1. INTRODUCTION

At least 50% of radio-quiet active galactic nuclei (AGNs) exhibit evidence for photoionized outflows in their X-ray spectra (Reynolds 1997; George et al. 1998; Crenshaw et al. 2003; Porquet et al. 2004; Blustin et al. 2005; McKernan et al. 2007). The signatures of these winds consist of absorption and emission features at soft (0.4–2 keV) and hard (6–8 keV) X-ray energies, coincident with ionized O, N, Ne, Mg, Si, and Fe lines blueshifted in the observer’s rest frame. The inferred velocities of the winds are typically in the range 100–1000 km s\(^{-1}\) but can be as high as \(\sim 0.1c\) in some sources (Chartas et al. 2002, 2003; Pounds et al. 2003; Reeves et al. 2003, 2008). It is also possible that the energy budget of the outflows of some AGNs can approach a significant fraction of the bolometric or even Eddington luminosity (King & Pounds 2003).

In stark contrast, the X-ray evidence for nuclear outflows is very scarce in broad-line radio galaxies (BLRGs) and in radio-loud AGNs generally. Previously, the radio-loud quasar 4C +74.26 showed weak absorption features at \(\sim 1\) keV with ASCA (Ballantyne 2005), while the BLRG Arp 102B showed neutral X-ray absorption with ASCA and a UV outflow of a few hundred km s\(^{-1}\) (Eracleous et al. 2003). Furthermore, two radio galaxies, 3C 445 and 3C 33 (Sambruna et al. 2007; Evans et al. 2006), also exhibit soft X-ray emission lines below 2 keV, which could originate from spatially extended material (in 3C 33; Torresi et al. 2009a). Disk winds are also expected in radio-loud AGNs as ingredients for jet formation (Blandford & Payne 1982).

To differentiate between radio-loud and radio-quiet AGNs, here we adopt the radio-loudness parameter \(R_L = \log_{10}(f_5\,\text{GHz}/f_{4400})\), where \(f_5\,\text{GHz}\) is the core 5 GHz radio flux and \(f_{4400}\) is the flux at 4400 Å, both in units of mJy (Kellerman et al. 1989). Generally, \(R_L > 1\) for radio-loud AGNs (Wilkes & Elvis 1987), while for 3C 382, \(R_L = 1.9\) (Lawson & Turner 1997). If the extended radio emission from 3C 382 is also included, then \(R_L\) may be considerably higher.

In this Letter we present direct evidence for outflowing gas from the nucleus of the nearby \((z = 0.05787)\), bright BLRG 3C 382. A re-analysis of our 118 ks Chandra high energy transmission grating (HETG) observations (Gliozzi et al. 2007) revealed several blueshifted absorption lines between 0.7 and 2.0 keV which suggest the presence of a large-scale (10–1000 pc) outflow in this source with a velocity of 800 km s\(^{-1}\). The organization of this Letter is as follows. In Section 2 we describe the Chandra data reduction and analysis; in Section 3 the results of the spectral analysis; discussion and conclusions follow in Section 4. Throughout this Letter, a concordance cosmology with \(H_0 = 71\) km s\(^{-1}\) Mpc\(^{-1}\), \(\Omega_M = 0.73\), and \(\Omega_{\Lambda} = 0.27\) (Spergel et al. 2003) is adopted. Errors are quoted to 90% confidence for one parameter of interest (i.e., \(\Delta \chi^2 = 2.71\)).

2. THE CHANDRA HETG DATA

Chandra observed 3C 382 with the HETG for a net exposure of 118 ks between 2005 November 27 and 30. The \(\pm 1\) order spectra were summed for the MEG (medium energy grating) and HEG (high energy grating) respectively, along with their response files. The summed first-order count rates for the MEG and HEG are 0.867 counts s\(^{-1}\) and 0.379 counts s\(^{-1}\) respectively, while the MEG data were fitted between 0.5–7.0 keV and the HEG from 1.0–9.0 keV.

3. THE WARM ABSORBER IN 3C 382

The Chandra HETG data were first analyzed by Gliozzi et al. (2007), who focused on the continuum and its variability. Our results are in agreement with theirs. Specifically, the MEG and HEG data were fitted by an absorbed power law with photon index \(\Gamma = 1.66 \pm 0.01\) plus a blackbody with \(kT = 92 \pm 6\) eV to parameterize the soft excess below 1 keV (Gliozzi et al. 2007), absorbed by a Galactic line of sight column of \(N_{\text{H, Gal}} = 7.0 \times 10^{20}\) cm\(^{-2}\) (Dickey & Lockman 1990). Figure 1 shows the broadband HETG spectrum fitted with an absorbed power law.
law only, to illustrate that a soft excess is clearly present below 1 keV. The 0.5–9 keV band flux is $6.4 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. Even upon adding a blackbody to parameterize the soft excess, the fit is still formally unacceptable ($\chi^2$/dof = 632/477, null probability $2.4 \times 10^{-6}$) as there are clear residuals around 1 keV that indicate the presence of a warm absorber.

To analyze the warm absorber in detail, the HEG and MEG spectra were binned more finely to sample the resolution of the detector, at approximately HWHM the spectral resolution (e.g., $\Delta \lambda = 0.01$ Å bins for the MEG). For the fits, the C-statistic was used (Cash 1979), as there are fewer than 20 counts per resolution bin. The absorption lines were modeled with Gaussian profiles and the continuum model was adopted from above. Table 1 lists the detected lines with their observed and inferred properties, and their significance as per the C-statistic. Figure 2 shows the portions of the HETG spectrum containing the strongest lines, with the model overlaid.

### Table 1

Summary of HETG Absorption Line Parameters

| E(obs) | E(rest) | ID | EW$^a$ | $\sigma_{\lambda}$ | $\Delta \lambda$ |
|--------|---------|----|--------|----------------|-----------------|
| 868.5  | 918.8$^{+1.1}_{-0.9}$ | Fe xix 2p–3d (917.0) | $-1.4 \pm 0.5$ | 590$^{+100}_{-90}$ | 509$^{+470}_{-216}$ |
| 874.1  | 924.7$^{+0.6}_{-0.7}$ | Ne ix 1s–2p (922.0) | $-1.9^{+0.5}_{-0.4}$ | 875$^{+195}_{-230}$ | 493$^{+357}_{-200}$ |
| 915.8  | 968.9$^{+0.5}_{-0.9}$ | Fe xx 2p–3d (967.3) | $-1.6 \pm 0.5$ | 460$^{+100}_{-120}$ | 516$^{+490}_{-400}$ |
| 956.6  | 1012.0$^{+0.7}_{-0.7}$ | Fe xxii 2p–3d (1009.0) | $-1.4^{+0.4}_{-0.5}$ | 890 $\pm 210$ | 296$^{+140}_{-71}$ |
| 969.0  | 1025.1$^{+0.4}_{-0.4}$ | Ne x 1s–2p (1021.5) | $-2.1^{+0.4}_{-0.5}$ | 1050 $\pm 120$ | 289$^{+114}_{-102}$ |
| 1767.7 | 1870.0$^{+1.2}_{-1.3}$ | Si xii 1s–2p (1865.0) | $-1.6^{+0.4}_{-0.6}$ | 800$^{+190}_{-210}$ | 255$^{+272}_{-165}$ |
| 1901.0 | 2011.1$^{+0.3}_{-1.2}$ | Si xiv 1s–2p (2004.4) | $-2.2 \pm 0.7$ | 1000$^{+300}_{-180}$ | 284$^{+308}_{-180}$ |
| 1281.4 | 1355.6$^{+1.0}_{-1.0}$ | Mg xii 1s–2p (1352.4) | $-1.0 \pm 0.4$ | 750 $\pm 220$ | 340$^{b}$ |
| 1395.4 | 1476.2$^{+1.0}_{-1.0}$ | Mg xx 1s–2p (1472.2) | $-0.8 \pm 0.4$ | 810 $\pm 203$ | 340$^{b}$ |

Notes.

$^a$ Observed energy of absorption line in eV.

$^b$ Energy of absorption line in rest frame of 3C 382, in units eV.

$^c$ Line identification and lab frame energy in eV in parenthesis. Atomic data are from http://physics.nist.gov.

$^d$ Equivalent width, units eV.

$^e$ Outflow velocity of absorption line, in units km s$^{-1}$.

$^f$ 1σ velocity width of absorption line, in units km s$^{-1}$.

$^g$ Improvement in C-statistic, upon adding line to model.

$^h$ Parameter is fixed in the model.

The seven absorption lines in Table 1 and Figure 2 are all detected at high confidence (corresponding to $\Delta C > 18$, or $> 99.9\%$ confidence for two parameters of interest). The lines likely arise from the 1s–2p transitions of Ne ix, Ne x, Si xii, and Si xiv and the 2p–3d lines of Fe xix–xxi. The two statistically weaker 1s–2p lines of Mg xii and Mg xxii may also be present, which have outflow velocities consistent with the other lines.

Initially we assume that the lines have the same velocity width within the errors. The velocity width of the absorption lines is then $\sigma = 340 \pm 70$ km s$^{-1}$ (or $780 \pm 160$ km s$^{-1}$ FWHM) and the lines are clearly resolved. Even at 99% confidence ($\Delta C = 9.2$ for two parameters), the velocity width is constrained to $\sigma = 340 \pm 140$ km s$^{-1}$. Upon allowing the velocity width of the individual lines to vary, then they are constrained to lie within the range $\sigma = 250–500$ km s$^{-1}$ as shown in Table 1. The mean outflow velocity is $-810$ km s$^{-1}$. The overall fit statistic is $C = 3804$ for 3811 bins.

We used the photoionization code xstar (Kallman et al. 2004) to derive the parameters of the absorber, assuming the baseline continuum described above, including the soft excess. Solar abundances are assumed throughout (Grevesse & Sauval 1998).

An important input parameter is the turbulent velocity, which can affect the absorption line equivalent widths and hence the derived column density. We experimented with two different values of the turbulent velocity chosen to represent two likely extremes: (1) a lowest value of $v_{\text{turb}} = 100$ km s$^{-1}$ and (2) $v_{\text{turb}} = 300$ km s$^{-1}$, the latter being consistent with the measured width of the absorption lines. The fitted continuum parameters are $\Gamma = 1.68 \pm 0.02$ and for the blackbody, $kT = 110 \pm 8$ eV. For case (1), then $N_\sigma = (3.2 \pm 0.6) \times 10^{21}$ cm$^{-2}$, the ionization parameter is $\log \xi = 5.45^{+0.13}_{-0.08}$ and the outflow velocity is $v_{\text{out}} = -810^{+60}_{-55}$ km s$^{-1}$. The fit statistic is $C/\text{bins} = 3795/3811$. For case (2), then $N_\sigma = (1.30 \pm 0.25) \times 10^{21}$ cm$^{-2}$, log $\xi = 2.45^{+0.06}_{-0.05}$ and the outflow velocity $v_{\text{out}} = -840^{+60}_{-50}$ km s$^{-1}$. The fit statistic is $C/\text{bins} = 3783/3811$. If the warm absorber is not included in the model, then the fit statistic is substantially worse by $\Delta C = 220$ (compared to model (2)). Only a single outflowing layer of gas is required to model the warm absorber.

The units of $\xi$ are erg cm s$^{-1}$.

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Figure 1. Chandra HETG MEG (black) and HEG (red) spectra of 3C 382, binned coarsely at four times the resolution of the gratings, in order to show the broadband continuum spectrum. The data are plotted as a ratio against an absorbed power law, of photon index $\Gamma = 1.66$. A clear excess of counts is present in the soft X-ray band below 1 keV, while significant residuals below unity are also present between 0.7 and 1.0 keV, indicating that a warm absorber is present.
The higher turbulence velocity model is statistically preferred and is consistent with the measured 340 km s⁻¹ widths of the lines. Either model yields an outflow velocity of ~800 km s⁻¹ within a statistical error of <10%. Hereafter we adopt the parameters from model (2), as the turbulent velocity is consistent with widths of the individual absorption lines. However, in neither model is the fitted column density of the absorber as high as the value of \( N_{\text{HI}} \approx 3 \times 10^{22} \) cm⁻² reported by Torresi et al. (2009b) from an analysis of a short 34.5 ks XMM-Newton/RGS observation of 3C 382 on 2008 April 28. If the column density of the warm absorber is fixed to the value of \( N_{\text{HI}} \), then the fit statistic is considerably worse (~10%). Hereafter we adopt the more conservative lower luminosity value of \( 1.2 \times 10^{45} \) erg s⁻¹.

4. DISCUSSION AND CONCLUSIONS

The Chandra HETG spectra have revealed an ionized outflow in the BLRG 3C 382. The outflow parameters are well determined, with \( N_{\text{HI}} = (1.30 \pm 0.25) \times 10^{21} \) cm⁻², \( \log \xi = 2.45^{+0.06}_{-0.07} \), and \( v_{\text{out}} = -840^{+60}_{-50} \) km s⁻¹, while the absorption line widths are resolved with \( \sigma = 340 \pm 70 \) km s⁻¹.

To characterize the outflow, we define the (unabsorbed) ionizing luminosity \( L_{\text{ion}} \), which in \( x_{\odot} \) is determined by \( \xi = L_{\text{ion}}/N_{\text{HI}} \). The lower bound to the wind radius \( R_{\text{out}} \) is determined by the escape velocity, i.e., for the gas to escape the system as an outflow then \( R_{\text{esc}} > c^2 (2GM/c^2)^{1/2} \). The upper bound to the wind radius \( R_{\text{esc}} \) is determined by the ionizing luminosity \( L_{\text{ion}} \), which in \( x_{\odot} \) is determined by \( \xi = L_{\text{ion}}/N_{\text{HI}} \). The lower bound is formed by the escape velocity, i.e., for the gas to escape the system as an outflow then \( R_{\text{esc}} > c^2 (2GM/c^2)^{1/2} \).

Figure 2. Fluxed HETG spectra showing the comparison between the data binned at HWHM resolution and the best-fit absorption line model (solid line) described in the text. Several absorption lines are present in the HETG spectrum, as labeled in the above figure and listed in Table 1.

4.1. The Location of the Absorber

The upper bound to the wind radius \( R_{\text{esc}} \) is determined by geometrical constraints, i.e., if the thickness of the absorber \( \Delta R/R \ll 1 \) (valid for a thin shell) and \( N_{\text{HI}} = nR \), where \( n \) is the electron number density. As the ionization parameter of the absorber is defined as \( \xi = L_{\text{ion}}/N_{\text{HI}} \), then \( R_{\text{out}} \approx L_{\text{ion}}/N_{\text{HI}} \). The lower bound is formed by the escape velocity, i.e., for the gas to escape the system as an outflow then \( R_{\text{esc}} > c^2 (2GM/c^2)^{1/2} \).

Table 1

| Element | Observed Energy (keV) | Flux (keV cm⁻² s⁻¹) | Flux (keV cm⁻² s⁻¹) |
|---------|----------------------|---------------------|---------------------|
| Ne IX   | 0.85                 | 2×10⁻³              | 5×10⁻³              |
| Fe XIX  | 0.95                 | 0.02                | 0.02                |
| Si XII  | 1.75                 | 5×10⁻³              | 2×10⁻³              |
| Si XIV  | 1.85                 | 0.01                | 0.01                |
| Si XVII | 1.9                  | 0.01                | 0.01                |

The coincidence between the soft X-ray absorption in 3C 382 and any rest–frame UV absorption could be tested with future simultaneous Chandra and Hubble Space Telescope observations.

6. The line reported at 1.356 keV by Torresi et al. (2009b) may also be associated with the 1s→2p line of Mg x, as noted in Table 1.

7. Note that the same radius is obtained by integrating down the line of a sight of a homogeneous radial outflow.
The density of the outflow is then $n = \frac{L_{\text{ion}}}{\xi R^2}$. For the parameters above, then $n = 0.4-2400$ cm$^{-3}$. While loosely constrained, this is consistent with typical expected NLR densities of $\sim 10^3$ cm$^{-3}$ in AGNs (Koski 1978). The mass outflow rate for a uniform spherical flow is $M_{\text{out}} = \frac{4\pi n R^2 m_p v_{\text{out}}}{\xi}$, where $n R^2 = \frac{L_{\text{ion}}}{\xi}$ and $m_p$ is the proton mass. Hence for the measured warm absorber parameters for 3C 382, $M_{\text{out}} = 7.2 \times 10^{27}$ g s$^{-1}$ or $M_{\text{out}} = 100 M_{\odot}$ yr$^{-1}$.

However, the low rate of appearance of such absorbers amongst BLRG’s or radio-loud AGN generally might suggest that the solid angle subtended by individual absorbing filaments is much smaller than $4\pi$ steradians. Therefore, the mass outflow rate could be considerably smaller than the above estimate. Subsequently the kinetic power of the soft X-ray outflow (for $v_{\text{out}} = -800$ km s$^{-1}$) is then $E = \frac{1}{2} M_{\text{out}} v_{\text{out}}^2 < 2 \times 10^{43}$ erg s$^{-1}$, which energetically is a fairly insignificant 2% of the ionizing luminosity and is unlikely to contribute significantly toward AGN feedback (King 2003).

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