A search for high-redshift quasars among GB/FIRST flat-spectrum radio sources

I. M. Hook,1*† R. H. Becker,2† R. G. McMahon3† and R. L. White4†

1Astronomy Department, University of California, Berkeley, CA 94720, USA
2University of California at Davis, Davis, CA 95616, USA
3Institute of Astronomy, Madingley Road, Cambridge CB3 0HA
4Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

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ABSTRACT

We present the method and first results of a survey for high-redshift (z > 3) radio-loud quasars, which is based on optical identifications of 2902 flat-spectrum radio sources with S_{5 GHz} ≥ 25 mJy. The radio sample was defined over a 1600 deg^2 region using the 5-GHz Green Bank survey and the 1.4-GHz VLA FIRST survey. 560 sources were identified to a limit of E = 19.5 on APM scans of POSS-I plates, and 337 of these optical counterparts are unresolved. From these a complete sample of 73 sources for spectroscopic follow-up was defined based on criteria of red (O - E ≥ 1.2) optical colour. We have obtained spectra for 36 of these, and an additional 14 have redshifts in the literature, thus 70 per cent of the spectroscopic sample is completed. Six objects in the sample were found to be radio-loud quasars with z > 3, of which two were previously known. The efficiency of the spectroscopic phase of the survey is therefore about 1 in 9, whereas without the colour selection criterion the efficiency would have been 1 in ~40. The six z > 3 quasars were found in an effective area of 1100 deg^2, implying a surface density of one flat-spectrum z > 3 radio-loud quasar per 190 deg^2 to limits of E = 19.5 and S_{5 GHz} ≥ 25mJy. This survey has also produced the first known radio-loud BAL quasar, 1556+3517 with z = 1.48, which has been reported in an earlier paper. This object has a redder optical colour (O - E = 2.56) than all the z > 3 quasars found in this survey to date. In addition, we have obtained spectra of 22 GB/FIRST sources that are not part of the complete sample. We give positions, E (red) magnitudes, O - E colours, radio fluxes, radio spectral indices and redshifts where possible for objects for which we have obtained spectra. We give spectra and finding charts for the z > 3 quasars.

Key words: quasars: general – radio continuum: galaxies.

1 INTRODUCTION

We have begun a search for high-redshift quasars selected using the VLA FIRST survey (Becker, White & Helfand 1995). The aim of this work is to extend recent searches for radio-loud high-redshift quasars (e.g. Hook et al. 1995, 1996; Shaver et al. 1996; Hook & McMahon 1998) fainter in radio flux density by a factor of ~10, and, ultimately, to use the new sample to constrain the faint end of the radio quasar luminosity function at high redshift. In addition, the sample can be used to provide an unbiased sample of damped absorption systems, which can then be used to study galaxy evolution at high redshift.

Whilst radio-loud quasars are only a small subset of the quasar population, radio-loud quasar samples are less prone to selection effects than are optical samples, since radio emission is unaffected by either intrinsic or extrinsic absorption due to dust. Fall & Pei (1993) discuss how dust within intervening galaxies may affect the observed evolution in optically selected samples of quasars.

Our survey technique involves optical identification of a large number of radio sources, followed by selection of the optically red, unresolved objects. The technique is similar to that used by Hook et al. (1995, 1996) to find ~30 z > 3 quasars at higher radio flux densities than covered in the current survey, and complements the FIRST Bright Quasar Sample (FBQS: Gregg et al. 1996).

The radio data are described in Section 2 of this paper and the optical identification of the radio sample and selection of the spectroscopic sample are described in Section 3. The spectroscopic observations are described in Section 4, and the results are presented in Section 5. Finally, tables of redshifts, and optical and radio
data are given for the objects for which we have obtained spectra, along with the spectra and finding charts for the $z > 3$ quasars.

2 DEFINITION OF THE RADIO SAMPLE

This study uses as its starting point the 5-GHz 87GB catalogue of Gregory & Condon (1991). By defining the sample at high frequency, flat-spectrum core-dominated objects, which are usually identified with quasars, are preferentially selected. Spectral index information and the accurate positions (better than $\pm 1.0$ arcsec) needed for optical identification are provided by the $S_{1.4\text{GHz}} = 1 \text{ mJy}$ VLA FIRST survey (Becker et al. 1995). The sample covers an area of $0.49 \text{ sr} (1600 \text{ deg}^2)$, limited by the extent of the FIRST survey which at the commencement of this work covered the region $\alpha(2000) < 17^h 30^m$, $\delta(2000) < 41^\circ 30'$.

Objects with $S > 25 \text{ mJy}$ from the 5-GHz 87GB catalogue were matched to the FIRST catalogue with a matching radius of 1 arcmin. In cases where more than one FIRST object matched the 5-GHz source (about 50 per cent of the time), the FIRST source with the strongest flux was selected (i.e. the source with the steepest spectrum). The reason for this is that if that source then passes the flat-spectrum selection criterion, there is certain to be a flat-spectrum source associated with the 5-GHz source.

Matched sources with radio spectral index flatter than $\alpha_{1.4\text{GHz}} > -0.5$ (where $S \propto \nu^\alpha$) were then selected. The exact spectral index criterion chosen was somewhat arbitrary, but this has proved successful in the past at separating the quasar and radio galaxy populations. The ‘total’ (rather than ‘peak’) fluxes from the 1.4-GHz FIRST catalogue were used to compute the spectral index. A total of 2902 sources ($\sim 2 \text{deg}^{-2}$) meet these criteria.

3 OPTICAL IDENTIFICATION AND SELECTION OF THE SPECTROSCOPIC SAMPLE

Optical identification of the radio sources was carried out using APM (the Automated Plate Measurement Facility at Cambridge) scans of POSS-I $E$ (red) and $O$ (blue) plates. The identification procedure and selection of candidates are similar to those in Hook et al. (1996), and more details can be found there along with a description of the APM POSS-I catalogue.

Identifications were made based on positional coincidence of the FIRST radio position with an optical counterpart on the POSS-I $E$ plate. The sample of candidate high-redshift quasars was then selected using the APM image classification, $\nu_\alpha$, measured from the $E$ plate, and the $O - E$ colour. The basis for the colour selection method is that the $O - E$ colours of quasars with $z > 2$ become rapidly redder with redshift, owing to absorption by intervening Ly$\alpha$ (see fig. 1 in Hook et al. 1995). To define a sample with a high level of completeness at $z > 3$ we chose a limit of $O - E \geq 1.2$. A magnitude limit of $E \leq 19.5$ was imposed (0.5 mag brighter than the $E$ plate limit) so that spectroscopy with the Lick 3-m would be more feasible. The APM star/galaxy separation is also more reliable away from the plate limit.

Based on results from the $S \geq 200 \text{ mJy}$ high-redshift radio quasar survey of Hook et al. (1996) and on results from the FBQS (Gregg et al. 1996), stricter selection criteria were used for this new survey. The criterion for positional coincidence used by Hook et al. (1996) was $\Delta r \leq 3.0$ arcsec, and for the FBQS it was $\Delta r \leq 2.0$ arcsec (Gregg et al. 1996). Even that was found to be too generous: 64 out of 69 (93 per cent) spectroscopically confirmed quasars in the FBQS were found to have $\Delta r \leq 1.0$ arcsec, and 97 per cent have $\Delta r \leq 1.1$ arcsec (the outliers were extended radio sources). Since the current high-redshift survey goes 2 mag fainter in $E$ than the FBQS, we adopt a more conservative criterion of $\Delta r \leq 1.5$ arcsec.

Fig. 1 shows this limit in relation to the histogram of $\Delta r$ for identifications with $E \approx 19.5$. The distribution peaks for the stellar objects with $\Delta r \leq 1.5$ arcsec. The solid sloping lines show fits to the histograms in the range $40.0 < \Delta r < 100.0$ arcsec, which determine the background counts. The upper line corresponds to 1.03 background sources with $E \approx 19.5$ per arcmin$^2$. The lower line corresponds to 0.64 stellar sources per arcmin$^2$ to the same magnitude limit.
and non-stellar identifications at $\Delta r \sim 0.5$ arcsec. However, whereas beyond \( \sim 3 \) arcsec the stellar histogram is indistinguishable from the derived background, the non-stellar identifications show an excess. There is evidence from Fig. 1(a) that this may persist out to a radius of \( \sim 40 \) arcsec [and possibly further, although this would not be apparent in Fig. 1(a) since the background was determined by fitting the distribution from 40 to 100 arcsec]. This may be due to either the clustering of galaxies or the fact that the peak of the radio emission is not on the optical counterpart as would be expected for extended asymmetric radio sources. Since the extended or resolved optical counterparts are not the subject of this paper, we do not consider this issue any further. This issue will be discussed further in a forthcoming paper (McMahon et al., in preparation) on the optical identifications of all FIRST sources using the APM POSS-I catalogue.

There is a small excess of 34 stellar objects above the background level between radii of 1.5 and 3.0 arcsec (see Fig. 1b). If we assume that these are real identifications that are excluded from the spectroscopic sample, then the incompleteness owing to the $\Delta r \lesssim 1.5$ arcsec criterion is \( \sim 9 \) per cent. This agrees with the fact that, of the 13 $z > 3$ quasars found in the survey of Hook et al. (1996) (with limiting magnitude $E \leq 20$), only one would not have satisfied the criterion of $\Delta r \lesssim 1.5$ arcsec.

The background counts for stellar sources with $E \leq 19.5$ were found to be 0.64 per square arcmin (see Fig. 1 and its caption). Thus within a search radius of 1.5 arcsec we expect 3.6 false identifications amongst the stellar identifications, i.e. 1.1 per cent. The corresponding background for red ($O - E \geq 1.2$) stellar sources is 0.54 per square arcmin, and we therefore expect 3.1 false red stellar identifications. In Section 5 this number is compared with the number of stars found in our sample.

We also now adopt a stricter criterion for stellar image classification. In Hook et al. (1996) a criterion of $|N_{\sigma_{c}}| \leq 3.0$ was used [where $N_{\sigma_{c}}$ can be considered as the number of standard deviations that a particular object is from having a stellar profile: see Hook et al. (1996) for a more detailed explanation]. However, only one of the 13 $z > 3$ quasars found in that survey had $|N_{\sigma_{c}}| > 2.0$, an object with $E = 19.93$, fainter than the limit of the current survey. Thus we now adopt a criterion of $|N_{\sigma_{c}}| \leq 2.0$. Whilst using these stricter criteria on $\Delta r$ and $N_{\sigma_{c}}$ has little effect on the completeness of the final high-redshift quasar sample compared with that in Hook et al. (1996), the number of candidates requiring spectroscopy is reduced by \( \sim 40 \) per cent.

In summary the selection criteria are: (i) $S_{5 \text{GHz}} \geq 25$ mJy; (ii) flat radio spectral index $\alpha_{1.4 \text{GHz}} \geq -0.5$; (iii) positional coincidence, $\Delta r \leq 1.5$ arcsec; (iv) red optical colour $O - E \geq 1.2$; (v) unresolved image on the $E$ plate, $|N_{\sigma_{c}}| \leq 2.0$; (vi) $E \geq 19.5$ mag. The optical counterpart was not required to be detected on the $O$ plate.

There is little overlap between this sample and the FBQS. The FBQS does not have a radio spectral index cut and reaches $S_{1.4 \text{GHz}} \sim 1$ mJy. The FBQS now has a blue optical colour criterion of $O - E < 2.0$ and has a significantly brighter optical limit of $E = 17.5$. Hence the two quasar samples are largely complementary.

Of the 2902 flat-spectrum sources (as defined in Section 2) in the GB/FIRST survey area, 560 have optical identifications brighter than $E = 19.5$ within 1.5 arcsec. The histogram of their $O - E$ colours, shown in Fig. 2, has a bimodal distribution. The bluer peak is dominated by stellar identifications (the vast majority of which are low-redshift quasars) and the redder peak is dominated by galaxies. By imposing a red colour selection criterion on the sample of stellar identifications, the majority of low-redshift quasars are eliminated. Of the 560 identifications, 337 are classified as stellar and 73 of these satisfy the colour criterion above $(O - E \geq 1.2)$. This sample of 73 objects will be referred to as the ‘spectroscopic sample’, and they are shown in the colour–magnitude diagram in Fig. 3.

14 of the spectroscopic sample had published spectroscopic data, leaving 59 objects requiring spectroscopy. The previously known objects were not re-observed, and their properties are summarized in Table 1. Two of the previously known objects are radio-selected $z > 3$ quasars (0933+2845: Gregg et al. 1996; 1340+3754: Hook et al. 1995).

## 4 Optical Spectroscopy

The aim of the spectroscopic phase of this project is to obtain classification (high-redshift quasar or not) for the complete spectroscopic sample defined above. This does not require redshifts to be obtained for all the objects: for example, many ‘featureless’ spectra could be rejected as possible $z > 3$ quasars by the lack of Ly$\alpha$ forest absorption. The strategy was therefore to take short exposures at low dispersion to obtain spectra of sufficient quality for the nature of the object and, where possible, the redshift to be determined.

Most of the spectroscopy was carried out in 1995 April and 1996 May using the KAST double-spectrograph at the Cassegrain focus of the 3-m Shane Telescope at Lick Observatory. Typical exposure times were 600–900 s. For the 1996 May run, a grating giving 4.6 Å pixel$^{-1}$ dispersion was used on the red side, and on the blue side the selected grism gave a dispersion of 2.54 Å pixel$^{-1}$. A dichroic at $\sim 5500$ Å was used. The set-up was such that the blue side of the spectrum covered 2900–6000 Å and the red side covered 5080–10610 Å. For the 1995 April run a grating giving 2.32 Å pixel$^{-1}$ dispersion was used on the red side, and on the blue side the selected...
NVSS flux is the sum of two components: the closest source has a NVSS flux corresponding to about 0.8 arcsec \(^{-1}\). The CCD chips were windowed in the spatial direction to reduce the readout time.

Seven objects from the spectroscopic sample were observed at the Keck Telescope with the Low Resolution Imaging Spectrograph (LRIS). These observations were carried out as a backup programme during a run to obtain spectra of distant supernovae. A 300 line mm\(^{-1}\) grating was used on LRIS and covered the wavelength range 4900–9900 Å with a resolution of 2.5 Å pixel\(^{-1}\). In addition, one object was observed at the 4.2-m William Herschel Telescope (WHT), La Palma, in 1993 April, and another by R. Weymann at the Palomar 5-m in 1991 December, as part of other programmes.

For all observations the width of the slit was adjusted to be compatible with the seeing at the time of observation (1–2 arcsec), and the data were taken with a long slit at the parallactic angle. Some of the objects were too faint to be easily visible on the acquisition TV at the Lick 3-m, so accurate offsetting from nearby stars was used to position the target object in the slit. Spectrophotometric standards were observed to calibrate the spectra.

The reduction of the data was carried out using standard software from the IRAF package.

### Table 1. Optical and radio data for objects in the spectroscopic sample that had spectroscopic data in the literature.

| \(\alpha\) | Optical Position J2000 | \(\delta\) | \(z\) | \(\sigma_e\) | \(E\) mag | \(\Delta\) mag | \(S_{\text{GB}}\) mJy | \(S_{\text{B91}}\) mJy | \(S_{\text{FIRST}}\) mJy | \(S_{\text{NVSS}}\) mJy | \(S_{\text{5 GHz}}\) mJy | Reference/Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09 | 11 | 47.71 | +33 | 49 | 49.76 | − | 1.75 | 18.62 | 1.56 | 0.78 | 250 | 207 | 391.2 | H96 / featureless |
| 09 | 30 | 55.28 | +35 | 03 | 36.9 | − | 0.12 | 19.18 | 1.24 | 0.85 | 383 | 381 | 518.8 | H96 / featureless |
| 09 | 33 | 37.31 | +28 | 45 | 32.3 | 3.42 | 0.27 | 17.50 | 1.27 | 0.16 | 66 | 63 | 120.9 | H96 / featureless |
| 10 | 50 | 58.15 | +34 | 30 | 10.8 | 2.52 | 1.43 | 18.98 | 1.40 | 0.30 | 298 | 291 | 547.3 | H95 / QSO |
| 11 | 49 | 00.29 | +29 | 58 | 41.0 | 0.15 | 1.15 | 17.05 | 2.72 | 0.34 | 41 | 39 | 53.2 | G96 FBQS / QSO |
| 12 | 35 | 05.79 | +36 | 21 | 18.7 | 1.60 | −0.20 | 19.06 | 1.26 | 0.47 | 250 | 251 | 157.5 | H96 / QSO |
| 13 | 24 | 12.09 | +40 | 48 | 12.4 | 0.50 | 0.16 | 19.49 | 2.56 | 0.07 | 413 | 423 | 369.4 | H95 / QSO |
| 13 | 40 | 22.94 | +37 | 54 | 44.4 | 3.10 | 0.08 | 17.85 | 1.68 | 0.85 | 305 | 301 | 284.3 | H95 / QSO |
| 13 | 50 | 35.95 | +33 | 42 | 17.2 | 0.01 | −0.85 | 11.41 | 1.35 | 0.93 | 76 | 90 | 100.5 | H95 / QSO |
| 14 | 04 | 14.63 | +28 | 46 | 36.5 | − | 0.84 | 16.03 | 1.49 | 1.03 | 38 | 36 | 12.5 | H96 / QSO |
| 14 | 21 | 25.62 | +39 | 43 | 29.4 | 0.62 | 1.43 | 18.33 | > 3.65 | 0.79 | 67 | 64 | 43.6 | H86 / QSO |
| 15 | 58 | 44.88 | +37 | 20 | 21.6 | 0.33 | −0.67 | 18.22 | 1.70 | 0.68 | 591 | 591 | 271.9 | V96 / QSO |
| 15 | 58 | 55.21 | +33 | 23 | 19.3 | 1.65 | −0.13 | 16.49 | 1.24 | 0.83 | 88 | 86 | 145.5 | V96 / QSO |
| 16 | 33 | 02.12 | +39 | 24 | 27.4 | 1.02 | −0.25 | 15.02 | 1.21 | 0.34 | 40 | 38 | 54.7 | CCH90 / QSO |

Notes on column headings: 
- \(S_{\text{GB}}\) is the 5-GHz flux from Gregory & Condon (1991), and \(S_{\text{B91}}\) is the 5-GHz flux from the Becker, White & Edwards (1991) catalogue. \(S_{\text{NVSS}}\) was determined by summing up the fluxes from sources in the 1.4-GHz NRAO–VLA Sky Survey catalogue (NVSS: Condon et al. 1994) within 60 arcsec of the FIRST position. \(S_{\text{FIRST}}\) is the 'Total' flux from the 1.4-GHz FIRST catalogue, and \(S_{\text{5 GHz}}\) is the spectral index between \(S_{\text{FIRST}}\) and \(S_{\text{GB}}\).
- NVSS flux is the sum of two components. The central component has \(S = 97.3\) mJy and a second component 20 arcsec away has \(S = 6.5\) mJy.
- The NVSS flux is the sum of two components: the closest source has \(S = 62.3\) mJy and a second, probably unrelated source 42 arcsec away has \(S = 20.6\) mJy.

References: F86 = Foltz et al. (1986), G96 = Gregg et al. (1996), H95 = Hook et al. (1995), H96 = Hook et al. (1996), HGC95 = Huchra, Geller & Corwin (1995), V90 = Vigotti et al. (1990), V96 = Vermeulen et al. (1996), W84 = Wampler et al. (1984), CCH90 = Crampton, Cowley & Hartwick (1990).
the efficiency would have been lower by a factor of ~4.5. The \( z > 3 \) quasars are marked on the colour–magnitude diagram (Fig. 3) with stars. A further seven new quasars in the range \( 2 < z < 3 \) were found (but note that the colour selection criterion means that the sample is substantially incomplete for \( z < 3 \)).

The remaining observed objects were found to be low-redshift (\( z < 2 \)) quasars, emission- or absorption-line galaxies, and objects with featureless spectra which could be ruled out as possible high-redshift quasars. Two objects were found to be stars and are probably chance coincidences with the radio position (both have \( \Delta r > 1.0 \) arcsec). This agrees well with the number of false identifications expected (see Section 3). We expect 3.1 false, red, stellar identifications in the full spectroscopic sample, thus after observing 70 per cent of these objects we expect to have found 2.1 stars.

The first radio-loud BAL quasar, 1556+3517 with \( z = 1.48 \), was discovered in this survey and was reported in an earlier paper (Becker et al. 1997). Note that this object is redder \( (O - E = 2.56) \) than any of the \( z > 3 \) quasars in the sample so far.

Of the 50 objects with spectroscopic data, 35 have a definite redshift based on emission or absorption features (including the two stars). Their redshift distribution is shown in Fig. 4. The 15 'featureless' objects are represented by the open box, while objects with no spectral information are represented by the hatched box.

In addition we have observed 22 objects that do not meet one or more of the selection criteria of the spectroscopic sample, but which satisfy a less stringent set of selection criteria: \( \Delta r \leq 3.0 \) arcsec; \( O - E \leq 1.0 \); \( \pm \Delta r \leq 3.0 \); \( E \leq 20 \) mag. None of them was found to have \( z > 3 \). The results for these objects are summarized in Table 3. They are plotted as pluses on the colour–magnitude diagram in Fig. 3 and represented by the solid shading in the redshift histogram in Fig. 4.
5.1 The new sample of $z > 3$ quasars

A summary of the six $z > 3$ quasars in the sample to date is given in Table 4, their spectra are shown in Fig. 5 and finding charts are given in Fig. 6. Note that the spectra obtained at the Keck (0847+3851 and 0902+3957) have been corrected for atmospheric absorption bands while the others have not. The spectrum of 0933+2845 ($z = 3.42$: Gregg et al. 1996) was obtained at Lick on 1995 July 3 as part of the FBQS. 1283+2909 was re-observed at the Lick 3-m on 1996 March 15 to obtain a spectrum of higher signal-to-noise ratio. This spectrum, rather than the discovery spectrum, is shown in Fig. 5.

Two $z > 3$ radio-loud quasars are known to lie within the survey area but were not found by this survey. FBQS J1021+3001 with $z = 3.1$ (Gregg et al. 1996) is in the FIRST catalogue but is below the flux limit used in this search. B3 1239+376 with $z = 3.82$ (Vermeulen et al. 1996) is optically fainter than the limit of the APM scans.

6 CONCLUSIONS

In this paper we have described a survey for high-redshift radio-loud quasars with a limiting flux density of 25 mJy, about a factor of 10 fainter than previous surveys. This survey has become feasible because of new accurate positions for large numbers of faint radio sources supplied by the VLA FIRST survey. Six $z > 3$ quasars have so far been found in an area of 0.49 sr (~1610 deg$^2$), after completing follow-up for 70 per cent of the spectroscopic sample. The effective area covered so far is thus 70 per cent ×1610 = 1130 deg$^2$. Therefore we find a surface density of flat-spectrum $z > 3$ quasars of one per 190 deg$^2$ to a radio flux limit of $S_{1.4 GHz} \geq 25$ mJy and an optical limit of $E = 19.5$ mag. After completion of the

Table 3. Optical and radio data for objects observed spectroscopically that were not part of the complete spectroscopic sample. These objects satisfy a less stringent set of selection criteria described in Section 5 (15 of these have definite redshifts and seven have ‘featureless’ spectra).

| $\alpha$ | Optical Position | $\delta$ | $z$ | $N_{\sigma_{1}}$ | $E_{mag}$ | $O - E_{mag}$ | $\Delta_{\sigma}$ | $S_{\text{FIRST}}$ | $S_{\text{NVSS}}$ | $S_{1.4 GHz}$ | $\text{Tel/Class}$ |
|---------|-----------------|---------|-----|----------------|---------|--------------|-------------|----------------|---------------|------------|-----------------|
| 08      | 35 19.76        | +29 09  | 21.2| 1.27 1.37      | 19.72   | 2.14         | 0.55        | 36 45 41.3    | 38.9         | -0.11     | L04/95 QSO      |
| 09      | 00 30.44        | +33 30  | 09.7| -1.09 19.91    | 12.25   | -0.86        | 81 77 72.4   | 82.5 0.09     | L03/97 QSO   | K03/97 featureless |
| 06      | 02.49           | +41 16  | 27.6| 0.41 3.00      | 17.85   | > 3.82       | 2.75 279 776 | 771.1 0.80    | K03/97 QSO   | L04/95 QSO      |
| 08      | 53.08           | +30 47  | 38.3| 1.91 0.65      | 19.63   | 1.08         | 0.27 35 32   | 40.1 0.02     | L04/95 QSO   | L04/95 QSO      |
| 24      | 38.22           | +30 47  | 36.6| 0.27 2.95      | 17.76   | 3.11         | 0.70 27     | 4.0 0.10      | L03/97 QSO   | L05/95 QSO      |
| 09      | 27.39           | +30 34  | 17.3| 1.20 0.24      | 19.59   | 1.41         | 0.87 57 56   | 46.1 0.51     | L04/95 QSO   | L04/95 QSO      |
| 11      | 05 50.05        | +30 01  | 46.2| -2.07 19.36    | 1.39    | 0.79         | 53 50 64.2  | -0.15 L04/95 featureless |
| 12      | 24 29.65        | +31 25  | 25.3| 1.35 1.08      | 19.04   | 1.10         | 0.46 31 22.3  | 24.0 0.26     | L04/95 QSO   | L04/95 QSO      |
| 12      | 27 29.21        | +37 56  | 12.4| -0.09 16.40    | > 2.00  | 1.13         | 70 67 66.4  | 78.3 0.04     | L05/96 featureless ? |
| 12      | 11 34.02        | +28 47  | 33.1| -0.81 16.65    | > 2.26  | 0.17         | 35 33 32.9  | 32.0 0.05     | L04/95 ?     |
| 12      | 24 09.80        | +28 35  | 10.3| 0.40 0.89      | 19.82   | 2.06         | 0.84 77 74   | 18.6 297 0.8  | L04/95 Gal (em.) |
| 12      | 19 14.99        | +40 49  | 55.2| 1.31 0.37      | 17.55   | 1.18         | 1.02 78 74   | 65.7 70.3 0.13 | L05/96 QSO   |
| 13      | 01 56.57        | +29 04  | 55.7| 2.29 0.57      | 19.19   | 1.10         | 0.44 50 48   | 97.5 103.1 0.52 | L04/95 QSO   |
| 13      | 24 57.44        | +32 51  | 46.2| 1.74 0.11      | 17.91   | 1.01         | 1.21 92 92   | 57.6 56.7 0.37 | L05/96 QSO   |
| 13      | 26 13.76        | +28 01  | 43.6| 1.29 1.25      | 18.14   | 1.04         | 0.69 31 46   | 20.9 36.8 0.31 | L05/96 QSO   |
| 08      | 25 35.27        | +36 17  | 59.7| -1.09 18.28    | 1.01    | 0.31         | 82 79 128.3 3.33 0.35 | L05/96 featureless |
| 13      | 13 13.65        | +41 16  | 37.8| 2.61 1.41      | 17.71   | 1.06         | 0.34 35 33   | 26.7 30.3 0.21 | L05/96 QSO   |
| 13      | 26 31.24        | +29 11  | 31.6| 0.17 1.01      | 18.77   | 2.09         | 1.63 41 38   | 45.6 53.6 0.08 | L05/96 Gal   |
| 14      | 27 30.70        | +30 51  | 28.6| 0.42 2.51      | 19.01   | 2.84         | 0.57 35 107 104.9 0.49 | L05/96 QSO   |
| 15      | 26 74.77        | +37 42  | 05.9 | -0.41 19.53    | > 1.99  | 1.00         | 41 49 47.0 0.11 | L05/96 featureless |
| 15      | 03 22.63        | +38 30  | 29.0| 1.08 1.73      | 18.33   | 1.25         | 1.56 52 49   | 97.4 104.9 0.49 | L05/96 QSO   |
| 17      | 07 35.97        | +35 39  | 50.0| -2.13 16.66    | 2.71    | 0.51         | 53 51 100.1 | -0.50 L05/96 featureless |

* Uncertain redshift.

The source has complex structure in the FIRST map. The FIRST flux given is the flux of the central component only. The NVSS flux is the sum of four components within 60 arcsec, the most central of which has $S = 110.6$ mJy.
spectroscopic observations, the new sample will be used in an analysis of the space density of quasars at high redshift.

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Figure 5. Spectra of the $z > 3$ quasars in the GB/FIRST flat-spectrum sample to date.
Table 4. Summary of the $z > 3$ QSOs in the sample to date.

| Name         | $z$ | $N_{\sigma}$ | $E$ | $O - E$ | $\Delta r'$ | $S_{\text{GB}}/\text{mJy}$ | $\alpha_{1400/1400}$ | Comments                      |
|--------------|-----|--------------|-----|---------|-------------|-----------------------------|-----------------------|-------------------------------|
| 0847+3831    | 3.18| -1.01        | 17.55| 1.37    | 0.31        | 124                         | -0.32                 | Keck 03/97                    |
| 0902+3857    | 3.08| 0.83         | 17.56| 1.24    | 0.14        | 31                          | -0.03                 | Keck 03/97                    |
| 0933+2845    | 3.42| 0.27         | 17.50| 1.27    | 0.16        | 66                          | -0.48                 | Previously known, Gregg et al. 1996 |
| 1258+2909    | 3.47| 0.32         | 18.52| 2.06    | 0.48        | 32                          | 0.19                  | Lick 04/95                    |
| 1340+3754    | 3.10| 0.08         | 17.85| 1.68    | 0.85        | 305                         | 0.06                  | Previously known, Hook et al. 1995 |
| 1523+3814    | 3.15| -1.09        | 18.38| 1.40    | 0.40        | 27                          | -0.45                 | Lick 05/96                    |

Notes
1-Based on J2000 position.

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