ROSAT X-ray spectra of Quasars with a Range of Continuum Properties and Redshift.

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Abstract

We report soft X-ray spectral observations of 3 targeted and 2 serendipitous quasars with the ROSAT PSPC. These quasars were observed as part of a program to observe objects covering the full range of the quasar population to study the range and evolution of their X-ray spectra and eventually their full wavelength distributions. The initial sample includes three radio-loud, all with z>0.5 and two low-redshift, radio-quiet quasars, one with a known excess from *Einstein* observations. The highest redshift object (PKS0438-436, z=2.85) is the first high luminosity quasar to show a significant absorbing column in excess of the Galactic value and calls into question the inverse absorption/luminosity correlation found at low redshift. Only two of the three radio-loud quasars follow the *Einstein* observed correlation between X-ray slope and core-dominance (R) parameter.

1 Introduction

X-ray spectral observations of quasars have been confined to low redshift, X-ray strong objects ($z \leq 0.5$) whose proximity makes them bright enough to study in detail. The high sensitivity of ROSAT now allows us to expand our spectral studies to include quasars at higher redshifts, including objects with significantly higher luminosities than those nearby, and weaker relative X-ray flux. Thus, for the first time, we can investigate the X-ray spectra of quasars covering the full range of continuum properties observed.

This paper reports the first results of our ROSAT observing program. Observations of 5 quasars give us our first glimpse of a quasar at high redshift, with somewhat surprising results, allow us to extend our *Einstein* investigation of X-ray spectra as an orientation indicator and afford us a first, instrument-limited spectrum of a low-redshift quasar.

2 Observations

The observations were made with the Position Sensitive Proportional Counter (PSPC, Pfeffermann *et al.* 1987) on ROSAT. Observational details are given in Table 1.

Table 1: ROSAT Observations of Five Quasars

Quasar	RA. (J2000)	Dec. (J2000)	z	V	Gal'c N_H (10^{20}cm^{-2})	Date	Filter	Exposure (sec)
PKS0438-436	04 40 17.18	−43 33 09.0	2.85	18.8	1.5±0.6	2/91	Open	10725
PKS0439-433	04 41 16.1	−43 13 28	0.593	16.4		2/91	Open	10725
PG1426+015	14 29 06.59	+01 17 06.2	0.086	15.05	2.3±0.2	7/90	Open	6483
						7/90	Boron	5998
PG1617+175	16 20 11.66	+17 24 26.8	0.114	15.53	4.35±0.6	2/91	Open	6031
3C334	16 20 21.8	+17 36 24	0.555	16.41		2/91	Open	6031

Table 2: Single power law fits with free N_H

Quasar	Counts	Energy index	N_H (10^{20}cm^{-2})	χ^2	Channels[a]	F(1 keV)[b]
PKS0438-436	625	$0.7^{+0.4}_{-0.3}$	$6.9^{+5.4}_{-2.1}$	22.2	5:34	0.52
PKS0439-433[c]	1022	$1.3^{+0.3}_{-0.3}$	$2.0^{+0.8}_{-0.7}$	24.0	2:34	0.44
PG1426+015	9767	$1.31^{+0.06}_{-0.05}$	2.1 ± 0.1	62.3	3:34	6.23
(Boron)	3174			95.9	3:34	
PG1617+175	1026	1.1 ± 0.2	$3.6^{+0.7}_{-0.6}$	42.1	3:34	1.11
3C334	600	1.1 ± 0.3	$3.5^{+1.1}_{-1.0}$	30.7	3:34	0.54

a: On a 34 channel scale as used by the SASS (MPE pipeline processing).
b: Observed flux density at 1 keV in 10^{-12} erg cm^{-2} s^{-1} Hz-1
c: 2′ circle used for count extraction, see text.

Counts were extracted from a 1.5′ circle with background from an annulus with inner and outer radii 2′ and 4′ respectively (unless otherwise noted). Both regions are centered on the source centroid. The full-width at zero intensity of a source inside the ribs of the PSPC is ~1.5′ and thus this radius circle contains $\gtrsim$95 % of the counts, those lost being due to mirror scattering over the whole detector. The 34 channels used by the MPE SASS pipeline processing were used in this analysis.

The quasar PKS0439-433 is situated just outside the central ring of the PSPC window support. The source counts are thus spread into a larger circle due to the degraded point response this far off-axis. The count distribution has a full-width at half maximum ~ 2× that of the on-axis sources. Counts were extracted from a 2′radius circle with the background estimated from a 3′ - 5′ annulus above the source, excluding image portions occulted by the ribs.

3 Results

The results of single power law fits with free N_H are given in Table 2. The best-fitted slopes in this soft (0.05-2 keV) energy band range from 0.7 - 1.4 in energy spectral index. This covers most of the range previously observed to be present for low redshift quasars in the harder *Einstein* IPC energy band (0.2-3.5 keV).

3.1 PG1426+015

Although the χ^2 values for the single power law fit indicates that the fit is not a good one. However no other spectral form improved on this fit, neither did the inclusion of a soft excess component. The spectrum has very high signal-to-noise, with > 1300 counts, and is thus limited by instrumental effects rather than photon statistics. We believe that the fit will improve once the up-to-date response matrix for the PSPC is available (Snowden, private communication).

The quasar was also observed by *Einstein* and EXOSAT (Masnou *et al.* 1992, Comastri *et al.* 1992). Figure 1 shows the ROSAT spectral fit in comparison with these two observations. Clearly the X-ray spectrum is steepening towards lower energies. It is not possible to distinguish between the presence of a soft excess $\lesssim$0.6 keV (*e.g.* Masnou *et al.* 1992) combined with a reflection hump $\gtrsim$5 keV (Pounds *et al.* 1990) and a single, continually steepening, component (Schwartz, Qian and Tucker 1990). A more detailed investigation, with reference to the updated response matrix, is necessary for further progress.

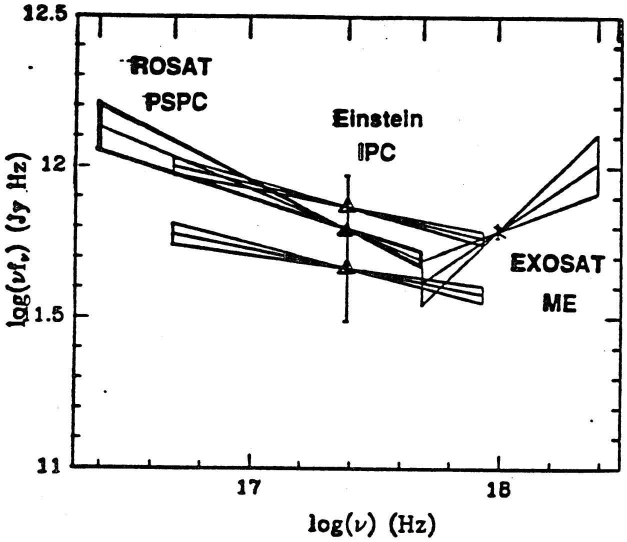

Figure 1: ROSAT, *Einstein* and EXOSAT spectra of PG1426+015

3.2 The absorption in PKS0438-436

The equivalent hydrogen absorbing column density indicated by the X-ray spectrum of PKS0438-436 is significantly larger than the Galactic column density. The second quasar in the field, PKS0439-433, shows a spectrum, with similar signal-to-noise but consistent with the Galactic column density. The excess absorption must therefore lie outside our Galaxy along the line-of-sight (los) to PKS0438-436. The rest frame energy range seen by the PSPC for this quasar is 0.3−9 keV and thus, if the absorption is intrinsic to the quasar, the spectrum is absorbed up to 2 keV and a much higher column density is implied. Figure 2a shows the confidence contours for energy index and intrinsic N_H assuming additional absorption by the Galactic column density at z=0 and yields $9.1^{+0.8}_{-0.3} \times 10^{21}$cm^{-2} (reduced χ^2=0.75). We do not know the redshift at which the absorption is occurring. Figure 2b shows the column density deduced from a spectral fit as a function of its redshift.

This is the first high-luminosity quasar observed to have excess absorption in the X-rays. Prior to this MR2251-178, with an X-ray luminosity of $\sim 4 \times 10^{44}$ergs^{-1} (0.5-4.5 keV rest frame (Wilkes *et al.* 1992) was the only absorbed quasar (*i.e.* active galaxy with $M_B < -23$ (Halpern 1984) known, despite the large number studied (see *e.g.* Wilkes and Elvis 1987, Canizares and White 1989, Worrall and Wilkes 1989). PKS0438-436 is much more luminous with an *Einstein* X-ray luminosity[1] of $1.7 \pm 0.1 \times 10^{47}$ergs^{-1} (Wilkes *et al.* 1992). Significant absorption ($\sim 10^{22}$cm^{-2}) has been seen in low luminosity active galaxies ($\lesssim 10^{43}$ergs^{-1}) and it has been suggested (Lawrence and Elvis 1982, Reichert *et al.* 1985, Kruper, Urry and Canizares 1990) that the amount of intrinsic absorption is inversely related to the luminosity of the active galaxy. PKS0438-436 apparently does not follow such a correlation unless the absorption proves to be along the los rather than intrinsic to the quasar.

The ROSAT data do not allow us to distinguish between excess absorption along the line-of-sight or intrinsic to the quasar, we thus consider both possibilities.

The most common absorbers along the los to quasars, the "Lyman α forest" clouds, have column densities ($\sim 10^{14}$cm^{-2}) too small to explain that observed in the soft X-ray for PKS0438-436. Lyman α disk systems (Turnshek *et al.* 1989 and references therein) have higher column densities, $\sim 10^{20} - 10^{21}$cm^{-2}. The optical spectrum of PKS0438-436 shows no

[1]Note that the ROSAT luminosity, also estimated at $\sim 1.7 \times 10^{47}$ergs^{-1}, is uncertain and likely to be higher depending on the percentage of the exposure time the source was behind a window support wire.

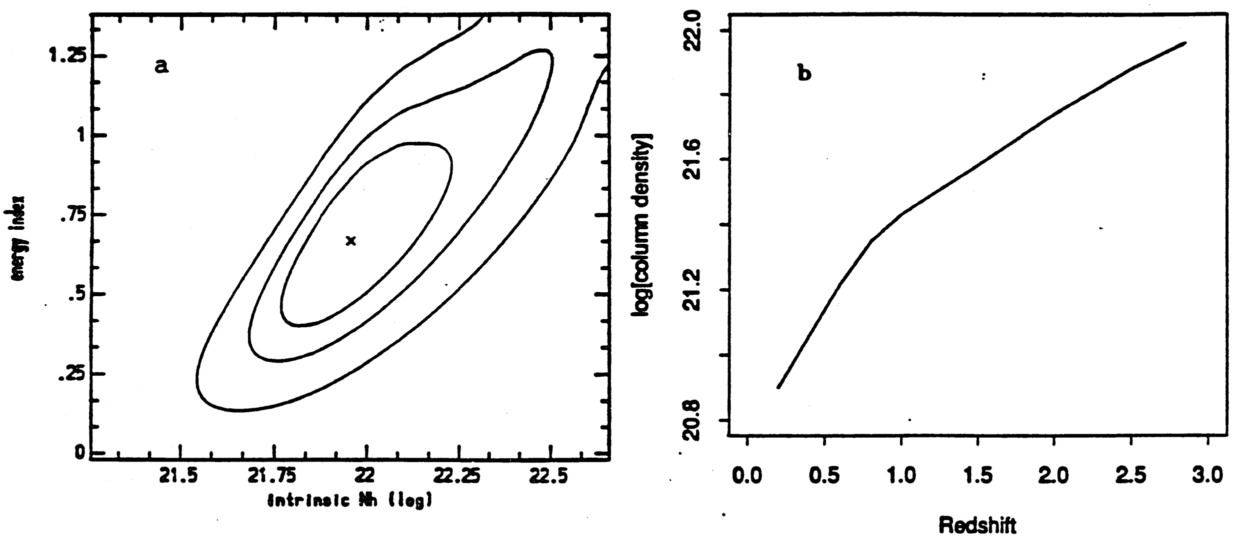

Figure 2: a: The 68%, 90% and 99% confidence contours of energy index and absorption for a single power law fit assuming Galactic plus intrinsic (z=2.85) N_H b: The dependence of the deduced equivalent hydrogen column density of the absorber on its assumed redshift.

evidence for strong Lyman α absorption down to 3500 Å (*i.e.* redshift 1.88, Morton, Savage & Bolton 1978). The observed space density of these systems yields a 55% probability that one occurs at z<1.88 along the line of sight to PKS0438-436. Given that a single system is insufficient, unless it is at z<0.4 (Figure 2b), and that all those found to date are at z$\sim$ 2, it seems unlikely that Lyman α disks are responsible for the absorption we see.

If, instead, the absorption is intrinsic, this may be related to its high redshift, high luminosity or the apparent importance of beaming, since little previous X-ray spectral information exists for any of these regimes. Typical intrinsic X-ray column densities seen in low luminosity active galaxies are also $\sim 10^{22}$cm^{-2} so our result may not be surprising. If PKS0438-436 were at low redshift the absorption would reduce its X-ray flux by a factor $\sim$ 10, and it would not be readily detected in the soft energy bands of *Einstein* or ROSAT. The lack of observations of such systems to date could be a selection effect due to the higher X-ray flux limit of previous X-ray missions.

PKS0438-436 has no broad absorption lines, ruling out a broad absorption line cloud as an absorption candidate. It has broad emission lines, so a cloud in this region (typical column density $\sim$ 2.5 $\times 10^{22}$cm^{-2}, Kwan & Krolik 1981) is a possibility. However their typical size, $\sim 10^{13}$ cm, is likely smaller than the X-ray source implying partial covering, as in MR2251-178 (Halpern 1984). Leakage of soft photons would then be expected whereas the X-ray spectrum shows no evidence for this so the absorbing cloud must be larger than the typical broad line cloud.

PKS0438-436 has very strong, core-dominated, radio emission and high optical polarization implying that it is relativistically beamed towards us. Naïvely one would expect such an object to be less likely to contain intrinsic absorbing material along our line-of-sight. However, BL Lac objects, which have many similar properties, also have unexpected X-ray absorption (Canizares & Kruper 1984, Madejski *et al.* 1991,1992). This absorption has been identified as an OVIII Lyα feature from hot ($\sim 10^6$ K) or highly ionized material with $N_H \sim 2 \times 10^{22}$cm^{-2}, probably entrained in the beam of the radio source. The absorption in PKS0438-436, is broad and does not recover at low energies, implying cooler material ($\lesssim 10^6$ K for coronal ionization and $\lesssim 10^4$ K for photoionization equilibrium, Kallman & Krolik 1986).

The discovery of X-ray absorption at high redshifts, whatever its cause, provides us with a new opportunity to study the metallicity of gas at high redshifts since X-ray absorption is strongly metal sensitive. Optical lines in emission or absorption, the only metallicity indicator to date, have proved unreliable due to uncertainties in the ionization conditions and due to saturation and blending of the lines. The X-ray absorption column is, however, a direct measure of the K edge strengths of O,Ne,Mg,Si,S and is insensitive to ionization state as long as the gas is not fully ionized. As we observe more high-redshift quasars, a study of the distribution of intrinsic N_H values at a range of redshifts will yield information on the evolution of the metallicity with redshift.

The existence of an obscured population of quasars with column densities of $\sim 10^{22}$cm^{-2} has also been suggested to reconcile the *Einstein* Extended Medium Sensitivity Survey number counts with those from *Ginga* fluctuation analysis at higher energies (Warwick and Stewart 1989). Based on the results for PKS0438-436, this obscured population may encompass the whole AGN population rather than just the low luminosity objects.

4 X-ray Spectra: An Orientation Indicator?

It has recently been shown (Shastri *et al.* 1992) that the *Einstein* X-ray spectral index of radio-loud quasars correlates with the radio core-dominance (R) parameter such that core-dominated quasars have flatter X-ray slopes. This is interpreted in terms of a beamed, flat-spectrum, X-ray component, linked to the beamed radio component, which dominates the X-ray emission in core-dominated, face-on quasars. The current ROSAT sample contains 3 radio-loud quasars, 2 of which are core-dominated. Since the ROSAT PSPC energy range significantly overlaps that of the *Einstein* IPC, the ROSAT spectrum may provide a similar orientation indicator.

Figure 3 shows the *Einstein* figure from Shastri *et al.* (1992) with the ROSAT points included. Clearly 2 of the quasars follow the correlation while the third (PKS0439-433) is completely inconsistent being core-dominated but with a steep X-ray spectrum. One possibility is that PKS0439-433 has an abnormally strong soft excess which causes the discrepancy. However the ROSAT spectrum shows no evidence for a spectrum more complex than a simple power law. Clearly it is necessary to obtain ROSAT spectra for more radio-loud quasars to further investigate this question.

5 References

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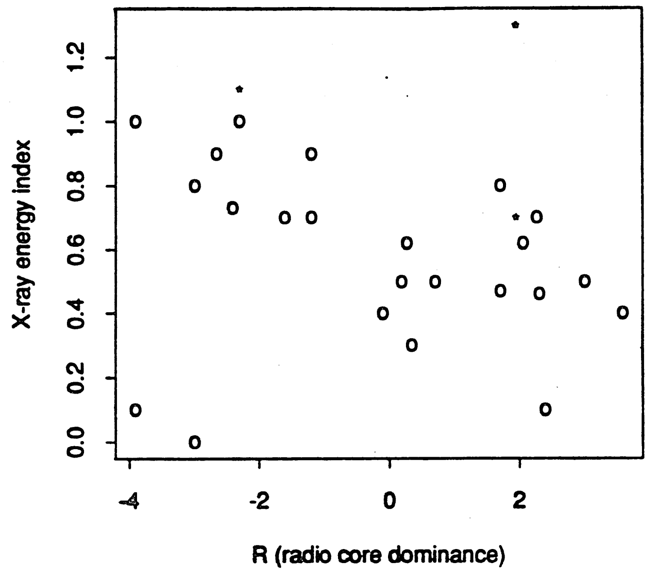

Figure 3: *Einstein* X-ray spectral slope vs. radio core-dominance (R) parameter taken from Shastri *et al.* (1992) with the current ROSAT data indicated with a '*'

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