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XMM-NEWTON OBSERVATIONS OF HIGH-REDSHIFT QUASARS¹

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ABSTRACT

We report on our *XMM-Newton* observations of the high-redshift quasars BR 2237–0607 ($z = 4.558$) and BR 0351–1034 ($z = 4.351$). We also report on *XMM-Newton* observations of 19 other $z > 4$ objects available in the public archive of which 14 were detected. We find that the optical to X-ray spectral index α_{ox} is correlated with the luminosity density at 2500 Å but does not show a correlation with redshift, which is consistent with earlier results. Radio-loud quasars are brighter and have flatter X-ray slopes compared to radio-quiet quasars. There is some evidence for the jet-dominated sources to be intrinsically absorbed. The mean intrinsic 2–10 keV power-law slope of the 10 high-redshift radio-quiet quasars in our sample for which a spectral analysis can be performed is $\alpha_X = 1.21 \pm 0.52$ (ranging between 0.32 and 1.96), which is more like the $\alpha_X = 1.19 \pm 0.10$ found from the *ASCA* observations of low-redshift narrow-line Seyfert 1 galaxies (NLS1s) but different from the $\alpha_X = 0.78 \pm 0.11$ found for low-redshift broad-line Seyfert galaxies. The steep X-ray spectral index suggests high Eddington ratios L/L_{Edd} . These observations give credence to the hypothesis of Mathur that NLS1s are low-luminosity cousins of high-redshift quasars. Comparison with other results from the literature indicates that perhaps the most luminous quasars, from low to high redshift, have similarly steep X-ray spectra suggestive of high Eddington luminosities.

Key words: galaxies: active — quasars: general — quasars: individual (BR 2237–0607, BR 0351–1034)

1. INTRODUCTION

High-redshift quasars can tell us about the evolution of the central engines of quasars, the star formation history in the early universe (e.g., Bromm & Larson 2004; Di Matteo et al. 2004; Granato et al. 2004; Dietrich et al. 2002a), and the intergalactic medium between the high-redshift quasar and us (e.g., Storrie-Lombardi et al. 1996; Péroux et al. 2001). The high-redshift quasars, however, are typically observed to be faint, making it difficult to analyze them in detail and to determine their aggregate properties. Quasars are generally classified as radio-loud and radio-quiet based on the ratio of their optical to radio luminosity (Kellerman et al. 1989). Most quasars are radio-quiet, with only about 10% being radio-loud. In addition, a fraction of radio-loud quasars, called blazars, have strong jets pointed toward our line of sight. Many discoveries and subsequent studies of high-redshift quasars were of blazars, which are relatively brighter due to their relativistically enhanced beamed emission. Naturally, results from these studies cannot be considered representative of the majority of the radio-quiet quasars. Before the Sloan Digital Sky Survey (SDSS; York et al. 2000) and the *Chandra* Deep Surveys (e.g., Brandt et al. 2001b; Giacconi et al. 2002; Barger et al. 2002; Alexander et al. 2003), only a handful of

high-redshift quasars were detected in X-rays. The only $z > 4$ quasar detected in X-rays before the launch of *Röntgensatellit* (*ROSAT*; Trümper 1982) was GB 1508+5714 ($z = 4.30$; Mathur & Elvis 1995) detected by *Einstein*. The first X-ray-selected high-redshift quasar was RX J1759.4+6632 ($z = 4.32$; Henry et al. 1994) found in a deep *ROSAT* Position Sensitive Proportional Counter (PSPC; Pfeffermann et al. 1987) observation. Only one high-redshift quasar was discovered during the *ROSAT* All-Sky Survey (RASS; Voges et al. 1999), RX J1028.6–0844 (Zickgraf et al. 1997). Other sources were detected in X-rays but selected in other wavelength bands, typically by their radio emission, e.g., GB 1428+4217 ($z = 4.72$; Boller et al. 2000) or at optical wavelengths (e.g., Q0000–263, $z = 4.111$; Bechtold et al. 1994). Up to the end of 2004 about 85 $z > 4$ quasars with X-ray detections were known.³

For the majority of these 85 quasars the number of photons detected is not sufficient to perform individual spectral analysis. As a result, derived quantities such as the X-ray loudness⁴ α_{ox} depend on the assumptions made for the spectral shape and the absorbing column density. In addition, quasar variability and lack of simultaneous optical and X-ray observations also contribute to the error on measuring α_{ox} (Strateva et al. 2005), leading to conflicting results for the properties of high-redshift quasars.

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³ A complete list of $z > 4$ quasars with X-ray detections is given at <http://www.astro.psu.edu/users/niel/papers/highz-xray-detected.dat> (Brandt et al. 2002a).

⁴ The X-ray loudness is defined by Tananbaum et al. (1979) as $\alpha_{\text{ox}} = -0.384 \log(f_2 \text{ keV}/f_{2500 \text{ Å}})$.

Studies by, e.g., Wilkes et al. (1994) and Mathur et al. (2002) showed that α_{ox} depends on luminosity and not on redshift (see also Avni & Tananbaum 1986), while studies by Brinkmann et al. (1997), Beckmann et al. (2003), and Vignali et al. (2003b) of high-redshift quasars claim that α_{ox} increases with redshift. Vignali et al. (2003a) studied large samples stretching from low-redshift active galactic nuclei (AGN) to high-redshift quasars and found that the trend of α_{ox} increasing with redshift is a selection effect and that α_{ox} correlates with the luminosity density at 2500 Å (see also Yuan et al. 1998a). X-ray spectroscopy is necessary to resolve these conflicting results. It has also been claimed by, e.g., Elvis et al. (1994) and Cappi et al. (1997) from *ROSAT* and *ASCA* observations that high-redshift quasars show high intrinsic absorption. Recent spectroscopic observations by, e.g., Ferrero & Brinkmann (2003) and Grupe et al. (2003) with *XMM-Newton* contradict these results. Brocksopp et al. (2004) present *XMM-Newton* spectra of four quasars (two radio-loud and two radio-quiet) at $z = 2.96\text{--}3.77$ and find that excess absorption is present in one radio-loud and one radio-quiet quasar. The X-ray properties of the absorbed quasars, however, appear to be dominated by jet emission.

High-redshift quasars appear to have high-mass black holes (e.g., Dietrich & Hamann 2004; Vestergaard 2004; Netzer 2003). Recent work, e.g., by Merloni (2004), suggests that high-mass black holes grow rapidly at high redshift. Mathur (2000) suggested that they are similar to low-redshift narrow-line Seyfert 1 galaxies (NLS1s; Osterbrock & Pogge 1985), which are objects that accrete at high Eddington ratios (e.g., Boroson 2002; Sulentic et al. 2000; Grupe 2004). Like high-redshift quasars, NLS1s are also thought to be AGNs in an early evolutionary state (Grupe 1996, 2004; Mathur 2000). It has also been found by Mathur et al. (2001) that NLS1s deviate from the well-known $M_{\text{BH}}\text{--}\sigma$ relation (e.g., Gebhardt et al. 2000; Ferrarese & Merritt 2000; Merritt & Ferrarese 2001), suggesting that these AGNs also have rapidly growing, although smaller mass, black holes (Grupe & Mathur 2004; Mathur & Grupe 2005a, 2005b).

To understand high-redshift quasars, and to compare them to their low-redshift cousins, we have initiated a program to obtain X-ray spectra of high-redshift quasars using *XMM-Newton*. The sample consists of both radio-loud and radio-quiet quasars to probe differential evolution between the two classes, if any. We have published the results of the *XMM-Newton* observations of the radio-loud quasar RX J1028.6–0844 and the radio-quiet quasar BR 0351–1034 (Grupe et al. 2004a). In the present paper we report the observations of the radio-quiet quasar BR 2237–0607 and a second observation of BR 0351–1034. In addition, we have selected all high-redshift quasars with $z > 4.0$ for which public archival data could be retrieved from the *XMM-Newton* archive at VILSPA (2004 December). These 21 quasars are listed in Table 1, 16 of which are radio-quiet quasars, representative of the majority of the quasar population, and five are radio-loud quasars.

The paper is organized as follows: in § 2 we describe the observations and data reduction, followed by a description of the analysis of the data in § 3, which also contains notes for individual sources. In § 4 we present the results of the X-ray observations, which are discussed in § 5.

Throughout the paper spectral indexes are energy spectral indexes with $F_\nu \propto \nu^{-\alpha}$. The X-ray spectral index α_X refers to the rest-frame energy range 2.0–10.0 keV, except where otherwise noted. Luminosities are calculated assuming a Λ CDM cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, and a Hubble constant of $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$, using the formulae by Hogg (1999). In order to determine the X-ray loudness α_{ox} , we estimated the flux density

at rest-frame 2500 Å from rest-frame ultraviolet (UV) spectra at 1450 Å from the literature by assuming a UV spectral index $\alpha_{\text{UV}} = +0.45$, as found from composite spectra of quasars (e.g., Vanden Berk et al. 2001; Dietrich et al. 2002b). The rest-frame flux density at 2 keV was determined from the *XMM-Newton* pn spectra. All errors are 1σ unless stated otherwise. We also note that most of the optical and X-ray observations are separated by years.

2. OBSERVATIONS AND DATA REDUCTION

2.1. BR 2237–0607

The quasar BR 2237–0607 ($z = 4.558$) was observed for the first time in X-rays by the *ROSAT* PSPC in 1993 May (Kaspi et al. 2000a). The mass of the black hole of BR 2237–0607 was estimated by Dietrich & Hamann (2004) to about $(2.9 \pm 0.8) \times 10^9 M_\odot$. The black hole mass estimates are made using the virial theorem and the measurements of C IV emission-line width, optical luminosity, and the relationship between the luminosity and the radius of the broad emission-line region (Kaspi et al. 2000b; Vestergaard 2002). Storrie-Lombardi et al. (1996) found several possible intervening damped Ly α absorption systems in the line of sight of BR 2237–0607. As per the definition of Kellermann et al. (1989), $R = 10$ marks the radio-loud/radio-quiet division, where $R = f_{5 \text{ GHz}}/f_{4400 \text{ Å}}$. While the 5 GHz flux of BR 2237–0607 is not available in the literature, the source can be considered radio-quiet based on 1.4 GHz observations (Isaak et al. 1994).

BR 2237–0607 was observed by *XMM-Newton* (Jansen et al. 2001) on 2003 May 17 05:52–15:44 (UT) for a total of 32.5 ks with the EPIC pn (Strüder et al. 2001) and 34.2 ks with the EPIC MOS (Turner et al. 2001) detectors using thin filters. A high background flare was present during part of the exposure, especially toward the end of the observation. We excluded these times by creating a good time interval (GTI) file accepting only times when the background count rate of photons with energies $> 10 \text{ keV}$ was less than $0.1 \text{ counts s}^{-1}$. The GTI screening results in a total observing time of 23.1 ks for the pn data and of 30.0 ks for the MOS data. Source photons in the EPIC pn and MOS were collected in a circle with a radius of $25''$, and the background photons in a circle of a radius of $75''$ close by. We selected single and double events ($\text{PATTERN} \leq 4$) for the pn and single, double, triple, and quadruple events ($\text{PATTERN} \leq 12$) for the MOS. Because of the much higher efficiency of the *XMM-Newton* XRT/pn array compared to the MOS, we concentrate on the spectral analysis of the pn data and use the MOS data for consistency checks only.

For comparison purposes we also retrieved the *ROSAT* data from the public archive at the Max-Planck-Institut für extraterrestrische Physik, Garching. The data were analyzed by the Extended X-Ray Scientific Analysis System (EXSAS; Zimmermann et al. 1998), version 01APR.⁵

2.2. BR 0351–1034

The quasar BR 0351–1034 ($z = 4.351$) was discovered with the Automatic Plate Measuring Facility (APM) high-redshift quasar survey by Irwin et al. (1991). It is radio-quiet (Isaak et al. 1994). Storrie-Lombardi et al. (1996) reported that BR 0351–1034 was one of the most unusual sources in their survey of high-redshift APM quasars with intervening absorption systems. They found saturated C IV absorption and a large number of absorption lines associated with damped Ly α absorption systems

⁵ See <http://wave.xray.mpe.mpg.de/exsas/user-guide>.

TABLE 1
 $z > 4.0$ QUASARS WITH *XMM-Newton* OBSERVATIONS

No.	Object	$\alpha_{J2000.0}$	$\delta_{J2000.0}$	z	<i>XMM-Newton</i> Obs. ID	UT Date	T_{acc}^a	Counts	<i>XMM-Newton</i> Reference
1.....	Q0000–2619	00 03 22.92	–26 03 18.7	4.100	0103060301	2002 Jun 25	37.8	1366 ± 46	Ferrero & Brinkmann (2003)
2.....	SDSS 0040–0915	00 40 54.65	–09 15 26.8	4.980	0065140101	2002 Jan 07	3.4	49 ± 8	Schneider et al. (2003)
3.....	BRI 0103+0032	01 06 19.20	+00 48 23.3	4.440	0150870201	2003 Jul 15	3.7	53 ± 11	...
4.....	PSS J0248+1802	02 48 54.30	+18 02 49.2	4.422	0150870301	2003 Feb 14	7.4	161 ± 16	...
5.....	BR 0351–1034	03 53 46.91	–10 25 19.0	4.351	^b	^b	39.1	254 ± 30	Grupe et al. (2004a)
6.....	PMN J0525–3343	05 25 06.17	–33 43 05.3	4.400	^c	^c	72.9	28809 ± 177	Worsley et al. (2004c)
7.....	RX J1028.6–0844	10 28 37.70	–08 44 23.6	4.276	0093160701	2002 May 15	4.4	1809 ± 44	Grupe et al. (2004a)
8.....	SDSS 1030+0524	10 30 27.10	+05 24 55.0	6.28	0148560501	2003 May 22	67.5	342 ± 33	Farrah et al. (2004)
9.....	BRI 1033–0327	10 36 23.80	–03 43 19.3	4.49	0150870401	2002 Dec 20	26.5	56 ± 14	...
10.....	SDSS 1044–0125	10 44 33.04	–01 25 02.2	5.740	0125300101	2000 May 28	34.1	32 ± 9	Brandt et al. (2001a)
11.....	RX J1052.4+5719	10 52 25.90	+57 19 07.0	4.450	^d	^d	535.7 ^d	368 ± 52	Worsley et al. (2004a)
12.....	VLA J1236+6213	12 36 42.00	+62 13 31.0	4.420	^e	^e	205 ^e	...	...
13.....	CXOHDFN J123647+620941	12 36 47.90	+62 09 41.0	5.180	^e	^e	205 ^e	...	...
14.....	CXOHDFN J123719+621025	12 37 19.00	+62 10 25.0	4.130	^e	^e	205 ^e	...	...
15.....	CXOCY J125304–090737	12 53 04.00	–09 07 37.0	4.180	0112270701	2003 Jan 15	8.1	...	...
16.....	SDSS J1401+0244	14 01 46.53	+02 44 34.7	4.380	0098010101	2000 Jun 28	32.7	115 ± 20	Schneider et al. (2003)
17.....	GB 1428+4217	14 30 23.78	+42 04 26.3	4.720	^f	^f	14.2	8476 ± 92	Worsley et al. (2004b)
18.....	GB 1508+5714	15 10 02.23	+57 03 04.9	4.300	0111260201	2002 May 11	9.4	1437 ± 39	...
19.....	RX J1759.4+6638	17 59 27.76	+66 38 53.6	4.320	^g	^g	6.9	12 ± 7	...
20.....	CXOMP J213945–234655	21 39 45.00	–23 46 55.0	4.930	0008830101	2001 Apr 29	11.5 ^h	...	...
21.....	BR 2237–0607	22 39 53.57	–05 52 20.0	4.558	0149410401	2003 May 17	23.1	381 ± 29	This paper

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

^a Accepted GTI screened exposure times given in kiloseconds.

^b Merged event file from observation IDs 0093160201 and 0203460201 (orbits 495 and 759; 2002 August 23 and 2004 January 31, respectively).

^c Merged event file from the observations as listed in Table 5.

^d Merged event file from the observations as listed in Table 6; note the exposure time is not derived from the exposure map.

^e Merged event file from the observations as listed in Table 7; note the exposure time is not derived from the exposure map.

^f Merged event file from observation IDs 0111260101 and 0111260701 (orbits 549 and 569; 2002 December 9 and 2003 January 17, respectively).

^g Merged event file from observation IDs 0112310401 and 0112310801 (orbits 457 and 523; 2002 June 8 and October 18, respectively).

^h Note the exposure time is not derived from the exposure map.

at $z = 3.633, 4.098$, and 4.351 . The source was first detected in X-rays by *ROSAT* in a 9.1 ks pointed PSPC observation with 54 ± 13 counts (Kaspi et al. 2000a). The source has been observed once before by *XMM-Newton* (Grupe et al. 2004a). Due to high background radiation throughout, a second *XMM-Newton* observation was made in 2004 January and is reported here.

BR 0351–1034 was observed by *XMM-Newton* on 2004 January 31 12:02–21:47 (UT) for a total of 32.1 ks with the EPIC pn and 33.8 ks with the EPIC MOS detectors using thin filters. Due to high background radiation during the last half of the observation, part of the pn observation was not usable (the MOS background was much lower, so the entire exposure time was useful). The PN data were screened as discussed above, resulting in a total of 23.7 ks observing time. Source counts of the pn data were collected in a circle with a radius of $20''$, and the background from a nearby circular region with a radius of $40''$. Because of its small number of counts (§ 3.2), only the EPIC pn data with single and double events ($\text{PATTERN} \leq 4$) were used for the spectral analysis. Because of the faintness of the source, proper background subtraction is important. We determined background from a second nearby region as well and found the results with the two different backgrounds to be consistent within errors.

In order to increase the signal-to-noise ratio (S/N) of the spectral data, we merged the GTI screened event files of the two *XMM-Newton* observations of 2002 August 23 (Grupe et al. 2004a) and 2004 January 31 (this work) into one event file using the *XMM-Newton* Science Analysis Software (XMMSAS) task *merge*. The data for the spectra were selected as described above. For the background, a region was chosen that was observed on the pn CCD4 in both observations. The pn data were binned with GRPPHA to have at least 15 photons per bin. The merged data sets result in total observing times of 39.1 ks for the pn and 53.0 and 53.1 ks for MOS1 and MOS2, respectively. For a consistency check we also fitted the spectra of the 2002 and 2004 observations simultaneously using XSPEC. The analysis and results of the first *XMM-Newton* observation have been discussed in Grupe et al. (2004a).

2.3. $z > 4$ Quasars with *XMM* Observations

For all $z > 4$ quasars found in the *XMM-Newton* archive we retrieved the Observational Data Files (ODFs) and created the EPIC pn event files using the XMMSAS task *epchain*. The data were screened for high background radiation events using the same screening criteria as for BR 0351–1034 and BR 2237–0607. All $z > 4$ quasars with *XMM-Newton* observations are listed in Table 1; multiple observations are available for eight of these sources.

All *XMM-Newton* data were reduced using the XMMSAS, version 6.0.0, and the X-ray spectra were analyzed using XSPEC 11.3.1. The spectra were grouped by GRPPHA 3.0.0 in bins of at least 20 counts per bin, except otherwise noted. The ancillary response matrix and the detector response matrix were created by the XMMSAS tasks *arfgen* and *rmfgen*. In case of multiple observations, the event files were merged with the XMMSAS task *merge*, and the ancillary response matrices and detector response matrices were combined by the FTOOLS commands *addarf* and *addrmf*, respectively. For the count rate conversions between different X-ray missions, PIMMS 3.6c was used.

3. ANALYSIS

3.1. BR 2237–0607

3.1.1. *XMM-Newton* Observation

During the GTI screened observations 381 ± 29 source counts were detected in the pn, 109 ± 16 counts in MOS1, and $143 \pm$

TABLE 2
SPECTRAL-FIT PARAMETERS TO THE EPIC PN DATA OF BR 2237–0607

XSPEC Model	$N_{\text{H,Gal}}$ (10^{20} cm^{-2})	$N_{\text{H,intr}}$ (10^{22} cm^{-2})	α_{X}	χ^2 (dof)
1.....	8.89 ± 4.32	...	1.17 ± 0.29	21.1 (29)
1.....	3.84 (fix)	...	0.84 ± 0.14	26.1 (30)
2.....	3.84 (fix)	1.84 ± 1.50	1.10 ± 0.23	23.1 (29)

NOTES.—XSPEC Model: (1) power law with Galactic absorption; (2) power law with Galactic absorption and redshifted neutral absorption at $z = 4.558$.

18 counts in MOS2. This results in count rates of 0.0165 ± 0.0012 , $(3.67 \pm 0.56) \times 10^{-3}$, and $(4.77 \pm 0.59) \times 10^{-3} \text{ counts s}^{-1}$ for the pn, MOS1, and MOS2, respectively.

The results of the spectral analysis are given in Table 2. The data are well fitted by a single power law plus Galactic absorption $N_{\text{H}} = 3.84 \times 10^{20} \text{ cm}^{-2}$ (from the H I maps of Dickey & Lockman [1990]). While this simple model describes the data well, with no need for excess absorption, we looked for a signature of excess absorption in the spectrum to test whether we can rule it out, because there exist two intervening absorption systems along the line of sight of this source. Figure 1 displays the power-law fit to the pn data (*left*) and a contour plot between the power-law slope and intrinsic N_{H} (*right*). Leaving the absorption parameter free results in a best-fit value in excess of Galactic (Fig. 1). The addition of absorption in excess of Galactic improves the χ^2 by 2.6 for 30 degrees of freedom, corresponding to an *F*-test significance of $F = 3.25$ with probability $P = 0.082$. An intrinsic absorber at the redshift of BR 2237–0607 results in a column density of $N_{\text{H}} = (1.84 \pm 1.50) \times 10^{22} \text{ cm}^{-2}$. A Ly α candidate system at $z = 4.08$ and a Lyman limit system at $z = 4.28$ are observed along the line of sight to BR 2237–0607 (Storrie-Lombardi et al. 1996). Due to the limited S/N of the spectrum, however, the redshift of the absorber is not constrained. If the absorber redshift corresponds to the two intervening absorbers, the implied column densities are $N_{\text{H}} = (1.6 \pm 1.4) \times 10^{22} \text{ cm}^{-2}$ ($z = 4.28$) and $N_{\text{H}} = (1.5 \pm 1.2) \times 10^{22} \text{ cm}^{-2}$ ($z = 4.08$). These column densities are a factor of about 50 larger than the $N_{\text{H,I}} = 2.5 \times 10^{20} \text{ cm}^{-2}$ estimated by Storrie-Lombardi et al. (1996) for the Ly α system at $z = 4.08$ and would imply unusually large abundances for the intervening systems. Even though the errors on X-ray column density measurements are large, the intervening absorption is excluded at more than 3σ . Therefore, we conclude that the additional absorption, if present, is intrinsic to the quasar and not to an intervening system. We reiterate, however, that the possibility of intrinsic absorption is only a 1σ result.

The rest-frame unabsorbed 2.0–10.0 keV flux is $2.6 \times 10^{-17} \text{ W m}^{-2}$ ($2.6 \times 10^{-14} \text{ ergs s}^{-1} \text{ cm}^{-2}$), which gives a rest-frame 2–10 keV luminosity of $\log L_{2-10 \text{ keV}} = 38.68$ (W) ($45.68 [\text{ergs s}^{-1}]$). From the rest-frame UV spectrum (Dietrich et al. 2003) and the power-law fit to the pn data, we derived an X-ray loudness $\alpha_{\text{ox}} = 1.58 \pm 0.08$.

3.1.2. Comparison with *ROSAT*

From the 9.4 ks *ROSAT* PSPC observation we measured 37.0 ± 14.1 photons corresponding to a count rate of $(3.92 \pm 1.48) \times 10^{-3} \text{ counts s}^{-1}$ in the 0.1–2.0 keV band. However, this is a factor of about 1.5 lower than that reported previously by Kaspi et al. (2000a), who gave a PSPC count rate of $(6.2 \pm 1.4) \times 10^{-3} \text{ counts s}^{-1}$. We tried different background regions in order to search for differences in the background subtraction but found this not to be the cause. Our measured count rate,

FIG. 1.—Power-law fit with neutral Galactic absorption (fixed to Galactic value) and intrinsic absorption with solar metal abundance to the EPIC pn spectrum of BR 2237–0607: *left*, fit to the pn data; *right*, contour plot between the photon spectral index Γ and the intrinsic column density N_{H} .

however, is consistent with the count rate of $(2.94 \pm 0.67) \times 10^{-3}$ counts s^{-1} given in the *ROSAT* source catalog and in Vignali et al. (2001), which supports the results of our analysis. The PSPC count rate is a factor of about 1.6 higher than expected, based on the pn count rate. However, due to the low number of PSPC photons and the associated error, the source flux is constant within 2σ .

From the *ROSAT* PSPC data we measured a hardness ratio⁶ $\text{HR} = 0.37 \pm 0.34$. The HR derived from the *XMM-Newton* pn spectrum with a power-law model with Galactic and intrinsic absorption as given in Table 2 suggests a much harder spectrum with $\text{HR} = 0.82$. On the other hand, if we use the power-law model ($\alpha_X = 0.87$) with Galactic absorption only, the resulting $\text{HR} = 0.52$, which is consistent with the HR measured from the PSPC. We also checked if additional information is obtained by subdividing the PSPC energy range to define two hardness ratios HR1 and HR2.⁷ We again found that the observed values are more consistent with a model containing Galactic absorption only rather than with that containing excess absorption. The softer spectrum and higher count rate during the *ROSAT* observation suggest that the BR 2237–0607 spectrum is variable, but the limited S/N of both the *XMM-Newton* and the *ROSAT* spectra do not allow us to draw any firm conclusions.

3.2. BR 0351–1034

The mean count rates during the 2004 January observations are $(5.38 \pm 0.03) \times 10^{-3}$ counts s^{-1} for the EPIC pn and $(2.12 \pm 0.41) \times 10^{-3}$ and $(1.37 \pm 0.37) \times 10^{-3}$ counts s^{-1} for the EPIC MOS1 and MOS2, respectively. This results in total numbers of background-subtracted source counts of 127 ± 22 for the pn and 71 ± 14 and 44 ± 12 for the MOS1 and MOS2, respectively. The count rates are similar to those obtained during the first *XMM-Newton* observation on 2002 August 23 (Grupe et al. 2004a). The merged spectra of the 2002 August and 2004 January observations have a total of 234 ± 30 , 98 ± 18 , and 86 ± 18 source counts for the pn, MOS1, and MOS2, respectively. The number of counts in the pn detector are sufficient to perform a basic spectral analysis; therefore, we focus on the merged pn data only.

Figure 2 displays power-law fits to the 2004 January and the 2002+2004 merged data including contour plots between the intrinsic N_{H} and the photon index Γ . Table 3 summarizes the results of spectral fits to the EPIC pn data of BR 0351–1034. Since the results of the spectral analysis of the 2004 January and the merged data from the 2002 August and 2004 January data are consistent, we discuss the merged data here. The merged data are consistent with a power law with the absorption parameter set to the Galactic value $N_{\text{H}} = 4.08 \times 10^{20} \text{ cm}^{-2}$, with a best-fit power-law slope $\alpha_X = 0.42 \pm 0.17$. Leaving the absorption parameter free results in an absorption column at $z = 0$ of $(1.0 \pm 0.9) \times 10^{21} \text{ cm}^{-2}$. Thus, even though the best-fit column density implies absorption in excess of Galactic, this is not a secure result because of the large error on N_{H} . If the absorber is placed at the redshift of the quasar, the fit results in an upper limit of the absorption column of $2.9 \times 10^{22} \text{ cm}^{-2}$. With the absorbing column fixed at Galactic, the power-law spectral index is $\alpha_X = 0.42 \pm 0.17$, unusually flat for a radio-quiet quasar. On the other hand, *ROSAT* data suggest a steep spectral slope with $\alpha_X = 3.5$ (see Grupe et al. [2004a] for a detailed discussion on comparison with *ROSAT* data). Motivated by these results, we fitted the merged data with a broken power-law model with $\alpha_{X,\text{soft}} = 3.5$. The resulting fit is good, with $\alpha_{X,\text{hard}} = 1.42 \pm 0.18$, but the data quality is not good enough to favor one fit over others (see Table 3). For comparison purposes we also fitted the 2002 August and 2004 January data simultaneously in XSPEC. As shown in Table 3, we do not find significant differences between the fits to the merged data set or the simultaneous fit to the two single data sets.

The absorption-corrected rest-frame 2–10 keV flux of the merged spectrum is $\log F_X = -17.1$ (W m^{-2}) (-14.1 [$\text{ergs s}^{-1} \text{ cm}^{-2}$]). This flux converts to an unabsorbed rest-frame 2–10 keV log luminosity of 38.13 (W) (45.13 [ergs s^{-1}]). The X-ray loudness is $\alpha_{\text{ox}} = 1.59 \pm 0.08$, using the rest-frame UV spectrum given in Storrie-Lombardi et al. (1996). We note that Kaspi et al. (2000a) and Vignali et al. (2001) quote α_{ox} of 1.35 and 1.6, respectively.

3.3. High-Redshift Quasars with XMM-Newton Observations

Here we describe the analysis of all high-redshift quasars with *XMM-Newton* observations publicly available (2004 December). All these sources are listed in Table 1. If enough photons were collected for a source, we performed a power-law fit with Galactic

⁶ The hardness ratio is defined as $\text{HR} = (H - S)/(H + S)$ with soft band S in the energy range 0.1–0.4 keV and H in the range 0.5–2.0 keV.

⁷ HR1 is the same as HR defined above, and HR2 is between the soft and hard bands of 0.5–0.9 and 0.9–2 keV, respectively.

FIG. 2.—Power-law fit with neutral Galactic absorption (fixed to Galactic value) and intrinsic absorption with solar metal abundance to the EPIC pn spectrum of BR 0351–1034: *left*, fit to the 2004 January pn data; *right*, fit to the merged data of the 2002 and 2004 observations; *top*, spectral fits to the data; *bottom*, contours with the photon spectral index Γ and the intrinsic absorption parameter N_{H} .

TABLE 3
SPECTRAL-FIT PARAMETERS TO THE EPIC PN DATA OF BR 0351–1034

Obs. Date	XSPEC Model	$N_{\text{H,Gal}}$ (10^{20} cm^{-2})	$N_{\text{H,intr}}$ (10^{22} cm^{-2})	$\alpha_{\text{X,soft}}$	$\alpha_{\text{X,hard}}$	χ^2 (dof)
2004 Jan.....	1	15.3 ± 14.5	...	...	0.81 ± 0.61	6.8 (14)
	2	4.08 (fix)	...	...	0.37 ± 0.26	7.9 (15)
	3	4.08 (fix)	5.34 ± 4.30	...	0.75 (fix)	6.5 (15)
Merged 2002+2004.....	1	10.26 ± 8.51	...	...	0.69 ± 0.37	22.5 (25)
	2	4.08 (fix)	...	...	0.42 ± 0.17	23.5 (26)
	3	4.08 (fix)	<6.3	...	0.67 ± 0.30	22.0 (25)
	4	4.08 (fix)	...	3.50 (fix)^a	0.42 ± 0.18	22.3 (26)
Simultaneous fit ^b	1	9.65 ± 8.09	...	...	0.82 ± 0.39	29.8 (33)
	2	4.08 (fix)	...	...	0.55 ± 0.13	30.8 (34)
	3	4.08 (fix)	<2.15	...	0.76 ± 0.31	29.8 (33)

NOTES.—XSPEC model: (1) power law with absorption parameter free; (2) power law with Galactic absorption $4.08 \times 10^{20} \text{ cm}^{-2}$; (3) power law with Galactic absorption and redshifted neutral absorption at $z = 4.351$; (4) broken power law with Galactic absorption.

^a The expression $\alpha_{\text{X,soft}}$ refers to the soft X-ray spectral slope that is suggested by fits to the *ROSAT* data that suggest a break at 0.45 keV (Grupe et al. 2004a).

^b Simultaneous fit to the 2002 August and 2004 January data in XSPEC.

TABLE 4
RESULTS OF POWER-LAW FITS WITH GALACTIC (AND INTRINSIC) ABSORPTION TO THE *XMM-Newton* PN DATA OF $z > 4.0$ QUASARS AS LISTED IN TABLE 1

No.	Object	RL/RQ ^a	$N_{\text{H,Gal}}^{\text{b}}$	$N_{\text{H,intr}}^{\text{b}}$	α_{X}	χ^2/ν	$\log F_{2-10 \text{ keV}}^{\text{c}}$	$\log L_{2-10 \text{ keV}}^{\text{c}}$	$\log L_{2500 \text{ \AA}}^{\text{c}}$	α_{ox}	Comments
1.....	Q0000–2619	RQ	1.67	...	1.15 ± 0.06	75/80	–16.33	38.83	24.52	1.82 ± 0.03	Gal $\times$ Power Law
2.....	SDSS 0040–0915	RQ	3.37	...	1.43 ± 0.34	2/3	–16.59	38.76	24.60	1.39 ± 0.14	Gal $\times$ Power Law
3.....	BRI 0103+0032	RQ	3.19	...	1.96 ± 0.50	5/6	–16.70	38.54	24.63	1.41 ± 0.36	Gal $\times$ Power Law
4.....	PSS J0248+1802	RQ	9.18	...	1.10 ± 0.18	16/13	–16.36	38.88	24.62	1.47 ± 0.07	Gal $\times$ Power Law
5.....	BR 0351–1034	RQ	4.08	...	$0.42 \pm 0.17^{\text{d}}$	23/15	–17.10 ^d	38.13 ^d	24.49	$1.59 \pm 0.08^{\text{d}}$	(Gal + Intr) $\times$ Power Law
6.....	PMN J0525–3343	RL	2.21	1.56 ± 0.10	0.71 ± 0.01	601/600	–15.24	39.98	24.68	1.04 ± 0.01	(Gal + Intr) $\times$ Power Law
7.....	RX J1028.6–0844	RL	4.59	0.07 ± 0.01	0.30 ± 0.05	92/84	–15.32	39.88	23.17	0.86^{d}	(Gal + Intr) $\times$ Power Law
8.....	SDSS 1030+0524	RQ	3.20	6.51 ± 3.74	1.65 ± 0.34	32/39	–16.83	38.76	24.55	1.72^{e}	(Gal + Intr) $\times$ Power Law
9.....	BRI 1033–0327	RQ	4.79	...	1.34 ± 0.47	8/6	–17.50	37.75	24.68	1.80 ± 0.20	Gal $\times$ Power Law
10.....	SDSS 1044–0125	RQ	4.19	...	...	...	–17.54 ^f	37.96 ^f	24.35	1.86^{f}	<i>XMM-Newton</i> detection
11.....	RX J1052.4+5719	RQ	0.56	...	1.58 ± 0.30	73/73	–17.96	37.28	22.86	1.20 ± 0.15	Gal $\times$ Power Law
12.....	VLA J1236+6213	RL	1.49	...	...	...	–18.92 ^g	36.74 ^g	22.11	1.52^{g}	No <i>XMM-Newton</i> detection
13.....	CXOHDFN J123647+620941	RQ	1.48	...	...	...	–18.38 ^g	37.02 ^g	22.86	1.51^{g}	No <i>XMM-Newton</i> detection
14.....	CXOHDFN J123719+621025	RQ	1.29	...	...	...	–18.54 ^g	36.63 ^g	22.03	1.41^{g}	No <i>XMM-Newton</i> detection
15.....	CXOCY J125304–090737	RQ	2.96	...	...	...	–17.65 ^h	37.53 ^h	22.68	1.35^{h}	No <i>XMM-Newton</i> detection
16.....	SDSS J1401+0244	RQ	2.36	...	0.32 ± 0.39	9/8	–17.09	38.13	24.06	1.77^{i}	Gal $\times$ Power Law
17.....	GB 1428+4217	RL	1.40	2.13 ± 0.23	0.86 ± 0.03	299/310	–15.09	40.21	23.69	0.84 ± 0.01	(Gal + Intr) $\times$ Power Law
18.....	GB 1508+5714	RL	1.47	...	0.55 ± 0.04	75/66	–15.77	39.43	24.07	1.07 ± 0.02	Gal $\times$ Power Law
19.....	RX J1759.4+6638	RL	4.23	...	...	...	–16.29 ^j	38.92 ^j	24.43	1.45^{j}	<i>XMM-Newton</i> detection
20.....	CXOMP J213945–234655	RQ	3.55	...	...	...	–17.59 ^k	37.76 ^k	23.58	1.52^{k}	No <i>XMM-Newton</i> detection
21.....	BR 2237–0607	RQ	3.84	1.84 ± 1.50	1.10 ± 0.23	23/29	–16.58	38.68	24.55	1.58 ± 0.08	(Gal + Intr) $\times$ Power Law

NOTE.—Fluxes and luminosities are given in the rest frame.

^a Radio-loud (RL) and radio-quiet (RQ), using the definition of Kellermann et al. (1989). References on the radio loudness are given in § 3.3.

^b Galactic column density $N_{\text{H,Gal}}$ in units of 10^{20} cm^{-2} and intrinsic column density $N_{\text{H,intr}}$ in units of 10^{22} cm^{-2} .

^c Rest-frame unabsorbed flux $F_{2-10 \text{ keV}}$ in units of watts per square meter, luminosity $L_{2-10 \text{ keV}}$ in units of watts, and luminosity density at 2500 Å in units of watts per hertz. References for the luminosity density at 2500 Å are given for each individual object in § 3.3.

^d Estimated from the merged 2002 and 2004 spectra.

^e The α_{ox} value is from Mathur et al. (2002).

^f Based on the data given in Brandt et al. (2001a) converted into flux using PIMMS and α_{ox} taken from Brandt et al. (2001a).

^g Flux and luminosity values from the *Chandra* ACIS-S count rates and X-ray slopes given in Vignali et al. (2002) and α_{ox} taken from Vignali et al. (2002).

^h Estimated from the *Chandra* ACIS-S flux and X-ray slope given in Castander et al. (2003) and α_{ox} taken from Castander et al. (2003).

ⁱ The α_{ox} value is taken from Schneider et al. (2003).

^j Estimated from the *ROSAT* PSPC flux and X-ray slope given in Kaspi et al. (2000a) and α_{ox} taken from Kaspi et al. (2000a).

^k Estimated from the *Chandra* flux given in Silverman et al. (2002) and α_{ox} from Silverman et al. (2002).

FIG. 3.—Best fits to the *XMM-Newton* EPIC pn spectra of the high-redshift quasars with *XMM-Newton* observations as listed in Table 4.

absorption and intrinsic absorption if needed by the data. The results of these fits and the rest-frame 2–10 keV fluxes and luminosities are given in Table 4. All EPIC pn spectra are shown in Figure 3. Several sources have less than 100 detected counts, resulting in only approximate X-ray spectral slopes; α_X derived from these data sets should be treated with caution. The errors given for α_{OX} were estimated from the errors in the X-ray spectral index and the normalization of the spectrum. This is a lower limit of the error, because it does not take into account errors in the optical spectrum, e.g., we assume a general optical/UV slope of $\alpha_{UV} = 0.45$ (e.g., Vanden Berk et al. 2001; Dietrich et al. 2002b). Another source of errors in the optical spectrum is reddening, which is difficult to compute.

3.3.1. Q0000–2619

The *XMM-Newton* observation of the $z = 4.1$ radio-quiet quasar Q0000–2619 (e.g., Bechtold et al. 1994) was discussed in detail in Ferrero & Brinkmann (2003). The pn spectrum is well fitted by a single power law with Galactic absorption. Adding an intrinsic absorber at the redshift of the quasar does not improve the fit, and the column density cannot be constrained. The best-fit power-law slope is $\alpha_X = 1.15 \pm 0.06$. The X-ray loudness $\alpha_{OX} = 1.82 \pm 0.03$ was determined from the dereddened rest-frame UV spectrum given in Bechtold et al. (1994), and the rest-frame 2 keV flux was determined from the pn spectrum. This value agrees, within errors, with the $\alpha_{OX} = 1.85$ given in Ferrero &

Brinkmann (2003) and Bechtold et al. (1994) but differs from the $\alpha_{\text{ox}} = 1.65$ and 1.71 derived from *ROSAT* data reported in Kaspi et al. (2000a) and Vignali et al. (2001), respectively. The *ROSAT* data presented by Kaspi et al. (2000a) contained only 180 counts. While this was a secure detection, the power-law slope of the spectrum was not as well determined as from the *XMM-Newton* spectrum, and so α_{ox} was not well determined; different optical slopes also contribute toward different values of α_{ox} .

3.3.2. SDSS 0040–0915

The $z = 4.98$ radio-quiet quasar SDSS 0040–0915 (Schneider et al. 2003) was serendipitously observed by *XMM-Newton* during a 9 ks observation of the galactic cluster Abell 85 (Durret et al. 2005). The 50 photons detected during this observation only allow a rough estimate of the spectral slope of the X-ray spectrum. The data were rebinned in groups of at least 10 counts per bin. The absorption parameter was fixed to the Galactic value, which is consistent with the data. The data can be fitted by a single power law with $\alpha_{\text{X}} = 1.43 \pm 0.34$. The X-ray loudness $\alpha_{\text{ox}} = 1.39 \pm 0.14$ was estimated from the rest-frame UV spectrum given in Schneider et al. (2003) and the pn spectrum and is in agreement within the errors with the $\alpha_{\text{ox}} = 1.55$ given in Schneider et al. (2003). The steeper X-ray loudness found by Schneider et al. (2003) can be explained by their assumption of an X-ray spectral index $\alpha_{\text{X}} = 1.0$ and the lower count rate and therefore lower flux in the pn energy band. Note also that Schneider et al. (2003) use an UV spectral slope $\alpha_{\text{UV}} = 0.79$ to extrapolate to the flux density at rest-frame 2500 Å.

3.3.3. BRI 0103+0032

This $z = 4.44$ radio-quiet quasar (Smith et al. 1994; Stern et al. 2000) was observed by *XMM-Newton* for only 4 ks. Only 50 source photons were detected during the observation, allowing only a rough spectral fit with a power-law model with $\alpha_{\text{X}} = 1.96 \pm 0.50$ and the absorption parameter fixed to the Galactic value. The data do not indicate additional intrinsic absorption. This is the steepest α_{X} known for a high-redshift quasar. Even if the actual value of α_{X} is lower by 1σ , it is still very steep, comparable to that of NLS1s at low redshift (Fig. 6). The X-ray loudness $\alpha_{\text{ox}} = 1.41 \pm 0.36$ given in Table 4 was derived from the rest-frame UV spectrum (Dietrich et al. 2003) and the *XMM-Newton* EPIC pn X-ray data.

Dietrich & Hamann (2004) give a black hole mass of $(1.0 \pm 0.3) \times 10^9 M_{\odot}$ and an Eddington ratio $L/L_{\text{Edd}} = 3.5$; the black hole mass was determined using the C IV emission-line width and the broad-line-region radius–luminosity relation as mentioned above. This high L/L_{Edd} may explain the steep X-ray spectrum of the source; L/L_{Edd} and α_{X} have been found to be closely correlated in low-redshift AGNs (Grupe 2004; Williams et al. 2004). Even though black hole masses derived from C IV and Mg II widths are highly uncertain, even an order of magnitude lower L/L_{Edd} is still high and is comparable to that of low-redshift NLS1s.

3.3.4. PSS J0248+1802

The $z = 4.422$ quasar PSS J0248+1802 was discovered by Kennefick et al. (1995) from a multicolor survey using the Second Palomar Observatory Sky Survey. This radio-quiet quasar (Stern et al. 2000) has been a target of *Chandra* (Vignali et al. 2001), as well as of *XMM-Newton*. It was observed by *XMM-Newton* in 2003 February for a GTI screened time of 7.4 ks (Table 1) yielding 160 photons. The data were grouped in bins of at least 15 counts per bin. A fit to the pn data is consistent with a single power law with $\alpha_{\text{X}} = 1.10 \pm 0.15$ with Galactic

TABLE 5
XMM-Newton EPIC PN OBSERVATIONS OF PMN J0525–3343
(WORSLEY ET AL. 2004c)

Orbit	Obs. ID	UT Obs. Date	$T_{\text{obs}}^{\text{a}}$ (ks)
216.....	0050150101	2001 Feb 11	9.8
324.....	0050150301	2001 Sep 15	20.2
583.....	0149500601	2003 Feb 2	9.2
588.....	0149500701	2003 Feb 24	9.3
593.....	0149500801	2003 Mar 6	9.0
598.....	0149500901	2003 Mar 16	7.6
671.....	0149501201	2003 Aug 8	7.6

^a Screened GTIs.

absorption. Vignali et al. (2001) suggested from the *Chandra* observation that the source seem to be intrinsically absorbed with a column density larger than $5 \times 10^{23} \text{ cm}^{-2}$. However, this claim was based on only 19 source photons and is not supported by *XMM-Newton* data; the best-fit value of intrinsic absorption is an upper limit $N_{\text{H}} = 3 \times 10^{20} \text{ cm}^{-2}$ (90% error). We estimate the X-ray loudness $\alpha_{\text{ox}} = 1.47 \pm 0.07$ from the optical/UV spectrum (Dietrich et al. 2003) and the pn spectrum. The black hole mass was measured by Dietrich & Hamann (2004) to be $(6.6 \pm 1.6) \times 10^9 M_{\odot}$ with an Eddington ratio $L/L_{\text{Edd}} = 0.91$.

3.3.5. PMN J0525–3343

The *XMM-Newton* observations of the blazar PMN J0525–3343 ($z = 4.40$) have been presented and discussed in detail in Worsley et al. (2004c), who reported the presence of a warm absorber in this source, confirming a claim based on *BeppoSAX* observations (Fabian et al. 2001). Table 5 summarizes the observations, which we merged into one event file. Note that the GTI screened times given in Table 5 deviate from those given in Table 1 in Worsley et al. (2004c). The reason is a different screening for the GTIs (M. Worsley 2004, private communication). We did not use the observations performed during orbits 603 and 608 due to very high background radiation throughout those orbits.

A single power-law fit to the data with the absorption column density fixed to the Galactic value $N_{\text{H}} = 2.21 \times 10^{20} \text{ cm}^{-2}$ as given in Table 1 does not give an acceptable fit ($\chi^2/\text{dof} = 927/601$). The result suggests intrinsic absorption at the redshift of the quasar. Adding an absorber at the location of the quasar significantly improved the fit. The best fit results in an intrinsic cold absorber with $N_{\text{H}} = 1.6 \times 10^{22} \text{ cm}^{-2}$ and an X-ray spectral slope $\alpha_{\text{X}} = 0.71 \pm 0.01$, which agrees with the value given by Worsley et al. (2004c; 0.67 ± 0.03); an additional warm absorber was not required by the data (see residuals to the fit in Fig. 3).

PMN J0525–3343 shows a slight increase in its EPIC pn count rate from $0.311 \pm 0.006 \text{ counts s}^{-1}$ during the 2001 February observation to $0.457 \pm 0.008 \text{ counts s}^{-1}$ during the 2003 August observation. The X-ray loudness $\alpha_{\text{ox}} = 1.04 \pm 0.01$ was estimated from the *R* magnitude measured from the APM scans given in Péroux et al. (2001) and the pn spectrum. There is a large uncertainty in determining α_{ox} for PMN J0525–3343, because we do not know the optical reddening. The intrinsic absorption column $N_{\text{H}} = 1.6 \times 10^{22} \text{ cm}^{-2}$ suggests that the source may be reddened in the optical. However, the source is detected in the rest-frame UV, suggesting that the reddening is not severe. In order to determine the reddening, near-infrared spectra are needed to measure the Balmer decrement.

3.3.6. RX J1028.6–0844

The $z = 4.276$ radio-loud quasar RX J1028.6–0844 was the only $z > 4$ quasar discovered during the RASS (Zickgraf et al. 1997). From a long *ASCA* observation, Yuan et al. (2000) suggested that the quasar is intrinsically highly absorbed ($N_H = 2 \times 10^{23} \text{ cm}^{-2}$). However, a 4.4 ks observation with *XMM-Newton* did not confirm the presence of a strong intrinsic absorber (Grupe et al. 2004a). Due to the capability of the EPIC pn to observe down to low X-ray energies of 0.2 keV, Grupe et al. (2004a) measured an intrinsic absorption column N_H of at most a few times 10^{22} cm^{-2} . From a 10 times longer *XMM-Newton* observation Yuan et al. (2005) confirmed that, indeed, the source is not as highly absorbed as claimed from the *ASCA* data; the best-fit intrinsic cold absorption is $N_H = 2.1^{+0.4}_{-0.3} \times 10^{22} \text{ cm}^{-2}$. Yuan et al. (2005) argue for an additional warm absorber with column density $N_H > 2 \times 10^{22} \text{ cm}^{-2}$.

3.3.7. SDSS J1030+0524

Petric et al. (2003) found an upper limit of the radio flux at 1.4 GHz $S_{1.4 \text{ GHz}} < 61 \mu\text{Jy}$, which makes this source radio-quiet. With a redshift of $z = 6.28$, SDSS J1030+0524 is currently the quasar with the highest redshift detected in X-rays. The quasar was detected by *Chandra* (Mathur et al. 2002; Brandt et al. 2002b). It was also observed by *XMM-Newton* in 2003 May (Farrah et al. 2004) for 67 ks with the pn (Table 1), resulting in 340 source counts. While a spectral fit to the pn data with only Galactic absorption provides a good fit ($\chi^2/\nu = 39/40$), the fit improves significantly with the addition of intrinsic absorption of $(6.5 \pm 3.7) \times 10^{22} \text{ cm}^{-2}$ ($\chi^2/\nu = 32/39$). An *F*-test results in an *F*-test value of 8.4 with probability $P = 0.006$. The X-ray spectral slope $\alpha_X = 1.65 \pm 0.34$ is one of the steepest in the high-redshift quasar sample presented here. These results are consistent with those of Farrah et al. (2004) within 2σ errors.

3.3.8. BRI 1033–0327

The $z = 4.49$ quasar BRI 1033–0327 has been found by Isaak et al. (1994) to be radio-quiet. The 55.7 ± 13.6 counts found in the 26.5 ks pn observation of BRI 1033–0327 allow only a very rough spectral fit to the data. The data were binned with at least 10 counts per bin and are consistent with a simple power law with $\alpha_X = 1.34 \pm 0.47$ and Galactic absorption (Table 4). The X-ray loudness $\alpha_{\text{ox}} = 1.80 \pm 0.20$ was estimated from the rest-frame UV spectrum shown in Storrie-Lombardi et al. (1996) and the fit to the pn data. Given the correlation between α_{ox} and optical luminosity (Fig. 4; Strateva et al. 2005), large values of α_{ox} are expected in highly optically luminous quasars. BRI 1033–0327, however, is not very luminous, with $\log l_{2500 \text{ \AA}} = 24.68$ (luminosity density in watts per hertz; Table 4), making the source unusually X-ray weak. Note that the error on α_{ox} is large. Moreover, even though the data are consistent with Galactic absorption only, strong intrinsic absorption cannot be excluded. This would result in underestimating the intrinsic X-ray luminosity, as well as the power-law slope.

3.3.9. SDSS J1044–0125

This $z = 5.74$ quasar was discovered by Fan et al. (2000) and has been found to be radio-quiet (Petric et al. 2003). It was clearly detected by *XMM-Newton* in 2000 May with 31.7 ± 8.5 counts in the observed 0.5–2.0 keV range in the pn (Brandt et al. 2001a). The *XMM-Newton* data have been analyzed and discussed in detail by Brandt et al. (2001a) and Mathur (2001). The ≈ 30 photons in this *XMM-Newton* observation do not allow any direct spectral analysis. Mathur (2001) performed a hardness ratio analysis

FIG. 4.—X-ray spectral slope α_X vs. α_{ox} : squares, radio-loud quasars; circles, radio-quiet quasars. The dash-dotted lines show the mean values of 2–10 keV α_X of low-redshift BLS1s and NLS1s ($\alpha_X = 0.78$ and 1.19, respectively) as given in Leighly (1999). The dotted lines mark the standard deviations around the mean.

and argued that the intrinsic X-ray spectral slope may be steep with $\alpha_X = 1.5$ absorbed by a partially covering absorber.

3.3.10. RX J1052.4+5719

This high-redshift quasar ($z = 4.45$) was discovered from *ROSAT* observations (Schneider et al. 1998) of the Lockman Hole (Hasinger et al. 1998). We used all *XMM-Newton* observations as listed in Worsley et al. (2004a) for which RX J1052.4+5719 was in the field of view, using the medium filter (Table 6). From the screened event files we created a merged event file with a total observing time of 535 ks (this is the total observing time; the exposure time at the source is smaller by about a factor of 2). At the position of the source we found 368 ± 52 source photons. Although the number of photons would suggest good spectral data, this is not the case for RX J1052.4+5719 due to the high background in the *XMM-Newton* EPIC-pn detector. The observed count rate is low, $6.88 \times 10^{-4} \text{ counts s}^{-1}$, so the data are dominated by background in the pn detector. We fitted a single absorbed power law to the data with the absorption column density fixed to the Galactic value. The fit results in a relatively steep energy spectral slope $\alpha_X = 1.58 \pm 0.30$ and does not require any additional intrinsic absorption.

We estimated an optical/UV–X-ray spectral index $\alpha_{\text{ox}} = 1.20 \pm 0.15$ from the spectrum given in Schneider et al. (1998)

TABLE 6
XMM-Newton OBSERVATIONS OF RX J1052.4+5719
WITH THE PN AND MEDIUM FILTER

Orbit	Obs. ID	UT Obs. Date	T_{obs} (ks) ^a
344.....	0022740101	2001 Oct 25	14.6
345.....	0022740201	2001 Oct 27	38.6
349.....	0022740301	2001 Nov 04	31.9
524.....	0147510901	2002 Oct 19	57.9
525.....	0147511001	2002 Oct 21	73.8
526.....	0147511101	2002 Oct 23	53.0
544.....	0147511601	2002 Nov 27	97.9
547.....	0147511701	2002 Dec 04	88.5
548.....	0147511801	2002 Dec 06	79.5

^a Screened GTIs.

TABLE 7

XMM-Newton OBSERVATIONS OF VLA J1236+6213, CXOHDFN J123647+6209, AND CXOHDFN J123719+6210 WITH THE PN AND THIN FILTER

Orbit	Obs. ID	UT Obs. Date	T_{obs} (ks) ^a
264.....	0111550101	2001 May 18	37.5
264.....	0111550201	2001 May 19	35.1
268.....	0111550301	2001 May 27	23.8
271.....	0111550401	2001 Jun 01	81.0
725.....	0162160201	2003 Nov 24	10.5
731.....	0162160401	2003 Dec 06	8.1
735.....	0162160601	2003 Dec 14	9.2

^a Screened GTIs.

and the pn spectrum presented here. The actual, exposure-corrected α_{ox} is somewhat smaller, about $\alpha_{\text{ox}} = 1.08 \pm 0.15$. Kaspi et al. (2000a) reported that RX J0152.4+5719 was not detected in the NRAO VLA Sky Survey (Condon et al. 1998) and gave an upper limit for the radio loudness of $R < 190$. This makes it difficult to determine whether RX J0152.4+5719 is a radio-loud or a radio-quiet quasar; the X-ray spectral index $\alpha_X = 1.58$ suggests that it is radio-quiet.

3.3.11. HDF-N Objects

Three spectroscopically confirmed AGNs were detected in the Hubble Deep Field–North (HDF-N) by *Chandra*: VLA J1236+6213, CXOHDFN J123647.9+620941, and CXOHDFN J123719.0+621025 (Brandt et al. 2001b; Barger et al. 2002). This field has also been the target of several *XMM-Newton* observations (Table 7). The merged event file of these observations results in a background-screened total observing time of 205 ks (Table 7). However, due to the significantly higher background in the EPIC pn detector compared to *Chandra*’s ACIS-S, and the much shorter observing time with *XMM-Newton*, none of the three sources could be detected above the background.

3.3.12. CXOCY J125304–090737

The $z = 4.180$ quasar CXOCY J125304–090737 was discovered by Castander et al. (2003) in a 49.2 ks ACIS-S observation of the Hickson group of galaxies HCG 62. It was also observed serendipitously in the field of view during an 8 ks *XMM-Newton* observation of HCG 62, but we did not detect the source. Converting the ACIS-S count rate into EPIC pn and assuming $\alpha_X = 0.7$ and the Galactic absorption column density $3 \times 10^{20} \text{ cm}^{-2}$, as given in Castander et al. (2003), results in $0.0011 \text{ pn counts s}^{-1}$. This low count rate in the pn would be dominated by the detector background. We would have expected to detect only about eight source photons during the entire *XMM-Newton* observation, which explains the nondetection in the pn.

3.3.13. SDSS J1401+0244

The $z = 4.38$ quasar SDSS J1401+0244 was serendipitously observed by *XMM-Newton* in an observation of the galactic cluster A1835 (Schneider et al. 2003). We measured 115 ± 20 source counts at the position of the source, allowing us to do a rough analysis of the X-ray spectrum. The pn spectrum can be fitted with a very flat X-ray spectrum with $\alpha_X = 0.32 \pm 0.39$ and Galactic absorption. As suggested by Schneider et al. (2003), there is no evidence of intrinsic X-ray absorption in SDSS J1401+0244. The radio loudness of SDSS J1401+0244 is uncertain. From the Faint Images of the Radio Sky at Twenty cm radio sur-

vey (Becker et al. 1995) we get a 5σ upper limit of 0.95 mJy. With an i magnitude $i = 18.6 \text{ mag}$ (Schneider et al. 2003) we can derive an upper limit to the radio loudness of $R < 100$. The rather flat X-ray spectrum of this quasar suggests that it is a radio-loud quasar, while the X-ray loudness $\alpha_{\text{ox}} = 1.77$ (Schneider et al. 2003) suggests it is radio-quiet. Deeper radio observations of SDSS J1401+0244 are necessary to clarify the radio nature of this source. Because we do not have any evidence that the source is radio-loud, we tentatively consider it to be radio-quiet. Alternatively, the intrinsic X-ray spectrum may be complex but appears simple in the low-S/N data, leading to underestimation of the true flux.

3.3.14. GB 1428+4217

The radio-loud $z = 4.72$ quasar GB 1428+4217 was discovered by Hook & McMahon (1998) and was a target of several X-ray satellites (Fabian et al. 1997 [*ROSAT*], 1998 [*ASCA*]; Boller et al. 2000 [*ROSAT*]). GB 1428+4217 was actually the last source ever observed by *ROSAT* in 1998 December (Boller et al. 2000). It was recently observed also by *XMM-Newton* (Worsley et al. 2004b). Spectral fits to the pn data of GB 1428+4217 are consistent with a power law with Galactic and intrinsic absorption, confirming earlier results from *ROSAT* and *ASCA* (Boller et al. 2000 and Fabian et al. 1998, respectively). The best-fit power-law slope is $\alpha_X = 0.86 \pm 0.03$. While Fabian et al. (2001) argue for the presence of an intrinsic warm absorber, a fit with cold absorption describes the *XMM-Newton* data well, with $N_{\text{H}} = (2.13 \pm 0.23) \times 10^{22} \text{ cm}^{-2}$. The X-ray loudness $\alpha_{\text{ox}} = 0.84 \pm 0.01$ was determined from the flux density at $8550 \text{ \AA}$ [$=1500 \text{ \AA}(1+z)$] given in Hook & McMahon (1998) and from the pn X-ray spectrum.

3.3.15. GB 1508+5714

The $z = 4.3$ radio-loud quasar GB 1508+5714 was discovered in X-rays from an *Einstein* observation by Mathur & Elvis (1995). From *Chandra* ACIS-S observations Yuan et al. (2003) and Siemiginowska et al. (2003) reported the discovery of an X-ray jet that was also detected in radio at 1.4 GHz with Very Large Array (VLA) observations (Cheung 2004). GB 1508+1514 was observed twice by *XMM-Newton* during orbits 443 and 529 on 2002 May 11 and October 30. However, due to very high background radiation during the second observation, only the 2002 May 11 observation is useful. The jet is not resolved in *XMM-Newton* data, so the *XMM-Newton* spectrum is a combined spectrum of the core and the jet. The flux in the jet is only $\sim 2\%$ of the core flux; therefore, the combined spectrum is dominated by the core component of the quasar itself. This is clearly seen by the fact that the spectral fit to the pn data results in a power law with $\alpha_X = 0.55 \pm 0.04$ and Galactic absorption, compared to $\alpha_X = 0.55 \pm 0.06$ found with *Chandra* data (Siemiginowska et al. 2003). Adding an intrinsic absorber to the model does not improve the fit. The X-ray loudness $\alpha_{\text{ox}} = 1.07 \pm 0.02$ was determined from the UV spectrum given in Storrie-Lombardi et al. (1996) and the pn spectrum given in Table 4.

3.3.16. RX J1759.4+6838

The $z = 4.32$ quasar RX J1759.4+6838 was the only X-ray-selected $z > 4$ quasar that was discovered by *ROSAT* in a long PSPC observation of the north ecliptic pole (Henry et al. 1994). The source was serendipitously observed during two EPIC pn observations of NGC 6552 (Table 1). Assuming an unabsorbed flux of $\log F_{0.5-2.0 \text{ keV}} = -17 \text{ (W m}^{-2}\text{)}$ ($-14 \text{ [ergs s}^{-1} \text{ cm}^{-2}\text{]}$), as given by Henry et al. (1994), and a power law with $\alpha_X = 1$ and absorption with a column density $N_{\text{H}} = 4 \times 10^{20} \text{ cm}^{-2}$, we

would have detected about 40 source counts during the effective 5.9 ks (measured from the combined exposure map). However, the *XMM-Newton* observation only results in 11.5 ± 6.9 pn counts suggesting that either the spectral shape, the normalization, or the absorption changes on a timescale of about 2 yr (rest frame), resulting in a factor of 4 change in the observed flux. Kaspi et al. (2000a) estimated the radio loudness $R = 30$, which makes this source a moderately radio-loud quasar as per the definition of Kellermann et al. (1989).

3.3.17. CXOMP J213945–234655

This $z = 4.93$ quasar was discovered by Silverman et al. (2002) through the *Chandra* Multiwavelength Project (ChaMP; Wilkes et al. 2001). The source was detected on the *Chandra* ACIS-I detector with 16.7 ± 7.7 counts in the observed 0.3–2.5 keV range during a 41 ks observation. CXOMP J213945–234655 was also observed by *XMM-Newton* serendipitously during a 12 ks observation of MS 2137–23. We could not detect any source at the position of CXOMP 213945–234655 due to the low flux of the source and the higher instrumental background of the pn compared to ACIS-S. There is no source in the NVSS (Condon et al. 1998) at the position of CXOMP J213945–234655. Deeper radio observations at the position of CXOMP J213945–234655 are necessary to clarify whether it is a radio-loud or radio-quiet quasar. The X-ray loudness $\alpha_{\text{ox}} = 1.52$ (Silverman et al. 2002) suggests a radio-quiet nature.

4. RESULTS

4.1. BR 2237–0607

Our spectral analysis of the pn data of BR 2237–0607 has shown that it does not show significant intrinsic absorption, if present at all. This result is in agreement with earlier findings from *XMM-Newton* data by, e.g., Ferrero & Brinkmann (2003, for radio-quiet quasars) and Grupe et al. (2004a, for radio-loud and -quiet quasars) that high-redshift quasars are not intrinsically more absorbed than low-redshift AGNs.

Dietrich & Hamann (2004) estimated the mass of the central black hole to be $(2.9 \pm 0.8) \times 10^9 M_{\odot}$, which corresponds to an Eddington luminosity of $\log L_{\text{Edd}} = 39.4$ (W). The bolometric luminosity $\log L_{\text{bol}} = 39.7$ (W) implies an Eddington ratio L/L_{Edd} of about 2 and requires a mass accretion rate of $10 M_{\odot} \text{ yr}^{-1}$. However, even if L/L_{Edd} is lower by factors of several, it would be still high, comparable to those found among low-redshift NLS1s (e.g., Grupe 2004). Typically, NLS1s have Eddington ratios L/L_{Edd} of order 1, while broad-line Seyfert 1 galaxies (BLS1s) have L/L_{Edd} about 1 or 2 orders of magnitude smaller (see Fig. 13 in Grupe 2004).

We can estimate a FWHM($H\beta$) of BR 2237–0607 from the bolometric luminosity using the relation of Kaspi et al. (2000b). This results in $\text{FWHM}(H\beta) \approx 4500 \text{ km s}^{-1}$, clearly much larger than the 2000 km s^{-1} boundary used to define NLS1s at low redshift. The definition of “narrowness” of FWHM($H\beta$) should be a function of luminosity. Only then can we meaningfully expand the NLS1 class to narrow-line quasars to include all highly accreting objects. This result is similar in spirit to recent results from Corbett et al. (2003) and Shemmer et al. (2004). Using data from the Two Degree Field (2dF) quasar redshift survey, Corbett et al. have found that the width of the $H\beta$ line correlates with luminosity, leading to the correlation of BH mass with luminosity. Similarly, Shemmer et al. have found that the Eddington luminosity ratio is proportional to the 0.4 power of luminosity and inversely proportional to the square of the $H\beta$ width. Thus,

FIG. 5.—Luminosity density at 2500 Å vs. α_{ox} . Symbols are as in Fig. 4. For objects without error bars, α_{ox} was taken from the literature as given in Table 4. The dashed lines display the α_{ox} of low-redshift AGNs, as given in Yuan et al. (1998a).

quasars with a high Eddington luminosity can have a broader $H\beta$ width, dependent on the luminosity.

4.2. BR 0351–1034

The spectral analysis of the second *XMM-Newton* observation from 2004 January of the radio-quiet quasar BR 0351–1034 is in agreement with our earlier results from the 2002 August observation (Grupe et al. 2004a). In both cases the data are consistent with a single power law with Galactic absorption. The merged data sets also yield similar results. As discussed in § 3.2, a broken power law appears to be an appropriate spectral model for this source (Table 3). Such a steep soft X-ray spectrum with $\alpha_X = 3.5$ would suggest that BR 0351–1034 is an AGN with a high Eddington ratio L/L_{Edd} , following the correlation between X-ray spectral index and L/L_{Edd} found among low-redshift AGNs by Grupe (2004) and among NLS1s by Williams et al. (2004). The hard X-ray power-law slope is 0.42 ± 0.18 with only Galactic absorption and is 0.67 ± 0.21 allowing for intrinsic absorption (Table 3). However, intrinsic absorption is not required.

4.3. $z > 4$ Quasars

Figure 4 displays the relation between the X-ray spectral index α_X and the X-ray loudness α_{ox} . As expected from earlier results by, e.g., Wilkes & Elvis (1987), the radio-loud quasars have much flatter X-ray spectra and smaller α_{ox} than the radio-quiet AGNs, similar to that observed at low redshift. We did not find a clear correlation between α_X and α_{ox} among the radio-quiet AGNs. There is, however, a mild trend that sources with steeper X-ray spectra tend to be stronger in X-rays, i.e., have smaller α_{ox} ($r_s = -0.40$, $T_s = -1.2$, and $P = 0.26$). For our high-redshift quasars the observed *XMM-Newton* energy range of 0.2–10 keV corresponds to a rest-frame range of ≈ 1 –55 keV. It is therefore important to compare the α_X values of our sample to the hard X-ray power-law slopes of low-redshift AGNs, as observed by *ASCA*. The dash-dotted lines mark the mean value of the 2–10 keV X-ray slope α_X of low-redshift NLS1s (23 sources) and BLS1s (17 sources) of the *ASCA* sample of Leighly (1999). Most of the high-redshift radio-quiet AGNs of our sample have steep X-ray slopes similar to NLS1s, suggesting similar high Eddington ratios L/L_{Edd} . The X-ray spectral slopes of radio-quiet

FIG. 6.—Redshift z vs. α_{ox} . Symbols are as defined in Fig. 4. The dotted line displays the mean value of $z > 2$ quasars in the sample of Yuan et al. (1998a).

AGNs with X-ray spectra in our sample range between 0.32 and 1.96 and give a mean $\langle\alpha_X\rangle = 1.21 \pm 0.52$, which compares to $\langle\alpha_X\rangle = 1.19 \pm 0.10$ found by Leighly (1999) for low-redshift NLS1s. The mean α_X of the low-redshift BLS1s, on the other hand, is 0.78 ± 0.11 (Leighly 1999). These values are similar to those found by Brandt et al. (1997) for low-redshift Seyfert galaxies. One should be careful, however, in comparing the spectral shape of our high-redshift quasar sample to low-redshift Seyfert galaxies. The X-ray spectra of Seyfert galaxies often show complex shapes including warm absorbers and Compton reflection components. If the reflection component is not modeled properly, the underlying power-law slope may be underestimated. As shown in Brandt et al. (1997), however, the error introduced is only of order $\Delta\Gamma \approx 0.12$, much larger than the dispersion around the mean that we find in our high-redshift sample.

Figure 5 displays the relation between the rest-frame luminosity density at 2500 Å, $l_{2500\text{ Å}}$, and X-ray loudness, α_{ox} . As found from earlier studies, e.g., Yuan et al. (1998b) and Vignali et al. (2003a), there is a trend of AGNs with higher luminosity densities at 2500 Å to be more X-ray weak than those with lower $l_{2500\text{ Å}}$. A Spearman rank-order correlation test of the 15 radio-quiet AGNs in our sample shows that α_{ox} and $l_{2500\text{ Å}}$ are weakly correlated with a correlation coefficient $r_s = 0.28$ and a Student's t -test $t_s = 1.1$ ($P = 0.14$). The dashed lines in Figure 5 mark the mean values for the luminosity intervals of low-redshift AGNs as given in Yuan et al. (1998a). Thus, we see that the high-redshift quasars in our sample do not show any significant deviation from the values of low-redshift radio-quiet AGNs.

In Figure 6 we plot α_{ox} as a function of redshift. We do not find a correlation between the two quantities, again consistent with earlier studies (Yuan et al. 1998b; Mathur et al. 2002; Vignali et al. 2003a). Recent work by Strateva et al. (2005) has also found that the primary dependence of α_{ox} is on luminosity, rather than on redshift. The dotted line displays the mean value of the $z > 2$ radio-quiet quasar sample of Yuan et al. (1998a) observed with *ROSAT*. The mean $\alpha_{\text{ox}} = 1.57 \pm 0.20$ of our 15 radio-quiet sources agrees with the $\alpha_{\text{ox}} = 1.69 \pm 0.03$ for $z > 2$ objects in the sample of Yuan et al. (1998a). The mean and the range of α_{ox} values are also consistent with the values in Strateva et al. (2005; see their Fig. 11, *bottom*).

As shown in Figure 7, radio-loud quasars are brighter by about 2 orders of magnitude in the 2–10 keV band than their radio-quiet cousins for a given luminosity density at 2500 Å. This result

FIG. 7.—Rest-frame luminosity density at 2500 Å, $\log l_{2500\text{ Å}}$, vs. rest-frame 2–10 keV X-ray luminosity, $\log L_{2-10\text{ keV}}$. Symbols are as defined in Fig. 4.

suggests that the X-ray emission of radio-loud objects is dominated by beamed emission from the jet.

5. DISCUSSION

In this paper we present *XMM-Newton* detections of 16 high-redshift ($z > 4$) quasars, 5 radio-loud and 11 radio-quiet. Spectral shapes were determined for 4 radio-loud and 10 radio-quiet quasars (Table 4). Five other quasars previously detected by *Chandra* could not be detected by *XMM-Newton*. This sample is not complete; objects were chosen based on their availability in the *XMM-Newton* public archive. The sample of our own *XMM-Newton* observations was based on previous X-ray detections, although we focused on observing radio-quiet objects that are more representative ($\sim 90\%$) of the general quasar population. Nonetheless, with 14 spectroscopic observations we are finally in a position to look for trends in the X-ray properties of high-redshift quasars.

Our results presented here confirm earlier studies by, e.g., Yuan et al. (1998a) and Vignali et al. (2003a) that α_{ox} depends on luminosity (Fig. 5) and show that there is no clear dependence of α_{ox} on redshift (Fig. 6). The agreement of the mean $\alpha_{\text{ox}} = 1.57$ of our radio-quiet sources with the radio-quiet $z > 2$ sample of Yuan et al. (1998a) suggests no evolution of α_{ox} with redshift. Strateva et al. (2005) reached a similar conclusion independently. We find a mild trend of α_{ox} decreasing with α_X , but this is not a secure correlation.

High-redshift radio-loud quasars are more luminous in X-rays and have flatter X-ray spectra compared to the radio-quiet quasars. This difference in the two populations is similar to that observed at low redshift (Wilkes & Elvis 1987). Based on studies of hardness ratios and flux estimates of a handful of sources, Bechtold et al. (1994) claimed that high-redshift radio-loud quasars are more absorbed than their radio-quiet cousins, suggesting an intrinsic difference above that already present at low redshift. Elvis et al. (1994) obtained *ROSAT* spectra of three radio-loud and three radio-quiet quasars. Among the radio-loud objects, only one showed 3σ absorption. Statistically significant ($>2\sigma$) intrinsic absorption is present only in two out of five radio-loud quasars in our sample. Thus, there is some evidence for the high-redshift radio-loud quasars to be more absorbed than the radio-quiet quasars, even though the sample size is small; the X-ray spectra of absorbed quasars, however, appear to be dominated by the jet emission.

We find clear evidence for the 10 radio-quiet quasars with X-ray spectra in our sample to have steep spectral slopes $\langle\alpha_X\rangle = 1.23 \pm 0.48$, comparable to those in NLS1s at low redshift. If we exclude SDSS J1401+0244, which may be a radio-loud quasar, the mean and standard deviation change to $\langle\alpha_X\rangle = 1.33 \pm 0.38$. If we use a flatter slope for BR 0351–1034 (without intrinsic absorption), then the mean and standard deviation become $\langle\alpha_X\rangle = 1.20 \pm 0.48$ for all the 10 radio-quiet sources and $\langle\alpha_X\rangle = 1.30 \pm 0.44$ excluding SDSS J1401+0244. This is an exciting new result and gives credence to the hypothesis of Mathur (2000) that NLS1s are low-redshift cousins of high-redshift quasars, in that they are highly accreting and contain rapidly growing black holes. Moreover, the high Eddington luminosities independently derived for some of our targets, e.g., BRI 0103+0032, PSS J0248+1802, and BR 2237–0607, support the general result. The mean spectral slope that we find is consistent with those found by Vignali et al. (2005) and Shemmer et al. (2005) within the errors. A joint fit performed on *Chandra* and *XMM-Newton* data of eight radio-quiet $z > 4$ quasars led to an “average” $\alpha_X = 0.97^{+0.06}_{-0.04}$ by Shemmer et al. (2005). Similarly, Vignali et al. performed a joint fit to 48 radio-quiet quasars and got an average $\alpha_X = 0.93^{+0.10}_{-0.09}$. We have shown above that the comparison of spectral shapes between high-redshift quasars and low-redshift Seyfert galaxies is not significantly affected by the spectral complexity of lower luminosity Seyfert galaxies. It is very useful to make such a comparison because we have well-determined Eddington luminosities only for the Seyfert population. While we are making progress in determining spectral shapes, black hole masses, and Eddington luminosities in luminous quasars, these studies are still not done for well-defined samples and are fraught with difficulties.

Shemmer et al. (2004) studied high-redshift quasars in the redshift range $2 < z < 3.5$ and came to conclusions very similar to ours. They determined black hole masses using $H\beta$ widths for their sample objects and found them to have high Eddington luminosities, similar to NLS1s and distinct from BLS1s. They also found that such highly accreting sources, including NLS1s, have high metallicities, as suggested by Mathur (2000) (see also Fields et al. 2005). Thus, there appears to be mounting evidence for a similarity of properties between NLS1s and high-redshift quasars. Whether all luminous quasars share these properties remains to be seen.

In a recent study Piconcelli et al. (2005) performed a systematic analysis of low-redshift ($z \leq 1.72$) luminous quasars

from the Palomar-Green bright quasar sample. They found a mean power-law slope of $\langle\alpha_X\rangle = 0.89 \pm 0.11$ for radio-quiet quasars. This slope is also statistically consistent with what we find for $z > 4$ quasars and similar to those of NLS1s.

The above results imply that perhaps *most* luminous quasars radiate at close to the Eddington luminosity, based on their X-ray spectral shape. This may not be a correct interpretation of the observations if the correlation of α_X with L/L_{Edd} seen in Seyfert galaxies (e.g., Williams et al. 2004) does not extend to luminous quasars with high-mass black holes. However, there is some indication in the literature that such an interpretation may in fact be true. Corbett et al. (2003) estimated black hole masses for a large number of quasars over a range of luminosities and found that the black hole mass is proportional to luminosity. This implies that the Eddington luminosity of all quasars may be similar. Given the large error in the correlation equation in Corbett et al., it is not obvious, however, what that Eddington ratio is. That they all may have high Eddington luminosities, similar to those of NLS1s, is only speculative at this stage (but see Shemmer et al. 2004); we wish to draw definitive conclusions on the properties of our own sample only.

The evidence presented in this paper, and other results quoted above, support the idea that both high-redshift quasars and NLS1s accrete at a high Eddington rate. There is, however, one major difference in the two populations. The high-redshift quasars are also very luminous objects, containing massive black holes of $\approx 10^9 M_\odot$ or so (e.g., Dietrich & Hamann 2004; Vestergaard 2004; Netzer 2003). Thus, it appears that while high-mass black holes accrete at high rates and grow most of their mass at high redshift, the low-mass black holes, as in some NLS1s, accrete at high rates and grow most of their mass at low redshift. This scenario appears to be consistent with “antihierarchical” black hole growth found from studies of the X-ray background (e.g., Merloni 2004).

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