On the nature of the $z = 0$ X-ray absorbers: I. Clues from an external group

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Abstract Absorption lines of O\textsc{vii} at redshift zero are observed in high quality \textit{Chandra} spectra of extragalactic sightlines. The location of the absorber producing these lines, whether from the corona of the Galaxy or from the Local Group or even larger scale structure, has been a matter of debate. Here we study another poor group like our Local Group to understand the distribution of column density from galaxy to group scales. We show that we cannot yet rule out the group origin of $z = 0$ systems. We further conclude that to argue for a Galactic or an extragalactic origin of $z = 0$ systems is premature as they likely contain both components and predict that future higher resolution observations will resolve the $z = 0$ systems into multiple components.

Keywords Galaxy: halo · Local group · Galaxies: clusters: general · Galaxies: clusters: individual (NGC 1600) · Intergalactic medium · X-rays: galaxies: clusters

1 Introduction

\textit{Chandra} and \textit{XMM–Newton} observations have detected absorption lines due to highly ionized elements, notably O\textsc{vii}, at redshift zero toward all extragalactic sight lines with sufficiently high quality grating spectra. The location of the absorber producing these lines has been a matter of debate, centering primarily on two scenarios: (1) in the extended halo of our Galaxy or (2) in the Local Group (LG) or the large scale structure around the Galaxy (see Bregman 2007 and references therein). There are good arguments in support of both (1) and (2). Wang et al. (2005) find O\textsc{vii} absorption toward the large Magellanic cloud (LMC). Bregman and Lloyd-Davies (2007) find that for the Galaxy, the O\textsc{vii} absorption line intensity is correlated with soft X-ray emission. Similar observations and theoretical arguments by Fang et al. (2006) support scenario (1). Galactic fountain models (Shapiro and Field 1976) also predict a hot halo around star-forming spiral galaxies, perhaps including the Galaxy itself. Models of large scale structure and galaxy formation, on the other hand, suggest that scenario (2) is a plausible source for local absorption. Comparison of O\textsc{vii} absorption strength with the emission measure suggests a low-density extended environment (Rasmussen et al. 2003). Direct determinations of temperature and density through photo- and collisional-ionization models of the observed absorption line ratios do not rule out either scenario (Williams et al. 2005, 2006, 2007), but in at least two cases the velocity dispersion and/or centroid of the O\textsc{vii} is inconsistent with known lower-ionization Galactic components. The idea of linking quasar absorption lines to intra-group medium is not new; Mulchaey et al. (1996) proposed the use of high ionization UV lines (e.g. O\textsc{vi}) to trace the warm-hot gas in spiral-rich groups such as the LG. Indeed, O\textsc{vi} absorption from the thick disk of our Galaxy and from the high velocity clouds (HVCs) has been observed (Wakker et al. 2003). Are the O\textsc{vi} HVCs related to the $z = 0$ O\textsc{vii} absorption lines? Or is the O\textsc{vii} absorber related to the O\textsc{vi} from the Galactic disk? The O\textsc{vi}/O\textsc{vii} ratio is a powerful probe...
of the temperature of the warm-hot gas, so understanding the relation between the two is very important.

The importance of this debate hinges on the total mass probed by the O VII absorption lines, which in turn depends upon the assumed path length. If the O VII absorbers are related to the Galaxy, then the associated mass is insignificant (though it can provide an important constraint on models of galaxy formation and feedback). On the other hand, if they trace the large intergalactic scale (or LG) structure, the associated baryon reservoir becomes comparable to the baryonic mass of all Local Group galaxies combined. It is well known that a fraction of LG baryons are “missing”; the total mass inferred from known galaxies and in observed cold and hot gas falls short of the dynamical mass of the LG assuming the baryon fraction is 15% of the dark matter (Kahn and Woltjer 1959; Nicastro et al. 2002 and references therein). It is likely that these missing baryons are in the not-yet observed warm-hot phase, which would be traced by O VII absorption lines.

It is difficult to resolve this issue with simple observations, because the spectral resolution of current X-ray gratings is insufficient to resolve the absorption lines into Galactic and LG components; this is why a variety of approaches were undertaken by different groups cited above. In fact, there is almost certainly hot gas associated with the thick disk of the Galaxy. What we need to know is whether there are components to the z = 0 systems from the Galactic corona, LG, and extended structures, and if so, what is their relative contribution. In this article we attempt to answer a simple question: given what is seen in other poor groups of galaxies, can we rule out O VII absorption from intra-group gas at strengths as observed as in z = 0 systems? We determine, from the perspective of an observer centered within NGC 1600 (a poor group of galaxies comparable to the Local Group), how much the galactic and intragroup media would each contribute to the local warm-hot column density.

2 Method

The Local Group is a poor group of galaxies, consisting of two main galaxies and a number of satellite galaxies. Needless to say, there are other poor groups in the Universe. The physical properties of the intra-group gas, such as temperature and luminosity, and its radial distribution are governed by the group gravitational potential. It would be of interest, therefore, to study the distribution of gas in and around individual galaxies and in the intra-group medium in a poor group similar to the Local Group.

One such group, for which Chandra data already exist, is NGC 1600. The high spatial resolution offered by Chandra is important here, as it allows exact decomposition of observed intensity profile into the galactic and group components; this will be clear in the following discussion. This group is also poor, made of three galaxies, NGC 1600, NGC 1601, and NGC 1603 of which NGC 1601 is a lenticular galaxy while the other two are ellipticals. Admittedly, the galaxies in this group are different from the LG galaxies; this caveat is discussed further in Sect. 4.

The NGC 1600 group was observed with Chandra in September 2002. The details of the observations and data reduction are presented in Sivakoff et al. (2004, hereafter Paper I). While the focus of their work was on the bright elliptical galaxy NGC 1600, the entire image of the group was analyzed by these authors (see their Fig. 1). They find that the X-ray emission extends all the way from the center of the central galaxy to the outskirts of the group. From visual inspection of the group emission, it is clear that there is a smooth transition from the central galaxy emission to the group emission. The surface brightness profile of the diffuse X-ray emission is well fit by the sum of two beta models, each defined as:

\[
I_X(\alpha) = I_0 \left[ 1 + \left( \frac{\alpha}{\alpha_c} \right)^{2\beta+1/2} \right]^{-3\beta+1/2}
\]

where one component corresponds to the interstellar medium of the central galaxy and the other to the intra-group gas; \(I_0\) and \(\alpha_c\) are the central surface brightness and core radius respectively. In the inner “galactic” component, the fit parameters were found to be \(\beta_{in} = 1.18^{+0.33}_{-0.20}\), \(I_{0, in} = 0.97^{+0.08}_{-0.07}\) and \(\alpha_c = 14.4^{+3.3}_{-2.3}\) arcsec. The parameters of the outer “group” components were found to be \(\beta_{out} = 0.36^{+0.01}_{-0.01}\), \(I_{0, out} = 0.039^{+0.005}_{-0.005}\) and \(\alpha_c = 25.0\) arcsec. The group emission starts to dominate beyond about 25 arcsec from the center corresponding to 7.3 kpc at the source. The emission from the central galaxy is soft while that from the group is harder. There is also soft extended emission in/around the other two smaller galaxies. In addition there is a tail of soft emission connecting NGC 1603 and NGC 1600 (see Paper I, Fig. 7). The center of the group potential lies close to, but to the northeast of the galaxy NGC 1600. The temperature of the group gas is \(\sim 1.5\) keV as deduced from the spectral fits, and consistent with the temperature of other X-ray bright groups. In Paper I, the X-ray emitting hot gas was fitted with an optically thin thermal plasma model (MEKAL model in XSPEC). In this model, the luminosity is simply \(L = P' \times EM\) and \(EM\), the emission measure is \(\int n_e^2 dV\). The multiplicative factor \(P'\) at each wavelength depends on density, temperature and metal abundances (Mewe et al. 1985). Thus, by fitting the observed X-ray spectrum in the 0.3–8 keV band, one can determine the three free parameters of the model, viz. temperature, density and abundance. In Paper I, the metallicity of the intra-group gas was not well constrained, but was found to be consistent with approximately solar (albeit with a factor of \(\sim 2\) uncertainty).