THE NEARBY DAMPED Lyα ABSORBER SBS 1543+593: A LARGE H i ENVELOPE IN A GAS-RICH GALAXY GROUP

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ABSTRACT

We present a Very Large Array H i 21 cm map and optical observations of the region around one of the nearest damped Lyα absorbers beyond the Local Group, SBS 1543+593. Two previously uncataloged galaxies have been discovered, and a redshift has been determined for a third. All three of these galaxies are at the redshift of SBS 1543+593 and are ≤185 kpc from the damped Lyα absorber. We discuss the H i and optical properties of SBS 1543+593 and its newly identified neighbors. Both SBS 1543+593 and RBTB 154542.8+591132 have baryonic components that are dominated by neutral gas—unusual for damped Lyα absorbers, for which only ~5% of the H i cross section originates in such strongly gas-dominated systems. What remains unknown is whether low-mass gas-rich groups are common surrounding gas-rich galaxies in the local universe and whether the low star formation rate in these systems is indicative of a young system or a stable, slowly evolving system. We discuss these evolutionary scenarios and future prospects for answering these questions.

Key words: galaxies: dwarf — galaxies: individual (SBS 1543+593, MCG +10-22-038) — galaxies: structure — quasars: absorption lines — radio lines: galaxies

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1. INTRODUCTION

Damped Lyα absorbers (DLAs) are clouds of high column density neutral hydrogen gas seen in absorption in the spectrum of a bright background source, usually a QSO. These are the highest column density absorption systems and are generally found in galaxies in which the gas is predominantly neutral (for a detailed description and review of DLA studies, see Wolfe et al. [2005]). These absorption-line systems are particularly useful for tracing the densest neutral hydrogen gas, and thereby tracing gas-rich galaxies, throughout the universe.

DLA observations are unique in that they allow us to detect high-redshift galaxies in a manner that is almost entirely independent of galaxy luminosity; the requirement to detect a DLA is a bright background QSO and a high enough column density of H i gas in the foreground galaxy. In this way a large number of gas-rich galaxies and/or protogalaxies have been identified in the distant universe. In order to determine the properties of these systems, Wolfe & Prochaska (1998) and Prochaska & Wolfe (1997) have used the kinematics of DLA absorption lines to argue that DLAs originate in massive spiral galaxies. However, there is a growing body of evidence that these systems span the range of gas-rich galaxy morphologies (e.g., Rosenberg & Schneider 2003; Bowen et al. 2001b; Bouché et al. 2001; Steidel et al. 1994; Lanzetta et al. 1997; Le Brun et al. 1997; Pettini et al. 2000; Turnshek et al. 2001; Colbert & Malkan 2002; Kulkarni et al. 2005). DLAs are gas-rich galaxies, some of which are massive, luminous, and easy to detect, but many others are compact, low-luminosity, or low surface brightness (LSB) systems that are difficult to detect at large distances.

Because many of the galaxies associated with DLAs remain undetected, it can be difficult to make the connection between the dense neutral gas and the properties of the galaxy within which it resides. For this reason, the small number of DLAs for which the associated galaxy has been identified provide important information about the properties and environment of DLAs. In this paper we present a discussion of the properties and environment of SBS 1543+593, one of these select systems for which the associated galaxy has been identified.

SBS 1543+593 is one of the nearest known DLAs outside of the Local Group (only NGC 4203/Ton 1480 is closer; Miller et al. 1999). A QSO was discovered at the position of this system as part of a QSO survey. Subsequently, it was realized that the QSO lay behind this nearby foreground galaxy (Reimers & Hagen 1998). The galaxy is an LSB [μ(R) = 22.4; Bowen et al. 2001b] with an H i mass of ~1.3 × 10^8 M☉ (Bowen et al. 2001a; Chengalur & Kanekar 2002). The QSO sight line has provided a probe of the interstellar medium in the foreground galaxy as discussed in detail in Bowen et al. (2005).

The galactic environment in which a DLA resides can have a significant impact on its properties and its evolution. However,
the galactic environment of DLAs, particularly on small scales and in the local universe, remains largely unknown. For one system at \( z_{\text{abs}} = 3.39 \), at least four galaxies have been detected within 5 h\(^{-1}\) Mpc, and the H\(_\alpha\) in the DLA is found to be highly turbulent (Ellison & Lopez 2001). At \( z \sim 3 \) there have also been a number of studies of the clustering of DLAs. Several of these studies failed to detect any clustering of Lyman break galaxies (LBGs) with DLAs at \( z \sim 3 \) (Gawiser et al. 2001; Bouché & Lowenthal 2004) because of poor statistics. However, other larger studies arrive at inconsistent results on the clustering of these populations; Cooke et al. (2006) find that the DLA-LBG cross-correlation is comparable to the LBG autocorrelation, implying that DLAs are strongly clustered massive halos, while Adelberger et al. (2003) find that the DLA-LBG clustering implies that the DLAs are less strongly clustered and therefore reside in lower mass halos.

Because of the importance of environment on the evolution of galaxies, we use the data on SBS 1543+593 not only to probe the properties of this nearby DLA but also to probe its gaseous environment. Previous studies of LSB galaxies like SBS 1543+593 have shown that DLAs are generally less clustered on scales of a few megaparsecs than their higher surface brightness counterparts (Rosenbaum & Bomans 2004; Mo et al. 1994). Nevertheless, it is not unusual for LSBs to reside in small groups on scales of \( \sim 0.5 \) Mpc (Bothun et al. 1993). The low redshift of SBS 1543+593 makes it possible to study the environment of this LSB DLA in detail.

In this paper we use Very Large Array (VLA)\(^2\) 21 cm observations to map the neutral gas in and around SBS 1543+593 and present \( V \)-band data for its three newly identified companions. We discuss the VLA and optical observations of SBS 1543+593 and the new companions in \( \S \) 2. In \( \S \) 3 we present the results, including a discussion of the relationship between the H\(_\alpha\) and optical distributions in SBS 1543+593 (\( \S \) 3.1) and in the newly identified dwarf galaxies (\( \S \) 3.2). Most of the work that has been done on the environment of LSB galaxies has relied on the optical detection of their neighbors. H\(_\alpha\) observations provide a means of tracing the gas in the region. In \( \S \) 3.3 we discuss the small-scale H\(_\alpha\) environment and large-scale structure in this region. Finally, in \( \S \) 4 we discuss the impact of our findings.

We assume a value of \( H_0 = 70 \) km s\(^{-1}\) Mpc\(^{-1}\) throughout this paper.

2. OBSERVATIONS

2.1. 21 cm Data

We use VLA C-configuration data of SBS 1543+593 to study the H\(_\alpha\) distribution and environment of this nearby DLA. Within these data we identify SBS 1543+593, the LSB galaxy observed as a DLA along the sight line to the QSO HS 1543+5921 (\( z = 0.807 \)) and three previously unknown companions within \( \sim 185 \) kpc of the galaxy (see Fig. 1 for a picture of the region).

The VLA data were taken on 2001 August 13 and 14 and consist of 283 minutes of observations on the source plus observations of 3C 286 as a flux and bandpass calibrator and of 3C 343 as a complex gain calibrator. The observations were made in two IF mode with the bandpass centered at 14.069 GHz (2971 km s\(^{-1}\)), close to the systemic velocity of the galaxy measured from single-dish observations by Bowen et al. (2001a). One IF covered a bandwidth of 1.5 MHz with a velocity resolution of 5.0 km s\(^{-1}\).

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\(^2\) The Very Large Array is part of the National Radio Astronomy Observatory, which is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.
include MCG +10-22-038, a previously cataloged galaxy without a known redshift, and two previously uncataloged systems, RBTB 154542.8+591132 and RBTB 154607.7+591013. For simplicity we refer to the latter two galaxies as dwarf 1 and dwarf 2. The rms in the region of these detections falls to \(1.6\) mJy, corresponding to \(1.6 \times 10^8 M_\odot\), so these newly identified dwarfs are near the detection limit at this distance from the center of the field. Figure 1 shows optical and H\(i\) 21 cm maps of this region. The bottom panel is the POSS II blue image of the region; the top panel is the corresponding VLA H\(i\) map. The three new galaxies form a tight group slightly offset from SBS 1543+593. No other galaxies were identified in the VLA data.

The equivalent single-dish spectra for the galaxies are shown in Figure 2. The spectrum of SBS 1543+593 was created from the higher velocity, resolution smaller bandwidth IF data. The companion galaxy spectra were made from the larger bandwidth, lower velocity resolution data. The lack of noise in the baseline of these lower resolution spectra is a result of the noise clipping described above. Figure 2 shows that the companion galaxies all have similar recession velocities, which are offset from the velocity of SBS 1543+593 by \(-150\) km s\(^{-1}\). The velocities, velocity widths, and H\(i\) masses for the galaxies are calculated from these spectra, and the results are presented in Table 1. We assume a distance of 40.7 Mpc for all of the sources based on the recession velocity of SBS 1543+593.

The H\(i\) sizes for these galaxies were all computed at the 1 M\(_\odot\) pc\(^{-2}\) level. The sizes were computed by fitting isophotal contours to the data using the ELLIPSE routine, which is part of the STSDAS package in IRAF. Except for dwarf 2, which is well fitted by elliptical contours, we fitted the galaxies with circular isophotes to determine the sizes.

For SBS 1543+593 we measure an H\(i\) mass of \(1.2 \times 10^9 M_\odot\), consistent with the values measured by Chengalur & Kanekar (2002) and Bowen et al. (2001a). MCG +10-22-038 is the only previously known galaxy of the three neighbors to SBS 1543+593, but it did not have a cataloged redshift, so its proximity to the DLA was not previously known. Therefore, MCG +10-22-038 has an H\(i\) mass of \(1.1 \times 10^9 M_\odot\), while dwarf 1 and dwarf 2 are lower mass systems, with H\(i\) masses of \(1.8 \times 10^8\) and \(2.0 \times 10^8 M_\odot\), respectively.

### 2.2. Optical Data

The optical data for SBS 1543+593 and its neighbors consist of R-band imaging from the Apache Point 3.5 m telescope for
all of the objects except for MCG +10-22-038 (the only previously cataloged neighbor) and V-band imaging from the Kitt Peak National Observatory 0.9 m telescope for all of SBS 1543+593’s neighbors. The optical properties of SBS 1543+593 are discussed in detail in Bowen et al. (2001b) and are included here for discussion with respect to the properties of the neighbors. We also use the image of SBS 1543+593 taken with the Gemini Multi-Object Spectrograph (GMOS) r-G0303 (exposure time 1800 s) by Schulte-Ladbeck et al. (2005) for comparison with the H i data.

Standard calibration frames and a single I band image of the region surrounding MCG +10-22-038 were obtained at the Kitt Peak 0.9 m telescope in 2002 April. Standard IRAF procedures were used to bias-subtract, flat-field, illumination-correct, and cosmic-ray-clean the image. For a complete description of the flux calibration, see Stevenson et al. (2006). In order to subtract the background before photometry could be performed, a 5 pixel wide annulus was placed around each galaxy beyond the edge of the emission from the object. The median value from this annulus was used to subtract the background. Aperture photometry was then performed on each galaxy using ELLIPSE. For MCG +10-22-038 and dwarf 1 we used circular apertures, while for dwarf 2 we used an elliptical aperture with an ellipticity of 0.52 and a position angle of −29.3°.

The optical data that exist for these galaxies are R- and I-band measurements. However, because they tend to be blue systems, LSB galaxies are usually (in the literature) measured in the B band. In order to compare with results from the literature we assume colors for the conversion of the central surface brightnesses and magnitudes to the B band. For the B − V color of SBS 1543+593’s neighbors we assume the median color for dwarf LSB galaxies from the sample of van Zee et al. (1997), B − V = 0.49. For the B − R color of SBS 1543+593 we assume the mean color, B − R = 0.78, for LSB galaxies (not dwarfs) from de Blok et al. (1995).

Optical diameters of the galaxies were determined in three different ways to allow us to make comparisons with data from the literature. The measurements of the diameters are included in Table 2: (1) The galaxy diameter within which we compute the total magnitude. The diameter of the aperture was determined by fitting apertures until the flux stopped growing, indicating that we had hit the background (which was well inside the annulus used to fit the background). For dwarf 1 and dwarf 2, this aperture method was applied to the I-band images, and then the same aperture was used to derive the total R-band flux (D52). (2) The diameter at which the galaxy reaches an isophotal level of 25 mag arcsec−2 (D25). (3) The diameter measured at 6.4 times the scale length of the galaxy (D6.4s). As with the magnitudes, we have measured diameters in bands different from the literature values. In order to convert from our measurement of isophotal diameter to B-band isophotal diameter, we use D52/D25 = 1.4 from Swaters et al. (2002) and, by extrapolation, the fact that D52/D25 = 1.2. The galaxy scale length is assumed to be independent of wavelength in this optical range, as was found by Swaters et al. (2002) for their late-type dwarf galaxy sample.

Figure 3 shows the R-band surface brightness profile for SBS 1543+593 and the V-band surface brightness profiles for MCG +10-22-038, dwarf 1, and dwarf 2. Fits to the exponential region of the surface brightness profiles are shown with dashed lines. The central surface brightnesses (corrected to the B band) listed in Table 2 are the extrapolation of this fit to the center of the galaxy. All of these galaxies have low central surface brightnesses. The surface brightness rises sharply toward the center of SBS 1543+593 because of the combination of light from the nucleus and the background QSO. For SBS 1543+593 we have determined the B-band central surface brightness assuming (B − R) = 0.2 (Schulte-Ladbeck et al. 2004). Dwarf 1 has a B-band central surface brightness (assuming B − V = 0.49) of μ0(B) = 24.3 mag arcsec−2 and a flat surface brightness profile. MCG +10-22-038 has a small R1/4 bulge but a disk central surface brightness of μ0(B) = 21.9 mag arcsec−2. Dwarf 2 is unusual in having a slight depression in the central surface brightness with the surface brightness only reaching μ0(B) = 22.2 mag arcsec−2, while the extrapolated exponential disk surface brightness is μ0(B) = 21.8 mag arcsec−2.

3. RESULTS

3.1. The Relationship Between Optical and H i Emission in SBS 1543+593

The relative distributions of the optical and H i emission allow us to examine the relationship between stellar emission and gas density in a galaxy. Figure 4 shows the H i distribution in SBS 1543+593 overlaid on the GMOS r-G0303 image of SBS 1543+593 from Schulte-Ladbeck et al. (2005). The lowest level contour in the H i map is at 2 × 1020 cm−2, the column density above which the gas would result in a DLA if it were in the foreground of a QSO. This contour represents a 4 σ detection in a single channel of this map (the figure shows the integration of 20 channels).

The H i distribution shown in Figure 4 is consistent with the map of Chengalur & Kanekar (2002). The highest column density H i in the central region of the galaxy follows the optical light. Two regions of particular interest have been labeled in Figure 4. Region 1 is outside of the main spiral structure, has high gas density, and is a region of LSB stellar emission. This emission comes from slightly farther out than the spiral arms that are visible and appears to point in the opposite direction. The reason for this disturbance in the spiral arm structure is
| Name | Radius \((V)\)^a (arcsec) | \(V\) | \(R\) | \(M_V\) | \(M_R\) | \(\mu_0(V)\)^b (mag arcsec\(^{-2}\)) | \(\mu_0(B)\) (mag arcsec\(^{-2}\)) | \(D_h^R\) (arcsec) | \(D_{R,4a}\)^c (arcsec) | \(V - R\) | \(M_{HI}/L_B\) | \(D_{HI}/D_{HI,25}^d\) | \(D_{HI}/D_{HI,4a}\)^e |
|------|------------------|------|------|-------|-------|------------------|------------------|---------------|-------------------|--------|--------------|---------------|--------------|
| SBS 1543+593^f | 33.3 | ... | 16.3 | ... | -15.9 | 22.6 | 23.2 | 9.6 | 14.6 | ... | 4 | 15 | 2 |
| MCG +10-22-038 | 27.5 | 15.2 | ... | -17.7 | ... | 21.4 | 21.7 | 34.6 | 15.6 | ... | 0.5 | 4 | 2 |
| RBTB J154542.8+591132 (dwarf 1) | 9.4 | 19.1 | 18.8 | -13.8 | -14.0 | 23.8 | 24.2 | 11.0 | 7.5 | 0.3 | 5 | 10 | 2 |
| RBTB J154607.7+591013 (dwarf 2) | 22.0^g | 17.2 | 16.5 | -15.7 | -16.4 | 21.3 | 22.2 | 24.0 | 7.5 | 0.7 | 0.9 | 3 | 2 |

^a Galaxy diameter in \(V\) band, except for SBS 1543+593, for which it is the \(R\)-band size.

^b \(R\)-band central surface brightness.

^c The size at 6.4 times the optical scale-length.

^d The ratio of H\(\scriptstyle I\) size at 1 \(M_\odot\) pc\(^{-2}\) to the size at 25 mag arcsec\(^{-2}\).

^e The ratio of H\(\scriptstyle I\) size at 1 \(M_\odot\) pc\(^{-2}\) to the size at 6.4 times the optical scale length.

^f Data for SBS 1543+593 are from Bowen et al. (2001b).

^g This value is the semimajor axis of the aperture, which had an ellipticity of 0.52 and a position angle of -29.3°.
unclear but could point to a minor interaction in the past. The bright optical emission located near region 2 is a background spiral galaxy (discernible in the inset Space Telescope Imaging Spectrograph [STIS] image of the region). The most striking feature in the combination of the optical and H\textsc{i} images is that there is a large fraction of the H\textsc{i} disk that shows little evidence for stellar emission even in this deep GMOS image. Significant asymmetries exist in the inner regions of the galaxy and more minor asymmetries in the outer regions.

Figure 5 shows the H\textsc{i} column density distribution in gray scale overlaid with the H\textsc{i} velocity contours. The figure shows a regular velocity gradient as would be expected from the rotation of an inclined spiral galaxy. However, note that the velocity of region 1 is set off by closed contours, not exactly following the rotation curve of the galaxy. Nevertheless, this is not a large deviation from the rotation velocity, as it is not visible in the rotation curve of the northern side of the galaxy as shown in Figure 6. The velocity field as produced by AIPS was ported to GIPSY (van der Hulst et al. 1992) and was used to determine the rotation curve and orientation (inclination and position angle) of the galaxy. We used the task ROTCUR to perform a least-squares fit to the radial velocity field solving for the following parameters: the position of the dynamical center, and the systemic velocity. Fits were made using the conventional approach; reasonable starting values were provided for the galaxy center and its systemic velocity and were kept fixed while fits were made in 10" wide annuli to solve for the inclination, position angle, and rotation curve. These resulting values were then kept fixed, and ROTCUR was left to determine improved solutions for the position of the dynamical center and the systemic velocity. This was repeated until the process converged, resulting in the position of the kinematic center (in excellent agreement with the position of the optical nucleus), the systemic velocity ($v_{\text{sys}} = 2867.4$ km s$^{-1}$), inclination ($i = 40^\circ$), and position angle (P.A. = 344$^\circ$). These parameters are consistent with the values derived by Chengalur & Kanekar (2002): $v_{\text{sys}} = 2870$ km s$^{-1}$, $i = 50^\circ$, and P.A. = 344$^\circ$. Several runs were made, allowing one or more parameters to vary, investigating, for example, if there were indications of a warp. There was no compelling case, however, for either the inclination or position angle to vary with radius. The resulting rotation curve is plotted in Figure 6. In order to check for asymmetries we performed a fit on the northern and southern halves of the galaxy separately, and these results are plotted as well (dotted and dashed line). We derive slightly higher

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figures.png}
\caption{R-band surface brightness profile of SBS 1543+593 and the V-band surface brightness profiles for the three galaxy neighbors to SBS 1543+593. The solid lines show the surface brightness profiles derived from the images, and the dashed lines show exponential fits to the data. In the surface brightness profile of SBS 1543+593 the extremely steep rise in the innermost region is due to the QSO; the bump in the profile at $\sim5''$ is a star.}
\end{figure}
rotation velocities than Chengalur & Kanekar (2002) at each point; we find an inclination-corrected rotation speed at 60° of \( v_{\text{rot}} = 52 \text{ km s}^{-1} \), corresponding to a dynamical mass of \( M_{\text{dyn}}(60) = 7 \times 10^9 M_\odot \), as compared with their value of \( M_{\text{dyn}}(60) = 5 \times 10^9 M_\odot \). From our measurements the rotation curve appears to be flat or slightly rising out to at least 100°, indicating \( M_{\text{dyn}}(100) \geq 1 \times 10^{10} M_\odot \).

Figure 4 shows that the H I disk of SBS 1543+593 is much larger than the optical extent. The H I–to–optical size ratios, \( D_{\text{HI}}/D_{\text{opt}} = 15 \) and \( D_{\text{HI}}/D_{\text{6.48}} = 2 \), indicate that the galaxy has an extended H I disk relative to its stellar light. Spiral galaxies typically have H I disks that are extended relative to the stellar disks, with values of 1.7 for both of these ratios (Broeils & Rhee 1997). Dwarf galaxies tend to have even more extended H I disks, with values of 3.3 and 1.8 for these ratios, respectively (Swaters et al. 2002), making this a fairly normal gas-rich LSB galaxy once the extremely low surface brightness has been accounted for. In addition, SBS 1543+593 is unusually faint for a galaxy with this mass of H I: \( M_{\text{HI}}/L_B = 4 \pm 1 \), while the average value is only 1.5 for late-type dwarf galaxies (Swaters et al. 2002). SBS 1543+593 and its companions also fall along the H I size–H I mass relationship for galaxies from Rosenberg & Schneider (2003). SBS 1543+593 is slightly larger than most objects along that relation, but not by a significant margin.

Fig. 6.—Rotation curve of SBS 1543+593. Fits on the northern (receding; squares) and southern (approaching; triangles) halves of the galaxy were performed separately and are plotted as the dotted and dashed lines, respectively. The circles and solid line correspond to the fit for the entire galaxy.
of $4.5 \times 10^7 M_\odot$. For this best-guess stellar mass the ratio of gas mass to stellar mass is 27; the baryonic content of SBS 1543+593 is dominated by its gas. The optical light in the galaxy is dominated by stars that have formed recently. However, because it is impossible to rule out the existence of an underlying old stellar population with the available information, this may be a young galaxy, or it may be one that has been extremely inefficient in turning its gas into stars.

Systems like SBS 1543+593 with extended disks and high values of $M_\text{HI}/L_B$ are rare in the universe. Galaxies with $M_\text{HI}/L_B > 1$ are only expected to contribute 5% of the $H_i$ content. This galaxy has a lower total $H_i$ luminosity but moderate surface brightness disk with a few bright regions. The galaxy is less gas-rich than its neighbors with $M_\text{HI}/L_B \approx 0.5$, but this value is consistent with the average value for spiral galaxies (Broeils & Rhee 1997).

Overall the $H_i$ disk of SBS 1543+593 does not show evidence for strong star formation; it has optically low surface brightness even in the regions of high $H_i$ column density. The second contour in Figure 4 is only a factor of 2 below the upper end of the hydrogen mass surface density threshold for star formation that includes the molecular gas component (Kennicutt 1989). All of the high column density regions in this system show stellar emission, but for several regions the emission is extremely faint. Schulte-Ladbeck et al. (2005) estimate a star formation rate of only $0.006 h_{70}^{-2} M_\odot \text{yr}^{-1}$ over the whole galaxy. In addition, Bowen et al. (2005) have used the column density measurement at the position of the QSO to place a limit on the star formation rate surface density of $7 \times 10^4 M_\odot \text{yr}^{-1} \text{kpc}^{-2}$. The absorption-line measurements using the STIS ultraviolet spectrograph on the Hubble Space Telescope from Bowen et al. (2005) indicate that the line profiles in this central region are simple, also showing no evidence for more than a single absorption-line component in the low-ionization species (at 20 km s$^{-1}$ resolution). If there were an outflow at a large distance above the plane, there would be a chance of intersecting it along the line of sight to the QSO (the path is slightly longer than it would be for a face-on system). As with the $H_i$ emission, the absorption lines do not show evidence for starburst-induced outflows in the inner region of this galaxy. All in all, there is only a low level of star formation in this system.

3.2. Optical and $H_i$ Properties of SBS 1543+593’s Neighbors

MCG +10-22-038, dwarf 1, and dwarf 2 were all detected in the VLA observations of SBS 1543+593 because of their $H_i$ content. Figures 7–9 show the VLA maps of these three systems overlaid on the optical images. The $H_i$ in these galaxies is less extended relative to their optical scale lengths than SBS 1543+593, yet all of the galaxies are extremely gas-rich systems. Figure 7 shows that MCG +10-22-038 is a face-on, low-luminosity but moderate surface brightness disk with a few bright $H_i$ regions. The galaxy is less gas-rich than its neighbors with $M_\text{HI}/L_B = 0.5$, but this value is consistent with the average value for spiral galaxies (Broeils & Rhee 1997).

Dwarf 1 is the most unusual system in this small group. The galaxy is faint ($M_V = -13.8$), low surface brightness [$\mu_0(B) = 24.2$], blue ($V - R = 0.3$), and a factor of 3 more gas-rich than any of the late-type dwarf galaxies in the sample of Swaters et al. (2002) with $M_\text{HI}/L_B = 5$. The galaxy is faint and irregular with two higher surface brightness bands superposed on the faint disk (Fig. 8). Another irregularity in the system is that the $H_i$ extends to the north of the optically visible part of the galaxy. This galaxy has remained low luminosity and low surface brightness despite a reservoir of star-forming material and the presence of two close neighbors.

Dwarf 2 is an edge-on dwarf spiral, as can be seen in Figure 9. The galaxy has low luminosity ($M_B = -16.4$) with a redder $V - R$ color than the other galaxies in the vicinity due to either an older stellar population, extinction exacerbated by its orientation, or both. This galaxy has a lower total $H_i$ mass and a lower
peak H i column density than the other systems but an $M_{\text{HI}}/L_B$ that is higher than the value for MCG +10-22-038, the other dwarf spiral in the group. In dwarf 2 the gas follows the optical contours, showing only a slight irregularity in the lowest signal-to-noise ratio contours, which are not highly reliable because of the noise, which increases with distance from the center of the map.

The neighbors to SBS 1543+593 are, overall, gas-rich systems; MCG +10-22-038 is slightly below average for late-type dwarf galaxies, dwarf 2 is approximately average, and dwarf 1 has $M_{\text{HI}}/L_B = 5$, making it much more gas-rich than an average late-type dwarf galaxy, for which $M_{\text{HI}}/L_B = 1.5$ (Swaters et al. 2002). Altogether, these systems have an H i cross section to damped Ly$\alpha$ absorption that is $\sim 70\%$ of the cross section of SBS 1543+593. Galaxies with H i masses of $<10^9 M_\odot$ make up about 42% of the expected H i cross section at $z = 0$ (Rosenberg & Schneider 2003), so field dwarfs and/or small galaxy groups like this one are fairly common and are important contributors to the DLA population. At high redshift where young, gas-rich groups are more common, these kinds of systems may be even more significant contributors to the DLA cross section.

3.3. H i Environment

The small-scale environment (of order 200 kpc) of SBS 1543+593 includes three low-luminosity galaxies that have been identified in our VLA H i observations. These galaxies—MCG +10-22-038, dwarf 1, and dwarf 2—make up a tight group with projected distances of 183, 123, and 161 kpc from SBS 1543+593, respectively. For the small detection volume covered by our VLA map, a conservative estimate of the average galaxy density would predict $8.6 \times 10^{-2}$ galaxies down to log ($M_{\text{HI}}/M_\odot$) $= 8.07$, the detection limit of these observations at the distance of the detected galaxies, in the field using the H i mass function from Rosenberg & Schneider (2002). Because this region is not at an unbiased position, since it was centered around a known galaxy and galaxies tend to cluster, a higher than average galaxy density should not be surprising. However, the detection of three galaxies in the immediate vicinity of SBS 1543+593 indicates a significant overdensity with respect to the field. The high density is also significant given that LSB galaxies tend to have fewer near neighbors than their higher surface brightness counterparts (Taylor 1997). While the galaxy overdensity in this region is statistically significant, there is a large variation in the number of nearest neighbors to LSB galaxies [$\mu(B) \geq 23$ mag arcsec$^{-2}$] on scales less than 0.5 Mpc (Bothun et al. 1993), and the expected number of low-luminosity gas-rich neighbors is entirely unknown.

Finding DLAs in regions that contain several low-luminosity galaxies is not unusual. The possible presence of several low-luminosity systems makes it much more difficult at high redshift to unequivocally identify which object is responsible for the absorption. Steidel et al. (1997) found a DLA at $z = 0.656$ for which the associated galaxy is unidentified, but there are several other galaxies in the vicinity including a dwarf with $L_K = 0.07L_K^*$ that is more than 140 kpc from the line of sight. This system is at too high a redshift to be studied at 21 cm, so the gaseous properties of the system are unknown, but otherwise the environment of this DLA appears to be similar to that of SBS 1543+593. As we look deeper both in the optical and at 21 cm, we may find that it is not uncommon for DLAs to be associated with young gas-rich galaxy groups. In fact, the combination of rings, tidal features, and gas-rich neighbors could contribute to the multiple kinematic components often seen in high-resolution DLA observations (Wolfle & Prochaska 2000).

The presence of a significant amount of gas surrounding galaxy groups is also consistent with the determination that most of the low column density H i seen in absorption in the Ly$\alpha$ forest is also associated with galaxy groups (Ryan-Weber 2006; Morris & Jannuzi 2006).

On large scales, LSB galaxies [$\mu(B) \geq 23$ mag arcsec$^{-2}$] are found to follow the overall large-scale structure but are slightly less clustered than their higher surface brightness counterparts (Mo et al. 1994). Figure 10 shows the distribution of galaxies from the CfA Redshift Catalog$^3$ (Falco et al. 1999), which includes data from the CfA survey, as well as from several other galaxy surveys, in the region surrounding SBS 1543+593 (small filled circles). The triangle shows the position of SBS 1543+593, while the open circles show the positions of the newly identified galaxies (the points fall nearly on top of one another). The dashed line indicates the line of sight to the QSO HS 1543+5921. The plot shows that these new galaxies form a tight group (the individual galaxies cannot be distinguished on this scale; see Fig. 1 for the relative positions within the group) that in projection on the sky measures $\sim 185$ kpc from SBS 1543+593, significantly closer than any of the previously known higher surface brightness systems. All of these systems sit within a filament of galaxies that stretches off to the southwest of SBS 1543+593.

$^3$ See http://cfa-www.harvard.edu/~huancha/zcat.
Despite living in a dense galactic environment, these galaxies are low luminosity and low surface brightness, indicating that only a small fraction of the available gas has been turned into stars. That lack of a significant amount of star formation indicates that either the group is very young and has not had time to interact with the other galaxies or the timescales for interaction are long. The timescale that we can examine for this system is the crossing time derived from the velocity dispersion of the system. With a velocity dispersion of 132 km s$^{-1}$ and a size of 183 kpc, the crossing time is $1.4 \times 10^{9}$ yr. It might be expected that the tight subgroup of three neighbors—MCG +10-22-038, dwarf 1, and dwarf 2—is a more likely location for strong interactions, but the velocity dispersion is only 19 km s$^{-1}$, making the crossing time $3.3 \times 10^{7}$ yr over the region’s 63 kpc size. In either case the timescales are a few gigayears, indicating that these may not be extremely young objects, but if this group did form at a redshift significantly less than 1 as this implies, some low-mass gas-rich galaxy groups may have been assembled at fairly late times.

4. DISCUSSION

We have used the VLA in the C configuration to map the H$^{\text{I}}$ distribution in and around one of the nearest DLAs beyond the Local Group, SBS 1543+593. We identify two previously uncataloged galaxies and find a redshift for MCG +10-22-038. All of the galaxies are found to be low-luminosity gas-rich systems with $M_{HI}/L_B$ ranging between 0.5 and 5.

The low surface brightness of SBS 1543+593, despite a large reservoir of fuel for star formation, indicates that this galaxy is young or has not undergone a strong interaction in its recent past. However, SBS 1543+593 is not an isolated galaxy; on both small and large scales this is a fairly high-density region of the universe, yet the interaction timescale with its neighbors is moderate ($1.4$ Gyr).

Gas-rich, but still quiescent, galaxy groups in the local universe are very hard to find because they are low-luminosity systems, but they provide important information for understanding gas-accretion and star formation processes in these systems. The accretion of cold gas onto dwarf galaxies at late times (Mo et al. 2005; Kereš et al. 2005) is predicted to be an important mechanism for building up gas in dwarf galaxies, and theoretically it can occur without triggering a major star formation episode. The fueling of this accretion process by gas in the intergalactic medium surrounding this group is also consistent with the observations that most of the Ly$\alpha$ absorbers, which probe the intergalactic medium, are associated with galaxy groups (Ryan-Weber 2006).

If gas-rich galaxies were more likely to form at high redshift when the density of gas in the intergalactic medium was higher, then SBS 1543+593 might provide important information about the environment in which many of these DLAs may reside. These data also provide a warning about how easy it is to overlook dwarf galaxies even in the local universe. This is a nearby DLA that was previously thought to be isolated. In the high-redshift universe it becomes extremely difficult to detect galaxies like these, which have luminosities that are a small fraction of $L_c$; MCG +10-22-038, the highest luminosity system in the group, is only $\sim 0.13 L_c$ (adopting the value of $M_V = -19.91$ from de Lapparent [2003]).

DLAs cover a wide range of morphologies and surface brightnesses, but it has become clear that LSB systems are an important contributor to the population (e.g., Rosenberg & Schneider 2003; Bowen et al. 2001b; Bouchez et al. 2001; Steidel et al. 1994; Lanzetta et al. 1997; Le Brun et al. 1997; Pettini et al. 2000; Turnshek et al. 2001; Colbert & Malkan 2002; Kulkarni et al. 2005). Often LSB galaxies are thought to be isolated systems because they are less strongly clustered on large scales. However, on small scales the clustering around these galaxies is less well determined, especially when considering the role of gas-rich galaxies that might have been missed in optically selected samples. Learning more about the local environment of gas-rich galaxies and constraining the models of gas accretion onto galaxies, as well as understanding their local gaseous environments on small scales, requires a better understanding of the distribution of low-mass gas-rich galaxies in the local universe. The next generation of H$^{\text{I}}$ surveys for galaxies will provide both the sensitivity and the resolution needed to address these questions (Giovanelli et al. 2005) in much greater detail.
The goal will be to use this improved understanding of the gas distribution surrounding local galaxies to help interpret the observations of more distant gas-rich objects identified in DLA studies or by other means.

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