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X-ray absorption and re-emission from an ionised outflow in the Type 1 QSO 2MASS 234449+1221

K.A.Pounds[1], B.J.Wilkes[2] and K.L.Page[1]
[1] *Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH, UK*
[2] *Harvard/Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA*

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ABSTRACT

We report on the analysis of a short *XMM-Newton* observation of the reddened Type 1 QSO 2MASS 234449+1221 first identified in the Two Micron All-Sky Survey. The underlying X-ray continuum is found to be typical of a broad-line active galaxy, with photon index $\Gamma\sim1.9$. Low energy absorption can be modelled by a column $N_H\sim10^{22}$ cm^{-2} of moderately ionised gas or a smaller column of cold gas. Addition of a soft X-ray emission component significantly improves the fit in both cases. With the assumption that the soft X-ray flux represents emission from gas photoionised by the incident X-ray continuum, a comparison of the absorbed and emitted luminosities indicates a covering factor of ∼8-17%. The unusual opportunity to simultaneously observe and quantify ionised absorption *and* emission in 2MASS 234449+1221 is due to the relatively large opacity (for a Type 1 AGN) of the absorbing gas, which depresses the normally strong continuum below ∼1 keV. A comparison of the soft X-ray emission of 2MASS 234449+1221 with that of other Type 1 and Type 2 AGN suggests the existence of an inner turbulent extension to ionised outflows, not detected in current high resolution X-ray spectra.

Key words: galaxies: active – galaxies:general – galaxies: individual:2MASS 234449+1221 – galaxies:QSO – X-ray:galaxies

1 INTRODUCTION

X-ray spectra of Type 1 AGN are typically dominated by a power law continuum of photon index $\Gamma\sim1.8$-2 (Nandra and Pounds 1994), with an ionised outflow often imprinting an absorption line spectrum in the soft X-ray band (e.g. Kaspi et al. 2002, Steenbrugge et al. 2003). Type 2 AGN, in contrast, are usually heavily absorbed by cold gas (perhaps in the putative torus; Antonucci 1993), with soft X-ray lines showing up in emission. While it is a reasonable assumption that the soft X-ray emission and absorption come from the same ionised outflow (Kinkhabwala et al. 2002) both components are rarely seen in the same spectrum, since the continuum flux is generally dominant in Type 1 AGN. A few cases have been found, however, where a Type 1 AGN in a low flux state exhibits a dominantly emission line spectrum (e.g. Turner et al. 2003, Pounds et al. 2004b).

The Two Micron All-Sky Survey (2MASS) has revealed many highly reddened active galaxies (AGN) whose number density rivals that of optically selected AGN. Spectroscopic follow-up of red candidates reveals ∼75 percent are previously unidentified emission-line AGN, with ∼80 percent of those showing the broad optical emission lines of Type 1 Seyfert galaxies and QSOs (Cutri et al. 2001). These objects often have unusually high optical polarization levels, with ∼10 percent showing $P > 3$ percent indicating a significant contribution from scattered light (Smith et al. 2002) and suggesting substantial obscuration toward the nuclear energy source. *Chandra* observations of a sample of 2MASS AGN found them to be X-ray weak with generally flat (hard) spectra (Wilkes et al. 2002).

XMM-Newton spectra were recently obtained for a subset of five 2MASS AGN in an attempt resolve the effects of absorption from an *intrinsically* flat power law spectrum. The results of this study, which suggest absorption to be the main factor, are being published separately (Wilkes et al. 2005). Meanwhile, we report here the unusual X-ray spectrum of one AGN in the subset, 2MASS 234449+1221, a Type 1 QSO that exhibits an absorbed power law continuum together with a soft excess. The suppression of the continuum below ∼1 keV allows the form of the soft excess to be resolved with unusual clarity.

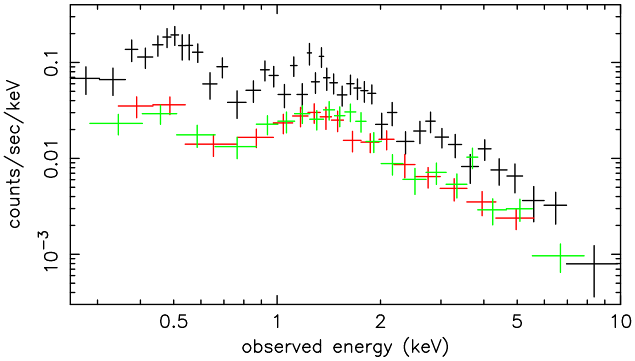

Figure 1. EPIC spectral data for 2MASS 234449+1221 from the pn (black), MOS1 (red) and MOS2 (green) cameras, each showing evidence for an absorption 'trough' below ∼1 keV

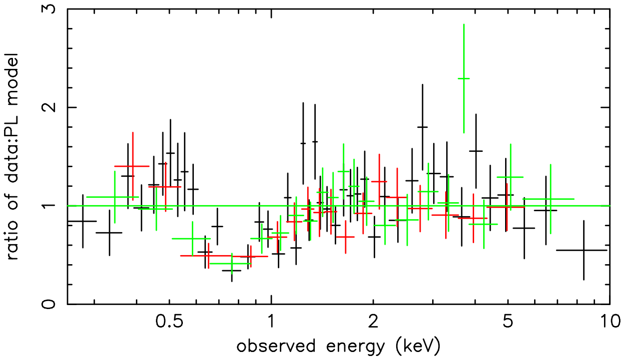

Figure 2. Ratio of the EPIC spectral data shown in figure 1 to a simple power law model fitted between 2-10 keV. The spectral structure indicates absorption below ∼1.5 keV and a 'soft excess' near 0.5 keV

2 OBSERVATION AND DATA REDUCTION

2MASS 234449+1221 (hereafter 2M23) is optically classified as a Type 1 QSO at a redshift of z = 0.199 (Cutri et al. 2003). It was selected as a 'red' AGN from the 2 MASS catalogue (J-K$_s$=2.00±0.06) and found to have a linear broad band polarisation of ∼1 % by Smith et al (2002). It was observed by *XMM-Newton* on 2003 July 3 (rev. 653) for 7885 s on target, with X-ray data from the EPIC pn (Strüder et al.2001) and MOS1 and MOS2 (Turner et al. 2001) cameras providing moderate resolution spectra over the energy band ∼0.2–10 keV. Each camera was set in full-frame mode, with the medium thickness filter to remove any optical/UV light from the target source. The particle background was found to be high during parts of the observation, and those data have been excluded from our spectral analysis. Using the recommended maximum background rates of 1 s^{-1} (pn camera) and 0.35 s^{-1} (MOS camera) the effective exposure times were thereby reduced to 4444 s (pn), 6321 (MOS1) and 6844 s (MOS2).

The X-ray data were screened with the XMM SAS v6.1 software and events corresponding to patterns 0-4 (single and double pixel events) selected for the pn data and patterns 0-12 for MOS1 and MOS2. A low energy cut of 200 eV was applied to all X-ray data and known hot or bad pixels were removed. Source counts were obtained from a circular region of 45″ radius centred on the target source, with the background being taken from a similar region offset from, but close to, the source. Individual EPIC spectra were binned to a minimum of 20 counts per bin to facilitate use of the χ^2 minimalisation technique in spectral fitting, which was based on the Xspec package (Arnaud 1996). All fits included absorption due to the line-of-sight Galactic column of N_H=4.66×10^{20} cm^{-2}. Errors are quoted at the 90% confidence level ($\Delta\chi^2$ = 2.7 for one interesting parameter).

3 THE COMPLEX EPIC SPECTRUM OF 2MASS 234449+1221

3.1 An absorbed power law

Given the limited number of background-subtracted counts (844 pn and 790 MOS) spectral fitting was carried out on the integrated data sets. Guided by the data (figure 1) we first fitted a power law above 2 keV, with a common spectral index, but untied normalisations, for the 3 EPIC cameras, obtaining a good fit (χ^2=24 for 25 degrees of freedom) for a rather flat (hard) photon index of Γ=1.65±0.2. Extrapolating this fit to 0.2 keV showed the spectrum to be complex at low energies (figure 2) with evidence of additional (intrinsic) absorption and (possibly) a soft excess yielding a very poor overall fit (χ^2=228/78).

To model the low energy absorption, we then added a photoionised absorber to the power law in Xspec, using a recent output (grid 18) of the XSTAR code (Kallman and Bautista 2001). The ionisation parameter and column density were left as free parameters, but tied for the 3 data sets, while the key metal abundances of C–Fe were fixed at their solar values. Grid 18 includes a turbulent velocity of 100 km s^{-1}. This addition yielded a much improved fit to the combined pn and MOS data (χ^2=89/76), with a column density N$_H$=1.0±0.1×10^{22} cm^{-2} of moderately ionised gas. The ionisation parameter $\xi(=L/nr^2$, where L is the ionising luminosity irradiating matter of density n at a distance r) = 11±3 erg cm s^{-1} was primarily constrained by the spectral upturn, observed below ∼0.7 keV, which corresponds mainly to the absorption of ionised OVII in the model (figure 3). Addition of the absorbing column resulted in a steepening of the power law index to Γ=2.05±0.14. Although the absorbed power law fit was statistically acceptable a visual examination of the data:model residuals showed significant structure remaining below∼1 keV (figure 4).

3.2 A separate soft emission component

An extended region of soft X-ray *emission* from outflowing photoionised gas is well established in Seyfert 2 galaxies (e.g. Kinkhabwala et al. 2002, Sako et al. 2000), while *absorption* from 'warm' gas is often seen in the X-ray spectra of Seyfert 1 galaxies (e.g. Kaspi et al. 2002, Steenbrugge et al. 2003). The residuals in figure 4 suggest both emission and absorption are affecting the soft X-ray spectrum of 2M23. To test that we then added a soft X-ray emission component to the model for 2M23, lying outside the cold absorbing matter affecting the power law continuum.

To represent such a soft X-ray emission component we again used the XSTAR code, with the ionisation parameter and luminosity (effectively the emission measure of the ionised gas) as free parameters. Adding an emission com-

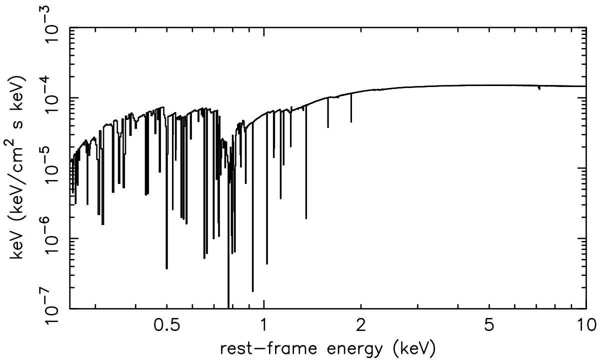

Figure 3. Power law model fit to the 2MASS 234449+1221 data attenuated by a column of 'warm ' ionised gas as described in Section 3.1. The energy axis is in the rest frame of 2MASS 234449+1221 to aid visual identification of the spectral features

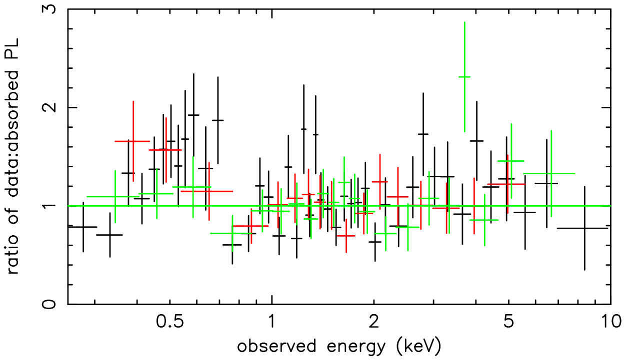

Figure 4. Ratio of the EPIC spectral data to the absorbed power law model of figure 3

ponent to the absorbed power law model in this way, with metal abundances again fixed at the solar values, yielded a further significant improvement to the 0.2-10 keV spectral fit (χ^2=70/73). The standard F-test showed the improvement in the fit by adding the soft X-ray emission spectrum was significant at 99.7%. The ionisation parameter of the emission component, essentially determining the energy profile of the soft emission in the EPIC data, was ξ=18±11 erg cm s^{-1}. This more complex model is reproduced in figure 5. The dominant emission lines are seen to correspond to resonance transitions in He- and H-like ions of C, N, O and Ne, and Fe L (0.7-0.9 keV). Strong radiative recombination continua of CVI, OVII and OVIII are also visible in the model spectrum. We deduce from this XSTAR modelling that the *shape* of the soft excess is well matched by the emission from a photoionised gas, the observed luminosity (see below) corresponding to an emission measure (EM=$\int$n$_e^2$dV) of order 2×10^{65} cm^{-3}.

A consequence of the additional soft X-ray emission was that the ionisation parameter of the absorbing column fell, to ξ=0.1±0.1, now being determined mainly by the downward curvature in the data below ∼1 keV. The column density of this 'cold' absorber also fell, to N$_H$=3±0.5×10^{21} cm^{-2}, due to the higher relative opacity of the colder gas.

The 0.2-2 keV luminosity in the 'soft' emission component in this model (hereafter Model 1) was found to be 6.1×10^{42} erg s^{-1} (H$_0$=70 km s^{-1} Mpc^{-1}). In comparison, the *observed* 0.2-10 keV luminosity of the power law continuum was 6.6×10^{43} erg s^{-1} , increasing to 1×10^{44} erg s^{-1} for a power law of Γ=1.9, correcting for intrinsic absorption. We note the luminosity of the soft emission component is ∼18% of the that removed from the power law continuum by absorption, suggesting that the soft emission arises by re-emission from the same matter, a possibility discussed in the next Section.

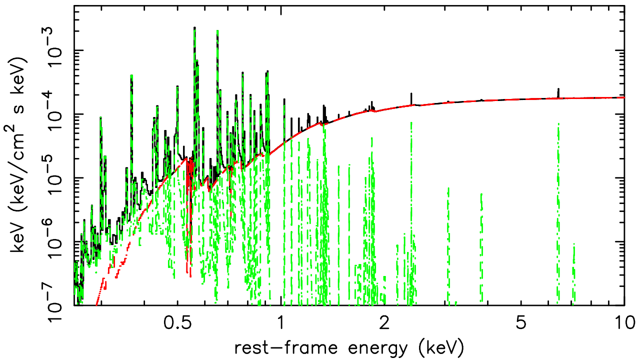

Figure 5. Best-fit spectral model for 2MASS 234449+1221 where the emission from ionised gas is added to the power law continuum, with the continuum now being attenuated by relatively cold gas. The energy axis is in the rest frame of 2MASS 234449+1221 to aid visual identification of the spectral features. Details of this spectral fit are given in Section 3.2

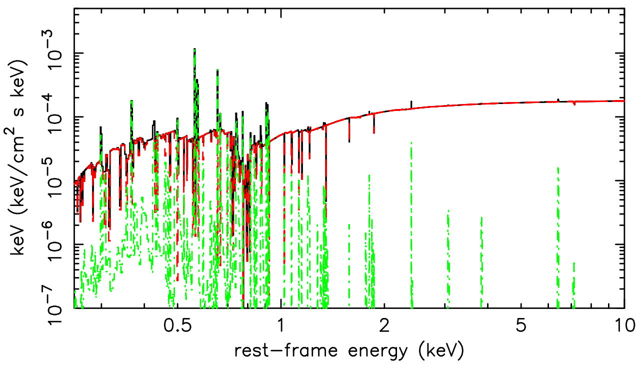

Figure 6. Alternative best-fit spectral model for 2MASS 234449+1221 where the ionisation parameters of the absorbing and emitting gas are tied. The energy axis is in the rest frame of 2MASS 234449+1221 to aid visual identification of the spectral features. Details of this spectral fit are given in Section 3.3

3.3 Absorption and re-emission from the same ionised gas

Given the implication in the above model of continuum energy being absorbed and then re-emitted in soft X-rays, it was important to check whether this re-processing matter could be the same gas. To test that possibility, a further spectral fit was tried, tying together the ionisation parameters of the absorbing and emitting matter in XSTAR. The fit was again acceptable (χ^2=72/74), for a tied ionisation parameter ξ=10±2 erg cm s^{-1}. This alternative 'best fit' model had an unchanged 'normal' power law with photon index Γ∼1.9, now absorbed by a column N$_H$∼1×10^{22} cm^{-2} of warm (moderately ionised) gas. Figure 6 illustrates this model (hereafter Model 2).

Although not quite such a good fit as Model 1, the common warm absorber/re-emitter model for the *XMM-Newton* EPIC spectrum of 2M23 has the attraction of involving one less physical component. Visual comparison of figures 5 and 6 shows the soft X-ray emission to be somewhat weaker in Model 2. Specifically, the 0.2-2 keV luminosity in the 'soft' emission component of Model 2 fell to 2.5×10^{42} erg s^{-1}, while the *observed* 0.2-10 keV luminosity of the power law continuum of 2M23 was 7×10^{43} erg s^{-1}, or 1×10^{44} erg s^{-1} correcting for intrinsic absorption. In Model 2 the luminosity of the soft emission component is then ∼8% of that removed from the power law continuum by absorption, a factor ∼2 less than in Model 1.

4 DISCUSSION

The *XMM-Newton* spectrum of 2M23 has a typical Type 1 AGN power law continuum slope ($\Gamma \sim 1.9$) when allowance is made for absorption. The nature of the line-of-sight column is unclear from our fitting, the low energy opacity (larger than usual for a Type 1 QSO) being modelled by a column $N_H \sim 3 \times 10^{21}$ cm^{-2} of 'cold' gas, or $N_H \sim 1 \times 10^{22}$ cm^{-2} of moderately ionised or 'warm' gas. Importantly, the attenuation of the power law component below ∼1 keV allows the spectral shape of the 'soft excess' to be resolved and quantified.

In the first spectral fit (Model 1) the X-ray absorbing gas is cold and embedded dust could also be responsible for the optical reddening seen in this 2MASS QSO. While it is possible that the BLR has a flattened geometry and therefore suffers less absorption than the (centrally located) continuum X-ray source, the Type 1 optical classification of 2M23 suggests such 'cold' matter lies close to the continuum source. If so, it must be relatively dense to survive.

We note the growing evidence for 'variable' cold absorbing matter in AGN (eg Risaliti et al. 2002). On the large scale this is seen in the tendency for some type 2 AGN switching between Compton-thick and Compton-thin X-ray absorption (eg Guainazzi et al. 2004). Again, a substantial column density of near-neutral matter was seen to shrink as the continuum X-ray brightness increased strongly in the luminous type 1 Seyfert 1H0419-577 (Pounds et al. 2004a). It is interesting to speculate that the 'cold' X-ray absorption in Type 1 AGN might be associated with the accretion process and related, for example, to the accreting clouds envisaged by Guilbert and Rees (1988) in their original paper predicting the subsequent discovery of X-ray 'reflection' (Pounds et al. 1990). Alternatively it may lie in dense structures at the base of an outflow or wind.

In the alternative spectral fit to 2M23 (Model 2) the absorbing gas has the same ionisation parameter as that of the soft X-ray emission. However, in the context of the 'red' near-infrared colour of 2M23, it is noteworthy that the ionisation parameter ($\xi \sim 10$) is lower than commonly found in Type 1 AGN. In this case the combination of a relatively low ionisation parameter and unusually high column density, $N_H \sim 1 \times 10^{22}$ cm^{-2}, may be causally linked with the designation of 2M23 as a 2MASS QSO.

The main result from our spectral modelling of 2M23 is that the soft excess - revealed with unusual clarity due to the effective removal of the soft power law component - has a spectral form well matched by the blended line emission from an ionised gas. A similar finding was reported in the low flux state spectrum of the Seyfert 1 galaxy NGC 4051 (Pounds et al.2004b), and proposed as the origin of a quasi-constant soft X-ray emission component in the luminous Seyfert 1 galaxy 1H0419-577 (Pounds et al. 2004a). It was speculated in those papers that such an emission component might be a stronger analogue of the extended soft X-ray emission seen in Seyfert 2 galaxies such as NGC 1068 (Brinkman et al. 2002, Kinkhabwala et al. 2002) and Mkn 3 (Sako et al. 2000, Pounds and Page 2005). In both those bright, nearby Seyfert 2 galaxies the high resolution soft X-ray spectrum is dominated by line emission from photoionised/ photoexcited gas, with the scattered continuum being weak. The shape of the soft emission in 2M23 suggests this is again the case.

To quantify the comparative strength of the soft X-ray emission in these Type 1 AGN with an archetypal Type 2 AGN, we list in Table 1 their observed and derived soft X-ray luminosities, together with the intrinsic 2-10 keV luminosities as a proxy for the relative ionising fluxes. From this admittedly small sample it is seen that the luminosity ratio of the soft X-ray emission to power law is up to an order of magnitude higher in the Type 1 AGN - including 2M23, compared with Mkn3.

In considering a common origin for the soft X-ray emission, we surmise that the ionised outflow seen in a Type 2 AGN is cut off from direct view at some minimum radius r by the same obscuring matter that hides the BLR, while in a Type 1 AGN the full extent of the outflow is visible. With the simplest assumption of a constant velocity, radial outflow, mass conservation yields a *total* emission measure of ionised gas which increases as r^{-1}. That would require the ionised gas to extend inward to $0.1 r_{cut}$, where r_{cut} is the minimum radius observed directly in Type 2 AGN. Taking r_{cut} as intermediate between the BLR and NLR, and a discriminating Keplerian velocity of 2×10^3 km s^{-1}, r_{cut} is then $\sim 10^4 r_g$, where r_g is the gravitational radius. To obtain a 10-fold increase in the integrated soft X-ray emission then implies the ionised flow in 2M23 to extend inward to $\sim 10^3 r_g$. Is that consistent with observation?

The escape velocity of gas at $\sim 10^3 r_g$ is $\sim 10^4$ km s^{-1}. Turbulence in such gas would result in very broad wings to the X-ray absorption lines, apparently at odds with reported *XMM-Newton* and *Chandra* grating spectra of BLAGN which are an order of magnitude narrower (e.g. Steenbrugge et al. 2003, Kaspi et al. 2002). However, those high dispersion instruments are notably insensitive to broad features and broad wings could well remain undetected. A similar - but more extreme - scenario was envisaged by Gierlinski and Done (1994) in suggesting low energy absorption in highly turbulent matter as an explanation of the common form of the soft X-ray spectra in many AGN.

In our proposed interpretation of the soft excess in 2M23 we would expect the energy absorbed from the power law continuum by line-of-sight matter to be related to the luminosity of an optically thin ionised gas by the the covering factor. The values we find, of ∼8-17%, are consistent with the typical solid angle of ∼1 sr *observed* in the biconical outflows of Type 2 AGN.

Table 1. The soft X-ray and intrinsic 2-10 keV luminosities of 2MASS 234449+1221 and two other Type 1 AGN, compared with those of the archetypal Type 2 AGN, Mkn3. The 2-10 keV luminosities are used as a proxy for the ionising flux irradiating the soft X-ray emission region in each case

Galaxy	optical type	L_{2-10}(ergs s^{-1})	L_{SX}(ergs s^{-1})	ratio (L_{SX}/L_{2-10})	reference
NGC 4051	Seyfert 1	3.5×10^{41}	3.5×10^{40}	10%	Pounds et al. 2004b
1H0419-577	Seyfert 1	2.7×10^{44}	2.9×10^{43}	11%	Pounds et al. 2004a
2M234449	QSO 1	5.3×10^{43}	6.1×10^{42}	11%	Model 1, this paper
2M234449	QSO 1	5.3×10^{43}	2.5×10^{42}	5%	Model 2, this paper
Mkn 3	Seyfert 2	2×10^{43}	2.5×10^{41}	1.2%	Pounds and Page 2005

5 SUMMARY

The *XMM-Newton* EPIC spectrum of the Type 1 QSO 2MASS 234449+1221 is unusual in showing low energy absorption at a level that allows a soft X-ray emission component to be resolved. Modelling of the absorption and emission with the XSTAR code allows the form and strength of the soft X-ray emission to be determined and shown to be consistent with the integrated emission from a warm photoionised gas. A plausibility argument is given which suggests this enhanced soft X-ray emission (which should be a common feature in Type 1 AGN) arises from an inward extension of the outflow responsible for the soft X-ray emission in Seyfert 2 galaxies. This is important in the context of the energy content, emission measure and origin of such outflows, since current high resolution spectra are not well-matched to the detection of broad spectral features that might arise in turbulent gas at the smaller radii implied by our analysis.

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