X-RAYING RELATIVISTIC QUASAR OUTFLOWS

G. Chartas[1], **W. N. Brandt**[1], **S. C. Gallagher**[2], **and D. Proga**[3]

[1]Pennsylvania State University, 525 Davey Lab, University Park, PA 16802
[2]University of California – Los Angeles, Mail Code 154705, 475 Portola Plaza, Los Angeles, CA 90095-1547
[3]University of Nevada, 4505 South Maryland Parkway, Las Vegas, NV 89154

ABSTRACT

Recent *XMM-Newton* and *Chandra* observations of the gravitationally lensed BAL quasars PG 1115+080 and APM 08279+5255 have provided new insights into the structure of quasar outflows and the enrichment of the intergalactic medium by quasar winds. The confirmation of relativistic outflows in most quasars would imply that these energetic winds have a significant impact in regulating the growth of the black hole, perhaps explaining the $M_{\rm BH}$-σ relation, and halting star formation and shaping the evolution of their host galaxies. We present new results from multi-epoch spectral analysis of BAL quasar PG 1115+080 with *XMM-Newton*. We find significant variability in the properties of the outflowing absorbers. Relativistic outflow velocities are inferred from the blueshifted highly ionized Fe lines detected in our analysis of the EPIC spectra. The depths of the Fe X-ray BALs in PG 1115+080 show a significant decrease between the first two observation epochs. We constrained the fraction of the total bolometric energy released by quasars PG 1115+080 and APM 08279+5255 into the IGM in the form of kinetic energy to be $\epsilon_{\rm k}$= $0.3^{+0.1}_{-0.2}$, and $\epsilon_{\rm k}$ = $0.09^{+0.03}_{-0.07}$, respectively. According to recent theoretical studies this range of efficiencies is large enough to influence significantly the formation of the host galaxy and regulate the growth of the central black hole. An analysis of the RGS spectra indicates the possible presence of two absorption lines at rest-frame energies of 3.36 keV and 3.73 keV.

Key words: Gravitational Lenses; X-rays; Quasar Outflows.

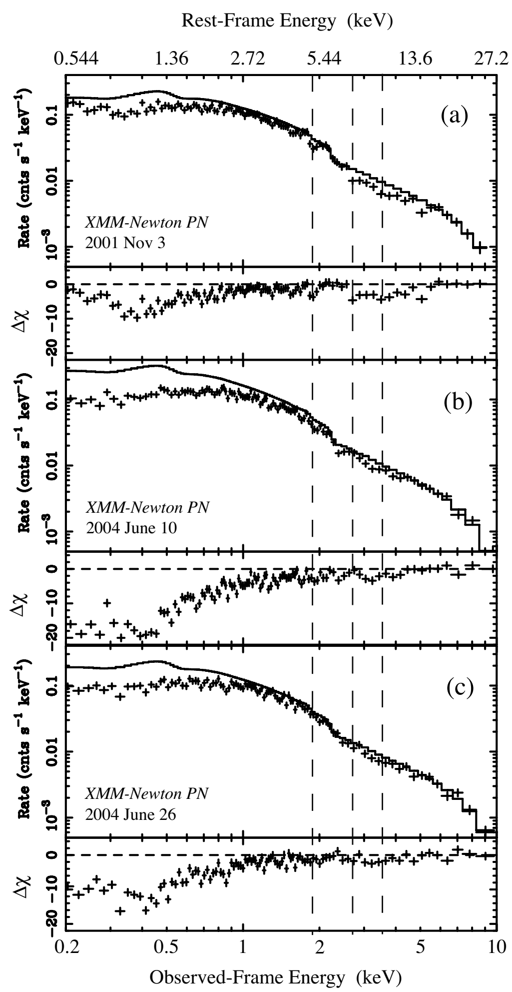

Figure 1. (a) The top panel shows the PN spectrum of the combined images of PG1115+080 for Epoch 1 fit with Galactic absorption and a power-law model to events with energies lying within the range of 5–10 keV. The lower panel shows the residuals of the fit in units of 1σ deviations. Several absorption features from 1.5–5.2 keV are noticeable in the residuals plot. (b) Same as (a) for Epoch 2. (c) Same as (a) for Epoch 3.

1. INTRODUCTION

In recent years there has been mounting evidence from both theoretical and observational studies for the importance of quasar outflows in regulating the growth of the supermassive black hole, controlling the formation of the host galaxy, and enriching the intergalactic medium. Recently, the potential importance of quasar outflows has been explicitly demonstrated in theoretical models of structure formation and galaxy mergers that incorporate the effects of quasar outflows [e.g., Scannapieco & Oh 2004 (SO04); Granato et al. 2004 (G04); Springel, Di Matteo, & Hernquist 2005 (SDH05)]. Recent X-ray observations of two BAL quasars have suggested the presence of relativistic outflows of X-ray absorbing material with velocities of up to $0.4c$ (Chartas et al. 2002, 2003). The inferred hydrogen column densities of the outflowing absorbers of about 10^{23} cm^{-2} and relativistic velocities of these outflowing X-ray absorbers imply mass-outflow rates that are comparable to the estimated accretion rates of a few $M\odot$ yr^{-1}. Additional observational evidence to support the presence of quasar feedback came with the detection of high-velocity blueshifted absorption-line features in the X-ray spectra of several quasars and Narrow-Line Seyfert 1 galaxies (Reeves et al. 2003; Pounds et al. 2003a, 2003b).

In this work we present recent results from monitoring X-ray observations of the BAL quasar PG 1115+080 (z = 1.72). The goal of these observations was to monitor the time variability of the absorption features and thereby constrain the kinematic, ionization, and absorbing properties of the quasar outflows in these X-ray-bright BAL quasars. Throughout this paper we adopt a Λ-dominated cosmology with H_0 = 70 km s^{-1} Mpc^{-1}, Ω_Λ = 0.7, and Ω_M= 0.3.

2. OBSERVATIONS AND RESULTS

PG 1115+080 was observed with XMM-Newton on 2001 Nov 25 (Epoch 1), 2004 June 10 (Epoch 2), and 2004 June 26 (Epoch 3), for 62.9 ks, 81.2 ks and 86.3 ks, respectively. A variety of models were fit to the spectra of PG 1115+080. For clarity we only show the higher S/N ratio PN data in Figure 1; however, all fits were performed simultaneously to the PN and MOS1+2. High-energy X-ray absorption lines are detected in three epochs of monitoring observations of BAL quasar PG1115+080. The energies and inferred outflow velocities of the lines are listed in Table 1. To quantify the variability of the high-energy absorption features we took ratios of the spectra. We find significant variability of the X-ray BALs in PG1115+080 between epochs 1 and 2 separated by 0.92 yr (rest-frame) and marginal variability of the X-ray BALs between epochs 2 and 3 separated by 5.9 d (rest-frame). Motivated by the apparent detection of high-energy absorption lines in the EPIC spectra we investigated the presence of absorption lines in the RGS. We report the possible detection of absorption lines at 3.36 keV and 3.73 keV (rest-frame) We caution that due to the low S/N of the present RGS spectra the significance of these features is relatively low and additional higher quality data are required to confirm this result. A plausible, but not unique, interpretation of these lines is that they arise from blueshifted S XVI Lya absorption. We have estimated the mass outflow rates and efficiency of the outflows in PG1115+080 and APM08279+5255 and listed our results in Table 2. The systematic uncertainties in estimating the outflow efficiencies are one sided in the sense that they lead to underestimates of the outflow efficiencies.

Table 1. Energies and Outflow Velocities of Absorption Lines Detected in PG 1115+080 During Epoch 1

Line	$E_{\rm obs}$ (keV)	$\sigma_{\rm rest}$ (keV)	$v_{\rm abs}$ (c)
Fe XXV 1s–2p	$2.67^{+0.14}_{-0.04}$	<0.44	$0.09^{+0.05}_{-0.02}$
Fe XXV 1s–2p	$3.60^{+0.29}_{-0.46}$	$3.07^{+1.82}_{-0.83}$	$0.40^{+0.09}_{-0.11}$
S XVI Lyα	$1.24^{+0.02}_{-0.02}$	<0.024	$0.26^{+0.01}_{-0.01}$
S XVI Lyα	$1.38^{+0.07}_{-0.07}$	< 0.23	$0.37^{+0.01}_{-0.04}$

Table 2. Mass-Outflow Rates and Efficiencies of PG 1115+080 and APM 08279+0552

Line	$\dot{M}$ ($M_\odot$ yr^{-1})	$\epsilon_{\rm k}$
PG 1115+080 Outflow		
Fe XXV 1s–2p	$0.006^{+0.004}_{-0.005}$	$3.4^{+2.1}_{-2.8} \times 10^{-4}$
Fe XXV 1s–2p	$0.27^{+0.17}_{-0.22}$	$3.0^{+1.9}_{-2.5} \times 10^{-1}$
S XVI Lyα	$0.026^{+0.016}_{-0.015}$	$1.3^{+0.8}_{-0.7} \times 10^{-2}$
S XVI Lyα	$0.025^{+0.015}_{-0.014}$	$2.4^{+1.5}_{-1.4} \times 10^{-2}$
APM 08279+5255 Outflow		
Fe XXV 1s–2p	$1.7^{+1.0}_{-1.0}$	$0.9^{+0.6}_{-0.6} \times 10^{-2}$
Fe XXV 1s–2p	$3.3^{+2.0}_{-2.4}$	$0.8^{+0.5}_{-0.6} \times 10^{-1}$

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