A high velocity ionised outflow and XUV photosphere in the narrow emission line quasar PG1211+143

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ABSTRACT

We report on the analysis of a ~60 ksec XMM-Newton observation of the bright, narrow emission line quasar PG1211+143. Absorption lines are seen in both EPIC and RGS spectra corresponding to H- and He-like ions of Fe, S, Mg, Ne, O, N and C. The observed line energies indicate an ionised outflow velocity of ~24000 km s^{-1}. The highest energy lines require a column density of \(N_H \approx 5 \times 10^{21} \text{cm}^{-2}\), at an ionisation parameter of \(\log \xi \approx -3.4\). If the origin of this high velocity outflow lies in matter being driven from the inner disc, then the flow is likely to be optically thick within a radius ~130 Schwarzschild radii, providing a natural explanation for the Big Blue Bump (and strong soft X-ray) emission in PG1211+143.

Key words: galaxies: active – galaxies: Seyfert: general – galaxies: individual: PG1211+143 – X-ray: galaxies

1 INTRODUCTION

One of the most striking recent developments in X-ray studies of AGN has been the observation, from high resolution grating spectra obtained with Chandra and XMM-Newton, of complex absorption indicating circumnuclear (often outflowing) matter existing in a wide range of ionisation states (eg Sako et al. 2001, Kaspi et al. 2002). Until recently, however, it has generally been assumed that this so-called ‘warm absorber’ was essentially transparent in the ‘Fe K spectral band above ~6 keV, with fluorescent line emission from the accretion disc being the main feature in AGN spectra at those energies (eg Reynolds and Nowak 2002).

In this paper we report on the spectral analysis of a ~60 ksec XMM-Newton observation of the bright quasar PG1211+143. At a redshift \(z = 0.0809\) (Marziani et al. 1996) PG1211+143 has a typical X-ray luminosity (2–10 keV) of \(\sim 10^{44} \text{erg s}^{-1}\), for \(H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}\). The Galactic absorption column towards PG1211+143 is \(N_H = 2.85 \times 10^{20} \text{cm}^{-2}\) (Murphy et al. 1996), rendering it visible over the whole (~0.2–12 keV) spectral band of the EPIC and RGS instruments on XMM-Newton.

PG1211+143 is a low redshift, optically bright quasar, with a strong ‘Big Blue Bump’ (BBB). It is unusual in the PG sample of bright quasars in having relatively narrow permitted optical emission lines (Boroson and Green 1992, Kaspi 2000). PG1211+143 was first detected in the X-ray band by Einstein, which found a steep spectrum in the ~0.2–2 keV band (Bechtold et al. 1997, Elvis et al. 1991). A subsequent analysis by Saxton et al. (1993), which combined EXOSAT and GINGA data, resolved a strong soft X-ray ‘excess’ above a harder power law component of photon index \(\Gamma \approx 2.1\). An early ASCA observation showed the soft excess to be variable, indicating a source region of \(\lesssim 10^{17} \text{cm}\) (Yaqoob et al. 1994). The improved spectral resolution of ASCA further refined the broad-band X-ray description of PG1211+143 (Reeves et al. 1997), with evidence for a broad Fe K emission line of equivalent width (EW) ~400–750 eV at ~6.4 keV. A more recent study of the overall (infra-red to X-ray) spectrum of PG1211+143 has been published by Janiuk et al. (2001), considering in particular the strong emission in the UV and soft X-ray bands and proposing its origin in a warm optically thick ‘skin’ on the accretion disc. This work also included an analysis of an extended RXTE observation in 1997, suggesting a cold reflection factor \(R = \Omega/2\pi\), where \(\Omega\) is the solid angle subtended by the reflecting matter, of order unity.

2 OBSERVATION AND DATA REDUCTION

PG1211+143 was observed by XMM-Newton on 2001 June 15 yielding a useful exposure of ~60 ksec. In this paper we use data from the EPIC pn camera (Strüder et al. 2001), which has the best sensitivity of any instrument flown to date in the ~6–10 keV spectral band, the combined EPIC
MOS cameras (Turner et al. 2001), and the Reflection Grating Spectrometer/RGS (den Herder et al. 2001). Reference to the Optical Monitor (Mason et al. 2001) confirmed the strong optical and UV emission was close to the typical level in PG1211+143. All X-ray data were first screened with the XMM SAS v5.3 software and events corresponding to patterns 0-4 (single and double pixel events) were selected for the pn data and patterns 0-12 for MOS1 and MOS2, the latter then being combined. A low energy cut of 200 eV was applied to all X-ray data and known hot or bad pixels were removed. We extracted source counts within a circular region of 45″ radius defined around the centroid position of PG1211+143, with the background being taken from a similar region, offset from but close to the source. The 0.2-10 keV X-ray pn light curve is reproduced as figure 1 and shows ∼30 percent flux changes over ∼6 ksec, similar to those seen in the ASCA data. Individual spectra were binned to a minimum of 20 counts per bin, to facilitate use of the χ^2 minimisation technique in spectral fitting. Response functions for spectral fitting to the RGS data were generated from the SAS v5.3.

Spectral fitting was based on the Xspec package (Arnaud 1996) and used a grid of ionised absorber models calculated with the XSTAR code (Kallman et al. 1996). All spectral fits include absorption due to the line-of-sight Galactic column of \( N_H = 2.85 \times 10^{20} \) cm\(^{-2} \). Errors are quoted at the 90% confidence level (\( \Delta \chi^2 = 2.7 \) for one interesting parameter).

## 3 1–10 KEV SPECTRUM

### 3.1 Power law

X-ray spectra of AGN at 2–10 keV are well fitted, to first order, with a power law of photon index \( \Gamma \) in the range \( \sim 1.6-2 \) for most radio quiet AGN, with a fraction (eg NLS1) having somewhat steeper indices. The widely held view is that this ‘hard’ X-ray continuum in Seyfert galaxies arises by Comptonisation of thermal emission from the accretion disc in a ‘hot’ corona (eg Haardt and Maraschi 1991), and produces additional spectral features by ‘reflection’ from dense matter in the disc (eg Pounds et al. 1990, Fabian et al. 2000).

We began our analysis of PG1211+143 by confirming there were no obvious spectral changes with source flux and then proceeded to fit the XMM-Newton pn and MOS data integrated over the full \( \sim 60 \) ksec observation. A simple power law fit over the 1–10 keV band yielded a photon index of \( \Gamma \sim 1.79 \) (pn) and \( \Gamma \sim 1.71 \) (MOS), with a broad excess in the data:model ratio between 3–7 keV, and evidence of absorption at higher energies in both data sets (figure 2). The fit was statistically unacceptable with an overall \( \chi^2/dof \) of 1541/1176. When extrapolated to 0.3 keV, the 1–10 keV fits to both pn and MOS data revealed a strong ‘soft excess’ (figure 3).
3.2 Fe K emission and absorption features

To improve the 1–10 keV fit we added further spectral components to match the most obvious features in the data. The indication of an extreme broad emission line suggested reflection from the inner accretion disc, conventionally modelled with a LAOR line in Xspec (Laor 1991). The addition of a LAOR line, with inclination initially fixed at 30° and $R_{\text{out}}=100R_g$ (where $R_g = GM/c^2$ is the gravitational radius for mass $M$), resulted in a significant statistical improvement ($\chi^2$/dof of 1304/1172), but with an unrealistically large EW of $\sim$1.4 keV (pn) and $\sim$1.1 keV (MOS). To better fit the broad line profile we added a gaussian line with energy tied to that of the LAOR line. (Physically such a gaussian line could represent emission from larger radii on the disc). This addition gave a further improvement in the fit, to $\chi^2$/dof of 1278/1167. The LAOR line still had a high EW of $\sim$0.6–0.9 keV, with disc emissivity index $\beta$$\sim$3.5, and inner radius $R_\text{in}$$\sim$1.5$R_g$. The gaussian emission line component had an rms width $\sigma=0.28\pm0.15$ keV and EW = 0.25$\pm$0.11 keV. The (poorly constrained) joint line energy was $\sim$6.2 keV, or $\sim$6.7 keV in the source rest frame, implying reflection from ionised matter.

We then attempted to fit the narrow absorption features visible in figure 2, initially with gaussian shaped absorption lines in Xspec. Adding a gaussian line with energy, width and equivalent width free gave a significantly better fit to the absorption near 7 keV than an absorption edge. The observed line energy was 7.02$\pm$0.03 keV, with $\sigma\leq$100 eV, and an EW of 98$\pm$28 eV. The addition of this gaussian absorption line improved the fit to $\chi^2$/dof = 1246/1164. The most likely identifications of this line are Lyα of FeXXVI or the primary 1s-2p resonance transition in He-like FeXXV. The rest energies of these lines are separated by 0.26 keV, which would be resolved (or at least produce a broad line) in the EPIC data. The narrowness of the observed feature at $\sim$7 keV suggests the former identification, with any absorption from the FeXXV line modifying the Fe K emission line. (We recall evidence for variable line-of-sight absorption superposed on the Fe K emission line has been previously seen in an XMM-Newton observation of Mkn 766; Pounds et al. 2003b).

A second narrow gaussian line at 7.9$\pm$0.04 keV was less significant, reducing $\chi^2$ to 1234 for 1161 dof. In this case a statistically better fit ($\chi^2$/dof of 1228/1161) was obtained with an absorption edge at $\sim$7.7 keV, or with a broader line of width $\sigma$ $\sim$0.3 keV centred at $\sim$8.05 keV (EW of 45$\pm$12 eV). We choose to proceed with the latter, and provisionally identify it with a blend of the FeXXV 1s-3p line and FeXXVI Ly$\beta$, while noting other contributions could be from absorption edges of less highly ionised Fe (XVII or higher), inner shell transitions as recently addressed by Palmeri et al. (2002), or Ni K. A higher (outflow) velocity component of the absorption line seen at $\sim$7 keV is a further possibility. Figure 2 suggests the presence of other narrow absorption features in the EPIC data, the most significant being at $\sim$2.7 keV, and near 1.5 keV. Fitting these 2 features by successively adding gaussians lines to the model yielded further reductions in $\chi^2$ of, respectively, 26 and 32 for 3 fewer dof in each case (figure 4).

Details of the absorption lines thus identified in the EPIC data are summarised in Table 1. When corrected for the redshift of PG1211+143, each line energy indicates an origin in the same relativistic outflow, with a velocity of $\sim$0.08−0.1c. The best determined line profile, for the line at $\sim$7.02 keV, is essentially unresolved, corresponding to a velocity dispersion of $\leq$12000 km s$^{-1}$. We shall see in Section 3.5 that a tighter line width constraint is obtained from the RGS data.

In summary, we find the 1–10 keV spectrum of PG1211+143 can be described by a broad Fe K emission line, together with absorption features which are best fitted with gaussian line profiles rather than absorption edges. The proposed identification of these lines, with resonance absorption from highly ionised Fe, S, and Mg, indicates an origin in outflowing ionised gas at a velocity of $\sim$0.08−0.1c.

3.3 An ionised absorber model

To quantify the highly ionised matter responsible for the observed absorption features we then replaced the gaussian absorption lines in the above model with a grid of photoionised absorbers based on the XSTAR code. These model absorbers cover a wide range of column density and ionisation parameters, with outflow (or inflow) velocities as a variable parameter. All abundant elements from C to Fe are included with the relative abundances as a variable input parameter. In order to limit processing time the fits assume a fixed width of each absorption line of 1000 km s$^{-1}$ FWHM. An absorber with ionisation parameter of log $\xi = \log (L/nr^2)$ $\sim$3.4, and column density of $N_H \sim 5 \times 10^{23}$ cm$^{-2}$, for solar abundances, was found to reproduce the observed absorption lines at $\sim$7 keV, $\sim$8 keV and $\sim$2.7 keV (figure 5), assuming their indicated identifications, and an outflow velocity of $\sim$0.08c. We note that most of the uncertainty in the derived column density is on the upside, since allowance for partial covering and saturation in the relatively narrow line profiles would both increase the above value. The feature attributed to MgXII was not well modelled by the log $\xi$ $\sim$3.4 absorber, indicating the presence of additional absorbing matter at a lower level of ionisation. This suggests that corresponding features
The ionisation parameter corresponds to equal abundance of the emitting and recombining ions. Should be evident in the RGS spectrum. We examine that prediction in Section 3.5.

3.4 Soft Excess

Extending the 1–10 keV power law fits for both pn and MOS spectral data to 0.3 keV shows very clearly (figure 3) the strong soft excess first indicated by Einstein and EXOSAT observations (Elvis et al.1991, Saxton et al.1993). In the EPIC data this can be adequately modelled with the addition of black body emission components together with 2 surrogate absorption edges. The parameters for PG1211+143 are a primary blackbody of kT ~110 eV with a weaker component of kT ~265 eV, and ‘edges’ at ~0.8 and ~0.98 keV. We note that a similar combination of black body emission superimposed by absorption edges has been found previously to be a good parameterisation of EPIC spectra of AGN (eg. Pounds et al. 2003a), though - interestingly - in the present case the edge energies are some 10 percent higher than if associated with the OVII and OVIII edges (at rest).

Based on this fit we obtain an average 0.3–10 keV flux for PG1211+143 of 7.5×10⁻¹² erg s⁻¹ cm⁻², corresponding to a luminosity of ~ 10⁴⁴ erg s⁻¹ (Hₒ = 75 km s⁻¹ Mpc⁻¹). The blackbody component is dominant in the 0.3–1 keV band, representing ~75 percent of the total flux in that band. The 2–10 keV flux was 2.7×10⁻¹² erg s⁻¹ cm⁻², with a corresponding luminosity of 3.3×10⁴⁵ erg s⁻¹.

3.5 Absorption lines in the RGS spectrum

The strongest absorption lines in the EPIC spectrum have been identified with Lyman alpha of FeXXVI and SXVI. The ionisation parameters where these ions and their (recombining) parent ions are in approximate balance are, respectively, logξ~3.8 and logξ~3.0, which essentially determines the effective high ionisation parameter in the relevant XSTAR fit. The detection of additional absorption in the EPIC data, including an absorption line attributed to MgXII at 1.47 keV, suggests the ionised outflow includes matter over a range of ionisation states, which should be evident in the RGS spectra of PG1211+143. To check this, we began by jointly fitting the RGS-1 and RGS-2 data with a power law and black body continuum (from the EPIC fit) and examining the residuals by eye. The most obvious spectral features were found to be in absorption, as is usually the case with Seyfert 1 spectra, a broad line tentatively identified with the forbidden line of OVII (observed at ~23.8 Angstrom) being the most obvious emission line. A number of weak absorption features are probably due to Fe L shell absorption, but we concentrate here on the relatively unambiguous identifications associated with H- and He-like resonance absorption in C, N, O and Ne, since these offer a direct confirmation of the ionised outflow seen in the EPIC spectrum. Figures 6–9 show the combined RGS1 and RGS2 spectra with the best fit XSTAR model superimposed. We retained the high ionisation absorber fitted to the EPIC data in the XSTAR model, and added an intermediate ionisation component to better reproduce the observed absorption in C, N, O and Ne. A third, low ionisation component was added to match the Fe L edge near 17 Angstrom. The best-fit parameters of this model were:

1) N_H = 5×10²³ cm⁻² at an ionisation parameter of logξ~3.4;
2) N_H = 6×10²¹ cm⁻² at an ionisation parameter of logξ~1.7;
3) N_H = 8×10²² cm⁻² at an ionisation parameter of logξ~0.9.

Importantly, a large outflow velocity was confirmed from this fit with both of the highly ionised components yielding a velocity of ~24000 km s⁻¹. The ionisation parameter at which each detected ion has a similar abundance to its parent ion in a photoionised plasma is listed in Tables 1 and 2 (Kallman and McCray, 1982), and range from logξ=1.7–2.2, close to the second outflow component in our XSTAR model fit. Clearly, a single zone photoionised absorber is unable to explain both EPIC and RGS spectra. The consistent outflow velocities suggest a more complex ionisation structure may be due to density variations across the flow.

A visual examination of the RGS spectrum was then carried out to determine the individual line energies, check

| Line     | E_obs (keV) | E_source (keV) | E_lab (keV) | Velocity (km s⁻¹) | EW (eV) | log ξ |
|----------|------------|----------------|-------------|-------------------|--------|------|
| FeXXVI Lyα | 7.02±0.03  | 7.59±0.03      | 6.96        | 24900±1200        | 98±28  | 3.8  |
| SXVI Lyα  | 2.69±0.04  | 2.91±0.04      | 2.62        | 29900±4000        | 32±10  | 3.0  |
| MgXII Lyα | 1.49±0.02  | 1.61±0.02      | 1.47        | 28600±4100        | 13±4   | 2.4  |

Figure 5. Unfolded spectrum illustrating the XSTAR fit to the XMM-Newton observation of PG1211+143 as detailed in Section 3.3. For clarity we only show the pn data.
the line identifications, and hence the deduced outflow velocities. Although quite deep, the individual line profiles are not very well determined due to the limited statistics in the PG1211+143 data, and this is reflected in the estimated uncertainty in the line equivalent widths. Nevertheless, we conclude there is no doubt on the identification of the listed lines and their consistent ‘blueshift’. The results of this visual check, summarised in Table 2, yield a weighted mean outflow velocity of \(3400 \, \text{km s}^{-1}\). As noted above, the individual line profiles are not well determined, but are clearly narrow. A ‘combined’ Lyman alpha profile from the RGS data, shown in figure 10, has a measured FWHM of \(\sim 2000 \, \text{km s}^{-1}\), or \(\leq 1000 \, \text{km s}^{-1}\) after allowing for the RGS resolution. Comparison with the measured outflow velocity suggests the material is streaming outward with relatively little turbulence, and that we are viewing down (rather than across) the flow.

The only obvious emission feature in the RGS spectrum, observed at \(\sim 23.8 \, \text{A} (\lambda_{1s\alpha}=22.1 \, \text{A})\), is most likely due to OVII forbidden line emission dispersed across the outflow. Unlike the absorption lines, this line is resolved in the RGS data, with FWHM \(\sim 6000 \, \text{km s}^{-1}\). The measured EW is 165\pm30 \, \text{mA}, a part of which may be due to OVII resonance and intercombination line emission. The observed flux in the OVII emission line (\(6 \times 10^{-5} \, \text{photon s}^{-1} \, \text{cm}^{-2}\)) is \(\sim 2.5\) times greater than that in the OVII resonance absorption line. As noted elsewhere the latter may be saturated in the core of the line, but the strength of the emission line strongly suggests the outflow has a large covering factor, ie the cone angle is wide. The measured profile and low projected outflow velocity for the OVII emission line gives further support to such a geometry for the outflow. Assuming \(T_{\text{e}} \sim 10^6 \, \text{K}\), and a recombination coefficient (to OVII) of \(10^{-12} \, \text{cm}^3 \, \text{s}^{-1}\) (Verner and Ferland 1995), the observed OVII emission corresponds to an emission measure \(n^2 \, V \sim 10^{53} \, \text{cm}^{-3}\) for a solar abundance of oxygen and fractional ion abundance of 0.5. Combining this emission measure with the line-of-sight column density \(n^2 \, V = 5 \times 10^{29} \, \text{cm}^{-2}\) allows an estimate of the radius for a hemispherical outflow (with assumed filling factor 0.1) of \(3 \times 10^{15} \, \text{cm}\), with \(n=3 \times 10^8 \, \text{cm}^{-3}\). Formally these estimates are upper and lower limits, respectively, but they are consistent with the product of \(n^2\) derived in Section 4.1 from the highest ionisation parameter in the XSTAR fit. Also, the dominance of the forbidden emission line in the OVII triplet indicates \(n \leq 10^{10} \, \text{cm}^{-3}\) (Bautista and Kallman 2000).

4 DISCUSSION

Analysis of the XMM-Newton observation of PG1211+143 has revealed several remarkable features.

The unusually strong soft excess indicated in previous observations is confirmed. The dominance of this component below \(\sim 1 \, \text{keV}\) suggests an origin as intrinsic thermal emission from the accretion disc, though it has long been known that the temperature of a standard ‘thin disc’ is too low in AGN to radiate strongly in the X-ray band. Comptonisation of cooler disc photons in a warm ‘skin’ on the disc surface has previously been invoked as an explanation of the soft X-ray excess in PG1211+143 (eg Janiuk et al. 2001), while Bechtold et al. (1987) first suggested the soft X-ray flux was a physical extension of the BBB bump, which is particularly strong in PG1211+143 and contains much of the bolometric luminosity. We suggest, in Section 4.2, that this dominant ‘thermal emission’ is a natural consequence of the high density outflow.

A second notable feature in the EPIC spectrum is the broad Fe K line emission, exhibiting an extreme ‘red wing’. We note that the extreme parameters of this emission line, including the equivalent width, are reduced (but not removed) when absorption visible in the 7–10 keV band is accounted for. We suggest a possible alternative to the ‘relativistic’ Fe K emission line in Section 4.3.

The most interesting revelation in the XMM-Newton observation of PG1211+143 is the discovery of an absorption line structure, in both EPIC and RGS data, indicating a high column, high ionisation absorber outflowing at...
Table 2. Absorption lines identified in the RGS spectrum of PG1211+143. All wavelengths are in Angstroms. The ionisation parameter corresponds to equal abundance of the emitting and recombining ions.

| Line            | $\lambda_{\text{obs}}$ | $\lambda_{\text{source}}$ | $\lambda_{\text{lab}}$ | velocity km s$^{-1}$ | EW (mA) | log$\xi$ |
|-----------------|-------------------------|-----------------------------|--------------------------|----------------------|---------|----------|
| NeX Ly$\alpha$  | 12.07 ±0.03             | 11.17                       | 12.13                    | 23700±800            | 50±20   | 2.2      |
| NeIX 1s-2p      | 13.40 ±0.05             | 12.40                       | 13.45                    | 23400±1100           | 70±15   | 1.8      |
| OVIII Ly$\beta$ | 15.98 ±0.07             | 14.78                       | 16.01                    | 23000±1300           | 60±25   | 1.9      |
| OVIII Ly$\alpha$| 18.90 ±0.03             | 17.49                       | 18.97                    | 23400±740            | 120±25  | 1.9      |
| OVII 1s-2p      | 21.55 ±0.05             | 19.94                       | 21.60                    | 23100±700            | 60±15   | 1.7      |
| OVII 1s-3p      | 18.60 ±0.05             | 17.21                       | 18.63                    | 22900±810            | 25±10   | 1.7      |
| NVII Ly$\alpha$ | 24.78±0.03              | 22.93                       | 24.78                    | 22400±360            | 50±10   | 1.8      |
| CVI Ly$\alpha$  | 33.62±0.03              | 31.10                       | 33.72                    | 23900±270            | 90±25   | 1.7      |

Figure 8. RGS spectrum from 15–20 Angstrom showing resonance absorption lines at 18.90 Angstrom (OVIII Ly$\alpha$), 18.60 Angstrom (OVII 1s-3p) and 15.98 Angstrom (OVIII Ly$\beta$)

Figure 9. RGS spectrum from 10-15 Angstrom showing absorption lines at 13.40 Angstrom (NeIX 1s-2p) and 12.17 Angstrom (NeX Ly$\alpha$). Several Fe L lines are also indicated and we note that both Ne lines are probably blended with lines of Fe XVII-XXI, limiting their present value in characterising the outflow from PG1211+143.

Figure 10. A composite profile of the Ly$\alpha$ lines of CVI, NVII, OVIII and NeX showing the relatively narrow line width discussed in Section 3.5.

4.1 A high velocity ionised outflow.

Previous high resolution X-ray spectra of Seyfert 1 galaxies have found a broad range of (low to moderate) ionisation states and outflow velocities of typically 100–1000 km s$^{-1}$. The long Chandra exposure of the Seyfert galaxy NGC 3783 is a template of such studies (Kaspi et al. 2002). However, until now, any absorption in the Fe K band (above ~7 keV) has generally been attributed to continuum (edge) absorption associated with reflection from the accretion disc. A velocity of ~24000 km s$^{-1}$. The remarkable agreement of the implied velocities from a wide range of absorption lines leaves little doubt that they have a common origin, although the co-existence of ions with ionisation energies as disparate as FeXXVI and CVI implies a range of ionisation parameter. Although the coincidence of the measured outflow with the redshift of PG1211+143 is also remarkable, and we note that PG1211+143 is viewed through the Magellanic Stream and the Virgo Cluster (eg Impey et al. 1999), the presence of a large column density of highly ionised gas in either location would be a major surprise. The detection of OVII emission at a velocity closer to the systemic velocity of PG1211+143 further supports the ionised matter being intrinsic to the AGN. For the remainder of this paper we therefore continue to consider our results in terms of absorption in PG1211+143.
recent exception was the report of an absorption feature in the X-ray spectrum of a high redshift BAL quasar (APM 08279+5255), which has been alternatively identified with the absorption edge of Fe XV-XVIII (Hasinger et al. 2002), or with strongly blue-shifted resonance absorption lines of Fe XXV or XXVI (Chartas et al. 2002). An earlier ASCA observation also found evidence for an ‘absorption line’ superimposed on the ‘red wing’ of a broad Fe K emission line in the Seyfert galaxy NGC 3516 (Nandra et al. 1999). The question remains whether highly ionised gas capable of imparting Fe K absorption features on AGN spectra is a significant component in the outflow of many AGN, and is simply remaining undetected due to the poor sensitivity of current observations of AGN spectra above 7 keV. In the latter respect it may be instructive to note that ionised resonance absorption lines of Fe XXV and XXVI are clearly seen in the Chandra HETGS spectrum of the (much brighter) microquasar GRS 1915+105 (Lee et al. 2002).

An important aspect of our present observations is that the column density of the most highly ionised matter in the line-of-sight is high. In the case of PG1211+143 we find an equivalent hydrogen column (assuming solar abundances) approaching 10^{24} cm^{-2}. Although the geometry of the outflow is unknown, it is a reasonable expectation that near its source the flow is optically thick. The interesting consequence, which we note in Section 4.2, is that the outflow predicts an inner ‘photosphere’ which is then a natural source of a major part of the radiated luminosity (BBB to soft X-ray emission) of PG1211+143.

Other important implications following from the detection of a high column, high velocity outflow in PG1211+143 are a mass loss and kinetic energy comparable to the accretion mass and the bolometric luminosity. For the observed Fe XV-XVIII absorption line log \xi \approx -3.8 (Table 1). With an ionising X-ray luminosity (\geq 7 keV) of 3 \times 10^{43} erg s^{-1} we estimate \eta \sim 10^{39} cm^{-1}. Assuming a spherically symmetric flow, at an outflow velocity of 0.08c, the mass loss rate is then of order \sim 3.5 M_{\odot} yr^{-1}, which provides for the collimation of the flow. Assuming the measured outflow velocity is the same as the launch velocity (ie the material is then ‘coasting’), the associated kinetic energy is 6.5 \times 10^{44} erg s^{-1}.

### 4.2 An XUV photosphere

The previous subsection shows that the column density of the outflow seen in PG1211+143 is close to being optically thick in the continuum. In fact this is inevitable if the mass outflow rate is comparable to the accretion rate required to power radiation at the Eddington limit.

We assume that the outflow quickly reaches a terminal velocity v and thereafter coasts. Then mass conservation shows that the outflow density is

\[ \rho = \frac{\dot{M}}{4\pi v b r^2} \]

at radius r, where \dot{M} is the mass loss rate. The electron scattering optical depth through the outflow, viewed from infinity down to radius R, is

\[ \tau = \int_R^{\infty} \kappa_o dr = \frac{\kappa \dot{M}}{4\pi v b R} \]

where \kappa \approx \sigma_T/m_H is the opacity. The Eddington accretion rate is

\[ \dot{M}_{\text{Edd}} = \frac{4\pi GM}{\eta c} \]

where \eta c^2 is the accretion yield from unit mass. Combining these equations then gives

\[ \tau = \frac{1}{2\eta} \frac{R_e c \dot{M}}{R v \dot{M}_{\text{Edd}}} \]

where we have taken \eta \approx 0.1 at the last step. Since \dot{M} < R_{\text{in}}c, we see that \tau_{\text{Edd}} > R_e for any outflow rate \dot{M} of order \dot{M}_{\text{Edd}}. In other words, any black hole source accreting above the Eddington limit is likely to have a scattering photosphere at several tens of R_e. This fact is exploited by Mukai et al. (2003) and Fabbiano et al. (2003) in interpreting bright supersoft sources (including supersoft ULXs), and explored in more detail in a companion paper (King and Pounds 2003).

Since a scattering optical depth \tau degrades photons of energy \sim 500 \pi^{-2} keV we note the observed medium-to-hard X-ray flux must be emitted at radii \dot{\tau} \gtrsim \tau_{ph}, and suggest shocks in the outflow as a promising candidate. This limits the medium–energy X-ray luminosity to a fraction of the outflow kinetic energy \dot{M} v^2/2, a constraint easily satisfied for PG1211+143.

In PG1211+143 we estimate \dot{M}/b \sim 3.5 M_{\odot} yr^{-1}. With \dot{M}_{\text{Edd}} = 1.6 M_{\odot} yr^{-1}, appropriate for a non-rotating SMBH of \dot{M} = 4 \times 10^7 M_{\odot} (Kaspi et al. 2000), we find \tau_{ph} \approx 130 R_e or 1.5 \times 10^{15} cm. A wide angle outflow is indicated by the strength and low projected velocity of the OVII emission line (Section 4.1), corresponding to case 1 in King and Pounds 2003, where the flow geometry limits the leakage of photons from the side of the cone. For PG1211+143 we therefore assume a value of b \sim 0.8, which then yields an outflow mass rate of \dot{M} \sim 3 M_{\odot} yr^{-1}, and a kinetic energy \sim 5 \times 10^{44} erg s^{-1}. This is clearly adequate to power a large fraction of the X-ray luminosity \gtrsim 2 keV of 6 \times 10^{43} erg s^{-1}.

The scattering photosphere discussed above must be larger than the thermalisation region where true absorption dominates and the soft thermal continuum (BBB) is formed. This implies an effective blackbody temperature \gtrsim 6 \times 10^4 K for a luminosity of 4 \times 10^{45} erg s^{-1}, broadly consistent with the strong BBB continuum which dominates the bolometric luminosity of PG1211+143.

### 4.3 The relativistic Fe K emission line

An important question raised by the existence of an optically thick photosphere above the inner accretion disc is how the relativistic Fe K line could be seen, if the innermost accretion disc is obscured. However, the detection of a large column density of highly ionised matter in the line-of-sight to the hard X-ray source suggests that the extreme ‘red wing’, evident between \sim 3-6 keV in a simple power law fit to PG1211+143, may actually be an artefact of absorption
The luminosity of order $4\times10^{44}$ erg s$^{-1}$ is needed for the dominant BBB to be at a typical value, with a bolometric XMM-Newton observation during our simultaneous observation with the Optical Monitor on XMM-Newton during our observation.

The average 0.3–10 keV band luminosity of PG1211+143 has revealed evidence of a high velocity outflow from PG1211+143 broadens the scope of such studies. BAL QSOs show absorption in a variety of, mainly high-ionisation, UV resonance transitions with velocity widths up to $\sim 30000$ km s$^{-1}$ (e.g. Weymann et al. 1991). About 10% of optically selected QSOs display BALs. As BAL QSOs appear otherwise similar to non-BAL QSOs, an ‘orientation model’ is traditionally invoked in which BAL QSOs are those in which the particular line-of-sight intersects an outflow which may be intrinsic to all QSOs. This model has recently been questioned by the discovery of a relatively high fraction (15 – 20%) of radio-loud BAL quasars in the VLA FIRST survey bright quasar survey (Becker et al. 2000). Becker et al. propose BAL objects may be young or have recently been fuelled. In any case, the higher fraction of quasars that have BALs implies a higher fraction of the line-of-sight to the nucleus is covered with substantial absorbing material.

Determining the amount of gas along the line-of-sight to a BAL is generally problematic due to a poor understanding of the relation between UV and X-ray absorption and the geometry of the flow. Fitting UV absorption lines suggests $N_H \geq 10^{22}$ cm$^{-2}$, whereas the generally weak X-ray fluxes imply columns an order of magnitude or more higher (e.g. Hamann 1998; Sabra & Hamann 2001; Gallagher et al. 2002). Models in which the BAL gas is launched more or less vertically off a disk and then accelerated by radiation pressure (Murray et al. 1995; Proga et al. 2000) are reasonably consistent with the UV data but have difficulty in accelerating the large columns of material seen in X-rays unless they are launched from very close to the black hole - as we propose for PG1211+143.

In summary, while PG1211+143 has strong soft X-ray emission and is not a BAL QSO in the UV, it does display a fast moving outflow and a line-of-sight column density which are similar to those required to explain, respectively, the UV and X-ray properties of BAL QSOs. Whether the outflow in PG1211+143 becomes capable of producing BAL features further out in the flow, but we simply do not intersect such a line of sight, is unclear. Neither do we yet know how common are X-ray absorption features as reported here for PG1211+143, nor whether the X-ray absorbing gas causing BAL QSOs to be ‘X-ray weak’ is in outflow. However, it seems likely that the BAL phenomena and the high velocity outflow in PG1211+143 are closely related.

### 4.5 Relation to Broad Absorption Line QSOs

Hitherto most evidence for extreme outflows in AGN has been found in UV studies of Broad Absorption Line (BAL) QSOs. The observation reported here, of a massive high velocity outflow from PG1211+143 broadens the scope of such studies. BAL QSOs show absorption in a variety of, mainly high-ionisation, UV resonance transitions with velocity widths up to $\sim 30000$ km s$^{-1}$ (e.g. Weymann et al. 1991). About 10% of optically selected QSOs display BALs. As BAL QSOs appear otherwise similar to non-BAL QSOs, an ‘orientation model’ is traditionally invoked in which BAL QSOs are those in which the particular line-of-sight intersects an outflow which may be intrinsic to all QSOs. This model has recently been questioned by the discovery of a relatively high fraction (15 – 20%) of radio-loud BAL quasars in the VLA FIRST survey bright quasar survey (Becker et al. 2000). Becker et al. propose BAL objects may be young or have recently been fuelled. In any case, the higher fraction of quasars that have BALs implies a higher fraction of the line-of-sight to the nucleus is covered with substantial absorbing material.

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In summary, while PG1211+143 has strong soft X-ray emission and is not a BAL QSO in the UV, it does display a fast moving outflow and a line-of-sight column density which are similar to those required to explain, respectively, the UV and X-ray properties of BAL QSOs. Whether the outflow in PG1211+143 becomes capable of producing BAL features further out in the flow, but we simply do not intersect such a line of sight, is unclear. Neither do we yet know how common are X-ray absorption features as reported here for PG1211+143, nor whether the X-ray absorbing gas causing BAL QSOs to be ‘X-ray weak’ is in outflow. However, it seems likely that the BAL phenomena and the high velocity outflow in PG1211+143 are closely related.

### 5 CONCLUSIONS

1. An XMM-Newton observation of the bright quasar PG1211+143 has revealed evidence of a high velocity ionised outflow, with a mass and kinetic energy comparable to the accretion mass and bolometric luminosity, respectively.

2. A further implication of the high observed column density is that the inner flow is likely to be optically thick, providing a natural explanation for the strong BBB and soft X-ray emission in PG1211+143.

3. An extreme relativistic Fe K emission line apparent in a simple power law fit to the data can, alternatively,
A high velocity outflow from PG1211+143

be explained in terms of partial covering of the continuum source by overlying matter in a lower ionisation state.

(4) We suggest the above properties might be common in AGN accreting at or close to the Eddington limit.

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