1. INTRODUCTION

The plethora of low column density, intervening Ly\(\alpha\) absorption lines in the spectra of high redshift QSO's (the "Ly\(\alpha\) forest") was first recognized by Lynds (1971) and has been described in detail by Sargent et al. (1980) and in many recent reviews and articles (Bajtlik 1993; Weymann 1993; Bechtold 1993; Rauch et al. 1992; Rauch et al. 1993; Lu et al. 1991; Smette et al. 1992). A considerable amount has been learned about the nature of these systems at redshifts \(z \geq 1.6\), the redshift above which Ly\(\alpha\) is observable from the ground. These redshifts are generally too large to directly detect the absorbing objects in emission. However, more recently, a modest number of Ly\(\alpha\) absorbers at low redshift have been detected in the UV (Morris et al. 1991; Bahcall et al. 1991). The proximity of these systems make them ideal targets for searches for H\,I and optical emission from the vicinity of these clouds. One can also seek possible identifications of parent objects with which the clouds might be associated.

The first low-redshift Ly\(\alpha\) forest absorption lines were...
discovered in the IUE spectrum of PKS 2155–304 by Maraschi et al. (1988). Since then, the HST has revealed many low column density absorbers in the nearby universe (Bahcall et al. 1991; Bahcall et al. 1993; Morris et al. 1991; Bruhweiler et al. 1993; Stocke et al. 1995; Shull et al. 1996). Statistical studies have been made to determine the relative correlation between these Lyα absorbing clouds and optical galaxies (Morris et al. 1991; Salzer 1992; Stocke et al. 1995; Lanzetta et al. 1995; Mo & Morris 1994; Morris et al. 1993; Morris & van den Bergh 1994). The current consensus is that the systems do correlate weakly with bright galaxies, but less so than these galaxies with other galaxies (Stocke et al. 1995). Lanzetta et al. (1995) find good evidence that some of the stronger Lyα absorbers are physically close to galaxies, but there are also examples of clouds with no optical galaxy to within a few Mpc (Stocke et al. 1995; Shull et al. 1996). Morris et al. (1991) find, in one instance, an anti-correlation between a region of very high galaxy density and Lyα forest absorbing clouds. Stocke et al. (1995) find more generally that: "the higher equivalent width absorbers are distributed more like galaxies than the lower equivalent width absorbers, which are distributed in a manner statistically indistinguishable from clouds randomly placed with respect to galaxies."

In this paper, we present a search for H I emission from the vicinity of seven nearby Lyα absorbers. H I imaging surveys routinely find gas-rich, optically uncataloged galaxies, and as such our search is complementary to the optical surveys mentioned above. In addition to searching for a possible parent population of the Lyα absorbers, the H I morphology of galaxies close to the line of sight might betray hints of unusually large gaseous extents. In the first study of this kind (van Gorkom et al. 1993) a deep search for H I emission was made around two Lyα clouds on the 3C 273 line of sight, which are located in the outskirts of the Virgo Cluster. No obvious associations between these two Lyα clouds and H I emitting galaxies were found. The seven systems studied here are located in a wide range of cosmic environments. The absorbers seen along the sight line toward Mrk 501 are located in a void and a very low density region, respectively, while the other five absorbers are located in regions of moderately high galaxy density, along the sight lines toward PKS 2155–304 and Mrk 335. The results of the H I search near the sight line toward Mrk 501 have already been presented by Stocke et al. (1995). Here, those observations will be presented in somewhat more detail. We describe the systems and observations in Secs. 2 and 3. We present the results in Sec. 4, and in Sec. 5 we briefly discuss their implications.

Throughout this paper we adopt heliocentric velocities, using the optical definition, $V_{opt} = cz$, where $c$ is the speed of light and the redshift is defined as $z = \lambda - \lambda_0 / \lambda_0$, where $\lambda$ and $\lambda_0$ are the observed and rest wavelengths, respectively.

2. THE SYSTEMS

The seven absorption-line systems have been discovered by different authors and their properties can be found in the literature. In Table 1 we summarize the sources against which they have been found, the heliocentric velocities of the lines, and the measured equivalent widths. In this table we also give the projected distance to our H I detection closest to the line of sight and the difference between the velocity of the absorption line and the systemic velocity of the galaxy as derived from the H I.

Two of the systems are seen in absorption against the BL Lac object Mrk 501, which is located in the "Great Wall" of galaxies at heliocentric velocity 10 300 km s$^{-1}$. The two absorbing systems are at 73 500 km s$^{-1}$ and 4660 km s$^{-1}$ (Stocke et al. 1995). The 73 500 km s$^{-1}$ system is located in the void between us and the great wall, it has no cataloged optical galaxies within 4.5h$^{-1}$ Mpc, where $h$ is the Hubble constant in units of 100 km s$^{-1}$ Mpc$^{-1}$. The 4670 km s$^{-1}$ system has a sparse chain of galaxies located to the southwest, the closest of which is 25' (340h$^{-1}$ kpc) off the line of sight to Mrk 501.

The detections of five, and possibly six, local Lyα forest lines have been reported for the sight line toward the BL Lac object PKS 2155–304 (Bruhweiler et al. 1993; Maraschi et al. 1988; Allen et al. 1993). We did an H I search around the three stronger lines, at 5100 km s$^{-1}$, 16 488 km s$^{-1}$ and 17 088 km s$^{-1}$, respectively. The last two velocities are uncertain by about 140 km s$^{-1}$. The lower velocity system is on the edge of the Perseus–Pisces supercluster; its nearest cataloged galaxy is ESO 466–G032, 15' (230h$^{-1}$ kpc) east of the sight line toward PKS 2155–304 with a systemic velocity of 5187 km s$^{-1}$. The higher velocity systems have a number of cataloged galaxies at similar velocities not far from the line of sight. The closest is 2155–3033 (from the CfA redshift catalog), an Sb spiral 6.4' (305h$^{-1}$ kpc) to the NE of the sight line toward Mrk 335 and with a systemic velocity of 2309 km s$^{-1}$.

The third sight line that we investigated is toward Mrk 335, which has four Lyα absorption lines (Stocke et al. 1995). Here, we observed the two lower velocity systems, which are close together in velocity at 1970 and 2290 km s$^{-1}$. These systems are located in a supercluster region. The closest cataloged galaxy is NGC 7817, an SAbc spiral, 46.5' (311h$^{-1}$ kpc) to the NE of the sight line toward Mrk 335 and with a systemic velocity of 2309 km s$^{-1}$.

The H I column densities for the absorbing systems are all in the range of $10^{15}$–$10^{16}$ cm$^{-2}$ (assuming a Doppler parameter $b = 30$ km s$^{-1}$), except for the complex absorption lines around 17 000 km s$^{-1}$. For these, a large column density, $\sim 10^{18}$ cm$^{-2}$, has been derived (Maraschi et al. 1988), placing it in the lower column density range of heavy element.

<table>
<thead>
<tr>
<th>Source</th>
<th>Velocity$^a$ km sec$^{-1}$</th>
<th>Equivalent Width$^a$ mA</th>
<th>Impact Parameter $^b$ h$^{-1}$ kpc</th>
<th>$\Delta V^b$ km sec$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKN 501</td>
<td>4600</td>
<td>154</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MKN 501</td>
<td>7530</td>
<td>48</td>
<td>230</td>
<td>0</td>
</tr>
<tr>
<td>PKS 2155–304</td>
<td>5100</td>
<td>480</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>PKS 2155–304</td>
<td>16 488</td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PKS 2155–304</td>
<td>17 100</td>
<td>810</td>
<td>305</td>
<td>0</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>1970</td>
<td>170</td>
<td>68</td>
<td>20</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>2290</td>
<td>73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Heliocentric corrected central velocity, optical definition.  
$^b$V$_{opt}$–V$_{sys}$ of nearest galaxy.
quasar absorption line systems. Thus far, no firm detections of metal lines have been made in this system, implying a metallicity < 0.1 solar (Bruhweiler et al. 1993). Note that more recent ORFEUS observations by Appenzeller et al. (1995) find a column density of 5 × 10^{16} cm^{-2} for this system.

3. OBSERVATIONS AND DATA PROCESSING

One of the sight lines, the one toward Mrk 501, was observed with the Westerbork Synthesis Radio Telescope (WSRT), while the other searches were done with the Very Large Array (VLA). We describe the observations and data processing for each of the sight lines separately. Table 2 summarizes the observations.

### 3.1 Mrk 501

The two Lyα absorption systems towards Mrk 501 were observed with the WSRT. Two 12 hour synthesis observations were made centered at 4885 km s^{-1} at a resolution of 17 km s^{-1}. The total velocity range covered in each case was 1000 km s^{-1} at a resolution of 17 km s^{-1}. Standard calibration of the data was performed using the NEWSTAR data reduction software package at NFRA. Further data editing, imaging, and analysis were performed using the AIPS package.

Mrk 501 is a radio continuum source, with an observed flux density at 1.4 GHz of 1.3 Jy. The source is unresolved at 15'' resolution, with a position of 10^{6} 52'' 11.65, 39° 50' 27.1'' (B1950). For the high-velocity system, the pointing center corresponded to the position of the continuum source, while the observations at 4675 km s^{-1} were made pointing 5' to the southwest of Mrk 501 in order to increase sensitivity at the sparse chain of galaxies to the southwest.

Subtraction of the continuum emission from the line data was performed in two ways. The first involved linear fits in frequency to the calibrated complex visibilities (Cornwell et al. 1992). The second involved linear fits in frequency to the multi-channel image cube. The results from the two methods were similar, although the residual artifacts towards the edges of the field were worse for the image-plane subtraction (as expected), and the analysis presented herein relies on the uv-data continuum subtraction method.

Images of Mrk 501 were made using "natural" weighting of the visibilities. The FWHM of the WSRT synthesized beam was 25''×15''. The image cubes were smoothed in velocity to 34 km s^{-1} resolution and visually inspected for 21 cm emission signal. No H I signal is seen anywhere in the field.

### Table 2. Observing log.

<table>
<thead>
<tr>
<th>Source</th>
<th>Telescope</th>
<th>Date</th>
<th>Configuration</th>
<th>Velocity / km sec^{-1}</th>
<th>Channel Width / kHz</th>
<th>No. Channels</th>
<th>Integration Time / Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKN 501</td>
<td>WSRT</td>
<td>1993 Dec 18</td>
<td>54m</td>
<td>4675</td>
<td>78</td>
<td>63</td>
<td>12</td>
</tr>
<tr>
<td>MKN 501</td>
<td>WSRT</td>
<td>1994 Jan 9</td>
<td>36m</td>
<td>7530</td>
<td>78</td>
<td>63</td>
<td>12</td>
</tr>
<tr>
<td>MKN 501</td>
<td>WSRT</td>
<td>1994 Feb 3</td>
<td>36m</td>
<td>4675</td>
<td>78</td>
<td>63</td>
<td>12</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>VLA</td>
<td>1993 Sept 26</td>
<td>DmC</td>
<td>5100</td>
<td>48.8</td>
<td>63</td>
<td>4</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>VLA</td>
<td>1993 Sept 30</td>
<td>DmC</td>
<td>17400</td>
<td>48.8</td>
<td>63</td>
<td>3</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>VLA</td>
<td>1995 Apr 24</td>
<td>D</td>
<td>16880</td>
<td>195</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>VLA</td>
<td>1995 May 1</td>
<td>D</td>
<td>16880</td>
<td>195</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>VLA</td>
<td>1995 Apr 24</td>
<td>D</td>
<td>2135</td>
<td>97.7</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>VLA</td>
<td>1995 May 1</td>
<td>D</td>
<td>2135</td>
<td>97.7</td>
<td>63</td>
<td>2</td>
</tr>
</tbody>
</table>

*Shortest WSRT spacing in meters, or VLA configuration.

*Heliocentric corrected central velocity, optical definition.

### Table 3. Sensitivities.

<table>
<thead>
<tr>
<th>Source</th>
<th>Velocity Range / km sec^{-1}</th>
<th>Beam FWHM / arcsec</th>
<th>Velocity Resolution / km sec^{-1}</th>
<th>Noise / mJy per beam</th>
<th>Mass / 10^{+17} M_{\odot}</th>
<th>Column Density / 10^{20} cm^{-2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrk 501</td>
<td>4175-5175</td>
<td>25×15</td>
<td>34</td>
<td>0.55</td>
<td>5</td>
<td>2.7</td>
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<tr>
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<td>4175-5175</td>
<td>25×15</td>
<td>68</td>
<td>0.35</td>
<td>7</td>
<td>3.5</td>
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<tr>
<td>Mrk 501</td>
<td>4175-5175</td>
<td>38×38</td>
<td>34</td>
<td>0.90</td>
<td>8</td>
<td>1.1</td>
</tr>
<tr>
<td>Mrk 501</td>
<td>7030-8030</td>
<td>25×15</td>
<td>34</td>
<td>0.80</td>
<td>18</td>
<td>3.9</td>
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<tr>
<td>Mrk 501</td>
<td>7030-8030</td>
<td>25×15</td>
<td>68</td>
<td>0.55</td>
<td>25</td>
<td>5.5</td>
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<td>Mrk 501</td>
<td>7030-8030</td>
<td>38×38</td>
<td>34</td>
<td>1.40</td>
<td>31</td>
<td>1.6</td>
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<tr>
<td>PKS 2155-304</td>
<td>4844-5409</td>
<td>66×39</td>
<td>21</td>
<td>0.60</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>4844-5409</td>
<td>66×39</td>
<td>43</td>
<td>0.43</td>
<td>6</td>
<td>0.4</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>17100-17723</td>
<td>53×45</td>
<td>46</td>
<td>0.23</td>
<td>34</td>
<td>0.2</td>
</tr>
<tr>
<td>PKS 2155-304</td>
<td>16283-17525</td>
<td>98×47</td>
<td>46</td>
<td>0.3</td>
<td>50</td>
<td>0.16</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>1660-2660</td>
<td>65×53</td>
<td>25</td>
<td>0.40</td>
<td>0.5</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*rms per channel.

^b5σ H I mass per beam per channel at the field center.

^c5σ I column density per channel at the field center.
cube above five times the rms in a given channel. The image cube was then smoothed in both velocity and spatially to 68 km s^{-1} channel^{-1} and to 38'' spatial resolution. Again, no emission is seen anywhere in the cubes above five times the rms at any velocity or spatial resolution. The noise values at various resolutions are listed in Table 3.

3.2 PKS 2155–304

PKS 2155–304 was observed twice with the VLA. The first set of observations was done with the 1 km array with an extended (3 km) north arm (DnC configuration) to compensate for the southern declination of the source. The low-velocity system was observed for 4 hours, centered at 5100 km s^{-1}, covering 560 km s^{-1} with a velocity resolution of 21 km s^{-1}. The high velocity systems were observed for a total of 10 hours. These observations were centered at 17400 km s^{-1} in an effort to also include a possible Lyα system at 17700 km s^{-1}. However, more recent HST data, obtained with the Faint Object Spectrograph and G130H grating do not confirm the reality of that system (Allen et al. 1993). The total velocity range covered was 620 km s^{-1} with a velocity resolution of 23 km s^{-1}. All those data suffered from rather serious interference. The high velocity system was reobserved with the VLA in the 1 km (D) configuration to make up for the loss of data due to interference and to cover also the Lyα system at 16488 km s^{-1}. The time on source was again 10 hours. The observations were centered at 16880 km s^{-1} and covered 1280 km s^{-1} with a resolution of 46 km s^{-1}. Unfortunately, these observations were made during daytime and the data suffered rather badly from solar interference.

PKS 2155–304 is a radio continuum source, with a variable flux density. We measured a flux density of 0.45 Jy at 1.4 GHz. All observations were centered at the radio position of the BL Lac object, 21^h 55^m 58.30^s, -30°27' 54.4'' (B1950). Standard calibration procedures were followed, giving special care to the bandpass calibration. A bandpass calibrator was observed once every 2 hours, and for each data point we used the bandpass solution closest in time. Initially, we subtracted the continuum by making a linear fit in frequency to the calibrated complex visibilities, using the inner 75% of the band. After the continuum subtraction, the data were clipped to remove solar and man-made interference. Images were made of each of the observing runs separately. After inspection of the cubes to locate the channels with H I emission, the subtraction of the continuum was re-done, making a fit to the line free channels only.

For the low velocity system, images were made using natural weighting, resulting in a FWHM of the synthesized beam of 66'' × 39''. For the high-velocity systems the data of the various observing runs were combined in the uv plane, after Hanning smoothing the data of the first run down to the resolution of the second run. Images were made using natural weighting, resulting in a synthesized beam of 97.8'' × 47.2''. Several galaxies were detected in H I, one in the low-velocity data and three in the high-velocity data. These results are described in Sec. 4.

3.3 Mrk 335

We observed Mrk 335 with the VLA in the 1 km (D) array for 4 hours in total. The observations were centered at 2135 km s^{-1} in between the velocities of the two Lyα absorbers, covering a range of 1000 km s^{-1} with a velocity resolution of 25 km s^{-1}. The observations were centered at the optical position of the Seyfert galaxy, at 19° 55' 28.6'' (B1950). The Seyfert galaxy itself is not a radio continuum source. We subtracted background continuum sources by making a linear fit to the calibrated complex visibilities. Images were made using natural weighting, resulting in a synthesized beam of 62.8'' × 52.7''. One previously uncataloged galaxy was discovered in H I. We describe this result in the next section.

For the H I detections, we made images of the total hydrogen emission by smoothing the data spatially and in velocity, using the smoothed cube as a mask for the full resolution data. Only pixels above 2σ in the smoothed cube were used in the sum. Throughout this paper we use images of the digitized POSS to show overlays of neutral hydrogen emission on optical images.

4. RESULTS

4.1 Upper Limits

Although the more interesting result of this work is the detection of so many galaxies, the upper limits we can place...
on any H I in emission close to the Lyα absorbers are important too. In Table 3 we list the mass and column density limits for each of the systems. These are 5σ limits at the field center. Farther from the center, they need to be corrected for the change in primary beam response. The primary beam pattern is roughly Gaussian with a FWHM of 36' and 30' for the WSRT and the VLA, respectively. For example, the VLA limits are a factor of two worse at 15' from the field center, and 10 times worse at 25'. At the position of the sparse group to the SW of Mrk 501, the mass and column density limits are a factor of five worse than at the field center. Although these limits put serious constraints on the presence of small, gas-rich dwarf galaxies very close to each of the lines of sight, the small dwarf detected toward Mrk 335 at 12' from the line of sight could only have been detected in the observations toward Mrk 335 and in the low-velocity system toward PKS 2155-304. Interestingly, in both these observations (and only those) a small galaxy was found very close to the velocity of the absorber, but at rather large projected distance from the line of sight. It should also be noted that in the sight line toward Mrk 501, the one observation in which no galaxies were detected at all the surface brightness sensitivity is ten times worse than that of the other observations. In fact, some of the most gas-rich, but low H I surface density galaxies such as Malin 1 could have escaped detection in those data.

4.2 H I Detections

4.2.1 Mrk 335

Perhaps the most exciting result of these observations is the detection of the small dwarf near the sight line toward Mrk 335. Contour images of the velocity channels are shown in Fig. 1. Although the emission is not resolved in individual channels, the peak of the emission clearly shifts in position with velocity. The maximum displacement of the peaks gives us a lower limit to the H I extent, which is $45''$ or $4.2h^{-1}$ kpc. A position – velocity profile along the major axis of the galaxy (at a PA of $0^\circ$) is shown in Fig. 2. To put things in perspective, we show in Fig. 3 an overlay of the total H I emission onto an optical image, which includes Mrk 335 as well. Although the H I is more extended than the optical emission of this tiny dwarf galaxy, there is a huge distance ($68h^{-1}$ kpc) between the lowest H I contour (at $4.8\times10^{19}$ cm$^{-2}$) and the sight line toward Mrk 335. The H I properties derived from this observation are summarized in Table 4. The systemic velocity as derived from the H I differs by only $20$ km s$^{-1}$ from that of the higher column density absorber at $1970$ km s$^{-1}$.

4.2.2 PKS 2155–304

At low velocities, we detect H I emission from ESO 466–G032, located $230h^{-1}$ kpc to the east of the line of

![Fig. 2. A position velocity plot along the major axis, taken at a position angle of 0°, of the dwarf in the Mrk 335 field. Contour levels are at −1.2, 1.2, 2.4, 3.6, 4.8, and 6.0 mJy per beam.](image1)

![Fig. 3. An overlay of the H I emission (contours) on an image of the digitized POSS showing Mrk 335, lower left corner and the dwarf detected in H I. The contour interval is $4.8 \times 10^{19}$ cm$^{-2}$. The arrow points to Mrk 335.](image2)
sight to PKS 2155–304. This is the closest optically cata-
loged galaxy to the line of sight. The H I is seen over the
velocity range 5080 km s\(^{-1}\) to 5130 km s\(^{-1}\). Contour images
of the velocity channels at 11.7 km s\(^{-1}\) resolution are shown
in Fig. 4. Crosses mark the optical position of the H I emit-
ting galaxy. The systemic velocity as derived from the H I
emission is 5100 km s\(^{-1}\], significantly less than the reported
systemic velocity of 5187 km s\(^{-1}\]. Optically, the galaxy looks
rather disturbed, with a spiral arm (or tidal feature?) extend-
ing to the southwest. The H I emission is just barely above
the noise. Although it appears to be slightly extended in the
direction of the extended optical feature, the synthesized
beam is extended in the same direction. There is a hint of
rotation along the optical major axis of the galaxy, with the
receding side to the northeast (Fig. 4). The angular resolution
of the current data is not sufficient to say any more about the
H I morphology; the signal is only barely resolved. The H I
parameters derived from these observations are listed in Table 4. Finally, to put things
in perspective we show in Fig. 5 an H I overlay on an optical
image including both the galaxy and the BL Lac object.

The high-velocity data cube covers the velocity range
from 16 240 km s\(^{-1}\) to 17 720 km s\(^{-1}\), but the quality varies
across the band. At velocities in excess of 17 500 km s\(^{-1}\],
the data quality is poor. We detect H I emission from three
galaxies. The galaxy closest to the line of sight, 2155–3033,
is at a projected distance of 305h\(^{-1}\) kpc to the south. The
H I emission from this galaxy is barely above the noise. A
weak signal is seen over velocities from 16 900 km s\(^{-1}\) to
17 300 km s\(^{-1}\], with no detectable H I in the two middle
channels (Fig. 6). The systemic velocity derived from the H I
is 17 100 km s\(^{-1}\], the optical redshift gives a velocity of
17 300 km s\(^{-1}\].

A much stronger H I emitter is found to the southeast at a
projected distance of 610h\(^{-1}\) kpc. This is an IRAS source,
F21569-330, with a hitherto unknown redshift. The H I emis-
sion can be seen over a velocity range from 16 650 km s\(^{-1}\)
to 16 925 km s\(^{-1}\] (Fig. 7). The kinematic major axis lies along
the optical major axis at a PA of \(-40^\circ\), with the north side
receding. A position velocity profile along the major axis is
shown in Fig. 8.

Almost due north of PKS 2155–304 we detect an opti-
cally uncataloged galaxy at a projected distance of 515h\(^{-1}\)
kpc from the line of sight. H I can be seen in emission from 17 063 km s\(^{-1}\) to 17 248 km s\(^{-1}\) (Fig. 9). The kinematic
major axis is east–west and a position velocity profile along
this axis is shown in Fig. 10. Optically the galaxy looks
distorted, slightly extended to the northwest with what are
possibly two dwarf companions. The H I parameters derived
from these observations are listed in Table 4. Finally, to put
things in perspective, we show in Fig. 11 an overlay of the
H I emission of the three galaxies detected in the high veloc-
ity cube on an optical image, which shows, in addition to the
galaxies, PKS 2155–304.

5. DISCUSSION

Our search for H I emission from the vicinity of nearby
Lyα absorbers has resulted in the detection of five galaxies,
two of which were previously uncataloged. We shall first
discuss whether this detection rate is unusual in any sense:
does the presence of a Lyα absorber increase the chance of
finding H I in emission? Following that, we shall discuss
what we have learned from the detections, and whether there
is any indication that the HI in emission is related to the
Lyα absorption. Finally we will discuss whether the present
observations have illuminated the nature of the nearby Lyα
absorbers.

A variety of data is available to assess whether our detec-
tion rate of H I-rich systems is unusual in any way. Briggs
(1990) summarized the results of all major unbiased H I surveys, while the currently most accurate H I luminosity function has been constructed by Rao & Briggs (1993). More specific and directly comparable to our result is the work by Weinberg et al. (1991) and Szomoru et al. (1994, 1996), who used the VLA to do unbiased H I surveys in environments of differing galactic density. Szomoru et al. (1994) probed voids as well as supercluster environments and compared fields centered on optically known galaxies and optically blank fields.

For simplicity sake, we take as the volume searched in our survey the region within a radius of 22' from the pointing center. This is the 20% point of the primary beam; beyond that, the shape of the beam is highly uncertain. Our search within that volume is complete to the 5σ limits listed in Table 3, multiplied by five (correcting for the primary beam response). The volume searched down to a mass limit of $2 \times 10^9 M_\odot$ of H I is $60h^{-3}$ Mpc$^3$. In this volume, we detected three galaxies with H I masses of a few times $10^9 M_\odot$ of H I, giving a density of $0.05 \pm 0.02$ Mpc$^{-3}$. The volume searched down to $5 \times 10^8 M_\odot$ of H I is much smaller, $6.8h^{-3}$ Mpc$^3$. Two galaxies of even smaller masses were detected in that volume, bringing the galaxy density in the mass range of $10^7 M_\odot$ to $5 \times 10^8$ to $0.3 \pm 0.2h^3$ Mpc$^{-3}$. These H I mass densities are quite consistent with the results of Briggs (1990), who found a density of $0.07h^3$ Mpc$^{-3}$ and $0.1h^3$ Mpc$^{-3}$ for H I masses of a few times $10^9 M_\odot$ and
10^8 M_☉, respectively. Only a small fraction of the volume searched, 7h^{-3} Mpc^3, is in a true void; the remaining volume is more characteristic of supercluster densities. Weinberg et al. (1991) found a cumulative space density of 0.13h^3 Mpc^{-3} for gas rich dwarfs above 10^8 M_☉ of H I in the Perseus-Pisces supercluster, a result similar to ours. In conclusion, although the statistics are small, it appears that the presence of nearby Lyα forest absorbers has not significantly altered the detection rate of H I emitting objects in either the void or the high-density regions.

5.1 The Markarian 335 Sight Line

Nevertheless, the detections of two galaxies almost exactly at the velocity of their nearby Lyα absorbers, and the fact that these are the only detections in a 500 and 1000 km s^{-1} range for PKS 2155–304 and Mrk 335, respectively, beg the question whether there is a possible association between the galaxies and the absorbers. The most tantalizing system is the uncataloged dwarf galaxy at a projected distance of 68h^{-1} kpc from the line of sight toward Mrk 335. The absolute magnitude of this dwarf has been estimated to be M_B = -15.4 based upon a linear extrapolation of the calibration supplied by eight, nearby HST guide stars on the digitized version of the POSS-E plate material. This approximate magnitude assumes that H_0 = 100 km s^{-1} Mpc^{-1} despite the location of this object within the bounds of the local supercluster. The proximity, spatially and in velocity, of the Lyα absorber and dwarf irregular could mean no more than that they originated in a common larger scale structure, e.g., a filament (Cen et al. 1994; Hernquist et al. 1996; Miralda-Escudé et al. 1996; Mücke et al. 1996). Alternatively, it could imply that the Lyα cloud is gravitationally bound to the dwarf. Perhaps, it is still falling in or has been ejected in a galactic wind. The kinematic structure does not help to choose between these various possibilities. The minimum dynamical mass in the Lyα cloud + dwarf galaxy system needed to make it a bound system can be derived by requiring that the total kinetic energy of the system is less or equal to the potential energy. Thus,

\[ M_{\text{dyn}} = \frac{1}{2G} (\Delta V)^2 \Delta R, \]  

where G is the gravitational constant, ΔV the line-of-sight velocity difference, and ΔR the projected distance between absorber and galaxy. The minimum dynamical mass is 4.6×10^9 M_☉. A crude estimate of the mass of the dwarf galaxy can be obtained from the H I kinematics. Assuming a total H I extent of 3.8 kpc and a rotation velocity of 55 km s^{-1}, we find \( M = 6.7 \times 10^9 M_☉ \). Thus, in order for the Lyα
cloud be bound to the galaxy, the dwarf needs to be embedded in a massive dark halo.

An intriguing possibility is that the Lyα absorption arises from within a mostly ionized gas disk of the dwarf galaxy. Maloney (1992) and Stocke et al. (1995) discussed the possibility that nearby Lyα lines could be produced by gas at large radii in the disks of spiral and irregular galaxies. Maloney concludes that the unexpectedly large number of low-redshift Lyα absorption lines seen with HST toward 3C 273 can be produced by extended ionized gas disks in the halos of spiral and irregular galaxies. The observed frequency of absorbers requires that either $L_*$ galaxies have huge (several hundred kpc) halos or, more plausibly, that the decrease of absorption cross section with declining luminosity is slow enough for low-luminosity galaxies to dominate the integrated cross section. Shull et al. (1996) make the case that, for absorbers of mean radius $R = (100 \text{ kpc}) R_{100}$, only dwarf galaxies have the comoving space densities

$$\phi_0 = (0.9 \text{ Mpc}^{-3}) R_{100}^{-2}$$  \hspace{1cm} (2)

necessary to explain the frequency of low-redshift Lyα clouds. For reference, this density is over 20 times that of $L_*$ galaxies, recently estimated as $\phi(L_*) = 0.04 h^3 \text{ Mpc}^{-3}$ (Marzke et al. 1994).

A first hint that low-luminosity galaxies may indeed dominate the cross section comes from the discovery (Barcons et al. 1995) of possibly corotating Lyα absorption at large (50 kpc) projected distance from two small, late-type spiral galaxies. Contrary to the cases found by Barcons et al. (1995), we have no evidence for corotation of the ionized gas with the galaxy, the Lyα absorption occurs too close to the minor axis of the galaxy. The small velocity difference between the absorber and the systemic velocity of the galaxy is of course not inconsistent with corotation, but at that large distance anything that is bound to the galaxy is expected to have a velocity close to the systemic velocity of the galaxy.

Although Stocke et al. (1995) discussed the problems with huge ionized halos around a single bright spiral galaxy, it might be possible that the Lyα absorption at $68 h^{-1} \text{ kpc}$ from the dwarf arises in an ionized halo. Using
the model calculations of Maloney (1992) and Dove & Shull (1994), we find that an ionized 80–100 kpc halo is not at all unlikely for a dwarf galaxy. For example, consider a spherical dark-matter halo, with central density $\rho_0$, core radius $r_0$, and asymptotic halo velocity $v_A = (4\pi G\rho_0 r_0^2)^{1/3} = (50 \text{ km s}^{-1})v_0$. The three-dimensional velocity dispersion is $\langle v^2 \rangle = (3/2)v_A^2$. In equilibrium, the gaseous hydrogen will settle into an atmosphere above the disk plane, with density

$$n_H(z) = n_H(0)\exp \left( -\frac{z^2}{2\sigma_H^2} \right),$$

(3)

where $\sigma_H = (18.1 \text{ km s}^{-1})T_4^{1/2}$ is the thermal velocity of hydrogen at temperature $T = (10^4.3 \text{ K})T_4$. At a radius $R = (100 \text{ kpc})R_{100}$ from the galactic center, we may express the total hydrogen density at the disk midplane as,

$$n_H(0) = \frac{N_H v_A}{(2\pi)^{1/2}\sigma_H R} = (5.57 \times 10^{-6} \text{ cm}^{-3})N_{18050}R_{100}^{-1/2}T_4^{1/2},$$

(4)

where $N_H = (10^{18} \text{ cm}^{-2})N_{18}$ is the total column density of hydrogen, neutral and ionized, integrated through the disk.

In the optically thin limit, the neutral hydrogen density is set by photoionization equilibrium,

$$n(H^0) = \frac{n_f n_f a_H(1)}{\Gamma_H},$$

(5)

where we adopt a case-A radiative recombination rate coefficient

$$a_H(1) = (2.48 \times 10^{-13} \text{ cm}^3 \text{s}^{-1})T_4^{-0.726}$$

(6)

and a hydrogen photoionization rate $\Gamma_H = (2.64 \times 10^{-14} \text{s}^{-1})I_{14}$. Here, we express the metagalactic ionizing radiation field, $I_0 = I_0(v/v_0)^{-\alpha}$, with

$$I_0 = (10^{-23} \text{ ergs cm}^{-2} \text{s}^{-1} \text{ Hz}^{-1})I_{14},$$

(7)

at $hv_0 = 13.6$ eV and adopt a spectral index $\alpha \approx 1.5$. For a fully ionized gas with $n_H/n_f = 0.1$ and $n_f/n_H = 1.2$, we find

$$n(H^0) = (11.25)n_f T_4^{1/2}T_4^{-1}.$$

(8)

Note that $N_{HI}$ is proportional to $N_H/R$, owing to the $n_H^2$ dependence of the recombinations that form H I. In the inner portions of disks, where the gas layer is optically thick to external ionizing radiation, the H I radial distribution, $N_{HI}(R)$, closely tracks that of total hydrogen, $N_H(R)$. However, in the extended disk, beyond the radius at which the integrated column of H I drops below several times $10^{19}$ cm$^{-2}$, the disk becomes optically thin to ionizing radiation, and the above photoionization analysis applies. In this regime, the radial H I distribution falls off as $N_H^2/R$, which in an exponential gaseous disk results in a very sharp falloff in H I. However, in disks with power-law gaseous distributions, $N_H(R) \approx R^{-\Gamma}$ ($1 \leq \Gamma \leq 2$), the H I decreases with radius as $N_H(R) \approx R^{-(2+\Gamma)}$.

Let us now compare these expectations to the observed Lyα absorbers, which typically have columns $N(HI) \approx 10^{13} - 14$ cm$^{-2}$. From Eq. (8), if the HST-observed Lyα cloud has H I column density, $10^{13.5}$ cm$^{-2}$ at $R = (68 \text{ kpc})h^{-1}$, the gaseous disk at that radius must have a total hydrogen column density

$$N_{HI}(R) = (0.87 \times 10^{18} \text{ cm}^{-2})u_2^{-1/2}h^{-1/2}T_4^{1/2},$$

(9)

assuming the optically-thin limit. The VLA observations of the dwarf H I galaxy toward Mrk 335 yield an H I column of $N_0 = 2.4 \times 10^{19}$ cm$^{-2}$ at 1', corresponding to $R_0 = 5.73h^{-1}$ kpc at the recessional velocity of 1790 km s$^{-1}$. If we assume that the radial distribution of total hydrogen column density is $N_{HI}(R) = N_0(r/r_0)^{-\Gamma}$ (i.e., $\Gamma = 1$) and integrate over radii $R_0 < r < R_{max}$, where $R_{max} = 68h^{-1}$ kpc, the total gaseous mass of the extended disk is

$$M_{disk} = 2\pi N_0 \mu R_0 (R_{max} - R_0) = (6 \times 10^8 M_\odot)h^{-2},$$

(10)

where we adopt a mean molecular mass $\mu = 1.4m_H$.

The mass of the isothermal dark-matter halo required to confine the gas in equilibrium is given by

$$M_{halo} = \frac{2(\langle v^2 \rangle)R}{G} = (4 \times 10^{10} M_\odot)v_{50}^2h^{-1}.$$

(11)

The ratio of halo mass to gas mass is therefore $66v_{50}^2/h$, not dissimilar from values in other galaxies.

5.2 The PKS 2155–304 Sight Line

A possible physical association between the Lyα absorber at 5100 km s$^{-1}$ seen toward PKS 2155–304 and ESO 466–G032 is even less clear cut. The projected distance between the two is 230h$^{-1}$ kpc. Lanzetta et al. (1995) find that only 1 out of 9 galaxies at projected distances larger than 160h$^{-1}$ kpc from the line of sight toward HST spectroscopic target QSO's gives rise to associated Lyα absorption, while 5 out of 5 galaxies at distances less than 70h$^{-1}$ kpc give rise to associated Lyα absorption. However more recent data by Bowen et al. (1996) and Le Brun et al. (1996) show that the covering factor of galaxies between 50 and 300h$^{-1}$ kpc is roughly 0.5 for equivalent widths larger than 0.3 Å. Thus, our discovery does not seem that unusual.

The galaxy is a small Sb spiral with $M = -19.2$. It would be quite extraordinary if it had a gaseous halo extending out to 250 kpc or so. The long dynamic time scales at those distances make it unlikely that the gas has virialized or settled into a disk (Stocke et al. 1995). Note, however, that Zaritski & White (1994) find that isolated spirals have dark halos extending out to 200 or 300 kpc, thus even if the Lyα absorber is not part of a halo of ionized gas, it may still sit in the potential of the galaxy. As in the case of Mrk 335, the kinematics of the galaxy do not help to elucidate the situation, the Lyα absorber is at the systemic velocity of the galaxy.

In the high-velocity range toward PKS 2155–304, we see three galaxies at rather large projected distances from the line of sight. The three galaxies have a mean velocity of 17 021 km s$^{-1}$ and a line of sight velocity dispersion of 138 km s$^{-1}$, typical of a loose group of galaxies. The Lyα absorption at 17 100 km s$^{-1}$ occurs close to the mean velocity. In this case, it seems more plausible that the absorption...
arises in some general intergalactic gas within a small group, rather than from one galaxy in particular (Mulchaey et al. 1993, 1996). The galaxy to the southwest is in projection closest to the line of sight toward the quasar at a distance of 305h^{-1} kpc. Thus, if the absorption arises in the halo of the nearest galaxy, the halo would have to extend well beyond 300 kpc. The existence of such a huge ionized halo is problematic by itself (Stocke et al. 1995), in a group environment it will definitely not survive. Of course the intragroup gas may be just that, the remains of the shredded halos. It is interesting that the absorption at 17 100 km s^{-1} is one of the stronger absorption systems. The situation is reminiscent of the absorbers found toward 3C 273 in the outskirts of the Virgo cluster (Bahcall et al. 1991; Morris et al. 1991). Several galaxies are found at distances of 200 to 300 kpc from the sight line, but it is not possible to associate the absorbers with individual galaxies (Morris et al. 1993; Salpeter & Hoffman 1995; Rauch et al. 1996). As in the present case, the absorbers toward 3C 273 have slightly higher column density. Although the current data for the PKS 2155-304 system, plagued as they are by interference, are not sensitive enough to detect small gas rich dwarfs, such as the one found toward Mrk 335, the 3C 273 data definitely rule out the existence of such dwarfs within 100 kpc from the line of sight toward 3C 273 (van Gorkom et al. 1993).

The absorption at 16 488 km s^{-1} seems more difficult to explain. It is quite far off from the mean velocity of the group. The HI emission from F21569-330 at a projected distance of 610h^{-1} kpc comes closest in velocity going down to 16 650 km s^{-1}, but not only is the distance to the sight line huge, the approaching side of the galaxy is on the far side from the sight line to the quasar. Since for this group we have only sampled the upper end of the HI mass function it is not unlikely that other galaxies are present which have HI at the same velocity as the absorber. Thus it seems plausible that this absorber is associated with the group as well.

In a recent paper Lanzetta et al. (1996) report the identification of a group of galaxies at a redshift of 0.26, that produce a complex of corresponding Lyα absorption lines. As in the present case one of the absorption systems has a slightly higher column density. Thus it seems that Lyα absorption arising in intra group gas may be quite common and that the column densities in those environments may be somewhat higher than what is seen near more isolated galaxies.

### 5.3 The Nature of Nearby Lyα Absorbers

A search for HI emission from the vicinity of nearby Lyα absorbers has resulted in the discovery of some low luminosity galaxies at the same redshift of some of the absorbers, but at large (70 to 250 kpc) projected distances from the sight line. In addition a group of galaxies was found near two absorbers at a velocity of about 17 000 km s^{-1}. This confirms previous suggestions that nearby Lyα absorbers are weakly correlated with galaxies. Individual, more isolated, galaxies may have absorbers that are physically associated with them, either due to infall, galactic winds or tidal disturbances. In regions of higher galactic density this material may be stripped from individual galaxies and distributed more uniformly through the intergalactic medium.

This project was undertaken in the hope of finding a possible parent population associated with nearby Lyα absorbers: either luminous galaxies with very extended gaseous envelopes or very low luminosity, but gas rich galaxies, which could have escaped optical detection. We did indeed find a few optically uncataloged galaxies, which turned out to be very close in velocity to, but at large projected distances from the Lyα absorbers. Two of the absorbers appear associated with a group of galaxies. These results are very similar to searches for a possible parent population at optical wavelengths. Most absorbers at low redshift appear to coincide with the large scale structure outlined by the more luminous galaxies (Rauch et al. 1996; Stocke et al. 1995) as was first suggested by Oort (1981).

One of the outstanding questions is whether the nearby Lyα absorbers are actually connected to individual galaxies or simply coincide in redshift. Our observations do to a certain extent strengthen the idea that at least some nearby Lyα absorbers may be arising in mostly ionized halos of individual galaxies. The discovery in our most sensitive observation of a very small galaxy at 68h^{-1} kpc from the line of sight toward Mrk 335, suggests that: (1) deeper surveys may turn up more such candidates; and (2) the suggestion (Maloney 1992; Shull et al. 1996) that the ionized halos of smaller galaxies may contribute significantly to the total Lyα absorbing cross section in the nearby universe may be valid. The strongest evidence for a physical connection between nearby Lyα absorbers and galaxies comes from the statistical work by Lanzetta et al. (1995), who showed that within 70h^{-1} kpc from a galaxy there is a 100% chance of detecting Lyα absorption. There are however also some Lyα clouds with no optical galaxy within a few Mpc (Stocke et al. 1995; Shull et al. 1996). In one case, an anticorrelation between a region of high galaxy density and Lyα forest absorbing clouds has been found (Morris et al. 1991). The difference between these results may primarily be due to a difference in cloud column densities. The Lanzetta et al. (1995) absorbers have significantly higher HI column densities than those studied by Morris et al. (1991), Stocke et al. (1995) and Shull et al. (1996).

Even if a physical connection is apparent, it is not obvious what the nature of the extended gas is. While Barcons et al. (1995) find in two cases Lyα absorption that could possibly be interpreted as arising in a corotating halo, there are several examples of even higher column density absorbers and metal lines, where the gas, although clearly associated with galaxies, is not corotating, but instead arises in tidally disturbed gas (e.g., Womble 1992; Carilli & van Gorkom 1992; Bowen et al. 1995). Thus the final verdict is not yet out. Low column density gas is likely to be found near galaxies, and many possible scenarios can bring it there: retarded infall, outflow, corotating ionized disks, tidal disturbances. Quite likely, all of these occur. Perhaps most puzzling are the clouds that don't have any galaxies within many Mpcs. These may arise in the filamentary structures as produced in simulations of gravitational structure formation (Cen et al. 1994; Hernquist et al. 1996; Miralda-Escudé et al. 1996).
Mücket et al. (1996), or they may be associated with as yet undetected dwarf galaxies.

This brings us to the final question, what is the connection, if any, between the high redshift Lyα forest clouds and nearby Lyα absorbers? As was pointed out by Rauch et al. (1996), the size estimate for coherent Lyα absorption at large redshifts (Bechtold et al., 1994; Dinhaw et al., 1994; Fang et al. 1996) is typically larger than the transverse separation between galaxies near low redshift Lyα absorbers. This not only argues against single extended gaseous disks or halos as the main origin for the coherent absorption on large scales seen at high redshifts. It also argues against the low redshift absorbers being physically the same as the high redshift absorbers. However, it may well be that at low redshifts galaxies and absorption systems trace the general matter distribution on large scales, a hypothesis that can only be tested statistically using a large ensemble of nearby Lyα clouds.

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