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Confirming the high velocity outflow in PG1211+143

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ABSTRACT

An *XMM–Newton* observation of the bright quasi-stellar object PG1211+143 was previously reported to show evidence for a massive, energetic outflow, with an outflow velocity of $v \sim 0.1c$ based on the identification of blueshifted absorption lines detected in both EPIC and Reflection Grating Spectrometer (RGS) spectra. Subsequently, an order of magnitude lower velocity has been claimed from an ion-by-ion model fit to the RGS data. We show here, in a re-analysis of the higher signal-to-noise ratio EPIC data, that the high velocity is confirmed, with the resolution of additional absorption lines yielding a revised outflow velocity in the range ∼0.13–0.15c. Confirmation of a massive and energetic outflow in a non-BAL active galactic nucleus (AGN) has important implications for metal enrichment of the intergalactic medium and for the feedback mechanism implied by the correlation of black hole and galactic bulge masses. We note the near-Eddington luminosity of PG1211+143 may be the critical factor in driving such an energetic outflow, a situation likely to be common in AGN at higher redshift.

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

1 INTRODUCTION

An analysis of the EPIC and Reflection Grating Spectrometer (RGS) spectra from an *XMM–Newton* observation of the bright narrow emission-line quasi-stellar object (QSO) PG1211+143 in 2001 provided evidence for a highly ionized outflow with a velocity of ∼0.1c (Pounds et al. 2003; hereafter P03), though a lower velocity has recently been claimed from a separate analysis, principally based on the low signal-to-noise ratio RGS data (Kaspi & Behar 2006). Confirmation of the high velocity outflow is important since the mechanical energy in the flow, if not highly collimated, is a significant fraction of the bolometric luminosity of PG1211+143 and could be typical of active galactic nucleus (AGN) accreting near the Eddington rate (King & Pounds 2003), while also providing an example of the feedback required by the linked growth of supermassive black hole (SMBH) in AGN with their host galaxy (King 2005). Subsequently, the same *XMM–Newton* observation of PG1211+143 has been used by Gierlinski & Done (2004) to suggest how strong absorption of the intrinsic X-ray continuum in a 'velocity-smeared', high column, of moderately ionized gas can provide a physically preferred explanation (to Comptonisation) for the strong soft excess widely seen in type 1 AGN (Wilkes & Elvis 1987; Turner & Pounds 1989). A similar study by Chevallier et al. (2006), which also considered an ionized reflection origin of the soft excess, concluded that absorption was the more likely cause of a strong soft excess (as in PG1211+143).

In this paper, we re-examine the *XMM–Newton* EPIC data of PG1211+143 which formed the strongest evidence for the high velocity claimed in P03. We use the latest calibration files and – in particular – take advantage of the higher spectral energy resolution of the MOS cameras demonstrated in recent studies of the type 2 Seyferts Mkn3 (Pounds & Page 2005) and NGC 1068 (Pounds & Vaughan 2006).

We assume a redshift for PG1211+143 of $z = 0.0809$ (Marziani et al. 1996).

2 OBSERVATION AND DATA REDUCTION

PG1211+143 was observed by *XMM–Newton* on 2001 June 15 for ∼53 ks. In this paper, we concentrate on data from the EPIC pn (Strüder et al. 2001) and MOS (Turner et al. 2001) cameras, which were deployed in large and small window mode, respectively, both with the medium filter. All X-ray data were first screened with the XMM SAS v6.5 software and events corresponding to patterns 0–4 (single and double pixel events) selected for the pn camera and patterns 0–12 for the MOS1 and MOS2 cameras. We extracted source counts within a circular region of 45 arcsec 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. After removal of data during periods of high background the effective pn exposure was ∼49.5 ks while the MOS cameras were combined to give a single-camera equivalent exposure of ∼107 ks. Individual spectra were binned to a minimum of 20 counts per bin, to facilitate use of the χ^2 minimalization technique in spectral fitting.

Spectral fitting was based on the XSPEC package (Arnaud 1996), version 11.3. All spectral fits include absorption due to the

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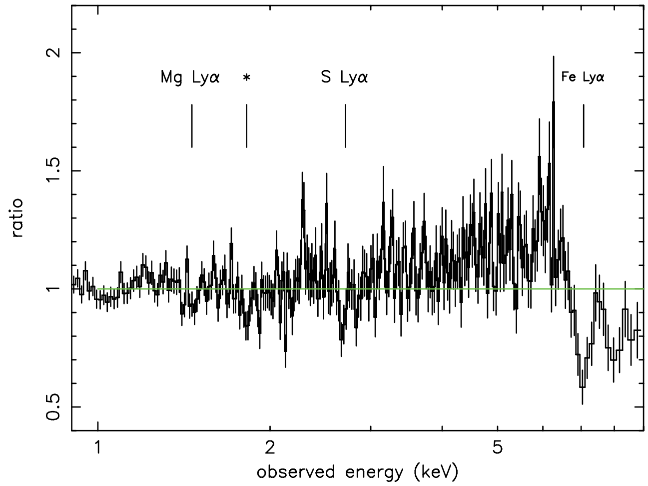

Figure 1. EPIC pn camera data from the observation of PG1211+143 in 2001 compared with a simple power-law fit over the energy band 1–10 keV. Three narrow spectral features in the 2001 data and their proposed identification in P03 with absorption lines of highly ionized Mg, S and Fe are indicated. A further significant 'absorption line', marked by an asterix, lies close to the neutral Si absorption edge and was therefore ignored in P03.

line-of-sight Galactic column of $N_{\rm H} = 2.85 \times 10^{20}\,\rm cm^{-2}$ (Murphy et al. 1996) and errors are quoted at the 90 per cent confidence level ($\Delta\chi^2 = 2.7$ for one interesting parameter).

3 ABSORPTION LINES IN THE EPIC DATA

Fig. 1 reproduces the ratio plot of pn data to a simple power-law fit (photon index of $\Gamma \sim 1.78$) over the 1–10 keV band, as modelled in P03. Marked on the figure are three statistically significant 'narrow' absorption lines, with their identification as proposed in P03, where they formed a key part of the case for a high velocity outflow. Denoted by an asterix in Fig. 1 is a further 'absorption line' at ∼1.8 keV, which was not included in the P03 analysis due to prevailing uncertainties in the detector calibration near the neutral Si edge. Repeating the analysis in P03 by successively adding Gaussian lines to the power-law model in XSPEC the observed absorption lines can be quantified. Fitting first the strongest line at ∼7 keV improves the fit by $\Delta\chi^2$ of 69 for three fewer degrees of freedom, with a line energy of 7.07 ± 0.03 keV (observer frame), width $\sigma = 168 \pm 46$ eV and flux $-5.7 \pm 0.9 \times 10^{-6}$ ph cm^{-2} s^{-1}, corresponding to an equivalent width against the power-law continuum of $\sim 210 \pm 35$ eV. Fitting additional Gaussians to the weaker spectral features at ∼2.7 and ∼1.5 keV, with line width fixed at $\sigma = 50$ eV, gives further significant improvements to the fit, with $\Delta\chi^2$ of 17 and 16, respectively, each for two additional degrees of freedom. The best-fitting line energies, again in the observer frame, are 2.7 ± 0.03 and 1.47 ± 0.02 keV, with respective fluxes of -4.5×10^{-6} ph cm^{-2} s^{-1} and -5.7×10^{-6} ph cm^{-2} s^{-1} (EWs of ∼30 eV and ∼14 eV, accurate to a factor of ∼2). Identifying the three absorption lines with the resonance Lyα transitions of Fe XXVI, S XVI and Mg XII then yields the mean outflow velocity of $\sim 0.09 \pm 0.01c$ reported in P03.

3.1 Examining the higher resolution MOS spectrum

As noted in P03, the outflow velocity of $\sim 0.09c$ is conservative in that identifying the ∼7 keV feature with Fe XXV Heα, rather than Fe XXVI Lyα, would require a larger energy shift and correspondingly higher velocity. Encouraged by the impressive low energy spectra from the (higher resolution) MOS cameras, demonstrated in two recent studies of the Seyfert 2 galaxies Mkn3 (Pounds & Page 2005) and NGC 1068 (Pounds & Vaughan 2006) we have re-examined the spectral structure in the *XMM–Newton* observation of PG1211+143, concentrating on the MOS data. Our aim was to clarify the spectral structure at medium and low energies in the hope of removing the ambiguity in identifying the ∼7 keV absorption line, and hence improving confidence in the deduced outflow velocity.

With the higher energy resolution of the MOS camera the absorption features at ∼1.47 and ∼2.71 keV now both appear as a resolved line pair, with the energy spacing of the respective Heα and Lyα resonance lines of Mg and S. Furthermore, additional narrow absorption features are seen to match with same K-shell resonance lines of Ne, Si and possibly Ar.

To quantify these absorption features we explored the MOS data with XSPEC. We first fitted the MOS data at 1–5 keV with a power law to provide a baseline. Several narrow features clearly visible in the data-to-power-law-model ratio plot (Fig. 3, upper panel) contributed to a poor statistical fit ($\chi^2 = 351/266$). Fitting Gaussians to the visible features, with a fixed width of $\sigma = 10$ eV, found six significant negative (absorption) lines. The overall improvement to the fit was very significant with χ^2 reduced to 268/254. The fitted line energies and fluxes are listed in Table 1 where the observed line energy is in each case compared with the most likely identification, chosen as the nearest resonance transition of an abundant ion. Crucially, all six line energies exhibit a 'blue shift' in the range ∼5–7 per cent. Assuming the same ratio for the absorption line observed at ∼7.07 keV gives a preferred identification with Heα of Fe XXV (Fig. 2). In the rest frame of PG1211+143 the revised identification of the absorption spectrum now yields an increased outflow velocity in the range $v \sim 0.13$–$0.15c$.

4 COMPARISON WITH AN IONIZED OUTFLOW

To test the compatibility of the visual absorption line set with a physical absorber we then compared the MOS data with a photoionized gas modelled using the XSTAR code (Kallman et al. 1996). Free parameters of the absorber in this comparison were the column density and ionization parameter, with outflow (or inflow) velocities included as an adjustment to the apparent redshift of the absorbing gas. All relevant abundant elements from Ne to Fe were included with the relative abundances constrained to within a factor of 2 of solar.

Since our primary aim was to check the energies and relative strength of the principal absorption lines identified in the visual spectral fit shown in Fig. 2, the model did not attempt to match

Table 1. The six strongest absorption lines identified in the MOS spectrum of PG1211+143. Line energies are in keV and give the observed and laboratory values, and their ratio. The fitted line fluxes are units of 10^{-6} ph cm^{-2} s^{-1}, with EW against the continuum in eV. The improvement in the 1–5 keV fit is given by $\Delta\chi^2$ for the addition of each absorption line in turn.

Line	Energy$_{\rm obs}$	Energy$_{\rm lab}$	Ratio	Line flux	EW	$\Delta\chi^2$
NeX Lyα	1.078 ± 0.05	1.022	1.055	-3.9 ± 2.2	5	7
MgXI 1s-2p	1.434 ± 0.14	1.352	1.061	-3.4 ± 2	7	5
MgXII Lyα	1.546 ± 0.02	1.473	1.050	-6.4 ± 1.5	16	29
SiXIII 1s-2p	2.003 ± 0.02	1.866	1.073	-4.5 ± 1.3	17	12
SXV 1s-2p	2.625 ± 0.06	2.460	1.067	-3.3 ± 1.9	21	10
SXVI Lyα	2.765 ± 0.03	2.620	1.055	-3.8 ± 1.1	26	20

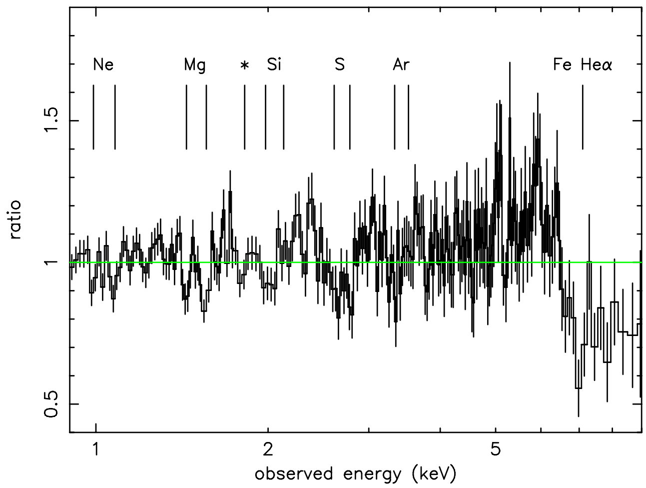

Figure 2. EPIC MOS camera data from the observation of PG1211+143 in 2001 compared with a simple power-law fit over the energy band 1–10 keV. Narrow spectral features and their proposed identification with K-shell absorption lines of Ne, Mg, Si, S, (Ar?) and Fe are indicated.

the broad excess flux near ∼6 keV; it therefore consisted only of a power law with photoionized absorber. Fitting over the 1–10 keV band the addition of the photoionized absorber improved the spectral fit from χ^2 of 522 for 358 degrees of freedom to 465/345. The best-fitting column density was $N_{\rm H} \sim 2 \times 10^{22}$ cm^{-2}, with an ionization parameter of $\log \xi = 2.9 \pm 0.4$ and nominal relative abundances of Ne, Mg, Si, S, Ar and Fe of 0.5, 1, 0.5, 1, 0.5 and 0.5. Fig. 4 (middle panel) reproduces this absorbed power-law model, with the strongest predicted absorption lines (in order of increasing energy) corresponding to K-shell resonance transitions of Ne, Mg, Si, S, Ar and Fe, supporting the visual assessment of Fig. 2. Additionally, we note the Lyβ line of Mg XII would occur at ∼1.83 keV, suggesting much of the observed deficit at that energy may be real (and that our MOS calibration models the neutral Si edge rather well).

To clarify the comparison with the MOS data in the lower energy band, the top panel of Fig. 4 illustrates the photoionized absorber with the Fe abundance set to zero. Removing Fe from the absorber also shows that potential confusion from Fe L absorption is limited above ∼1.2 keV. The apparent redshift read from the XSTAR model was $(-4.9 \pm 0.3) \times 10^{-2}$, corresponding to an outflow velocity (in the rest frame of PG1211+143) of $v \sim 0.130 \pm 0.003c$. While this value is consistent with the range of velocities of 0.13–0.15c deduced from the individual line fitting in XSPEC, the implied precision is probably not justified given the simplicity of the single absorber XSTAR model.

Although the addition of a lower ionization absorber would improve the match to the observed line ratios, in particular in providing stronger absorption for He-like Mg and Ne, we have not included a second absorber in the model, having already achieved our objective of modelling a high velocity outflow across multiple ions. However, it is interesting to note that the addition of a lower ionization component would also enhance the 'red wing' to the Fe K absorption, already showing up in the XSTAR plot in Fig. 4 (middle panel), due to increased contributions from ions of Fe XX−XXIV, and thereby explain the apparently resolved ∼7 keV absorption line ($\sigma = 168 \pm 46$ eV) in the pn spectrum.

In summary, modelling the MOS absorption spectrum with a photoionized absorber shows it to be physically compatible with a highly ionized outflow of velocity in the range 0.13–0.15c, as derived from individual line fitting.

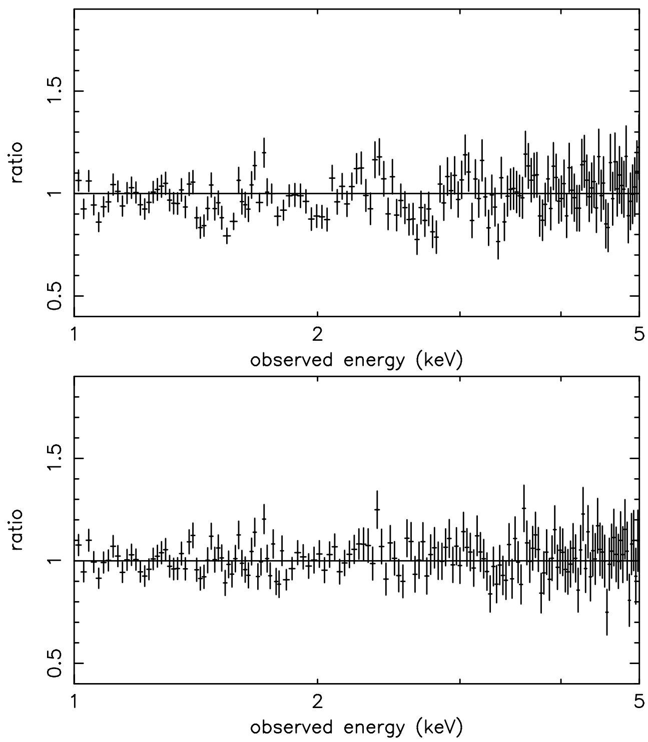

Figure 3. Upper panel: ratio of MOS camera data to a simple power-law fit over the energy band 1–5 keV. Several narrow spectral features contibute to a statistically poor fit. Lower panel: ratio plot after inclusion of six absorption lines with the parameters listed in Table 1 yielding a reduction in χ^2 of 83 for 12 fewer degrees of freedom.

4.1 A revised mass rate and energy in the high velocity flow

In their previous analysis of the PG1211+143 absorption line spectrum P03 showed that, provided the high velocity outflow was not tightly collimated, then the mass loss rate and mechanical energy in the flow would be comparable to the mass accretion rate and ∼10 per cent of the bolometric luminosity. We can now re-estimate those quantities. In doing so we use an estimate of 10 per cent for the covering factor of the fast outflow, calculated by comparing the absorbed and re-emitted power in the highly ionized gas derived from a broad band fit to the full 0.3–10.0 keV spectrum of PG1211+143 (Pounds & Reeves, in preparation).

Assuming a radial flow, the outflow mass rate is then $\dot{M}_{\rm out} = 0.3\pi n r^2 v m_{\rm p} \sim 0.2\pi L_{\rm ion}/\xi v m_{\rm p}$, where n is the particle density at a radius r, and $L_{\rm ion} \sim 10^{44}$ erg s^{-1} is the ionizing luminosity. With the observed ionization parameter $\log \xi \sim 3$, we find $\dot{M}_{\rm out} \sim 2.5 \times 10^{26}$ gm s^{-1}($\sim$3.5 M$_\odot$ yr^{-1}).

The corresponding mechanical energy in the fast, highly ionized outflow is then $\sim 2 \times 10^{45}$ erg s^{-1}, compared with an estimated bolometric luminosity for PG1211+143 of $\sim 5 \times 10^{45}$ erg s^{-1}. We note this ratio is a factor of ∼3 higher than the ratio v/c expected from a radiation driven wind (King & Pounds 2003). However, given the undoubted simplification of our single-absorber model, and uncertainties in derivation of the covering factor, it is probably premature to adopt the popular appeal to magnetic forces to drive the outflow.

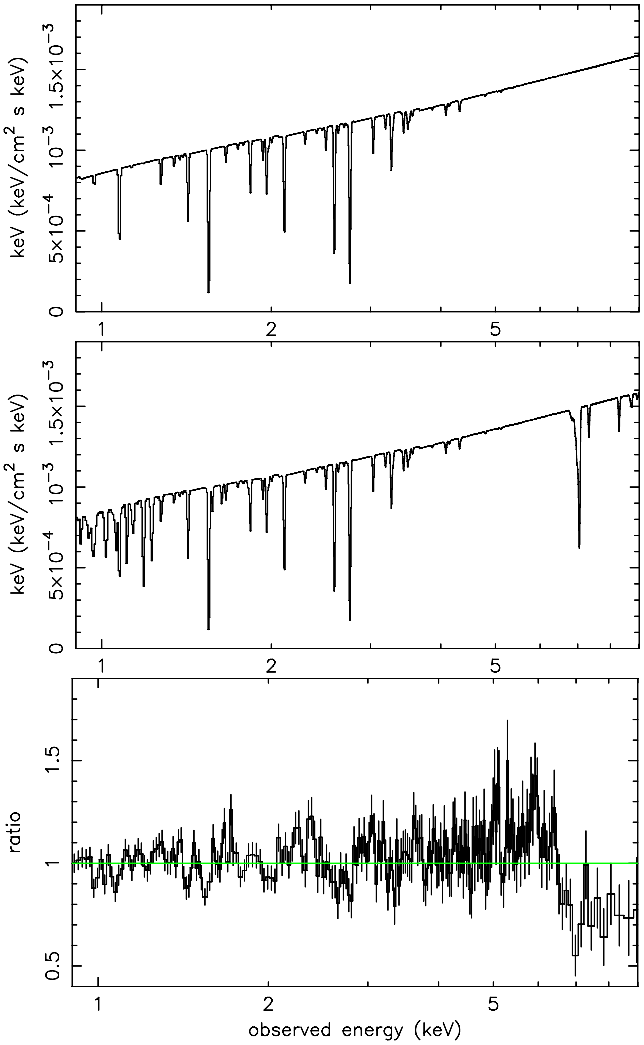

Figure 4. Top panel: photoionized absorber model as described in the text, with principal absorption lines, in order of increasing energy, of Ne, Mg, Si, S and Ar, but with no Fe; middle panel: photoionized absorber as above but with Fe now included and bottom panel: repeat of the data-to-power-law model ratio shown in Fig. 2.

5 HOW COMMON ARE ENERGETIC, HIGH VELOCITY FLOWS?

The black hole winds model of King & Pounds (2003) provided a simple physical basis whereby massive, high velocity outflows can be expected in AGN accreting near the Eddington limit. A simultaneous observation of PG1211+143 in 2001 with the *XMM–Newton* optical monitor (Mason et al. 2001) showed the energetically dominant BBB to be at a typical value, indicating a bolometric luminosity of $\sim 5 \times 10^{45}$ erg s^{-1}. With a reverberation mass estimate for the SMBH in PG1211+143 of $M \sim 4 \times 10^7$ M$_\odot$ (Kaspi et al. 2000) that luminosity suggests accretion in PG1211+143 is indeed near the Eddington rate, a conclusion consistent with the optical description of PG1211+143 as a Narrow Line QSO (Boroson & Green 1992; Kaspi et al. 2000), given that a high accretion ratio has been causally linked with Narrow Line Seyfert 1 galaxies (e.g. Pounds & Vaughan 2000, and references therein). It may well be that energetic outflows are a signature of Eddington-limited accretion in AGN. This might be the case for the bright Seyfert 1 IC4329A, which Markowitz, Reeves & Braito (2006) have recently shown to exhibit a strongly blueshifted Fe K absorption line indicating a highly ionized outflow at $v \sim 0.1c$. While relatively rare in the local universe such X-ray spectra could be common for luminous, higher redshift AGN.

6 SUMMARY

(1) A previous analysis of the 2001 *XMM–Newton* observation of the bright quasar PG1211+143 reported evidence of a high velocity ionized outflow, with a mass and kinetic energy comparable to the accretion mass and bolometric luminosity, respectively (P03).

(2) This finding is now confirmed, with the previous uncertainty in the derived velocity removed by securing the identification of the main observed absorption lines.

(3) We suggest that fast, energetic outflows may be a typical signature of type 1 AGN accreting at or above the Eddington limit.

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