Mon. Not. R. Astron. Soc. **312**, 207–210 (2000)

An X-ray-absorbed radio-quiet QSO with an intervening strong metal absorption-line system

M. J. Page,[1] J. P. D. Mittaz[1] and F. J. Carrera[1,2]
[1]*Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT*
[2]*Instituto de Física de Cantabria (Consejo Superior de Investigaciones Científicas–Universidad de Cantabria), 39005 Santander, Spain*

Accepted 1999 September 21. Received 1999 June 28; in original form 1999 March 15

ABSTRACT

We find evidence for significant X-ray absorption in the QSO RX J005734.78−272827.4, along with strong absorption lines in its optical spectrum. We propose that the absorption lines are due to an intervening metal-line system at a redshift of $z = 0.628$, and show that this intervening system is also the probable cause of the X-ray absorption. The intervening absorber is inferred to have an X-ray column of $\sim 10^{22}\,\mathrm{cm}^{-2}$. This is the first time that an absorption-line system has been identified with an X-ray absorber in a radio-quiet object.

Key words: quasars: absorption lines – quasars: individual: RX J005734.78−272827.4 – X-rays: galaxies.

1 INTRODUCTION

Systems of narrow, metal-rich absorption lines in QSO spectra are thought to be due to intervening gas associated with galaxies; studies of these systems provide important information on the properties of galactic haloes and their evolution with redshift. So far, only a few X-ray astronomers have seriously considered the possible effect of these intervening systems on X-ray observations of high-redshift objects. The only reported case of X-ray absorption from a known absorption-line system is for the BL Lac object AO 0235+164, which has a strong metal-line system at $z = 0.524$. However, the X-ray column appears to vary significantly (Madejski et al. 1996) and because X-ray absorption has been reported for a number of other BL Lac objects *without* strong absorption-line systems (e.g. Sambruna et al. 1997; Stocke et al. 1992) it is possible that some of the X-ray absorption in AO 0235+164 is intrinsic to the object. Elvis et al. (1994) suggested that intervening systems might be responsible for the absorption seen in *ROSAT* observations of high-redshift ($z \sim 3$) radio quasars because absorption is not commonly seen in lower redshift examples. However, an intrinsic origin for the X-ray absorption in high-redshift radio quasars now seems more likely than intervening systems, because absorption has only been found in radio-loud objects (Bechtold et al. 1994).

More recently, the probability of X-ray absorption by intervening systems was considered by O'Flaherty & Jakobsen (1997). They used current statistics of QSO absorption-line systems to predict the probability of detecting significant X-ray absorption in QSOs as a function of redshift. They concluded that only the densest absorption-line systems would be capable of producing detectable X-ray absorption, and that this is expected in at most a few per cent of high-redshift QSOs. None the less, this does mean that X-ray absorption by the strongest, low-redshift ($z < 1$), absorption-line systems, *should* be observable with current instrumentation.

In this paper we present evidence for an object of this type: RX J005734.78−272827.4 appears to be a non-broad-absorption-line QSO showing strong X-ray absorption together with a strong metal absorption-line system, and was discovered as part of a survey for hard-spectrum *ROSAT* sources.

2 X-RAY DATA

RX J005734.78−272827.4 was selected as part of a survey of *ROSAT* sources aimed at finding the population of hard-spectrum sources that must produce a significant fraction of the 1–2 keV X-ray background at faint fluxes (Page, Mittaz & Carrera 1999). The criterion for inclusion in the sample was that a power law fitted to the Position Sensitive Proportional Counter (PSPC) spectrum of each source must be significantly harder than the spectrum of the extragalactic X-ray background ($\alpha \sim 0.5$: Miyaji et al. 1998).

RX J005734.78−272827.4 was initially detected using the Starlink point source search (PSS) algorithm scanning the central 20 arcmin radius region of *ROSAT* observation rp701223n00. The source has 40 ± 7 source counts in 43.7 ks and a PSS position of $00^{\mathrm{h}}\,57^{\mathrm{m}}\,34\overset{\mathrm{s}}{.}78$, $-27^{\circ}\,28'\,27\overset{''}{.}4$ (J2000) with an uncertainty of 3.9 arcsec. The source was included in our sample of hard-spectrum sources using the following procedure. Source and background counts were extracted from the *ROSAT* event list in three energy bands: channels 11–41, 52–90 and 91–201. Source counts were extracted in a 50-arcsec aperture around the PSS position; background counts were extracted from a much larger, source-free area. Source and background counts are given in Table 1. A spectrum was then fitted to the count distribution using the Cash statistic. The method for extracting source and background counts and the fitting procedure are described in detail in Mittaz et al. (1999). Assuming a power-law model ($F_\nu \propto \nu^{-\alpha}$) for the QSO spectrum and $N_{\rm H}$ fixed at the Galactic value of $1.9 \times 10^{20}\,{\rm cm}^{-2}$ (from Dickey & Lockman 1990, using the FTOOL 'nh') we obtain $\alpha = -0.33^{+0.57}_{-0.99}$, significantly harder than the extragalactic X-ray background $\alpha \sim 0.5$.

Only one optical counterpart is visible on the digitized sky survey SERC J plate that is consistent with the X-ray position, an ~18.5-mag point-like object at $00^{\rm h}\ 57^{\rm m}\ 34\overset{\rm s}{.}9\ -27^\circ\ 28'\ 28\overset{''}{.}7$ (J2000). This object was previously catalogued as a QSO, SGP4:14 at a redshift of 2.174 by Boyle et al. (1990), and LBQS0055−2744 at a redshift of 2.195 by Morris et al. (1991). It is classed as radio quiet by Sirola et al. (1998), confirmed by the absense of the source in the NRAO VLA 5 kg Survey (NVSS, Condon et al. 1998), which implies it has a 1.4-GHz flux of <2.5 mJy. The X-ray emission is highly atypical for a QSO: it is unusually hard (compared with a typical *ROSAT* QSO value of $\alpha \sim 1$: Romero-Colmenero et al. 1996; Mittaz et al. 1999; Blair et al. 1998) and is rather weak for its optical magnitude.

A very hard X-ray spectral shape suggests absorption, particularly in a type of source that normally has a soft spectrum. Uncertainty in the measured value of Galactic $N_{\rm H}$ is not responsible: an additional $2.9^{+1.7}_{-1.6} \times 10^{21}\,{\rm cm}^{-2}$ compared with the measured Galactic column of $1.9 \times 10^{20}\,{\rm cm}^{-2}$ would be required to harden an intrinsically normal (spectral index $\alpha = 1$) QSO spectrum to that observed. If absorption is responsible for the hard spectrum, then the absorber must be intrinsic to the source or the absorption be caused by some unrelated extragalactic intervening material.

Table 1. PSPC source counts and background counts normalized to the same aperture.

Channels	Source counts	Background counts
11–41	59	57.5
52–90	19	8.5
91–201	32	5.9

3 THE OPTICAL SPECTRUM

The optical spectrum of RX J005734.78−272827.4 is shown in Fig. 1. It was taken on 1998 November 22 with the EFOSC2 spectrograph on the European Southern Observatory (ESO) 3.6-m telescope at La Silla, Chile, in dark, photometric conditions. EFOSC2 was used with the 5000-Å blaze, 300 line mm^{-1} grating through a 1.5-arcsec slit on to a Loral 2048 × 2048 pixel CCD binned 2 × 2 on readout. This yielded 8.5-Å resolution (σ measured from arc lines through the same slit) projected at 4 Å per pixel. The instrumental response was obtained from observations of the standard stars Feige 110 and GD 50 using the photometric data of Oke (1990). RX J005734.78−272827.4 was observed at the parallactic angle through an airmass of 1.03. The spectrum shown is the sum of three separate 500-s exposures, and has a signal-to-noise ratio of ~30 per pixel; much higher than the discovery spectra of Boyle et al. (1990) and Morris et al. (1991). We determine an emission redshift of 2.185 from the peaks of the C IV, C III] + Al III and Si IV emission lines; the redshifts obtained from the peaks of these lines and by fitting Gaussians to their profiles agree to within ±0.005.

We identify two strong and two weak absorption features to the blue of C IV in the spectrum, two of which have apparent widths in excess of 2000 km s^{-1} (see Table 2). These features are visible in all three subexposures, and in the raw counts spectra before correction for instrumental response (which is a smooth function). Also very notable from the spectrum shown in Fig. 1 is the suppression of Lyα emission relative to N V; again this is present in all three of our subexposures and it is also seen in the identification spectra of Boyle et al. (1990) and Morris et al. (1991). At the position of Lyα a narrow emission line is seen on

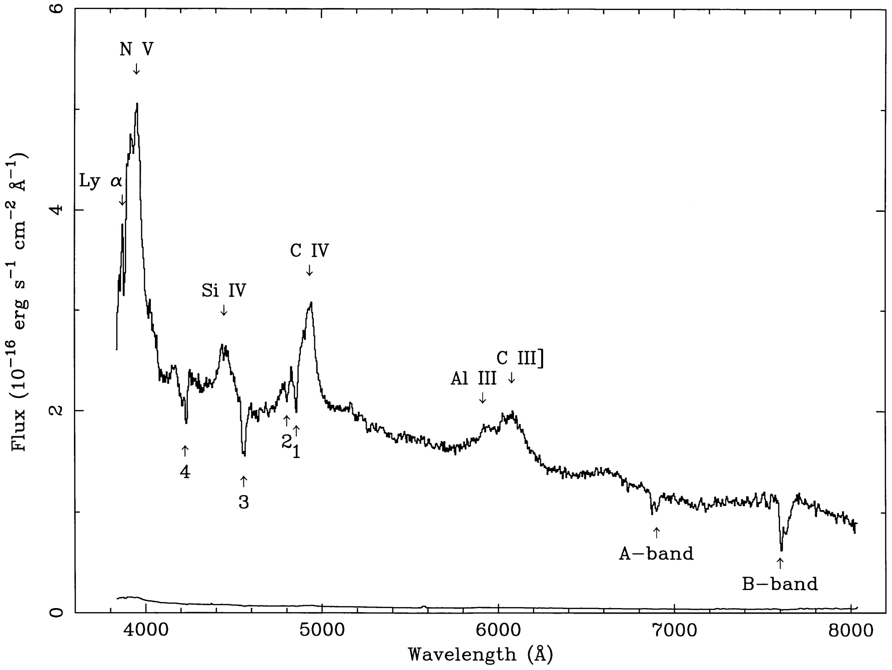

Figure 1. Optical spectrum of RX J005734.78−272827.4 with significant emission lines and absorption features marked. The lower curve shows the 1σ uncertainty on each point.

the blue wing of the broad line centred on N v. The lack of Lyα emission and the strong absorption features are not typical in QSO spectra.

4 DISCUSSION

Both the optical and X-ray spectra suggest that this source is viewed through a significant absorbing column of gas. If this gas is intrinsic to the source, we can estimate the column density from both the X-ray spectrum and the X-ray to optical ratio. Assuming that RX J005734.78−272827.4 has a normal radio-quiet QSO X-ray spectrum of $\alpha = 1$ (e.g. Mittaz et al. 1999; Romero-Colmenero et al. 1996), absorbed by cold solar abundance material at the source redshift of 2.185, we obtain a fitted column of $4.0^{+3.2}_{-2.6} \times 10^{22}\,\mathrm{cm}^{-2}$ from the three-colour *ROSAT* spectrum. This is even larger than the columns found by Elvis et al. (1994) for high-redshift quasars, and is approaching the range of columns inferred for broad absorption line (BAL) QSOs from *ROSAT* measurements (Green & Mathur 1996). The X-ray to optical ratio also indicates absorption; it is commonly parametrized as α_{ox}, the slope of the power law that would connect the optical flux $F_\nu(2500\,\mathrm{Å})$ to the X-ray flux $F_\nu(2\,\mathrm{keV})$ in the active galactic nucleus (AGN) rest frame. We computed α_{ox} taking the optical flux from the spectrum shown in Fig. 1 and the X-ray flux from the X-ray spectral fit. This yields $\alpha_{\mathrm{ox}} = 1.9 \pm 0.2$, where the uncertainties are calculated from the errors on the X-ray spectral fit and a conservative uncertainty of 20 per cent on the optical flux is assumed to account for slit losses. Again, this is more consistent with values found for BALQSOs ($\alpha_{\mathrm{ox}} > 1.8$) than for typical QSOs ($\alpha_{\mathrm{ox}} \sim 1.6$).

Table 2. Absorption features in the spectrum of RX J005734.78−272827.4.

ID	Balnicity[a] (km s^{-1})	EW[b] Å	Central Wavelength Å
1	0	4	4858
2	0	2	4804
3	16	7	4559
4	22	8	4226

[a] See Weymann et al. (1991).

[b] Continuum obtained by linear interpolation.

However, this object is probably *not* a BALQSO. It *does* have Lyα 1215-Å line emission heavily attenuated relative to N v 1240, common in BALQSOs, and broad absorption features blueward of C iv 1550 and Si iv 1397, which are just broad enough to be BALs from their 'BALnicity index' (Weymann et al. 1991), but these potential broad absorption lines have different velocities: feature 3 covers ~20 900–23 900 km s^{-1} blueward of the C iv emission line while feature 4 lies ~13 500–18 400 km s^{-1} blueward of the Si iv emission line. In all known bona fide BALQSOs with Si iv absorption, C iv absorption is also found at the same velocities. In RX J005734.78−272827.4 there is no sign of broad C iv absorption at the velocities of the Si iv absorption, implying that this object is *not* a BALQSO.

An alternative, more plausible, explanation for the absorption features is that they are an intervening absorption-line system at redshift $z = 0.628$. Fig. 2 shows the absorption features with the positions of strong interstellar metal lines (from the *Hubble Space Telescope* QSO absorption lines key project list in Bahcall et al. 1993) at a redshift of $z = 0.628$. This can account for both the deep absorption features and the lack of Lyα relative to N v, although it does not explain the weaker features (1 and 2 in Fig. 1); these are probably caused by less dense, more distant absorbers.

Can an intervening absorber at $z = 0.628$ also explain the weak hard X-ray spectrum? Assuming an intrinsically normal radio-quiet QSO X-ray spectrum of $\alpha = 1$, but this time absorbed by solar abundance gas at $z = 0.628$, the fitted *ROSAT* column is $8^{+6}_{-5} \times 10^{21}\,\mathrm{cm}^{-2}$. An alternative method of estimating the X-ray column is to assume that RX J005734.78−272827.4 has an

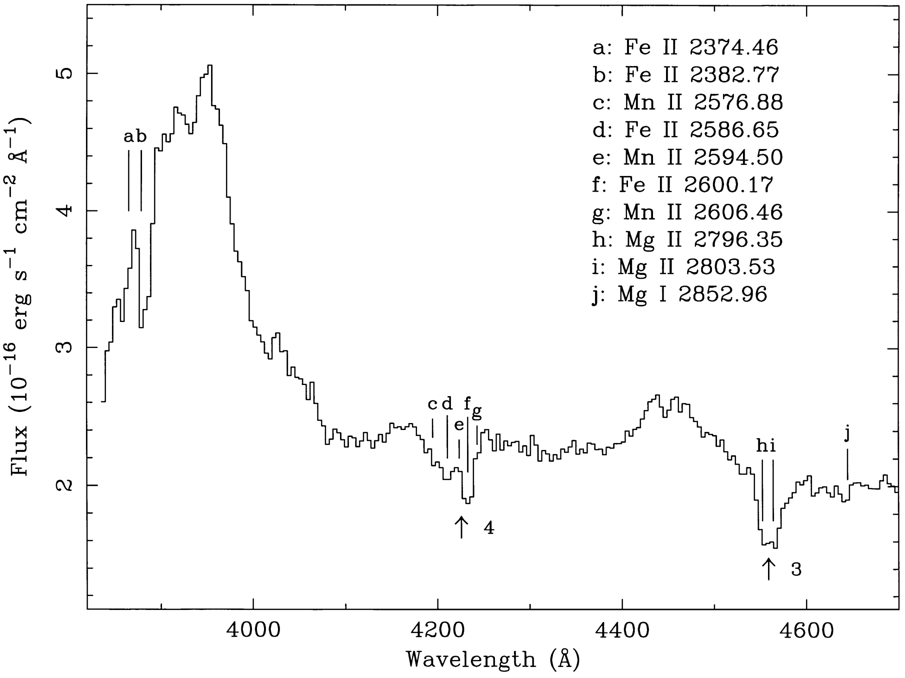

Figure 2. Optical spectrum enlarged around strong absorption features, with positions marked for absorption lines in the standard list of Bahcall et al. (1993) at a redshift $z = 0.628$.

intrinsic $\alpha_{\rm ox}$ of 1.6 and X-ray spectral slope of $\alpha = 1$, typical for radio-quiet QSOs, and to calculate the X-ray column required to reduce the *ROSAT* count rate to the observed value. This method has been used by Green & Mathur (1996) and Gallagher et al. (1999) to estimate the column in BALQSOs. Assuming 20 per cent uncertainty on the optical flux and using the *ROSAT* count rate and count rate error obtained from the PSS algorithm, we infer a consistent column of $10^{+9}_{-4} \times 10^{21}\,{\rm cm}^{-2}$. This is comparable to the column densities inferred for the strongest metal-line systems by Tytler et al. (1987). The resolution of our optical spectrum is insufficient to separate the interstellar lines, but the high rest equivalent widths of the absorption features (Table 2) imply that this is indeed a particularly strong, metal-line system. We also note that the rest equivalent widths of the blended lines that make up features 3 and 4 in RX J005734.78−272827.4 are similar to those found in the $z = 0.524$ system in AO 0235+164 (Wolfe & Wills 1977).

Systems with a total Mg II 2796 + Mg II 2803 rest equivalent width as large as, or larger than, the ∼4-Å rest equivalent width of the blend seen in this object are rare, especially at low redshift: surveys of 35 and 24 QSOs for Mg II absorbers in the aproximate redshift ranges $0.13 < z < 0.41$ and $0.45 < z < 0.75$, respectively, found no systems as strong as this (Boissé et al. 1992; Tytler et al. 1987). At higher redshift where Mg II systems are more common, systems of this strength are still unusual: Lanzetta, Turnshek & Wolfe (1987) surveyed 32 QSOs for absorbers with $1.2 < z < 2.0$ and found only two systems stronger than that in RX J005734.78−272827.4. The rarity of absorption-line systems of this strength at similar redshifts makes it unlikely that the metal-line system is coincidental and unrelated to the hard X-ray spectrum.

Radio-quiet AGN are more numerous by an order of magnitude than their radio-loud cousins, and the presence of intervening absorbers should be unrelated to the intrinsic radio properties of a background object. It was therefore a significant discrepancy that the only intervening X-ray absorber candidates were radio loud, and in particular the only strong candidate (AO 0235+164). The discovery of RX J005734.78−272827.4 relieves this problem by providing a strong candidate for a radio-quiet object with an intervening X-ray absorber.

The discovery of objects with intervening X-ray absorbers is important because, in principle, spectroscopy of X-ray absorption edges allows the column density of different elements to be determined more or less independently of the ionization state of the absorbing material. This is a significant advantage over UV absorption-line studies in which the derived column densities depend very strongly on ionization state, and may facilitate elemental abundance measurements of gas in the discs of galaxies over a wide range of redshifts. Unfortunately RX J005734.78−272827.4 is too faint for the current X-ray data to be useful for this purpose, although it ought to be possible with the large-area X-ray observatories currently being planned, such as *XEUS* and *Constellation-X*.

5 CONCLUSIONS

We have found a faint, hard-spectrum *ROSAT* source coincident with a bright, radio-quiet QSO. The optical spectrum of this QSO shows marked absorption features which are probably due to a strong, intervening metal-line system at $z = 0.628$. We show that X-ray absorption by this intervening system is the probable cause for the faint, hard *ROSAT* spectrum of the object. This is the second strong candidate found so far for X-ray absorption from an intervening absorption-line system, and the first strong candidate in which the background object is radio quiet.

ACKNOWLEDGMENTS

We thank the anonymous referee for his extremely useful comments. FJC thanks the DGES for partial financial support, under project PB95-0122. This research was based on observations collected at the European Southern Observatory, Chile, ESO No. 62.O-0659. This research has made use of data obtained from the Leicester Database and Archive Service at the Department of Physics and Astronomy, Leicester University, UK. This research has also made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Bahcall J. et al., 1993, ApJS, 87, 1
Bechtold J. et al., 1994, AJ, 108, 759
Blair A. J., Stewart G. C., Georgantopoulos I., Boyle B. J., Almaini O., Shanks T., Gunn K. F., Griffiths R. E., 1998, Astron. Nachr., 319, 25
Boissé P., Boulade O., Kunth D., Tytler D., Vigroux L., 1992, A&A, 262, 401
Boyle B. J., Fong R., Shanks T., Peterson B. A., 1990, MNRAS, 243, 1
Condon J. J., Cotton W. D., Greisen E. W., Yin Q. F., Perley R. A., Taylor G. B., Broderick J. J., 1998, AJ, 115, 1693
Dickey J. M., Lockman F. J., 1990, ARA&A, 28, 215
Elvis M., Fiore F., Wilkes B., McDowell J., Bechtold J., 1994, ApJ, 422, 60
Gallagher S. C., Brandt W. N., Sambrura R. M., Mathur S., Yamasaki N., 1999, ApJ, 519, 549
Green P. J., Mathur S., 1996, ApJ, 462, 637
Lanzetta K. M., Turnshek D. A., Wolfe A. M., 1987, ApJ, 322, 739
Madejski G., Takahashi T., Tashiro M., Kubo H., Hartmann R., Kallman T., Sikora M., 1996, ApJ, 459, 156
Mittaz J. P. D. et al., 1999, MNRAS, 308, 233
Miyaji T., Ishisaki Y., Ogasaka Y., Ueda Y., Freyberg M. J., Hasinger G., Tanaka Y., 1998, A&A, 334, L13
Morris S. L. et al., 1991, AJ, 102, 1627
O'Flaherty K. S., Jakobsen P., 1997, ApJ, 479, 673
Oke J. B., 1990, AJ, 99, 1621
Page M. J., Mittaz J. P. D., Carrera F. J., 1999, Proc. X-ray astronomy 1999: Stellar Endpoints, AGN and the Diffuse Background. Astrophysical Letters & Communications, Gordon & Breach, in press
Romero-Colmenero E., Branduardi-Raymont G., Carrera F. J., Jones L. R., Mason K. O., McHardy I. M., Mittaz J. P. D., 1996, MNRAS, 282, 94
Sambruna R. M., George I. M., Madejski G., Urry C. M., Turner T. J., Weaver K. A., Maraschi L., Treves A., 1997, ApJ, 483, 774
Sirola C. J. et al., 1998, ApJ, 495, 659
Stocke J. T., Wurtz R., Wang Q., Elston R., Jannuzi B. T., 1992, ApJ, 400, 17
Tytler D., Boksenberg A., Sargent W. L. W., Young P., Kunth D., 1987, ApJS, 64, 667
Weymann R. J., Morris S. L., Foltz C. B., Hewett P. C., 1991, ApJ, 373, 23
Wolfe A. M., Wills B. J., 1977, ApJ, 218, 39

This paper has been typeset from a TEX/LATEX file prepared by the author.