CHANDRA DETECTS RELATIVISTIC BROAD ABSORPTION LINES FROM APM 08279+5255

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ABSTRACT

We report the discovery of X-ray broad absorption lines (BALs) from the BAL quasar APM 08279+5255 originating from material moving at relativistic velocities with respect to the central source. The large flux magnification by a factor of ~100 provided by the gravitational lens effect combined with the large redshift (z = 3.91) of the quasar have facilitated the acquisition of the first high signal-to-noise X-ray spectrum of a quasar containing X-ray BALs. Our analysis of the X-ray spectrum of APM 08279+5255 places the rest-frame energies of the two observed absorption lines at 8.1 and 9.8 keV. The detection of each of these lines is significant at a greater than 99.9% confidence level based on the F-test. Assuming that the absorption lines are from Fe xxv Kα, the implied bulk velocities of the X-ray BALs are ~0.2c and ~0.4c, respectively. The observed high bulk velocities of the X-ray BALs combined with the relatively short recombination timescales of the X-ray–absorbing gas imply that the absorbers responsible for the X-ray BALs are located at radii of \( \lesssim 2 \times 10^{17} \) cm, within the expected location of the UV absorber. With this implied geometry, the X-ray gas could provide the necessary shielding to prevent the UV absorber from being completely ionized by the central X-ray source, consistent with hydrodynamical simulations of line-driven disk winds. Estimated mass-outflow rates for the gas creating the X-ray BALs are typically less than a solar mass per year. Our spectral analysis also indicates that the continuum X-ray emission of APM 08279+5255 is consistent with that of a typical radio-quiet quasar with a spectral slope of \( \Gamma = 1.72 \pm 0.05 \).

Subject headings: galaxies: active — gravitational lensing — quasars: absorption lines — quasars: individual (APM 08279+5255) — X-rays: galaxies

On-line material: color figure

1. INTRODUCTION

It is commonly accepted that most quasars contain energetic outflows of ionized gas emerging from their accretion disks at speeds ranging from \( \approx 5000 \) to \( 30,000 \) km s\(^{-1}\) (e.g., Turnshek et al. 1988; Weymann et al. 1991). These outflows imprint broad absorption features blueward of the resonant UV emission lines of C\( _{\text{iv}} \), Si \( _{\text{iv}} \), N \( _{\text{v}} \), and O \( _{\text{vi}} \). Broad absorption features are expected to be observed only for lines of sight that traverse the outflow. The outflow is thought to be driven by radiation pressure on spectral lines from UV photons of the central source (e.g., Arav et al. 1995; Murray et al. 1995; Proga, Stone, & Kallman 2000; Srianand et al. 2002). An estimate of the mass-outflow rate may result from the study of the properties of the outflowing winds of quasars. This quantity may be used to evaluate the contribution of outflowing winds in distributing accretion disk material into the vicinity of the quasar central engine and into the host galaxy over a typical lifetime of a quasar. Constraining this rate is also important for understanding the connection between black hole and bulge growth in the host galaxy (e.g., Fabian 1999).

An estimate of the mass-outflow rate requires knowledge of the velocities and locations of the various ions that contribute to the wind. Broad absorption features in the UV band often show multiple detached components with different velocities, column densities, and ionization states. One needs to include the contributions of all components to obtain an accurate value of the total mass-outflow rate. Present estimates of mass-outflow rates are based mostly on the contributions from ions absorbing in the rest-frame UV band. The present X-ray data for broad absorption line quasars (BALQSOs) are sparse, and only poor to moderate signal-to-noise ratio (S/N) spectra are available (e.g., Chartas et al. 2001; Gallagher et al. 2001, 2002; Green et al. 2001; Oshima et al. 2001; Brinkmann, Ferrero, & Gliozzi 2002). The few moderate S/N X-ray spectra of BALQSOs available show that their X-ray faintness is due to absorption with typical hydrogen column densities ranging from \( \approx 10^{22} \) to \( 10^{24} \) cm\(^{-2}\). The ionization, kinematic, and spatial properties of the X-ray–absorbing material are not well constrained. The physical relationship between the UV and X-ray absorbers is unclear. Is the X-ray absorber part of the outflow? Another unresolved issue is how moderately ionized species can survive the extreme UV and soft X-rays produced by the central source. To account for this, theoretical studies have postulated the presence of an optically thick layer of shielding gas between the central source and the outflow that prevents the outflow from becoming completely ionized (e.g., Murray et al. 1995). Recent simulations by Proga et al. (2000) indicate that the outflow is self-shielding, i.e., the shielding gas is an integral component of the outflow. The observed X-ray–absorbing gas in BALQSOs has been suggested as a candidate for the shielding gas; however, there has been little direct observational evidence for this association. Recently, narrow absorption lines (NALs) in the X-ray band have been detected in Chandra and XMM-Newton observations of bright Seyfert 1 galaxies (e.g., Kaspi et al. 2002). The NALs are blueshifted relative to the systemic velocity, suggesting that the NAL material is part of an outflow with a mean outflow velocity of a few hundred km s\(^{-1}\).
To improve our understanding of the X-ray absorption in BALQSOs, we performed a long Chandra observation of the bright, gravitationally lensed BAL quasar APM 08279+5255. The flux magnification of APM 08279+5255, estimated to be ~100 (Egami et al. 2000; Muñoz, Kochanek, & Keeton 2001) in the X-ray band, and its high redshift of $z = 3.91$ allowed us to study the kinematic and ionization properties of a BAL quasar in the X-ray band. Specifically, the high redshift of APM 08279+5255 places the strong Fe K features at energies where the telescope effective area is much larger. Here, we present the results of these observations.

2. OBSERVATION AND DATA REDUCTION

APM 08279+5255 was observed as part of the guaranteed time observer program with the Advanced CCD Imaging Spectrometer (ACIS) instrument (G. P. Garmire et al. 2002, in preparation) on board the Chandra X-Ray Observatory on 2000 October 11 and 2002 February 24 for 9.2 and 88.8 ks, respectively. The pointing of the telescope placed APM 08279+5255 on the back-illuminated S3 chip of ACIS. In Table 1 we list the observation epochs, exposure times, and detected event rates for the lensed images (see § 3). For preparing the Chandra data for analysis, we used the CIAO 2.2 and CALDB 2.12 products provided by the Chandra X-Ray Center (CXC). To improve the spatial resolution, we removed a ±0.25′′ randomization applied to the event positions in the CXC processing and employed a sub-pixel resolution technique developed by Tsunemi et al. (2001). To account for the recently observed quantum efficiency decay of ACIS, possibly caused by molecular contamination of the ACIS filters, we have applied a time-dependent correction to the ACIS quantum efficiency based on the presently available information from the CXC. The ACIS quantum efficiency decay is insignificant for energies above 1 keV and does not affect the main results of our analysis.

3. RELATIVE ASTROMETRY AND PHOTOMETRY

The Chandra image of APM 08279+5255 obtained from the 88.8 ks observation is shown in Figure 1. To improve the spatial resolution, we have applied the Lucy-Richardson (L-R) maximum likelihood deconvolution technique (Richardson 1972; Lucy 1974). For the deconvolution, we supplied a point-spread function (PSF) created by the simulation tool MARX3 (Wise et al. 1997). The X-ray spectrum used to generate the PSF was that determined from our spectral analysis (see § 4). We find a separation between the X-ray images A and B of 0.38 ± 0.01. Recent observations of APM 08279+5255 with the NICMOS camera on board HST (Ibata et al. 1999) imply the presence of three images with a separation between the two brightest images A and B of 0.38 and between A and the fainter image C of 0.1. To estimate the X-ray flux ratios, we modeled the Chandra images of A, B, and C with point-spread functions generated by the simulation tool MARX. The X-ray event locations were binned with a bin size of 0.02′. The simulated PSFs were fitted to the Chandra data by minimizing the Cash C statistic formed between the observed and

Fig. 1.—Deconvolved image of the 2002 February 24 Chandra observation of APM 08279+5255. North is up, and east is to the left.

### Table 1

| Observation Date | Observation ID | Exposure Time (s) | $R_A$ (counts s$^{-1}$ pixel$^{-1}$) | $R_B$ (counts s$^{-1}$ pixel$^{-1}$) | $R_C$ (counts s$^{-1}$ pixel$^{-1}$) | $R_{tot}$ (counts s$^{-1}$ pixel$^{-1}$) | $R_{bkg}$ (counts s$^{-1}$ pixel$^{-1}$) |
|------------------|----------------|-------------------|-----------------------------------|-----------------------------------|-----------------------------------|--------------------------------------|--------------------------------------|
| 2000 Oct 11 ......| 1643           | 9137              | $\ldots$                         | $\ldots$                         | $\ldots$                         | 10.96 ± 0.34                        | 1.68 ± 0.22                          |
| 2002 Feb 24 ......| 2979           | 88,817            | 3.1 ± 0.07                       | 2.8 ± 0.06                       | 0.66 ± 0.07                      | 6.56 ± 0.09                         | 0.99 ± 0.05                         |

$R_A$, $R_B$, and $R_C$ are the event rates for images A, B, and C estimated from a two-dimensional fit to the Chandra image of APM 08279+5255. Only events with standard ASCA4 grades 0, 2, 3, 4, 6, and with energies from 0.2 to 10 keV were used in the binned images.

$R_{tot}$ is the detected event rate from APM 08279+5255 extracted from a circular region centered on the midpoint of images A and B with a radius of 3″.

Only events with standard ASCA4 grades 0, 2, 3, 4, 6, and with energies from 0.2 to 10 keV were extracted.

$R_{bkg}$ is the detected background event rate per ACIS pixel (1 ACIS pixel = 0″492) extracted from an annulus centered on APM 08279+5255 with inner and outer radii of 10″ and 30″, respectively. Only events with standard ASCA4 grades 0, 2, 3, 4, 6, and with energies from 0.2 to 10 keV were extracted.

It was not possible to determine the individual count rates for the first observation of APM 08279+5255 because of the low S/N and the presence of moderate photon pileup.

3 The MARX 3.0 User Guide. CXC Internal Document is available at http://space.mit.edu/ASC/MARX/.
simulated images of APM 08279+5255. The relative positions of the images were fixed to the observed NICMOS values. We find X-ray flux ratios of \((f_C/f_A)_X = 0.21 \pm 0.02\) and \((f_B/f_A)_X = 0.88 \pm 0.03\). The X-ray flux ratios are close to the flux ratios measured in the HST F160 band of \((f_C/f_A)_{F160} = 0.22 \pm 0.01\) and \((f_B/f_A)_{F160} = 0.78 \pm 0.01\). We briefly comment that X-ray flux variability is detected in both images of APM 08279+5255, and this issue will be the focus of a future paper.

4. SPECTRAL ANALYSIS

Spectra of APM 08279+5255 from the combined images for the two epochs were first extracted and analyzed separately to search for any significant long-term variability. The source spectra were extracted from circular regions centered on the midpoint between images A and B with radii of 3", the background was determined by extracting events within a source-free annulus centered on the midpoint between images A and B with inner and outer radii of 10" and 30", respectively. All derived errors below are at the 90% confidence level unless quoted otherwise. Results from spectral fits to the 9.1 ks observation of APM 08279+5255 were reported in Gallagher et al. (2002). The X-ray flux of APM 08279+5255 appears to have decreased by a factor of ~2 between the first and second epochs (see Table 1). Unfortunately, there was a moderate degree of photon pileup in the first observation of APM 08279+5255, which can lead to spectral distortions and loss of events. We therefore did not combine the spectra of the first and second epochs. The second observation of APM 08279+5255 was performed in a subarray mode to reduce the effects of pileup. The reduced X-ray flux of APM 08279+5255 during the second epoch and the reduced CCD frame time of 2.5 s used for this observation significantly reduced the effects of pileup, which is negligible in the subsequent analysis. In the spectral analysis that follows, we focus on the data obtained from the 88.8 ks observation of APM 08279+5255.

A variety of models were fitted to the 88.8 ks spectrum of APM 08279+5255 employing the software tool XSPEC version 11 (Arnaud 1996). The spectrum was initially fitted with a model consisting of a simple power law with Galactic absorption due to neutral cold gas with a column density of \(N_H = 3.9 \times 10^{20}\) cm\(^{-2}\) (Stark et al. 1992). The model also included neutral intrinsic absorption at \(z = 3.91\). Our fits support the presence of an intrinsic absorber with a column density of \(N_H = (6.0^{+0.8}_{-0.6}) \times 10^{22}\) cm\(^{-2}\) (see Table 2). The fit is not acceptable in a statistical sense with \(\chi^2 = 182.1\) for 109 degrees of freedom (dof). The fit residuals show several absorption features between 1.5 and 3 keV that contribute to the unacceptable fit. To better illustrate the presence of these absorption features and the absorption at energies below 1 keV, we fitted the APM 08279+5255 data above the rest-frame energy of 10.8 keV with a simple power-law model modified by Galactic absorption and extrapolated this model to lower energies. The spectrum above 10.8 keV (rest frame) is less susceptible to intrinsic absorption and excludes the absorption features. Following this analysis strategy, the low-energy residuals indicate that intrinsic absorption is present in the spectrum. In addition, the spectrum shows two strong absorption lines from 1.5 to 3 keV; these are presented in Figure 2a. We attempt to model the residual features by considering a range of models of increasing complexity. We first add to our absorbed power-law model a redshifted Gaussian component near the most obvious absorption feature appearing at an energy of \(\approx 1.65\) keV (observed frame). Including one Gaussian component in our model leads to a significant improvement in fit quality at the greater than 99.9% confidence level (according to the F-test) with \(\chi^2 = 146.9\) for 106 dof. The best-fit energy of the absorption feature is \(E_{abs1} = 8.05^{+0.17}_{-0.07}\) keV (rest frame). This absorption feature is in a well-calibrated energy region, and the combined effective area of the Chandra mirrors and ACIS is known to vary smoothly near this energy. The absorption feature is not resolved by ACIS; we place an upper limit on its width of 140 eV (corresponding to a FWHM of \(< 12,300 \text{ km s}^{-1}\) at the 90% confidence level. We next add a second Gaussian component near 1.9 keV to model the remaining residuals near this energy. This fit is significantly improved compared to the previous fit at the greater than 99.9% confidence level and yields \(\chi^2 = 106.7\) for 103 dof; the fit is now statistically acceptable. The best-fit value for the photon index is \(\Gamma = 1.72^{+0.05}_{-0.03}\), consistent with the range of \(\Gamma\) measured for large samples of radio-quiet quasars at lower redshifts (e.g., George et al. 2000; Reeves & Turner 2000). The best-fit energy for the second absorption line is \(E_{abs2} = 9.79^{+0.20}_{-0.19}\) keV with a width of \(\sigma_{abs2} = 0.41^{+0.19}_{-0.16}\) keV. The second absorption feature falls near the instrumental iridium edge produced by the Chandra mirrors. To ascertain any systematic calibration uncertainties near the mirror edge, we have fitted the spectra of several test sources with expected smooth power-law spectra near the 2 keV iridium edge. Because \(\chi^2\) residuals depend on the statistics, we filtered the test source data in time to produce spectra with a total number of counts equal to that observed in the second observation of APM 08279+5255. Typical \(\chi^2\) residuals for these test sources near the mirror edge are less than \(\sim 1\) \(\sigma\), indicating that the observed \(5 \sigma\) residuals near 2 keV are real and not due to systematic errors in the calibration of the effective area of the Chandra mirrors. We find a ratio of \(\sim 0.5\) between data and model near the two absorption features for the second observation of APM 08279+5255. This ratio is significantly less than the observed ratio of \(< 0.95\) between data and model for our test sources. The fit that includes two Gaussian absorption-line components shows positive residuals near 8.4 and 11.2 keV (rest frame). These residuals may at least partially be the result of the simplistic absorption-line models that we have adopted in the present analysis. UV BALs usually show multiple absorption components with non-Gaussian profiles, and such complex profiles may also be present in X-ray BALs. To further test the robustness of our modeling, we also attempted to fit the 1.5–3 keV residuals in Figure 2a with a model that included an absorption edge. Specifically, for a model consisting of a simple power law with Galactic absorption, intrinsic absorption, and one absorption edge, we find a best-fit energy and optical depth of the edge of \(E_{edge1} = 7.68^{+0.21}_{-0.25}\) keV and \(\tau_{edge1} = 0.37^{+0.14}_{-0.13}\) respectively. This model did not provide an acceptable fit with \(\chi^2 = 146\) for 107 dof. In Figure 2b we show that the fit of the APM 08279+5255 spectrum with a one-edge model produces significant residuals. The reason for these large residuals is that

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4 The test sources observed with ACIS S3 are the supernova remnant G21.5–0.9, observed on 2001 March 18, the millisecond pulsar J0437–4715, observed on 2000 May 29, and the radio-loud quasar Q0957+561, observed on 2000 April 16.
the absorption edge is too broad to fit the narrow absorption lines. The addition of a second absorption edge to the model did not result in a significant improvement of the fit.

5. DISCUSSION AND CONCLUSIONS

Our analysis of the Chandra spectrum of APM 08279+5255 shows strong evidence for the presence of absorption lines at rest-frame energies of 8.05±0.08 and 9.79±0.16 keV (fit 3 of Table 2). Of all the abundant elements, iron absorption lines would be the closest in energy to the observed features. In this sense, our interpretation that the absorption lines are associated with Fe K absorption is the most conservative one possible (e.g., absorption lines from relativistic oxygen would require much larger blueshifts). At higher atomic numbers than iron (corresponding to higher absorption-line energies), there are no abundant elements. Observationally, Fe K absorption lines have been seen from other objects, such as the X-ray binaries GRS 1915+105 (Kotani et al. 2000), Circinus X-1 (Brandt & Schulz 2000), and GX 13+1 (Ueda et al. 2001) and possibly the AGN NGC 3516 (Nandra et al. 1999). We note that the expected ratios of the energies of the iron Kα to Kβ transitions of Fe xxv and Fe xxvi are just outside the 2σ confidence limits of the ratio of the energies of the two observed absorption lines. Because of the possible presence of multiple components within each of the observed absorption lines, we expect that future X-ray observations of APM 08279+5255 with higher energy resolution will unambiguously show whether the observed absorption lines correspond to the Kα and Kβ transitions of Fe xxv or Fe xxvi.

A plausible site that may be producing the absorption features is the outflowing disk wind. Complex absorption features are also observed in the UV spectrum of APM 08279+5255. In particular, recent high-resolution spectroscopy of APM 08279+5255 reveals multiple velocity components of C iv λ(1548, 1551 Å), at ~4670, ~9670, and ~12,400 km s⁻¹ (Srianand & Petitjean 2000). Broad absorption due to O viλ(1032, 1037 Å), N vλ(1238, 1242 Å) and Si ivλ(1393, 1402 Å) is also detected. The wide range of ionization levels, velocities, and column densities inferred from the UV BALs of APM 08279+5255 implies that the wind may be composed of multiple regions of different densities, with large ionization gradients (Srianand & Petitjean 2000). For our estimate of the ejection velocities of the absorbers, we assume as argued above that the X-ray absorption fea-

| Parametersa,b | Valuec,d |
|--------------|----------|
| $\Gamma_{AB}$ | 1.72±0.03 |
| $N_{H,AB}$ | (6.0±0.8)×10²² cm⁻² |
| $\chi^2/\nu$ | 182.1/109 |
| $P(\chi^2/\nu)$ | 1.4×10⁻⁵ |

**Fit 2: PL, Neutral Absorption at Source, and One Gaussian Absorption Line at Source**

| Parametersa,b | Valuec,d |
|--------------|----------|
| $\Gamma_{AB}$ | 1.73±0.06 |
| $N_{H,AB}$ | (6.4±0.8)×10²² cm⁻² |
| $E_{abs1}$ | 8.05±0.15 keV |
| $\sigma_{abs1}$ | <0.140 keV |
| $EW_{abs1}$ | 0.23±0.06 keV |
| $\chi^2/\nu$ | 146.9/106 |
| $P(\chi^2/\nu)$ | 5.3×10⁻⁵ |

**Fit 3: PL, Neutral Absorption at Source, and Two Gaussian Absorption Lines at Source**

| Parametersa,b | Valuec,d |
|--------------|----------|
| $\Gamma_{AB}$ | 1.72±0.03 |
| $N_{H,AB}$ | (6.7±0.9)×10²² cm⁻² |
| $E_{abs1}$ | 8.05±0.08 keV |
| $\sigma_{abs1}$ | <0.140 keV |
| $EW_{abs1}$ | 0.24±0.06 keV |
| $E_{abs2}$ | 9.79±0.19 keV |
| $\sigma_{abs2}$ | 0.41±0.19 keV |
| $EW_{abs2}$ | 0.43±0.17 keV |
| $\chi^2/\nu$ | 106.7/103 |
| $P(\chi^2/\nu)$ | 0.41 |

*a All model fits include fixed, Galactic absorption of $N_H = 3.9×10^{20}$ cm⁻² (Stark et al. 1992).
*b All absorption-line parameters are calculated for the rest frame.
*c All errors are for 90% confidence with all parameters taken to be of interest except absolute normalization.
*d $P(\chi^2/\nu)$ is the probability of exceeding $\chi^2$ for $\nu$ degrees of freedom.
Fig. 2.—(a) Top panel shows the Chandra observed-frame spectrum of the combined images of APM 08279+5255 fitted with Galactic absorption and a power-law model above 2.2 keV (10.8 keV rest frame) that is extrapolated to lower energies. Bottom panel represents the ratio of the data to the model. Two absorption features within 1.5–3.0 keV are noticeable in the ratio plot. (b) Top panel shows the Chandra spectrum of the combined images of APM 08279+5255 fitted with Galactic absorption, neutral absorption at the source, a power-law model, and an absorption edge. In the bottom panel, the ratio plot of data to model for fit 3 of Table 2 indicates that this model can account for most of the spectral features in APM 08279+5255.
Fig. 3.—Wind velocity as a function of radius from the central source for a radiation pressure driven wind. For a qualitative comparison, we have estimated the wind velocities for launching radii of $2 \times 10^{17}$, $5 \times 10^{17}$, and $1 \times 10^{18}$ cm. We have overplotted the observed C IV BAL (dashed lines) and Fe xxv BAL (dotted lines) velocities.

however, that the largest unknown in this estimation is the value of $\Gamma_f$, which will depend on the ionization state and velocity structure of the gas. If the observed X-ray absorption is due to Fe xxv, the high ionization parameter of this gas indicates that only heavier metals will still have any electrons. In this case, the dominant radiation pressure may be provided by X-rays rather than UV photons. Specifically, such highly ionized gas will be driven primarily by bound-free absorption and Compton scattering, although considerable nonthermal broadening may cause bound-bound absorption to contribute significantly as well (e.g., Chelouche & Netzer 2001; D. Chelouche 2002, private communication). A comparison between the recombination timescale of the ionized wind, $t_{\text{recomb}}$, and the travel time, $t_{\text{travel}} = \int_{R_{\text{in}}}^{R_{\text{out}}} \tau_{\text{wind}} dR$, for the gas to reach a certain distance from the launching radius can constrain the location of the material making the X-ray BALs. For $t_{\text{recomb}} \ll t_{\text{travel}}$, we expect the X-ray BAL material to be at small radii (near the launching radius) to account for the high ionization. If $t_{\text{recomb}} \gg t_{\text{travel}}$, the X-ray BAL can be located significantly away from the launching radius. The recombination timescale for Fe xxv is $t_{\text{recomb}} \sim 3 \times 10^4 Z^{-2} T_5^{-7/2} \tau_{\text{eff}}^{-1}$ s, where $T = 0.5 T_5$ K is the electron temperature, and $n = 10^n n_9^{-1}$ cm$^{-3}$ is the electron number density (Allen 1973). For a range of electron densities of $1 \times 10^7$ cm$^{-3}$ to $1 \times 10^{10}$ cm$^{-3}$ (hydrodynamical models of line-driven disk winds by Proga et al. 2000 predict electron number densities at the base of the wind of $5 \times 10^7$ to $5 \times 10^9$ cm$^{-3}$) we find the recombination timescales to range between $4.4 \times 10^3$ and $4.4 \times 10^4$ s. For a launching radius of $2 \times 10^{16}$ cm, the amount of time needed for the radiatively driven gas to reach a distance of $5 \times 10^{16}$ cm from the launching radius is $\sim 4 \times 10^6$ s. We conclude that $t_{\text{recomb}} \ll t_{\text{travel}}$, implying that the X-ray BAL material is located at relatively small radii (less than $2 \times 10^{16}$ cm) near the launching radius of the wind. Again, this geometry explains both the high velocity of the observed X-ray BALs and the high ionization needed to obtain Fe xxv or Fe xxvi.

Using a curve-of-growth analysis (Spitzer 1978), we estimated the hydrogen column densities implied by the observed equivalent widths of the two absorption lines at 8.05 and 9.79 keV. Assuming the ion species responsible for the X-ray absorption in both lines is Fe xxv and $b$ parameters of the order of the observed widths of the lines ($b = \sqrt{2} \sigma_\nu$, where $\sigma_\nu$ is the velocity width of the line), we calculate that the column densities of the absorbers are $N_{\text{Fe xxv abs1}} \approx (3.4 \pm 0.7) \times 10^{18}$ cm$^{-2}$ and $N_{\text{Fe xxv abs2}} \approx (3.8 \pm 1.7) \times 10^{18}$ cm$^{-2}$, respectively. For no ionization correction and assuming solar abundances, the implied total hydrogen column densities of these absorbers are $N_{\text{H abs1}} \approx (1.0 \pm 0.5) \times 10^{23}$ cm$^{-2}$ and $N_{\text{H abs2}} \approx (1.1 \pm 0.5) \times 10^{23}$ cm$^{-2}$, respectively. We emphasize that there are significant limitations with the present curve-of-growth analysis; the absorption lines may contain multiple unresolved components, implying that the equivalent widths and $b$ parameters used should be considered as upper limits. In addition, the velocity widths estimated from fits of Gaussian lines to observed absorption features can only be used to derive $b$ parameters when the absorber is optically thin.

It is not clear from the present data if the intrinsic absorber that attenuates the low-energy continuum and the absorber responsible for the absorption lines are the same. The models adopted in Table 2 assume neutral absorption at $z = 3.91$. For an ionized absorber or for the case in which there is partial covering, one expects the estimated hydrogen column density to be even larger than the value estimated assuming a neutral absorber (i.e., a fit to the spectrum of APM 08279+5255 with an ionized absorber having an ionization parameter of $U = 1$ yields a column density of $N_H \approx 7.5 \times 10^{22}$ cm$^{-2}$). We note that the low-energy absorption could include overlapping BALs from H-like and He-like ions of Mg, Si, and S that perhaps could still survive along with the highly ionized H-like and He-like ions of Fe (e.g., Kallman & Bautista 2001). Based on our estimated column densities of the X-ray BALs, we calculated the strengths of the associated absorption edges of Fe xxv (Fe xxvi) to be $\tau_{\text{Fe xxv}} \approx 0.07 (\tau_{\text{Fe xxvi}} \approx 0.04)$. We added these absorption edges to our spectral model for APM 08279+5255 (fit 3 of Table 2) and found that we do not expect them to be detectable, consistent with the data.

The observed relativistic velocities, crude estimates of the column densities, and locations of the X-ray BALs allow us to place constraints on the mass-outflow rate for APM 08279+5255. We estimated the mass-outflow rate as a function of the distance $R$ to the absorber for $R/\Delta R$ ranging from 1 to 10, where $\Delta R$ is the thickness of the absorber. We assumed a hydrogen column density of $N_H \approx 1 \times 10^{23}$ cm$^{-2}$, a covering fraction of 0.2, and a wind velocity of 0.2$c$. To obtain a reasonable mass-outflow rate (e.g., Proga et al. 2000) of less than 1 $M_\odot$ yr$^{-1}$, the radial location of the gas creating the X-ray BALs must be less than $\sim 10^{17}$ cm, which is consistent with the radius implied from the observed high velocities and ionization states of the X-ray BALs.

To summarize, we have reported on the discovery of the first X-ray BALs in the gravitationally lensed quasar APM 08279+5255. The energies of the two observed absorption features of 8.05 and 9.79 keV (rest frame) suggest the presence of two distinct absorption systems with velocities of $\sim 0.2c$ and $\sim 0.4c$, respectively. The combination of estimated short recombination timescales for Fe xxv and/or Fe xxvi and the observed relativistic velocities suggest that the X-ray absorbers are launched at radii of less than $2 \times 10^{17}$ cm. Curve-of-growth estimates imply column densities of the two X-ray BALs in APM 08279+5255 of the order of $1 \times 10^{23}$ cm$^{-2}$. One of the key implications of our
results is that X-ray BALs appear to be located within the UV BAL region and may therefore represent the shielding gas proposed in several theoretical studies of line-driven disk winds (e.g., Murray et al. 1995; Proga et al. 2000). We expect future follow-up observations of APM 08279+5255 with the Chandra high-energy transmission grating and the XMM-Newton Reflection Grating Spectrometer to identify the absorbing ions and resolve the X-ray absorption features into multiple components allowing for tighter constraints of the properties of X-ray BALs. We also plausibly expect variability of the absorption-line profiles over short timescales of approximately days, based on our estimates of the launching radii of the X-ray absorbers.

*Note added in manuscript.*—During the review of this paper, a related paper was published in the *Astrophysical Journal Letters* by Hasinger, Schartel, & Komossa (2002). They report the detection of an ionized Fe K edge in APM 08279+5255 with XMM-Newton. A visual comparison between the XMM-Newton and Chandra spectra of APM 08279+5255 suggests the presence of the two absorption features in both cases; however, the equivalent widths of the absorption features appear to be reduced during the deep XMM-Newton observation. The edge model adopted in the analysis of the XMM-Newton spectrum of APM 08279+5255 does not provide an acceptable fit to the Chandra spectrum of this object. This may imply significant variability of the X-ray BALs as suggested in our paper.

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