Ca II AND Na I QUASAR ABSORPTION-LINE SYSTEMS IN AN EMISSION-SELECTED SAMPLE OF SDSS DR7 GALAXY/QUASAR PROJECTIONS. I. SAMPLE SELECTION

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Received 2010 February 4; accepted 2011 July 28; published 2011 September 13

ABSTRACT

The aim of this project is to identify low-redshift host galaxies of quasar absorption-line systems by selecting galaxies that are seen in projection onto quasar sightlines. To this end, we use the Seventh Data Release of the Sloan Digital Sky Survey to construct a parent sample of 97,489 galaxy/quasar projections at impact parameters of up to 100 kpc to the foreground galaxy. We then search the quasar spectra for absorption-line systems of Ca II and Na I within ±500 km s\(^{-1}\) of the galaxy’s velocity. This yields 92 Ca II and 16 Na I absorption systems. We find that most of the Ca II and Na I systems are sightlines through the Galactic disk, through high-velocity cloud complexes in our halo, or Virgo Cluster sightlines. Placing constraints on the absorption line rest equivalent width significance (\(\geq 3.0 \sigma\)), the local standard of rest velocity along the sightline (\(\geq 345 \text{ km s}^{-1}\)), and the ratio of the impact parameter to the galaxy optical radius (\(\leq 5.0\)), we identify four absorption-line systems that are associated with low-redshift galaxies at high confidence, consisting of two Ca II systems (one of which also shows Na I) and two Na I systems. These four systems arise in blue, \(\sim L^*\) galaxies. Tables of the 108 absorption systems are provided to facilitate future follow-up.

Key words: catalogs – galaxies: general – quasars: absorption lines – quasars: individual (Ca II, Na I)

Online-only material: color figures, machine-readable and VO tables, supplemental data (FITS) file (tar.gz)

1. MOTIVATION

The project we describe in this paper was motivated by the fact that the Sloan Digital Sky Survey (SDSS) database contains spectroscopically observed galaxy/quasar projections that can be used to study quasar absorption-line systems arising from known galaxies with redshifts between 0 < \(z\) < 0.6. QSO absorption lines provide a wealth of information on the physical conditions of gaseous structures along random sightlines through the universe. The strongest absorption-line systems seen are the hydrogen absorption systems (damped Ly\(\alpha\) absorbers or DLAs, sub-DLAs, Lyman-limit (LL), and Ly\(\alpha\)-forest systems). Quasar spectra also exhibit metal-line absorption systems with Ca II and Na I causing the strongest lines at rest-frame optical wavelengths. There is much current interest in studying the connection of quasar absorption-line systems with the galaxies or galaxy environments in which they are thought to arise since this can provide new information on the evolving morphological structures that they represent (Williams et al. 2005; Wolfe et al. 2005; Baugh 2006; Benson 2010; Dekel & Birnboim 2006; Kereš et al. 2005, 2009; Steidel et al. 2010; Kimm et al. 2011; Stewart et al. 2011). With this project we seek to discover and to characterize new low-redshift absorber galaxies with an emphasis on Ca II and Na I absorbers.

1.1. Absorber–Galaxy Associations

There are two main approaches to uncovering the connection between the absorber host galaxy and the absorbing gas seen in quasar spectra. The first more traditional approach involves selecting quasar absorption-line systems through spectroscopic observations of quasars. This method is independent of the absorber host galaxy as the line is found first with follow-up imaging performed to locate the host galaxy. However, this approach has not produced a large body of galaxy/quasar pairs. With few galaxy identifications, for most absorption systems the analysis of the host properties relies on what can be gleaned from the study of the absorption lines themselves, e.g., Wolfe et al. (2005).

The second approach to uncovering the connection between the absorbing gas and the absorber host galaxy is by searching for known low-redshift galaxies with quasars projected along lines of sights toward the galaxy. One well-known example of this approach is the dwarf galaxy SBS 1543+593 which gives rise to a DLA. The galaxy/quasar pair was first discovered by Reimers & Hagen (1998) and then extensively studied in absorption and emission (Schulte-Ladbeck et al. 2004, 2005; Bowen et al. 2005; Rosenberg et al. 2006).

A few previous attempts have been made to generate large galaxy/quasar pair catalogs. Burbidge et al. (1990) compiled a catalog of over 400 galaxy/quasar pairs with angular separations <10’. Bukhmastova (2001) compiled a catalog from the literature of 8382 galaxy/quasar pairs separated by <150 kpc at the galaxy redshift.

Even more useful than single pairs is the identification of multiple quasars projected behind one particular foreground galaxy, allowing comparisons of the absorbing gas along multiple lines of sight through the galaxy. This approach requires the foreground galaxy to have a large angular extent so its cross-section covers a large sky area for random sightlines and constrains the foreground galaxy to extremely low redshift. Crampton et al. (1997) identified 16 active galactic nuclei behind the Magellanic Clouds selected via their X-ray emission and 146 quasar candidates behind nearby galaxies. Kozłowski & Kochanek (2009) identified 5000 possible quasar candidates behind the Magellanic Clouds using a mid-IR color selection scheme. These and other catalogs have provided valuable source lists for follow-up observations of galaxy/quasar projections.

1.2. Project Description

With the vast numbers of galaxies and quasars found in SDSS, the SDSS is the ideal place to search for galaxy/quasar projections on a large scale. The power of using the SDSS for
this project is that it provides spectra. The SDSS spectra cover the wavelength range from 3900 Å to 9200 Å. The pixel size is 69 km s$^{-1}$ (varying from 0.9 Å at the blue end to 2.1 Å at the red end of the spectra); this gives a resolution of about 170 km s$^{-1}$. Additional information about the seventh and final SDSS data release (SDSS-DR7) can be obtained from Abazajian et al. (2009)

The first goal of this project is to identify and characterize a large number of galaxy/quasar projections in which the galaxies are projected onto quasar sightlines. Section 2 of this paper describes how we generated a catalog of spectroscopic galaxy/quasar pairs, hereafter referred to as the parent sample, from the SDSS-DR7. We include a discussion of the basic characteristics of the parent sample.

The second goal of this project is to find Ca II and Na I absorbers associated with the galaxies in the galaxy/quasar parent sample. The lines that produce the strongest interstellar absorption lines at optical wavelengths are the Ca II doublet at $\lambda \lambda$ 3934.77, 3969.59 (K, H), and the Na I D doublet at $\lambda \lambda$ 5891.58, 5897.56 (D2, D1). Both Ca II and Na I have ionization potentials that are smaller than that of H I, 11.9 eV and 5.1 eV versus 13.6 eV, respectively, and are therefore thought to be probes of the neutral gas in and around galaxies. In Section 3, we describe the identification and selection of the Ca II and Na I absorber galaxies; in Section 4, we analyze and discuss the basic observational characteristics of the Ca II and Na I absorbers, and in Section 5, we describe the absorber systems attributed to extragalactic sources.

In Section 6, we summarize the characteristics of the new absorbers and their host galaxies and make suggestions for follow-up studies.

2. GALAXY–QUASAR PARENT SAMPLE

The SDSS-DR7 quasar catalog provides the parent quasar sample (Schneider et al. 2010). This catalog of bona fide quasars, which have redshifts checked by eye and luminosities and line widths that meet the formal quasar definition, contains 105,783 spectroscopically confirmed quasars, and represents the final product of the SDSS-I and SDSS-II quasar survey. The quasar catalog uses a cosmology with $H_0 = 70$ km s$^{-1}$, $\Omega_m = 0.3$, and $\Omega_{\Lambda} = 0.7$, which we adopted for the remainder of this paper.

The SDSS-DR7 SpecPhoto View provided the parent galaxy sample. The SpecPhoto table includes only those objects where the SpecObj is a sciencePrimary, and the BEST PhotoObj is a PRIMARY object and the object has clean spectra. We selected from this table all objects that were morphologically typed as a galaxy (type = galaxy) and have the spectrum of a galaxy (specClass = galaxy). This returned 798,948 galaxy spectra.

2.1. Parent Sample Definition

We identified all pairs for which (1) the quasar’s spectrum is projected within 100 kpc of a galaxy’s spectrum and (2) the quasar’s spectrum has a redshift larger than the galaxy’s, $z_{QSO} > z_{gal}$, by an amount equal to the total redshift error, $\sigma_z$, of the galaxy and the quasar, $z_{QSO} - z_{gal} > \sqrt{\sigma_z^2 + \sigma_{z_{gal}}^2}$.

Steps 1 and 2 yielded 97,489 pairs of galaxy/quasar spectra. We refer to these pairs as the galaxy–quasar parent sample. The full list of pairs is available for download as a FITS table in the online version of this paper, a sample of which is provided in Table 1. Prior to the absorber selection we also apply an additional constraint on the parent sample where (3) we remove cases in which intervening Lyα-forest lines potentially cause misidentification.

We perform step 3 for both Ca II and Na I, thus creating two parent samples, one of 95,651 pairs (Na I) and one of 81,912 pairs (Ca II). For the remainder of this section we discuss the overall parent sample of 97,489 pairs.

An issue that affects the construction of our sample is the 55$''$ fiber collision problem in SDSS. On a given tile in SDSS, there are a maximum of 592 possible fibers for placement onto a viable target. The spacing between each fiber on a tile is 55$''$, so that lie less than 55$''$ from each other are spectroscopically unobservable unless recovered with overlapping tiles on the sky. About 6% of all SDSS targets are missed in this manner (Blanton et al. 2003). With approximately 1.1 million objects targeted for spectroscopy, 6% corresponds to ~66,000 objects. This however does not necessarily imply that the incompleteness of close pairs is ~6%. The spectroscopic incompleteness of our sample in particular (close pairs within 100 kpc) will be addressed in a future paper. At the mean redshift for SDSS galaxies ($z \sim 0.1$), 55$''$ corresponds to ~101 kpc. For the majority of our galaxies, we are searching well within the fiber collision radius.

2.2. Parent Sample Characteristics

Figure 1 shows the redshift distributions of the galaxy and quasar spectra in the parent sample of 97,489 pairs. The mean redshift of the galaxy spectra is $\langle \mu, \sigma \rangle = (0.00649, 0.00005)$, and the mean redshift of the quasar spectra is $\langle \mu, \sigma \rangle = (1.6, 0.8)$. We see that, indeed, the distribution of QSOs lies mostly behind that of the galaxies. Figure 2 displays the impact parameter distribution of the pairs. We find an increasing number of pairs as the impact parameter increases. This distribution is expected given the large number of low-redshift galaxies seen in Figure 1. The 100 kpc search radius around these low-redshift galaxies

![Figure 1. Shown here are the redshift distributions for the parent galaxy and quasar sample. As expected given our catalog constraints, the distribution of quasars does indeed lie behind the distribution of galaxies. The inset plot shows a zoomed region of $z < 0.5$.](image-url)
Table 1
Parent Sample of 97,468 Galaxy–Quasar Pairs

| Galaxy                  | z_{glos} | Quasar                  | z_{QSO} | 100 kpc Scale ('') | b ('') | b (kpc) | in Ca | in Na | Ca Flag | Na Flag | V_{Ca ii} | V_{Na i} |
|-------------------------|----------|-------------------------|---------|-------------------|--------|---------|-------|-------|---------|---------|-----------|---------|
| SDSS J000055.3−011258.9 | 0.03170 ± 0.00009 | SDSS J235958.66−011225.3 | 1.77180 | 2.63              | 1.80   | 68.63   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J000066.7+003016.7 | 0.10916 ± 0.00015 | SDSS J000006.53+003055.2 | 1.82460 | 0.84              | 0.64   | 76.84   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J000277.97−002653.4 | 0.07897 ± 0.00015 | SDSS J000030.37−002732.4 | 1.80550 | 1.12              | 0.88   | 79.24   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J000310.98−103322.0 | 0.07713 ± 0.00015 | SDSS J000035.75−103305.3 | 1.21820 | 1.14              | 0.97   | 84.75   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J024910.78−074924.6 | 0.00457 ± 0.00001 | SDSS J024945.00−075626.9 | 1.58460 | 17.69             | 11.02  | 62.28   | 1     | 1     | Q       | N       | 4         | ...     |
| SDSS J024910.78−074924.6 | 0.00457 ± 0.00001 | SDSS J024950.68−075949.9 | 0.97360 | 17.69             | 14.36  | 81.17   | 1     | 1     | N       | Q       | ...       | 7       |
| SDSS J024910.78−074924.6 | 0.00457 ± 0.00001 | SDSS J024957.31−075617.0 | 2.16360 | 17.69             | 13.42  | 75.84   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J025346.70−072344.0 | 0.00449 ± 0.00001 | SDSS J025407.68−074023.0 | 0.73160 | 18.00             | 17.44  | 96.88   | 1     | 1     | N       | N       | ...       | ...     |
| SDSS J025346.70−072344.0 | 0.00449 ± 0.00001 | SDSS J025414.61−073435.4 | 1.47220 | 18.00             | 12.87  | 71.51   | 1     | 1     | N       | Q       | ...       | 4       |
| SDSS J025346.70−072344.0 | 0.00449 ± 0.00001 | SDSS J025420.59−073745.5 | 2.16710 | 18.00             | 16.35  | 90.80   | 1     | 1     | Q       | N       | 3         | ...     |
| SDSS J122037.63+283803.3 | 0.02764 ± 0.00011 | SDSS J122037.22+283752.0 | 2.20420 | 3.00              | 0.21   | 6.92    | 1     | 1     | N       | A       | ...       | 1       |
| SDSS J141746.33+162509.3 | 0.24229 ± 0.00001 | SDSS J141746.03+162512.2 | 1.71690 | 0.44              | 0.11   | 25.16   | 1     | 1     | A       | N       | 1         | ...     |

Notes. The columns are (1) SDSS galaxy name, (2) SDSS galaxy redshift, (3) SDSS quasar name, (4) SDSS quasar redshift, (5) the 100 kpc search radius scale in arcmin, (6) impact parameter in arcmin, (7) impact parameter in kpc, (8) and (9) flags indicating the inclusion “1” or exclusion “0” due to Lyα-forest contamination, (10) and (11) flags indicating absorber candidate (A), questionable candidate (Q), non-detection (N), interloping doublet (D), removal due to sky line (S), (12) and (13) flags indicating our visual classification of the absorber or questionable candidate.

(This table is available in its entirety in FITS format in the online journal.)
produces a much larger search area on the sky, from which a greater number of sightlines will be observed. The mean impact parameter of the distribution is \((\mu, \sigma) = (66, 24)\) kpc.

The spectra which define the galaxy–quasar parent sample do not necessarily belong to unique galaxy/quasar pairs. There are two reasons for this. First, the SDSS database contains multiple spectra for some galaxies. A typical example is a nearby star-forming galaxy for which the SDSS targeted for its nucleus plus one or more bright H\textsc{ii} regions. Second, some nearby galaxies cover such a large area on the sky that they intercept two or more quasar sightlines. If the coverages of multiple nearby galaxies overlap, then it is also possible to have more than one galaxy intercept the same quasar sightline.

3. ABSORBER GALAXIES

We searched all quasar spectra in the parent sample for Ca\textsc{ii} and Na\textsc{i} absorption lines located at the redshift of the foreground galaxy, permitting a deviation of \(\pm 500\) km s\(^{-1}\) from the systemic galaxy velocity to allow for the possibility that the quasar sightline intercepts the galaxy’s gas where it has an additional internal motion due to rotation, inflow, or outflow.

3.1. Absorber Selection

Our line identification procedure is as follows. First, we use an automated line finder to create a candidate list of Ca\textsc{ii} and Na\textsc{i} systems. Second, we review the candidate features by eye to produce final line lists. We perform the automated line identification on the two reduced parent samples of 95,651 and 81,912 pairs for Na\textsc{i} and Ca\textsc{ii}, respectively. The later visual inspection of the candidate detections also showed a small number of possible intervening Mg\textsc{ii}, Fe\textsc{ii}, or C\textsc{iv} systems that interfered with a positive identification of the doublet lines.

We adopted the automated line finder of the Hubble Space Telescope Quasar Absorption Line Key Project (Schneider et al., 1993) which is optimized to look for weak, unresolved quasar absorption lines. We followed the prescription as outlined in C. Churchill (in preparation). The prescription searches for significant unresolved features by weighting each pixel by the Instrumental Spread Function (ISF), a Gaussian that describes how the pixel counts are redistributed below the limiting resolution of the instrument. The ISF, \(\Phi\), is defined as

\[
\Phi(\lambda' - \lambda) = \frac{1}{2\pi \sigma} \exp \left[ -\frac{(\lambda' - \lambda)^2}{2\sigma^2} \right].
\]

In practice, the ISF is discretized as a Gaussian model, \(P_i\), symmetric about a pixel \(i\), that spans \(M = 2J0+1\) elements, where \(J0 = 2p\), and \(p\) is the number of pixels per resolution element. The discretized ISF is given as

\[
P_i = \exp \left[ -\frac{x_{ij}^2}{\sigma_{ISF}^2} \right] \exp \left[ -\frac{\lambda_k - \lambda_j}{\sigma_{ISF}} \right],
\]

normalized to ensure conservation of counts within the region spanned by the ISF. In the above, \(\sigma_{ISF} = \lambda_j/(2.35R)\) is the Gaussian width of the ISF at pixel \(j\), where \(R\) is the spectral resolution and \(k = j + (i-1) - J0\) is the wavelength index relative to the central pixel \(j\).

The procedure is outlined as follows:

1. **Weight the flux decrement in each pixel by the ISF.** The weighted equivalent width and uncertainty in pixel \(j\) is defined as

\[
eqw_j = \frac{-\Delta \lambda_j}{P^2} \sum_{i=1}^{M} P_i D_k
\]

\[
\sigma_{\text{eqw}_j} = \frac{\Delta \lambda_j}{P^2} \left( \sum_{i=1}^{M} P_i^2 \sigma_{D_k}^2 \right)^{1/2},
\]

where

\[
P^2 = \sum_{i=1}^{M} P_i^2,
\]

\(D_k = 1-\frac{I_k/I_i}\) is the flux decrement in pixel \(k\) and \(\Delta \lambda_j = 0.5 \times (\lambda_{j+1} - \lambda_{j-1})\) is the wavelength dispersion in pixel \(j\).

2. **Search the spectrum for pixels satisfying the condition.**

\[
\frac{\text{eqw}_j}{\sigma_{\text{eqw}_j}} \leq -N_\sigma,
\]

where \(N_\sigma\) is a user-specified significance threshold.

3. **Determine the pixels spanned by feature \(i\).** For a given pixel that satisfies the above condition, identify the start and end pixels of feature \(i\) by scanning the spectrum blueward and redward of pixel \(j\) until the conditions

\[
\frac{\text{eqw}_j^-}{\sigma_{\text{eqw}_j^-}} \geq -1.0; \quad \frac{\text{eqw}_j^+}{\sigma_{\text{eqw}_j^+}} \geq -1.0
\]

are met.
4. Determine the significance of the candidate feature. Once the pixel span of feature $i$ has been identified, the observed equivalent width, EW, and uncertainty, $\sigma_{EW}$, of feature $i$ are

$$\text{EW}_i = \sum_{k=j}^{j^*} e_k$$

and

$$\sigma_{EW}^2 = \sum_{k=j}^{j^*} \sigma_{ek}^2,$$

where $e_k = \Delta \lambda_k D_k$ is the unweighted equivalent width in pixel $k$ and $\sigma_e = \Delta \lambda_e \sigma_{Dk}$ is the uncertainty in $e_k$. The final step is to calculate the significance, $S_i$, of feature $i$ and check that it satisfies your required significance threshold.

$$S_i = \frac{\text{EW}_i}{\sigma_{EW}}, \quad S_i \geq N_\sigma. \quad (10)$$

If the candidate feature satisfies the above criteria, then it is kept as a candidate absorption line.

The line finder algorithm expects a normalized flux array as input. We therefore divided the quasar spectra by the global continuum fit stored in the “spSpec” one-dimensional spectral fits file. In some cases the sought-after doublets were superimposed on a broad emission line in the quasar’s spectrum. We thus re-defined a local continuum anchored to the quasar’s normalized spectrum within ±1000 km s$^{-1}$ of the expected doublets.

We automatically searched for lines that are located to within ±500 km s$^{-1}$ of their expected positions, given the galaxy redshift. The significance of a candidate line was calculated based on Equation (10). We chose a significance threshold, $N_\sigma$, of two. All lines with significances less than this threshold were automatically rejected. This step eliminated a very large number of pairs. Lines were kept as candidates for visual inspection if their significances were equal to or exceeded our specified significance threshold.

3.1.1. Ca $\upiota$ Doublet Sample

We created three candidate line lists. The first list contained Ca$\upiota$ doublets. For optically thin gas, the ratio of the primary and secondary lines is 2:1, while for saturated lines, the doublet ratio approaches 1:1. We use this allowed region to define the acceptable strengths of the weaker, Ca$\upiota$ H line, i.e., the Ca$\upiota$ H equivalent width must be, at least, half as strong as the Ca$\upiota$ K line and, at most, equal in strength to the Ca$\upiota$ K line. Questionable candidates, which passed the line finder but not the visual inspection, were moved to a separate list. Among the parent sample for Ca$\upiota$ systems, we claim 92 detections (A in Table 1), 1641 questionable candidates (Q in Table 1), and 80,179 non-detections (N in Table 1). The main reasons why a doublet was rejected during visual inspection include: (1) the possibility of confusion with an interloping non-Ca$\upiota$ system, (2) a pixel pattern in the doublet region which looked inconsistent with the profile of a real doublet, and (3) a low signal-to-noise ratio in the doublet region. For the 92 detections, the line finder yields a mean line significance level of the Ca$\upiota$ K line of $(\mu, \sigma) = (2.9 \pm 0.1, 0.6 \pm 0.1)$. The Ca$\upiota$ absorber catalog consists of 92 detections involving pairs of individual galaxy and quasar spectra. These 92 detections result from 13 unique galaxy spectra and 61 unique quasar spectra. Listed in Table 2 are the individual Ca$\upiota$ absorber galaxies, with the number of quasars found associated with each particular galaxy, along with any notes regarding that particular galaxy. Table 2 highlights the fact that a low-redshift galaxy may have a large search radius such that many quasar sightlines are intersected, producing a large number of non-unique spectral pairs. With more than one of these galaxies, it is therefore also possible to have one quasar be considered in multiple pairs with different galaxies. These facts combine to produce the numbers of unique galaxy and quasar spectra above. For example, the galaxy SDSS J21633.70+130153.6 had 21 quasars identified within 100 kpc which exhibited Ca$\upiota$ absorption located within ±500 km s$^{-1}$ of the galaxy redshift. This system would then account for 1 out of 13 unique galaxy spectra, 21 out of 61 unique quasar spectra, and 21 out of 92 Ca$\upiota$ detections. Also see the last paragraph of Section 2.2.

3.1.2. Na $\upiota$ Doublet Sample

The second line list contained Na$\upiota$ systems. Some of the Na$\upiota$ doublets are resolved and some are blended. For partially blended doublets, occasionally the line finder failed to distinguish both components of the doublet, instead treating the entire doublet as the Na$\upiota$ D2 line. It then attempted to find a “false” weaker component for Na$\upiota$. This led us to treat the Na$\upiota$ candidates differently from the Ca$\upiota$ candidates. We required that the

| Galaxy | Zindex | QSO Count | Notes |
|--------|--------|-----------|-------|
| SDSS J091338.99+193707.4 | 0.00143 ± 0.00001 | 1 | Inconsistent spectrum, not a part of NGC 3245A |
| SDSS J102703.86+283721.9 | 0.00020 ± 0.00001 | 7 | Inconsistent spectrum |
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00001 | 1 | KUG 1210+301B |
| SDSS J113420.50−033525.4 | 0.00006 ± 0.00007 | 12 | See also Zych et al. (2007) |
| SDSS J114637.59+405036.6 | 0.00280 ± 0.00002 | 2 | In NGC 4190 |
| SDSS J121323.27+295518.4 | 0.00042 ± 0.00001 | 1 | SDSS J121344.76+363802.4 | 0.00045 ± 0.000018 |
| SDSS J121633.70+130153.6 | 0.00006 ± 0.00007 | 21 | VCC 200 (dE2) |
| SDSS J122843.30+114518.1 | 0.00054 ± 0.00007 | 1 | VCC 1125 (S0(9)) |
| SDSS J122844.91+124835.1 | 0.00004 ± 0.000033 | 41 | VCC 1129 (dE3) |
| SDSS J123745.22+070618.3 | 0.00011 ± 0.000032 | 3 | VCC 1726 (Sdm IV) |
| SDSS J141745.62+162509.3 | 0.24229 ± 0.000015 | 1 | SDSS J155752.51+342142.8 | 0.11366 ± 0.000006 |

**Note.** “Inconsistent spectrum” refers to an inconsistency between the reported SDSS redshift with the galaxy spectrum.
line finder identify the “Na i D2 line” of the doublet only, then visually rejected as questionable candidates lines showing profile shapes that appear inconsistent with a blended physical doublet. As with the Ca ii systems, we also visually rejected Na i systems that had (1) the possibility of an interloping non-Na i system and (2) systems with low signal-to-noise within the doublet region. Among the parent sample for Na i systems, we claim 583 detections, 3796 questionable candidates, and 91,272 non-detections. Many of the candidate systems were found at very low velocity and were affected by incomplete Na i sky-line subtraction. This turned out to be a severe problem. To minimize contamination from incorrect sky subtraction, we excluded from the sample all candidate lines that fell between 5888.0 Å and 5901.0 Å (S in Table 1). This reduced the number of Na i detections down to 16 systems. For the 16 detections, the line finder yields a mean line significance of \((\mu,\sigma) = (2.8 \pm 0.2,0.7 \pm 0.3)\). These 16 detections result from 15 unique galaxy spectra and 12 unique quasar spectra. Listed in Table 3 are the individual Na i absorbers galaxies, with the same columns as in Table 2.

3.1.3. Ca ii K and Na i D2 Sample

We generated a third list in which both the Ca ii K line and the Na i D2 line were detected by the line finder. In this list we use the Ca ii K line as the “confirmation” line for the Na i D2 line, and vice versa. This required that we impose a limit on the velocity agreement between the two species. We adopted a mean line significance for the Na i D2 component. Due to this, we decided to remeasure the equivalent widths manually to ensure each line has a proper value. To be consistent, we remeasured all the lines within the absorber sample. We measured the rest equivalent width (\(\text{rEW}\)), equivalent width error, central wavelength, and central wavelength error of the lines. The equivalent widths were computed from a direct summation of the pixels within the line region. The line equivalent width error is the total error of the sum of the pixel equivalent width errors. The central wavelength of a line is the equivalent-width-weighted mean of the pixels’ wavelengths; its errors are the uncertainty of the mean.

Table 4 is our absorber catalog.1 The columns of the catalog are galaxy spectrum IAU designation, galaxy redshift, quasar Galactic coordinates, quasar spectrum IAU designation, quasar redshift, quasar Galactic coordinates, impact parameter, the ratio of impact parameter to \(r\)-band Petrosian radius, and an identifier of impact parameter to \(r\)-band Petrosian radius, and an identifier for which absorber list it belongs to. Table 6 is a list of the measured line parameters for each absorber. The columns are galaxy spectrum, SDSS redshift, the catalog the absorber belongs to, the local standard of rest (LSR)

1 This catalog does not include Mrk 1456 and SDSS J211701.26−002633.7 (Cherinka et al. 2009). Mrk 1456 was selected from a visual inspection of the SDSS-DR3 spectrum of its background quasar. Here (DR7) it remained in the questionable candidate list of Ca ii doublets. SDSS J211701.26−002633.7 was selected from the SDSS-DR5 using the same automated line finder but with slightly different parameters. Here it also remained in the questionable candidate list of Ca ii doublets.

### Table 3

| Galaxy         | \(Z_{\text{abs}}\) | QSO Count | Notes                                      |
|----------------|---------------------|-----------|--------------------------------------------|
| SDSS J1102703.86+283721.9 | 0.00020 ± 0.00016 | 1         | Inconsistent spectrum, not in NGC 3245A    |
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00016  | 1         |                                             |
| SDSS J113420.50−033525.4 | 0.00008 ± 0.00007  | 2         | Inconsistent spectrum                      |
| SDSS J114313.05+193646.9 | 0.02085 ± 0.00009  | 1         | In A1367                                   |
| SDSS J114318.07+193401.3 | 0.02262 ± 0.00015  | 1         | In A1367                                   |
| SDSS J114336.98+193616.7 | 0.02201 ± 0.00019  | 1         | In A1367                                   |
| SDSS J115115.25+485331.0 | 0.02565 ± 0.00011  | 1         |                                             |
| SDSS J122037.63+283803.3 | 0.02764 ± 0.00011  | 1         |                                             |
| SDSS J122844.91+124835.1 | 0.00004 ± 0.00033  | 1         | VCC 1129 (DE3)                             |
| SDSS J124006.10+613609.5 | 0.00026 ± 0.00017  | 1         | In NGC 4605                                |
| SDSS J140613.22+153035.5 | 0.06040 ± 0.00018  | 1         |                                             |
| SDSS J142009.64+132626.7 | 0.14152 ± 0.00020  | 1         |                                             |
| SDSS J150400.94+240437.1 | 0.06894 ± 0.00010  | 1         | In group                                   |
| SDSS J150403.17+240559.8 | 0.06997 ± 0.00019  | 1         | In group                                   |
| SDSS J151154.63+071510.6 | 0.04393 ± 0.00019  | 1         |                                             |

### Table 4

| Galaxy         | \(Z_{\text{abs}}\) | QSO Count | Notes                                      |
|----------------|---------------------|-----------|--------------------------------------------|
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00016  | 1         |                                             |
| SDSS J1155752.51+342142.8 | 0.11366 ± 0.00006  | 1         |                                             |

### Table 3

| Galaxy         | \(Z_{\text{abs}}\) | QSO Count | Notes                                      |
|----------------|---------------------|-----------|--------------------------------------------|
| SDSS J102703.86+283721.9 | 0.00020 ± 0.00016 | 1         | Inconsistent spectrum, not in NGC 3245A    |
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00016 | 1         |                                             |
| SDSS J113420.50−033525.4 | 0.00008 ± 0.00007 | 2         | Inconsistent spectrum                      |
| SDSS J114313.05+193646.9 | 0.02085 ± 0.00009 | 1         | In A1367                                   |
| SDSS J114318.07+193401.3 | 0.02262 ± 0.00015 | 1         | In A1367                                   |
| SDSS J114336.98+193616.7 | 0.02201 ± 0.00019 | 1         | In A1367                                   |
| SDSS J115115.25+485331.0 | 0.02565 ± 0.00011 | 1         |                                             |
| SDSS J122037.63+283803.3 | 0.02764 ± 0.00011 | 1         |                                             |
| SDSS J122844.91+124835.1 | 0.00004 ± 0.00033 | 1         | VCC 1129 (DE3)                             |
| SDSS J124006.10+613609.5 | 0.00026 ± 0.00017 | 1         | In NGC 4605                                |
| SDSS J140613.22+153035.5 | 0.06040 ± 0.00018 | 1         |                                             |
| SDSS J142009.64+132626.7 | 0.14152 ± 0.00020 | 1         |                                             |
| SDSS J150400.94+240437.1 | 0.06894 ± 0.00010 | 1         | In group                                   |
| SDSS J150403.17+240559.8 | 0.06997 ± 0.00019 | 1         | In group                                   |
| SDSS J151154.63+071510.6 | 0.04393 ± 0.00019 | 1         |                                             |

### Table 3

| Galaxy         | \(Z_{\text{abs}}\) | QSO Count | Notes                                      |
|----------------|---------------------|-----------|--------------------------------------------|
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00016 | 1         |                                             |
| SDSS J1155752.51+342142.8 | 0.11366 ± 0.00006 | 1         |                                             |
velocity along the sightline to the quasar, then for line 1 in the
doublet: the rEW of the line, the significance of the line
(rEW/σrEW), the heliocentric redshift of the line, and the
velocity offset of the line from that of the expected position.
For line 2, we list the rEW of the line, the heliocentric redshift
of the line, and the velocity offset of the line from that of the
expected position. For blended Na features, line 1 reports the
blended values, while line 2 is blank.

In Figures 3–5, we show a few examples of absorbers from the
“Ca ii,” “Na i,” and “Both” samples, ordered by IAU galaxy
name. All absorbers shown were selected using the LSR velocity
cutoff (see Section 4.2). Each figure displays an image centered
on the galaxy, with the image size given in the lower left. The
galaxy name, redshift, and impact parameter to the quasar are
also displayed. If located within the image, the quasar is marked
with a white arrow. All objects with spectroscopy are indicated
by a red square. To the right of each image displays the Ca ii
or Na i doublet lines, centered, in velocity space, on the redshift
of the galaxy. The dotted line indicates the velocity offset of the
absorber from the galaxy position.

4. ANALYSIS OF THE ABSORBERS

This absorber catalog consists of 108 pairs of galaxy–quasar
spectra with either the Ca ii or Na i doublet detected, or both.
The absorbers can be broadly classified into Galactic or extra-
galactic systems. The selection of these systems may vary depending
on the science one wishes to explore through follow-up
observations.

4.1. Selection from Equivalent Width Significance

Figure 6 shows the significance of the equivalent width
measurements as a function of the rEW of the strong line in
a doublet (Ca ii K or Na i D2). The 3σ limit, or 99% confidence
limit, is indicated as a red horizontal line in the figure. We find
43 systems with the significance of either Ca ii K or Na i D2 line
>3.0, 53 systems with a significance between 2 and 3, and 12
systems with a significance <2.0. While we set the line finder
to only accept lines with a significance >2, manually remeasuring
the equivalent widths and errors has, in some instances, resulted
in different significances than what the line finder reported. This
is due to having slightly different boundaries defining the line
edges during the direct summation of the equivalent widths in
each pixel.

In the Milky Way, Ca ii and Na i equivalent widths have
measured values less than what has been observed in external
galaxies. Ca ii equivalent widths have been measured in the
range of 0.08–0.8 Å, with the median equivalent width around
0.18 Å (Bowen 1991). Welsh et al. (2010) searched Milky Way sightlines (within 400 pc of the Sun) and found
Ca ii K equivalent widths <0.3 Å, and Na i D2 equivalent
widths <0.5 Å. Bowen (1991) showed that the larger equivalent
widths seen in external galaxies can be recovered from the
smaller values seen in the Milky Way when taking into account
contributions from multiple, unresolved components, as well as
projection effects through a highly extended, inclined disk. He
showed that the equivalent widths seen in the Milky Way would
be roughly doubled when viewed from outside our Galaxy.

Equivalent widths, seen in nearby external galaxies, of Ca ii
and Na i range from 0.4 to 1.0 Å for the Ca ii K line
(Womble et al. 1990, 1992; Womble 1993; Zych et al. 2007; Boksenberg
& Sargent 1978; Boksenberg et al. 1980; Blades et al. 1981;
Bergeron et al. 1987; Bowen et al. 1991) and between
∼0.2 and 1.8 Å for the Na i D2 line (Junkkarinen & Barlow 1994; Womble et al. 1990), or ∼2.2 Å for blended Na i systems (Kunth
& Bergeron 1984).

There is overall agreement between our rEW values and those
typically seen in the Milky Way and in nearby external galaxies.
As seen in Figure 6, we find that the Ca ii absorbers and the
Na i absorbers naturally divide, with the Ca ii absorbers located
primarily at rEWs $\lesssim$0.5 Å and the Na i absorbers primarily
occupying the region with rEW $\gtrsim$0.5 Å. This division is

---

**Table 5**

Total Absorber Sample: Position Information

| Galaxy | $z$ | $l$ | $b$ | QSO $z_{\text{QSO}}$ | $l$ | $b$ | $b/r_{\text{Pen}}$ | Ion |
|--------|----|----|----|-----------------|----|----|----------------|----|
| SDSS J091338.99+193707.4 | 0.00143 ± 0.00001 | 209 | 40 | SDSS J091511.03+201248.3 | 1.23900 | 209 | 40 | 74.13 | 245.1 Ca ii |
| SDSS J102703.86+283721.9 | 0.00020 ± 0.00016 | 202 | 58 | SDSS J100417.96+282444.1 | 0.32820 | 201 | 53 | 57.85 | 411.5 Ca ii |
| SDSS J111849.76−002109.9 | 0.13179 ± 0.00016 | 260 | 55 | SDSS J111850.13−002100.7 | 1.02560 | 260 | 55 | 25.25 | 2.2 Na i |
| SDSS J113420.50−033525.4 | 0.00008 ± 0.00007 | 269 | 54 | SDSS J111850.13−002100.7 | 1.02560 | 260 | 55 | 25.25 | 2.2 Both |

Notes. “Ion” refers to which line list the absorber belongs to. Absorbers listed as Na i have the Na i doublet detected. Absorbers listed as Ca ii have the Ca ii doublet detected. Absorbers listed as Both have at least both the Ca ii K and Na i D2 lines detected.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)
Table 6
Total Absorber Sample: Line Measurements

| Galaxy                     | $z_G$   | Ion | $v_{LSR}$ (km s$^{-1}$) | $\text{rEW}_1$ (Å) | $\text{rEW}_1/\sigma_{\text{rEW}}$ | $\Delta v_1$ (km s$^{-1}$) | $\text{rEW}_2$ (Å) | $\Delta v_2$ (km s$^{-1}$) |
|----------------------------|---------|-----|-------------------------|---------------------|-----------------------------------|--------------------------|---------------------|--------------------------|
| SDSS J091338.99$+$193707.4| 0.00143 ± 0.00001 Ca Na | 32.2 | 0.30 ± 0.15 | 1.97 | $-0.00009$ ± $0.00047$ | $-455.6$ ± $139.9$ | 0.29 ± 0.13 | $-0.00008$ ± $0.00047$ | $-453.1$ ± $140.1$ |
| SDSS J102703.86$+$283721.9| 0.00020 ± 0.00016 Ca Na | 64.8 | 0.25 ± 0.09 | 2.66 | $-0.00021$ ± $0.00051$ | $-123.8$ ± $160.1$ | 0.21 ± 0.12 | $-0.00059$ ± $0.00055$ | $-237.8$ ± $172.4$ |
|                           | 0.00020 ± 0.00016 Ca Na | 79.9 | 0.44 ± 0.12 | 3.50 | $-0.00026$ ± $0.00038$ | $-139.0$ ± $125.5$ | 0.18 ± 0.12 | $-0.00015$ ± $0.00059$ | $-108.8$ ± $183.1$ |
|                           | 0.00020 ± 0.00016 Ca Na | 30.6 | 0.39 ± 0.10 | 3.81 | $-0.00009$ ± $0.00041$ | $-89.4$ ± $131.3$ | 0.32 ± 0.10 | $-0.00024$ ± $0.00044$ | $-132.7$ ± $141.8$ |
|                           | 0.00020 ± 0.00016 Ca Na | 53.5 | 0.31 ± 0.12 | 2.60 | $-0.00017$ ± $0.00046$ | $-113.1$ ± $145.5$ | 0.23 ± 0.13 | $-0.00015$ ± $0.00053$ | $-15.8$ ± $165.6$ |
|                           | 0.00020 ± 0.00016 Ca Na | 19.8 | 0.34 ± 0.10 | 3.35 | $-0.00007$ ± $0.00044$ | $-80.7$ ± $140.7$ | 0.29 ± 0.10 | $-0.00016$ ± $0.00047$ | $-109.8$ ± $149.8$ |
|                           | 0.00020 ± 0.00016 Na i | 216.9 | 0.81 ± 0.37 | 2.16 | $-0.00072$ ± $0.00019$ | $-277.8$ ± $75.2$ | 0.59 ± 0.28 | $-0.00046$ ± $0.00022$ | $-199.1$ ± $82.8$ |
|                           | 0.00020 ± 0.00016 Ca Na | 38.6 | 0.30 ± 0.15 | 1.93 | $-0.00013$ ± $0.00047$ | $-98.7$ ± $148.8$ | 0.23 ± 0.14 | $0.00001$ ± $0.00052$ | $-56.8$ ± $165.0$ |
|                           | 0.00020 ± 0.00016 Ca Na | 77.9 | 0.32 ± 0.14 | 2.26 | $-0.00026$ ± $0.00045$ | $-139.9$ ± $143.9$ | 0.36 ± 0.15 | $-0.00064$ ± $0.00042$ | $-251.6$ ± $135.5$ |
| SDSS J111849.76$-$002109.9| 0.13179 ± 0.00016 Na i | 39538.5 | 0.68 ± 0.27 | 2.51 | $0.13180$ ± $0.00019$ | $2.3$ ± $75.7$ | 0.31 ± 0.27 | $0.13187$ ± $0.00029$ | $22.1$ ± $98.7$ |
|                           | 0.13179 ± 0.00016 Ca Na | 39400.1 | 0.73 ± 0.32 | 2.32 | $0.13134$ ± $0.00028$ | $-136.1$ ± $96.7$ | 0.62 ± 0.28 | $0.13176$ ± $0.00030$ | $-10.6$ ± $102.5$ |
|                           | 0.13179 ± 0.00007 Both Na i | 39544.4 | 0.70 ± 0.24 | 2.89 | $0.13182$ ± $0.00019$ | $8.2$ ± $75.1$ | 0.31 ± 0.27 | $0.13187$ ± $0.00029$ | $22.1$ ± $98.7$ |
|                           | 0.13179 ± 0.00016 Both Ca Na | 39544.4 | 0.60 ± 0.23 | 2.58 | $0.13154$ ± $0.00031$ | $-76.7$ ± $104.8$ | 0.63 ± 0.25 | $0.13175$ ± $0.00030$ | $-14.3$ ± $101.9$ |
| SDSS J113420.50$-$033525.4| 0.00008 ± 0.00007 Na i | 190.8 | 1.30 ± 0.11 | 1.11 | $-0.00062$ ± $0.00015$ | $-209.7$ ± $49.4$ | 0.82 ± 0.77 | $-0.00024$ ± $0.00019$ | $-94.0$ ± $59.8$ |
|                           | 0.00008 ± 0.00007 Ca Na | 81.5 | 0.51 ± 0.28 | 1.78 | $-0.00027$ ± $0.00036$ | $-102.4$ ± $109.0$ | 0.37 ± 0.23 | $-0.00008$ ± $0.00042$ | $-46.0$ ± $126.5$ |
|                           | 0.00008 ± 0.00007 Ca Na | 33.6 | 0.33 ± 0.09 | 3.59 | $0.00012$ ± $0.00044$ | $12.8$ ± $134.8$ | 0.23 ± 0.10 | $0.00019$ ± $0.00053$ | $34.0$ ± $160.2$ |
|                           | 0.00008 ± 0.00007 Ca Na | 34.5 | 0.32 ± 0.12 | 2.73 | $0.00012$ ± $0.00045$ | $14.0$ ± $136.9$ | 0.23 ± 0.11 | $0.00019$ ± $0.00052$ | $-78.6$ ± $157.7$ |
|                           | 0.00008 ± 0.00007 Ca Na | 21.8 | 0.49 ± 0.18 | 2.72 | $-0.00007$ ± $0.00036$ | $-42.8$ ± $111.2$ | 0.59 ± 0.18 | $-0.00011$ ± $0.00033$ | $-55.5$ ± $100.6$ |
|                           | 0.00008 ± 0.00007 Ca Na | 24.8 | 0.22 ± 0.08 | 2.59 | $-0.00008$ ± $0.00055$ | $-46.7$ ± $165.5$ | 0.10 ± 0.09 | $-0.00010$ ± $0.00081$ | $-52.8$ ± $243.8$ |

Note. If the Na i doublet is blended, the values listed for line 1 are measurements based on the blend, while the values for line 2 are blanked out.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)
Figure 3. Subset of Ca\textsubscript{ii} absorbers: the image is centered on the galaxy position, scaled to focus on the galaxy in each pair. For cases where the QSO is within the image, it is marked with a white arrow. In other cases, scaling the image to show both the galaxy and QSO results in a loss of detail regarding both objects. All objects with an SDSS spectrum are marked with a red square. The galaxy name and redshift are displayed at the top. In the lower left is the image size. Below that is the impact parameter between the quasar and galaxy. The absorption lines detected are shown on the right. The y-axis shows the normalized flux. The middle panel displays the strong line at 3934.77 Å, with the weaker line at 3969.59 Å on the right. Each panel is centered in velocity space on the galaxy redshift. The dashed blue line marks the velocity offset of the line from the host galaxy. The red line marks the normalized continuum.

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

possibly due to a bias between the Ca\textsubscript{ii} and Na\textsubscript{i} samples, where the Ca\textsubscript{ii} systems include greater contributions from Galactic sightlines. While both samples should include contributions from Galactic and extragalactic sightlines, the cut we placed on the Na\textsubscript{i} sample to remove regions contaminated by incomplete Na\textsubscript{i} sky subtraction, and hence, low-velocity systems, may have effectively removed Galactic contributors. Since this cut was not placed on the Ca\textsubscript{ii} sample, it becomes biased toward Galactic absorbers. With this in mind, our Ca\textsubscript{ii} subset could be a mix of Galactic and extragalactic absorbers, weighted more toward Galactic contributions. There are 49 Ca\textsubscript{ii} systems with rEW > 0.3 Å that could be extragalactic in origin. Our Na\textsubscript{i} subset can also be a mix of Galactic and extragalactic systems, weighted more toward extragalactic systems. All of our Na\textsubscript{i} systems have a rEW > 0.5 Å, and thus could be considered extragalactic, based on their strength. There are two Na\textsubscript{i} systems that are resolved and have unusually high rEWs for what has been seen previously, but we have checked for interloping absorption systems and none could be identified.

Figure 7 shows the rEW of our absorbers as a function of SDSS galaxy redshift. We again see the split in rEW between the Ca\textsubscript{ii} and Na\textsubscript{i} absorbers, as well as a separation in redshift. Given the possible velocity overlap between Virgo Cluster galaxies and high-velocity clouds (HVCs; see Section 4.2), if we consider the redshift region $\geq 0.01,$\footnote{This redshift marks the estimate of Virgo’s outer boundary (Binggeli et al. 1993).} we find that the minimum rEW seen in the resulting absorbers is 0.5 Å.

While this cannot rule out extragalactic absorbers having rEW values below $\sim 0.5$ Å, this is consistent with rEW values seen in extragalactic absorbers so far. The large cluster of Ca\textsubscript{ii} systems
with $r_{\text{EW}} \lesssim 0.5$ Å at low redshifts also points to a domination by contributions from Galactic sightlines.

Examples of systems with $r_{\text{EW}} / \sigma_{r_{\text{EW}}} > 3.0$ are shown in Figures 3(c) and (d) for Ca\textsc{ii}, and Figures 4(e), (f), (g), (k), and (n) for Na\textsc{i}.

### 4.2. Selection from LSR Velocity

The absorber catalog contains a large number of low-redshift systems. Since we allowed velocity deviations of up to $\pm 500$ km s$^{-1}$ from the galaxies’ redshifts, it is possible that some of our detections overlap with Ca\textsc{ii} and Na\textsc{i} absorbers in the Milky Way, with absorbers in the Local Group, or with absorbers in the Virgo Cluster. One method of distinguishing Galactic absorbers from extragalactic ones is through an exploration of the $v_{\text{LSR}}$-galactic longitude-galactic latitude parameter space.

Wakker & van Woerden (1991) and Ben Bekhti et al. (2008) have mapped out Galactic HVC complexes around the Milky Way. Figures 2(b) and (e) of Wakker & van Woerden (1991) show $v_{\text{LSR}}$ versus $l$ and $b$, respectively, of HVC’s around the Milky Way. The HVCs are not uniform across the sky. They predominantly lie within two distinct regions. One region of HVCs, with $-500 < v_{\text{LSR}} < -90$ km s$^{-1}$, is located below the galactic plane ($b < 0^\circ$) and at $l < 180^\circ$. Another group of HVCs predominantly lies in the region $l < 180^\circ$, $b > 0^\circ$, with LSR velocities between 90 and 345 km s$^{-1}$. The region of space between $v_{\text{LSR}}$ $\pm$ 90 km s$^{-1}$ is primarily located within the Galactic disk. As most of the HVCs lie at $v_{\text{LSR}} < 345$ km s$^{-1}$, a cut above this limit will select out systems free from HVC contamination. Below this cutoff, one must place tighter constraints on galactic $l$ and $b$, or obtain higher-resolution data to disentangle likely contributions by Galactic gas to any absorber candidates.

In Figures 8 and 9, we show the LSR velocity of the Ca\textsc{ii} K or Na\textsc{i} D2 absorbers as a function of Galactic longitude and latitude along the sightline toward the quasar. Also plotted are lines indicating the $|v_{\text{LSR}}| > 345$ km s$^{-1}$ cutoffs. Most of our absorbers lie within the range that is easily confused with Galactic HVCs. We find that the majority of Ca\textsc{ii} systems
Figure 4. Subset of Na\textsc{i} absorbers: the image marks are the same as in Figure 3. The absorption line is shown in the right panel, centered on the expected position of the 5891.58 Å line from the galaxy redshift. The y-axis shows the normalized flux. The dashed blue line represents the velocity offset of the line from the expected position, or in the case of a blend, the offset as determined across the whole profile. (A color version of this figure is available in the online journal.)

4.3. Selection from Impact Parameter

An alternative to selecting on LSR velocity, one may also wish to select absorbers based on their impact parameter. Figure 10 shows the distribution of absorbers in impact parameter versus $b/r_{\text{Petro}}$ ratio. The striping seen at low Petrosian radii is due to the large search radius (in angular scale) for extremely low-redshift galaxies. Each stripe corresponds to multiple quasar sightlines being associated with one galaxy. As with the prior two selection criteria, we also find a natural division between the Ca\textsc{ii} and Na\textsc{i} systems. Most of the Ca\textsc{ii} systems seen at low Petrosian radii are due to the large search area around low-redshift galaxies picking up Galactic sightlines.

DLAs are an absorber class of immense interest due to their large column densities and the fact that they trace the bulk of the neutral hydrogen content in the universe. Rao et al. (2003) studied the properties of low-redshift DLA galaxies (0.05 < $z$ < 1.0) and found them out to an impact parameter of 38 kpc, with a mean value of 12 kpc (converted to our cosmology). Rao et al. (2011) recently identified a set of host galaxies within the redshift range 0.1–1.0 exhibiting DLA, sub-DLA, and LL absorption. They found a median impact parameter of 17.4 kpc for the DLAs increasing to 36.4 kpc for the LL systems, with the full range extending out to 100 kpc. Considering a mean impact parameter of 12 kpc, there are three systems found at small impact parameters that would be of interest. For an impact parameter of 38 kpc, covering the entire range of DLA...
detections, there are 17 sightlines (nine galaxies) that are within the range where DLAs have been found.

From H\textsc{i} maps of the Milky Way, as well as many nearby galaxies, we know the neutral hydrogen extent of a galaxy can extend many times past the optical radius of the galaxy. Cayatte et al. (1994) and Broeils & Rhee (1997) have shown that neutral hydrogen can extend to at least twice the optical radius for spirals, and as much as 4–5 times in dwarf galaxies (Swaters et al. 2002; de Blok et al. 1996). It may be useful then to select systems based on the ratio of the impact parameter to the optical radius of the galaxy. Here we use the r-band Petrosian radius as a proxy for the radius of the galaxy. In some cases the Petrosian radius may miss extended light from the galaxy (Stoughton et al. 2002), so this radius can be thought of as a lower limit to the optical radius of the galaxy. With this sample, we find seven galaxies that lie within 5 times the Petrosian radius, three of which lie within the optical disk of the galaxy ($b/r_{\text{Petro}} < 1$).

For extragalactic systems, the median impact parameter seen for Ca\textsc{ii} and Na\textsc{i} is $\sim 15$ kpc and $\sim 14$ kpc, respectively (Womble et al. 1990, 1992; Womble 1993; Zych et al. 2007; Boksenberg & Sargent 1978; Boksenberg et al. 1980; Blades et al. 1981; Bergeron et al. 1987; Bowen et al. 1991; Junkkarinen & Barlow 1994). Considering this area of parameter space in Figure 10, we find that our Ca\textsc{ii} and Na\textsc{i} absorbers are located close in to galaxies with Petrosian radii $\sim 10$ kpc, the median value seen in the SDSS SpecPhoto sample we draw from. These systems then are most likely extragalactic. Examples of systems with $b/r_{\text{Petro}} < 5$ are shown in Figures 3(a), (c), and (d), for Ca\textsc{ii} and Figures 4(a), (e), (f), (g), and (h) for Na\textsc{i}.

4.4. Notes on Individual Absorbers

Here we provide a few notes on individual absorbers from our absorber list.

1. SDSS J102703.86+283721.9. This galaxy spectrum has an SDSS redshift of 0.00020 $\pm$ 0.00016, classified manually with high confidence, and has a z warning of “Absorption lines inconsistent.” The galaxy is not associated with NGC 3245A, which has a redshift of 0.00441 $\pm$ 0.000008. Within the 100 kpc search radius, seven quasar sightlines were identified with Ca\textsc{ii} absorption, and one sightline with Na\textsc{i} absorption. However, the uncertainty of this galaxy’s redshift may have resulted in erroneous matches and calls into question the apparent association of this galaxy with these sightlines. We exclude this galaxy from Figures 10 and 11.

2. SDSS J113420.50-033525.4. This galaxy has an SDSS redshift of 0.00008 $\pm$ 0.00007 at high confidence. Twelve
quasar sightlines were identified with Ca\textsc{ii} absorption and four sightlines with Na\textsc{i} absorption. Upon viewing the spectrum for this galaxy, there appear to be several absorption lines indicating a stellar spectrum that corroborates the reported SDSS redshift. Light from a star may have entered the fiber when the spectrum was taken. This galaxy is also identified in the 2dFGRS as N171Z241, with a reported redshift of \(0.1151 \pm 0.0003\). The spectrum for N171Z241 visually does not agree with the spectrum from SDSS. Although the sightlines discovered through this association are real detections of Na\textsc{i} or Ca\textsc{ii}, this discrepancy in the galaxy redshift leaves some doubt as to the associations between this galaxy with these quasar sightlines. We exclude this galaxy from Figures 10 and 11.

3. **SDSS J114313.05+193646.9.** The galaxy lies at a redshift of \(0.02085 \pm 0.00009\). There is one quasar (SDSS J114323.71+193448.0) located 81 kpc from the galaxy position. This galaxy is in the cluster A1367 (as indicated in the NASA Extragalactic Database), along with SDSS J114318.07+193401.3 and SDSS J114336.98+193616.7. As these three galaxies intersect the same sightline to the quasar SDSS J114323.71+193448.0, it is unknown which galaxy is responsible for the absorbing gas, or if the gas is intracluster material.

4. **SDSS J114318.07+193401.3.** The galaxy lies at a redshift of \(0.02262 \pm 0.00015\) and is located 42 kpc from the quasar. This galaxy is in the cluster A1367.

5. **SDSS J114336.98+193616.7.** The galaxy lies at a redshift of \(0.02201 \pm 0.00019\) and is located 92 kpc from the quasar. This galaxy is in the cluster A1367.

6. **SDSS J150400.94+240437.1.** The galaxy lies at a redshift of \(0.06894 \pm 0.00010\). The quasar, SDSS J150359.48+240532.8, is located 78 kpc from the galaxy position. This galaxy is possibly in a group with SDSS J150403.17+240559.8. The two galaxies intersect the same sightline to the quasar SDSS J150359.48+240532.8, so it is unclear which galaxy is responsible for the absorber, or whether the absorption is coming from intragroup material.

7. **SDSS J150403.17+240559.8.** The galaxy lies at a redshift of \(0.06997 \pm 0.00019\) and is located 77 kpc from the quasar. This galaxy is in a group with SDSS J150400.94+240437.1.

5. **CHARACTERISTICS OF EXTRAGALACTIC ABSORBER GALAXIES**

In the previous section, we described various ways to differentiate Galactic absorbers from extragalactic ones. While the absorbers in the Galactic disk or in HVCs are interesting in and
of themselves, our original purpose was to identify Ca\textsc{ii} and Na\textsc{i} systems due to, as well as residing close to, nearby external galaxies.

5.1. Emission-selected Systems

Considering the criteria $b/r_{\text{Petro}} < 5$, $|v_{\text{LSR}}| \geq 345$ km s$^{-1}$, and $r_{\text{EW}}/\sigma_{r_{\text{EW}}} \geq 3$, there are four absorption systems that satisfy all three conditions. There are two systems detected in Ca\textsc{ii}, one of which was also detected in Na\textsc{i}, and two detected in Na\textsc{i}. These systems are SDSS J141745.62+162509.3 (Figure 3(c)), SDSS J155752.51+342142.8 (Figures 3(d) and 5(b)), SDSS J122037.63+283803.3 (Figure 4(f)), and SDSS J140613.22+153035.5 (Figure 4(g)). These four systems have a mean $g-r$ color of 0.6 $\pm$ 0.2 and a mean $M_r$ of $-20.1 \pm 1.8$. Adopting an 0.1$^\text{r}$-band $L^*_r$ of $-21.28$ (Blanton et al. 2003), we find an average $L^*_{r,0.1}$ of $0.8 \pm 0.4 L_\odot$. All colors and magnitudes were calculated using Kcorrect v4.2 (Blanton & Roweis 2007) and bandshifted to $z = 0.1$, indicated with the 0.1 superscript. The mean impact parameter of the four systems is $13.6 \pm 9.8$ kpc, while the mean $b/r_{\text{Petro}}$ ratio is $1.0 \pm 0.6$.

Figure 11 shows the galaxy rest-frame $g - r$ color versus the SDSS absolute $r$-band magnitude, bandshifted to 0.1. As one galaxy may have multiple quasar sightlines associated with it, we plot only the 22 unique galaxies. The two galaxies with uncertain redshifts have been excluded from the plot. Adopting a red/blue color separation from Yan et al. (2006), we find 2 red galaxies and 20 blue galaxies. In both the red and blue samples we find a mix of galaxies with Ca\textsc{ii} and Na\textsc{i} sightlines. Our four extragalactic Ca\textsc{ii} and Na\textsc{i} systems lie in the lower right portion of the figure, and would be classified as blue, $\sim L^*_r$ galaxies.

5.2. Comparison with Absorption-selected Systems

Zych et al. (2007) selected Ca\textsc{ii} systems from the SDSS using the more traditional approach of identifying the absorption line in the quasar spectrum first, with follow-up imaging to locate the associated host galaxy. They identified five Ca\textsc{ii} absorption systems in this manner and found them primarily located in blue, $\sim L^*_r$ star-forming galaxies with the Ca\textsc{ii} located at small impact parameters (11.6 $\pm$ 8.4 kpc). Of the five pairs reported by Zych et al. (2007), one is found in our sample, the galaxy SDSS J111849.76-002109.9 (Figures 3(a) and 4(a)). The Ca\textsc{ii} equivalent width we measure for SDSS J111849.76-002109.9 is $3^\text{Mean value calculated using data from their Table 5.}$
consistent with that reported in Zych et al. (2007). We also detect Na\textsc{i} from this galaxy. This galaxy, along with one additional Na\textsc{i} system, is included in our list of extragalactic absorbers if we relax the condition on absorption line significance. Of the other four galaxies in Zych’s sample, one galaxy was detected within the fiber of the quasar and the other three do not have spectroscopy in SDSS, and thus are not in our sample of DR7 galaxies.

Figure 4. (Continued)
It is interesting to note that there is a general agreement in the overall galaxy properties between our emission-selected absorbers and their absorption-selected absorbers. Both methods returned blue, $\sim L^*$ galaxies.

6. SUMMARY

We have searched the SDSS-DR7 for low-redshift galaxy–quasar pairs, where the quasar is projected within 100 kpc of the galaxy, and found 97,489 galaxy/quasar pairs from a sample of 105,783 spectroscopic quasars and 798,948 spectroscopic galaxies. From this list of pairs, we searched for Ca\textsc{ii} and Na\textsc{i} absorbers, using an automated process followed by visual inspection, and found 108 absorption-line systems, 92 of which are Ca\textsc{ii}, 16 of which are Na\textsc{i}, along with $\sim$5600 questionable candidate features. Within our sample of 108 absorbers, we find many sightlines that coincide with sightlines through the Galactic disk or through HVC complexes in our halo.

Our goal was to identify Ca\textsc{ii} and Na\textsc{i} systems that lie within or near known low-redshift galaxies. To this end, we placed constraints on the absorber line significance ($r_{EW}/\sigma_{EW} \geq 3$), on the LSR velocity ($|v_{LSR}| \geq 345$ km s$^{-1}$), and on the ratio of impact parameter to $r$-band Petrosian radius ($b/r_{Petro} < 5$). We find four bona fide extragalactic galaxies with Ca\textsc{ii} and/or Na\textsc{i} absorption detected along sightlines to nearby quasars. One is detected in Ca\textsc{ii} only, two are detected in Na\textsc{i} only, and one is detected in both Ca\textsc{ii} and Na\textsc{i}. These absorption systems arise in blue, $\sim L^*$ galaxies. With the absorbers’ impact parameters within the range seen for low-redshift DLAs, these systems would be good candidates for follow-up H\textsc{i} 21 cm or UV observations to determine neutral hydrogen column densities.

Future work, forthcoming in Paper II, will consist of a statistical exploration of different galaxy properties for the Ca\textsc{ii}
Figure 6. Plot of the significance ($rEW/\sigma_{rEW}$) of the Ca $\text{II}$ K or Na $\text{I}$ D2 lines vs. the rest equivalent width, for the list of absorbers. Open green squares refer to the Na $\text{I}$ D2 line. Filled green squares refer to blended Na $\text{I}$ systems. Open orange diamonds refer to the Ca $\text{II}$ K line. Symbols connected by a dotted line indicate absorbers with both Na $\text{I}$ and Ca $\text{II}$ detected. (A color version of this figure is available in the online journal.)

Figure 7. Plot of absorber rest equivalent width vs. SDSS galaxy redshift, for the list of absorbers. Symbols are the same as in Figure 6. The dashed vertical line separates absorbers with $z \geq 0.01$. This redshift separator was chosen as a guide to separate absorbers due to Galactic sightlines and Virgo Cluster galaxies from “true” extragalactic systems, based on the outer boundary to the Virgo Cluster (Binggeli et al. 1993). (A color version of this figure is available in the online journal.)

Figure 8. Plot of the LSR velocity of the Ca $\text{II}$ K or Na $\text{I}$ D2 line (or Na $\text{I}$ doublet, if blended) against the Galactic latitude along the quasar sightline, for the list of absorbers. The two solid lines at $\pm 345$ km s$^{-1}$ indicate the velocity cutoff separating Galactic high-velocity cloud complexes from extragalactic absorbers (Wakker & van Woerden 1991). There are several pairs with $v_{\text{LSR}} > 600$ km s$^{-1}$ not shown on the plot. (A color version of this figure is available in the online journal.)

Figure 9. Plot of the Galactic latitude against the LSR velocity of the Ca $\text{II}$ K or Na $\text{I}$ D2 line (or Na $\text{I}$ doublet, if blended) along the quasar sightline, for the list of absorbers. The two solid lines at $\pm 345$ km s$^{-1}$ indicate the velocity cutoff separating Galactic high-velocity cloud complexes from extragalactic absorbers (Wakker & van Woerden 1991). There are several pairs with $v_{\text{LSR}} > 600$ km s$^{-1}$ not shown on the plot. (A color version of this figure is available in the online journal.)
and NaI absorbers and non-absorbing systems via stacking techniques. Another area of future work will be to compare the emission line properties of the absorbing galaxies in our sample with those from the absorption-selected samples.

Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the European Southern Observatory, the National Aeronautics and Space Administration.

We acknowledge the help of Matt Chornick, a University of Portsmouth physics undergraduate researcher. We also thank Jeff Newman and Sandhya Rao for their help with some of the spectra.

We acknowledge the usage of the HyperLeda database.

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Figure 10. Plot of quasar impact parameter vs. SDSS r-band Petrosian radius, for the list of absorbers. The line at 38 kpc represents the impact parameter out to which low-z DLAs have been found by Rao et al. (2003). The three curved lines indicate the ratio of the impact parameter to the r-band Petrosian radius (1, 2, and 5, respectively). The vertical striping apparent in the data at low Petrosian radii is a result of multiple QSO sightlines being found within the 100 kpc search radius of a low-redshift galaxy. The absorbers marked with “E” and “Z” represent the four extragalactic absorbers, and the Zych absorber, discussed in Section 5.

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

Figure 11. Plot of galaxy g−r color vs. galaxy SDSS r-band absolute magnitude, for the list of absorbers. The purple line corresponds to the average of the red/blue galaxy cutoffs from Yan et al. (2006). Applying the cut divides our sample into 5 red galaxies and 19 blue galaxies. Galaxies between the red and blue regions are more ambiguous in their classification. The absorbers marked with “E” and “Z” represent the four extragalactic absorbers, and the Zych absorber, discussed in Section 5. All absolute magnitudes were calculated using distances derived from heliocentric redshifts, with the exception of the four Virgo Cluster galaxies. For those galaxies, distances were derived from redshifts corrected for the Local Group infall toward Virgo, taken from HyperLeda (Paturel et al. 2003).

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

This research has made use of NASA’s Astrophysics Data System and of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

We acknowledge the help of Matt Chornick, a University of Pittsburgh physics undergraduate researcher. We also thank Jeff Newman and Sandhya Rao for their help with some of the spectra.

We acknowledge the usage of the HyperLeda database.
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