Redshifts of galaxies close to bright QSO lines of sight

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ABSTRACT

To expand the known number of low-redshift galaxies which lie close to bright (V < 17.2) QSO lines of sight, we have identified 24 galaxies within 11 arcmins of nine QSOs which have been observed with the Hubble Space Telescope (HST). Galaxies are found between redshifts of 0.0114 — 0.145 and lie between 39 — 749 h−1 kpc from QSO sightlines. Knowing the redshifts of these galaxies has already proved important in understanding results from HST programmes designed to search for UV absorption lines from low-redshift galaxies, and will enable future observations to probe the halos of these galaxies in detail.

Key words: galaxies:distances and redshifts — quasars: absorption lines

1 INTRODUCTION

Finding low-redshift galaxies close to high-redshift QSOs on the plane of the sky is important for probing the interstellar medium (ISM) of the disks and halos of present epoch galaxies, since the light of the background QSO may be absorbed by gas along the line of sight. Both optical and ultraviolet (UV) absorption lines which arise in nearby galaxies have been studied previously [see Bowen, Blades & Pettini (1995; hereafter BBP) and refs therein]; in particular, the detection of UV lines is important not only for understanding the physics of galaxy ISMs other than that of the Milky Way, but because these are the same lines observed out to redshifts of ~ 4 in QSO spectra obtained from ground-based observatories. The intention is to find low redshift analogs to the high redshift systems, which will enable us to understand the origin and evolution of absorbing gas from the earliest epochs.

Previous compilations of QSO-galaxy pairs (Monk et al. 1986; Burbidge et al. 1990) have collated well known cases of QSO-galaxy pairs and added additional data where available. Often though, not listed in these catalogs are other (fainter) galaxies closer to the QSO sightline which can also be probed once their redshifts have been determined. More seriously, searching for UV absorption lines from nearby galaxies requires the use of the Hubble Space Telescope (HST). Unfortunately, the most severe constraint in studying galaxies in this way is the small number of QSOs which are bright enough (particularly in the far UV where the satellite’s spectrographs are less sensitive) and close enough to a galaxy to be of interest. Hence finding galaxies near to UV bright QSOs is extremely important.

In this paper we present the redshifts of 26 objects which lie within 11 arcmins of nine QSO lines of sight. Three QSOs were originally observed with HST as part of BBP’s Mg II survey; the field around these QSOs clearly showed galaxies other than those which were being probed, but which had no known redshifts. The lines of sight to two QSOs were also discussed by Bowen, Blades, & Pettini (1996) in a HST Archival programme designed to search for Lyα absorption from low-redshift galaxies. The remaining QSOs were observed as part of the HST Faint Object Spectrograph Qasar Absorption System Snapshot Survey (‘AbSnap’) programme (Bowen et al. 1994; Tytler et al. 1996). A subsample of the AbSnap target fields showed numerous faint galaxies close to the QSO lines of sight in the digitised images collated by Bowen et al. (1994). These galaxies are interesting because although the exposure times for the AbSnap QSOs were short, the QSOs are some of the brightest available.

2 OBSERVATIONS

Galaxies were identified from 16.7 arcmins square images extracted from the STScI Digitized Sky Survey (DSS), although the galaxies nearest a QSO sightline were selected preferentially for spectroscopic follow up. Magnitudes of the galaxies could not be calculated due to the saturation of the...
digitised images at magnitudes of $V \leq 15$ and a lack of photometry of any fainter objects from which to calculate a reliable photometric zero point. The $V$ magnitude limit for these images is $\sim 19.5$ (Golombeck 1993), so all galaxies are brighter than this limit.

Reproduction of parts of the DSS images of interest are reproduced in Figures 1–5. Table 1 lists the QSO fields studied (col. 1), and the QSO’s redshift and $V$ magnitude taken from Véron-Cetty & Véron (1993) (cols. 3 and 2). The positions of galaxies for which spectra were obtained are given in column 5. Galaxies labelled in Figures 1–5 are identified in column 4, while separations between QSO and galaxy on the plane of the sky in arcmins, $\rho$, are given in column 6.

Spectroscopic observations of candidate galaxies were made using GOLDCAM and a FORD chip on the KPNO 2.1 m telescope between 2 – 6 September 1993. A 2 arcsec slit aligned north-south was used with the 300 lines mm$^{-1}$ grating blazed at 6750 Å to obtain galaxy spectra with a resolution of 7.2 Å. The total wavelength range covered was $\sim 3800 – 7500$ Å. Where possible, galaxy redshifts were measured by cross-correlating the galaxy spectra with template spectra of two radial velocity standards, HD 171391 and HD 182572 using the fxcor routine in IRAF. For some galaxies, only emission lines of H$\alpha$, [N II], and [S II] were visible, and for these objects redshifts were measured by fitting gaussians to the emission lines. The resulting redshifts are given in column 7 of Table 1—a blank entry means that a spectrum was obtained of the object but no redshift could be measured due to the low signal-to-noise of the spectrum. The error in the redshifts is $\Delta z \approx \pm 0.0003$. The corresponding distance of the galaxy from the QSO sightline, $\rho$, is given in column 8 in units of $h^{-1}$ kpc, where $h = H_0/100$, $H_0$ is the Hubble constant, and $q_0 = 0$.

3 RESULTS

Below, we outline the results for each of the fields studied, and draw attention to what is already known about the absorbing properties of some of the galaxies. For each sightline studied, we have also searched the NASA Extragalactic Database (NED) for any other known low-redshift galaxies within 0.5 $h^{-1}$ Mpc from the QSO line of sight. No galaxies are found in this way unless otherwise stated in §3.1–3.9 below.

3.1 Q0026+1259

Galaxy G4 in Figure 1b (G0026+1304) was originally identified by Monk et al. (1986) to be at a redshift of $z = 0.0058$, placing it only 28 $h^{-1}$ kpc from the QSO line of sight. However, H$\alpha$, [N II] and [S II] are clearly identified at a redshift of $z = 0.0394$. This means that the separation between galaxy and QSO sightline is 158 $h^{-1}$ kpc. No Ly$\alpha$ absorption is found from G4 to an equivalent width limit of 0.65 Å (Bowen, Blades & Pettini 1996). G5 (G0027+1302) is an irregularly shaped galaxy at the same redshift as the QSO, $z = 0.1453$, 749 $h^{-1}$ kpc from the QSO line of sight.

3.2 Q0100+0205

We have measured the redshift of galaxy G12 in Figure 1b to be $z = 0.0444$. The galaxy is 8.92 arcmins from the QSO line of sight which corresponds to $\rho = 324 h^{-1}$ kpc. This galaxy is not the closest known identified object however: galaxy G11 is UGC0656 (at RA = 01 : 01 : 10.48 DEC = 02 : 00 : 54, a more accurate position than that given in the NED). Its position corresponds to a separation of 9.0 arcmins from the QSO line of sight, or $\rho' = 140.6 h^{-1}$ kpc at a redshift of $z = 0.01841$. Even closer, however, is the dwarf irregular galaxy, IC 1613. The sightline to the QSO passes $\sim 28.5$ arcmins from the galaxy; assuming a distance of $\sim 0.7$ Mpc to IC 1613 (Huterer et al. 1996, and refs therein) this separation corresponds to 5.8 kpc. The sightline to Q0100+0205 will therefore provide a valuable probe of the outer regions of the interstellar medium of a dwarf galaxy for future $HST$ observations.

3.3 Q0122–0021

This QSO line of sight passes 2 degrees, or 1.8 $h^{-1}$ Mpc, from the center of Abell 194 (Chapman et al. 1988). There are three galaxies at the cluster velocity which lie within 500 $h^{-1}$ kpc of the QSO sightline, UGC 0998, CGCG 385–115, and CGCG 385–141, at separations of 13.9, 20.5 and 22.4 arcmins, respectively, which correspond to 201, 326, and 353 $h^{-1}$ kpc at the galaxies’ redshifts. The galaxy whose redshift we have measured, labelled G1 in Figure 3a, is at a velocity of $cz = 6386$ km s$^{-1}$. The velocity dispersion of the Abell 194 is $\sim 450$ km s$^{-1}$, which means that if G1 is a member of the cluster, its velocity is $2\sigma$ away from the cluster’s systemic velocity.

Whether or not G1 is a member of Abell 194, it lies 2.51 arcmins from the QSO line of sight, which corresponds to only 44.8 $h^{-1}$ kpc. There are three other galaxies which lie between Abell 194 and the Milky Way and which are within 0.5 $h^{-1}$ Mpc of the QSO line of sight: UGC 1011, UM 323, and UGC 0931, which, with velocities of 1923, 1799, and 1948 km s$^{-1}$, and separations of 26.4, 38.1 and 49.3 arcmins, pass 146, 198 and 277 $h^{-1}$ kpc from the QSO sightline.

3.4 Q0219+4248

The galaxies close to the line of sight of Q0219+4248 previously identified by Arp (1968) are members of Abell 347. Galaxy G1 labelled in Figure 2a is galaxy D measured by Arp, and our redshift of $z = 0.0198$ measured from absorption lines agrees well with his value of $z = 0.0200$. G5 is Arp’s Galaxy C, and we measure $z = 0.0219$, identical to Arp’s original value. More details on the environment of the galaxies, and the search for Mg II along the line of sight, can be found in BBP.

In addition to confirming the redshifts of G1 and G5, we have also obtained redshifts of 6 other galaxies. G7 and G8 are probably also members of Abell 347 with $z = 0.0230$ and $z = 0.0184$ respectively. However, we have found three galaxies (G2, G4 and G6) with redshifts of $z \approx 0.067$, all within 300 $h^{-1}$ kpc of the sightline to Q0219+4248. It therefore seems likely that the QSO line of sight intercepts a second cluster behind Abell 347, and there is already ev-
**Figure 1.** Portions of the ‘Quick-V’ POSS plates extracted from the Digitised Sky Survey (DSS) images available at STScI, showing the galaxies close to (a) Q0026+1259 (top) and (b) Q0100+0205 (bottom) for which spectra were obtained. North East is to the top left for all images. Scales are different for each image, and are shown in the bottom right corner.
Figure 2. Same as Figure 1, for (a) Q0122–0021 (top) and (b) Q0219+4248 (bottom).
find few galaxies with known redshifts close to the line of incidence for the existence of \lyalpha absorption at this cluster velocity (Bowen, Blades & Pettini 1996).

### 3.5 Q1544+4855

G1 (G1543+4856) and G2 (G1543+4854) were originally identified by Monk et al. (1986) although no redshifts were available. We have confirmed the redshifts measured by Bowen et al. (1991), and in addition, we have shown that two of the objects close on the plane of the sky are stars (Figure 3a). The existence of Mg II absorption at the velocity of these two galaxies has been discussed in detail by BBP, who postulate that the absorption arises from gas distributed away from the galaxies as a result of galaxy-galaxy interactions. An R-band CCD image of the field can also be found in BBP. G5 is actually at a lower redshift than the G1/G2 pair, at z = 0.0382, so although it is nearly twice as far on the sky as G2, the separation to the line of sight is only 75 \( h^{-1} \) kpc.

### 3.6 Q1631+3930

We find only one low-redshift galaxy clearly visible near Q1631+3930. G4 in Figure 3b is 9.57 arcmins from the QSO sightline, and has a redshift of 0.0291. The separation therefore corresponds to 232.6 \( h^{-1} \) kpc. A search in the NED finds few galaxies with known redshifts close to the line of sight; only IC 4610 with \( cz = 9260 \) km s\(^{-1}\) lies within 0.5 \( h^{-1} \) Mpc, 12.7 arcmins, or 339 \( h^{-1} \) kpc away.

### 3.7 Q1701+6102

The field around Q1701+6102 is dominated by NGC 6292, labelled G4 in Figure 4 which lies 7.43 arcmins away from the QSO line of sight. We measure its velocity to be \( cz = 3418 \) km s\(^{-1}\), which places it 72.6 \( h^{-1} \) km s\(^{-1}\) from the QSO sightline. This redshift measurement is at odds with that measured optically by Bottinelli et al (1993; listed in the NED) who found \( cz = 3805 \) km s\(^{-1}\). However, our redshift, measured from strong H\(\alpha\), [N II], and [S II] lines, agrees well with an earlier 21 cm H I measurement by Richter and Huchtmeier (1991), who found \( cz = 3407 \) km s\(^{-1}\). Closer to the QSO on the plane of the sky is G1, which is only 1.04 arcmins away, an irregularly shaped galaxy whose redshift we find to be 0.0659, which places it only 54 \( h^{-1} \) kpc from the QSO line of sight.

The closest galaxies we identify to the QSO line of sight are labelled G2 and G3 in Figure 4. The spectra are of low signal to noise, but a redshift for G3 of \( z = 0.0541 \) is clear from the identification of H\(\alpha\), [N II], and [S II] emission lines. G2 is even fainter, and few lines are discernable in a spectrum with even poorer signal-to-noise than G3. However, there is an emission line at the same wavelength as the H\(\alpha\) emission line in the spectrum of G3. We therefore tentatively

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**Table 1. New Redshifts of galaxies close to HST target QSOs**

| QSO (1) | V (2) | \( z_{\text{QSO}} \) (3) | Galaxy ID | Galaxy RA & DEC (1950.0) | \( \rho \) (4) | \( z \) (5) | \( \rho' \) (h\(^{-1}\) kpc) |
|---------|-------|--------------------------|-----------|---------------------------|------------|--------|-----------------|
| Q0026+1259 | 15.4 | 0.142 | G4 | 00 26 39.68 | 13 04 21.2 | 4.88 | 0.0394 | 158.3 |
| Q1000+0305 | 16.4 | 0.394 | G12 | 01 00 15.20 | 02 05 17.0 | 8.92 | 0.0444 | 323.6 |
| Q0122-0021 | 16.7 | 1.070 | G1 | 01 22 55.43 | -00 19 02.4 | 2.51 | 0.0213 | 45.2 |
| Q0219+4248 | 15.2 | 0.444 | G1\(^a\) | 02 19 21.60 | 42 50 16.8 | 2.37 | 0.0198 | 39.7 |
| G2 | 02 19 18.32 | 42 47 09.2 | 2.53 | 0.0667 | 133.6 |
| G3 | 02 19 40.76 | 42 50 10.2 | 2.59 | ... | ... |
| G4 | 02 19 41.18 | 42 45 37.6 | 3.52 | 0.0674 | 187.7 |
| G5\(^b\) | 02 19 48.91 | 42 47 04.4 | 3.74 | 0.0219 | 69.1 |
| G6 | 02 19 48.37 | 42 45 15.7 | 4.66 | 0.0675 | 248.8 |
| G7 | 02 19 54.13 | 42 41 08.1 | 8.58 | 0.0230 | 166.3 |
| G8 | 02 19 39.85 | 42 53 10.9 | 5.03 | 0.0184 | 78.5 |
| Q1544+4855 | 16.5 | 0.400 | G1 | 15 43 56.89 | 48 56 00.0 | 0.76 | 0.0746 | 44.4 |
| G2 | 15 43 56.24 | 48 54 11.7 | 1.40 | 0.0753 | 82.5 |
| G5 | 15 43 49.72 | 48 57 06.6 | 2.38 | 0.0382 | 75.0 |
| G7 | 15 43 48.96 | 48 56 33.1 | 2.13 | 0.0 | ... |
| G8 | 15 43 57.61 | 48 54 32.3 | 0.99 | 0.0 | ... |
| Q1631+3930 | 16.0 | 1.023 | G1 | 16 30 43.70 | 39 37 21.3 | 9.57 | 0.0291 | 232.6 |
| Q1701+6102 | 17.0 | 0.164 | G1 | 17 01 31.22 | 61 01 59.8 | 1.04 | 0.0659 | 54.3 |
| G2 | 17 01 32.08 | 61 03 22.7 | 0.47 | 0.0451 | 20.5 |
| G3 | 17 01 32.12 | 61 03 33.8 | 0.63 | 0.0451 | 27.5 |
| G4\(^c\) | 17 02 27.05 | 61 06 44.1 | 7.43 | 0.0114 | 72.6 |
| Q2215-0347 | 17.2 | 0.241 | G1 | 22 15 12.29 | -03 47 27.5 | 0.23 | ... | ... |
| G4 | 22 14 57.85 | -03 48 20.1 | 3.64 | 0.0615 | 178.6 |
| G5 | 22 14 59.64 | -03 50 03.9 | 3.94 | ... | ... |
| G6 | 22 14 44.01 | -03 45 47.8 | 7.29 | 0.0560 | 322.9 |
| G7 | 22 14 40.83 | -03 54 43.3 | 10.53 | 0.0568 | 480.3 |
| G10 | 22 14 39.13 | -03 54 19.3 | 10.59 | 0.0574 | 487.7 |
| Q2349-0125 | 15.3 | 0.174 | G4 | 23 49 08.27 | -01 17 44.7 | 8.90 | 0.0385 | 282.4 |

\(^a\) UGC 1832; \(^b\) UGC 1837; \(^c\) NGC 6292
Figure 3. Same as Figure 1, for (a) Q1544+4855 (top) and (b) Q1631+3930 (bottom).
Figure 4. Same as Figure 1, for (a) Q1701+6103 (top) and (b) Q2215–0347 (bottom).
Figure 5. Same as Figure 1, for Q2349−0125.
conclude that G2 and G3 are a pair of galaxies at the same redshift, $z = 0.0541$.

This field is also of interest because of the proximity of Q1701+6102 to another QSO, Q1704+6048 ($\approx 3C$ 351), 23 arcmins away. Bowen, Blades and Pettini (1996) searched for Lyα absorption from five galaxies lying within 124 – 270 $h^{-1}$ kpc of the QSO line of sight, but found none to 3σ equivalent width limits of 0.32 Å. Four of these galaxies also lie within 500 $h^{-1}$ kpc of Q1701+6102, and although their separations from the sightline are larger, 359 – 408 $h^{-1}$ kpc, this sightline may prove useful in determining whether Lyα absorbing gas is distributed only sparsely around groups of galaxies.

### 3.8 Q2215 – 0347

The field around Q2215 – 0347 shows many bright galaxies, two of which, labelled G4 and G7 in Figure 3b, show signs of tidal disturbances, at least in the DDS image. If the galaxies are disturbed, it is unlikely that they are interacting with each other, since G4 has a redshift of 0.0615, while G7 has a redshift of 0.0568, $\sim 1300$ km s$^{-1}$ apart. Figure 3b shows that there are many other galaxies in the field, for which we were able to measure the redshifts of two, G6 and G10. Both have redshifts close to G7, but that of G10 is based on a $a$ priori knowledge of the redshifts of the other galaxies in the field and the measurement of Na I alone, close to that predicted from the redshifts of the other galaxies. Its redshift is therefore highly uncertain and is labelled as such in Table 1.

The NED lists only one other galaxy within 0.5 $h^{-1}$ Mpc of Q2215–0347, that of MCG-01-56-005, 15.7 arcmins on the plane of the sky, or 221 $h^{-1}$ kpc at the galaxy’s velocity of 4969 km s$^{-1}$.

### 3.9 Q2349 – 0125

We find only one bright galaxy close to the sightline of Q2349–0125, labelled G4 in Figure 4. This galaxy lies 8.90 arcmins away and has a redshift of 0.0385, which means that it passes 282 $h^{-1}$ kpc from the QSO line of sight.

### 4 SUMMARY

We have presented new redshifts for 26 objects which lie close to nine QSO lines of sight, 24 of which are galaxies. The galaxies span a redshift range of 0.0114 – 0.145 and lie 39 – 749 $h^{-1}$ kpc from the QSO line of sight, although most have $z < 0.1$ and are found within several hundred $h^{-1}$ kpc of the sightline, the goal originally set for this programme. The QSOs themselves have V-band magnitudes of 15.4 – 17.2, and are therefore excellent sources with which to probe the intervening galaxies with HST; several have already been successfully utilized to search for Mg II or Lyα absorption, and it is hoped that further observations of all the QSOs will yield valuable insights into the nature of galaxy disks and halos.

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