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X-RAY SPECTRAL SURVEY OF WGACAT QUASARS. II. OPTICAL AND RADIO PROPERTIES OF QUASARS WITH LOW-ENERGY X-RAY CUTOFFS

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ABSTRACT

We have selected quasars with X-ray colors suggestive of a low-energy cutoff, from the *ROSAT* Position Sensitive Proportional Counter (PSPC) pointed observations archive. We examine the radio and optical properties of these 13 quasars. Five out of the seven quasars with good optical spectra show associated optical absorption lines, with two having high Δv candidate systems. Two other cutoff quasars show reddening associated with the quasar. We conclude that absorption is highly likely to be the cause of the X-ray cutoffs, and that the absorbing material is associated with the quasars, not intervening along the line of sight. The suggestion that gigahertz peaked sources are associated with X-ray cutoffs remains unclear with this expanded sample.

Subject headings: quasars: general — radio continuum: galaxies — X-rays: galaxies

1. INTRODUCTION: LOW-ENERGY X-RAY CUTOFFS IN QUASARS

The first X-ray spectra of high-z quasars showed strong, unanticipated, low-energy cutoffs (Elvis et al. 1994). A tantalizing connection of these cutoffs with gigahertz peaked source (GPS) quasars was also suggested, raising the possibility that these cutoffs were due to a hot, galaxy-scale medium that also confined the radio sources. If nuclear absorbing material produces the cutoffs, a different environment must be common at high redshifts. We have now investigated these cutoffs further.

In the first paper in this series (Fiore et al. 1998, hereafter Paper I) we used the *ROSAT* Position Sensitive Proportional Counter (PSPC) soft X-ray slope (α_S) derived from the *ROSAT* pointed PSPC observations database (using the WGA catalog [WGACAT; White, Giommi, & Angelini 1995) and found the following results:

1. Radio-loud quasars have X-ray colors which differ ($P_{\rm chance} = 1\%$) from those of radio-quiet quasars. Most of these lie in the zone indicating a low-energy X-ray cutoff. In order to affect radio-loud and radio-quiet quasars differently, these cutoffs must be associated with the quasars, and not with intervening systems.Spectral fits (Paper I) to the better signal-to-noise PSPC spectra give more confidence that absorption is at work. Three levels of confidence in the presence of a low-energy X-ray cutoff were defined (Table 1): (A) Five quasars require (at greater than 99.9% confidence) absorption in a power-law plus absorption model. 3C 109 also shows excess absorption (Allen & Fabian 1992), but was excluded from our initial search because it had too large a Galactic column density. Since it has interesting properties (§§ 2 and 4), we include it for comparison with the other objects. (B) In five more quasars, the fit suggests absorption but less strongly (at greater than 95% confidence). (C) In three quasars either absorption or an extremely flat spectrum ($\alpha < 0.25$) is required. Absorption is thus a good working hypothesis to explain the low-energy X-ray cutoffs in this sample of 13 quasars. Absorption only in radio-loud quasars implies that radio-loud and radio-quiet quasar environments must differ at high z. Agreement of the results of Paper I with other *ROSAT* and *ASCA* work is good (Paper I).

2. Among the radio-loud quasars, those at high redshift have a lower mean α_S than those at low redshift ($P = 0.04\%$). The difference is due mainly to a group of objects which lie in the zone suggestive of X-ray cutoffs. A partial correlation analysis shows that the change in α_S is a redshift, and not a luminosity, effect. The X-ray cutoffs, and so presumably the quasar environments, thus show evolution with cosmic epoch.

If the cutoffs are due to photoelectric absorption, then the X-ray column densities of $\sim 10^{22}$ cm^{-2} are implied at the quasar. The small range of observed values is probably induced by the spectral range of *ROSAT*, limiting effective observed cutoff energies to the range $\sim$0.5–1.5 keV. An instrument covering both higher and lower energies, with sufficient sensitivity, is needed to find the true range of cutoffs in high-z quasars.

An absorbing column density of this size will produce observable effects at other wavelengths. For standard Galactic dust composition and dust-to-gas ratio (Jenkins & Savage 1974) strong reddening ($A_V \sim 5.5$) is predicted. Neutral material would show strong hydrogen absorption in a damped Lyman-α system. Ionized material instead will show absorption lines from other ions, e.g., C IV and O VI (cf. NGC 5548; Mathur, Elvis, & Wilkes 1996), unless the material is highly ionized (or primordial).

In this paper we seek evidence from optical spectroscopy for or against absorption in the same sample. We use our positive findings to investigate the nature of the absorbers. We also examine the radio properties of the quasars. We assume a Friedmann cosmology with $H_0 = 50$ km s^{-1} Mpc^{-1} and $\Omega = 0$.

2. OPTICAL ABSORPTION FEATURES

To search for the predicted optical obscuration, we have compiled data, from the literature, on absorption local to the quasars in our sample (Table 1), using NED.[5]

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[5] The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

TABLE 1

OPTICAL PROPERTIES OF SAMPLE, REDSHIFT ORDERED

Quasar	Cutoff Class	z	α_{OUV}	Associated Absorption	Δv (km s^{-1})	Notes	References
3C 219 (0917+45)......	C	0.174	Red[a]	...	...	$A_V = 1.8$	1, 2
3C 109 (0410+11)......	A	0.305	−3	Unknown[a]		$A_V > 2.7$	1, 3
PKS 1334−127	B	0.539	−2.0	Unknown[a]	...	10% polarization	4,[b] 5,[b] 6
3C 207 (0838+13)......	A	0.684	−1.83	O VI, C IV, Lyα	<300		7[c]
3C 212 (0855+14)......	A	1.043	−3.6	Mg II	−1830		8, 9
S4 0917+624	C	1.446	...	Unknown[b]	...		10[b]
S4 0917+449	B	2.18	Blue[d]	Unknown[e]	...	...	[e]
PKS 2351−154	B	2.665	Blue[d]	C IV, Si IV, Lyα	−1050		11, 12
PKS 0438−436	A	2.852		Lyα?[b]	−8400 +3600 +9300	4% polarization[f]	5, 13
PKS 0537−286	C	3.119		C IV	−4200 −40000		14
S4 0636+680	C	3.174		C IV	−35000		15
PKS 2126−158	A	3.266	−0.5	C IV, Si IV	−14900	$A_V < 1$	16, 17
S4 1745+624	B	3.889	−1.3	Unknown[b]	...		18,[b] 19

[a] Galaxy-dominated spectrum.
[b] Insufficient signal-to-noise ratio or resolution in optical spectrum.
[c] Absorption lines are present in the Wills et al. 1995 *HST* spectrum (S. Mathur 1996, private communication).
[d] No photometry.
[e] No published optical spectrum.
[f] But see Fugmann & Meisenheimer 1988.

REFERENCES.—(1) Yee & Oke 1978. (2) Fabbiano et al. 1986; Hill et al. 1996. (3) Rudy et al. 1984; Elvis et al. 1984. (4) Wilkes et al. 1983. (5) Impey & Tapia 1988. (6) Stickel & Kühr 1993a. (7) Wills et al. 1995. (8) Smith & Spinrad 1980. (9) Aldcroft et al. 1994. (10) Stickel & Kühr 1993b. (11) Roberts et al. 1978. (12) Barthel et al. 1990. (13) Morton et al. 1978. (14) Wright et al. 1978. (15) Sargent et al. 1989. (16) D'Odorico et al. 1997. (17) Kuhn 1996. (18) Stickel & Kühr 1993a. (19) Hook et al. 1995.

Seven of the quasars have optical spectra with adequate signal-to-noise ratio and resolution to detect absorption lines within the broad emission lines. Five of these show associated absorption lines (Table 1), and two more have candidate systems at high Δv. Two other quasars have red optical continua (Table 1). Red continua, and absorption lines close to the emission-line redshift, are quite rare, and both suggest absorbing material near the quasar. Hence, to find one or the other in nine out of 11 X-ray cutoff quasars, strongly supports the interpretation of the X-ray cutoffs as due to absorption.

Four of the lowest redshift quasars are from the 3CR radio catalog. (3C 219, once classified as a narrow-line radio galaxy, is now known to have broad Hα and Paα emission lines; Hill, Goodrich, & DePoy 1996). Three of the four have red continua ($\alpha_{O,UV} \sim 3$; Table 1), which are found in some 15% of 3CR quasars (Smith & Spinrad 1980). The binomial probability of finding three red quasars in a sample of four by chance is 1%. We conclude that X-ray cutoffs and red continua are linked. The red color of these quasars could be due to an intrinsic spectral shape (Wills et al. 1995), as in some blazars (Giommi, Ansari, & Micol 1995). However, we have additional evidence that in these objects the steep slope is almost certainly due to reddening by dust: 3C 219 has Paα/Hα/Hβ emission-line ratios that imply $A_V = 1.8 \pm 0.3$ (Hill et al. 1996), consistent with the X-ray column density (Allen & Fabian 1992); 3C 109 has a polarized optical spectrum that shows broad lines, as in NGC 1068, implying $A_V > 2.7$ (Goodrich & Cohen 1992). For the continuum of 3C 212 to be a reddened version of a normal quasar requires the similar reddening ($A_V = 2.8$) implied from the observed X-ray cutoff ($A_V \sim 5.5$, for a Milky Way dust-to-gas ratio; Savage & Mathis 1979). The X-ray cutoffs in the 3CR quasars are thus surely due to absorption.

For the rest of the sample, absorption lines near the quasar emission redshift are common (Table 1). When absorption lines lie within $\Delta v = 5000$ km s^{-1} or so of the emission-line redshift (the criteria are not well defined), they are likely to be "associated," i.e., physically connected, with the quasar (Weyman et al. 1979). Associated absorbers are quite rare, about 20% of the Weyman et al. sample. Table 1 shows that four out of seven quasars with adequate optical spectra have associated absorbers with $\Delta v < 5000$ km s^{-1} ($P_{chance} = 0.03\%$, using a binomial probability), and two more at higher Δv. Hence a link between X-ray cutoffs and absorbing material is implied for these high-z quasars. Associated absorbers have been found, via variability, with Δv as high as $-24{,}000$ km s^{-1} (Hamman, Barlow, & Junkkarinen 1997), so the high-velocity systems in PKS 2126−158, PKS 0636+680, and PKS 0537−286 may also be physically associated with the quasar. Given that absorption exists near the quasars, photoelectric absorption is the presumptive cause of the X-ray cutoffs.

Since the X-ray absorption is more common at high z (Paper I), the same should be true of the optical/UV associated absorbers. Unfortunately, associated absorbers are not well studied below $z \sim 1$, where the main UV lines can be studied only from space. Studies of Seyfert galaxies hint at a lower proportion of associated absorbers (Ulrich 1988; G. Kriss 1997, private communication).

3. RADIO PROPERTIES

The radio properties of the quasars are quite varied. We collected information from the literature on the radio structure and spectra of all the sample sources (Table 2, Fig. 1) using the NED database.

The 3C quasars are large (~100 kpc diameter) classical doubles with simple, almost pure power-law, spectra (Table 2). Despite their large size, the intermediate values of their

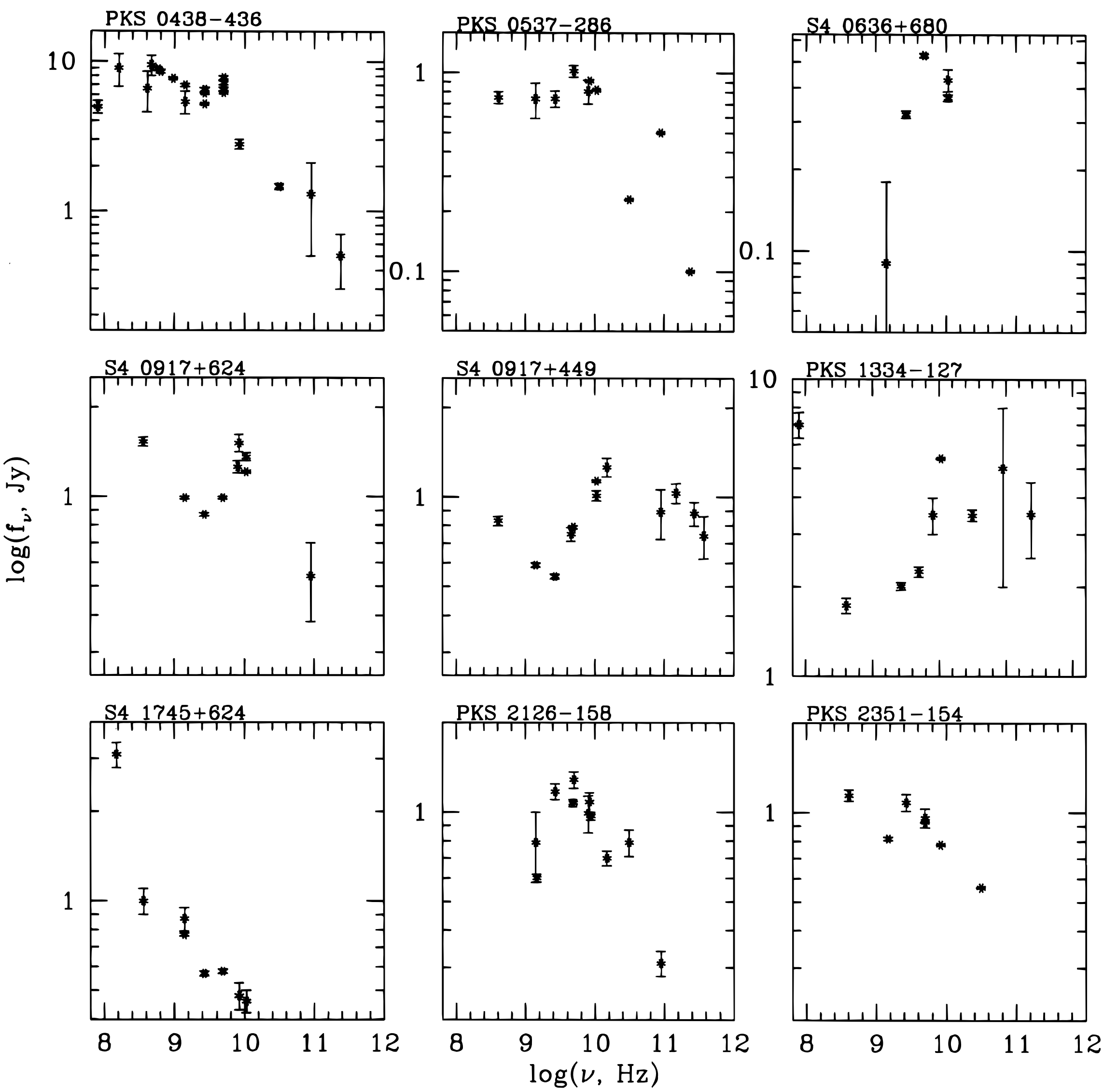

FIG. 1.—Radio spectra of nine X-ray cutoff sources. PKS 0438−436: Morton et al. 1978; PKSCAT90, Kühr et al. 1981, Tornikoski et al. 1996; PKS 0537−286: Parkes Catalogue 1990, Kühr et al. 1981, Wright et al. 1978, Tornikoski et al. 1996; PKS 0636+680: Kühr et al. 1981; S4 0917+624: Douglas et al. 1996, Kühr et al. 1981, Owen et al. 1980, Patnaik et al. 1992; S4 0917+449: Ficarra et al. 1985, Kühr et al. 1981, Bloom et al. 1994; PKS 1334−127: Parkes Catalogue 1990, Kühr et al. 1981, Condon et al. 1978, Bååth et al. 1981, Tornikoski et al. 1996; S4 1745+624: Hales et al. 1990 (6C Catalog), White & Becker 1992, Brundage et al. 1971, Kühr et al. 1981, Patnaik et al. 1992, McMahon et al. 1994; PKS 2351−154: Parkes Catalogue 1990, Quiniento & Cersosimo 1993, Kühr et al. 1981, Neff & Hutchings 1990; PKS 2126−158: Quiniento & Cersosimo 1993, Kühr et al. 1981, Wright et al. 1991, Steppe et al. 1988, Robson et al. 1985.

core-dominance parameters (log R_{cl} at 5 GHz; Table 2) do not indicate an extreme edge-on orientation (log $R_{cl} < -1.5$; Browne & Murphy 1987) or an extreme pole-on orientation, (log $R_{cl} > 1.5$).

The high-z quasars instead are compact and have complex radio spectra (Fig. 1):

1. *S4 0636+680 and PKS 2126−158* are good gigahertz peaked source (GPS) candidates (O'Dea 1990).

2. *S4 0917+624, S4 0917+449, PKS 1334−127* have evidence for cutoffs below a few gigahertz, with lower frequency excesses. S4 0917+624 appears to be steep at high frequency, and is a weaker GPS candidate. A lower frequency "excess" suggests a compact structure surrounded by "relic" larger scale emission. This in turn would imply repeated outbursts, an important datum. The latter two sources probably have flat high-frequency spectra and are likely to be blazars. In particular, PKS 1334−127 shows 3 mm and 1.3 mm band variability, by a factor of 2 on timescales of a year (observed frame; Tornikoski et al. 1996), and is optically polarized (Impey & Tapia 1988).

3. *S4 1745+624*, as noted by Stickel (1993), has a steep low-frequency spectrum, with a flat spectrum above 10 GHz (not shown in Fig. 1).

4. *PKS 0438−436, PKS 0537−286, and probably PKS 2351−154* have flat spectra below ∼10 GHz and steep ($\alpha \sim -2$) spectra at higher frequencies, as seen in some blazars (Bloom et al. 1994). Like PKS 1334−127, PKS 0438−436 shows 3 mm band variability, by a factor of 2 on timescales of 3 years (rest frame; Tornikoski et al. 1996), and is optically polarized (Impey & Tapia 1988).

The core-dominance ratio (log R_{cl}, Table 2) of the non-3C quasars are all large (>0.5). For normal radio sources this would strongly indicate quite core-dominated objects, probably dominated by relativistic beaming.

TABLE 2

RADIO PROPERTIES OF SAMPLE, REDSHIFT ORDERED

Quasar	z	Diameter (arcsec)	Diameter (kpc)	log R_{cl}	Spectrum[a]	Notes
3C 219 (0917+45)......	0.174	86	342 [1]	−1.22 [3]	Power law $\alpha = -0.9$ [2]	
3C 109 (0410+11)......	0.305	47	280 [1]	−0.38 [4]	Concave $\alpha = -(0.9–0.7)$ [2]	
PKS 1334−127	0.539	0.0001[5]	0.0008	0.6 [6]	GHz cutoff+MHz excess	b
3C 207 (0838+13)......	0.684	5.5	52 [1]	−0.15 [7]	Concave $\alpha = -(0.9–0.4)$ [2]	
3C 212 (0855+14)......	1.043	5.1	56 [1]	−0.31 [8]	Power law $\alpha = -0.8$ [2]	
S4 0917+624	1.446	0.021 [8]	0.25	0.6[9]	GHz cutoff+MHz excess	
S4 0917+449	2.18	0.019 [10]	0.25	...	GHz cutoff+MHz excess+GHz high-frequency cutoff	c
PKS 2351−154	2.665	d	...	...	...	c
PKS 0438−436	2.852	0.035 [13]	0.47	1.2 [11]	MHz peak?	b
PKS 0537−286	3.119	d	...	1.8 [11]	Flat, millimeter cutoff	
S4 0636+680	3.174	0.0006 [13]	0.01	...	GPS	
PKS 2126−158	3.266	4.6 [12]	90	>1.1 [11]	GPS	c
S4 1745+624	3.889	0.005[13]	0.07	...	Flat, large MHz excess [3]	

NOTE.—Numbers in brackets following an entry refer to the References listed below.

[a] Spectrum references given in legend to Fig. 1, except as noted.

[b] Millimeter variable by factors of 2–4 over years (observed frame; Tornikoski et al. 1996).

[c] Core-jet (A. Marscher 1997, private communication; Neff & Hutchings 1990).

[d] No published radio map.

REFERENCES.—(1) Saikia et al. 1995. (2) Herbig & Readhead 1992. (3) Branson et al. 1972. (4) Riley & Pooley 1975. (5) Linfield et al. 1990. (6) Browne & Perley 1986. (7) Pooley & Henbest 1974. (8) Jenkins et al. 1977. (9) Xu et al. 1995. (10) Murphy et al. 1993. (11) Browne & Murphy 1987. (12) Neff & Hutchings 1990. (13) Taylor et al. 1994.

However both compact steep spectrum (CSS) and gigahertz peaked spectrum (GPS) sources have large R_{cl} based on 1″, VLA-style maps. The small size of their lobes, which dominate their radio emission, leads to a misleadingly large R_{cl}. Closer examination is needed.

The radio survey NVSS (Condon et al. 1997) provides polarization measurements. These indicate that 3C 212, S4 0636+680, and PKS 2126−158 have low polarization (0.2%, 0.0%, and 0.3%, respectively) and so are likely not to be blazars (Marchã et al. 1996). Four other quasars, S4 0917+449, PKS 2351−154 and S4 1745+624, have high polarization (3.0%, 1.6%, 4.6%, and 5.6%, respectively) and so are probably blazars. At 0.6% PKS 0537−286 is indeterminate.

Although the limited VLBI data can be ambiguous, three of the radio sources (S4 0917+449, PKS 2351−154, and PKS 2126−158) may have a core-jet rather than double lobe geometry, supporting a blazar interpretation of these sources.

This view is somewhat strengthened by the observation that PKS 2351−154 varied at 1.6 μm (V-band in the rest frame) by 1.1 ± 0.2 mag in 4 months (rest frame) and by 0.3 mag in about 1 week (rest frame; Soifer et al. 1983).

4. DISCUSSION

We have found that a large fraction of the quasars with low-energy X-ray cutoffs and good optical spectra, show absorption lines and/or reddening, associated with the quasar. We conclude that photoelectric absorption by the same obscuring material is the cause of the X-ray cutoffs.

The redshifts of the optical lines relative to the quasar emission redshift can suggest a site for the absorbers. Velocities within 2000 km s^{-1} of the emission redshift (PKS 2351−154, 3C 207, 3C 212; Table 1) can arise as a result of motions within a surrounding cluster of galaxies. They could also be due to material at rest in the host galaxy, since the redshift of the high-ionization emission lines typically differ systematically from the host redshift by about this amount ($\langle \Delta v \rangle \sim 1500$ km s^{-1}, Tytler & Fan 1992).

Larger velocities are most plausibly associated with motions connected to the active nucleus itself, since the velocities needed are clearly present in active galactic nuclei (AGNs): the widths of the broad emission lines are 5000–10,000 km s^{-1}, and velocities within jets approach $v = c$. Absorbers with large Δv probably indicate outflows (PKS 2126−158, PKS 0537−286). Good optical spectra for the rest of the sample would help decide which type of system is the more common.

The objects divide into at least two groups, which may not share a common cause for the observed absorption. The high-ionization absorber in the high-redshift quasars and in 3C 207 have features in common. The three other 3C quasars form a separate group of heavily obscured objects (see § 2). If the absorbers in the red 3C AGNs are unrelated to the rest, then the others will show even stronger evolution with redshift than that derived in Paper I.

3C 109 resembles a Seyfert 2 galaxy, in which a nuclear torus, viewed edge-on, obscures the broad emission line region and continuum source (e.g., Urry & Padovani 1995), since 3C 109 has a polarized optical spectrum showing a normal broad emission line quasar spectrum (Goodrich & Cohen 1992), as does that of the prototype Seyfert 2 galaxy, NGC 1068 (Antonucci & Miller 1985). The 3C quasars in this sample are all large-diameter (∼100 kpc) radio sources with simple, quasi–power-law spectra, and so could well be viewed close to edge-on.

The tori in these luminous ($M_V \sim -27$) radio-loud AGNs may be larger than in Seyferts, though. Mathur (1994) notes for 3C 212 that the dust must lie more than 10 pc from the quasar continuum source in order not to evaporate ($T < 1750$ K). 3C 109 and 3C 219 have similar luminosities, and so the dust must be similarly distant. This distance is about 100 times the broad emission line region (BELR) radius for this luminosity (∼100 light-days; Kaspi et al. 1996). A closer equivalent situation may be the ionized absorbers in Seyfert galaxies. These are, marginally, consistent with being at a similarly large relative distance from the BELR (Mathur et al. 1996) and so could be due to the same phenomenon. If, however, infrared measurements show that much of the dust is colder, and so more distant (Elvis et al. 1984), or if absorption-line variability is faster in Seyferts (requiring a denser absorber closer to the continuum source), then a new type of absorber may be needed for the 3C absorbers. In 3C 212 the X-ray absorber is partially ionized (Mathur 1996). Such dusty, ionized absorbers are common in Seyfert galaxies (Reynolds 1997).

The absorbers in the higher redshift, higher luminosity quasars, and in 3C 207, all show high ionization. Similar absorbers are known in Seyfert galaxies (e.g., Mathur et al. 1996). The high-velocity associated absorber in Q2343+125 (Hamman et al. 1997) has high ionization, and the authors suggest a link with the broad absorption line quasars that may apply here too. To have significant fractional ionization in C IV ($>10^{-4}$) requires an ionization parameter $U < 3$ (e.g., Mathur et al. 1996). With this U the X-ray continuum should recover to its unabsorbed level at energies below the oxygen K edge. The ionization could be produced either by the quasars' photoionizing continuum or from the absorbing medium itself being hot ($T \sim 10^7$ K). In these high-luminosity quasars [$L_{\rm opt} \sim 50L$(3C 273) $\sim 10^{13}$–10^{14} $L_\odot$; Véron-Cetty & Véron 1996] a standard quasar spectrum can ionize out to $r \sim 20n^{-1/2}L_{13}^{+1/2}\ U^{-1/2}$ kpc (where n is the electron density in cm^{-3} and L_{13} is the luminosity in units of $10^{13}L_\odot$). This radius is on a galaxy scale for typical ISM densities, or on a larger scale for the central densities typical of strong cooling flows ($n = 0.1$; Fabian 1994). If the absorbers have the same densities as the ionized absorbers in Seyfert galaxies ($n_e \sim 10^5$–10^9 cm^{-3}; Mathur et al. 1996), then they will lie at radii of ~ 1 pc, a plausible distance. The ionization state thus allows both nuclear and large-scale locations for the absorbers.

At least some of the higher redshift quasars show blue continua (Table 1). PKS 2126−158 has an accurately power-law–like spectrum ($\alpha_{\rm OUV} = -0.51 \pm 0.09$; Kuhn 1996). The lack of curvature in this spectrum requires any reddening (with an SMC reddening law) to have $A_V < 1.0$ (3 σ; Kuhn 1996), a factor of 10 lower than is implied by the X-ray cutoff (for a Milky Way dust-to-gas ratio). A similar ratio is often encountered in Seyfert galaxies (Reichert et al. 1985; Schachter et al. 1997). We can invert the argument used above for the red 3C quasars: If the gas was initially dusty, then heating by the quasar continuum radiation has probably raised the dust to temperatures above 1750 K, causing dust loss through sublimation. This implies a maximum distance for the gas from the continuum source of ~ 10 pc, and hence $n > 10$ cm^{-2}. This somewhat supports a nuclear origin for the absorbers. Any changes in continuum luminosity will be tracked by nuclear high-density absorbers, which offers a diagnostic for their location.

Since the absorbers are common (~ 40% at high z; Paper I), they must have a large covering factor, unless a special geometry applies. This is similar to the case of Seyfert galaxies where X-ray– ionized absorbers are seen in at least half the objects (Reynolds 1997), although only 10%–25% show UV absorption lines (Ulrich 1988; G. Kriss 1997, private communication) probably because the absorber is too highly ionized. Using the arguments of Mathur et al. (1996), this large covering factor would imply mass-loss rates that could be as large as $\sim 100\ M_\odot$ yr^{-1}.

The associated absorption lines seen in this sample are mostly of metal species: O VI, C IV, N V. This implies an enriched absorbing medium. The abundances in the absorbers will give a clue to their origin. Quasar nuclei at $z \sim 3$ often seem to show large (a factor of 10) overabundances relative to solar (Hamman & Ferland 1993). Galaxies at these redshifts are more likely to have undergone little star formation and so have the low abundances found in damped Lyman-α systems (Wolfe et al. 1994). It will soon be possible to obtain better X-ray and optical spectra that will allow abundance determinations.

The radio properties of the sample are unclear. Only two of the objects have clear GPS spectra. However, another three may show GHz cutoffs with MHz excesses (Table 2, Fig. 1). Other sources have spectra that are not well defined. Radio spectra compiled from the literature can be misleading because of variability. O'Dea (1990) found that about half of the radio-loud quasars at high redshift ($z > 3$) were GPS candidates based on a similar literature search of spectra. We conclude that the tentative connection of X-ray cutoffs with GPSs (Elvis et al. 1994) remains ambiguous with this larger sample. Simultaneous 0.3–30 GHz spectra of all these quasars would clarify the situation.

If the quasars are dominated by emission from a relativistic jet, i.e., are blazars, then the picture is quite different: A special geometry clearly applies, and photoionization by the normal quasar continuum could well be irrelevant. The presence of millimeter variability in PKS 0438−436 and PKS 1334−127 and of radio core-jet structures in S4 0917+449, PKS 2351−154, and PKS 2126−158, and the large velocities of the absorbers in PKS 0537−286 and PKS 2126−158, suggest that the presence of blazar properties may be related to the absorbers. (Note, however, that neither of the millimeter-variable quasars has known optical absorption lines.) Ionized absorbers are known in blazar X-ray spectra (Canizares & Kruper 1984; Marscher 1988; Madejski et al. 1991), and also in the Galactic superluminal sources GRO J1655−40 and GRS 1915+105 (Ueda et al. 1997). If the absorbers are seen only in end-on jets, then the special orientation required would eliminate the covering factor and mass-loss arguments above. Good radio spectral and polarization measurements can decide which of these quasars are blazars. VLA measurements are scheduled.

If the absorbers are jet related, we might identify the Δv of the ionized absorber as the hot spot speed of advance. Similar hot spot advance speeds are derived in compact steep-spectrum (CSS) quasars (Readhead et al. 1996). (The larger velocities, $v \sim 0.3c$, required to explain the relativistic beaming effects in jets may well be much larger than the advance speed of the hot spot; Pearson 1996.) The absorber may be the boundary layer between the jet and the surrounding medium. In this case the absorber may be shock ionized, rather than photoionized by the quasar continuum. Entrainment of ambient material in the jet at the boundary layer (e.g., De Young 1996) may then be probed by X-ray and optical absorption, allowing study of the entrainment process and of the composition of the ambient medium.

Although the arguments here favor a nuclear, probably jet-related, origin for the X-ray absorption found in Paper I, it is hard in this picture to explain the evolution of this absorption with redshift. Instead, there is strong evidence that high-z quasars and radio galaxies do lie in a galaxy-scale high-density medium which probably has large column densities. Strong, highly polarized, Ly-α-emitting gas with knotty complex morphology is seen aligned with the radio structures—the "alignment effect" (di Serego Alighieri et al. 1988). Radio galaxies sometimes show large Lyα H I halos and disks with a column density of $\sim 10^{19}$ cm^{-2} (Röttgering et al. 1995). In unified schemes for AGNs (Barthel 1989; Urry & Padovani 1995) the central engine would illuminate this medium in other directions, causing it to be highly ionized. When we observe a quasar, we will be looking through this medium, which will show an X-ray/UV absorber. (The column density seen will depend on the degree of flattening of the medium.) In fact CSS quasars show an excess of associated UV absorbers (Baker & Hunstead 1996). In PKS 2351−154 (and possibly PKS 0537−286), in which the absorber Δv is small, the observed X-ray absorption may be from this large-scale medium. Future X-ray observations targeted to this end should show absorption and so reveal a great deal about this galaxy-scale high-z medium.

Better X-ray data are essential. In particular, high-resolution X-ray spectra will be able to measure the redshift of the oxygen edge in high-redshift quasars. This will test the association with the optical absorption lines and will directly measure the ionization state and constrain the abundances in the absorber. For O VII this edge will appear at $0.7/(1+z)$ keV, i.e., around 0.2 keV. As an example, the AXAF Low Energy Transmission Gratings (LETGs) have a resolution $E/\Delta E \sim 1500$ at this energy and so can determine an edge velocity to ~ 200 km s^{-1}. The LETGs effective area is 10–20 cm^{-2}, requiring long exposure times even on the brightest high-z quasars. Areas of several square meters (cf. Elvis & Fabbiano 1997) are needed to exploit the available spectral information for a reasonable range of quasar luminosities at high z.

5. CONCLUSIONS

Paper I showed that high-redshift radio-loud quasars often show low-energy X-ray cutoffs associated with the quasars, with an increasing fraction of cutoffs being found at high redshifts. In this paper we have shown that X-ray cutoffs and optical absorption associated with the quasar are statistically linked, and hence that the X-ray cutoffs are indeed due to photoelectric absorption. A prediction is that lower redshift radio-loud quasars will have fewer associated UV absorbers.

In contrast to the low-z absorbed quasars in the sample, which are often dusty, the high-z absorbers have low dust content and are highly ionized. The location of the absorber is probably nuclear, based on the large velocities in some, and on the absence of dust. The evolution with redshift would be more naturally explained, however, if the absorbers were on the scale of the host galaxy or larger. The absorbers may be associated with the jets in these sources, given the large number of core-jet and highly variable radio sources. In this case the absorbers may be entrained material, located at the boundary layer between the jet and the surrounding medium. Far more work will be needed to establish this association, however. The association with GPS radio sources is still ambiguous and requires better radio data to be confirmed or rejected.

X-ray spectroscopy is the most powerful means of following up this work: Velocity measurements could clinch the optical absorber/X-ray absorber association; identifying the relative ionization states of oxygen via the oxygen K edges will reveal the ionization state of the absorber; combining optical and X-ray spectroscopy will allow abundance measurements, perhaps determining the origin of the absorbing material. Other tools include optical/X-ray variability, which could definitively associate the absorber with the nucleus. Also, searches for a large-scale absorbing medium around high-z quasars could improve the case for a large-scale origin in some cases. Studies of radio spectra and polarization (which are in progress) and VLBI mapping could definitively determine the nature of the quasars in the sample, be it GPS, blazar, or another type. Larger samples of cutoff X-ray quasars can be created using the hitherto unidentified sources in the *ROSAT* database. In intermediate, lower luminosity quasars, direct X-ray imaging could search for extended X-ray hot atmospheres. X-rays can thus give us a new set of tools to investigate the high-z quasar environment.

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