ENVIRONMENTAL DEPENDENCE OF THE NATURE OF GASEOUS ENVELOPES OF GALAXIES at $z < 1$

N. Yahata$^1$, K. M. Lanzetta$^1$, J. K. Webb$^2$, & X. Barcons$^3$

$^1$State University of New York at Stony Brook, Stony Brook, U.S.A.
$^2$University of New South Wales, Sydney, Australia
$^3$Instituto de Física de Cantabria, Universidad de Cantabria, Santander, Spain

Abstract

We present new statistical study on the origin of Ly$\alpha$ absorption systems that are detected in QSO fields. The primary objective is to investigate environmental dependence of the relationship between galaxies and Ly$\alpha$ absorption systems. We find that galaxies exhibit no environmental dependence in giving rise to Ly$\alpha$ absorbers in their halos. Conversely, Ly$\alpha$ absorbers do not exhibit preference as to the environment where they reside.

1 Introduction

Understanding the environmental dependence of the relationship between galaxies and Ly$\alpha$ absorption systems is crucial to understanding the nature of extended gas around galaxies and the origin of Ly$\alpha$ absorption systems. Early observations of high-redshift Ly$\alpha$ absorption systems indicated that the absorbers are unclustered or only weakly clustered in redshift, suggesting that the absorbers are not distributed like galaxies [1]. More recent observations of the large-scale galaxy environments of low-redshift Ly$\alpha$ absorption systems indicate that the absorbers are less clustered with galaxies than galaxies are clustered with each other, suggesting that the absorbers trace the same large-scale structures as galaxies but are not directly associated with individual galaxies [2][3][4].

Yet recent observations by Lanzetta et al. (1995) indicate that many or most Ly$\alpha$ absorption systems at redshifts $z < 1$ arise in extended gaseous envelopes of galaxies of roughly 160 $h^{-1}$ kpc radius and unit covering factor, suggesting that the absorbers are directly associated with individual galaxies [5][6]. There is also an identification of two groups or clusters of galaxies that do produce corresponding Ly$\alpha$ absorption lines, demonstrating that at least some groups or clusters of galaxies produce Ly$\alpha$ absorption systems and that at least some Ly$\alpha$ absorption systems arise in groups or clusters of galaxies [7][8].

If the absorbers are directly associated with individual galaxies, then why is it that the absorbers are apparently unclustered or only weakly clustered in redshift and are apparently less clustered with galaxies than galaxies are clustered with each other? These results may be reconciled if (1) the absorbers generally arise in galaxies but avoid galaxies in regions of higher
than average density and are thus significantly less clustered than galaxies or (2) the clustering measurements underestimate the actual clustering of the absorbers. To address these issues, it is necessary to establish the environmental dependence of the relationship between galaxies and absorption systems. Here we investigate this relationship at redshifts $z < 1$ based on an ongoing imaging and spectroscopic survey of faint galaxies in fields of Hubble Space Telescope (HST) spectroscopic target QSOs.

### 2 Galaxy and Absorber Data

The analysis is based upon an ongoing imaging and spectroscopic survey of faint galaxies in fields of HST spectroscopic target QSOs. Detailed descriptions of the observations have been and will be presented elsewhere (e.g. [5][6][8][9][10]), but in summary the observations consist of (1) optical images and spectroscopy of objects in the fields of the QSOs, obtained with various telescopes and from the literature, and (2) ultraviolet spectroscopy of the QSOs, obtained with HST using the Faint Object Spectrograph (FOS) and accessed through the HST archive.

The current sample contains 348 galaxies and 229 absorbers toward 24 QSOs. Redshifts of the galaxies span $z_{\text{gal}} = 0.0218 - 0.7873$, with a median of $z = 0.2998$. Redshifts of the absorbers span $z_{\text{abs}} = 0.0155 - 1.0361$, with a median of $z = 0.4679$. Absorption systems are detected according to a $5\sigma$ detection threshold. Measurement uncertainties in redshift are typically $\approx 150 \text{ km s}^{-1}$ for galaxy redshifts and $\approx 30 \text{ km s}^{-1}$ for absorber redshifts. Because the object of the present analysis is to examine the correlations of intervening (rather than intrinsic) galaxies and absorbers, it is necessary to exclude galaxies and absorbers that are physically related to the QSOs. Accordingly, we exclude from the analysis all galaxies and absorbers with relative velocities to the background QSOs within $\pm 3000 \text{ km s}^{-1}$. This leaves 263 galaxies and 212 absorbers toward 24 QSOs included into the analysis.

### 3 Environment Traced through Galaxy Auto-Correlation Functions

Because galaxies of the sample are sparsely sampled, it is impossible for us to establish the local galaxy environment around any particular absorber to within a meaningful degree of precision. Instead, we must apply a statistical measure of the local galaxy environment. It is well known that galaxies in the local universe exhibit a morphology–density relationship in that early-type galaxies are preferentially found in regions of higher-than-average galaxy density while late-type galaxies are preferentially found in regions of lower-than-average galaxy density. This relationship applies from galaxy clusters through sparse groups through the field (see [11] and references therein). The existence of a morphology–density relationship implies that early-type galaxies typically trace regions of higher-than-average galaxy density while late-type galaxies typically trace region of lower-than-average galaxy density—in other words, galaxy morphology is a measure of local galaxy environment in a statistical sense.

We use measurements of spectroscopic morphology to divide the galaxy sample into early-type and late-type samples. Figure 1(a) shows the galaxy auto-correlation function for early-type (43 galaxies) and late-type galaxies (220 galaxies) at impact parameter range $0 \leq \rho \leq 200 h_0^{-1} \text{ kpc}$. It is seen that early-type galaxies are more strongly clustered (by a factor of $10.0 \pm 2.7$ in terms of the correlation amplitude within $v = 1000 \text{ km s}^{-1}$), confirming that the morphology–density relationship established in the local universe also applies at higher redshifts ($z_{\text{med}} \approx 0.3$).
4 Environmental Dependence

The galaxy–absorber cross-correlation function (GACCF), \( \xi_{ga}(v, \rho) \), is defined in such a way that the probability of finding an absorber within \( dv \) of a randomly chosen galaxy is

\[
dP = m_a H_0^{-1}[1 + \xi_{ga}(v, \rho)]dv,
\]

where \( m_a \) is the absorber number density per unit length and \( H_0 \) is the Hubble constant. Figure 1(b) shows the GACCF for early- and late-type galaxies in our sample. We find that they are statistically identical to each other, which implies that the absorbers do not strongly favor or avoid regions of higher-than-average or lower-than-average galaxy density, at least over the range of densities probed by the current samples.

The GACCF is dominated by different functions according to the scale in impact parameter (see [12] for detailed discussion). First, at small impact parameters (\( \rho \lesssim \rho_0 \approx 200 \text{ kpc}, [5][6] \)), the GACCF is dominated by the galaxy halo distribution function. Integrating the GACCF within \( \rho \lesssim \rho_0 \) then yields the “integrated probability” that a given galaxy produces a Ly\( \alpha \) absorption system somewhere in its halo. For our sample, we find that this integral does not vary substantially according to galaxy type—the ratio of the integral for early-type to late-type galaxies is \( 1.6 \pm 0.7 \). Together with the morphology–density relation established in the sample, this suggests that there is no significant environmental dependence for galaxy halos that produce Ly\( \alpha \) absorption systems.

Second, at large impact parameters (\( \rho \gtrsim \rho_0 \)), the GACCF is dominated by galaxy correlation functions, specifically:

\[
\begin{align*}
\xi_{1a} &= f_1 \xi_1 + f_2 \xi_{21} \\
\xi_{2a} &= f_2 \xi_2 + f_1 \xi_{12}
\end{align*}
\]

where \( \xi_{ia} \) is the GACCF, \( \xi_i \) is the galaxy auto-correlation function, \( \xi_{ij} \) is the galaxy–galaxy cross-correlation function (\( i \neq j \) = \{1, 2\} specify galaxy type; 1 for early-type, 2 for late-type). Here, \( f_1, f_2 \) are the fractions of Ly\( \alpha \) absorbers that arise in halos of early- and late-type galaxies, respectively, which from our sample we find \( f_1 = 0.07 \pm 0.12 \) and \( f_2 = 0.59 \pm 0.16 \). Note that the ratio \( f_2/f_1 \approx 8 \) is roughly consistent with the ratio of early- to late-type galaxies in the sample. Therefore, these results suggest that the Ly\( \alpha \) absorbers arise in halos of galaxies irrespective of the galaxy type, and hence the environment where they reside.

5 Conclusion

We investigated the environmental dependence of the relationship between galaxies and absorption systems. We confirmed that the morphology–density is established in our galaxy sample \( (z_{med} \approx 0.3) \) in that early-type galaxies are more strongly clustered than late-type galaxies. Within this environment we found that galaxies exhibit no environmental dependence in giving rise to Ly\( \alpha \) absorbers in their halos. Conversely, Ly\( \alpha \) absorbers do not exhibit preference as to the environment where they reside. We therefore conclude that the previous clustering measurements of Ly\( \alpha \) absorbers is likely to have underestimated their actual clustering properties.

Acknowledgements. This research was supported by NASA grant NAGW–4422 and NSF grant AST–9624216.
Figure 1: (a) [top] Galaxy auto-correlation functions for early- and late-type galaxies. (b) [bottom] Galaxy–absorber cross-correlation functions.

References

[1] Sargent, W. L. W., Young, P. J., Boksenberg, A., & Tytler, D., 1980, Astrophys. J. Suppl. Ser. 42, 41
[2] Morris, S. L., Weymann, R. J., Dressler, A., McCarthy, P. J., Smith, B. A., Terrile, R. J., Giovanelli, R., & Irwin, M., 1993, Astrophys. J. 419, 524
[3] Bowen, V. D., Blades, J. C., & Pettini, M., 1996, Astrophys. J. 464, 141
[4] Brun, V. L., Bergeron, J., & Boissé, P., 1996, Astr. Astrophys. 306, 691
[5] Lanzetta, K. M., Bowen, D. V., Tytler, D., & Webb, J. K., 1995, Astrophys. J. 442, 538
[6] Chen, H.-W., Lanzetta, K. M., Webb, J. K., & Barcons, X., 1998, Astrophys. J. 498, 77
[7] Lanzetta, K. M., Wolfe, A. M., Altan, H., Barcons, X., Chen, H.-W., Fernández–Soto, A., Meyer, D. M., Ortiz-Gil, A., Savaglio, S., Webb, J. K., & Yahata, N 1997, Astron. J. 114, 1337
[8] Ortiz-Gil, A., Lanzetta, K. M., Webb, J. K., & Barcons, X., 1998, in preparation
[9] Barcons, X., Lanzetta, K. M., & Webb, J. K., 1995, Nature 376, 321
[10] Lanzetta, K. M., Webb, J. K., & Barcons X., 1996, Astrophys. J. Lett. 456, L17
[11] Dressler, A., 1984, Ann. Rev. Astron. Astrophys. 22, 185
[12] Yahata, N., Lanzetta, K. M., Webb, J. K., & Barcons, X., 1998, in preparation