THE ASTROPHYSICAL JOURNAL, 456:L17–L20, 1996 January 1

THE GASEOUS EXTENT OF GALAXIES AND THE ORIGIN OF Lyα ABSORPTION SYSTEMS. II. IDENTIFICATION OF A GROUP OR CLUSTER OF Lyα ABSORBING GALAXIES AT $z \approx 0.26$

KENNETH M. LANZETTA
Astronomy Program, Department of Earth and Space Sciences, State University of New York at Stony Brook, Stony Brook, NY 11794-2100

JOHN K. WEBB
School of Physics, University of New South Wales, P.O. Box 1, Kensington, NSW, Australia

AND

XAVIER BARCONS
Instituto de Física de Cantabria, Consejo Superior de Investigaciones Científicas, Universidad de Cantabria, Facultad de Ciencias, 39005 Santander, Spain

Received 1995 May 24; accepted 1995 October 20

ABSTRACT

We report the identification of a group or cluster of galaxies at redshift $z \approx 0.26$ toward the quasi-stellar object (QSO) 1545+2101 that produces a complex of corresponding Lyα absorption systems. This observation demonstrates that at least *some* groups or clusters of galaxies produce Lyα absorption systems and that at least *some* Lyα absorption systems arise in groups or clusters of galaxies. Furthermore, this observation suggests that previous measurements may have significantly underestimated the degree of clustering of Lyα absorption systems on velocity scales of several hundred kilometers per second.

Subject headings: galaxies: clusters: general — galaxies: evolution — quasars: absorption lines

1. INTRODUCTION

Over the past several years, we have been conducting an imaging and spectroscopic survey of faint galaxies in fields of *Hubble Space Telescope* (*HST*) spectroscopic target quasi-stellar objects (QSOs) (Lanzetta et al. 1995a; Lanzetta, Webb, & Barcons 1995b; Barcons, Lanzetta, & Webb 1995). One of the main results of the survey is that many or most moderate-redshift ($z \approx 0.05$–0.8) Lyα absorption systems with Lyα equivalent widths satisfying $W \gtrsim 0.3$ Å are directly associated with normal galaxies. The major difficulty in interpreting this result is that it appears to be at odds with previous observations that high-redshift ($z \gtrsim 1.6$) Lyα absorption systems appear not to be strongly clustered in redshift, whereas galaxies are strongly clustered in space. How can the apparent lack of clustering of high-redshift Lyα absorption systems be reconciled with the strong clustering of galaxies, if many or most moderate-redshift Lyα absorption systems arise in galaxies?

One way to address this question is to establish directly the relationship between Lyα absorption systems and groups or clusters of galaxies by explicitly comparing the presence or absence of Lyα absorption systems identified in absorption system surveys with the presence or absence of groups or clusters of galaxies identified in galaxy surveys. The first results along these lines were presented by Morris et al. (1993), who reported the identification of a group or cluster of galaxies at redshift $z \approx 0.08$ toward the QSO 3C 273 that does *not* produce a corresponding Lyα aborption system. Consideration of this observation, together with the previous observation that Lyα absorption systems are not clustered strongly in redshift, led Morris et al. (1993) to suggest that Lyα absorption systems may avoid regions of high galaxy density.

Here we report the identification of a group or cluster of galaxies at redshift $z \approx 0.26$ toward the QSO 1545+2101 that *does* produce a complex of corresponding Lyα absorption systems. The main difference between the group or cluster of galaxies reported here and the group or cluster of galaxies reported by Morris et al. (1993) is that the galaxies reported here occur at smaller impact parameters to the QSO than do the galaxies reported by Morris et al. (1993). This observation demonstrates that at least *some* groups or clusters of galaxies produce Lyα absorption systems and that at least *some* Lyα absorption systems arise in groups or clusters of galaxies. Furthermore, this observation suggests that previous measurements may have significantly underestimated the degree of clustering of Lyα absorption systems on velocity scales of several hundred kilometers per second. We adopt a dimensionless Hubble constant $h = H_0/(100 \text{ km s}^{-1} \text{ Mpc}^{-1})$ and a deceleration parameter $q_0 = 0.5$ throughout.

2. OBSERVATIONS

As part of a survey of faint galaxies in fields of *HST* spectroscopic target QSOs, we obtained new imaging and spectroscopic observations of faint galaxies in the field surrounding 1545+2101, and we analyzed existing spectroscopic observations of 1545+2101. Details of the survey have been and will be presented elsewhere (e.g., Lanzetta et al. 1995a, b; Barcons, Lanzetta, & Webb 1995); here we describe only those observations relevant to the present study.

Imaging observations of the field surrounding 1545+2101 were obtained with the European Southern Observatory (ESO) New Technology Telescope (NTT) on the night of 1993 July 12, using the EMMI spectrograph in direct imaging mode with an *R*-band filter and a Loral CCD detector. Observations of standard stars were obtained at intervals throughout the night. The observations were bias subtracted and corrected for flat-field variations in the usual way. The individual exposures were registered to a common origin and co-added, and the resulting image was calibrated onto a flux scale using an efficiency derived from the standard star observations. The spatial resolution of the final image was measured to be

TABLE 1

SELECTED GALAXIES AND ABSORPTION SYSTEMS TOWARD 1545+2101

Galaxies							Absorption Systems		
$\Delta\alpha$ (arcsec)	$\Delta\delta$ (arcsec)	θ (arcsec)	R	z_{gal}	ρ (h^{-1} kpc)	$M_R - 5\log h$	z_{abs}	W(Lyα) (Å)	W(C IV) (Å)
16.6	−8.7	18.7	19.9	0.2640	47.6	−19.7	0.2641	0.63	< 0.16
58.3	31.2	66.1	19.2	0.2636	167.9	−20.4	...	...	...
−21.8	98.8	101.2	18.8	0.2665	258.7	−20.8	...	...	...
85.2	−81.3	117.8	18.8	0.2648	300.0	−20.8	...	...	...
−38.7	−118.3	124.5	20.1	0.2513	306.6	−19.4	0.2526	0.22	< 0.18
7.0	166.5	166.6	20.6	0.2637	423.3	−19.0	...	...	...

NOTES.—$\Delta\alpha$ and $\Delta\delta$ are the offset of the galaxy from the QSO in right ascension and declination, θ is the angular distance of the galaxy from the QSO, R is the observed R-band magnitude, z_{gal} is the redshift of the galaxy, ρ is the impact parameter of the galaxy to the QSO, M_R is the absolute R-band magnitude, z_{abs} is the redshift of the absorption system, and W(Lyα) and W(C IV) are the rest-frame equivalent widths of the Lyα and C IV absorption lines.

FWHM ≈ 1.″7, and the limiting magnitude of the final image was measured to be $R \approx 23.5$. Objects were detected and measured in the final image using algorithms similar to those described by Lanzetta et al. (1995a).

Spectroscopic observations of objects in the field surrounding 1545+2101 were obtained with the ESO NTT on the night of 1993 July 14, using the EMMI spectrograph in multi-object spectroscopy mode with a 360 line mm^{-1} grism, a Loral CCD detector, and slitlets of 2.″5 width and of typically 10″ length. Observations of a He-Ar arc lamp, of a continuum lamp, and of standard stars were obtained at intervals throughout the night. The observations were bias subtracted, corrected for flat-field variations, optimally extracted, and wavelength calibrated in the usual way. The individual exposures were co-added, and the resulting spectra were calibrated onto flux scales using efficiency curves derived from the standard star observations. The spectral resolution of the final spectra was measured to be FWHM ≈ 12 Å. Galaxy redshifts were measured from the final spectra using procedures similar to those described by Lanzetta et al. (1995a).

Spectroscopic observations of 1545+2101 were accessed from the *HST* archive. The observations were obtained with the *HST*, using the Faint Object Spectrograph with the G130H grating. The observations were reduced using standard pipeline reduction techniques. The individual exposures were co-added, and the zero point of the wavelength scale of the final spectrum was calibrated by requiring that low-ionization Galactic interstellar absorption lines occur at rest. The spectral resolution of the final spectrum was measured to be FWHM ≈ 1.1 Å. Absorption lines were detected and measured in the final spectrum using algorithms similar to those described by Lanzetta, Turnshek, & Wolfe (1987).

3. RESULTS

The observations described in § 2 identify 15 galaxies and one star in the field surrounding 1545+2101 and six Lyα absorption systems toward 1545+2101. Here we focus on six galaxies at $z \approx 0.26$ that appear to be associated with two Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$. The observations are summarized in Table 1 and Figure 1. Table 1 lists properties of selected galaxies and absorption systems toward 1545+2101. Figure 1 shows a portion of the spectrum of 1545+2101, together with tick marks indicating the predicted wavelengths of Lyα at the redshifts of the galaxies listed in Table 1.

The observations summarized in Table 1 and Figure 1 suggest that the Lyα absorption system at $z = 0.2641$ is produced by material that shares the virial motion of the concentration of five galaxies at $z \approx 0.265$, rather than by material that is associated with only one galaxy or by material that is associated with the QSO itself. First, the Lyα absorption line at $z = 0.2641$ is spectroscopically resolved, in contrast to the Lyα absorption line at $z = 0.2526$ and the interstellar Si II λ1526 absorption line, which are spectroscopically unresolved. Second, the redshift centroid and velocity dispersion of the Lyα absorption line at $z = 0.2641$ are in excellent agreement with the redshift centroid and velocity dispersion of the concentration of five galaxies at $z \approx 0.265$. Specifically, the redshift centroid and velocity dispersion of the Lyα absorption line are $z = 0.26406 \pm 0.00012$ and $\sigma = 416 \pm 31$ km s^{-1}, respectively, and the redshift centroid and velocity dispersion of the concentration of galaxies are $z = 0.26452 \pm 0.00054$ and $\sigma = 285 \pm 89$ km s^{-1}, respectively. Finally, the Lyα absorption line at $z = 0.2641$ shows suggestive (if not formally significant) hints of velocity structure. Such structure is expected if the absorption line is produced by the cumulative effect of several overlapping galaxy envelopes.

The observations summarized in Table 1 and Figure 1 also suggest that the Lyα absorption system at $z = 0.2526$ is produced by material that is associated with the galaxy at $z = 0.2513$. The impact parameter of the galaxy at $z = 0.2513$ is $\rho = 306.6\ h^{-1}$ kpc, and the velocity difference between the galaxy and the absorption system is $\Delta v = -311.3$ km s^{-1}. These values are comparable to (but slightly larger than) those of typical galaxy and absorption system pairs identified by Lanzetta et al. (1995a).

The relatively large velocity dispersion of the Lyα absorption system at $z = 0.2641$ and the concentration of five galaxies

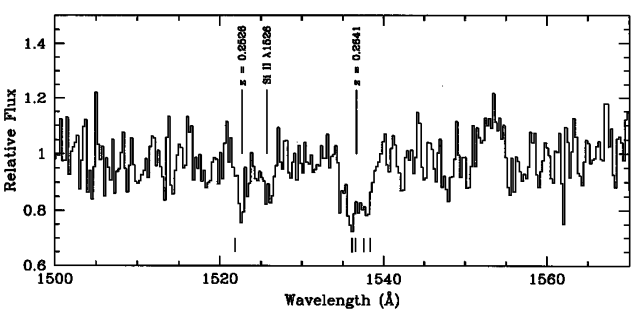

FIG. 1.—Portion of the spectrum of 1545+2101 together with tick marks indicating the predicted wavelengths of Lyα at the redshifts of the identified galaxies. The Lyα absorption lines at $z = 0.2526$ and $z = 0.2641$ and the interstellar Si II λ1526 absorption line are indicated.

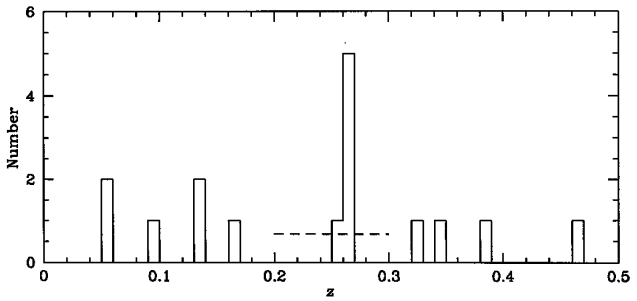

FIG. 2.—Redshift distribution of identified galaxies in the field of 1545+2101 (*solid curve*) together with an estimate of the mean galaxy density per field over the redshift interval $z = 0.2$–0.3 (*dashed curve*).

at $z \approx 0.265$ is difficult to reconcile with the relatively small velocity differences between Lyα absorbers along adjacent lines of sight recently found by Dinshaw et al. (1995), although the results of Dinshaw et al. (1995) apply at higher redshifts and are based on only a small number of velocity differences.

What is the nature of the concentration of galaxies at $z \approx 0.26$? It is very unlikely that most of the galaxies of the concentration of galaxies at $z \approx 0.26$ are physically unassociated. This is illustrated in Figure 2, which shows the redshift distribution of the identified galaxies toward 1545+2101, together with an estimate of the mean galaxy density per field over the redshift interval $z = 0.2$–0.3. (This estimate of the mean galaxy density per field was determined from observations of four other fields that were observed during the same observing run in which the field surrounding 1545+2101 was observed.) Although difficult to quantify, it appears that the concentration of galaxies at $z \approx 0.26$ constitutes a significant excess above the mean galaxy density. Given the mean galaxy density per field, the a posteriori probability of finding five galaxies within one bin in Figure 2 is just 5.6×10^{-4}, and the a posteriori probability of finding six galaxies within two bins is just 2.1×10^{-3}. We conclude that most or all of the galaxies of the concentration of galaxies at $z \approx 0.26$ are physically associated.

Of course, it may be the case that the concentration of five galaxies at $z \approx 0.265$ belongs to one physical structure and the galaxy at $z = 0.2513$ belongs to another physical structure. The velocity dispersion of the concentration of five galaxies at $z \approx 0.265$ is $\sigma = 285 \pm 89$ km s^{-1}, which is comparable to the velocity dispersion of a loose groups of galaxies. The velocity dispersion of the concentration of six galaxies at $z \approx 0.26$ is $\sigma = 1306 \pm 405$ km s^{-1}, which is comparable to the velocity dispersion of a rich cluster of galaxies. Further observations are required to determine whether the galaxies are distributed in one or two physical structures and whether these structures trace a group or cluster of galaxies.

What is the nature of the Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$? Although the Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$ occur within 3000 km s^{-1} of the redshift of the QSO, they are *not* members of the class of "associated" absorption systems. In contrast to members of the class of associated absorption systems, the Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$ show Lyα absorption lines with only modest equivalent widths and show no absorption lines of highly ionized species such as C IV and N V (or indeed of any metal ions at all). We conclude that the Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$ are members of the class of intervening absorption systems that by chance occur near the emission redshift of the QSO.

4. DISCUSSION

The observations described in § 3 suggest that the Lyα absorption system at $z = 0.2641$ and perhaps the Lyα absorption system at $z = 0.2513$ arise in a group or cluster of galaxies. What are the implications of this result?

First, it demonstrates that at least *some* groups or clusters of galaxies produce Lyα absorption systems. The main difference between the group or cluster of galaxies reported here, which does produce a corresponding Lyα absorption system, and the group or cluster of galaxies reported by Morris et al. (1993), which does not produce a corresponding Lyα absorption system, is that the galaxies reported here occur at smaller impact parameters than do the galaxies reported by Morris et al. (1993). Specifically, the impact parameters of the galaxies reported here range from 47.6 to 423.3 h^{-1} kpc, whereas the impact parameters of the galaxies reported by Morris et al. (1993) range from 473 to 4011 h^{-1} kpc. Our previous results indicate that even isolated galaxies rarely produce Lyα absorption systems with equivalent widths $W \gtrsim 0.3$ Å beyond impact parameters of $\approx 160\ h^{-1}$ kpc (Lanzetta et al. 1995a, b); hence it is not surprising that the group or cluster of galaxies reported by Morris et al. (1993) does not produce a corresponding Lyα absorption system. We conclude that Lyα absorption systems do not always avoid regions of high galaxy density and that there is as yet no evidence that galaxies in dense galaxy environments are more or less likely to produce corresponding Lyα absorption systems than are galaxies in poor galaxy environments.

Second, it demonstrates that at least *some* Lyα absorption systems arise in groups or clusters of galaxies. This result runs contrary to the standard picture obtained at high redshifts of Lyα-forest absorption systems as unclustered, intergalactic clouds, although it is consistent with our previous result obtained at moderate redshifts that many or most Lyα absorption systems are directly associated with normal galaxies. We conclude that moderate-redshift Lyα absorption systems do not necessarily arise in an unclustered or weakly clustered population of galaxies.

Finally, it suggests that previous measurements may have significantly underestimated the degree of clustering of Lyα absorption systems on velocity scales of several hundred kilometers per second. According to the usual criteria applied in absorption-line surveys, the Lyα absorption line at $z = 0.2641$ would almost certainly be counted as a single absorption line. Yet, as described in § 3, there is suggestive evidence that in fact it is comprised of several discrete velocity components. If there are other similar Lyα absorption lines that have gone unrecognized, then current estimates of the autocorrelation function of Lyα absorption systems could be in error. Indeed, eight of 91 moderate-redshift ($0 \lesssim z \lesssim 1$) "Lyα-forest" absorption lines identified by Bahcall et al. (1993) have measured velocity dispersions satisfying $\sigma > 300$ km s^{-1}, which suggests that there are other moderate-redshift Lyα absorption systems that might arise in groups or clusters of galaxies. And if this effect is significant in moderate-redshift samples, then it could well be even more important in higher redshift samples, where severe blending of Lyα absorption lines makes measurement of the degree of clustering of Lyα absorption systems more difficult. We conclude that there may be strong clustering of Lyα-forest absorption systems that is as yet undetected.

5. SUMMARY AND CONCLUSIONS

Here we report the identification of a group or cluster of galaxies at redshift $z \approx 0.26$ toward the QSO 1545+2101 that produces a complex of corresponding Lyα absorption system. The main implications of this observation are that (1) at least *some* groups or clusters of galaxies produce Lyα absorption systems, (2) at least *some* Lyα absorption systems arise in groups or clusters of galaxies, and (3) previous measurements may have significantly underestimated the degree of clustering of Lyα absorption systems on velocity scales of several hundred kilometers per second.

Are the Lyα absorption systems at $z = 0.2526$ and $z = 0.2641$ produced by individual galaxies within the group or cluster of galaxies at $z \approx 0.26$ or by other material associated with the group or cluster of galaxies? If the absorption systems are produced by individual galaxies within the group or cluster of galaxies, then we would expect (1) discrete velocity components of the Lyα absorption lines to be identified with corresponding galaxies on a component by component and galaxy by galaxy basis and (2) galaxies at smaller impact parameters to produce stronger velocity components or to stand a greater chance of producing velocity components than galaxies at larger impact parameters. These possibilities can be tested by obtaining a high spectral resolution spectrum of the Lyα absorption lines at $z = 0.2526$ and $z = 0.2641$. Because 1545+2101 is particularly bright, and because the Lyα absorption lines at $z = 0.2526$ and $z = 0.2641$ are located near the peak of the Lyα emission line, acquisition of a high-resolution spectrum is extremely practical. While it is possible that other groups or clusters of galaxies that produce Lyα absorption systems will be found, it is very unlikely that any will be found toward brighter background sources. Hence, 1545+2101 provides a unique opportunity to study the relationship between Lyα absorption systems and groups or clusters of galaxies.

REFERENCES

Bahcall, J. N., et al. 1993, ApJS, 87, 1
Barcons, X., Lanzetta, K. M., & Webb, J. K. 1995, Nature, 376, 321
Dinshaw, N., Foltz, C. B., Impey, C. D., Weymann, R. J., & Morris, S. L. 1995, Nature, 376, 321
Lanzetta, K. M., Bowen, D. V., Tytler, D., & Webb, J. K. 1995a, ApJ, 442, 538
Lanzetta, K. M., Turnshek, D. A., & Wolfe, A. M. 1987, ApJ, 322, 739
Lanzetta, K. M., Webb, J. K., & Barcons, X. 1995b, in QSO Absorption Lines, ed. G. Meylan (Berlin: Springer), 263
Morris, S. L., Weymann, R. J., Dressler, A., McCarthy, P. J., Smith, B. A., Terrile, R. J., Giovanelli, R., & Irwin, M. 1993, ApJ, 419, 524