THE GASEOUS EXTENT OF GALAXIES AND THE ORIGIN OF QSO ABSORPTION LINE SYSTEMS

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Abstract

We present results of an ongoing program to study the gaseous extent of galaxies and the origin of QSO absorption line systems. For Ly$\alpha$ absorption systems, we find that absorption equivalent width depends strongly on galaxy impact parameter and galaxy $B$-band luminosity, and that the gaseous extent of individual galaxies scales with galaxy $B$-band luminosity as $r \propto L_B^{0.40\pm0.09}$. Applying the results to galaxies in the Hubble Deep Field to calculate the predicted number density of Ly$\alpha$ absorption lines as a function of redshift and comparing it with observations, we find that at least 50% and perhaps as much as 100% of Ly$\alpha$ absorption systems with $W \gtrsim 0.32$ Å can be explained by the extended gaseous envelopes of normal galaxies. The anti-correlation analysis has also been performed on C IV absorption line systems, and the results show that the ionized gas cross section scales with galaxy $B$-band luminosity as $r \propto L_B^{0.76\pm0.26}$.

1 Background

The absorption line systems observed in the spectra of background QSOs have provided a unique probe to the distant universe and an unbiased way to study the extended gas surrounding intervening galaxies. Comparison of galaxy and absorber redshifts along common lines of sight shows that there exists a distinct anti-correlation between Ly$\alpha$ absorption equivalent width $W$ and galaxy impact parameter $\rho$ at $z < 1$, although with a substantial scatter about the mean relation \cite{1}. This result suggests that Ly$\alpha$ absorption systems arise in extended gaseous envelopes of normal galaxies and that the gas cross section is dependent on more than galaxy impact parameter.

To investigate how the gas cross section depends on the properties of individual galaxies, we have initiated a program to obtain and analyze HST WFPC2 images of galaxies identified in fields of HST spectroscopic target QSOs. We measure structural parameters, angular inclinations and orientations, luminosities, and rough morphological types of 117 galaxies in 17 QSO fields \cite{2}. Galaxy and absorber pairs are then formed according to the comparison of redshifts.
Figure 1: Residuals of the $W$ vs. $\rho$ anti-correlation as a function of different galaxy parameters. Solid circles represent late-type disk galaxies; crosses represent early-type disk galaxies; and triangles represent elliptical or S0 galaxies. Arrows indicate 3$\sigma$ upper limits in $W$.

2 The extent of H I gas surrounding galaxies

To see how the gas cross section depends on galaxies of different properties, we show in Fig. 1 the residuals of the $W$ vs. $\rho$ anti-correlation, defined to be $\log W - \alpha \log \rho - C$, where $\alpha$ and $C$ are determined from a maximum likelihood analysis, as a function of galaxy $B$-band absolute magnitude $M_B$, redshift $z$, mean surface brightness $\langle \mu \rangle$, and disk-to-bulge ratio $D/B$. Apparently, the residuals exhibit a tight correlation with galaxy $B$-band absolute magnitude but no correlation at all with galaxy redshift, mean surface brightness, or disk-to-bulge ratio. Including all the measurable galaxy parameters in the anti-correlation analysis, we find that the amount of gas encountered along the line of sight depends on galaxy impact parameter and $B$-band luminosity, but does not depend strongly on galaxy redshift, mean surface brightness, and disk-to-bulge ratio [2]. Given the relationship between the gaseous extent $r$ and galaxy $B$-band luminosity, we can derive a scaling law which is analogous to the Holmberg relation regarding the distribution of luminous matter in galaxies. Supplementing results of Chen et al. with new measurements, we find that the gaseous extent of individual galaxies scales with galaxy $B$-band luminosity by $r/r_*= (L_B/L_B^*)^{1/4}$ with $t = 0.40 \pm 0.09$ and $r_* = 204 \pm 33~h^{-1}$ kpc at $W = 0.3$ Å, adopting $q_0 = 0.5$ and $H_0 = 100$ km s$^{-1}$Mpc$^{-3}$.

Based on our analysis, we conclude that extended gaseous envelopes are a common and generic feature of galaxies of a wide range of luminosity and morphological type. In addition, the result provides for the first time a means of quantitatively relating statistical properties of Ly$\alpha$ absorption systems to statistical properties of faint galaxies.
Figure 2: Comparison of the observed number densities of Ly$\alpha$ absorbers with an absorption equivalent width $W > 0.32$ Å (closed circles) and the predicted ones produced in extended gaseous envelopes of galaxies observed in HDF (open circles). The crosses with dashed bars indicate the faint-end corrected number densities calculated from equation (1) with $L_{B_{\text{min}}} = 0$.

3 The origin of Ly$\alpha$ absorption systems

Given the known gas cross section derived from the galaxy survey, we can estimate the incidence of Ly$\alpha$ absorption lines originating in extended gaseous envelopes of galaxies as

\[ n(z) = \frac{c}{H_0} (1 + z)(1 + 2q_0 z)^{-1/2} \int_{L_{B_{\text{min}}}}^{\infty} dL_B \Phi(L_B, z) \pi r^2(L_B), \]

where $c$ is the light speed and $r$ is the gaseous extent scaled with galaxy luminosity according to the scaling law described in the last section. Adopting a galaxy luminosity function $\Phi(L_B, z)$ obtained from the Autofib survey at redshifts $0.15 < z < 0.35$ [3], we find that luminous galaxies can explain at least 60% of the observed number density of Ly$\alpha$ absorbers [4].

Meanwhile, given that complete and accurate photometric redshift measurements are available for galaxies in the Hubble Deep Field (HDF) [5], we can derive the predicted number density of Ly$\alpha$ absorbers by multiplying the surface density of galaxies, measured empirically from HDF, with the mean gas cross section averaged over the sample galaxies, assuming that the gas cross section obtained at $z < 1$ applies to galaxies at all redshifts with no evolution. Equation (1) is now rewritten as

\[ n(z) = \frac{S}{(z_2 - z_1)} \sum_{z_1 \leq z_i < z_2} \frac{\pi r^2(L_{B_i})}{D_A^2(z_i)} / N, \]

where $(z_1, z_2)$ marks the boundary of each chosen redshift bin, $D_A$ is the angular distance, $S$ is the surface density of galaxies at redshifts $z_1 < z < z_2$, and $N$ is the total number of galaxies included in the redshift bin. The predicted number density of Ly$\alpha$ absorbers as a function of redshift is shown in Fig. 2 together with the observations obtained by Bechtold [6] and Weymann et al. [4]. We also show the predicted number density after correcting for galaxies at the faint end of galaxy luminosity function that are missing in HDF, adopting a faint-end slope obtained by Ellis et al. [3].
Clearly, at least 50% and perhaps as much as 100% of Ly\(\alpha\) absorption systems with \(W > 0.32\) Å can be explained by normal galaxies. We conclude that a significant amount of Ly\(\alpha\) absorption systems arise in galaxies and that Ly\(\alpha\) absorption systems trace galaxies at all redshifts.

4 Studies of C IV absorption systems

It is generally believed that C IV absorption systems arise in the halos of intervening galaxies, but the association with galaxies has not been firmly established. We repeat the anti-correlation analysis for C IV absorbers, and find that, of all the measurable galaxy properties, the ionized gas cross section only depends strongly on galaxy impact parameter and \(B\)-band luminosity.

We show in Fig. 3 that the C IV absorption equivalent width vs. galaxy impact parameter anti-correlation is significantly improved after accounting for the galaxy \(B\)-band luminosity. Consequently we find that the extent of ionized gas around galaxies scales with galaxy \(B\)-band luminosity by \(r/r_* = (L_B/L_B^*)^t\) with \(t = 0.76 \pm 0.26\) and \(r_* = 53 \pm 7\) \(h^{-1}\) kpc at \(W = 0.3\) Å. It is especially interesting to see that the gas cross section has a much steeper scaling relation with galaxy luminosity and that the scaling relation does not evolve strongly with redshift at \(z < 1\). A more extensive analysis will be presented elsewhere.

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