, however, that *all* associated absorption arises in cluster galaxies, since quasars having cosmologically distributed Mg II absorption show neither unusually red

colors nor high polarization (based on the large sample of SS). The correlation of spectral index with both the incidence and strength of associated C IV absorption (Foltz et al. 1988) is also difficult to understand if the absorbers are isotropically distributed galaxies in a cluster. Selection of quasars by spectral index could preferentially include clusters, which would produce the correlation with incidence, but not with line strength.
Intracluster material – The observation of soft X-ray (White et al. 1991; Johnstone et al. 1992; Mushotzky 1992; Allen et al. 1993) and 21 cm absorption (McNamara, Bregman, & O'Connell 1990; Jaffe 1990, 1992) due to cold clumpy intracluster material raises the interesting possibility that associated absorption arises in this way. The optical signature of this material is not well known, although large amounts of dust are not expected (White et al. 1991 and references therein). Deep optical and high-resolution X-ray imaging to search for an associated cluster and cooling flow could test this idea.
Material intrinsic to quasar – This interpretation is favored for at least three of the eight Mg II absorbed quasars: In 3C 196, HST spectroscopic observations show strong and broad ($\Delta V \approx 1000$ km sec^{-1}) absorption in O VI and N V (Diplas et al. 1994); In 3C 212, Mathur (1994) has shown that the X-ray (Elvis et al. 1994) and Mg II absorbers can be the same highly-ionized material, and that O VII absorption is likely present in the X-ray spectrum; In 3C 205, the Mg II line varied by a factor of two in 1.7 years (Barthel, Tytler, & Thomson 1990; ABE), strongly indicating an origin near the quasar nucleus.

In current unified schemes (Antonucci 1993), steep spectra and lobe dominance imply an edge-on geometry, and the red color, Mg II absorption, and high polarization we have found can all be explained if these quasars are viewed edge-on through a dusty disk of moderate optical depth (Figure 3. The mechanism producing the polarization is not yet constrained: scattering by dust, or electrons, and transmission through aligned dust, are all allowed. The C IV selected absorbed quasars can then be explained naturally as objects which are seen over a larger range of angles, through a dust-free halo, perhaps blown off the dusty disk. Difficulties with this interpretation include the misalignment of the polarization and radio jet axes in 3C 68.1 and 3C 212, and the core-dominance of 3C 422. The possibility that the red quasars in our sample have (for reasons unknown) intrinsically steep optical spectra cannot be definitely ruled out, although the high optical polarization in two of them would require an alternate explanation.

Finally, it is interesting to point out a parallel between broad absorption line (BAL) quasars, which are exclusively radio quiet (Stocke et al. 1992), and AALQs. In both cases the C IV absorbers have continuum properties consistent with the unabsorbed parent population, whereas the rarer Mg II absorbers are notably redder (Weymann et al. 1991). An apparent excess of Mg II BAL quasars in a sample selected by IRAS colors indicates the presence of dust in these systems (Low et al. 1989). Furthermore, BALs are linked with non-variable high polarization (Glenn, Schmidt, & Foltz 1994). These connections between intervening material, color, and polarization are similar to those in AALQs, and suggest that the absorbing material in BALQSOs also arises in equatorial outflows. Sprayberry & Foltz (1992) and Glenn, Schmidt, & Foltz (1994) have considered such pictures to explain BALQSOs (but see Boroson & Meyers (1992) for a different view).

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FIGURE CAPTIONS

Figure 1 – Plot of absolute magnitude versus spectral index for samples ABE (cross) and SS (solid circle). The objects with associated MgII absorption are circled.

Figure 2 – Histogram showing the rest frame B-V distribution of quasars in samples ABE (solid line), SS (dashed line), and Mg II AALQs in ABE (filled squares). The three anomalously red quasars all have associated Mg II absorption. Note that one of the absorbed quasars does not have a measured B-V color.

Figure 3 – Schematic picture showing unified scheme for associated absorption in radio-loud quasars.

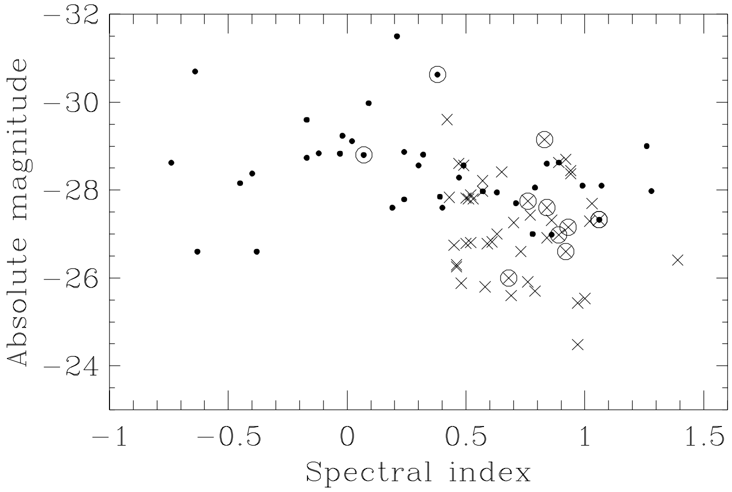
Absolute magnitude
Spectral index
−32
−30
−28
−26
−24
−1
−0.5
0
0.5
1
1.5

Fig. 1.—

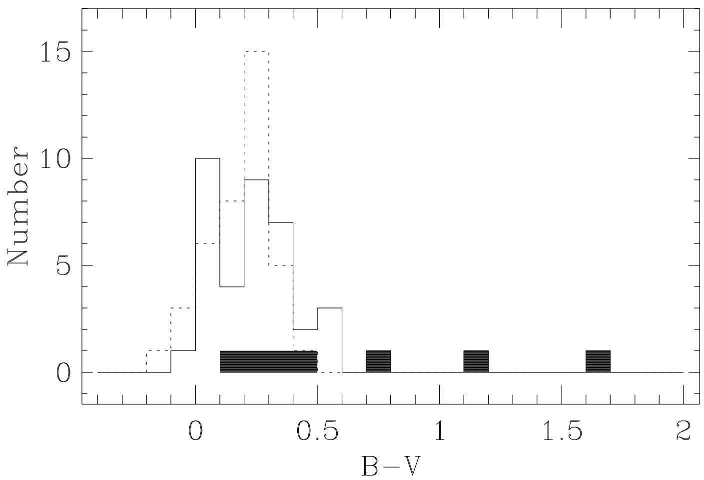
Number
B−V
15
10
5
0
0
0.5
1
1.5
2

Fig. 2.—

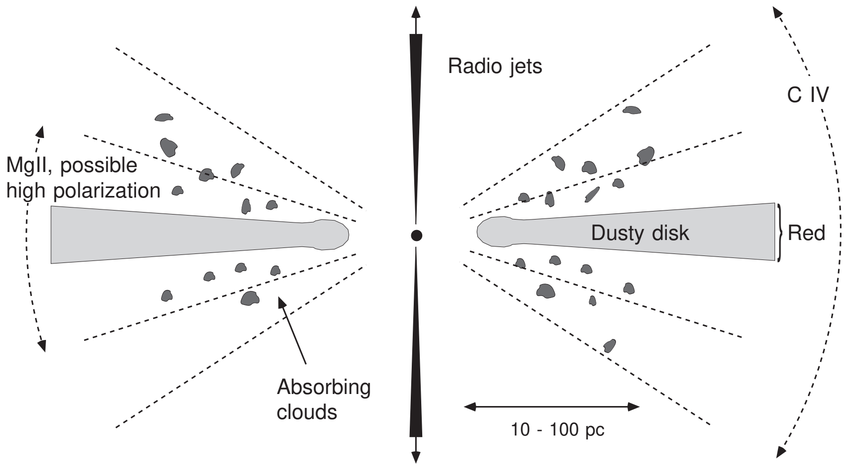
Radio jets
C IV
MgII, possible
high polarization
Dusty disk
Red
Absorbing
clouds
10 - 100 pc

Fig. 3.—

Table 1: Properties of MgII absorbed quasars

Object	z_{em}	v_e $\mathrm{km\,s^{-1}}$	M	B-V	α_r	LD	MgII W_0 Å	FWHM $\mathrm{km\,s^{-1}}$	MgI W_0 Å	P %	θ deg	Refs[a]
3C 68.1	1.238	1770	-26.1	1.62	0.84	1.00	3.5	560	0.6	7.3–7.5±1.3	45–58±5	1,2
3C 196	0.871	-60	-26.2	0.37	0.93	1.00	0.6	..	0.2	0.7–0.8±0.6	2–18±22	1,4,5
3C 205	1.534	-990	-28.1	0.45	0.83	0.97	0.3	140	< 0.1	...	...	6
3C 212	1.060	1590	-25.5	0.74	0.76	0.67	0.8	0	...	5.3–7.4±2.1	53–71±11	1,2
3C 270.1	1.519	2270	-27.1	0.16	0.89	0.92	1.3	300	< 0.5	...	...	...
3C 336	0.927	5500	-26.7	0.24	1.06	0.96	1.6	300	< 0.3	1.0–4.2±1.4	0–117±14	2
4C -02.79	1.457	5720	-26.6	...	0.92	0.04	0.7	30	...	...	...	...
3C 422	0.942	560	-24.7	1.10	0.68	0.00	2.8	340	1.4	2.5–3.2±1.7	-12–10±14	1,3

[a]Refs – 1. Moore & Stockman (1984), 2. Moore & Stockman (1981), 3. Fugmann & Meisenheimer (1988), 4. Impey, Lawrence, & Tapia (1991), 5. Mg I and Mg II from Foltz, Chaffee, & Wolfe (1988), 6. Mg I and Mg II from Barthel, Tytler, & Thomson (1990)

Table 2: Important characteristics of MgII absorbed quasars

Object	Steep-spec. $\alpha > 0.6$	Lobe-dom. LD>0.6	Red B-V > 0.7	HPQ $P > 3\%$
3C 68.1	$\surd$	$\surd$	$\surd$	$\surd$
3C 196	$\surd$	$\surd$	$\times$	$\times$
3C 205	$\surd$	$\surd$	$\times$	...
3C 212	$\surd$	$\surd$	$\surd$	$\surd$
3C 270.1	$\surd$	$\surd$	$\times$	...
3C 336.0	$\surd$	$\surd$	$\times$	$\surd$
4C -02.79	$\surd$	$\times$	...	...
3C 422	$\surd$	$\times$	$\surd$	$\surd$?[a]

[a]Possibly high polarization