PROBBING THE IGM/GALAXY CONNECTION. IV. THE LCO/WFCCD GALAXY SURVEY OF 20 FIELDS SURROUNDING UV-BRIGHT QUASARS

J. Xavier Prochaska1, B. Weiner2, H.-W. Chen3, K. L. Cooksey4,6, and J. S. Mulchaey5

1 Department of Astronomy and Astrophysics & UCO/Lick Observatory, University of California, 1156 High Street, Santa Cruz, CA 95064, USA; xavier@ucolick.org
2 Steward Observatory, University of Arizona, 933 N. Cherry Ave., Tucson, AZ 85721, USA; bjw@as.arizona.edu
3 Department of Astronomy, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637, USA; hchen@oddjob.uchicago.edu
4 MIT Kavli Institute for Astrophysics & Space Research, 77 Massachusetts Avenue, 37-611, Cambridge, MA 02139, USA; kcooksey@space.mit.edu
5 Carnegie Observatories, 213 Santa Barbara St., Pasadena, CA 91101, USA; mulchaey@obs.carnegiescience.edu

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ABSTRACT

We publish the survey for galaxies in 20 fields containing ultraviolet bright quasars (with \( z_{\text{em}} \approx 0.1-0.5 \)) that can be used to study the association between galaxies and absorption systems from the low-\( z \) intergalactic medium (IGM). The survey is magnitude limited (\( R \approx 19.5 \) mag) and highly complete out to 10' from the quasar in each field. It was designed to detect dwarf galaxies (\( L \approx 0.1L^* \)) at an impact parameter \( \rho \approx 1 \) Mpc (\( z = 0.1 \)) from a quasar. The complete sample (all 20 fields) includes \( R \)-band photometry for 84,718 sources and confirmed redshifts for 2800 sources. This includes 1198 galaxies with \( 0.005 < z < (z_{\text{em}} - 0.01) \) at a median redshift of 0.18, which may associated with IGM absorption lines. All of the imaging was acquired with cameras on the Swope 40' telescope and the spectra were obtained via slit mask observations using the WFCCD spectrograph on the Dupont 100' telescope at Las Campanas Observatory. This paper describes the data reduction, imaging analysis, photometry, and spectral analysis of the survey. We tabulate the principal measurements for all sources in each field and provide the spectroscopic data set online.

Key words: galaxies: statistics – intergalactic medium – quasars: absorption lines

Online-only material: color figures, machine-readable tables

1. INTRODUCTION

The intergalactic medium (IGM) is the gas and dust which permeates the space between galaxies in our universe. The IGM is inferred to be the dominant repository of baryons in our universe; it provides the fuel for galaxies and serves as a "sink" for the metals they expel. The IGM is almost exclusively observed through absorption-line techniques in the spectra of distant objects, e.g., quasars, gamma-ray bursts. The so-called Ly\( \alpha \) forest, for example, is the thicket of H\( \text{I} \) absorption lines which trace modest overdensities in the universe.

Despite its name, which suggests a disconnect from galaxies, the IGM exhibits several characteristics which connect it to them. Chief among these is the presence of metals, generally in the form of highly ionized species like C\( iv \), Si\( iv \), and O\( vi \) absorption. The medium is too diffuse and ionized to support in situ star formation, therefore it is expected that these metals were produced within galaxies and transported by one or more mechanisms to the IGM (e.g., galactic-scale winds, tidal stripping). Identifying the timing, the processes, and the precise interplay between galaxies and the IGM remains a very active area of current astrophysical research (e.g., Scannapieco et al. 2006; Oppenheimer & Davé 2009; Wiersma et al. 2010).

For several decades now, researchers have surveyed the fields surrounding bright quasars with the goal of connecting galaxies that they discover to specific characteristics of the IGM (as revealed by rest-frame UV spectroscopy of the quasars). These include surveys to explore the association of galaxies with the Ly\( \alpha \) forest (Morris et al. 1993; Lanzetta et al. 1995; Stocke et al. 1995; Shull et al. 1996; Bowen et al. 2002; Chen et al. 2005; Shone et al. 2010), searches for galaxies related to strong Mg\( ii \) lines (Bergeron & Boisse 1991; Steidel 1993; Barton & Cooke 2009; Chen et al. 2010), and studies of the structures giving rise to O\( vi \) absorption (Tripp & Savage 2000; Bowen et al. 2001; Savage et al. 2002; Sembach et al. 2004; Tumlinson et al. 2005; Prochaska et al. 2006; Stocke et al. 2006; Tripp et al. 2006; Cooksey et al. 2008; Chen & Mulchaey 2009; Wakker & Savage 2009). The latter ion has received considerable attention because it has been proposed to trace the \( T \approx 10^5-10^7 \) K phase of the IGM, termed the warm-hot intergalactic medium (WHIM). Although the WHIM is a generic prediction of cosmological simulations (Cen & Ostriker 1999; Davé et al. 2001; Fang & Bryan 2001), its low density and modest temperature make it especially elusive to empirical detection. The O\( vi \) doublet, however, has been extensively surveyed and owing to its high ionization state may track a portion of the WHIM.

Motivated by the analysis of O\( vi \) and its relation to galaxies and the WHIM, we initiated a program to survey galaxies in the fields surrounding UV-bright, \( z_{\text{em}} \approx 0.1 \), quasars that were targetted (or likely to be targetted) by the Far Ultraviolet Spectroscopic Explorer (FUSE) and/or the Hubble Space Telescope (HST). Prior to the commissioning of the Cosmic Origins Spectrograph (COS), there were only a small set of known quasars that were bright enough for such observations. The sources are widely separated across the sky such that existing, ongoing, and/or planned galaxy surveys (e.g., SDSS, 2dF) do not cover the fields or are often too shallow for studying \( L > L^* \) galaxies beyond \( z \approx 0.05 \). Therefore, we designed a survey with two main observational goals: (1) achieve high completeness for galaxies as faint as \( z=0.1L^* \); (2) survey an area corresponding to at least 1 Mpc at \( z = 0.1 \). Technically, this implied a magnitude limit of \( R \approx 19.5 \) mag and a field of view (FOV) of roughly 10' radius around each quasar. These requirements were well suited to the WFCCD spectrograph
on the 100′′ Dupont Telescope at Las Campanas Observatory (LCO). Over the course of several years, we targeted 20 fields at equatorial and Southern declinations (Table 1). Early results from this survey have been used to explore the IGM/galaxy connection for Ovi absorbers (Prochaska et al. 2006; Cooksey et al. 2008), the Lyα forest (Chen et al. 2005), and a Lyman limit absorber (Lehner et al. 2009).

With this paper, we provide the full data release of the LCO/WFCCD survey. This stands, for now, as the largest spectroscopic data set for exploring the association between the IGM and galaxy connection with this data set. We analyze the IGM parameters were set to require a minimum detection area of 5 yr WMAP cosmology (Dunkley et al. 2009): ΩΛ = 0.74, Ωm = 0.26, and H0 = 72 km s⁻¹ Mpc⁻¹. Furthermore, all distances are quoted in proper units unless otherwise denoted.

2. OBSERVATIONS AND DATA REDUCTION

We selected 20 fields accessible from LCO (declination δ < 25°) surrounding UV-bright quasars with emission redshifts z_em > 0.05. These quasars had existing UV spectroscopy from the HST or FUSE telescopes, had planned UV spectroscopic observations with one of these telescopes, and/or have sufficiently high UV flux to permit UV spectroscopic observations with one of these facilities. The quasars were also chosen to have a wide range of right ascension to enable a year-round observing campaign. The quasars and their UV spectroscopic data sets are summarized in Table 1.

All of the fields in our survey were imaged with the Swope 40′′ telescope using a direct imaging camera. The majority were taken with the SITE1 CCD which has 0′′6946 pixels in a 2048 × 2048 array. The remainder were observed with the SITE3 CCD which has 0′′435 pixels in a 2048 × 3150 array. All of the fields were imaged through an R-band filter and also most had contemporaneous B-band images taken. The data were obtained in a series of dithered exposures intended to map at least a 20′ × 20′ FOV. This was designed to enable a survey to approximately a 1 Mpc impact parameter ρ at z ≈ 0.1. Most of the imaging data were obtained under photometric conditions; Table 2 summarizes the weather and provides a log of the observations. Most of the data were acquired in good seeing conditions, i.e., FWHM ≈ 1′′.

The imaging data were reduced with standard IRAF routines to overscan subtract and flat field the images. We used custom routines to determine integer offsets between the dithered images and combined the frames after weighting by a global measure of the inverse variance. We derived a photometric solution for each night from analysis of Landoldt standard stars (Landolt 1992) that were observed at a range of airmass. We solved for the zero point, airmass, and (B − R) color terms. We estimate the systematic uncertainty related to the photometric solution to be approximately 0.05 mag.

Each combined R-band image was analyzed with the SExtractor (v2.0; Bertin & Arnouts 1996) package. The parameters were set to require a minimum detection area of 6 pixels and a detection threshold of 1.5σ above the rms of the sky background. For each object detected, SExtractor reports a star–galaxy (S/G) classifier with values ranging from 0 to 1 where unity indicates a point-spread-function consistent with a point source (i.e., a likely star). Finally, we produced a segmentation map of each field and calculated B and R

Table 1

| Quasar | R.A. (J2000) | Decl. (J2000) | z_em | HST UV Spectroscopic Data Sets | FUSE* | Rmax | Nspec | C^c^19.5 | 〈10^10〉 |
|--------|-------------|--------------|------|-------------------------------|-------|------|-------|-----------|------------|
| Q0026+1259 | 00:29:13.8 | +13:16:04 | 0.142 | GRS/G270M | 20 | 20.0 | 60 | 100 | 91 |
| Ton S 180 | 00:57:20.0 | −22:22:56 | 0.062 | STIS/G140M,G230MB | 132 | 19.7 | 7 | 100 | 93 |
| Ton S 210 | 01:21:51.5 | −28:20:57 | 0.116 | STIS/E140M,E230M | 57 | 20.0 | 7 | 86 | 90 |
| PKS0312-77 | 03:11:55.2 | −76:51:51 | 0.223 | STIS/E140M | 20.0 | 56 | 100 | 97 |
| PKS0405-123 | 04:07:48.4 | −12:11:37 | 0.573 | STIS/E140M,G230M,G160M,G200M | 71 | 20.0 | 565 | 100 | 97 |
| PKS0558-504 | 05:39:47.4 | −50:26:52 | 0.137 | STIS/G230MB | 400 | 20.0 | 16 | 100 | 99 |
| PG1004+130 | 10:07:26.1 | +12:48:56 | 0.240 | STIS/G140M | 85 | 19.5 | 61 | 74 | 71 |
| HE1029−140 | 10:31:54.3 | −14:16:51 | 0.086 | STIS/G140M | 19.8 | 8 | 100 | 95 |
| PG1116+215 | 11:19:08.7 | +21:19:18 | 0.176 | STIS/G140M,E140M,E230M,GHRS/G140L | 76 | 20.0 | 74 | 76 | 79 |
| PG1211+143 | 12:14:17.7 | +14:03:13 | 0.081 | STIS/G140M,E140M,GHRS/G140L,G270M | 52 | 19.5 | 25 | 61 | 56 |
| PG1216+069 | 12:19:20.9 | +06:38:38 | 0.331 | STIS/E140M,GHRS/G140L | 13 | 20.0 | 101 | 100 | 89 |
| 3C273 | 12:29:6.7 | +02:03:9.0 | 0.158 | STIS/E140M,GHRS/G130F,G190F,G270G,160M | 42 | 20.0 | 32 | 81 | 84 |
| Q1230+094 | 12:33:25.8 | +09:31:23 | 0.415 | GRS/G140L | 13 | 19.5 | 99 | 83 | 77 |
| PKS1302−102 | 13:05:33.0 | −10:33:19 | 0.286 | STIS/E140M | 140 | 19.5 | 63 | 89 | 65 |
| PG1307+085 | 13:09:47.0 | +08:19:49 | 0.155 | STIS/G230MB | 11 | 19.5 | 41 | 79 | 75 |
| MRK1383 | 14:29:06.4 | +01:17:06 | 0.086 | STIS/E140M,G140L | 64 | 19.5 | 5 | 79 | 68 |
| Q1553+113 | 15:55:43.0 | +11:11:24 | 0.360 | STIS/E140M,G140L | 20 | 20.0 | 106 | 90 | 85 |
| PKS2005−489 | 20:09:25.4 | −48:49:54 | 0.071 | STIS/E140M | 48 | 20.0 | 52 | 97 | 97 |
| FZ2155−0922 | 21:55:01.5 | −09:22:50 | 0.192 | STIS/E140M,G230MB | 46 | 20.0 | 105 | 100 | 95 |
| PKS2155−304 | 21:58:51.8 | −30:13:30 | 0.116 | STIS/E140M,GHRS/G160M,LECH-B,G140L | 123 | 20.0 | 43 | 96 | 96 |

Notes. Columns 9 and 10 list the completeness percent of the spectroscopic survey in each field to R = 19.5 mag for a radius of 5 and 10 arcminutes, respectively.

* Total integration time in ks.

** Number of spectroscopically determined galaxy redshifts for objects with 0 < z < z_em.
### Table 2
Log of Imaging Observations

| Field          | UT Date | CCD Filter | Exp. | Conditions  |
|----------------|---------|------------|------|-------------|
| Q0026+1259     | 2000 Oct 26 | STTe1 | B 2 × 450 s | Photometric |
| Q0046+112      | 2000 Oct 26 | STTe1 | R 3 × 600 s | Photometric |
| Ton S 180      | 2000 Oct 26 | STTe1 | B 2 × 450 s | Photometric |
| HE0153—4520    | 2001 Sep 14 | STTe3 | B 3 × 600 s | Photometric |
| Ton S 210      | 2000 Oct 26 | STTe1 | B 3 × 600 s | Photometric |
| PKS0312—770    | 2002 Oct 3 | STTe3 | R 6 × 600 s | Photometric |
| PKS0405—123    | 2002 Oct 4 | STTe3 | R 5 × 600 s | Photometric |
| PKS0558—504    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| B0736+017      | 2002 Oct 4 | STTe3 | R 4 × 600 s | Photometric |
| PG0832+25      | 2002 Oct 4 | STTe3 | R 6 × 600 s | Photometric |
| IR0914—6206    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| PG1001+054     | 2002 Oct 4 | STTe3 | R 4 × 600 s | Photometric |
| PG0104+130     | 2002 Oct 4 | STTe3 | R 6 × 600 s | Photometric |
| PG1011—104     | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| HE1015—1618    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| HE1029—140     | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| HE1050—2711    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| HE1115—1735    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| PG1116+215     | 2002 Oct 4 | STTe3 | R 6 × 600 s | Photometric |
| HE1122—1649    | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| MRK 1298       | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| PG1126+215     | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| PG1216+069     | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| 3C273          | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |
| LBQS1230+0947  | 2002 Oct 4 | STTe3 | R 3 × 600 s | Photometric |

The true galaxy magnitudes, therefore, may be up to a few tenths magnitude brighter especially for low-surface brightness galaxies.

Proper astrometry for each field was applied with the publicly available Image World Coordinate Setting Program imwcs version 3.6.8. First, several World Coordinate System (WCS) keywords were added to the reduced and combined image header in order to define its estimated pointing and plate scale (0′/6964 pixel\(^{-1}\) for the STTe1 CCD and 0′/4349 pixel\(^{-1}\) for STTe3). Next, we used imwcs to fit a plane-tangent projection, using stars in the image that imwcs identified and stars from a reference catalog, namely, the US Naval Observatory astrometric catalog USNO-A2.0. The imwcs algorithm typically matched a dozen or more stars and converged in six iterations, with a mean arcsec offset of 0′/15 in any given image. Finally, all astrometized images were visually compared to the USNO-A2.0 sample to verify that the solution held across the whole field (e.g., no systematic rotation was obvious toward the outskirts of the image).

Table 2 (Continued)

| Field          | UT Date | CCD Filter | Exp. | Conditions  |
|----------------|---------|------------|------|-------------|
| PKS1302—102    | 2001 Feb 23 | STTe1 | B 2 × 450 s | Photometric |
| PG1307+085     | 2001 Feb 23 | STTe1 | R 3 × 600 s | Photometric |
| HE1326—0516    | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| PKS1352+183    | 2001 Mar 1 | STTe1 | R 3 × 600 s | Photometric |
| PKS1302—102    | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| PKS2005—489    | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| B2145+067      | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| B2145+067      | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| PKS2155—304    | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |
| Q2251—178      | 2001 Mar 1 | STTe1 | B 2 × 450 s | Photometric |

7 http://tdc-www.harvard.edu/software/wcstools/imwcs/index.html
8 http://tdc-www.harvard.edu/software/catalogs/ua2.html
Based on our SExtractor analysis of the images, we designed a set of slit masks for each field to be used with the WFCCD instrument on the DUPONT 100” telescope. Targets were identified as follows. First, we examined the isophotal area versus $R$ magnitude from the imaging of a given field. In all cases, stars trace out a well-defined locus for $R < 19.5$ mag (see Figure 1 of Prochaska et al. 2006, for example). We traced this locus and discarded all objects that fall within the stellar region or fall just outside the locus and have an $S/G$ value greater than 0.98. We also did not target the few, very bright ($R < 15$ mag) and very large (angular diameter $> 10^\prime$) galaxies that exist in the survey fields. Most of these have previously published redshifts and/or lie at too low redshift ($z < 0.01$) for our main scientific program.

For those that remained, we targeted all objects with $R \leq R_{\text{max}}$ and $\theta < \theta_{\text{max}}$ of the QSO. We set $R_{\text{max}} > 19.5$ mag, adopting fainter values for fields with a lower surface density of targets on the sky or where we had particular scientific interest in the field (see Table 1). For all but two of the fields, $\theta_{\text{max}} = 10^\prime$. The two exceptions are PKS0312−770 and PKS0405−123, where we expanded the survey to cover $\theta_{\text{max}} \approx 15^\prime$ and $\approx 20^\prime$, respectively.

We performed multi-slit spectroscopy on each field with the WFCCD spectrometer using the blue grism and the Tek 5 CCD. This affords a spectral resolution FWHM $\approx 375$ km s$^{-1}$, a dispersion of $\approx 2$ Å pixel$^{-1}$, and a nominal wavelength coverage $\lambda \approx 3800$–9000 Å. Our standard integration was a pair of 1800 s exposures, and most of the data were obtained under clear conditions. Longer total exposure times were used for the faintest fields or in worse conditions. These exposure times generally achieved a signal-to-noise ratio ($S/N$) $> 3$ pixel$^{-1}$ for even the faintest objects. Table 3 shows a log of the WFCCD observations.

All of these WFCCD data were reduced with a custom IDL software package9 (see Prochaska et al. 2006 for a full description). The extracted and co-added one-dimensional spectra were analyzed with a modified version of the Sloan Digital Sky Survey (SDSS) pipeline task $zfind$ to establish the object’s redshift. This routine fits principal component analysis (PCA) templates derived from the SDSS data set (Early Data Release; Stoughton et al. 2002) to the emission and/or absorption lines in the object spectrum. In general, these redshift values have uncertainties of $\sigma_z \approx 10^{-4}$ (i.e., $\sigma_z \approx 30$ km s$^{-1}$). Each of the fits was inspected, and, when necessary, the redshift was modified to account for an obvious failure. With few exceptions, we determined an unambiguous redshift for every object on a given mask. The exceptions include rare cases where slit design or fabrication failed (e.g., significant portions of one slit overlapped another) and also faint sources that had no obvious spectral features. This PCA analysis yields eigenvalues for the four galaxy eigenspectra fitted to our data. As in Prochaska et al. (2006), we define $E_C$ to be the eigenvalue for the first eigenfunction (which is dominated by early-type spectral features) and $L_C$ is the second eigenvalue minus the sum of the third and fourth coefficients. All of the spectra are publicly available.10

In Figure 1, we plot the $S/G$ classifier from SExtractor for the targets with spectroscopic redshifts (1) $z < 0.005$, which are predominantly Galactic stars and (2) $z > 0.005$, which are exclusively distant galaxies. As one expects, the majority of the $z < 0.005$ objects have $S/G$ near unity; the exceptions

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9 http://www.ucolick.org/~xavier/WFCCD/index.html
10 http://www.ucolick.org/~xavier/WFCCDOV/index.html
Table 3 (Continued)

| Field       | UT Date | Mask | Exp. | Conditions   |
|-------------|---------|------|------|--------------|
| PG1211+143  | 2003 May 31 | M2   | 3600 | Cirrus       |
|             | 2003 Jun 2 | M1   | 3600 | Clear        |
| PG1216+069  | 2003 Jun 3 | M2   | 5150 | Cirrus       |
|             | 2003 Jun 3 | M1   | 3600 | Clear        |
|             | 2003 Jun 3 | M4   | 3600 | Clear        |
| 3C273       | 2001 Apr 17 | B1   | 1800 | Light cirrus |
|             | 2001 Apr 18 | B1   | 3600 | Photometric  |
|             | 2001 Apr 19 | S0   | 3600 | Photometric  |
|             | 2001 Apr 20 | S1   | 5400 | Light cirrus |
|             | 2001 Apr 20 | S0   | 2700 | Light cirrus |
|             | 2001 Apr 21 | B2   | 5400 | Cirrus       |
|             | 2001 Apr 22 | S2   | 3600 | Photometric  |
|             | 2003 Jun 6  | M2   | 3600 | Clear        |
|             | 2003 Jun 5  | M8   | 3600 | Cirrus       |
| Q1230+09    | 2001 Apr 21 | S0   | 3600 | Cirrus       |
|             | 2001 Apr 21 | B0   | 3600 | Cirrus       |
|             | 2001 Apr 22 | S1   | 3600 | Photometric  |
|             | 2001 Apr 22 | B1   | 3600 | Photometric  |
|             | 2003 Jun 2  | M8   | 1800 | Clear        |
|             | 2003 Jun 4  | B0   | 3600 | Clear        |
|             | 2003 Jun 5  | M8   | 3600 | Cirrus       |
| PKS1302−102 | 2001 Apr 17 | S0   | 3600 | Light cirrus |
|             | 2001 Apr 18 | B0   | 3600 | Photometric  |
|             | 2001 Apr 19 | B1   | 3600 | Photometric  |
|             | 2001 Apr 21 | B2   | 3600 | Cirrus       |
| PG1307+085  | 2003 May 31 | B0   | 3600 | Cirrus       |
|             | 2003 Jun 5  | B1   | 3600 | Cirrus       |
|             | 2003 Jun 6  | S0   | 3600 | Clear        |
| Q1307+085   | 2001 Apr 20 | S0   | 4500 | Light cirrus |
| MRK 1383    | 2001 Apr 17 | B0   | 5400 | Light cirrus |
|             | 2001 Apr 18 | S0   | 3600 | Photometric  |
|             | 2001 Apr 19 | S1   | 5400 | Photometric  |
|             | 2001 Apr 20 | S0   | 2700 | Light cirrus |
|             | 2001 Apr 21 | B1   | 3600 | Cirrus       |
|             | 2001 Apr 22 | S2   | 3600 | Photometric  |
|             | 2005 May 31 | B0   | 3600 | Photometric  |
| Q1553+113   | 2001 Apr 18 | t0   | 3600 | Photometric  |
|             | 2001 Apr 19 | t1   | 2700 | Photometric  |
|             | 2001 Apr 20 | t1   | 3600 | Light cirrus |
|             | 2001 Apr 21 | t2   | 3600 | Cirrus       |
|             | 2001 Apr 22 | t2   | 2700 | Photometric  |
|             | 2003 Jun 4  | M1   | 3600 | Clear        |
|             | 2003 Jun 4  | M2   | 3600 | Clear        |
|             | 2003 Jun 5  | M3   | 5400 | Clear        |
|             | 2003 Jun 6  | M1   | 3600 | Clear        |
| PKS2005−489 | 2003 May 31 | M1   | 3600 | Light cirrus |
|             | 2003 May 31 | M5   | 5400 | Light cirrus |
|             | 2003 Jun 1  | M2   | 3600 | Clear        |
|             | 2003 Jun 1  | M3   | 5400 | Clear        |
|             | 2003 Jun 1  | M4   | 5400 | Clear        |
|             | 2003 Jun 3  | M6   | 6600 | Bad seeing   |
|             | 2003 Jun 4  | M7   | 5400 | Clear        |
|             | 2003 Jun 4  | M2   | 1800 | Clear        |
|             | 2003 Jun 5  | M8   | 5289 | Cirrus       |
| FJ2155−092  | 2001 Sep 10 | M1   | 3600 | Photometric  |
|             | 2001 Sep 13 | M2   | 3600 | Clear        |
|             | 2001 Sep 15 | M3   | 3600 | Clear        |
|             | 2001 Sep 15 | M4   | 3600 | Clear        |
|             | 2001 Sep 16 | M5   | 3600 | Clear        |
|             | 2002 Nov 1  | M6   | 3600 | Clear        |
|             | 2002 Nov 2  | M7   | 3000 | Clear        |
| PKS2155−304 | 2001 Sep 10 | M1   | 3600 | Photometric  |
|             | 2001 Sep 11 | M2   | 3600 | Cloudy       |
|             | 2001 Sep 12 | M2   | 3600 | Clear        |

Figure 1. SExtractor S/G classifier as a function of the objects apparent R-band magnitude and having spectroscopic redshifts (a) \( z < 0.005 \) (predominantly Galactic stars) and (b) \( z > 0.005 \) (exclusively galaxies).

Galaxies with any other pair of coefficient values are labeled “unknown.” For every galaxy with an impact parameter

3. THE SURVEY FIELDS

In this section, we present the imaging data, photometry, and results from the WFCCD spectroscopy for each field. We also comment briefly on any obvious associations between the galaxies we detect and known (published) absorbers along the quasar sightlines. We stress that about half of these fields have been survey for galaxies by other efforts (e.g., SDSS). Our discussion, however, is primarily limited to the galaxies from our LCO/WFCCD survey. Table 4 summarizes properties of the galaxies discovered in the 20 fields restricted to \( 0 < z < 0.005 \) (exclusively galaxies).
Table 4
Summary of Galaxies at \( z < z_{\text{em}} + 0.01 \)

| ID                  | R.A.  | Decl.  | \( z_{\text{gal}} \) | \( L^* \) (\( L_\odot \)) | \( \rho^b \) (h\(^{-1}\) kpc) | Type* |
|---------------------|-------|--------|-----------------------|-----------------------------|--------------------------------|-------|
| Q0026+1259_1303     | 00:29:09.2 | +13:16:28 | 0.03295              | 0.02                         | 44                             | Late  |
| Q0026+1259_1500     | 00:29:01.3 | +13:13:12 | 0.03346              | 0.03                         | 158                            | Late  |
| Q0026+1259_1143     | 00:29:15.3 | +13:20:57 | 0.03931              | 1.38                         | 214                            | Early |
| Q0026+1259_1140     | 00:29:16.4 | +13:21:52 | 0.08043              | 0.11                         | 497                            | Unkn  |
| Q0026+1259_1722     | 00:28:53.5 | +13:24:19 | 0.05645              | 0.56                         | 595                            | Late  |
| Q0026+1259_1103     | 00:29:17.7 | +13:23:26 | 0.08073              | 0.08                         | 634                            | Unkn  |
| Q0026+1259_1901     | 00:28:45.5 | +13:20:08 | 0.08062              | 0.06                         | 695                            | Early |
| Q0026+1259_902      | 00:29:23.4 | +13:09:41 | 0.11253              | 1.09                         | 781                            | Late  |
| Q0026+1259_1125     | 00:29:16.0 | +13:10:03 | 0.13138              | 0.18                         | 791                            | Unkn  |
| Q0026+1259_512      | 00:29:37.5 | +13:10:21 | 0.09614              | 1.96                         | 821                            | Early |

Notes.
* Luminosity relative to \( L^* \) as measured from the apparent \( R \)-band magnitude. See the text for a detailed description.
* Impact parameter in physical distance.
* The galaxy type is a crude assessment of the spectrum based on a fit of eigenfunctions. See the text for a detailed description.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Table 5
Q0026+1259: Object Summary

| ID      | R.A.  | Decl.  | \( B \) (mag) | \( R \) (mag) | \( S/G^a \) | Area (\( \square \)) | Flg\(^b\) | \( z \) |
|---------|-------|--------|---------------|---------------|-------------|---------------------|---------|-------|
| 1       | 00:28:40.3 | +13:08:22 | 11.51 ± 0.11  | 10.20 ± 0.08  | 0.69        | 76.8                | 0       | ...  |
| 2       | 00:28:27.4 | +13:16:27 | 18.79 ± 0.12  | 17.43 ± 0.08  | 0.96        | 4.8                 | 0       | ...  |
| 3       | 00:28:27.6 | +13:26:27 | 19.12 ± 0.12  | 17.33 ± 0.08  | 1.00        | 2.6                 | 0       | ...  |
| 4       | 00:28:26.8 | +13:15:39 | 19.54 ± 0.12  | 18.21 ± 0.08  | 1.00        | 2.4                 | 0       | ...  |
| 5       | 00:28:27.2 | +13:24:49 | 20.46 ± 0.14  | 18.22 ± 0.08  | 1.00        | 2.4                 | 0       | ...  |
| 6       | 00:28:26.4 | +13:14:06 | 21.46 ± 0.23  | 19.60 ± 0.09  | 0.14        | 3.6                 | 0       | ...  |
| 7       | 00:28:26.1 | +13:13:18 | 21.76 ± 0.27  | 19.50 ± 0.09  | 1.00        | 2.9                 | 0       | ...  |
| 8       | 00:28:25.8 | +13:10:15 | 23.74 ± 1.00  | 21.42 ± 0.15  | 0.19        | 2.4                 | 0       | ...  |
| 9       | 00:28:25.8 | +13:10:33 | 21.64 ± 0.24  | 19.64 ± 0.09  | 0.87        | 2.6                 | 0       | ...  |
| 10      | 00:28:25.9 | +13:11:33 | 20.69 ± 0.16  | 18.26 ± 0.08  | 1.00        | 2.4                 | 0       | ...  |

Notes.
* Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.
* This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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Table 6
Ton S 180: Object Summary

| ID      | R.A.  | Decl.  | \( B \) (mag) | \( R \) (mag) | \( S/G^a \) | Area (\( \square \)) | Flg\(^b\) | \( z \) |
|---------|-------|--------|---------------|---------------|-------------|---------------------|---------|-------|
| 1       | 00:57:27.9 | −22:25:12 | 9.86 ± 0.08  | 9.37 ± 0.06   | 0.69        | 253.5               | 0       | ...  |
| 2       | 00:56:52.8 | −22:11:23 | 12.07 ± 0.08  | 11.42 ± 0.06  | 0.95        | 40.1                | 0       | ...  |
| 3       | 00:56:34.2 | −22:29:02 | 15.35 ± 0.09  | 14.34 ± 0.06  | 1.00        | 3.5                 | 0       | ...  |
| 4       | 00:56:33.8 | −22:15:29 | 19.34 ± 0.10  | 17.53 ± 0.06  | 0.02        | 5.8                 | 0       | ...  |
| 5       | 00:56:32.1 | −22:31:34 | 21.96 ± 0.20  | 20.94 ± 0.10  | 0.82        | 3.3                 | 0       | ...  |
| 6       | 00:56:32.0 | −22:28:30 | 19.97 ± 0.11  | 18.10 ± 0.06  | 0.48        | 4.5                 | 0       | ...  |
| 7       | 00:56:33.0 | −22:11:44 | 19.09 ± 0.10  | 17.16 ± 0.06  | 0.88        | 5.0                 | 0       | ...  |
| 8       | 00:56:32.4 | −22:11:41 | 23.32 ± 0.54  | 21.59 ± 0.13  | 0.20        | 4.3                 | 0       | ...  |
| 9       | 00:56:32.0 | −22:24:37 | 21.65 ± 0.18  | 20.28 ± 0.08  | 0.12        | 3.9                 | 0       | ...  |
| 10      | 00:56:32.6 | −22:15:52 | 21.40 ± 0.15  | 20.02 ± 0.07  | 0.31        | 2.9                 | 0       | ...  |

Notes.
* Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.
* This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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### Table 7

#### Ton S 210: Object Summary

| ID  | R.A.       | Decl.     | $B$ (mag)   | $R$ (mag)   | S/G$^a$ | Area (arcsec$^2$) | Flg$^b$ | $z$  |
|-----|------------|-----------|-------------|-------------|---------|-------------------|---------|------|
| 1   | 01:21:01.7 | −28:14:24 | 16.10 ± 0.10 | 13.75 ± 0.06 | 1.00    | 4.7               | 0       | ... |
| 2   | 01:21:09.1 | −28:13:04 | 18.81 ± 0.09 | 17.36 ± 0.07 | 0.47    | 10.4              | 0       | ... |
| 3   | 01:20:58.4 | −28:13:53 | 19.05 ± 0.09 | 17.87 ± 0.07 | 0.13    | 4.9               | 0       | ... |
| 4   | 01:20:56.6 | −28:30:40 | 21.65 ± 0.23 | 18.85 ± 0.07 | 0.19    | 4.9               | 0       | ... |
| 5   | 01:20:57.4 | −28:22:13 | 19.54 ± 0.10 | 18.31 ± 0.07 | 0.02    | 6.9               | 0       | ... |
| 6   | 01:20:57.7 | −28:16:38 | 19.50 ± 0.09 | 18.63 ± 0.07 | 0.09    | 5.1               | 0       | ... |
| 7   | 01:20:57.2 | −28:21:14 | 20.68 ± 0.12 | 18.19 ± 0.07 | 0.99    | 2.1               | 0       | ... |
| 8   | 01:20:57.1 | −28:19:15 | 24.85 ± 1.70 | 21.36 ± 0.12 | 0.98    | 3.1               | 0       | ... |
| 9   | 01:20:56.6 | −28:23:16 | 22.62 ± 0.29 | 19.87 ± 0.07 | 0.99    | 1.9               | 0       | ... |
| 10  | 01:20:55.9 | −28:30:45 | 22.82 ± 0.43 | 20.35 ± 0.09 | 1.00    | 4.3               | 0       | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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### Table 8

#### PKS0312−770: Object Summary

| ID  | R.A.       | Decl.     | $R$ (mag)   | S/G$^a$ | Area (arcsec$^2$) | Flg$^b$ | $z$  |
|-----|------------|-----------|-------------|---------|-------------------|---------|------|
| 1   | 03:11:42.7 | −76:33:44 | 12.65 ± 0.01 | 1.00    | 7.2               | 0       | ... |
| 2   | 03:12:28.6 | −76:33:42 | 18.71 ± 0.02 | 0.12    | 10.2              | 0       | ... |
| 3   | 03:12:10.2 | −76:33:40 | 17.71 ± 0.01 | 1.00    | 4.6               | 0       | ... |
| 4   | 03:14:33.7 | −76:33:39 | 16.63 ± 0.01 | 1.00    | 4.6               | 0       | ... |
| 5   | 03:12:34.0 | −76:33:31 | 19.25 ± 0.03 | 0.85    | 3.8               | 0       | ... |
| 6   | 03:12:52.3 | −76:33:23 | 20.89 ± 0.08 | 0.12    | 7.8               | 0       | ... |
| 7   | 03:12:52.6 | −76:33:25 | 19.44 ± 0.03 | 0.56    | 5.2               | 0       | ... |
| 8   | 03:10:19.9 | −76:33:15 | 20.60 ± 0.10 | 0.98    | 2.7               | 0       | ... |
| 9   | 03:13:01.0 | −76:33:22 | 21.29 ± 0.12 | 1.00    | 5.5               | 0       | ... |
| 10  | 03:14:36.7 | −76:33:23 | 20.19 ± 0.05 | 0.97    | 8.1               | 0       | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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### Table 9

#### PKS0558−504: Object Summary

| ID  | R.A.       | Decl.     | $B$ (mag)   | $R$ (mag)   | S/G$^a$ | Area (arcsec$^2$) | Flg$^b$ | $z$  |
|-----|------------|-----------|-------------|-------------|---------|-------------------|---------|------|
| 1   | 05:59:38.2 | −50:18:33 | 10.41 ± 0.09 | 9.57 ± 0.06 | 0.69    | 149.9             | 0       | ... |
| 2   | 05:59:20.5 | −50:17:37 | 11.53 ± 0.09 | 10.80 ± 0.06 | 0.73    | 48.9              | 0       | ... |
| 3   | 05:58:56.4 | −50:27:28 | 12.41 ± 0.09 | 11.06 ± 0.06 | 0.75    | 38.3              | 0       | ... |
| 4   | 05:58:48.3 | −50:17:10 | 9.97 ± 0.09  | 9.98 ± 0.06 | 0.69    | 97.9              | 0       | ... |
| 5   | 05:58:44.9 | −50:24:12 | 10.51 ± 0.09 | 10.05 ± 0.06 | 0.69    | 94.4              | 0       | ... |
| 6   | 05:58:45.6 | −50:25:13 | 14.00 ± 0.09 | 13.27 ± 0.06 | 1.00    | 5.8               | 0       | ... |
| 7   | 05:58:45.7 | −50:16:04 | 12.78 ± 0.09 | 12.20 ± 0.06 | 1.00    | 14.2              | 0       | ... |
| 8   | 05:58:39.9 | −50:26:41 | 18.09 ± 0.09 | 17.13 ± 0.06 | 1.00    | 2.5               | 0       | ... |
| 9   | 05:58:42.0 | −50:26:33 | 12.30 ± 0.09 | 11.76 ± 0.06 | 0.98    | 20.0              | 0       | ... |
| 10  | 05:58:43.5 | −50:22:24 | 13.99 ± 0.09 | 13.12 ± 0.06 | 1.00    | 6.4               | 0       | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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### Table 10
PG1004+130: Object Summary

| ID     | R.A.   | Decl.  | $B$    | $R$    | S/G$^a$ | Area ($\alpha'$) | Flg$^b$ | $z$   |
|--------|--------|--------|--------|--------|---------|------------------|---------|-------|
| 1      | 10:06:47.3 | +12:46:52 | 8.19 ± 0.00 | 8.74 ± 0.00 | 0.69 | 217.7 | 0 ... |
| 2      | 10:06:57.9 | +12:40:53 | 10.58 ± 0.00 | 11.13 ± 0.00 | 0.75 | 30.0 | 0 ... |
| 3      | 10:06:40.6 | +12:47:50 | 21.44 ± 0.24 | 21.99 ± 0.24 | 1.00 | 2.4 | 0 ... |
| 4      | 10:06:39.5 | +12:40:58 | 19.82 ± 0.06 | 20.37 ± 0.06 | 0.22 | 3.7 | 0 ... |
| 5      | 10:06:38.8 | +12:37:14 | 17.74 ± 0.01 | 18.29 ± 0.01 | 1.00 | 2.6 | 0 ... |
| 6      | 10:06:40.1 | +12:48:43 | 21.92 ± 0.30 | 22.46 ± 0.30 | 0.97 | 7.6 | 0 ... |
| 7      | 10:06:40.3 | +12:51:47 | 17.97 ± 0.01 | 18.51 ± 0.01 | 1.00 | 2.5 | 0 ... |
| 8      | 10:06:39.4 | +12:44:47 | 19.73 ± 0.07 | 20.28 ± 0.07 | 0.12 | 5.7 | 0 ... |
| 9      | 10:06:39.5 | +12:45:04 | 21.60 ± 0.29 | 22.15 ± 0.29 | 0.35 | 9.2 | 0 ... |
| 10     | 10:06:38.5 | +12:37:47 | 19.38 ± 0.05 | 19.93 ± 0.05 | 0.15 | 3.6 | 0 ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

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### Table 11
HE1029−140: Object Summary

| ID     | R.A.   | Decl.  | $B$    | $R$    | S/G$^a$ | Area ($\alpha'$) | Flg$^b$ | $z$   |
|--------|--------|--------|--------|--------|---------|------------------|---------|-------|
| 1      | 10:31:16.6 | −14:21:26 | 14.12 ± 0.00 | 13.23 ± 0.00 | 1.00 | 6.2 | 0 ... |
| 2      | 10:31:15.3 | −14:14:52 | 15.22 ± 0.00 | 13.97 ± 0.01 | 1.00 | 3.9 | 0 ... |
| 3      | 10:31:13.1 | −14:15:55 | 16.15 ± 0.01 | 14.62 ± 0.01 | 1.00 | 2.6 | 0 ... |
| 4      | 10:31:13.4 | −14:11:51 | 16.64 ± 0.01 | 15.80 ± 0.01 | 1.00 | 2.2 | 0 ... |
| 5      | 10:31:13.9 | −14:06:06 | 18.95 ± 0.03 | 17.90 ± 0.01 | 0.87 | 6.1 | 0.13066 |
| 6      | 10:31:11.8 | −14:21:00 | 16.48 ± 0.01 | 15.64 ± 0.00 | 1.00 | 2.8 | 0 ... |
| 7      | 10:31:12.5 | −14:16:26 | 17.81 ± 0.01 | 16.50 ± 0.01 | 1.00 | 2.1 | 0 ... |
| 8      | 10:31:12.2 | −14:13:53 | 19.50 ± 0.05 | 18.30 ± 0.02 | 0.28 | 4.9 | 7 0.19151 |
| 9      | 10:31:12.5 | −14:11:37 | 20.58 ± 0.07 | 18.95 ± 0.02 | 0.98 | 2.6 | 7 −0.00008 |
| 10     | 10:31:12.6 | −14:11:10 | 22.97 ± 0.45 | 20.40 ± 0.05 | 1.00 | 2.0 | 0 ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 12
PG1116+215: Object Summary

| ID     | R.A.   | Decl.  | $B$    | $R$    | S/G$^a$ | Area ($\alpha'$) | Flg$^b$ | $z$   |
|--------|--------|--------|--------|--------|---------|------------------|---------|-------|
| 1      | 11:18:30.2 | +21:17:08 | 18.76 ± 0.05 | 10.10 ± 0.03 | 0.98 | 125.2 | 0 ... |
| 2      | 11:18:29.2 | +21:14:00 | 17.34 ± 0.01 | 15.64 ± 0.01 | 0.07 | 8.0 | 7 0.06038 |
| 3      | 11:18:25.4 | +21:08:33 | 20.25 ± 0.05 | 19.17 ± 0.02 | 0.59 | 5.4 | 1 ... |
| 4      | 11:18:25.1 | +21:18:15 | 23.88 ± 1.14 | 21.55 ± 0.14 | 0.22 | 14.2 | 0 ... |
| 5      | 11:18:25.9 | +21:18:06 | 21.21 ± 0.18 | 19.83 ± 0.06 | 0.03 | 15.4 | 0 ... |
| 6      | 11:18:25.3 | +21:16:13 | 23.11 ± 0.57 | 20.92 ± 0.10 | 0.08 | 12.8 | 0 ... |
| 7      | 11:18:24.9 | +21:16:10 | 22.87 ± 0.59 | 20.75 ± 0.09 | 0.03 | 16.2 | 0 ... |
| 8      | 11:18:25.9 | +21:16:25 | 20.53 ± 0.10 | 18.95 ± 0.03 | 0.03 | 12.2 | 0 ... |
| 9      | 11:18:26.9 | +21:27:28 | 16.91 ± 0.01 | 15.06 ± 0.01 | 1.00 | 3.2 | 0 ... |
| 10     | 11:18:26.0 | +21:27:25 | 21.56 ± 0.21 | 18.46 ± 0.01 | 0.99 | 4.5 | 1 ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
### Table 13
PG1211+143: Object Summary

| ID | R.A.       | Decl.   | $B$ (mag) | $R$ (mag) | S/G$^a$ | Area (arcmin$^2$) | Flg$^b$ | $z$ |
|----|------------|---------|-----------|-----------|---------|-------------------|---------|-----|
| 1  | 12:14:00.7 | +14:13:16 | 12.30 ± 0.09 | 10.94 ± 0.07 | 0.99 | 28.4 | 0 | ... |
| 2  | 12:13:51.9 | +14:13:23 | 16.04 ± 0.09 | 14.81 ± 0.07 | 0.03 | 35.2 | 0 | ... |
| 3  | 12:13:58.3 | +14:13:05 | 14.94 ± 0.09 | 13.93 ± 0.07 | 1.00 | 5.9 | 0 | ... |
| 4  | 12:14:35.3 | +14:13:44 | 25.76 ± 2.12 | 22.05 ± 0.12 | 0.98 | 2.5 | 0 | ... |
| 5  | 12:14:29.6 | +14:14:05 | 19.90 ± 0.10 | 17.77 ± 0.07 | 0.07 | 6.9 | 7 | 0.15545 |
| 6  | 12:13:42.4 | +14:14:13 | 21.00 ± 0.11 | 19.93 ± 0.08 | 0.12 | 6.9 | 0 | ... |
| 7  | 12:14:45.0 | +14:13:57 | 21.25 ± 0.12 | 19.80 ± 0.07 | 0.13 | 4.8 | 0 | ... |
| 8  | 12:14:28.2 | +14:14:05 | 20.27 ± 0.10 | 18.88 ± 0.07 | 0.13 | 7.1 | 1 | ... |
| 9  | 12:14:40.8 | +14:14:01 | 19.92 ± 0.10 | 18.00 ± 0.07 | 0.78 | 7.2 | 1 | ... |
| 10 | 12:14:40.9 | +14:14:06 | 23.36 ± 0.32 | 21.58 ± 0.11 | 0.82 | 4.4 | 0 | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 14
PG1216+069: Object Summary

| ID | R.A.       | Decl.   | $B$ (mag) | $R$ (mag) | S/G$^a$ | Area (arcmin$^2$) | Flg$^b$ | $z$ |
|----|------------|---------|-----------|-----------|---------|-------------------|---------|-----|
| 1  | 12:18:32.1 | +06:32:29 | 28.60 ± 23.69 | 23.06 ± 0.41 | 1.00 | 1.6 | 0 | ... |
| 2  | 12:18:38.6 | +06:42:29 | 15.83 ± 0.00 | 14.86 ± 0.00 | 0.05 | 33.1 | 7 | 0.00667 |
| 3  | 12:18:35.1 | +06:29:41 | 19.17 ± 0.05 | 18.07 ± 0.02 | 0.03 | 20.7 | 0 | ... |
| 4  | 12:18:33.7 | +06:28:08 | 24.86 ± 1.37 | 22.17 ± 0.14 | 0.96 | 3.1 | 0 | ... |
| 5  | 12:18:33.7 | +06:29:06 | 22.62 ± 0.25 | 20.61 ± 0.05 | 1.00 | 2.6 | 0 | ... |
| 6  | 12:18:33.2 | +06:40:52 | 19.86 ± 0.13 | 16.77 ± 0.02 | 0.03 | 57.2 | 0 | ... |
| 7  | 12:18:33.6 | +06:46:39 | 14.59 ± 0.00 | 13.99 ± 0.00 | 1.00 | 3.4 | 0 | ... |
| 8  | 12:18:33.0 | +06:34:06 | 20.03 ± 0.04 | 18.67 ± 0.02 | 0.99 | 3.4 | 0 | ... |
| 9  | 12:18:33.4 | +06:38:45 | 24.76 ± 1.82 | 21.16 ± 0.10 | 0.12 | 5.6 | 0 | ... |
| 10 | 12:18:33.1 | +06:40:30 | 22.14 ± 0.37 | 18.97 ± 0.04 | 0.03 | 16.6 | 0 | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 15
3C273: Object Summary

| ID | R.A.       | Decl.   | $B$ (mag) | $R$ (mag) | S/G$^a$ | Area (arcmin$^2$) | Flg$^b$ | $z$ |
|----|------------|---------|-----------|-----------|---------|-------------------|---------|-----|
| 1  | 12:28:23.7 | +02:09:17 | 26.82 ± 5.73 | 23.58 ± 0.25 | 1.00 | 3.5 | 0 | ... |
| 2  | 12:28:22.2 | +01:55:30 | 23.45 ± 0.35 | 21.95 ± 0.07 | 1.00 | 2.1 | 0 | ... |
| 3  | 12:28:22.2 | +01:55:01 | 22.74 ± 0.23 | 21.31 ± 0.05 | 1.00 | 2.1 | 0 | ... |
| 4  | 12:28:22.1 | +01:54:39 | 23.44 ± 0.35 | 22.18 ± 0.08 | 0.98 | 1.7 | 0 | ... |
| 5  | 12:28:21.8 | +01:51:53 | 23.13 ± 0.31 | 21.53 ± 0.05 | 1.00 | 1.9 | 0 | ... |
| 6  | 12:28:23.7 | +02:09:08 | 24.55 ± 1.24 | 22.21 ± 0.11 | 0.98 | 3.4 | 0 | ... |
| 7  | 12:28:23.0 | +02:02:25 | 24.95 ± 1.82 | 22.59 ± 0.16 | 0.15 | 2.9 | 0 | ... |
| 8  | 12:28:23.1 | +02:02:11 | 28.23 ± 14.61 | 23.70 ± 0.32 | 0.98 | 1.3 | 0 | ... |
| 9  | 12:28:23.8 | +02:08:12 | 25.41 ± 1.28 | 24.00 ± 0.35 | 0.98 | 1.5 | 0 | ... |
| 10 | 12:28:23.5 | +02:05:35 | 24.12 ± 0.86 | 22.17 ± 0.13 | 0.90 | 5.6 | 0 | ... |

**Notes.**

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
### Table 16
Q1230+095: Object Summary

| ID | R.A.    | Decl.  | B (mag) | R (mag) | S/G^a | Area (arcsec^2) | Flg^b | z  |
|----|---------|--------|---------|---------|-------|-----------------|-------|----|
| 1  | 12:33:53.8 | +09:31:53 | 11.39 ± 0.01 | 9.17 ± 0.01 | 0.69 | 217.9 | 0 | ... |
| 2  | 12:32:44.9 | +09:39:38 | 11.28 ± 0.00 | 10.81 ± 0.00 | 0.72 | 46.6 | 0 | ... |
| 3  | 12:32:44.6 | +09:22:05 | 17.48 ± 0.01 | 16.13 ± 0.01 | 0.01 | 8.5 | 7 | 0.11526 |
| 4  | 12:32:42.9 | +09:20:40 | 19.51 ± 0.06 | 18.59 ± 0.03 | 0.03 | 12.2 | 1 | ... |
| 5  | 12:32:44.0 | +09:30:56 | 17.58 ± 0.01 | 16.02 ± 0.01 | 1.00 | 2.8 | 0 | ... |
| 6  | 12:32:43.0 | +09:24:56 | 18.57 ± 0.02 | 16.88 ± 0.01 | 1.00 | 2.6 | 0 | ... |
| 7  | 12:32:42.9 | +09:27:53 | 22.81 ± 0.45 | 20.24 ± 0.05 | 0.57 | 2.5 | 0 | ... |
| 8  | 12:32:43.6 | +09:35:56 | 21.20 ± 0.13 | 19.57 ± 0.04 | 0.18 | 2.9 | 0 | ... |
| 9  | 12:32:41.8 | +09:20:56 | 18.48 ± 0.02 | 16.35 ± 0.01 | 1.00 | 4.6 | 0 | ... |
| 10 | 12:32:43.6 | +09:36:08 | 22.53 ± 0.37 | 20.08 ± 0.05 | 0.40 | 3.0 | 0 | ... |

**Notes.**

^a Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

^b This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 17
PKS1302−102: Object Summary

| ID | R.A.    | Decl.  | B (mag) | R (mag) | S/G^a | Area (arcsec^2) | Flg^b | z  |
|----|---------|--------|---------|---------|-------|-----------------|-------|----|
| 1  | 13:05:43.7 | −10:30:07 | 10.28 ± 0.00 | 8.93 ± 0.01 | 0.69 | 334.3 | 0 | ... |
| 2  | 13:04:57.9 | −10:25:47 | 13.20 ± 0.00 | 12.36 ± 0.00 | 1.00 | 13.8 | 0 | ... |
| 3  | 13:04:57.8 | −10:26:05 | 17.48 ± 0.02 | 15.15 ± 0.01 | 1.00 | 3.2 | 0 | ... |
| 4  | 13:04:56.0 | −10:29:18 | 20.06 ± 0.11 | 18.11 ± 0.02 | 0.09 | 6.8 | 7 | 0.27252 |
| 5  | 13:04:54.6 | −10:39:58 | 18.85 ± 0.04 | 17.89 ± 0.01 | 0.13 | 4.6 | 7 | 0.04576 |
| 6  | 13:04:54.9 | −10:33:57 | 17.45 ± 0.01 | 15.92 ± 0.01 | 1.00 | 2.3 | 0 | ... |
| 7  | 13:04:56.1 | −10:25:29 | 23.12 ± 0.78 | 20.75 ± 0.08 | 0.98 | 1.9 | 0 | ... |
| 8  | 13:04:55.0 | −10:32:28 | 21.53 ± 0.25 | 19.65 ± 0.04 | 0.13 | 3.7 | 0 | ... |
| 9  | 13:04:56.0 | −10:21:04 | 20.36 ± 0.11 | 18.71 ± 0.02 | 0.15 | 3.6 | 1 | ... |
| 10 | 13:04:55.1 | −10:29:17 | 19.09 ± 0.03 | 18.13 ± 0.01 | 0.98 | 3.4 | 0 | ... |

**Notes.**

^a Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

^b This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 18
PG1307+085: Object Summary

| ID | R.A.    | Decl.  | B (mag) | R (mag) | S/G^a | Area (arcsec^2) | Flg^b | z  |
|----|---------|--------|---------|---------|-------|-----------------|-------|----|
| 1  | 13:09:49.7 | +08:11:05 | 11.72 ± 0.00 | 10.34 ± 0.01 | 0.69 | 84.1 | 0 | ... |
| 2  | 13:09:08.0 | +08:09:16 | 13.90 ± 0.00 | 13.12 ± 0.00 | 1.00 | 6.7 | 0 | ... |
| 3  | 13:09:07.3 | +08:09:35 | 20.00 ± 0.09 | 14.10 ± 0.02 | 1.00 | 4.8 | 0 | ... |
| 4  | 13:09:09.7 | +08:27:13 | 22.33 ± 0.33 | 20.41 ± 0.06 | 0.13 | 3.3 | 0 | ... |
| 5  | 13:09:09.5 | +08:27:09 | 21.29 ± 0.16 | 20.35 ± 0.07 | 0.15 | 5.2 | 0 | ... |
| 6  | 13:09:07.9 | +08:11:41 | 17.33 ± 0.01 | 16.59 ± 0.01 | 1.00 | 2.3 | 0 | ... |
| 7  | 13:09:09.1 | +08:23:48 | 17.21 ± 0.01 | 16.48 ± 0.01 | 1.00 | 2.3 | 0 | ... |
| 8  | 13:09:09.6 | +08:20:56 | 17.98 ± 0.01 | 16.94 ± 0.01 | 1.00 | 2.2 | 0 | ... |
| 9  | 13:09:07.6 | +08:09:48 | 23.62 ± 1.08 | 20.83 ± 0.10 | 0.20 | 5.1 | 0 | ... |
| 10 | 13:09:09.5 | +08:27:53 | 24.44 ± 1.45 | 20.89 ± 0.07 | 0.99 | 1.8 | 0 | ... |

**Notes.**

^a Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

^b This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
In each into either the late- or early-type category.

We then imposed a $k$-correction to the apparent magnitude using a redshifted template spectrum integrated with an $R$-band filter. We use an E/S0 template for the early-type galaxies and an Sc template for the late-type systems. No correction was made for galaxies classified as unknown. This $k$-correction generally amounts to only a tenth or few tenths correction to the magnitudes, with larger values for more distant galaxies ($\zeta > 0.2$). Finally, we converted the $k$-corrected, apparent $R$-band magnitudes into luminosities relative to $L^*$ with the luminosity distance calculated using the assumed Wilkinson Microwave Anisotropy Probe (WMAP) cosmology.

In total, we obtained spectra for 2933 sources and confirmed 2800 redshifts. Of these, there are 1198 galaxies with $0.005 < \zeta < (\zeta_{\text{em}} - 0.01)$ which are suitable for studying the association between galaxies and absorption lines in the low-$\zeta$ IGM. The properties of these galaxies are summarized in Table 4. Lastly, Table 1 lists the spectroscopic completeness of each field as a function of magnitude limit and angular offset from the quasar, e.g., $C_{10.5}$ gives the completeness percentile to $R = 19.5$ mag and $\theta_{\text{max}} = 5'$ offset from the quasar.

### 3.1. Q0026+1259

To date this quasar has no published list of IGM absorption lines, presumably because its UV spectroscopic data set is relatively sparse. Figure 2 shows the field and marks the galaxies surrounding the quasar with measured redshifts. Figure 3 shows a histogram of the redshifts of the galaxies in the field surrounding the quasar. There is a relatively large “spike” at the quasar redshift ($\zeta_{\text{em}} = 0.142$) which marks a galaxy group (several $L \approx L^*$ galaxies lie within $\rho = 300$ kpc). One identifies no other significant large-scale structures foreground to the quasar in our LCO/WFCCD survey. Table 5 summarizes the photometry and spectroscopy for galaxies and stars in the field surrounding Q0026+1259.

### 3.2. Ton S 180

The Ton S 180 sightline has been surveyed for Ly$\alpha$ absorption by Penton et al. (2004; STIS/G140M spectra) and for O$\upsilon$I absorption by Danforth et al. (2006) (FUSE). The latter report O$\upsilon$I absorbers at $\zeta = 0.0234, 0.0436$ and $\zeta = 0.0456$, each of which shows a galaxy within an impact parameter of $\rho < 300$ kpc and within a velocity offset of $|\delta v| < 300$ km s$^{-1}$. None of these were reported in Stocke et al. (2006)11 presumably because these galaxies were fainter than the magnitude limit of their galaxy compilation. Wakker & Savage (2009) also associated galaxies at $\zeta \approx 0$ with Ly$\alpha$ and O$\upsilon$I absorption along this sightline.

Figure 4 shows the field and marks the galaxies surrounding the quasar with measured redshifts. Given the low emission of which shows a galaxy within an impact parameter of $\rho < 300$ kpc and within a velocity offset of $|\delta v| < 300$ km s$^{-1}$. None of these were reported in Stocke et al. (2006)11 presumably because these galaxies were fainter than the magnitude limit of their galaxy compilation. Wakker & Savage (2009) also associated galaxies at $\zeta \approx 0$ with Ly$\alpha$ and O$\upsilon$I absorption along this sightline.

Figure 4 shows the field and marks the galaxies surrounding the quasar with measured redshifts. Given the low emission

\footnote{Indeed, they remarked that the O$\upsilon$I absorber at $\zeta = 0.436$ was the “most isolated” of their sample with no bright galaxy within 1 Mpc.}

### Table 19

| ID | R.A. | Decl. | $B$ (mag) | $R$ (mag) | S/G$^a$ | Area (arcminutes$^2$) | Flg$^b$ | $z$ |
|----|------|-------|-----------|-----------|---------|-----------------------|--------|-----|
| 1  | 14:29:00.6 | +01:26:39 | 10.44 ± 0.00 | 9.62 ± 0.00 | 0.69 | 140.4 | 0 | ... |
| 2  | 14:28:57.4 | +01:24:05 | 11.17 ± 0.00 | 10.52 ± 0.00 | 0.73 | 60.6 | 0 | ... |
| 3  | 14:28:29.6 | +01:07:36 | 12.80 ± 0.01 | 11.16 ± 0.01 | 0.87 | 34.0 | 0 | ... |
| 4  | 14:28:21.9 | +01:06:47 | 18.66 ± 0.04 | 17.19 ± 0.01 | 0.01 | 6.3 | 1 | ... |
| 5  | 14:28:21.3 | +01:06:46 | 23.57 ± 0.82 | 21.66 ± 0.13 | 0.98 | 2.4 | 0 | ... |
| 6  | 14:28:24.2 | +01:27:37 | 20.25 ± 0.09 | 18.02 ± 0.01 | 1.00 | 2.4 | 0 | ... |
| 7  | 14:28:24.2 | +01:27:51 | 22.63 ± 0.54 | 20.90 ± 0.10 | 0.12 | 2.9 | 0 | ... |
| 8  | 14:28:23.2 | +01:18:37 | 22.68 ± 0.57 | 19.94 ± 0.05 | 0.99 | 2.5 | 0 | ... |
| 9  | 14:28:23.7 | +01:26:27 | 22.09 ± 0.30 | 20.53 ± 0.07 | 0.93 | 2.5 | 0 | ... |
| 10 | 14:28:24.0 | +01:28:01 | 22.26 ± 0.37 | 19.38 ± 0.03 | 0.98 | 2.1 | 0 | ... |

### Notes.

$^a$ Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.

$^b$ This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
redshift of the quasar, there are only a handful of galaxies identified in its foreground. One also notes several bright galaxies coincident with the quasar redshift and at relatively small impact parameter ($\rho \approx 300$ kpc). Figure 5 shows a histogram of the redshifts of the galaxies in the field surrounding the quasar. Table 6 summarizes the photometry and spectroscopy of our survey for galaxies and stars in the field surrounding Ton S 180.

### 3.3. Ton S 210

Although the quasar Ton S 210 has an impressive UV spectroscopic data set, there is no published survey for IGM absorption beyond the very local universe (Wakker & Savage 2009). Coincidentally, we have discovered very few galaxies foreground to the quasar to our magnitude limit (Figure 6, Table 4) despite obtaining spectra for 71 extragalactic sources (Figure 7, Table 7). None of the foreground sources lie at close impact parameter.

### 3.4. PKS0312−770

We previously published the spectrum of a galaxy associated with the $z \approx 0.21$ Lyman limit system toward PKS0312−770.
Figure 4. Same as for Figure 2 but for the field surrounding Ton S 180 ($z_{\text{em}} = 0.062$).

(A color version of this figure is available in the online journal.)

Figure 5. Same as for Figure 3 but for the field surrounding Ton S 180 ($z_{\text{em}} = 0.062$).

(A color version of this figure is available in the online journal.)

Figure 6. Same as for Figure 2 but for the field surrounding Ton S 210 ($z_{\text{em}} = 0.116$).

(A color version of this figure is available in the online journal.)

Figure 7. Same as for Figure 3 but for the field surrounding Ton S 210 ($z_{\text{em}} = 0.116$).

(A color version of this figure is available in the online journal.)

3.5. PKS0405−123

This field has received significant attention over the past decade, largely because of its relatively high redshift but also because it exhibits several strong O\textsc{vi} absorbers (Chen & Prochaska 2000; Prochaska et al. 2004, 2006; Chen et al. 2005; Williger et al. 2006; Tripp et al. 2008; Howk et al. 2009; Wakker & Savage 2009; Savage et al. 2010). We published the results of our galaxy survey in Chen et al. (2005) and Prochaska et al. (2006); here we only summarize properties of the galaxies close to the sightline (Table 4). We also remind the reader that our galaxy survey had non-uniform spectral and imaging coverage beyond the inner $\approx 20' \times 20'$ FOV.

3.6. PKS0558−504

This quasar has a very limited UV spectral data set, and the only IGM analysis has been performed at $z \approx 0$ (Wakker &
Savage 2009). By chance, our survey also shows no galaxies at low impact parameters (Tables 4 and 9). Figure 10 shows the field and marks the galaxies surrounding the quasar with measured redshifts, and Figure 11 presents a redshift histogram.

3.7. PG1004+130

This sightline has been analyzed for Lyα absorption by Bowen et al. (2002) who associated a cluster of low-ζ Lyα absorption lines with a bright nearby galaxy (UGC 5454). A relatively high quality FUSE data set exists but has not yet been surveyed for O VI absorption. As discussed in Prochaska et al. (2011), we have also analyzed these UV data sets for Lyα and O VI absorption at the redshifts of the galaxies in our LCO/WFCCD survey with small impact parameter to the sightline (Table 4).

The photometry and spectroscopy of our full survey is listed in Table 10 and Figure 12 shows the field and marks the galaxies surrounding the quasars with determined redshifts. Figure 13 provides a redshift histogram.

3.8. HE1029−140

This quasar has a modest UV spectral data set and has been analyzed for Lyα absorption by Penton et al. (2004). Figure 14 shows the field and marks the few galaxies with \( z < \z_{\text{em}} \) that we have identified in the LCO/WFCCD survey. Table 11 summarizes the photometry and spectroscopy of all objects in the field and Figure 15 gives a redshift histogram of the galaxies from our survey.
Table 22
FJ2155−092: Object Summary

| ID | R.A. | Decl. | B (mag) | R (mag) | S/G* | Area (arcmin²) | Flg b | z |
|----|------|-------|---------|---------|------|----------------|-------|---|
| 1  | 21:54:16.5 | −09:20:36 | 13.37 ± 0.09 | 11.93 ± 0.06 | 1.00 | 19.4 | 0 | ... |
| 2  | 21:54:15.7 | −09:29:17 | 16.32 ± 0.09 | 14.94 ± 0.06 | 0.68 | 9.7 | 0 | ... |
| 3  | 21:54:13.4 | −09:14:10 | 15.51 ± 0.09 | 14.55 ± 0.06 | 1.00 | 3.2 | 0 | ... |
| 4  | 21:54:12.0 | −09:23:15 | 13.41 ± 0.09 | 12.65 ± 0.06 | 1.00 | 10.3 | 0 | ... |
| 5  | 21:54:12.0 | −09:12:53 | 20.31 ± 0.15 | 18.05 ± 0.07 | 0.22 | 3.8 | 0 | ... |
| 6  | 21:54:11.6 | −09:12:54 | 24.50 ± 2.61 | 21.14 ± 0.14 | 0.13 | 4.8 | 0 | ... |
| 7  | 21:54:11.4 | −09:20:01 | 20.78 ± 0.14 | 19.03 ± 0.07 | 0.99 | 2.3 | 0 | ... |
| 8  | 21:54:11.1 | −09:18:56 | 20.04 ± 0.14 | 17.71 ± 0.07 | 0.22 | 4.1 | 0 | ... |
| 9  | 21:54:11.0 | −09:19:03 | 21.20 ± 0.19 | 18.50 ± 0.07 | 0.99 | 2.5 | 0 | ... |
| 10 | 21:54:11.5 | −09:15:46 | 19.16 ± 0.10 | 17.82 ± 0.06 | 1.00 | 2.5 | 0 | ... |

Notes.

a Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.
b This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Table 23
PKS2155−304: Object Summary

| ID | R.A. | Decl. | B (mag) | R (mag) | S/G* | Area (arcmin²) | Flg b | z |
|----|------|-------|---------|---------|------|----------------|-------|---|
| 1  | 21:59:04.0 | −30:09:30 | 9.80 ± 0.08 | 9.27 ± 0.06 | 0.69 | 265.2 | 0 | ... |
| 2  | 21:58:12.6 | −30:17:46 | 12.89 ± 0.08 | 12.00 ± 0.06 | 0.99 | 21.0 | 0 | ... |
| 3  | 21:58:11.4 | −30:19:08 | 15.88 ± 0.09 | 14.82 ± 0.06 | 0.03 | 22.0 | 7 | 0.04528 |
| 4  | 21:58:08.2 | −30:11:58 | 13.55 ± 0.09 | 12.33 ± 0.06 | 1.00 | 15.6 | 0 | ... |
| 5  | 21:58:02.3 | −30:15:35 | 15.22 ± 0.08 | 14.49 ± 0.06 | 1.00 | 3.1 | 0 | ... |
| 6  | 21:58:03.0 | −30:06:04 | 19.50 ± 0.12 | 17.12 ± 0.06 | 0.04 | 6.3 | 0 | ... |
| 7  | 21:58:00.3 | −30:19:49 | 20.61 ± 0.14 | 18.30 ± 0.06 | 0.89 | 3.7 | 0 | ... |
| 8  | 21:58:01.8 | −30:02:37 | 21.55 ± 0.20 | 19.17 ± 0.07 | 0.48 | 4.0 | 0 | ... |
| 9  | 21:58:00.8 | −30:07:21 | 21.61 ± 0.18 | 19.21 ± 0.07 | 1.00 | 2.4 | 0 | ... |
| 10 | 21:57:59.4 | −30:21:38 | 19.98 ± 0.09 | 18.80 ± 0.06 | 0.98 | 2.1 | 0 | ... |

Notes.

a Star/galaxy classifier calculated by SExtractor. Values near unity indicate a stellar-like point-spread function.
b This binary flag has the following code: 1, survey target; 2, spectrum taken; 4, redshift measured.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

3.9. PG1116+215

This sightline has been studied by Tripp et al. (1998) and Sembach et al. (2004) for absorption lines and associated galaxies, along with several other more recent analyses (Tripp et al. 2008; Danforth & Shull 2008; Wakker & Savage 2009). They identify three O VI systems foreground to the quasar at $z = 0.0597$, 0.13879, and 0.1655. Each of these is associated with a galaxy at $\rho \approx 150$ kpc in our survey. For the $z = 0.0597$ system, we identify six galaxies within 1 Mpc including several with $L \geq L^*$ suggesting a group environment (Table 4). None of these galaxies were identified in previous surveys.

Table 12 summarizes the photometry and spectroscopy for the objects that we surveyed in the field surrounding PG1116+215. Figure 16 presents an image of the field and marks the galaxies surrounding the quasar with determined $z < z_{em}$ and Figure 17 shows a redshift histogram of the full galaxy survey.

3.10. PG1211+143

Tumlinson et al. (2005) analyzed this field for IGM absorption lines and corresponding galaxies. They reported a pair of O VI systems at $z = 0.0513$ and 0.0645 and associated these with $L \approx L^*$ galaxies at $\rho \approx 150$ kpc. Our survey includes these two galaxies (Table 4) and an additional, fainter galaxy at significantly smaller impact parameter for the system at $z = 0.0646$ ($\rho = 70$ kpc). We also identify additional galaxies associated with the galaxy group at $z = 0.0513$. Wakker & Savage (2009) also analyzed this field, focusing on $z \approx 0$.

Table 13 summarizes the photometry and spectroscopy for galaxies and stars in the field surrounding PG1211+143. Figure 18 shows the field and marks the galaxies surrounding the quasar while Figure 19 gives a galaxy redshift histogram.

3.11. PG1216+069

This sightline has been studied for absorption by multiple groups (Tripp et al. 2008; Thom & Chen 2008; Danforth & Shull 2008; Chen & Mulchaey 2009; Wakker & Savage 2009) with O VI systems reported at $z = 0.1236$, 0.268, and 0.282. Our survey reveals galaxies at every redshift, but only the lowest redshift system shows an example with small impact parameter ($\rho = 85$ kpc). In addition, we report an overdensity of galaxies at $z = 0.0805$ (five galaxies within 1 Mpc including an $L^*$ galaxy; Table 4) which is associated with strong Ly$\alpha$ absorption but no apparent O VI gas to a sensitive limit.

\[ ... \]
Figure 12. Same as for Figure 2 but for the field surrounding PG1004+130 ($z_{\text{em}} = 0.240$).

(A color version of this figure is available in the online journal.)

Figure 13. Same as for Figure 3 but for the field surrounding PG1004+130 ($z_{\text{em}} = 0.240$).

(A color version of this figure is available in the online journal.)

The sightline is also notable for intersecting Virgo, and Tripp et al. (2005) report on a strong H I absorber near the NGC 4261 group ($z = 0.0063$). No apparent O vi absorption is detected at the redshift of either structure although the equivalent width limits are poor from the FUSE spectra at these wavelengths.

Table 14 summarizes the photometry and spectroscopy, Figure 20 shows the field and marks the galaxies surrounding the quasars with determined redshifts. Figure 21 shows a histogram of the redshifts of the galaxies in the field surrounding the quasar.

3.12. 3C273

Because of its very high UV flux, this quasar and the field around it have been the subject of many previous studies including some of the first galaxy surveys along quasar sightlines (Morris et al. 1993). Tripp et al. (2008) report O vi detections at several redshifts, all at column densities that lie below the sensitivity limit of most other UV spectral data sets, i.e., $N(O^+) < 10^{13.5}$ cm$^{-2}$. None of these absorbers shows a corresponding galaxy in our survey with $\rho < 300$ kpc, but we do identify galaxies at larger impact parameter (Table 4). Wakker & Savage (2009) also analyzed this field, focusing on $z \approx 0$.

Table 15 summarizes the photometry and spectroscopy for galaxies and stars in the field surrounding 3C273. Figure 22 shows the field and marks the galaxies surrounding the quasars with determined redshifts. Figure 23 shows a histogram of the redshifts of the galaxies in the field surrounding the quasar.

3.13. Q1230+095

This quasar has a very sparse UV spectral data set and there is no published list of IGM absorption. We emphasize that the quasar’s redshift ($z_{\text{em}} = 0.415$) makes it a very promising...
Figure 16. Same as for Figure 2 but for the field surrounding PG1116+215 ($z_{\text{em}} = 0.177$). (A color version of this figure is available in the online journal.)

Figure 17. Same as for Figure 3 but for the field surrounding PG1116+215 ($z_{\text{em}} = 0.177$). (A color version of this figure is available in the online journal.)

sightline for studying the IGM/galaxy connection. Furthermore, there is a set of galaxies at small impact parameters revealed by our survey (Figure 24, Table 4). We encourage observations with the HST/COS instrument. Table 16 summarizes the full photometry and spectroscopy for objects in the field surrounding Q1230+095 and Figure 25 histograms the galaxy redshifts.

3.14. PKS1302−102

This field has been surveyed for Ly$\alpha$ and O$\text{vi}$ absorption by several groups (Danforth et al. 2006; Cooksey et al. 2008; Danforth & Shull 2008; Thom & Chen 2008; Tripp et al. 2008; Wakker & Savage 2009). These groups have reported O$\text{vi}$ detections at multiple redshifts: $z = 0.0423, 0.0647, 0.0940, 0.0989, 0.1453, 0.1916, 0.2256$, and 0.2274. Our survey has revealed nearly 100 galaxies foreground to the quasar including several at impact parameters $\rho < 100$ kpc (see also Cooksey et al. 2008). We detect galaxy

Figure 18. Same as for Figure 2 but for the field surrounding PG1211+143 ($z_{\text{em}} = 0.809$). (A color version of this figure is available in the online journal.)

Figure 19. Same as for Figure 3 but for the field surrounding PG1211+143 ($z_{\text{em}} = 0.809$). (A color version of this figure is available in the online journal.)

within 300 kpc and with $|\delta v| < 400$ km s$^{-1}$ for each absorber at $z < 0.2$ except at $z = 0.0989$. This includes two sub-$L_*$ galaxies that lie at low impact parameter ($\rho < 100$ kpc; Table 4, Figure 26). Table 17 summarizes the photometry and spectroscopy for galaxies and stars in the field, and Figure 27 presents a redshift histogram of all galaxies.

3.15. PG1307+085

This quasar has only a sparse data set of UV spectroscopy and there is no published list for Ly$\alpha$ or O$\text{vi}$ absorption systems. Its relatively high redshift ($z_{\text{em}} = 0.155$) marks it as a valuable sightline for future study and our survey provides a modest set of galaxies for cross-correlation analysis (Table 4). The full photometry and spectroscopy for objects from our survey in the field are listed in Table 18. Figure 28 presents an $R$-band image of the field and marks the surrounding galaxies with $z < z_{\text{em}}$. 17
Figure 20. Same as for Figure 2 but for the field surrounding PG1216+069 ($z_{\text{em}} = 0.331$). (A color version of this figure is available in the online journal.)

Figure 21. Same as for Figure 3 but for the field surrounding PG1216+069 ($z_{\text{em}} = 0.331$). (A color version of this figure is available in the online journal.)

Figure 22. Same as for Figure 2 but for the field surrounding 3C273 ($z_{\text{em}} = 0.158$). (A color version of this figure is available in the online journal.)

Figure 23. Same as for Figure 3 but for the field surrounding 3C273 ($z_{\text{em}} = 0.158$). (A color version of this figure is available in the online journal.)

Figure 29 shows a redshift histogram for the galaxies we have discovered.

3.16. MRK1383

Despite its low redshift and correspondingly small path length, this sightline has been studied extensively for Ly$\alpha$ and O vi absorption (Danforth et al. 2006; Danforth & Shull 2008; Wakker & Savage 2009). Our survey reveals only a handful of galaxies with $z < z_{\text{em}}$ (Table 4, Figure 30), but we also note that this field has one of the lowest completeness levels to $R = 19.5$ mag (80%). Table 19 summarizes the photometry and spectroscopy for galaxies and stars in the field surrounding MRK1383. Figure 30 provides an image of the field and marks the foreground galaxies, and Figure 31 shows a redshift histogram for the galaxies.

3.17. Q1553+113

This quasar boasts only a short FUSE exposure and no additional UV spectroscopy. It has been surveyed for IGM absorption only at $z \approx 0$ by Wakker & Savage (2009). Given the extensive data set of galaxies that we have discovered in the foreground (Table 4, Figure 32), we encourage future observations with HST/COS. The photometry and spectroscopy for objects from our survey in the field are listed in Table 20 and a redshift histogram for the galaxies is provided by Figure 33.

3.18. PKS2005−489

This sightline has been surveyed for Ly$\alpha$ and O vi absorption over the relatively short path length provided by this $z = 0.071$ active galactic nucleus (AGN; Penton et al. 2004; Danforth et al. 2006; Danforth & Shull 2008). There are no O vi
systems reported. Our survey reveals two sets of foreground galaxies at redshifts $z \approx 0.045$ and 0.057, but none at very close impact parameter to the sightline (Figure 34, Table 4). Table 21 summarizes the photometry and spectroscopy for all objects in the field surrounding PKS2005−489. Figure 35 presents a redshift histogram for all of the galaxies in our survey.

### 3.19. FJ2155−092

The quasar FJ2155−092, also known as PHL 1811, has a high quality UV spectral data set. Jenkins et al. (2005) have published an analysis of the Lyman limit system at $z = 0.081$ and its neighboring galaxies. Other groups have examined the spectra for Lyα and O vi absorption (Tripp et al. 2008; Danforth & Shull 2008; Wakker & Savage 2009). Altogether, the sightline boasts four O vi systems at $z = 0.0788, 0.1326, 0.1581, and 0.1769$, all of which have a neighboring galaxy in our survey with $\rho < 350$ kpc and $|\delta v| < 400$ km s$^{-1}$ but none at very low impact parameter. Figure 36 shows the field and marks the galaxies foreground to the quasar with determined redshifts. Table 22 lists the photometry and spectroscopy for galaxies and stars throughout the field and a redshift histogram of the galaxies is given in Figure 37.

### 3.20. PKS2155−304

This sightline has received significant attention, primarily because of the claimed (and debated) O vii and O viii absorption at $z \approx 0.055$ (Fang et al. 2002; Cagnoni et al. 2003). The high quality UV spectral data sets have also been surveyed for Lyα and O vi absorption (who report detections at $z = 0.0541$ and 0.0571; Danforth et al. 2006; Danforth & Shull 2008; Wakker & Savage 2009). We associate each of these with a bright
Figure 28. Same as for Figure 2 but for the field surrounding PG1307+085 ($z_{em} = 0.155$).

(A color version of this figure is available in the online journal.)

Figure 29. Same as for Figure 3 but for the field surrounding PG1307+085 ($z_{em} = 0.155$).

(A color version of this figure is available in the online journal.)

Figure 30. Same as for Figure 2 but for the field surrounding MRK1383 ($z_{em} = 0.086$).

(A color version of this figure is available in the online journal.)

Figure 31. Same as for Figure 3 but for the field surrounding MRK1383 ($z_{em} = 0.086$).

(A color version of this figure is available in the online journal.)

4. SUMMARY

This paper serves to define our LCO/WFCCD galaxy survey which was designed to study the IGM/galaxy connection at $z \lesssim 0.2$. We have listed $R$-band photometry for objects in each field, identified the objects which satisfy our targeting criteria, provide (online) the extracted and co-added one-dimensional spectra, and tabulate the redshifts for all sources with an unambiguous identification. Table 4 summarizes properties of the galaxies discovered in the 20 fields restricted to $0.005 < z < (z_{em} + 0.01)$. Again, we note that approximately half of the fields have been surveyed for galaxies by other groups that our results should not be considered a complete census. This table and the redshift histograms reveal the types of galaxy overdensities that are typical of other low-$z$ galaxy surveys.

Figure 40 presents a color–magnitude diagram for the galaxies and summarizes the redshift, luminosity, and impact parameter distributions of the sample. The set of galaxies with $z < (z_{em} - 0.01)$ is predominantly at redshifts $z = 0.1$–0.3, with luminosities $L = 0.1$–5 $L^*$, and located at impact parameters of several hundred kpc from the quasar. These distributions are a complex convolution of the magnitude limit and angular extent of the survey fields, and the emission redshift.
distribution of the targeted quasars. For example, the impact parameter distribution does not scale as $N \propto \rho$ because the fixed angular extent of the survey restricts galaxies to $\rho < 1 \text{ Mpc}$ at $z < 0.1$. Nevertheless, Figure 40 provides an overview of this survey’s utility for probing the low-$z$ IGM.

To crudely assess the completeness and global characteristics of the survey, we have also constructed an $R$-band luminosity function from the data set. Specifically, we restricted the survey of each field to $R_{\text{max}} = 19.5$ mag, $\theta_{\text{max}} = 10'$, and $0.02 < z < \min[\langle z_{\text{em}} - 0.01 \rangle, 0.2]$. The maximum redshift was imposed to minimize effects from having targeted fields with a known, luminous quasar and also to facilitate comparison with the SDSS. We calculated the effective comoving volume $V_{\text{eff}}$ for a given absolute magnitude $M$ and evaluated the luminosity function,

$$\Phi(M) = \frac{n_{\text{gal}}}{V_{\text{eff}} \Delta M},$$

within magnitude bins of $\Delta M = 0.5$ mag. The analysis was further restricted to the 17 fields which have a completeness percentile $C_{10^3} > 70\%$ (Table 1). The raw evaluation of $\Phi(M)$ is shown as black points in the lower panel of Figure 41, where the error bars reflect only Poisson uncertainty (1$\sigma$ equivalent) in $n_{\text{gal}}$. Upper limits correspond to 95% c.l. We have also performed a jack-knife analysis of the survey and recover similar scatter in the measurements albeit with a bias toward lower values.

We have also attempted to correct for incompleteness in the survey, using two approaches. The blue stars in the figure include a completeness correction estimated by scaling $n_{\text{gal}}$ in each field by its corresponding completeness, i.e., $1/C_{10^3}$. This increases $\Phi(M)$ in nearly every bin by $\approx 20\%$, i.e., the correction is...
essentially independent of apparent magnitude. As Figure 42 demonstrates, however, the survey has higher incompleteness for fainter galaxies. Therefore, we have used the results given in Figure 42 to increment the contribution of each galaxy to $\Phi(M)$ according to each galaxy’s apparent magnitude. These results are shown as the cyan diamonds in Figure 41.

Overplotted on our evaluations of $\Phi(M)$ are the luminosity functions derived for the $r$ band from the SDSS (Blanton et al. 2003; Montero-Dorta & Prada 2009), transformed to our assumed cosmology (e.g., $h = 0.72$). The agreement between our evaluation and the SDSS estimations is remarkably good. The only significant deviation is at the bright end where we have detected 2–3× more galaxies than predicted by the SDSS luminosity functions. The offset could be the result of an Eddington bias in our estimation of $\Phi(M)$ and/or a modest offset between our $R$-band photometry and the SDSS $r$ band (there is one notable for some of these galaxies which are also observed by SDSS). We also emphasize that the number of galaxies in these deviant bins is small (~20; upper panel of Figure 41). We conclude, therefore, that our combined survey provides a reasonably representative sample of galaxies for low-$z$ IGM analysis.

In future papers (e.g., Prochaska et al. 2011), we explore the association of galaxies and their structures to the IGM with particular focus on H$\text{I}$ Ly$\alpha$ and O$\text{VI}$ absorption. We also encourage the acquisition of new, more sensitive UV spectral data sets (i.e., with $HST$/COS) to further enhance this galaxy survey.

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Figure 40. (a) Color–magnitude diagram of all galaxies with redshifts $z > 0.005$ (blue dots) in LCO/WFCCD survey and galaxies with $0.02 < z < (z_{\text{em}} - 0.01)$ (black symbols). (b) Histogram of the galaxy redshifts for sources detected in our survey. The open (blue) histogram shows all sources with $z > 0.005$, while the solid black histogram is restricted to $0.02 < z < (z_{\text{em}} - 0.01)$ and therefore represents the sample that may be used to study associations with the low-$z$ IGM. (c) Distribution of impact parameters $\rho$ for the galaxies in our survey with $0.02 < z < (z_{\text{em}} - 0.01)$. The incidence of objects does not increase as $N \propto \rho$ for $\rho \gtrsim 400$ kpc because of the (nearly) fixed angular extent of the survey. (d) Luminosity distribution for the galaxies in our LCO/WFCCD survey restricted to the sample of sources with $z > 0.005$ (blue, open histogram) and $0.02 < z < (z_{\text{em}} - 0.01)$ (black, solid histogram).

(A color version of this figure is available in the online journal.)

Figure 41. Luminosity function estimated from the 17 fields of the LCO/WFCCD survey that have greater than 70% completeness to $10'$ from the quasar to $R \leq 19.5$ mag. Black points with error bars show the results without a correction for incompleteness and assume Poisson uncertainties based on the number of galaxies detected (upper panel). The blue stars and cyan diamonds show the estimated $\Phi(M)$ values after adopting magnitude-independent and dependent completeness corrections, respectively (see the text for a full description). The dashed (red) and dotted (green) curves show the luminosity functions derived from the SDSS by Blanton et al. (2003) and Montero-Dorta & Prada (2009), respectively, corrected to our assumed cosmology ($h = 0.72$). The offset at high luminosity may be the result of an Eddington bias in our estimation of $\Phi(M)$ and/or a modest offset between our $R$-band photometry and the SDSS $r$-band measurements.

(A color version of this figure is available in the online journal.)

Figure 42. The lower plots of each panel show histograms of the targeted (open, black) and observed (solid, blue) galaxies in the 17 fields used to estimate the luminosity function (Figure 41). These histograms are shown for (a) $\theta_{\text{max}} = 5'$ and (b) $\theta_{\text{max}} = 10'$. In the upper plot of each panel, we show the completeness percentile $C_{\phi}$ as a function of apparent magnitude. These values are used in the magnitude-dependent completeness correction of the luminosity function.

(A color version of this figure is available in the online journal.)

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