Absorption in the ROSAT X-ray Spectra of Quasars

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Abstract

The first ROSAT X-ray spectra of two high-redshift quasars reveal unexpectedly strong absorption when compared with similar luminosity objects at low-redshift. A third quasar shows none. A fourth, low-redshift, radio-loud quasar (3C351) with extended radio structure, shows absorption possibly due to a warm absorber with a strong OVII absorption edge.

1. Introduction

X-ray spectral observations of quasars have been confined to low redshift objects (z≤0.5) whose proximity makes them bright enough to study and also to those with relatively bright X-ray flux ($\alpha_{ox} \lesssim 1.5$). ROSAT, with its high sensitivity, enables us to observe the spectra of high redshift (z>2) and large α_{ox} quasars for the first time. We have begun a ROSAT observing program to study the X-ray spectra of quasars selected to cover the full range of continuum properties. In particular this sample includes objects at high redshift, with relatively faint X-ray flux and with a full range of radio properties: strong, weak, extended and compact. We are also carrying out a follow-up observing program to obtain multi-wavelength (infrared – ultra-violet) data for all our ROSAT-observed quasars.

2. Sampling the full quasar population with ROSAT

To date we have received and analysed data for > 25 quasars. Their spectra are generally steeper than those seen at higher (*e.g.* Einstein IPC) energies, as observed in general with ROSAT [1]. Our current sample includes 4 high-redshift (z>2.8) quasars with sufficient counts (> 350) to obtain spectral information (Table 1). Given the high redshift, the rest frame energy range is similar to the EXOSAT ME and *Ginga* energy ranges for low-redshift quasars ($\sim 1-10$ keV) allowing us to study any change in slope with redshift and luminosity respectively. A comparison of the 1.7-17.36 keV (rest frame) energy indices derived for radio-loud quasars from *Ginga* [15] and those

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observed with ROSAT as a function of redshift or luminosity shows no change in X-ray slope with either quantity (15% and 30% probability of a correlation [4]). The mean slope for the ROSAT observed radio-loud quasars is 0.88±0.12, well within the error bars of the *Ginga* slopes. The flattening seen in the *Ginga* data is due to the difference in X-ray slope between radio-loud and radio-quiet quasars [15, 12] and is likely the cause of a similar trend in the ROSAT survey data [7].

Table 1. ROSAT X-ray observations

Quasar	z	V	Date	$\log(L_x)^a$	$N_H{}^b$	Counts	exp(s)
S5 0014+81	3.384	16.5	3/91		14.4^c	398	5951
Q0420−388	3.123	16.9	2/91	46.82	2.07	360	15611
PKS0438−436	2.852	18.8	2/91	46.98	1.40	595	10725
3C351	0.371	15.28	10/91	44.93	2.26^d	1420	13068
PKS2126−158	3.275	17.3	5/91	47.83	4.95	572	3424

a: *Einstein* value in erg s^{-1}, [14]; b: $10^{20}cm^{-2}$ [10]; c: [11]; d: [3]

3. Absorption in high-redshift quasars

Two of the high-redshift quasars in our sample show strong absorption in excess of the measured Galactic column density: PKS0438-436, [13] and PKS2126-158 [4]. Q0420-388 shows no significant absorption while the Galactic column density towards S5 0014+81 is too high. Results for a single power law plus absorption fits are given in Table 2 along with the column density of the excess absorption assuming it is intrinsic to the quasar. The ROSAT/PSPC spectral resolution cannot distinguish between excess absorption along the line-of-sight or intrinsic to the quasar so both possibilities are considered.

Table 2. ROSAT X-ray spectral results for all the quasars

Quasar	α_E	3^{rd} parameter	$N_H(\mathrm{fit})^a$	χ^2(dof)
S5 0014+81	$1.1^{+1.2}_{-0.7}$	-	17^{+23}_{-8}	1.13(18)
Q0420−388	1.09±0.65	-	2.7±1.5	1.25(15)
PKS0438−436	$0.7^{+0.4}_{-0.3}$	$N_H(\mathrm{int})^b=1.0^{+0.7}_{-0.4}$	$7.0^{+6.1}_{-2.3}$	1.03(17)
PKS2126−158	0.6±0.6	$N_H(\mathrm{int})^b=2.1^{+1.7}_{-0.7}$	11^{+10}_{-4}	1.32(20)
3C351[5]:				
Single power law	0.47±0.16		0.39±0.25	2.18(28)
Double power law	$-0.04^{+0.34}_{-0.25}$	$\alpha > 3.1$	4.8±3.0	1.03(26)
Partial covering	$2.1^{+0.4}_{-0.3}$	$F_C = 0.93^{+0.04}_{-0.05}$	200^{+70}_{-40}	0.97(27)
Warm absorber	0.5 FIXED	$U = 0.12^{+0.006}_{-0.02}$	200^{+20}_{-90}	1.04(28)

a: $10^{20}cm^{-2}$; b: Intrinsic $N_H/10^{22}cm^{-2}$ with Galactic value at z=0.

Absorption along the line-of-sight to high redshift quasars is a well known and heavily studied phenomenon with "Lyman α forest" and metal line systems being the dominant sources. Given the X-ray column densities observed ($\sim 10^{21-22}cm^{-2}$), the only possible explanations are damped Lyman α systems at the high end of the observed range or highly-ionized metal line systems [13]. For PKS0438-436, the only published optical spectrum shows no obvious strong line-of-sight absorption features [6]. Additional observations are necessary. PKS2126-158 has > 10 metal line systems [9] which may explain the absorption.

Most low-redshift quasars of comparable luminosity do not show intrinsic absorption. Possible reasons for this difference are high redshift, high luminosity, importance of beaming or a selection effect since strong absorption significantly weakens the observed X-ray flux. Both absorbed quasars may well be highly beamed similar to the BL Lac object PKS2155-304 which has strong OVIII Lyα absorption [2, 13].

4. Absorption in low-redshift quasar 3C351

3C351 is a lobe-dominated quasar (z=0.371) and is among the most X-ray quiet of radio-loud quasars (α_{ox}=1.6). A single power-law fit to the X-ray spectrum of 3C351 yields a flat slope, N_H significantly below the Galactic value (Table 1) and a high χ^2(Table 2, Figure 1). The strong deficit between 0.6 and 0.9 keV is significant at $\sim 10\sigma$. Clearly a more complex model is required.

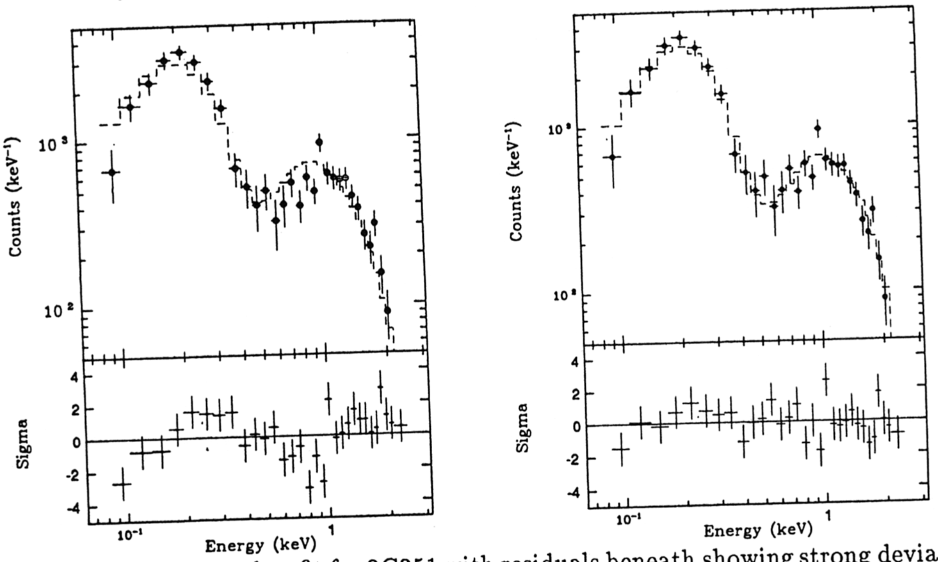

Figure 1. a) Single power law fit for 3C351 with residuals beneath showing strong deviations; b) best fit warm absorber model.

Three models were attempted: a double power law; partial covering; and a warm absorber. All three are acceptable (Table 2) although only the warm absorber model succeeds with typical values for the high energy power law slope. The parameters for the warm absorber model are not unique, equally acceptable fits can be found with a range of high energy slopes and ionization parameters [5]. The strongest absorption edge feature lies in the range 0.58–0.76 keV (1σ, one interesting parameter), implying OIV–OVII as the most likely absorbing ions. The ionization parameter and column density of the absorber are well constrained to $0.1 - 0.2$ and $0.5 - 2 \times 10^{22}$ atoms cm^{-2} respectively.

Whichever model is correct, this observation of 3C351 limits the possible causes for 'X-ray quietness'. Quasi-simultaneous X-ray, optical and ultraviolet (HST) observations of 3C351 rule out variability as the cause of its steep α_{OX}. Spectral fits that allow for intervening absorption increase the intrinsic emitted X-ray flux of 3C351 by only a minor part of the difference in α_{OX}. If a warm absorber model applies then the α_{OX} of 3C351 originates in weak X-ray emission relative to the optical while in the other models steep or hard continua contribute to the X-ray quietness of 3C351.

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