A HUGE RESERVOIR OF IONIZED GAS AROUND THE MILKY WAY: ACCOUNTING FOR THE MISSING MASS?

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ABSTRACT

Most of the baryons from galaxies have been “missing” and several studies have attempted to map the circumgalactic medium (CGM) of galaxies in their quest. We report on X-ray observations made with the Chandra X-Ray Observatory probing the warm-hot phase of the CGM of our Milky Way at about $10^6$ K. We detect O vii and O viii absorption lines at $z = 0$ in extragalactic sight lines and measure accurate column densities using both Ka and Kβ lines of O viii. We then combine these measurements with the emission measure of the Galactic halo from literature to derive the density and the path length of the CGM. We show that the warm-hot phase of the CGM is massive, extending over a large region around the Milky Way, with a radius of over 100 kpc. The mass content of this phase is over 10 billion solar masses, many times more than that in cooler gas phases and comparable to the total baryonic mass in the disk of the Galaxy. The missing mass of the Galaxy appears to be in this warm-hot gas phase.

Key words: cosmology; observations – Galaxy: halo – intergalactic medium – quasars: absorption lines – X-rays: galaxies

Online-only material: color figures

1. INTRODUCTION

We have known for a while that the baryonic mass of galaxies, including that of our own Milky Way, falls short of what is expected for their total mass (Sommer-Larsen 2006; Bregman 2007, and references therein). This “missing” mass is either ejected from galaxies into the intergalactic medium or still resides in the circumgalactic medium (CGM). Our Galaxy is a member of the Local Group of galaxies, and it is possible that the matter ejected from the Galaxy resides in the Local Group. In either the CGM or the Local Group medium (LGM), the baryonic mass is expected in a warm-hot gas phase at temperatures between $10^5$ and $10^7$ K. This is probably the reason why earlier studies probing only cooler gas could not account for it. The warm component of this phase at $10^5$–$10^6$ K has been observed in the UV traced by absorption lines of ionized metals, in particular O vi (Nicastro et al. 2003; Savage et al. 2003, 2005; Sembach et al. 2003). Recent observations with the Hubble Space Telescope have shown that the CGM around star-forming galaxies is large (150 kpc) and the mass of the warm phase traced by O vi exceeds that of the gas in the galaxies themselves (Tumlinson et al. 2011; Tripp et al. 2011). Using other absorption lines, e.g., Si iv and C iv in the UV, Lehner & Howk (2011) found that there is a large reservoir of warm ionized gas around our Galaxy as well.

The hotter phase of the warm-hot gas, at temperatures $10^6$–$10^7$ K can be probed by even more highly ionized metals. The dominant transitions from such ions lie in the soft X-ray band and indeed, absorption lines due to O vii and O viii at redshift zero have been detected toward extragalactic sight lines by the Chandra X-Ray Observatory and XMM-Newton (Nicastro et al. 2005; Rasmussen et al. 2003; Williams et al. 2005, 2007; Bregman et al. 2007). The distribution, spatial extent, and mass of the warm-hot gas provide important constraints to the models of large-scale structure formations (e.g., Cen & Ostriker 1999) and/or outflows/inflows from galaxies (e.g., Stinson et al. 2011), but these parameters are difficult to measure in part due to the limited spectral resolution of Chandra and XMM-Newton and in part because of the inherent difficulty in using the absorption line studies alone. Here, we use both absorption and emission observations to derive the physical properties of the warm-hot plasma. We show that the X-ray observations probe million degree gas, with low density, extending over 100 kpc and having a mass over 10 billion solar masses. This is several times more than previously found in the CGM of the Milky Way. Alternatively, the warm-hot gas we probe is from the extended LGM.

2. SAMPLE SELECTION AND DATA REDUCTION

We search for and measure the absorption lines from highly ionized gas at $z \sim 0$, as seen in the spectra of most of the extragalactic sight lines toward bright active galactic nuclei (AGNs). We use high signal-to-noise ratio (S/N) observations with Chandra High Energy Transmission Grating (HETG) or Low Energy Transmission Grating (LETG) with a focus on O vii and O viii absorption lines at $\lambda = 21.602$ Å and $\lambda = 18.967$ Å, respectively.

We began by selecting all the Chandra grating observations of AGNs that were publicly available as of 2011 October 30 and that had exposure times of at least 100 ks. This resulted in multiple observations of 50 targets with both grating spectrometers aboard Chandra (HETG and LETG).

We reduced the data using the standard Chandra Interactive Analysis of Observations (CIAO) software (v4.3) and Chandra Calibration Database (v4.4.2) and followed the standard Chandra data reduction threads. For the Chandra ACIS/HETG
and ACIS/LETG observations, we co-added the negative and positive first-order spectra and built the effective area files (ARFs) for each observation using the fullgarf CIAO script. Those pertaining to the ACIS/LETG observations were corrected for the ACIS quantum efficiency degradation. Unlike ACIS, the High Resolution Camera (HRC) does not have the energy resolution to sort individual orders, and each spectrum contains contributions from all the diffraction orders. For the HRC/LETG observations, we used the standard ARF files for orders 1–6 and convolved them with the relevant standard redistribution matrix file. For the targets with multiple observations, we added the grating spectra and averaged the associated ARFs using the CIAO script add_grating_spectra, to increase the S/N of the spectra. We only add the observations with the same instrumental configuration and the observations made with different instruments are analyzed separately.

Of the 50 sight lines initially selected, 29 have a good enough S/N near 21.602 Å to detect O\textsc{vii} absorption lines. The strong O\textsc{vii} Ka absorption lines near 21.602 Å are clearly visible in 21 out of 29 sources with good S/N spectra; thus the covering fraction of the O\textsc{vii} systems is 21/29 = 0.72. In 30% of the sources, significant O\textsc{viii} Ka lines near 18.967 Å are also observed. Here we consider a subsample of eight targets (Table 1), where both O\textsc{vii} and O\textsc{viii} Ka local absorption has been confidently detected (we have not included 3C273 in this sample of 29 sources because the $z = 0$ absorption lines in this sight line might be from a nearby supernova remnant). The detailed analysis of the complete sample will be presented in a forthcoming paper (A. Gupta et al. 2012, in preparation). The local ($z \sim 0$) O\textsc{vii} and O\textsc{viii} absorption lines in three of our eight targets have been reported previously by other authors, but to ensure the consistency of data analysis, we reanalyzed all the data and obtained the fit results independently; for the other five targets we present new detections of $z \sim 0$ lines.

### Table 1

Summary of the Targets Used in This Investigation

| Target   | $l$    | $b$    | Redshift | Exposure |
|----------|--------|--------|----------|----------|
| Mrk290   | 91.48  | 47.95  | 0.0304   | 250      |
| PKS2155-304 | 17.73 | -52.24 | 0.1160   | 530      |
| Mrk421   | 179.85 | 65.03  | 0.0300   | 720      |
| Mrk509   | 35.97  | -29.86 | 0.0344   | 460      |
| 3C382    | 61.30  | 17.44  | 0.0579   | 120      |
| Ark564   | 92.13  | -25.33 | 0.0247   | 250      |
| NGC 3783 | 287.45 | 22.94  | 0.0097   | 905      |
| H2106-099 | 40.26 | -34.93 | 0.0265   | 100      |

Our targets are nearby Type 1 AGNs, which have their own intrinsic absorption and emission features. We carefully study all the spectra to confirm that none of the AGN intrinsic features contamate the local ($z = 0$) absorption lines. Except for one source, NGC 4051, the intrinsic lines are sufficiently redshifted that they do not contaminate the local O\textsc{vii} and O\textsc{viii} absorption lines. For this reason we do not include NGC 4051 in our final sample. We then modeled all the statistically significant AGN intrinsic absorption and emission features with Gaussian components.

### 3.2. Local ($z \sim 0$) Absorption

After fitting the continuum and intrinsic features as described above, the local O\textsc{vii} and O\textsc{viii} Ka absorption lines were detected with $\geq 3\sigma$ and $\geq 2\sigma$ significance levels, respectively. In six sources, we also detected the O\textsc{vii} K$\beta$ absorption line near 18.62 Å. We fit these lines in Sherpa with narrow Gaussian features. Since with Chandra gratings (FWHM = 0.05 Å for low energy grating and FWHM = 0.023 Å for medium energy grating) the lines are unresolved, we fixed the line width to 1 mÅ. Errors were calculated using the projection command in Sherpa, allowing the overall continuum normalization to vary along with all parameters for each line. For the observations with no detection of O\textsc{vii} K$\beta$, we fixed the line centroid at 18.629 Å and obtained the upper limits on equivalent widths (EW). The best-fit line EWs and statistical uncertainties are given in Table 2 and the spectra are shown in Figure 1.

### 3.3. Column Density Measurement

For optically thin gas, the ionic column density depends simply on the observed EW: $N(\text{ion}) = 1.3 \times 10^{20}(\text{EW}/f\lambda^2)$, where $N(\text{ion})$ is the ionic column density (cm$^{-2}$), EW is the equivalent width (Å), $f$ is the oscillator strength of the transition, and $\lambda$ is in Å. However, at the measured column densities of $N(\text{O} \text{vii})$, saturation could be an important issue as suggested by simulations (Chen et al. 2003) and observational studies of Mrk421 (Williams et al. 2005). Therefore to correctly
convert the measured EWs to ionic column densities, we require knowledge of the Doppler parameter \( b \); at a fixed EW, column density decreases with increasing \( b \). The low-velocity resolution of Chandra gratings makes it infeasible to directly measure the O \( \text{vii} \) line width. If multiple absorption lines from the same ion are detected, the relative EWs of these lines can instead be used to place limits on the column density \( N(\text{O vii}) \) and the Doppler parameter \( b \) of the medium.

To use this technique, we searched for and detected the O \( \text{vii} \) K\( \beta \) line at 18.629 Å in six out of eight targets and measured the upper limit for the remaining two. For O \( \text{vii} \), the expected EW(K\( \beta \))/EW(K\( \alpha \)) ratio is \( f(\text{K}\beta) \times \lambda^2(\text{K}\beta)/f(\text{K}\alpha) \times \lambda^2(\text{K}\alpha) = 0.156 \). Our observations indicate that most O \( \text{vii} \) K\( \alpha \) lines are saturated (Table 2). To place quantitative constraints on \( N(\text{O vii}) \) and the \( b \) parameter we employed the technique described in detail in Williams et al. (2005). For a given absorption line with a measured EW and known oscillator strength \( f \) value, the inferred column density as a function of the \( b \) parameter can be calculated using the relations from Spitzer (1978). The \( b \) and \( N(\text{O vii}) \) can be determined for a range of Doppler parameters for which both K\( \alpha \) and K\( \beta \) transitions provide consistent \( N(\text{O vii}) \) measurements. Figure 2 shows such 1σ contours for the measured O \( \text{vii} \) K\( \alpha \) and K\( \beta \) transitions for NGC 3783. As the figure shows, the 1σ constraints on Doppler parameter \( b \) and O \( \text{vii} \) column densities are 45 < \( b \) < 128 km s\(^{-1}\) and 16.03 < \( \log N(\text{O vii}) \) < 16.68 cm\(^{-2}\), respectively. For Mrk421 and PKS2155-304, we used the \( b \) parameter values from Williams et al. (2005, 2007). Following the same method, we constrained the \( b \) parameter and O \( \text{vii} \) column densities for all other observations. Our measured column density toward Mrk 421 is consistent with that in Yao et al. (2008). The upper limit on the column density through the Galactic halo by Yao et al. is based on several assumptions which, in our opinion, are faulty, but a detailed discussion is beyond the scope

![Figure 2](image.png)

**Figure 2.** Contours of allowed column densities \( N(\text{O vii}) \) and Doppler parameters \( b \) for the O \( \text{vii} \) (black) and O \( \text{vii} \) (red).

*(A color version of this figure is available in the online journal.)*

### Table 2

| Target     | EW (O \( \text{vii} \) K\( \alpha \)) (mA) | EW (O \( \text{vii} \) K\( \beta \)) (mA) | EW (O \( \text{vii} \) K\( \alpha \)) (mA) | O \( \text{vii} \) (EW(K\( \beta \))/EW(K\( \alpha \))) | \( b \) (km s\(^{-1}\)) | \( \log N(\text{O vii}) \) (cm\(^{-2}\)) |
|------------|------------------------------------------|------------------------------------------|------------------------------------------|-------------------------------------------------|-----------------|-----------------|
| Mrk290     | 18.9 ± 4.5                               | 5.1 ± 3.7                                | 8.4 ± 2.9                                | 0.27 ± 0.21                                      | >55             | 16.14 ± 0.32    |
| PKS2155-304| 11.6 ± 1.6                               | 4.2 ± 1.3                                | 6.7 ± 1.4                                | 0.36 ± 0.12                                      | 35–94           | 16.09 ± 0.19    |
| Mrk421     | 9.4 ± 1.1                                | 4.6 ± 0.7                                | 1.8 ± 0.9                                | 0.49 ± 0.09                                      | 24–55           | 16.22 ± 0.23    |
| Mrk509     | 23.9 ± 5.0                               | 11.7 ± 4.1                               | 10.3 ± 4.3                               | 0.49 ± 0.20                                      | 70–200          | 16.7 ± 0.27     |
| 3C382      | 17.3 ± 5.0                               | 7.8 ± 3.0                                | 6.8 ± 3.8                                | 0.45 ± 0.22                                      | >40             | 16.50 ± 0.49    |
| Arp564     | 12.0 ± 1.9                               | <3.8                                     | 9.5 ± 4.1                                | ...                                              | >20             | 15.82 ± 0.20    |
| NGC 3783   | 14.4 ± 2.5                               | 5.6 ± 1.6                                | 4.5 ± 2.9                                | 0.39 ± 0.13                                      | 50–130          | 16.30 ± 0.25    |
| H2106-099  | 48.3 ± 18.0                              | <34.2                                    | 28.8 ± 13.8                              | ...                                              | >70             | 16.23 ± 0.16    |

**Note.** The lower limits on O \( \text{vii} \) column densities are calculated using the curve-of-growth analysis.
of this Letter. The O\textsc{vii} column densities for our sample range from \(\log N(\text{O\textsc{vii}}) = 15.82\) to 16.50 cm\(^{-2}\), with a weighted mean value of \(\log N(\text{O\textsc{vii}}) = 16.19 \pm 0.08\) cm\(^{-2}\). These values of \(N(\text{O\textsc{vii}})\) are higher than measured by other authors (Fang et al. 2006; Bregman et al. 2007) who assumed the lines to be unsaturated.

4. RESULTS

Column density ratios of different ions of the same element depend on the physical state of the medium and provide rigorous constraints on the temperature of the absorbing medium. Given that we detect both O\textsc{vii} and O\textsc{viii}, we place a tight constraint on the temperature \(T = 6.1 - 6.4\) K, assuming the gas to be in collisional ionization equilibrium.

With the spectral resolution of current X-ray gratings it is difficult to resolve the absorption lines into Galactic and Local Group components. However, a comparison between emission and absorption measurements provides us with a great tool to analyze the properties of the X-ray absorbers. The absorption lines measure the column density of gas \(N_H = \mu n_e R\), where \(\mu\) is the mean molecular weight \(\approx 0.8\), \(n_e\) is the electron density, and \(R\) is the path length. The emission measure (EM), on the other hand, is sensitive to the square of the number density of the gas \((EM = n_e^2 R\), assuming a constant density plasma). Therefore, a combination of absorption and emission measurements naturally provides constraints on the density and the path length of the absorbing/emitting plasma.

Henley et al. (2010) and Yoshino et al. (2009) using XMM-\textit{Newton} and \textit{Suzaku} data, respectively, found that the Galactic halo temperature is fairly constant across the sky, \((1.8 - 2.4) \times 10^4\) K, but the halo EM varies by an order of magnitude (0.0005 - 0.0005 cm\(^{-6}\) pc) with an average of \(EM = 0.030 \pm 0.0006\) cm\(^{-6}\) pc, assuming solar metallicity.\(^7\) Other measurements of Galactic halo emission (McCammon et al. 2002; Galeazzi et al. 2007; Gupta et al. 2009; Hagihara et al. 2010) also reported \(EM \sim 0.003\) cm\(^{-6}\) pc for solar metallicity, close to the average. Thus, using \(EM = 0.003(Z/\odot)(8.51 \times 10^{-4}/(A_O/A_H))\) cm\(^{-6}\) pc, we solve for the path length and electron density of the absorbing gas. Combining absorption and emission the density is

\[
n_e = (2.0 \pm 0.6) \times 10^{-4} \left(\frac{0.5}{f_{O\textsc{vii}}^2}\right)^{-1} \text{cm}^{-3} \tag{1}
\]

and the path length

\[
R = (71.8 \pm 30.2) \left(\frac{8.51 \times 10^{-4}}{(A_O/A_H)}\right) \left(\frac{0.5}{f_{O\textsc{vii}}^2}\right)^2 \left(\frac{Z}{\odot}\right) \text{kpc}. \tag{2}
\]

where the solar oxygen abundance of \(A_O/A_H = 8.51 \times 10^{-4}\) is from Anders & Grevesse (1989), \(f_{O\textsc{vii}}\) is the ionization fraction of O\textsc{vii}, and \(Z\) is the metallicity. Newer values of oxygen abundance are even lower (Holweger 2001; Asplund et al. 2009); making \(L\) larger. For the observed temperature of about \(\geq 10^6\) K, it is reasonable to expect \(f = 0.5\) (see, e.g., Figure 4 in Mathur et al. 2003). Cosmological simulations (Toft et al. 2002; Sommer-Larsen 2006) of the formation and evolution of disk galaxies show that outside the galactic disk the mean metallicity of gas is \(Z = 0.2 \pm 0.1\) Z\(_\odot\). These values of metallicities are also consistent with observational results for the outskirts of groups (Rasmussen et al. 2009) and clusters of galaxies (e.g., Tamura et al. 2004). Thus, it is highly unlikely that in the CGM metallicity is as high as Z\(_\odot\). As such, \(Z = Z\odot\) sets a lower limit on the path length and an upper limit on the electron density. The 1σ limits on the path length and density are \(L > 41.6\) kpc and \(n_e < 2.6 \times 10^{-4}\) cm\(^{-3}\). For \(Z = 0.3\) Z\(_\odot\), which is far more likely, the path length becomes as large as \(L = (239 \pm 100)\) kpc.

We can also estimate the total baryonic mass traced by the O\textsc{vii} absorbers, assuming a homogeneous spherically symmetric system:

\[
M_{\text{total}} = (2.3 \pm 2.1) \times 10^{11} \left(\frac{f_c}{0.72}\right) \left(\frac{8.51 \times 10^{-4}}{(A_O/A_H)}\right)^3 \left(\frac{0.3 Z\odot}{Z}\right)^3 \left(\frac{0.5}{f_{O\textsc{vii}}^2}\right)^5 M\odot \tag{3}
\]

for \(L = 239\) kpc and \(f_c\) is the covering factor, \(\sim 72\%\) for our entire sample.

For the 1σ lower limit on the path length (\(L > 139\) kpc), the mass is \(M_{\text{total}} > 6.1 \times 10^{10} M\odot\). For the solar abundance used by Tumlinson et al. (2011) \(M_{\text{total}} = 1.2 \times 10^{10} M\odot\), compared to \(2 \times 10^9 M\odot\) found by Tumlinson et al. (2011) in O\textsc{vii} systems. Thus, we find that the O\textsc{vii}/O\textsc{viii} systems probe the reservoir of gas in the CGM extending to over 100 kpc. The mass probed by this warm-hot gas is larger that that in any other phase of the CGM and is comparable to the entire baryonic mass of the Galactic disk \(\sim 6 \times 10^{10} M\odot\) (Sommer-Larsen 2006). The baryonic fraction \(f_0\) of this warm-hot gas varies from 0.09 to 0.23 depending on the estimates of the virial mass of the Milky Way, from \(10^{12} M\odot\) to \(2.5 \times 10^{12} M\odot\) (Anderson & Bregman 2010, and references therein), bracketing the universal value of \(f_0 = 0.17\).

The oxygen mass in the CGM as traced by O\textsc{vii}/O\textsc{viii} is

\[
M_{\text{oxygen}} = (6.8 \pm 5.9) \times 10^8 \left(\frac{0.5}{f_{O\textsc{vii}}^2}\right) M\odot \tag{4}
\]

and with the effective oxygen yield \(\sim 0.01\) for a Salpeter initial mass function, the stellar mass needed to produce this amount of oxygen is \(M_* = (6.8 \pm 5.9) \times 10^{10} M\odot\), which is of the order of the disk+bulge stars.

4.1. Comparison with Models

Ntormousi & Sommer-Larsen (2010) calculate all sky O\textsc{vii} column density distributions for halos of three Milky Way-like disk galaxies, resulting from cosmological high-resolution N-body/gas-dynamical simulations. These simulations predict the mean log\(N(\text{O\textsc{vii}})\) ranging from 13.46 to 14.55, which is significantly lower than the average column density we find. Our observations, however, are consistent with those of other such studies (Fang et al. 2006; Williams et al. 2005, 2007; Bregman et al. 2007). We note that in the "pure hot halo" models of Ntormousi & Sommer-Larsen (2010), the Local Group contribution is not included; this might be a part of the reason for the discrepancy (see Section 4.2).

Our path-length and density measurements are in excellent agreement with the recent estimates of the distribution of
hot \( (T \sim 10^6 \text{ K}) \) circumgalactic gas, based on high-resolution cosmological hydrodynamical simulations of Feldmann et al. (2012). These simulations predict the presence of ionized circumgalactic gas with a density of \( \sim 10^{-4} \text{ cm}^{-3} \) out to 100 kpc and beyond. Hydrodynamic simulations of CGM at \( z = 0 \) by Stinson et al. (2011) found that their simulated galaxies contain metal enriched warm-hot gas extending to approximately the virial radius (250 kpc). While their simulations do not track the O \( \text{vii} \) or O \( \text{viii} \) producing gas, it is of interest to note that the mass in the CGM is several times higher than the stellar mass of their simulated galaxies, similar to what we find. They argue that the missing baryons exist in the CGM.

### 4.2. Assumptions and Biases

We have combined our measurements of the O \( \text{vii} \) and O \( \text{viii} \) column densities with the published values of EM to derive physical conditions in the absorbing/emitting plasma, viz. temperature, density, path length, and mass. The constraint on the temperature is robust; it depends simply on the O \( \text{vii} \) to O \( \text{viii} \) column density ratio, under the assumption of collisional ionization equilibrium. For our measured density of a few times \( 10^{-4} \text{ cm}^{-3} \), which is several thousand times larger than the mean density of the universe \( (n = 1.88 \times 10^{-7} \text{ cm}^{-3}) \), photoionization becomes unimportant and collisional ionization is a reasonable assumption.

We have assumed that the absorbing/emitting plasma is of uniform density; this need not be the case. The distribution of warm-hot gas around several galaxies follows a \( \beta \)-model profile in which the density is high in the center and falls off with radius (see Mathur et al. 2008, and references therein); gas in clusters and groups of galaxies also follows a similar profile. In any case, if the gas is not of uniform density, the EW would be weighted by the denser gas and for the same observed column density the average density would be smaller and the inferred path length would be larger extending into the LGM. We cannot rule out the possibility that the warm-hot gas we trace is from the LGM instead. We note, however, that in the simulations of Feldmann et al. (2012), the density is roughly constant above the Galactic disk out to about 100 kpc.

As noted above, our sample is made of sight lines in which both O \( \text{vii} \) and O \( \text{viii} \) \( \text{K} \alpha \) absorption lines at \( z = 0 \) are securely detected. Does this mean that our sample is biased toward high column density systems? If so, the path length and the mass of the warm-hot plasma could be severely overestimated. In Figure 3, we have plotted the EW distribution of the O \( \text{vii} \) line in all 29 sources in the parent sample. The subsample of eight sources is marked by the red shaded region; it is clear that this subsample is not biased toward high EW systems. The high EW systems are not in the subsample of this Letter because they do not have clean detections of O \( \text{viii} \) \( \text{K} \alpha \) lines, in large part because of the contamination from intrinsic absorption. It is also worth noting that the upper limits on the EWs in targets with nondetections of the O \( \text{vii} \) \( \text{K} \alpha \) line is higher than the average of the parent sample in all but one case. Altogether, we argue that the average EW of our subsample is a fair representation of the large sample and that our sample is not biased toward high column density systems.

![Figure 3](image-url) Distribution of O \( \text{vii} \) \( \text{K} \alpha \) line EW for the parent sample. The solid black line corresponds to the distribution for the 21 observations in which O \( \text{vii} \) \( \text{K} \alpha \) lines are clearly visible. The black shaded region marked the 1\( \sigma \) upper limits on the O \( \text{vii} \) \( \text{K} \alpha \) EW for eight observations with no (or less than 1\( \sigma \) significance) detection. The red shaded region corresponds to the subsample selected for this study (see the text). (A color version of this figure is available in the online journal.)
5. CONCLUSIONS

For reasonable values of parameters and with reasonable assumptions, the Chandra observations of O\textsc{vii} and O\textsc{viii} absorption lines at $z = 0$ imply that there is a huge reservoir of ionized gas around the Milky Way. It may be in the halo of the Milky Way or in the surrounding Local Group. Either way, its mass appears to be very large.

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