THE 2DF QSO REDSHIFT SURVEY

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ABSTRACT. We present preliminary results from the 2-degree Field (2dF) QSO Redshift Survey currently under way at the Anglo-Australian Telescope. This survey aims to determine the redshifts of > 25000 QSOs over a redshift range of $0.3 < z < 3.0$ with the primary goal of investigating large-scale structure in the Universe to high redshift and at very large scales ($\sim 1000h^{-1}$Mpc). We describe the photometric procedure used to select QSO candidates for spectroscopic observation. We then describe results from our first 2dF observations, which have so far measured the redshifts for over 1000 QSOs. We already find a significant detection of clustering and have also found one close pair of QSOs (separation $17''$) which are gravitational lens candidates.
To keep up to date with the current progress of the survey see: `http://msowww.anu.edu.au/~rsmith/QSO_Survey/qso_surv.html`

1 Introduction and Aims

The 2-degree Field Instrument[1] at the AAT is a multi-object fibre-fed spectrograph, allowing up to 400 spectra to be obtained simultaneously. This technological achievement has allowed a new generation of redshift surveys to be undertaken which are an order of magnitude greater in size than previous samples. Previously, although ~ 10000 QSOs were known[2] the largest homogeneous catalogue only contained $\simeq 1000$ QSOs[3].

The 2dF QSO Redshift Survey aims to measure the redshifts of over 25000 QSOs selected in a homogeneous manner via UB_JR multi-colour selection (see Section 2). The sample will span the redshift range $0.3 < z < 3.0$ and will be $> 90\%$ complete at $z < 2.2$. The survey covers an area of 740 deg^2 in two declination strips which are each $75^\circ \times 5^\circ$, one strip is at $\delta = -30^\circ$ near the South Galactic Pole while the second is at $\delta = 0^\circ$ in the North Galactic Cap.

The main scientific goals of the QSO survey are the following:

1. To measure the QSO power spectrum from small scales $\sim 2h^{-1}$Mpc to the large scales probed by *COBE*, $> 1000h^{-1}$Mpc. This will also allow us to place limits on $\Omega_{\rm baryon}$ by searching for acoustic oscillation features (or "doppler peaks") present in the power spectrum when $\Omega_{\rm baryon}$ is a significant fraction of $\Omega_{\rm CDM}$.
2. Estimate cosmological parameters, in particular λ_0, the cosmological constant, from geometric distortions in the clustering of QSOs at high redshift.
3. Trace the evolution of QSO clustering from $z = 0.3$ to $z = 3$ to test models of structure formation and evolution in the Universe.

There are of course many other studies which can be carried out on a sample of this size, including: accurate determination of the QSO luminosity function to $z = 2.2$; investigation of the radio properties of QSOs; the study of broad-absorption-line QSOs; and searches for gravitational lenses. The catalogue will also provide a database of objects to be followed up, for example, with high resolution spectroscopy to find Lyα and metal absorption line systems.

2 Multi-colour Selection of QSO Candidates

The QSO candidate catalogue for spectroscopic observation is based on

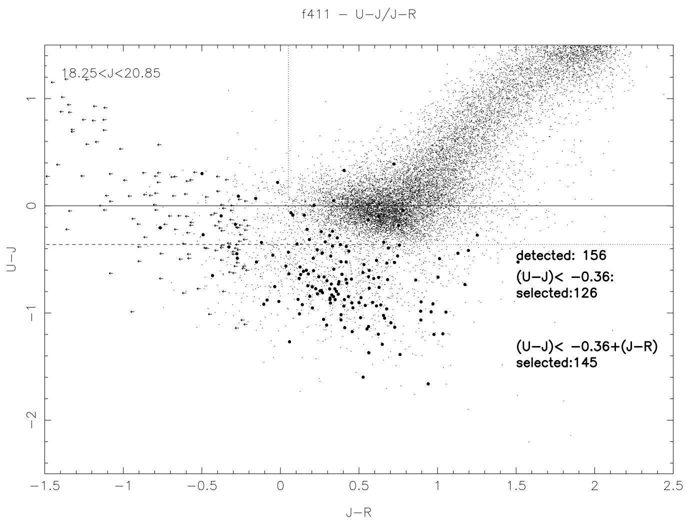

Figure 1. *Multi-colour QSO selection for the 2dF QSO Redshift Survey in the F411 UKST field. The small points indicate all stellar sources in this field while the arrows show objects which only have upper limits in the R band. The large points are known QSOs in this field. The dotted line is our final colour selection which selects more QSOs than a simple $U - B_J$ selection (dashed line).*

broad band UB_JR photometry from APM measurements of UKST photographic plates. The survey comprises 30 UKST fields, and in each of these fields one B_J plate, one R plate and up to 4 U plates/films are used. In each UKST field area we have obtained CCD photometry from the 0.9m Telescope at CTIO and the INT and JKT on La Palma in order to independently calibrate the photographic magnitudes[4, 5]. We also correct for the vignetting/variable desensitization in the photographic plates [6]. QSOs candidates are then selected by their blue colours in the $U - B_J$ vs. $B_J - R$ plane. An example of this is shown in Figure 1 for the F411 UKST field. This shows that our multi-colour selection process is more effective than a simple $U - B_J$ selection and based on previously known QSOs (discovered by a variety of methods) in our survey area we expect to be 93% complete[7]. The incompleteness is due scatter from both photometric errors and variability (when the photographic plates do not share similar epochs).

The magnitude limits of the survey are $18.25 < B_J < 20.85$ in the case of the 2dF observations. In order to provide a well determined luminosity function at bright magnitudes we observe brighter QSO candidates, $17.0 < B_J < 18.25$, using FLAIR on the UKST.

3 Results from the First 1500 QSOs

We have currently obtained redshifts for just over 1500 QSOs from a variety of sources. Over 1300 of these are from 2dF with the remainder from FLAIR observations of bright QSOs, Keck observations of radio-loud QSOs and observations of close pairs of QSOs from the 2.3m ANU Telescope. The 2dF observations are carried out in collaboration with the 2dF Galaxy Redshift Survey (see Maddox, this volume) as the QSO survey covers a subset of the galaxy survey area, so the two catalogues have been merged to increase the efficency of observations. The data are reduced using pipeline reduction software and QSO identification and redshift determination is carried out using software specifically designed for this task. Spectroscopy confirms that $\sim$ 53% of

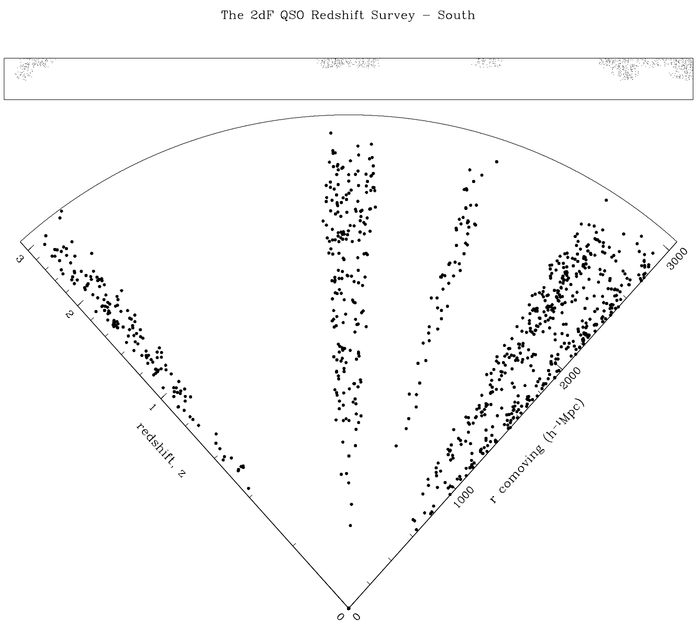

Figure 2. *The positions of observed QSOs in the SGP survey region ($\delta = -30°$). This area currently contains 910 QSOs. The rectangle at the top of the plot will eventually be completely filled with QSOs.*

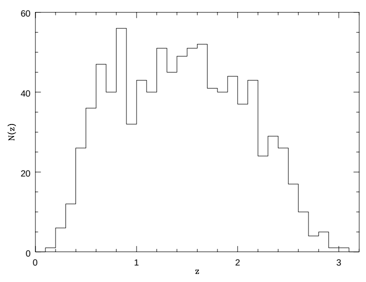

Figure 3. *The number-redshift histogram for the 2dF QSOs with currently measured redshifts.*

our candidates are positively identified as QSOs with the contamination consisting mainly of galactic subdwarfs and compact blue galaxies.

Although the survey is still only $\sim$ 4% complete, Figure 2 demonstrates the eventual scale of the survey. This plot shows the positions of all the QSOs with redshifts measured in the $\delta = -30°$ slice, which currently shows 910 QSOs, but will eventually contain in excess of $\sim$ 12500. The redshift distribution of the QSOs is shown in Figure 3. The multi-colour selection allows us to select QSOs at $z > 2.2$ although the survey is not highly complete above this redshift. The number-magnitude relation is shown in Figure 4 compared to the LBQS[3] and Durham/AAT[8] surveys. The 2dF QSO Survey is marginally lower than the Durham/AAT survey, consistent with our predicted completeness, however this slight incompleteness is compensated for by our much reduced contamination.

Although the area coverage of the survey is currently disjoint, we can make provisional estimates of the clustering. We use the integrated correlation function $\bar{\xi}$ out to a scale of $10h^{-1}$Mpc as a measurement of clustering. For QSOs with $0.3 < z < 2.2$ we find $\bar{\xi}(10) = 0.55 \pm 0.27$ from 929 QSOs. This is consistent with other measures, e.g. $\bar{\xi}(10) = 0.83 \pm 0.29$[9] from the Durham/AAT[8], LBQS[3] and CFHT[10] samples. We plot the clustering amplitude as a function of redshift in Figure 5, here we combine the 2dF data with the data discussed above. We see a marginal decrease in clustering from $z \sim 0.9$ to $z \sim 1.8$. Of course the errors in the final survey

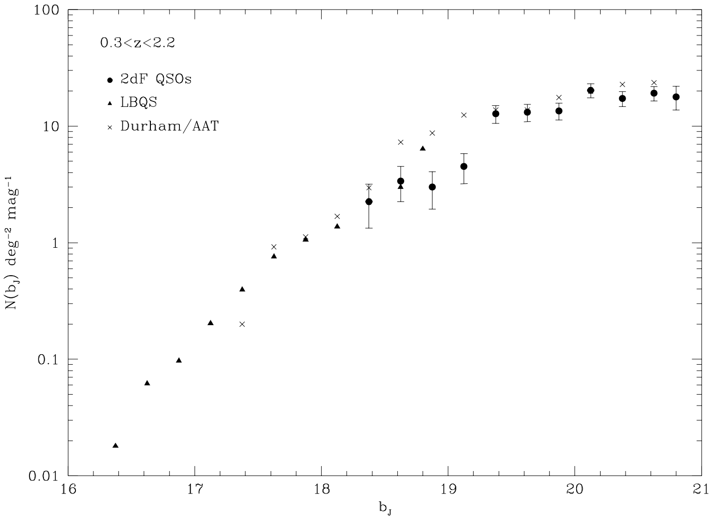

Figure 4. *The number-magnitude relation for 2dF QSOs (filled circles), compared to the LBQS (triangles) and Durham/AAT (crosses) surveys.*

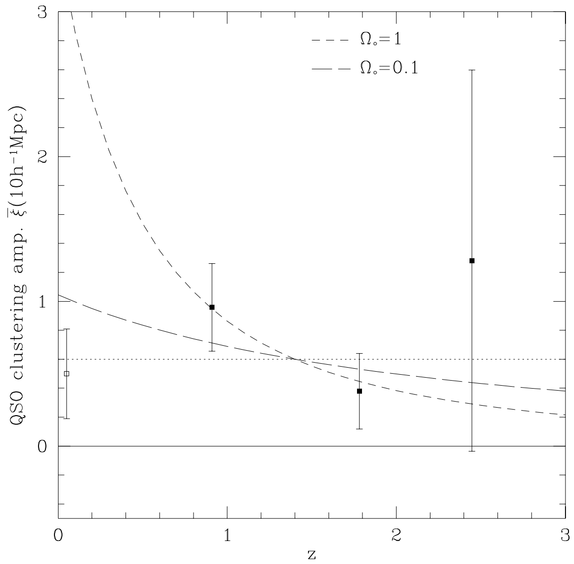

Figure 5. *Evolution of QSO clustering as measured by the 2dF QSO Survey combined with the Durham/AAT, CFHT and LBQS samples (filled squares). The low redshift result (open square) is a combination of the EMSS[11] and IRAS[12] AGN correlation functions. Two simple linear theory models are shown (for $\Omega_0 = 1$ and 0.1) as a comparison.*

will be more than $5\times$ smaller than the errors shown in this plot.

We have also begun a long-slit spectroscopic program to obtain redshifts for all the close pairs of QSO candidates ($\Delta\theta < 20''$) which cannot be simultaneously measured with 2dF (due to a limit on the minimum fibre separation). Such pairs are potentially some of the most in-

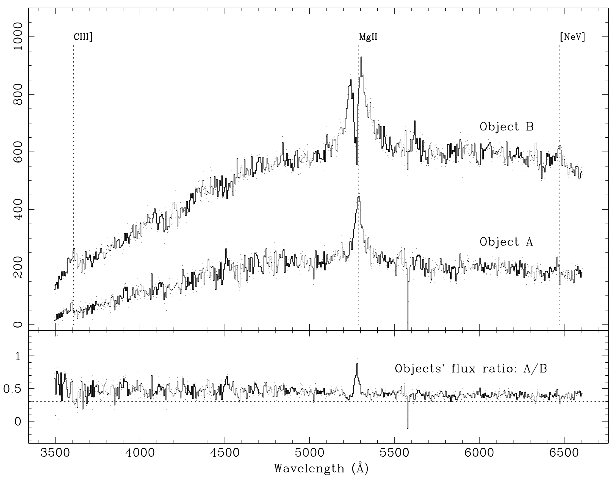

Figure 6. *Spectra of the close pair of QSOs at $z = 0.89$. The spectra were obtained using the RGO spectrograph at the AAT. Below the two spectra we show the flux ratio of the two, which is close to constant apart from absorption in the MgII line of object B.*

teresting objects in our catalogue as they are candidate wide-angle gravitational lenses or binary QSOs. With observations of $\sim 25\%$ of the close pairs complete, we have found 8 QSO pairs, but only one pair of QSOs with identical redshifts. This pair has a separation of $17''$ and is at a redshift of $z = 0.89$. Spectra of these two objects are shown in Figure 6. The number of these lens can be used to constrain λ_0.

4 Conclusions: A Survey of 25000 QSOs

The 2dF instrument allows the creation of a QSO survey some 25 times bigger than the previous largest sample. With spectroscopic observations only $\sim 4\%$ complete we have already discovered > 1000 QSOs. QSO clustering measurments already show significant detections of clustering, and possibly evolution in clustering. With the increasing efficiency of 2dF the rate of redshift measurement is increasing dramatically and the expected completion date of the survey is the end of 2000.

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