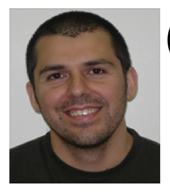
A STUDY OF THE X-RAYED OUTFLOW OF APM 08279+5255 THROUGH PHOTOIONIZATION CODES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We present results from multi-epoch spectral analysis of Chandra, XMM-Newton and Suzaku observations of the z = 3.91 gravitationally lensed broad absorption line (BAL) quasar APM 08279+5255. These results are obtained from spectral fits to all the long exposure observations using a new quasar-outflow photoionization model of a near-relativistic outflow. In every observation we confirm the presence of two strong features, one at rest-frame energies between 1-4 keV, and the other between 7-18 keV. We interpret the low-energy absorption as arising (1-4 keV rest-frame) from a low-ionization absorber with log $N_H \sim 23$ (CGS units) and the high-energy absorption (7-18 keV rest-frame) as due to lines arising from highly ionized ($2.75 < \log \xi < 4.0$; where ξ is the ionization parameter) iron in a near-relativistic outflowing wind. We find that the velocities in the outflow could get up to 0.7*c*. We also confirm strong variability of the high-ionization absorber with a rest-frame time scale of ~1 month. Our results also suggest that changes in the SED could be related with changes in the terminal velocities of the outflow. If this result is confirmed one possible interpretation is that radiation driving is the main mechanism controlling the dynamics of the outflow. We also present results obtained from CLOUDY simulations of the outflow. The main objective of these simulations is to better constrain the physical properties of the outflowing X-ray absorbing gas.

INTRODUCTION

The existence of a M_{BH}-σ relation in nearby galaxies (e.g., Ferrarese & Merritt 2000) suggests that a feedback mechanism exists regulating the co-evolution between the massive black hole at the center of a galaxy and the formation of its bulge. Quasar outflows could transport a fraction of the central black hole binding energy to the host galaxy by possibly shocking against the host interstellar medium (ISM) and therefore may be responsible for the M_{BH}-σ relation (e.g., King 2010).

Powerful winds are observed in Broad Absorption Line (BAL) quasars, which show deep and broad absorption features from highly ionized ultraviolet (UV) transitions. Due to their high intrinsic absorption (e.g., Gallagher et al. 2006), many BAL quasars appear as faint X-ray sources (e.g., Green & Mathur 1996). Partly because of this faintness, it is difficult to detect in X-ray spectra, and as a consequence, there are only a few cases where X-ray BALs have been detected in gravitationally lensed BAL quasars where the magnification effect results in increased signal-to-noise ratio spectra. Observations in X-rays of the BAL quasar APM 08279+5255, and the mini-BAL quasar PG 1115+080 have suggested the presence of near relativistic outflows of X-ray absorbing material in these objects (Chartas et al. 2002, 2003, 2007, 2009, Saez et al. 2009). The reported variability of the high-energy absorption features is over rest-frame time scales of 1.8 weeks in APM 08279+5255 and 6 days in PG 1115+080. The analysis of these high-redshift quasars implied that outflows should have a significant impact in shaping the evolution of their host galaxies and in regulating the growth of the central black hole.

Here we present the main conclusions extracted from recent studies that focused on long exposure X-ray observations (~100 ks) of APM 08279+5255 performed with Chandra, XMM Newton, and Suzaku. We also expand the previous studies in two topics. First in we describe how the use of photoionization models may help us better constrain the physical properties of the outflowing X-ray absorbing gas. Second we discuss how the SED of the central source may influence the dynamics of the outflow. The results of this work are presented in more detailed in Saez & Chartas 2011.

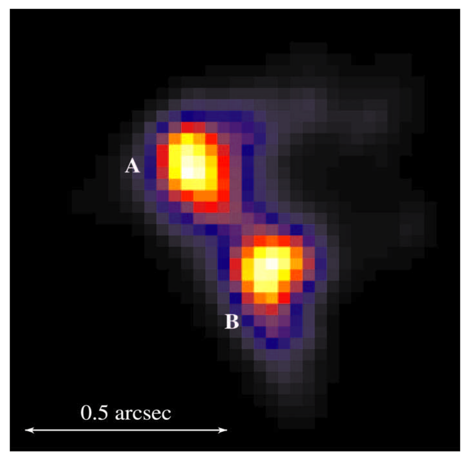

Figure1. Deconvolved image of the 2002 February 24 Chandra observation of APM 08279+5255. North is up, and east is to the left. From Chartas et. al (2002).

CHANDRA AND XMM-NEWTON OBSERVATIONS OF APM 08279+5255

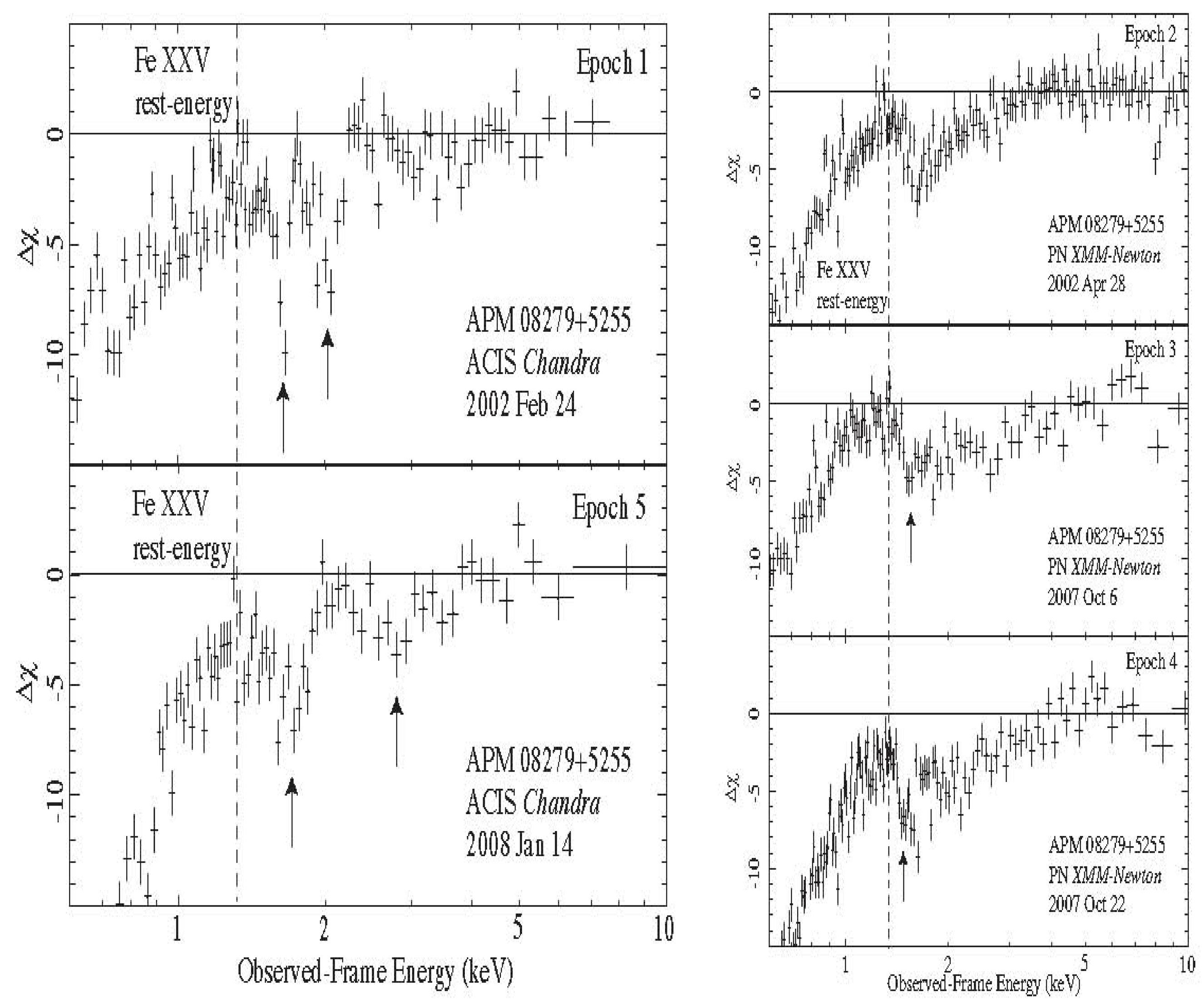

Figure2. Residuals from fitting Chandra (left panel) and XMM-Newton (right panel) spectra of the BAL quasar with a power-law plus Galactic absorption model (data from 4.5–10 keV are used n the fitting). The residuals are in units of sigma with error bars of size unity. Note that highly significant residuals from 1.5–3.5 keV, corresponding to 7–18 keV in the rest frame, are detected in all spectra. From Chartas et al. (2009); see this paper for further explanation.

CLOUDY SIMULATIONS OF NEARLY-RELATIVISTIC OUTFLOW SIGNATURES

Currently there are no proper tools available in the spectral fitting package XSPEC to model absorption profiles resulting from near-relativistic outflows. In this work we try a new model which is very similar to the one used in Schurch & Done 2007. Our new model is based on a multilayer approach which mimics the absorption and scattering through a nearly-relativistic outflow using the photoionization code CLOUDY (Ferland et al. 1998). The density profile used in our multilayer approach is chosen such that the ionization parameter is approximately constant along the outflow and relativistic corrections are also included in our analysis to account for the large outflow velocities observed. The next figures present results of our new model for an outflow accelerated by a source that has a power law spectrum from 1Rdy (~0.01 keV) to 10^4 Rdy (~100 keV). We assume a velocity profile of the p-type form $v(N_H)=v_{min}+(v_{max}-v_{min})(N_H/N_{HT})$; where is the v_{min} initial velocity, v_{max} is the final velocity and N_{HT} is the total column density of the outflow.

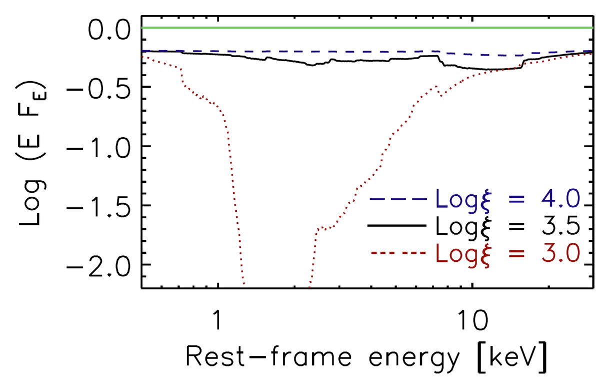

Figure3. Results from multilayered CLOUDY simulations of outflows. The assumed input spectrum is a power-law with Γ=2.0. The outflow has been accelerated between 0.1c-0.7c using a p-type form with p=1.0. The total column density of the outflow is log N_H = 23.75. We have calculated the output spectra for 3 different values of the ionization parameter (log ξ =3.0, 3.5 and 4.0).

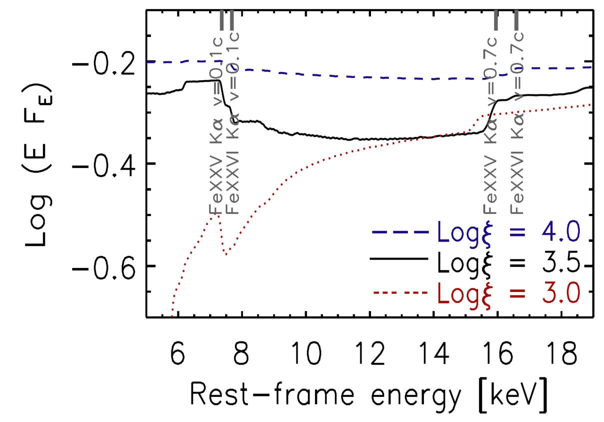

Figure4. Results from multilayered CLOUDY simulations of outflows. The assumed input spectrum is a power-law with Γ=2.0. The outflow has been accelerated between 0.1c-0.7c using. The total column density of the outflow is log N_H = 23.75. We have calculated the output spectra for 3 different values of the ionization parameter (log ξ =3.0, 3.5 and 4.0). Notice that this figure is just a zoom in of the 7-19 keV range of Fig 3. For reference the observed blueshifted energies of the Fe xxv K and Fe xxvi K lines with v = 0.1c and of the Fe xxv K and Fe xxvi K lines with v = 0.7c are highlighted.

FITS OF THE HIGH ENERGY X-RAY ABSORPTION FEATURES

We have re-analyzed 8 long exposure X-ray observations of APM 08279+5255 (2 Chandra, 3 XMM-Newton, and 3 Suzaku) using a new quasar-outflow model. This model is based on CLOUDY simulations of a near relativistic quasar outflow that were used to generate XSPEC table models. Through the X-ray fits we can constrain the following properties of the high-energy (7-13 keV) outflow signature: minimum velocity (v_{min}), maximum velocity (v_{max}), column density (N_H) and ionization parameter (ξ) . In general the models that the high-energy outflowing absorber tend to have ionization parameters in the range $3.2 < \log \xi < 3.7$. In the next figures we show how the important variations in our set of observations of the maximum and minimum velocity of the outflow.

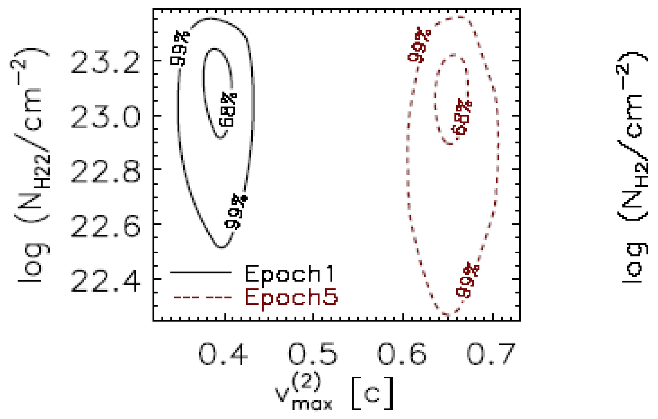

Figure5. Contour plots of the column density (log N_{H22}) versus maximum velocity ($v_{max}^{(2)}$) of the ionized outflow absorber. The contour plots have been calculated for the Chandra observations Epoch 1 (continuous line) and Epoch 5 (dashed line) at the 68% and 99% level of significance

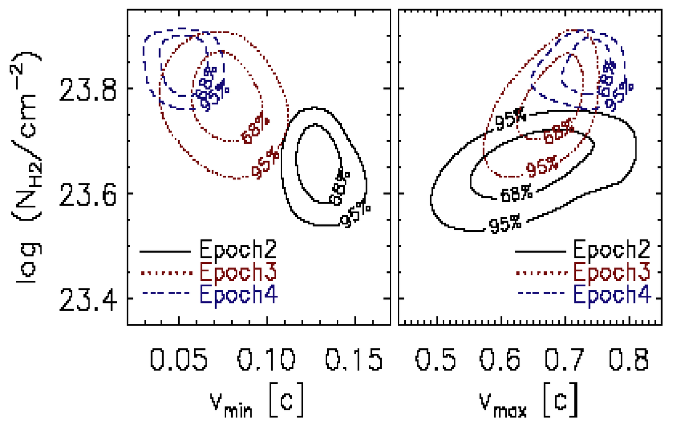

Figure6. Confidence contours of the total column density (log N_{H2}) versus minimum velocity (v_{min}; left panel) and maximum velocity (v_{max}; right panel) of the high-energy absorber. The contour plots have been calculated for the XMM-Newton observations Epoch 2 (solid line), Epoch 3 (dotted line) and Epoch 4 (dashed line) at the 68% and 95% level of significance using MODEL1 of Table 4.

IS THE SED CONTROLLING THE DYNAMICS OF THE OUTFLOW?

If the X-ray absorbers are partly driven by radiation from the hot corona we might expect to detect a correlation between the properties of the X-ray BALs and the properties of the X-ray spectrum. We notice a correlation between the maximum outflow velocity and the photon index and and possible trends between the maximum outflow velocity and the X-ray luminosity, and between the total column density and the photon index.

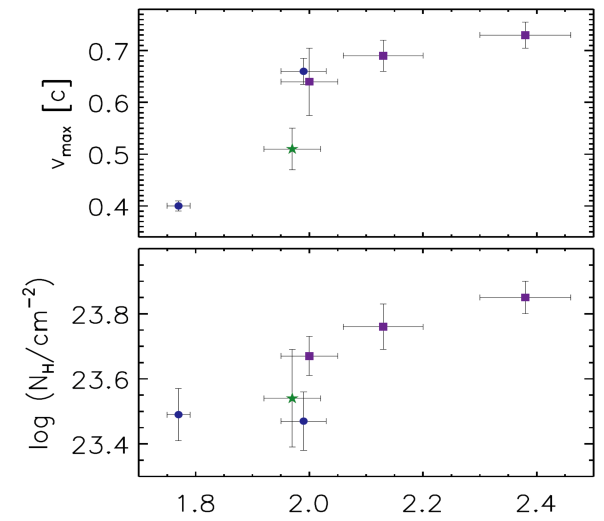

Figure7. Maximum velocity (vmax; upper panel) and total column density of the outflow (log N_H; lower panel) versus photon index (Γ) for our eight deep observations. Errors shown are at the 68% confidence level. In each panel the Suzaku data points are displayed as a single point that represents the weighted (by total counts) mean of the three Suzaku observations. Data shown with circles, a star, and squares are obtained from Chandra, Suzaku and XMM-Newton observations respectively.

We investigated our hypothesis of the origin of the possible Γ - v_{max} correlation by calculating the force multiplier as a function of the incident spectral energy distribution (SED). The force multiplier represents the ratio by which the bound-bound (line) and bound-free (continuum) opacity increases the radiation force relative to that produced by Thomson scattering alone.

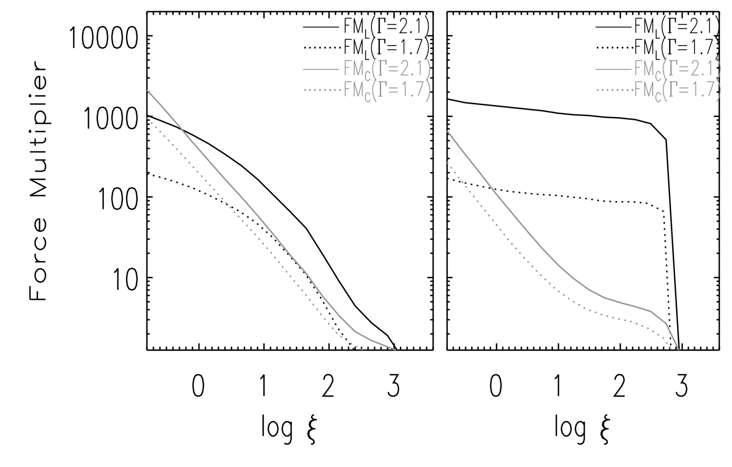

Figure8. The bound-free, M_C, and bound-bound, M_L, components of the force multiplier are shown as a function of the ionization parameter. Force multipliers are calculated for SEDs with photon indices of Γ=2.1 (dotted lines) and Γ=1.7 (dotted lines). In the left panel we have assumed no absorbing shield, whereas, in the right panel the soft and hard SEDs have been attenuated by an absorber with log N_H = 22.8. From Chartas et. al (2009).

DISCUSSION AND CONCLUSIONS

The maximum detected projected outflow velocity of ~0.76*c* constrains the angle between our line of sight and the wind direction to be <22º. The short time-scale (~month in the rest-frame) of the observed variability combined with the high ionization of the X-ray absorbing material imply that X-ray absorbers are launched from distances of ~10R_S from the central source (where R_S is the Schwarzschild radius).

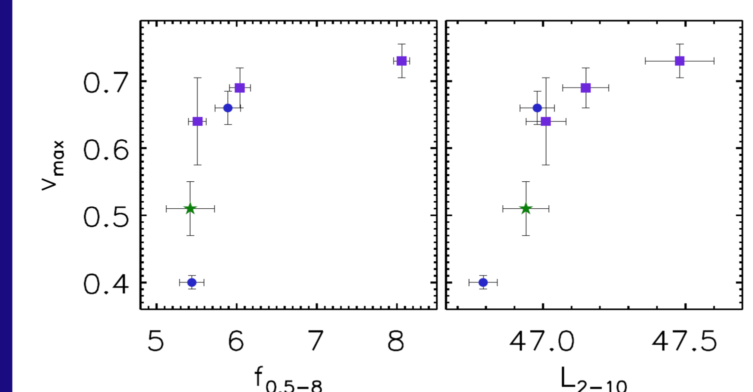

Figure9. Maximum velocity versus absorbed flux in the 0.5-8 keV band (left panel) and intrinsic luminosity in the 2-10 keV rest-frame band (right panel). Errors shown are at the 68% confidence level. In each panel the Suzaku data points are displayed as a single point that represents the weighted (by total counts) mean of the three Suzaku observations. Data shown with circles, a star, and squares are obtained from Chandra, Suzaku and XMM-Newton observations respectively.

We also confirm trends between the maximum projected outflow velocity (vmax) with the photon index (Figure 7; upper panel) and the intrinsic (unabsorbed) X-ray luminosity at the 2-10 rest-frame band (Figure 9); i.e. softer and more luminous X-ray spectra generate larger outflow terminal velocities. We also find that the total column density (N_H) of the outflow increases with Γ (Figure 7; lower panel). The trends found suggest that the wind becomes more powerful as the incident spectrum becomes softer. Additionally, we estimate that a significant fraction (>10%) of the total bolometric energy over the quasar's lifetime is injected into the intergalactic medium of APM 08279+5255 in the form of kinetic energy. The apparent trend of the photon index with the maximum projected outflow velocity suggests that the X-ray SED might be controlling the dynamics of the outflow, and thus radiative driving may be important in accelerating the outflow. Using CLOUDY simulations we find as expected (Chelouche & Netzer 2003). that the presence of a moderate absorbing shield results in more powerful outflows. A confirmation of the results found in our simulations of quasar outflow will require new deeper X-ray multi-wavelength observations of quasars that contain clear signs of fast outflow.

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