ADAPTIVE OPTICS IMAGING OF LOW-REDSHIFT DAMPED Lyα QUASAR ABSORBERS

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ABSTRACT

We have carried out a high angular resolution near-infrared imaging study of the fields of six quasars with seven strong absorption-line systems at $z < 0.5$, using the Hokupa’a adaptive optics system and the Quick Infrared Camera on the Gemini North telescope. These absorption systems include four classical damped Lyα absorbers (DLAs), two sub-DLAs, and one Lyman limit system. Images were obtained in the $H$ or $K'$ filters with FWHM between 0.2 and 0.5 with the goal of detecting the absorbing galaxies and identifying their morphologies. Features are seen at projected separations of $0.5'$–$16'/0$ from the quasars, and all the fields show features at less than 2" separation. We find candidate absorbers in all seven systems. With the assumption that some of these are associated with the absorbers, the absorbers are low-luminosity $<0.1L_\odot$ or $L_\odot$; we do not find any large, bright candidate absorbers in any of our fields. Some fields show compact features that are too faint for quantitative morphology but could arise in dwarf galaxies.

Key words: cosmology: observations — galaxies: evolution — infrared: galaxies — instrumentation: high angular resolution — intergalactic medium — quasars: absorption lines

1. INTRODUCTION

Damped Lyα absorption lines in quasar spectra are believed to arise from intervening galaxies and intergalactic matter at various cosmological epochs. The damped Lyα absorbers (DLAs) are classically defined as quasar absorbers with $\log N(H\ i) > 20.3$, while absorbers with $19.0 < \log N(H\ i) < 20.3$ are conventionally classified as sub-DLAs. This distinction is based on the observational constraints of an early spectroscopic study (Wolfe et al. 1986). Since the Lyα line shows dangling wings even at $\log N(H\ i) \sim 18$, in this paper we refer to both the sub-DLAs and DLAs as DLA systems.

At high redshifts DLAs are believed to contain a large fraction of the comoving density of neutral hydrogen in galaxies and possibly account for all the stars visible today (e.g., Wolfe et al. 1995; Peroux et al. 2003). The evolution of metallicities in these absorbers provides important probes of the chemical enrichment and star formation history of the universe (Khare et al. 2004; Kulkarni et al. 2005). Unfortunately, the connection between DLAs and galaxies has not been clearly established. To shed more light on this connection, it is necessary to complement the wealth of spectroscopic data on these absorbers with information on their morphologies, luminosities, colors, and image structure from direct imaging.

It has proven hard to obtain this information for most DLAs. The imaging of high-$z$ DLAs has been very difficult, and a large fraction of the attempts to detect the Lyα emission from high-redshift intervening ($z_{\text{abs}} < z_{\text{em}}$) DLAs have produced either nondetections or weak detections (e.g., Smith et al. 1989; Hunstead et al. 1990; Lowenthal et al. 1995; Djorgovski et al. 1996). Imaging studies of low-$z$ DLAs have been more encouraging. Although not always spectroscopically confirmed to be the absorbers, galaxies in images of low-redshift absorber fields often show a variety of morphologies: spiral, irregular, and low surface brightness (LSB) galaxies (e.g., Steidel et al. 1994, 1995; Le Brun et al. 1997; Bowen et al. 2001; Cohen 2001; Turnshek et al. 2001). Most of these previous searches had limiting flux sensitivity thresholds of $\sim0.2L^*$ and thus could not rule out LSBs, while all the near-infrared searches lacked adequate angular resolution to rule out dwarf galaxies close to the line of sight. It is not clear which of the several competing scenarios for DLAs are valid: large, bright, rotating protospirals (Wolfe et al. 1986; Wolfe & Prochaska 1998; Prochaska & Wolfe 1997, 1998), gas-rich dwarf galaxies (York et al. 1986; Matteucci et al. 1997), merging protogalactic fragments with cold dark matter (e.g., Haehnelt et al. 1998; Maller et al. 2001), collapsing halos with merging clouds (e.g., McDonald & Miralda-Escudé 1999), or LSB galaxies (Jimenez et al. 1999).

Here we present the first adaptive optics (AO) observations of low-redshift DLAs. We have obtained near-infrared images of seven absorbers at $0.1 < z < 1.3$ with the University of Hawaii Hokupa’a AO system and the Quick Infrared Camera (QUIRC) on the Gemini North telescope.

We discuss the observations and data reduction in § 2. The analysis of the data is presented in § 3, and the results from individual fields are discussed in § 4. Finally, in § 5 we characterize our sample of low-redshift DLAs based on our measurements of the sizes, impact parameters, and image structure. Throughout this paper we assume $\Omega_m = 0.3, \Omega_\Lambda = 0.7$, and $h = 0.73$.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Observations

Our sample consists of seven low-redshift absorption systems that have confirmed Lyα absorption features. The redshift range was constrained so that hour-long exposures would reach limiting magnitudes representative of LSB features at the redshift of the absorption systems. The most stringent observational constraint was set by the AO system’s requirement that the target
AO IMAGING OF LOW-

field have a sufficiently bright wavefront reference source for the AO system ($R \leq 17$) to provide a useful correction. In total, six fields with seven absorption systems were observed. We present the object field properties in Table 1, where we have preserved the nomenclature of “DLA” and “sub-DLA” for reference.

Between 2000 August and 2001 April, we observed the fields around the six quasars in the $H$ or $K'$ filter (Wainscoat & Cowie 1992) with the now-decommissioned University of Hawaii 36 element curvature AO system (Hokupa’a) (Graves et al. 2000) on the Gemini North telescope. In all cases the quasar was used as the wavefront reference source for the AO system. The University of Hawaii QUIRC (Hodapp et al. 1996), containing a 1024 x 1024 pixel HgCdTe detector, with a pixel scale of 0.020 pixel$^{-1}$, was used as the focal plane imager. All data were taken in better seeing conditions, with two fields observed under photometric conditions. Table 2 summarizes the observations.

Each field was observed as a dithered series of short exposures, each exposure being 30–180 s long. The sides of the dither pattern were 5 arcmin, as these are small (F. Rigaut 2005, private communication). After each cycle through a five-point dither pattern, we offset the telescope by roughly 0 arcmin and repeated the dither pattern. This offset was used to ensure that groups of bad pixels could be removed in the data reduction. This combination of offsets and dithers was made for field distortions in the Gemini Hokupa’a QUIRC images, as these are small (F. Rigaut 2005, private communication).

The final mosaic images have quasars with FWHM from 0.2 to just under 0.5. This should be considered as a rough estimate of the image resolution, since in general the quasar is not a point source but may contain a bright host galaxy.

### 2.2. Image Data Reduction

Standard data reduction techniques for near-infrared imaging were used to produce the final images. Individual frames were sky-subtracted and flat-fielded. Separate sky frames were constructed for each individual exposure by averaging source-masked dithered frames taken within 10–20 minutes of the individual exposure. Flat fields were constructed from dome flat images with the lamps on and off. We favor the use of dome flats over sky flats, because sky flats constructed from the object images do not account for the emission from dust on the telescope and instrument surfaces. This is especially important in $K'$, where the difference between the sky flats and the dome flats was as much as several percent. Bad pixels were identified as hot pixels in short dark frames, dead pixels in flat frames, and pixels with large standard deviations in either of the dark or flat sequences.

Individual frames were registered to the nearest pixel using the centroid of the quasar and averaged excluding bad pixels and deviations in the stack. The integer pixel registration is more than sufficient for these data, since in all cases we have 7–20 pixels across the FWHM of the images. No correction was made for field distortions in the Gemini Hokupa’a QUIRC images, as these are small (F. Rigaut 2005, private communication).

### 2.3. Subtraction of the Quasar Point-Spread Function

In order to properly study the area near the quasar, we need to remove the contribution to the image of the quasar and its host galaxy. This problem depends critically on our knowledge of both a point-spread function (PSF) not well described by an analytic function and the intrinsic nature of the quasar and its host galaxy. This section describes the QSO-subtraction techniques we used.

**TABLE 1**

| QSO       | $V$   | $z_{\text{em}}$ | $z_{\text{abs}}$ | log $N$($\text{H}^i$) | Absorber Type | $N$($\text{H}^i$) References |
|-----------|-------|----------------|-----------------|---------------------|---------------|-----------------------------|
| Q0054+144 | 16.1  | 0.171          | 0.103           | 18.3                | Lyman limit   | 1, 2                        |
| Q0234+164 | 15.5–19 | 0.940       | 0.524           | 21.65               | DLA           | 3                           |
| Q0738+313 | 16.1  | 0.635          | 0.0912          | 21.18               | DLA           | 4, 5                        |
| Q0738+313 | 16.1  | 0.635          | 0.2212          | 20.90               | DLA           | 4, 6                        |
| Q0850+440 | 16.4  | 0.5139         | 0.1638          | 19.81               | Sub-DLA       | 7                           |
| Q1127−145 | 16.9  | 1.184          | 0.3127          | 21.7                | DLA           | 3                           |
| Q1329+412 | 16.3  | 1.9300         | 1.282           | 19.7                | Sub-DLA       | 8                           |

**TABLE 2**

| QSO       | Filter | Total Integration Time (s) | FWHM$^a$ (arcsec) | 50% EED$^a$ (arcsec) | $1 \sigma$ $\mu_{\text{lim}}$$^b$ (mag arcsec$^{-2}$) | $3 \sigma$ $m_{\text{lim}}$$^c$ (mag) |
|-----------|--------|---------------------------|-------------------|----------------------|-------------------------------------------------|---------------------|
| Q0054+144 | $H$    | 23 x 120                  | 0.46              | 0.75                 | 19.6                                            | 21.9                |
| Q0234+164 | $H$    | 53 x 120                  | 0.50              | 0.82                 | 19.9                                            | 22.2                |
| Q0738+313 | $K'$   | 74 x 60                   | 0.19              | 0.28                 | 18.9                                            | 21.2                |
| Q0850+440 | $H$    | 39 x 120                  | 0.23              | 0.38                 | 20.0                                            | 22.3                |
| Q1127−145 | $H$    | 32 x 180                  | 0.33              | 0.54                 | 20.7                                            | 22.3                |
| Q1329+412 | $H$    | 48 x 180                  | 0.29              | 0.47                 | 20.1                                            | 22.4                |

$^a$ FWHM and 50% encircled energy diameter measured from the QSO.

$^b$ $1 \sigma$ per pixel$^{-1}$ limit.

$^c$ $3 \sigma$ limit within 75 pixels.

References.—(1) Lanzetta et al. 1995; (2) Turnshek et al. 2001; (3) Junkkarinen et al. 2004; (4) Rao & Turnshek 1998; (5) Chengalur & Kanekar 1999; (6) Lane et al. 1998; (7) Lanzetta et al. 1997; (8) Bechtold et al. 2002.
First, during the observation we observed stars as PSF calibrations. These PSF calibration targets were chosen to have a right ascension, declination, and visual magnitude similar to those of the wavefront reference sources (e.g., the quasars). Observations of the PSF calibration fields were made, interspersed with those of the quasar fields, to sample the changes in the intrinsic atmospheric seeing. In all cases, the shape of the calibration PSF did not match point sources in the quasar field. This occurred for several reasons. First, at the faint magnitudes of these guide stars, the correction of the AO system depends strongly on the photon flux in the wavefront sensor. While we attempted to select nearby stars with similar catalog magnitudes, matching the wavefront sensor photon flux was typically matched to no better than 10%–20%. Second, while we observed the PSF calibration fields interleaved with the quasar field, the timescale for seeing changes can be as short as a few minutes. This is too short for the PSF calibration star observations to, in practice, be made under exactly the same atmospheric conditions. Third, the calibration stars were faint in the $H$ and $K'$ bands and required long exposure times to reach a signal-to-noise ratio at large radii to make them useful for PSF subtraction. This was unrealistic, given the overheads required.

To circumvent these problems, we attempted three techniques to generate PSFs directly from the data. First, for quasar fields containing a stellar source, we have a PSF that was taken under identical atmospheric conditions. However, for all the observed fields, the quasar is the brightest source, so the signal-to-noise ratio at large radii in these stellar images did not match that of the quasar. In addition, in the few fields with stellar sources, the sources happened to be only a few arcseconds from the quasar. While this is well within the corrected field of view of the AO system (Chun 1998), extracting a clean PSF to a radius containing most of the stellar flux proved difficult. Knowledge of the PSF at these large radii is important, because the PSFs can have a significant fraction of energy outside their core. For example, the average 50% encircled energy diameter was $0.59$ in the $H$ band and $0.28$ in the $K'$ band.

Given that the quasar is the brightest object in the observed fields, we tried constructing a PSF from an azimuthally averaged image of the quasar itself. The azimuthally averaged profile is computed directly from the final image and, by construction, is not subject to differences in the guide star brightness or to variations in the intrinsic seeing. The resulting PSF-subtracted image is similar to an unsharp mask, but here the smoothing is done azimuthally. The technique assumes that the light near the quasar is well represented by the azimuthal average. Asymmetries in the PSF can arise from astrophysical sources (e.g., a host galaxy), as well as instrumental sources (e.g., telescope wind shake). In many cases the residual in the azimuthally averaged PSF-subtracted image contained one pair of symmetric positive flux lobes and another pair of symmetric negative flux lobes.

Finally, we constructed models of the PSFs using a principle component analysis or Karhunen-Loève (KL) decomposition. The KL decomposition has been previously used to quantify PSFs by Lupton et al. (2001) and Lauer (2002). Lauer (2002) suggested using the KL decomposition to quantify the field variations of the PSFs of AO systems. Here we have applied this technique to quantify the modes in which the PSF varies with time. The basic idea is to construct a basis function that characterizes the temporal variations of the image of the quasar. Any component in the final quasar image well fit by this basis function is assumed to be due to the AO PSF changing and is removed from the final quasar image. The KL decomposition provides the means to construct the basis function. A $4'' \times 4''$ region centered on the quasar in each of the individual reduced frames was binned $2 \times 2$ pixels, normalized, and centered on the quasar. From this set of images $(P_j)$ we construct the basis function by calculating the eigenvectors and eigenvalues for the PSF covariance matrix:

$$C_{ij} = \langle P_j P_i \rangle.$$  

Each eigenvector represents a mode in the basis function, and the eigenvalue represents the relative importance of each mode in the basis set. Once the basis function is determined, the quasar in the final image can be reconstructed using the first few modes (typically $\sim 30$) with the largest eigenvalues of the basis function. These first few modes are, by virtue of the KL expansion, those with the most variance within the data set. In using this reconstructed model PSF, we can, in principle, erroneously interpret some underlying parts of the true light from the quasar, host galaxy, or absorber galaxy as a component of the PSF, since some modes of the basis function could be similar to these light distributions. Since we have constructed the basis set from the covariance matrix, the modes of the basis set describe image structure that changes with time. Faint diffuse objects are less sensitive to changes in the image PSF than small unresolved objects.

For each quasar field we generated a KL basis set and then fit the image of the quasar in the final mosaic image with the first 30 modes. This model quasar was then subtracted from the field to look for objects close to the line of sight of the quasar. In fields with known stellar components we also fit the final stellar image with this same basis set as a measure of the residuals in the PSF-subtracted images.

Figure 1 shows a comparison of the techniques we used to remove the contribution of light from the quasar. Each of the four columns in the figure shows a different technique applied to the quasar and to the point source just south of the quasar in the Q0850+440 field. The cleanest quasar subtraction is using the KL PSF, although this analysis is CPU intensive and could only be applied within a couple of arcseconds from the quasar. Residuals in the stellar image subtraction extend to a radius of about $0.5''$. We take this radius as the minimum separation from the quasar line of sight for an object to be detected with this technique. As simple and as fast as it is, the azimuthally averaged quasar image worked surprisingly well. While the intensities in these residual images were larger than those in the KL QSO-subtracted image by a factor of 2, the extent of the residuals was nearly identical.

Figures 2–7 show the reduced image and the QSO-subtracted image for each field. For fields in which Hubble Space Telescope (HST) archival imaging data are available, we show the HST images for comparison. These archival data are from the HST programs of Bahcall (proposal ID 5343; Q0054+144), Burbidge (5096; Q0235+164), Lanzetta (5949; Q0850+440), Bechtold (9173; Q1127−145), and Steidel (5984; Q1329+412).

3. ANALYSIS

3.1. Object Detection

We used the automated software SExtractor (Bertin & Arnouts 1996) to detect sources in our images. We ran SExtractor on the regions with the highest signal-to-noise ratios of the azimuthally averaged QSO-subtracted images. These regions spanned approximately $15''$ on each side. In addition, we ran SExtractor on the regions centered at the position of the quasar in the KL quasar-subtracted images. These smaller regions measured $4'' \times 4''$. To look for extremely faint objects, we ran SExtractor on the
smoothed images. In this latter case, we used the azimuthally averaged quasar-subtracted images and convolved the images with a Gaussian with a FWHM of 20 pixels (0.4).

SExtractor requires a number of input parameters to work properly. Naturally, the driving parameters are the detection threshold and the number of connected pixels above that threshold. After many test runs, we chose a detection threshold per pixel of 1σ of the sky level and a minimum number of contiguous pixels of 75. Connected pixels are defined as pixels touching any of their sides or corners as implemented in SExtractor. Thus, for a detection to be triggered, there had to be 75 connected pixels each with an intensity at least 1σ above the sky. Our 1σ pixel\(^{-1}\) threshold corresponds to a surface brightness of \(\mu_{1\sigma, \text{lim}} \approx 20.0\) mag arcsec\(^{-2}\) in \(H\) and \(\mu_{1\sigma, \text{lim}} \approx 19\) mag arcsec\(^{-2}\) in \(K\) (Table 2). In comparison, the sky brightness in \(H\) at Mauna Kea is \(\mu_H \approx 13.4\) mag arcsec\(^{-2}\) (Tokunaga 1999) and \(\mu_K \approx 12.8\) mag arcsec\(^{-2}\) (Gemini Hokupa’a instrument Web site\(^1\)); thus, our limiting surface brightness is \(\approx 300–400\) times fainter than the sky.

At these flux limits, we expect to be able to measure image structure for the brighter disk galaxies and to detect dwarf galaxies. Disk galaxies in the Coma Cluster typically have \(\mu_e \approx 17.2\) mag arcsec\(^{-2}\) (Gavazzi et al. 2000),\(^2\) so that at the target absorbers with \(z \leq 0.2\) we expect disk galaxies to have \(\mu_e\) in the range 20.2–21.7 mag arcsec\(^{-2}\). These are just at the surface brightness limit of our data. Our object detection threshold is much fainter. For example, Virgo Cluster dwarf galaxies have a mean total \(H \approx 12\) mag (Gavazzi et al. 2001) and would measure \(H \approx 20\) mag at the redshifts of our sample, assuming a flat spectrum. The limiting magnitude of our observations, defined as the magnitude corresponding to a 3σ flux within an aperture of 75 pixels, is approximately \(H_{3\sigma, \text{lim}} \approx 23.3\) and \(K'_{3\sigma, \text{lim}} \approx 21\) (see Table 2). At our flux limits we easily detect typical dwarf galaxies at the redshifts of these absorbers.

The detected sources are presented in Table 3. We detect a total of 31 sources around six quasars. The naming convention for objects corresponds to the offset east and north in arcseconds from the quasar centroid. Each of the six quasar fields contains at least one object, and five of the six fields show objects that were previously undetected.

### 3.2. Photometry

Absolute photometry is based on observations of standard stars taken during the same night before and after the observations of the quasar field when observing conditions were photometric. For data obtained under nonphotometric conditions, we used the quasar and its Two Micron All Sky Survey catalog magnitude to bootstrap the photometry of the objects in the fields. This is reasonable as long as the quasar is not highly variable in the near-infrared. There are two cases in which the night is not photometric and the quasar is known to be highly variable. For Q0235+164 we report relative photometry only. In the case of Q1127–145, we used the photometry of object G1 from Chen et al. (2001), kindly provided to us by H.-W. Chen, to bootstrap the photometry for the rest of the objects in the field.

All photometry is reported here as AB magnitudes. The following relationship between the Vega and AB systems (Bessell 1979; Oke & Gunn 1983) was used:

\[
m_{\text{AB}} = m_{\text{Vega}} - 2.5 \log(f_{\nu,0}) + 8.90, \tag{2}
\]

where the zero-point flux is taken to be \(f_{\nu,0} = 1080\) Jy in \(H\) and \(f_{\nu,0} = 670\) Jy in \(K'\) (Tokunaga 1999). In Table 3 we list for each detected object the identification (right ascension and declination offsets relative to the quasar); the angular distance to the QSO, \(\Delta\theta\) in arcseconds; and the AB magnitude in the \(H\) or \(K'\) band as determined by SExtractor. These are the magnitudes determined using a metric radius defined as \(2.5\) times the first
moment of the light profile (Kron 1980): $r_{\text{metric}} = 2.5 \int I(r) r \, dr / \int I(r) \, dr$, where $I(r)$ is the intensity profile as a function of radius $r$.

### 3.3. Image Structure

The image properties of the detected sources allowed us to characterize their morphologies and to address the question of whether they are bulge-dominated or disk-dominated. We determined the structural parameters for roughly half of the detected sources by running GIM2D (Simard et al. 2002) on the azimuthally averaged subtracted images. Out of the 31 sources detected, we were able to extract image structural parameters for 19 sources. Fourteen sources had high total signal-to-noise ratios and were well separated from the quasar. For five of the sources, the structural parameters were largely uncertain (as seen by the errors in Table 4). The remaining objects were either too faint or too close to the quasar line of sight to estimate any image structural parameters. In the end, we were able to constrain the morphologies of 12 out of the 31 sources.

GIM2D fits two-dimensional intensity profiles with a combination of the Sérsic law and an exponential disk. Each source was fit with three types of models: (1) single $r^{1/n}$ laws, (2) exponential disks plus $r^{1/4}$ laws, and (3) exponential disks plus $r^{1/n}$ laws. In all cases the PSF provided to GIM2D was the azimuthally averaged quasar image.
The output quantities of GIM2D include the total luminosity, bulge-to-total ratio \( B/T \), effective radius \( r_e \), ellipticity of the bulge, position angle of the bulge, exponential disk scale length \( r_d \), inclination angle of the disk, position angle of the disk, \( x \)- and \( y \)-position offsets, background level, reduced \( \chi^2 \) value, half-light radius, and Sérsic exponent \( n \). These values are provided with their 99% confidence limits. If the distributions were normal, they would correspond to a 3 \( \sigma \) error. We assign a morphological class based on the values of \( B/T \), \( r_e \), \( r_d \), and \( n \) and their 99% confidence limits. Table 4 presents the derived image structural parameters for each object. We list the objects' identification, the bulge-to-total ratio \( B/T \), the scale lengths \( r_e \) and \( r_d \) in arcseconds, and the exponent \( n \) of the generalized \( r^{1/n} \) law. For the bulge-to-total ratio, scale lengths, and exponent, we also present the 99% confidence limits obtained with GIM2D.

An important motivation for the study was to determine whether bulge- or disk-dominated galaxies account for the low-redshift absorbers. As such, in assigning a morphological type,

![Image of Gemini Hokupa'a H-band image smoothed by a Gaussian of FWHM = 0.2. Top right: Quasar-subtracted H-band image of the central 4'' smoothed by a 3 pixel Gaussian. Contours overlaid on this image are 3 \( \sigma \) above the sky in the unsmoothed image. Bottom: HST WFPC2 F702W image for comparison. The bottom left panel shows the HST image corresponding to our full H-band image, while the bottom right panel shows the azimuthally averaged PSF-subtracted HST image. All figures are shown with a linear intensity scale, with north up and east to the left. We identify object +1.11±0.01 as the most likely candidate absorber. This object has been previously identified as a candidate absorber (e.g., object A1 in Yanny et al. 1989). The object seen 2'' south of the quasar is the BALQSO (object A, identified by Burbidge et al. 1996). There is a small extension southwest of the center of the field, but it is too close to the center of the field to be distinguished from the residuals of the quasar subtraction.](image)
we identified the objects as point sources, disk-dominated, bulge-dominated, or a combination of disk and bulge. Of the sources for which we could measure the structural parameters, three have FWHMs that are identical to the PSF. For these sources, GIM2D returned zero scale lengths, and we interpret these as point sources. Single $r^{1/n}$ fits were used to determine whether any of the sources were pure disks. A pure disk would have a value of $n = 1$ in the Sérsic-law-only fits. We found that only two sources are consistent with being pure disks. We found $n = 0.96^{+0.75}_{-0.05}$ for Q0235+164 $-5.85-2.69$ and $n = 1.43^{+0.12}_{-0.00}$ for Q1127$-145 +14.5-6.76$. These values are also consistent with the fits done with two components (see Table 4), where they have a small bulge ($B/T < 0.27$) and large disk scale length ($r_d \sim 0\farcs2$).

The outputs of the $r^{1/4}$ and the generalized $r^{1/n}$ fits are consistent with each other within the confidence limits. By and large we found that the $r^{1/n}+$disk fits showed a smaller residual signal, and we therefore provide the results of these decompositions instead of that of the $r^{1/4}+$disk. Even though we allowed $n$ to vary, 10 of the sources returned $n \sim 4$ as the best fit. We used the reduced $\chi^2$ values that were output by GIM2D to discard any bad fits. There are only two cases in which the reduced $\chi^2$ values are large. From the two component fits, we found that there are six
disk-dominated galaxies, three disk+bulge galaxies, two bulge-dominated galaxies, three point sources, and five unconstrained objects.

4. RESULTS

Below we present the astrometric, photometric, and morphological results derived for the features in each field. Table 5 summarizes the morphologies, impact parameters, luminosities, and scale lengths for the candidate objects, assuming that they are at the redshifts of the absorbers. The morphology is not listed for the objects that are too faint or too close to another object, since the profile fits for these objects are not robust. The scale lengths of the profiles are not listed for the point sources and those for which the profiles could not be fit. For candidate absorbers, we converted fluxes to luminosities using \( L = 4\pi d_L^2 F \), where \( d_L \) is the luminosity distance of the DLA candidate. These luminosities are express units of \( L^* \), where we have adopted \( L_H = 1.33 \times 10^{43} \text{ ergs s}^{-1} \) (Kulkarni et al. 2000) and \( L_K = 3.62 \times 10^{42} \text{ ergs s}^{-1} \) (Bell et al. 2003).

4.1. Q0054+144

Q0054+144 is a radio-quiet X-ray-bright QSO at a redshift of \( z_{\text{em}} = 0.171 \). This object was imaged with the HST Wide Field Planetary Camera 2 (WFPC2) (Bahcall et al. 1996; McLure et al. 2006).

Fig. 5.—Top: \( H \)-band images of the field around the quasar before and after subtraction of the PSF image. The full image (left) corresponds to \( \approx 54 \text{ kpc} \) at \( z = 0.1638 \). We found objects close to the line of sight to the quasar with several arcsecond extensions. The extent of the emission is shown in the \( 8'' \times 8'' \) region centered on the azimuthally averaged QSO-subtracted image (right). This image was smoothed by a Gaussian with FWHM = 0.2. The contours are 1, 2, and 3 \( \sigma \) above the sky in the smoothed, rebinned image. Bottom: HST F702W image (left) and its azimuthally averaged subtracted image (right).
These HST data indicate that the host galaxy is well described by an early-type galaxy. A DLA candidate absorber at $z = 0.103$ with a neutral hydrogen column density of $\log N(H\text{I}) = 20.1$ was suggested by Lanzetta et al. (1995) using International Ultraviolet Explorer (IUE) data. However, higher resolution HST Goddard High Resolution Spectrograph spectra showed that no DLA absorption is present at $z = 0.103$ (Bechtold et al. 2001), and no X-ray absorption was detected in Chandra observations of Bechtold et al. (2001). A low-ionization metal absorption-line system is present at $z = 0.103$, but the Ly$\alpha$ line is not damped, with $\log N(H\text{I}) = 18.3$ (Turnshek & Rao 2002). Thus, this is a Lyman limit system.

Figure 2 shows our $H$-band image of the field, the quasar-subtracted image of the central portion of the field, and the HST WFPC2 F606W image. Our $H$-band image is $20'' \times 20''$, which corresponds to $\approx 40 \times 40$ kpc$^2$ at $z = 0.103$. We detect an object approximately $0''/8$ southwest of the quasar only after the KL QSO subtraction. It is too close and too faint to measure its magnitude or structural parameters. It is in the same direction and approximately the same location as the object identified in McLure et al. (1999; see their Fig. A11) but is considerably less extended. This smaller extent may be due to the smaller region over which the quasar subtraction was applied with the KL technique. In addition, a number of faint objects are seen around this elliptical...
galaxy in both our image and the HST image. They are all small objects and could be companions to the host galaxy. An additional object lies approximately 12″ south of the quasar just at the edge of our field of view and appears to correspond to an object in the HST image of McLure et al. (1999). This object was excluded from our analysis due to its close proximity to the edge of our field.

4.2. Q0235+164

Q0235+164 (AO 0235+164) is a radio-loud, optically violently variable, X-ray and γ-ray emitting blazar. Roberts et al. (1976) measured a complex 21 cm absorption profile in the radio spectrum of AO centered at z = 0.524. Based on a UV spectrum of the QSO obtained with the HST Space Telescope Imaging Spectrograph, Cohen et al. (1999) confirmed that the absorber is a DLA with \( N_{\text{H}_1} \approx 5 \times 10^{21} \) cm\(^{-2}\). Junkkarinen et al. (2004) have detected the 2175 Å feature and diffuse interstellar bands at the redshift of this absorber. Two faint objects with [O ii] 3727 emission have been detected within 2″ of the QSO and have been suggested as possible sites for the \( z = 0.524 \) absorption system (Smith et al. 1977; Yanny et al. 1989). Burbidge et al. (1996), using the HST WFPC2 and Faint Object Spectrograph, resolved these two objects more clearly. The nearest one (A1 of Yanny et al. 1989) might contribute to the complex H i 21 cm absorption, while the object 2″ south of the QSO (A of Yanny et al. 1989) is an active...
galactic nucleus surrounded by faint nebulosity that can be classified as a BALQSO. In the optical and infrared imaging observations of the QSO, Chen & Lanzetta (2003) concluded that there is a group of galaxies at the redshift of the known DLA, several of which likely contribute to the DALA system. They found that the photometric redshift for the object 2' south of the QSO is consistent with the spectroscopic redshift of the known DLA. Yanny et al. (1989) found [O II] emission from both the A1 and A objects.

Figure 3 shows our H-band image of the field before and after subtraction of the quasar image, as well as the archival HST WFPC2 F702W image. The full images are 20″ × 20″, corresponding to ≈120 × 120 kpc² at z = 0.524. We identify six objects. The angular distances of these objects to the QSO range from Δθ = 0′.6 to 10′.2, corresponding to h₀ = 3−60 kpc. Objects other than object −4.93−7.47 have already been reported in the literature. It is unlikely to be the absorber, since at the redshift of the absorber it would have an impact parameter of more than 50 kpc, and its profile scale length is close to the FWHM of the quasar. Object −7.15−7.21 appears to be a point source in the HST images but shows a linear extension in both our H-band image and the HST image. Object +0.15−1.91 is the BALQSO object found by Burbidge et al. (1996). Its morphology in the near-infrared is extended and disk-dominated. An object is detected by SExtractor in the PSF-subtracted image at a separation of 0′.5 from the quasar centroid (−0.3−0.4). We have disregarded this object, since it falls within the region where PSF residuals are seen in PSF subtractions of stellar images. We regard +1.11−0.01 (object A1 in Burbidge et al. 1996) as the likely absorber. Its photometric redshift is consistent with it being at the absorber redshift (Chen & Lanzetta 2003), and its profile is consistent with a combination exponential disk and r¹/⁴. Absolute photometry was not possible from our data for this field, because the observations were made under nonphotometric conditions. SExtractor identifies another object 2'5 northeast of the quasar. This object was not reported in previous studies. While SExtractor identifies this and object +1.11−0.01 as separate objects, a one-dimensional cut across these two objects is well fit by a bulge+disk profile. If these are the same object, then it could be a spiral galaxy slightly inclined to our line of sight. At the redshift of the absorber, it would have an impact parameter of about 6−7 kpc.
We note that if object +2.40+0.93 is an extension of object +1.11−0.01, then the extension is in the northeast direction. This is perpendicular to the orientation suggested by Burbidge et al. (1996).

4.3. Q0738+313

Q0738+313 (O1 363) is a core-dominated, slightly variable quasar at $z_{em} = 0.635$. Rao & Turnshek (1998) reported the discovery of two DLA systems toward the quasar at $z = 0.0912$ and 0.2212 with $N(H) = (1.5 \pm 0.2) \times 10^{21}$ and $(7.9 \pm 1.4) \times 10^{20}$ cm$^{-2}$, respectively. They concluded that a galaxy at 5′′′ from the QSO line of sight is the only reasonable candidate at either absorption redshift. Coyote et al. (2001) reported galaxies at $z = 0.0912$ and 0.2212, respectively. They concluded that a galaxy at $z = 0.0912$ and 0.2212 is a “faint neutral-colored galaxy with dwarf galaxy-like K- and B-band luminosities.” Its spectrum is that of an early-type galaxy. Turnshek et al. (2001) also suggested that the putative $z = 0.0912$ DLA galaxy is likely to be all or part of the resolved light surrounding the quasar with armlike and jetlike features. They suggested that the DLA is an LSB dwarf galaxy, possibly an irregular or interacting system.

Six objects are detected in our image; five have previously been identified. Object +1.90−5.38, the dwarf galaxy at $z = 0.2212$ designated “G1” by others (Cohen 2001; Turnshek et al. 2001), is a disk-dominated galaxy with a bulge-to-total ratio of 0.34. This is consistent with an E/S0 galaxy suggested by Turnshek et al. (2001). Object +2.02+1.54, designated “S1” by Turnshek et al. (2001), is still unresolved in our images, and GIM2D identifies it as a point source.

The faint armlike and jetlike features discussed by Turnshek et al. (2001) are not apparent in our unbinned image. While our image has an angular resolution of about 0′′′2, our 1′′′ pixel$^{-1}$ limiting surface brightness is 18.9 mag arcsec$^{-2}$. The armlike and jetlike features discussed by Turnshek et al. (2001) are about 2 mag fainter. In order to achieve this sensitivity, we smoothed the image with a Gaussian with a FWHM equal to the FWHM of the quasar image, subtracted an azimuthally averaged PSF, and rebinned the image to 0′′′2 pixels. The resulting image is shown in Figure 4 (bottom right). In this image we used an azimuthally averaged PSF to subtract the light from the quasar, because the

### TABLE 5

| QSO      | Object | $b_{abs}^a$ (kpc) | log $(L/L_*)^b$ | Morphology$^c$ | $\rho_{rad}^d$ (kpc) | $r_d^d$ (kpc) |
|----------|--------|------------------|-----------------|---------------|---------------------|--------------|
| Q0054+145 |        | −0.29−0.74       | ...             | ...           | ...                 | ...          |
| Q0235+164 |        | −0.33−0.45       | ...             | ...           | ...                 | ...          |
|          | +1.11−0.01 | 6.66            | ...             | ...           | 0.0                 | 0.3          |
|          | +0.15−1.91 | 11.53           | ...             | B+D          | 0.0                 | 1.3          |
|          | +2.40+0.93 | 15.43           | ...             | ...           | ...                 | ...          |
|          | −5.85−2.69 | 38.66           | ...             | Dd           | 0.1                 | 1.2          |
|          | −4.93−7.47 | 53.73           | ...             | ...           | 0.5                 | 0.6          |
|          | −7.15−7.21 | 60.93           | ...             | B            | 2.0                 | 2.0          |
| Q0738+313 |        | +0.71+1.63       | −2.32,−1.48     | ...           | ...                 | ...          |
|          | +2.02+1.54 | 4.14, 8.69      | −1.80,−0.96     | P             | 0.0, 0.0             | 0.0, 0.0     |
|          | +5.40−0.11 | 8.80, 18.48     | −2.48,−1.64     | B+D          | 0.1, 0.1             | 0.2, 0.5     |
|          | +1.90−5.38 | 9.31, 19.54     | −1.20,−0.36     | B+D          | 0.1, 0.1             | 0.2, 0.5     |
|          | −6.58−1.64 | 11.05, 23.21     | −2.24,−1.40     | ...           | ...                 | ...          |
|          | −7.96+5.02 | 15.34, 32.21     | −1.84,−1.00     | P             | 0.0, 0.0             | 0.0, 0.0     |
| Q0850+440 |        | +0.56+0.32       | 1.77            | ...           | ...                 | ...          |
|          | +1.28+2.55 | 7.69            | −4.09           | ...           | ...                 | ...          |
|          | −2.56−2.01 | 8.77            | −4.53           | D             | 0.0                 | 0.6          |
|          | −0.20−3.49 | 9.44            | −1.25           | P             | 0.3                 | 0.0          |
|          | −9.04+1.53 | 24.74           | −1.33           | D             | 0.7                 | 1.1          |
| Q1127−145 |        | −0.13+0.57       | 2.55            | ...           | ...                 | ...          |
|          | −3.57+0.17 | 15.70           | −3.42           | ...           | ...                 | ...          |
|          | +5.42−1.40 | 24.63           | −2.62           | ...           | 0.5                 | 0.0          |
|          | +7.92−1.82 | 35.75           | −3.10           | ...           | 0.5                 | 1.4          |
|          | +8.86+3.98 | 42.70           | −0.98           | ...           | 1.0                 | 3.9          |
|          | +14.49−6.76 | 70.32          | ...             | ...           | 0.1                 | 1.0          |
| Q1329+412 |        | +0.20−0.69       | 4.30            | ...           | ...                 | ...          |
|          | +2.11−0.94 | 13.80           | −2.06           | D             | 10                  | 21           |
|          | −1.81+2.04 | 16.31           | −3.34           | ...           | 0.0                 | 1.6          |
|          | −4.23+3.04 | 31.13           | −2.90           | ...           | 0.4                 | 1.8          |
|          | +5.23−3.76 | 38.48           | −3.02           | ...           | 0.1                 | 1.0          |

$^a$ Projected impact parameter in units of $h^{-1}$ kpc, assuming the object to be at the absorber redshift with $h = 0.73$. In the case of Q0738+313, the two numbers given correspond to the two absorbers at $z = 0.0912$ and 0.2212, respectively.

$^b$ The object luminosities assume that the objects are at the absorber redshifts and are based on our photometry. Q0738+313 lists luminosities in $K$.

$^c$ Morphology codes: Dd = disk-dominated; D = disk; B+D = bulge plus disk; B = bulge; P = unresolved; ellipsis = unknown type.

$^d$ Observations were nonphotometric.

$^e$ Values correspond to $z_{abs} = 0.0912$ and 0.2212, respectively.

$^f$ Values correspond to $z_{abs} = 1.282$. 

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**Figure 4** (bottom right): In this image we used an azimuthally averaged PSF to subtract the light from the quasar, because the
KL analysis could not be performed over this large a field due to its computational requirements. The quasar contribution at the separation of the jet and arm are small, so this subtraction should be adequate. This image was then analyzed by SExtractor. The feature +5.40–0.11 east of the quasar is aligned with the bright knot in the Turnshek et al. (2001) “arm,” but the linear feature west-southwest of the quasar is found to be slightly rotated from the position shown in Figure 1 of Turnshek et al. (2001). In our image the linear feature extends along a line intersecting the quasar, whereas in Turnshek et al. (2001) the feature appears aligned east-west. The jet clearly shows a highly mottled linear morphology.

A new feature, +0.71+0.13, can be seen in the smoothed and binned image (Fig. 4). It is also seen in the KL PSF-subtracted image when it is similarly smoothed and rebinned. This feature is previously unidentified. It appears to have a core with faint emission extending several arcseconds to the north-northwest. It is not clear whether this emission is some component of a larger object encompassing all the faint nebulosity, but given its close proximity to the quasar line of sight (b = 3 or 6 kpc), it is likely to be associated with one of the absorption-line systems.

The feature seen less than 0.5 southwest of the quasar line of sight in the KL PSF-subtracted image is a possible source, but it is well within the region where PSF subtraction artifacts are large for stellar sources, so it is difficult to rule out that it is a PSF-subtraction artifact.

4.4. Q0850+440

This radio-quiet QSO has an associated absorption system at z = 0.1638. In an imaging and spectroscopic survey of faint galaxies, Lanzetta et al. (1995) reported a strong Lyα absorption system and a possible indication of weak C iv absorption at z = 0.1630. They also obtained an unambiguous redshift of z = 0.1635 for a galaxy relatively close to the quasar sight line. The subsequent UV spectroscopic survey of Lanzetta et al. (1997) showed that the Lyα absorption system at z = 0.1638 has log N(H i) = 19.8. They concluded that this system is associated with a moderate-luminosity early-type galaxy, although it may actually arise in one of several very faint galaxies close to the QSO line of sight seen in their HST WFPC2 images. These conclusions are supported by Chen et al. (2001), who confirmed the QSO system and the associated galaxy. Their photometric redshifts show that other galaxies in this field do not have the same redshift as the QSO system.

Four objects are identified in our H-band images. Object −9.04+1.53 is the galaxy designated “G1” by Lanzetta et al. (1997). We find that it is a diskyk galaxy with a bulge-to-disk ratio of ~0.3 and scale lengths of r_c ~ 0.7 and r_d ~ 1.0 kpc. Object −0.20–3.49 is the object designated “S1” by Lanzetta et al. (1997). It is a point source in our images, as well as the HST images of Lanzetta et al. (1997). Object +1.28+2.55 is a diffuse armlike feature that can be seen in our H-band image, as well as the HST images. The near-infrared emission appears to extend toward the quasar. We find an apparent H magnitude of 24.7 for this diffuse emission, while Lanzetta et al. (1997) find an apparent AB magnitude of m_HF02W = 22.5 mag. The F02W H color of ~2.2 is extremely blue. Object +0.56+0.32 is close to the line of sight to the quasar (0′64), but we believe it to be real, since we do not see a similar extension in the PSF-subtracted stellar image (see Fig. 1). In fact, we see extended emission to the east of the quasar in each of the four techniques used to remove the quasar light contribution. In addition, the emission at +1.28+2.55 and at +0.56+0.32 appears to be continuous (Fig. 5). We interpret the two emission features to be a single object, with object +1.28+2.55 being an extension of the emission. We regard it as the likely absorber. If this is the correct interpretation, then the QSO is sampling a region ~2 kpc from the center of a very blue galaxy. In addition, object −2.56+2.01, while identified as a separate object, is also very blue and could be part of this same emission. Object −2.56+2.01 is unresolved. We do not detect object −0023+0043 identified in Lanzetta et al. (1997).

4.5. Q1127−145

PKS B1127−145 is a compact, gigahertz-peaked radio source at z_em = 1.187, with a jet seen in radio and X-ray images and variability at radio wavelengths. Bergeron & Boisse (1991) identified Mg ii, Fe ii, and Mg i absorption in the spectrum of the quasar at z = 0.313. They spectroscopically confirmed two late-type galaxies at the redshift of the absorber separated from the quasar by 9°6 and 17°7 and identified the closer one as the Mg ii absorber. Lane et al. (1998), in a survey of H i 21 cm absorption in Mg ii−selected systems using the Westerbork Synthesis Radio Telescope, discovered 21 cm absorption at z = 0.3127. HST UV spectra show a damped Lyα profile with N(H i) = (5.1 ± 0.9) × 1011 cm−2 (Lane et al. 1998; Rao & Turnshek 2000). Lane et al. (1998) concluded that the galaxy that Bergeron & Boisse (1991) identified as the absorber is unlikely to be the QSO system, since its column density is unlikely to arise at the projected impact parameter (≥20 kpc). Instead, they suggested that the absorption comes from another galaxy with a separation 3′9 from the quasar or from tidal debris associated with a group of galaxies. Bechtold et al. (2001) detected X-ray absorption with the Chandra ACIS and suggested that the absorbing gas of the QSO has a metallicity of 23% solar. Rao et al. (2003) identified the QSO galaxy as a patchy/irregular LSB structure that encompasses four objects. They suggested that the QSO system is more likely associated with the faintest object in the group found at the absorber redshift. Chen & Lanzetta (2003) also found that a group of at least four galaxies are at the redshift of the QSO, and they concluded that because of the proximity of these galaxies to the QSO line of sight, it is difficult to separate the contribution of either of the galaxies to the QSO.

Six objects are identified in our image of this field. The angular distances of these objects to the QSO range from 0′6 to 16′′, corresponding to b_abs = 2.5–70 kpc. Object +8.86+3.98 corresponds to the object designated “G1” in Bergeron & Boisse (1991) at 9′7. Morphologically, G1 appears to have both a disk and a bulge with a bulge-to-total ratio of ~0.4. Tidal warping at the edge of this galaxy can be seen in both our H-band image and the HST F814W image. Our object −3.57+0.17 corresponds to the object identified as the likely absorber by Lane et al. (1998).

Our image adds to the already crowded field of Q1127−145. We regard object −0.13+0.57, appearing after PSF subtraction at an angular distance of 0′6, as another candidate absorber, simply due to its close proximity to the QSO line of sight. This object has not be identified previously, although the HST image shows a similar feature when the PSF is removed. We do not discount that the faint diffuse emission seen around the field could also contribute to the absorbing system, but this close object would have an impact parameter of only ~2.5 kpc. It has not been reported previously but appears to extend at least 1′′ away from the quasar. We do not detect all the faint nebulosity seen in the immediate vicinity of the quasar in the HST images but have detected very diffuse emission extending northwest 0′5 from the quasar.

4.6. Q1329+412

This radio-quiet QSO (z_em = 1.93) was observed by Sargent et al. (1988), who identified four distinct absorption redshifts in its spectrum. In a spectral survey of C iv absorption systems, they...
found a weak Mg II doublet at $z = 0.5009$. The IUE spectrum of this object shows a low-redshift candidate DLA system at $z = 0.5193$ with log $N$(H i) = 20.8 (Lanzetta et al. 1995). HST UV spectroscopy did not confirm the presence of this system (Turnshek & Rao 2002); however, subsequent HST spectra did reveal a DLA at the redshift ($z = 1.282$) of another Mg II system (Bechtold et al. 2002). Based on the equivalent width of the Lyα line at $z = 1.282$, the DLA system has a log $N$(H i) = 19.7. There are additional metal-line systems at $z = 1.6012, 1.8355$ (C iv + Mg ii) and $z = 1.4716, 1.9405$ (C iv).

Five objects are identified in our image of this field. The angular distances of these objects to the QSO range from $\Delta \theta = 2\farcs4$ to $6\farcs5$ corresponding to $\Delta \rho_{\text{abs}} = 20–54$ kpc at $z = 1.28$. There is no previous report of detection of these objects in the literature. Aragon-Salamanca et al. (1994) detected a faint object ($K \approx 19.75$) with an angular distance of $3\arcsec$ from the QSO line of sight, which could be object $-1.81+2.04$. Object $-1.81+2.04$ is evident in the HST F702W image. All objects are compact and faint. Objects $-4.23+3.04$ and $+2.11–0.94$ appear slightly extended; however, they would have impact parameters in excess of 20 kpc if they gave rise to the absorption. We regard the likely absorber as the faint emission $0\farcs7$ south of the quasar. This object is evident in both our near-infrared image and the HST image, although we do not have the resolution or the signal-to-noise ratio to determine its morphology.

5. SUMMARY AND FUTURE WORK

We present the first adaptive optics (AO) observations of low-redshift DLA systems. The images have revealed several objects at close angular separations to the quasar in each field. The AO images are comparable to the HST images in resolution, and several close features are seen in common with HST and with these AO images. In addition, we report the detection of two previously unidentified objects in the fields of Q0738+313, where there are no HST images, and Q1127–145, where the HST detection is marginal.

The objects found in these quasar absorption fields would be less than 0.1$L_*$ if they were at the absorber redshift, and most of the brighter objects appear to have disks. The census of the brighter objects in these six absorber fields is six disk-dominated galaxies, three disk+bulge galaxies, two bulge-dominated galaxies, three point sources, and five unconstrained objects. In addition, five of the six fields show objects between $0\farcs5$ and $1\farcs0$ to the line of sight to the quasar.

Our census has found likely candidates for all the DLA systems. The KL subtraction reveals a candidate object just offset from the quasar line of sight in Q0054+144, although the HST field appears to have several faint objects distributed about the field. The DLA in Q0235+164 appears to be the object previously identified $1\farcs5$ east of the quasar (Yanny et al. 1989). In Q0738+313 we find a new object to which we attribute the lower redshift DLA. This object would have an impact parameter of $\sim 3$ kpc. It appears to have emission extending several arcseconds to the northwest. This emission could be associated with the jet and arm features identified by Turnshek et al. (2001), although this emission is fainter than that of the new object detected here. The DLA at $z = 0.22$ in this field has been previously identified. In Q0850+440 Lanzetta et al. (1995) find a dwarf galaxy $9\arcsec$ from the quasar ($b \approx 25$ kpc). We identify another object very close to the quasar line of sight as a candidate absorber. It appears only after subtraction of the quasar, but if the absorption arises from this object, then the DLA arises close to the core of a very blue galaxy ($b \approx 2$ kpc). For Q1127–145 we find a faint diffuse object close to the line of sight of the quasar and extending north-northwest several arcseconds. The absorber in Q1329+412 is identified as arising from an object $0\farcs7$ south of the quasar. This object is also clearly seen in both our H-band image and an HST F702W image of the field.

All candidate absorbers are faint, with luminosities less than 0.1$L_*$ or $L_*$/3. Assuming that at least some of these objects are at the same redshift as the absorbers, we conclude that the absorbers in our fields are associated with relatively low-luminosity galaxies. Morphological analysis reveals that most of the brighter objects have a disk component. Their sizes, inferred from the surface brightness profiles, range from small to typical scale lengths for local disk galaxies. For reference, our Galaxy has a disk scale length of $r_d = 2.2$ kpc measured in the $K$ band (Maihara et al. 1978; Jones et al. 1981), and M31 has a scale length of $r_d = 3.9$ kpc in the $K$ band and $r_d = 4$ kpc in the $I$ band (Hiromoto et al. 1983). Table 5 summarizes the object morphologies and the derived linear impact parameter, luminosity, and scale lengths, assuming the objects are at the redshift of the absorber.

Rao et al. (2003) have suggested that the DLAs at $z < 1$ are dominated by dwarf or LSB galaxies. However, Chen & Lanzetta (2003), with more photometric redshifts, have suggested that the luminosity function of $z < 1$ DLAs could be much broader. Our observations, at higher resolution than both of these studies, have found all the candidate absorbers to be faint, with significant disk components for the majority of the objects. This suggests that a considerable fraction of low-$z$ DLAs may be faint LSB galaxies. Such a conclusion would appear to be consistent with the low metallicities found in low-$z$ DLAs (e.g., Khare et al. 2004; Kulkarni et al. 2005; and references therein). However, it would be necessary to obtain redshift confirmations for our candidates and to obtain similar high-resolution images of other low-$z$ DLAs to reach more definitive conclusions on the luminosity function of the absorbing galaxies.

Our observations have demonstrated the use of AO for direct high-resolution imaging of the galaxies giving rise to quasar absorbers. Deeper observations of the same fields in the future with higher order AO systems would help to improve the signal-to-noise ratios in the fainter objects. Furthermore, AO systems with laser guide stars are not constrained by the need to have a bright guide star in the quasar field and would thus be able to reach higher redshift absorbers.

It is crucial to also obtain spectroscopy (or at least narrowband imaging) of all the fields to better constrain the redshifts of the detected candidate absorbers. With spectroscopic PSF-subtraction procedures (such as those followed by Moller [2000]) it may be feasible to even verify the redshifts of the objects located very close to the line of sight of the quasar. It is essential to expand the sample of high-resolution broadband images, followed with spectroscopic confirmations, for quasar absorbers at low and high redshifts. Such a combination of high-resolution imaging and spectroscopic observations of quasar absorbers can give direct information on their luminosities, sizes, and star formation rates and thus the nature of these galaxies. Performing such observations on different types of quasar absorbers (e.g., DLAs, weak Mg II systems, and C iv systems) may help in understanding any trends between the absorption-line strengths and galaxy properties such as the luminosities and impact parameters. Finally, a comparison of these properties of quasar absorbers at low and high redshifts will allow us to study the evolution of the absorbing galaxies with cosmological time and the connection between the absorbers and the present-day galaxies.

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