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National Aeronautics and Space Administration

ASTROPHYSICS DATA PROGRAM

FINAL TECHNICAL REPORT FOR NAG 5-1240

Submitted to:
Mrs. Genevieve E. Wiseman
Grants Officer
Code 280.1
NASA
Goddard Space Flight Center
Greenbelt, MD 20771

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Title of Research:
"Strong Associated C IV Absorption in Low Redshift Quasars"

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ABSTRACT

We have used IUE spectra of quasars to determine the frequency of occurrence of strong associated C IV absorption systems at low redshifts ($0.017 \leq z \leq 0.894$, $< z >= 0.204$). We find four systems with rest frame equivalent widths REW > 5Å in the spectra of 38 quasars. This rate of occurrence of 0.12 (68% confidence interval: 0.055,0.19) is not significantly different from the rate of 0.064 (0.046,0.087) determined for high redshift quasars. The detected strong associated systems are all in low redshift quasars which have been imaged from the ground. One of the quasars is unusual, having two nuclei, a close companion and distorted isophotes. Two of the others also have close companion galaxies at projected distances of under 100 kpc. We conclude that a much larger sample is needed.

INTRODUCTION

Major ground based surveys have revealed three main types of QSO absorption system.

1. About 99% of all absorption systems show only lines of H I. These Lyman-α systems have low H I column densities (10^{12} to 10^{17}cm^{-2}. Their number density along the line of sight increases roughly as $(1 + z)^{2.3}$: hundreds are seen in the spectrum of individual high redshift quasars (Sargent, Young, Boksenberg and Tytler 1980, Murdoch *et al.* 1986, Tytler 1987a,b). Since they do not cluster strongly in velocity space, and they are too numerous to be identified with galaxies, they are normally considered to be intergalactic clouds.

2. The remaining 1% of all systems show metal lines in addition to H I. Only a few of these metal line systems are seen in the spectrum of a high redshift quasar. Their H I column densities are larger than those of the Ly-α systems, extending from about 10^{17} up to 10^{22}cm^{-2}, and they show pronounced clustering on velocity scales of under 1000 kms^{-1}.

The strongest lines in such systems are nearly always either Mg II or C IV, although about 10% of these systems have enough H I to show very strong damped Ly-α lines (Wolfe *et al.* 1986). The number density, clustering, and metal abundances (typically 0.01 to 0.1 solar) of these systems suggest that most of them arise in the outer regions of galaxies.

3. Some 5% of quasars are known as broad absorption line quasars, or BAL quasars. Their spectra show exceedingly strong trough like absorption systems, characterised by highly ionized species, in particular C IV. The C IV absorption lines are much broader (> 2000 kms^{-1}) than those in the ordinary metal line systems (10 to 100 kms^{-1}). These systems are best explained as material ejected from the quasars (Turnshek 1987).

The main reasons why the Ly-α systems and the metal lines systems are believed to arise in intervening material, unassociated with the quasars, is that they are found at all absorption redshifts, and the number of systems seen in individual quasar spectra are always consistent with a random sampling from a single parent population (Sargent *et al.* 1980, Young, Sargent and
Boksenberg 1982, Tytler 1982, Tytler *et al* 1987, Sargent, Boksenberg and Steidel 1988). However more detailed examination shows that this simple picture neglects some of the most important evidence about the origin of the absorption systems and the nature of the quasars themselves.

Weymann *et al.* (1979) were the first to present a detailed survey of the distribution of metal line systems showing strong C IV lines. They found that, in addition to the underlying background of intervening systems, there was a strong excess of systems at velocities similar to those of the quasars. These excess systems are known as associated systems because they have velocities within about 5000 kms^{-1} of the quasars. A largely independent sample presented by Young, Sargent and Boksenberg (1982) did not show any associated systems, yet Foltz *et al.* (1986) were able to confirm the excess in the original Weymann *et al.* sample.

These studies suggested that the absorption line properties of moderately sized samples of about 30 quasars show highly significant differences which must be related to the quasars themselves. Foltz *et al.* (1986) suggested that the difference may be related to the radio properties of the quasars: radio-loud quasars are more likely so show associated absorption, suggesting that the environments of those quasars are more gas rich. In support of this suggestion, Anderson *et al.* (1987) found that six out of a sample of twelve 3C and 3CR radio-loud quasars showed strong associated absorption. Möller and Jakobsen (1987) suggest that the dominant trend is actually a preference for associated absorption to occur in quasars of low optical luminosity, however Sargent, Boksenberg and Steidel (1988) find no evidence for this in their new large sample.

Recently Barthel, Tytler and Thomson (1990) presented the optical spectra of 67 QSOs which were obtained to study associated CIV absorption at moderate redshifts. Combining this data with that available in the literature, we have obtained the following results from the spectra of 208 quasars.

1. At redshifts of about two there is an average excess of 0.23 C IV systems per QSO with REW > 0.3Å in the velocity range $| v | < 5,000 \mathrm{kms}^{-1}$.

2. The excess systems are confined to this velocity range.

3. The fraction of systems in the above velocity range which are in excess increases from 16% at 0.3 – 0.6Å, to 70% at 1.5 – 5Å to 96% at REW > 5Å. The remaining systems are ordinary intervening systems which happen to have low velocities. This is equivalent to noting that the associated systems tend to have larger equivalent widths.

4. There is no statistically significant tendency for the excess systems to prefer either radio-loud or radio-quiet QSOs.

The above results apply to redshifts in excess of about 1.2, where the C IV doublet enters the optical. Here we use IUE spectra of QSOs to determine the number of associated systems at lower redshifts 0 to 1.2.

We will only be concerned with the strong associated systems, which have REW > 5Å, because the IUE spectra are normally not adequate to reliably detect weaker lines. The high redshift results show that there are essentially no (only 1 in 216 QSOs) intervening absorption systems with such large REW, thus we do not need to estimate and subtract off the number density of intervening C IV systems at low redshifts to leave the number of excess (associated) systems.

The associated systems are unusually importance because they provide a link between absorption and the quasars themselves. Following Weymann *et al.* (1979), it is speculated that the associated systems arise in clouds clustered within a few Mpc of the quasars. Alternatively the clouds could be inside the quasars' galaxies and they may be accelerated the the quasar. In either case, any change in their numbers with redshift would show that some part of the quasar environment changes over time. For example, the radio morphologies of quasars are known to become considerably more distorted as redshifts increase above about 1.4 (Barthel 1986). The two effects might be related since the radio distortion and the associated absorption are both the result of gas clouds near the quasars.

ASSOCIATED CIV ABSORBERS IN IUE QSO SPECTRA

Kinney, Bohlin and Blades (in preparation) have compiled an atlas of the IUE spectra of 69 QSOs, blazars and Seyfert 1 galaxies. The spectra were re-extracted and co-added to optimize the signal to noise ratio (S/N). For each object an estimate of the maximum REW of possible associated C IV systems was determined by placing artificial absorption features into the region within 5000 kms^{-1} of the CIV emission line. These upper limit REW values are listed in column (6) of Table 1.

There are three objects in which associated CIV absorption has possibly been detected, and five others in which it is believed to be real. These REW values are listed in columns (7) and (8) of Table 1.

Certain Associated Systems:

1004+130: Certain associated system, with strong CIV and NV. **1351+640:** Certain associated system, with strong CIV (REW = 2.1 ± 0.7 Å) and moderate NV, noted by Ulrich (1988). **1411+442:** Certain associated system with strong CIV and NV. The REW is probably in the range 8 to 16Å. Described as a BAL QSO by Malkan, Green and Hutchings (1987). **1807+698:** The CIV absorption will be regarded as real, though it is not as certain as the other cases. The REW is probably in the range 6 to 13Å. There is possibly also NV absorption. **2135-147:** Certain associated system showing CIV and Ly-α, discussed by Bergeron and Kunth (1983).

Possible Associated Systems:

0637-752: There is possible absorption centered about 5900 kms^{-1} to the blue of the CIV emission line in this noisy spectrum. **1613+658:** The irregular blue side of the peak of CIV suggests a possible associated system with REW $\simeq$ 1.8Å. **1833+326:** There is apparently absorption in the Ly-α and possibly also the CIV emission line, though at somewhat differing redshifts.

The search for associated absorption was limited to the region within 5000 kms^{-1} of the QSO CIV emission line. Tytler and Barthel (1990) have shown that associated absorption is restricted to this velocity range at high redshifts.

Quasar spectra usually have enhanced S/N in the CIV emission line. This sometimes allows the detection of lines which are considerably weaker than could be seen in the continuum, but in other cases there is no gain because the expected shape of the emission line is not well determined by other lines.

It is important to note that the resolution of the IUE spectra are similar to that which has been used recently in the large optical survey by Barthel, Tytler and Thomson (1989). The fact that the resolution is insufficient to resolve the C IV doublet is not a major problem because these lines are usually sufficiently strong in associated systems that the doublet members are totally blended even at high resolution. The identification of an absorption feature as C IV will be highly reliable because we are only searching in the C IV emission line, where optical spectra show that C IV is nearly always the correct identification, and because the background of intervening absorption systems (Mg II and Lyman limit data) is known to be low at low redshifts. There are no strong lines which could be confused with C IV at observed wavelengths of less then 2800Å, and we know from optical spectra that C IV is the only species occurring in the C IV emission line which shows extremely strong lines.

For the three possible associated systems and 1807+698 (which we treat as real) there is uncertainty about the reality of the absorption feature. However,

if the features are real then there is little doubt that they are CIV.

For most spectra REW values and upper limits are highly uncertain: a 30% uncertainty is common, while a factor of two uncertainty is not unlikely, primarily because of the low S/N.

There is currently no clear distinction between weak lined BAL absorption and strong associated systems. Consequently we follow Tytler and Barthel (1990) and adopt the observational criterion that an absorption feature is associated if and only if it has steep sides. Otherwise it is considered a BAL feature. This criterion is much harder to apply to the IUE spectra than to optical spectra, which typically have much higher resolution or S/N. Our best estimate is that all of the features listed above as certain and associated are indeed closer to the associated than the BAL category. The QSOs 0946+301 and 1700+518 were considered BAL, and were not included in the analysis.

ANALYSIS

Limiting detectable REWs are typically about 1 to 4Å. The existence of three ambiguous systems with REW in this same range indicates that the sample is not complete for REW under 4Å. For REW in excess of 4Å we have four associated systems from 38 objects, and the sample is unchanged for REW >5Å.

The frequency of occurrence of the associated systems with REW > 5Å in these low redshift IUE QSOs ($0.017 \leq z \leq 0.894$, $< z >= 0.204$) is 4/38 = 0.11, with a 68% confidence interval of (0.055,0.19).

At high redshifts, Tytler and Barthel (1990) found 13 strong associated systems amongst 204 QSOs, giving a frequency of 0.064 with 68% bounds of (0.046,0.087).

Adopting the null hypothesis that the frequencies are the same in each parent population, the overall mean frequency is 17/242. We can then use the difference between the observed and expected number of systems in each sample to form Chi-squared as a test the null hypothesis. We find $\chi_1^2 = 0.58$, which will be exceeded in 45% of trials. Thus there is no statistically significant difference in the density of strong associated systems at low and high redshifts. A test involving use of the actual redshifts of the the associated systems is not warranted because the low redshift systems all lie at about the same redshift (0.051,0.088,0.090,0.241), and there are too few systems.

In column (6) of Table 1 we list the reported 6 cm radio flux from the QSO, from Veron-Cetty and Veron (1985). Of the four QSOs with strong associated systems, three are reported radio-loud. This result is consistent with the result that 7 out of 13 QSOs with strong associated absorption were radio-loud.

a) Images

It is important to know what happens at the low redshifts only accessible to the IUE because additional information can be obtained about the quasar and its environment. Optical images are available for many of the lowest redshift quasars, showing whether the quasar lies in a cluster or group of galaxies. Yee and Green (1987) have found that radio-loud quasars at low redshift are found preferentially in clusters, and that the average galaxy-quasar covariance function increases by about a factor of three from $z \simeq 0.4$ to $z \simeq 0.6$. It is of great interest to test whether the incidence of associated absorption correlates with the presence of the quasar in a galaxy cluster or rich group. Ground-based data also provide data on the nature of the quasar's galaxy, such as absolute magnitude. The possibility clearly exists that the quasars showing associated absorption are in galaxies which are more gas-rich than on average.

References on optical images of the four quasars which have strong associated absorption are given in Hewitt and Burbidge (1987,1989).

2135-147 is most unusual having two nuclei and a companion galaxy , both with $R \simeq 19$, all within a common envelope which has distorted isophotes. The second nucleus may be active ([OIII]) and there appears to be systematic velocity shifts of [OII] and [OIII] which may be due to discrete clouds at different velocities.

1351+640 Hutchings *et al.* (1984) note that this quasar's galaxy is large and circular. There are two close companions (at 32" and 83", or 38 and 60 kpc for $H_0 = 100$ $\mathrm{kms^{-1}Mpc^{-1}}$) which are both of irregular

edge-on shapes and of similar magnitude and size to the quasar's galaxy. Either of these galaxies might cause the associated absorption.

1807+678 Arp (1970) found three close galaxies, one of which has a velocity only about 300 $\mathrm{kms^{-1}}$ greater than the quasar.

1004+130 Hutchings *et al.* (1988) report that this is a normal galaxy with an $r^{0.25}$ law brightness distribution.

b) Conclusion

The IUE spectra are capable of revealing strong associated absorption systems with rest frame equivalent widths in excess of 5Å. We have found four such systems. They occur in about 12% of low redshift quasars, a rate which is not statistically distinguishable from that at high redshifts. Images of these quasars do not reveal any outstanding characteristics which obviously account for the presence of associated absorption, except perhaps for the presence of close companions in three out of the four cases.

The main conclusion from this study must be that a much larger sample of low redshift associated systems is need.

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TABLE 1

IUE ASSOCIATED CIV ABSORPTION SYSTEMS

QSO	Name	V	z	Radio[d] S(6cm)Jy	REW (Å) Detection limit	Possible	Certain
Quasars							
0007+106	III Zw 2	15.4	0.089	0.42	1.7		
0044+030	PKS	16	0.624	0.039	3.6		
0121−590	Fairall 9	13.23	0.045	–	1.3		
0312−770	PKS	16.10	0.223	yes	2.2		
0316+413	NGC 1275	12.48	0.017	?	1.0		
0405−123	PKS	14.82	0.574	1.99	3.3		
0537−441	PKS	15.5	0.894	3.96	2.1		
0637−752	PKS	15.75	0.656	6.19		3.7[a]	
0735+178	PKS	14.84	0.424	yes	3.3		
0742+318	B2	15.7	0.462	0.96	6.6		
0804+761	PG	15.15	0.100	?	1.3		
0851+202	OJ 287	14	0.306	yes	2.8		
1004+130	PKS	15.15	0.241	0.42	4.0		6.8:[b]
1101+384	Mrk 421	13.5	0.031	yes	0.6		
1116+215	PG	15.17	0.177	–	0.3		
1133+704	Mrk 180	14.49	0.046	yes	3.2		
1202+281	PG	15.51	0.165	–	1.2		
1211+143	PG	14.63	0.085	–	1.0		
1226+023	3C 273	12.86	0.158	43.41	0.3		
1253−055	3C 279	17.75	0.538	15.34	1.8		
1351+640	PG	14.84	0.088	0.032	2.0		6[b]
1411+442	PG	14.99	0.090	–	4.0		12[b]
1426+015	Mrk 1383	14.87	0.086	–	1.8		
1553+113	PG	15	0.360	–	6.3		
1613+658	Mrk 876	15.23	0.129	–		1.8[a]	
1652+398	Mrk 501	13.8	0.034	yes	2.7		
1704+608	3C 351	15.28	0.371	1.21	7.5		
1721+343	4C 34.47	16.5	0.206	1.09	2.1		
1807+698	3C 371	14.22	0.051	yes	3.0		9.5[c]
1821+643	F	14.1	0.297	–	1.8		
2130+099	II Zw 136	14.46	0.061	–	1.9		
2135−147	PKS	15.91	0.20	1.31	1.0		2.1[b]
2155−304	PKS	14	0.117	yes	0.5		
2251−178	MR	14.36	0.068	0.003	1.2		
Seyfert Galaxies							
0119−013	II Zw 1	15.17	0.054	–	3.3		
0430+052	3C 120	15.05	0.033	5.09	1.5		
0513−002	AKN 120	13.92	0.033	–	1.4		
1119+120	Mrk 734	14.93	0.049	–	1.0		
1219+755	Mrk 205	14.5	0.070	–	1.4		
1229+204	TON 1542	15.3	0.064	–	1.4		
1833+326	3C 382.0	15.39	0.059	2.22		2.7[a]	

[a] Possible associated system, not considered real in the analysis. See notes on individual objects.
[b] Certain associated system.
[c] Highly likely associated system, treated as real in the analysis.
[d] 6 cm Radio flux from Veron-Cetty and Veron 1985. A dash indicates that the object is radio-quiet.