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V. Charmandaris, D. Rigopoulou, N. Kylafis

X-ray absorbed QSOs and the QSO evolutionary sequence

M.J. Page

*UCL, Mullard Space Science Laboratory, Holmbury St. Mary, Dorking,
Surrey RH5 6NT, UK*

F.J. Carrera, J. Ebrero

*Instituto de Física de Cantabria, Avenida de los Castros, 39005
Santander, Spain*

J.A. Stevens

*Centre for Astrophysics Research, University of Hertfordshire, College
Lane, Hatfield AL10 9AB, UK*

R.J. Ivison

*UK Astronomy Technology Centre, Royal Observatory, Blackford Hill,
Edinburgh, EH9 3HJ, UK*

Abstract. Unexpected in the AGN unified scheme, there exists a population of broad-line $z \sim 2$ QSOs which have heavily absorbed X-ray spectra. These objects constitute $\sim 10\%$ of the population at luminosities and redshifts characteristic of the main producers of QSO luminosity in the Universe. Our follow up observations in the submm show that these QSOs are often embedded in ultraluminous starburst galaxies, unlike most QSOs at the same redshifts and luminosities. The radically different star formation properties between the absorbed and unabsorbed QSOs implies that the X-ray absorption is unrelated to the torus invoked in AGN unification schemes. Instead, these results suggest that the objects represent a transitional phase in an evolutionary sequence relating the growth of massive black holes to the formation of galaxies. The most puzzling question about these objects has always been the nature of the X-ray absorber. We present our study of the X-ray absorbers based on deep (50-100ks) XMM-Newton spectroscopy. We show that the absorption is most likely due to a dense ionised wind driven by the QSO. This wind could be the mechanism by which the QSO terminates the star formation in the host galaxy, and ends the supply of accretion material, to produce the present day black hole/spheroid mass ratio.

1. Introduction

The prevalence of black holes in present day galaxy bulges, and the proportionality between black hole and spheroid mass (Merritt & Ferrarese 2001) implies that the formation of the two components are intimately linked. One way to probe star formation in distant QSOs is to observe them at submm wavelengths, and so measure the amount of radiation from young stars which is absorbed and

re-emitted by dust. With this in mind, we observed matched samples of X-ray absorbed and unabsorbed QSOs at $850\mu\text{m}$ with SCUBA. These observations revealed a remarkable dichotomy in the submm properties of these two groups of sources: almost all of the X-ray absorbed QSOs at $z > 1.5$ are ultraluminous infrared galaxies, while the X-ray unabsorbed QSOs are not. This suggests that the two types are linked by an evolutionary sequence, whereby the QSO emerges at the end of the main star-forming phase of a massive galaxy (Page et al. 2004; Stevens et al. 2005; Carrera et al. 2006; Stevens et al. this volume).

However, the nature of the X-ray absorption remains puzzling. These objects are characterised by hard, absorbed X-ray spectra, and assuming that this is due to photoelectric absorption from cold material with solar abundances, their column densities are $\sim 10^{22} \text{ cm}^{-2}$. On the other hand, they have optical/UV spectra which are typical for QSOs, with broad emission lines and blue continua. For a Galactic gas/dust ratio, the restframe UV spectra would be heavily attenuated by such large columns of material, so the absorber appears to contain very little dust.

The X-ray absorption could be due to gas located within the AGN structure, or from more distant material in the host galaxy, but in either case the lack of dust is surprising. If the absorber were associated with the obscuring dusty torus invoked in unification schemes (Antonucci 1993) we would expect significant dust attenuation, while the detection of the dust continuum at long wavelengths implies that the interstellar media of the host galaxies also have a high dust content. Therefore, in order to investigate the X-ray absorption, we have obtained deep (50–100ks) *XMM-Newton* observations of three submm bright, X-ray absorbed QSOs from our sample of hard-spectrum *Rosat* sources (Page, Mittaz & Carrera 2001).

2. Results

As a starting point, we fitted the *XMM-Newton* spectra with a power law and fixed Galactic absorption. The best fit photon indices are unusually hard for QSOs: the QSOs have $\Gamma \sim 1.4$ (see Fig. 1) compared to the $\Gamma = 1.9$ that is typical for X-ray selected QSOs (e.g. Mateos et al. 2005; Page et al. 2006). Furthermore, although the fits have acceptable χ^2/ν , the data show a systematic deficit of counts relative to the model at the softest energies, indicating that absorption is present. The original *Rosat* PSPC spectra and the *XMM-Newton* spectra show excellent agreement (see Fig. 1).

The hypothesis of a normal ($\Gamma = 2$) AGN X-ray spectrum and a cold absorber is strongly rejected for RXJ121803 and RXJ124913. Therefore we considered ionised absorber models for the X-ray absorption, using the ‘xabs’ model in SPEX, which includes both photoelectric and line absorption. For all three AGN an acceptable fit can be obtained with a $\Gamma = 2$ power law and an absorber with an ionisation parameter $\log \xi \sim 2$ and column densities of $10^{22.5} - 10^{23.5} \text{ cm}^{-2}$. These absorbers have similar properties to the high-ionisation absorber phases seen as outflows in some nearby Seyfert 1 galaxies and QSOs such as NGC 3783 and PG 1114+445 (Ashton et al. 2004).

At these ionisation parameters and column densities, the absorbers are likely to originate in the AGN themselves, rather than in the host galaxies. The de-

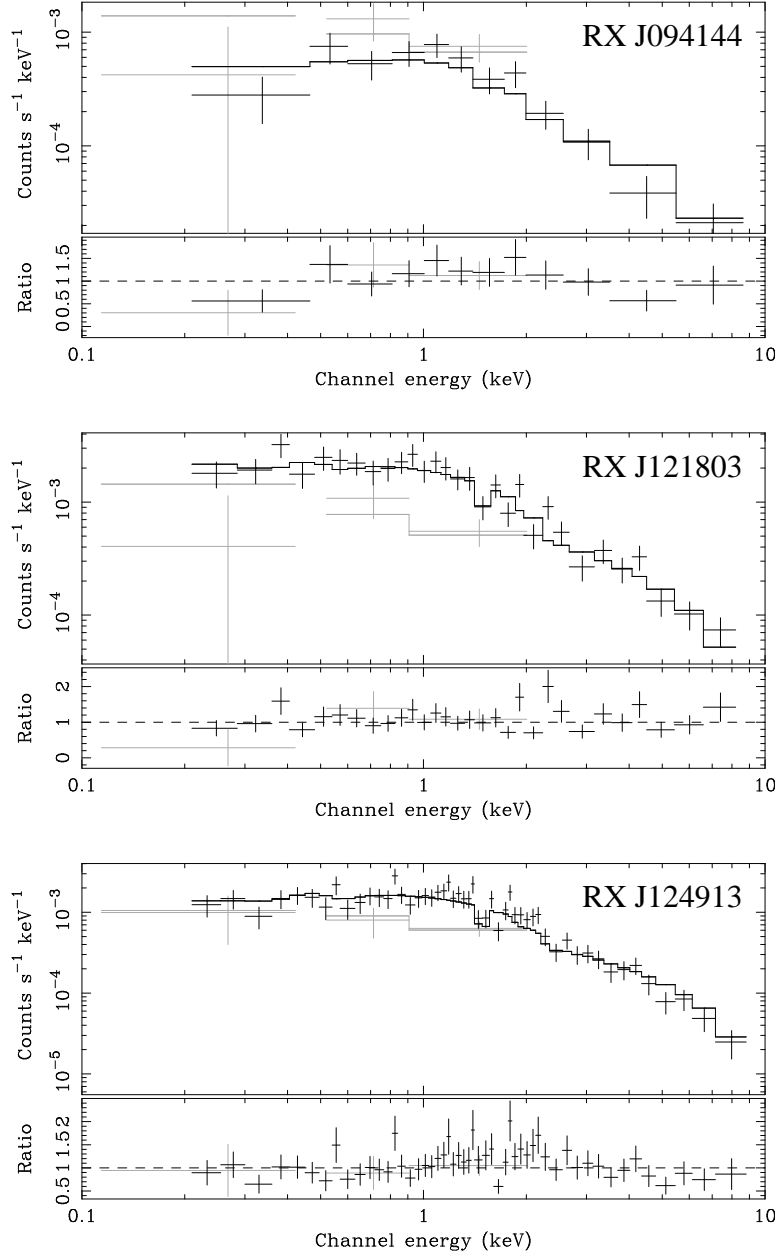


Figure 1. *XMM-Newton* EPIC spectra (black) and *Rosat* PSPC spectra (grey) of three X-ray absorbed QSOs. The model is a simple power law with fixed Galactic absorption. The best-fit power law photon indices Γ are 1.3 ± 0.1 , 1.4 ± 0.1 and 1.4 ± 0.1 for RX J094144, RX J121803, and RX J124913 respectively. Such photon indices are unusually hard for radio-quiet AGN. In all three objects there is a deficit of counts at the lowest energy, indicating that absorption is responsible for the hard spectral shape; this is also seen in the *Rosat* data. Furthermore, RX J094144 and RX J124913 show some systematic curvature relative to the power law model.

tection of blue-shifted absorption lines in the rest-frame UV spectra of several of our X-ray absorbed QSOs (Mittaz, Page & Carrera 2001) provides further evidence that the ionised absorbers originate in outflows from the QSO. This solution is attractive, because it is compatible with the lack of optical extinction in these objects: if the absorber is driven as a wind, either from the accretion disc or from evaporation of the inner edge of the molecular torus, then dust will be sublimated before (or as) it enters the flow. Identifying the X-ray absorption with an ionised wind also reconciles the properties of the X-ray absorbed QSOs with geometric unification models, because the submm detection statistics imply that the X-ray absorption in these objects is not due to their orientation with respect to the dusty torus. Instead, the detection of an ionised wind in absorption implies that these objects, like optical or X-ray selected QSOs in general, are observed pole-on rather than edge-on with respect to the torus.

3. Implications for AGN and galaxy evolution

As discussed by Page et al. (2004) and Stevens et al. (2005), the low space density of X-ray absorbed QSOs relative to unabsorbed QSOs and to distant ultraluminous galaxies detected in blank field SCUBA surveys, implies that X-ray absorbed QSOs are caught during a short-lived transitional phase. Before this brief phase, the AGN must be weak and heavily obscured, as found by Alexander et al. (2005); after this phase the host galaxy is essentially fully formed, and the naked QSO shines brightly until its fuel is consumed. The origin of the X-ray absorption, and the brief duration of the transitional phase were open questions from these studies. In Page et al. (2004) and Stevens et al. (2005) we suggested that the transition is mediated by a wind from the QSO, which terminates the star formation in the host galaxy by driving gas and dust into the intergalactic medium. Such a scenario has also been proposed on theoretical grounds (e.g. Fabian 1999; Di Matteo Springel & Hernquist 2005). The EPIC spectra of our X-ray absorbed QSOs suggest that the absorbers are ionised winds driven by the AGN, and therefore that the transition between buried AGN and naked QSO could indeed be mediated by a radiatively driven wind from the AGN.

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