The Clustering and Evolution of Optically-Selected QSOs

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Abstract
We are in the process of compiling a large catalogue of faint (B < 20.9 mag), UVX selected QSOs with complete spectroscopic identification using the fibre optic (FOCAP) system at the Anglo-Australian Telescope. From the 220 QSOs thus far identified we find that QSO evolution is most simply parameterised by a uniform increase in luminosity towards higher redshifts. We also find evidence for strong QSO clustering at scales < $10h^{-1}$ Mpc.

Data
Candidate QSOs are first selected using the ultra-violet excess (UVX) technique from COSMOS (MacGillivary and Stobie 1985) machine measurements of UK Schmidt telescope U and J plates. Details of the application of the UVX techinque to the COSMOS measurements may be found in Shanks et al. (1983) and Boyle et al. (1985). At present, faint (B < 20.9 mag) UVX stellar objects (U-B < -0.35) have been identified on seven, well separated 4°5 x 4°5 Schmidt plate areas (see Boyle et al. 1987). Subsequent spectroscopic observations with the FOCAP fibre optic system (Gray 1984), operated in conjunction with the IPCS and RGO spectrograph, at the Anglo-Australian Telescope have enabled spectra to be obtained for more than 600 of these UVX objects in 13 40 arcminute diameter fields. At the magnitude limit of our survey, the surface density of UVX objects (120 - 150 per square degree) means that the number of UVX objects in the 0.35 square degree FOCAP field is ideally matched to the number of fibres (45 - 50) available. Of the 600 UVX objects surveyed 220 are QSOs (the 9000 second integrations being sufficient to obtain unambiguous redshifts for 85% of the QSOs), 17 are white dwarfs, 25 are narrow emission line galaxies, the remainder being Galactic subdwarfs.

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Results

a. The Number Magnitude Counts

In figure 1 we present the differential number-magnitude relation for QSOs with z<2.2 (the redshift range for which the UVX technique is complete) found in this survey. Also presented are the surface densities of z<2.2 QSOs obtained from other complete spectroscopic surveys of UVX objects. At bright magnitudes (B < 19.5 mag) we see good agreement between the different surveys, with the QSO number-magnitude relation following a steep (dlogN/dB=0.86) slope. Beyond B = 19.5 mag, however, the counts obtained from our survey show a sharp break to a much flatter slope (dlogN/dB=0.33), with the integral surface density at B = 20.9 mag being 36 ± 4 per square degree, a factor of five lower than that predicted from a simple extrapolation of the steep slope seen at B < 19.5 mag. The error quoted on the surface density is obtained from the r.m.s. field-to-field variation and is consistent with a Poissonian distribution for the QSOs. We have established (see Boyle 1986) that this turn-over is certainly real and not caused by any magnitude dependent selection effect in our data. Indeed the surface densities for faint (B > 20 mag) QSOs presented here are in good agreement with those reported by other authors at this conference (Marano, Crampton, Koo) based on smaller but similar spectroscopic surveys of UVX-selected objects.

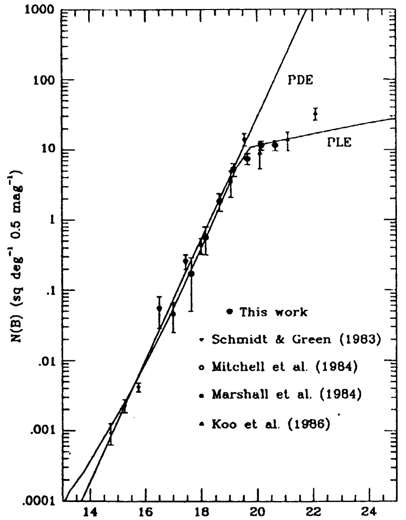

Figure 1 Number-magnitude counts for spectroscopically confirmed QSOs with z<2.2

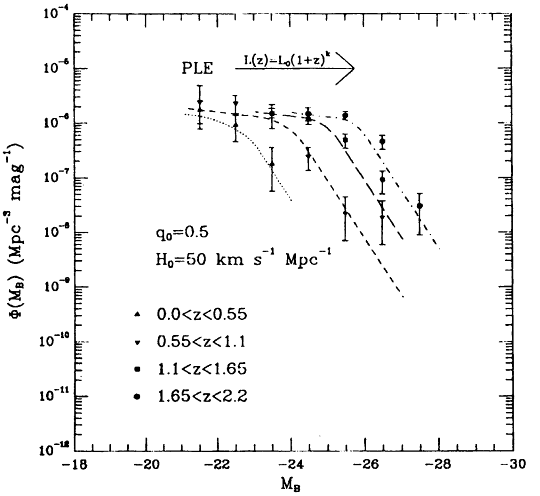

Figure 2 QSO luminosity functions derived from our survey.

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b. QSO Evolution

It is well known (see e.g. Cavaliere et al. 1983), that a pure density evolution model for QSOs is strongly ruled out by the appearance of a break in the QSO number-magnitude relation; such a feature being reflected in the shape of the QSO luminosity function itself. By tracking the position of this feature in QSO luminosity functions determined in different redshift ranges we may directly establish the form that the evolution takes. In figure 2 we present the QSO luminosity function as determined from our data in four separate redshift intervals between $0<z<2.2$. From figure 2 we see that, over the absolute magnitude and redshift ranges sampled by our survey, the QSO luminosity function may simply be represented by two power laws, with a steep slope ($\Phi(>L) \propto L^{-3.6}$) beyond a 'break' feature and a much flatter slope ($\Phi(>L) \propto L^{-1.2}$) fainter than the break. Futhermore, the redshift dependence of the luminosity function in this range may be expressed as a uniform shift towards higher luminosities at higher redshifts. More detailed statistical analysis (Boyle et al. 1987) reveals that a power law luminosity evolution of the form $L \propto L_0(1+z)^{3.7}$ provides the best fit to the data, with the predicted z=0 QSO luminosity function being similar to the Seyfert luminosity function derived by Cheng et al. (1985). A physical interpretation of this 'pure luminosity evolution' is, however, far from straightforward. The observed evolution could represent either the actual evolution of individual, long-lived (few billion years) QSOs or the evolution in average properties of succesive generations of short-lived (few million years) QSOs. Although the long-lived model may be a more natural explanation of pure luminosity evolution the requirement that massive (10^9 - 10^{10} $M_\odot$) exist in the centres of low redshift QSOs and Seyferts may severely constrain this model.

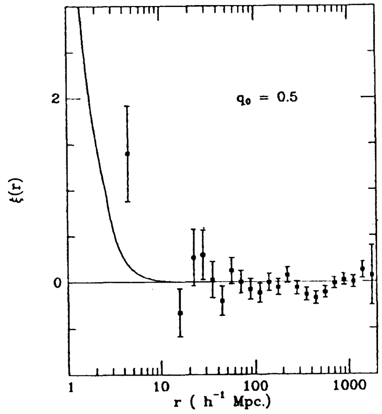

Figure 3 QSO 2-point correlation function. r is a comoving coordinate computed in an Einstein-de Sitter universe. Solid line is the predicted galaxy correlation function at z=1.5

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c. QSO Clustering

We have also investigated the spatial clustering of QSOs in this survey using the two-point correlation function; the high surface density and accurate spectroscopic redshifts obtained for the large number of QSOs in this survey enabling the first determination of the QSO correlation function at scales $<30h^{-1}$ Mpc based on a homogeneous QSO catalogue. The correlation function is shown in figure 3. At large scales ($>50h^{-1}$ Mpc) the amplitude of the correlation function is consistent with a random QSO distribution. At small scales ($<10h^{-1}$ Mpc), however, we find tentative evidence (3σ) for clustering amongst QSOs. Although statistics here are poor, we find 12 QSO pairs with separations $<10h^{-1}$ Mpc, where only 4 are expected based on a random hypothesis. Indeed it appears that QSOs may cluster more stongly than galaxies at these epochs ($<z>_{QSO}= 1.5$) based on predictions of the galaxy correlation function at z=1.5 assuming stable clustering (Shanks et al. 1987), with only 5.5 pairs expected were QSOs to cluster like galaxies.

Conclusions

We have presented the results obtained from a large catalogue of UVX-selected QSOs with complete spectroscopic identification. We find that the number-magnitude relation for UVX QSOs exhibits a sharp break at B = 19.5 mag, consistent with a feature in the QSO luminosity function. This feature may be used to track QSO evoultion, which we find to be simply expressed as a uniform increase in luminosity with increasing redshift. Tentative evidence for strong QSO clustering at scales $<10h^{-1}$ Mpc has been found but more data will be needed to confirm this result and to enable the evolution with redshift of the correlation function to be determined.

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Postscript. One week after this conference a further 3 clear nights were obtained for the spectroscopic survey, resulting in a further 130 QSOs being identified, bringing the total in the catalogue to 350.

DISCUSSION

BIRKINSHAW: What criteria in angular separation and redshift separation do you use to define a quasar "pair"?

BOYLE: We simply calculate the comoving separation between QSOs using the standard Osmer (1980) procedure. The pairs that I specifically referred to in the talk were those with a comoving separation of $<10h^{-1}$ Mpc, the scales at which we observe the correlation function to be positive.

SILK: Can you comment on the correlation length that you have measured for the quasar distribution and on the large-scale homogeneity limit that you can get?

BOYLE: The correlation length of the clustering is approximately $5h^{-1}$ Mpc (although it is still tentative) and the homogeneity limit at large scales is $\Delta\delta/\delta \lesssim 10\%$ although stronger limits will be placed on this figure as we increase our sample size.

CHEN: What do you mean the 10% unidentified objects? Does it mean by spectroscopic work?

BOYLE: Less than 10% of the objects for which we have spectra remain unidentified. They mainly comprise objects at the faint magnitude limit of our sample where insufficient signal-to-noise was obtained to reliably identify stellar features or weak emission lines. We expect most of these objects will be galactic stars, since, at low S/N stellar absorption features will be more difficult to detect than broad emission lines. However, none of our conclusions are affected even if we assume that all the unidentified objects are QSOs.

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