RESULTS FROM A FAINT QSO REDSHIFT SURVEY

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ABSTRACT.

We have used the FOCAP fibre optic coupler at the Anglo-Australian Telescope (AAT) to measure redshifts for a complete sample of ∿ 170 $B \leqslant 21^m$ QSO's selected using the ultraviolet excess (UVX) criterion. We present preliminary estimates of the QSO luminosity function in discrete redshift ranges and show how these observations differentiate between models of QSO evolution. We have also investigated the clustering of QSOs in this complete sample by estimating the QSO 2-point correlation function and we use this to derive direct constraints on the homogeneity of the Universe at large scales.

1. BASIC DATA

The data on which this paper is based are COSMOS (Stobie et al. 1979) machine measurements of deep U and J U.K. Schmidt plates. We now have U and B photometry on 7 $4^\circ\!.5 \times 4^\circ\!.5$ widely scattered high latitude fields. The B photometry is calibrated using a CCD to $B \sim 21^m$. The U calibration goes less deep ($B \sim 18^m\!.5$) and here we have calibrated at the faint limit on the assumption that the U-B colours of halo stars do not change significantly between $B = 18^m\!.5$ and $B = 21^m$. On the one field where we have U photometry to $U = 20^m$ this assumption proved reasonable and so presumably it will hold good on our other high latitude fields. With the limits $U\text{-}B \leqslant -0^m\!.35$ and $B \leqslant 21^m$ we find our samples produce approximately 100 UVX stars per square degree. As described later the spectroscopic surveys show that ∿ 40% of these stars are QSOs.

The initial use of these samples was to test the claim by Seldner and Peebles 1979 that high redshift QSO's in the Burbidge et al. 1977 catalogue are preferentially detected near low redshift Lick catalogue galaxies (Shanks et al. 1983). We have now checked the galaxy-QSO cross-correlation function on 5 fields with 'eyeballed' objective prism QSO surveys and on the above 7 COSMOS/UKST UVX catalogues (here restricted so that they are 70% QSO dominated). The result is that

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nowhere do we find a positive cross-correlation between galaxies and QSO's and so we cannot confirm the Seldner and Peebles result. If anything we find an anticorrelation, with the QSO density in both the objective prism and the UVX samples being 30% lower in the vicinity of average galaxy groups and clusters. This confirms our earlier result from a smaller sample and the interpretation is that dust in low redshift galaxy clusters is obscuring line-of-sight QSO's at cosmological distances. Because of the steepness of the QSO number counts at magnitudes brighter than $B = 20^m$ the average amount of dust absorption needed in each cluster is only $0\overset{m}{.}2$ in the B band.

2. THE SPECTROSCOPIC SURVEYS

We next proceeded to make spectroscopic surveys of subsets of the above UVX samples. As shown by Véron (1983) the UVX technique selects over 95% of QSO's in the redshift range $0 \leqslant Z \leqslant 2.2$. Because of this completeness redshift surveys of UVX QSO's have great potential for investigations of the QSO luminosity function and its evolution with redshift.

We first made a $B \leqslant 19^m$ survey at the AAT using conventional spectroscopic techniques and in 4 nights observing identified 23 QSO's out of 60 UVX stars observed (see Boyle et al. 1985). However, our observing efficiency improved dramatically with the advent of the FOCAP fibre coupler (Gray 1983) at the AAT which enables 45 UVX stars to be observed simultaneously. In 4 clear nights at the AAT we surveyed $\sim$ 500 UVX $B \leqslant 21^m$ stars in 12 40 arcmin diameter fields, observing at least 1 fibre field in 6 of our U.K. Schmidt fields. Of these 500 UVX stars, 170 proved to be broad line QSO's and we obtained unambiguous redshifts for 85% of these. Six QSO's showed broad absorption lines. We also found 22 narrow emission line galaxies ($Z \leqslant 0.42$), 13 White Dwarfs with the rest of the sample being halo stars. The overall QSO number redshift relation is reasonably flat between $0.4 \leqslant Z \leqslant 2.2$ with no peaks that are obviously due to redshift selection or any other effect.

3. QSO COUNTS AND LUMINOSITY FUNCTION

Figure 1 shows the differential number counts of the spectroscopically confirmed QSO's ($Z \leqslant 2.2$) in our fibre survey, together with the counts from several other authors. For $B \leqslant 19\overset{m}{.}5$ our n(m) relation has a slope consistent with the steep $0\overset{m}{.}86$ slope fitted by Braccesi et al. 1980 to other counts in this magnitude range. However, beyond $B = 19\overset{m}{.}5$ our QSO counts turn over in reasonable agreement with the fainter counts of Koo (1986). Cavaliere et al. (1983), Koo (1983) and Marshall et al. (1983a) have suggested that such a feature may be inconsistent with a pure density evolution model for the QSO's and also that the turnover in the counts may indicate a similar turnover in the QSO luminosity function. As we shall see when we consider the QSO luminosity function, we agree with this interpretation of the counts. The integral sky densities of QSO's we find are 26 ± 3 deg^{-2} at

$B = 20^{m}.5$ and $40 \pm 4\ \mathrm{deg}^{-2}$ at $B = 21^{m}.$ The field-to-field variation is consistent with a Poisson error distribution, implying a fairly isotropic distribution of QSO's on the sky.

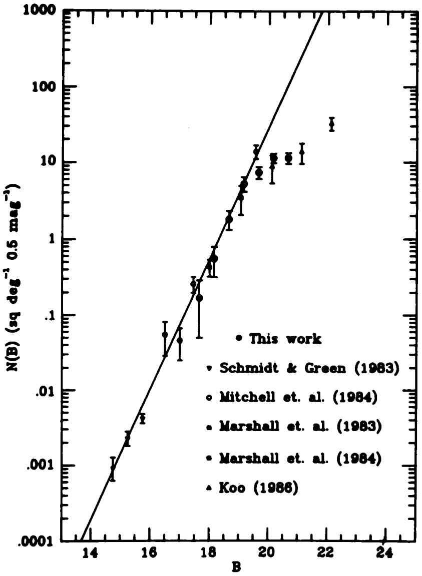

Fig. 1. Differential number count for spectroscopically confirmed QSO's.

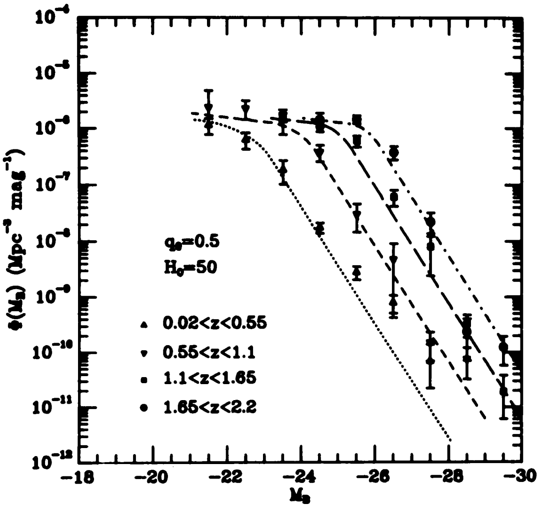

Fig. 2. QSO luminosity functions derived from our surveys combined with those of Schmidt and Green (1983), Marshall et al. (1983) and Marshall et al. 1984.

Since we have a large number of QSO's we can directly estimate the QSO luminosity function over a range of discrete redshift intervals. Figure 2 shows the results for the luminosity function based on our own and previous redshift surveys of UVX QSO's. (The details of the estimation procedure will be described elsewhere). Bright surveys such as that of Schmidt and Green (1983) dominate these estimates at high luminosities whereas at fainter luminosities our own survey dominates. We first note that at intermediate magnitudes there is good agreement between our luminosity function results and the other authors'. Secondly, in each of the 4 redshift bins in Figure 2, we see evidence for a feature in the QSO luminosity function; in each bin the luminosity function turns over to a flatter slope at faint absolute magnitudes. Finally, the luminosity function is seen to move predominantly in the luminosity direction with redshift, in the sense of increasing luminosity towards higher redshift.

Before further discussing these results we note that it is an intriguing coincidence in our data that the effect of evolution on the QSO luminosity function in the range $0.4 \leqslant Z \leqslant 2.2$ is just enough to cancel the effects of increasing distance. It is this cancellation which produces a turnover in the number counts as sharp as is observed, the feature in the luminosity function at each redshift always occurring in apparent magnitude at B ∿ $19^{m}.5$. This re-emphasises the already well known fact that the Hubble diagram of optically selected QSO's shows an extremely poor correlation between apparent magnitude and redshift.

The results in Figure 2 suggest that QSO evolution is well represented phenomenologically by pure luminosity rather than density evolution. We have also shown elsewhere (e.g. Boyle 1986 thesis) that our QSO luminosity function when extrapolated to z = 0 is not inconsistent with the luminosity function of nearby Seyfert galaxy nuclei as derived, for example, by Weedman (1986). The simplest model which is consistent with these observations is that all QSO's might have been created at a single epoch (z > 2) and that they dim in a manner independent of their luminosity to become the lower luminosity Seyfert galaxy nuclei which we see at the present day. However, this would imply that QSO's are long-lived and therefore have very large energy requirements. This could in the standard picture, result in some Seyfert nuclei containing very massive (10^{9} - 10^{10} $M_{\odot}$) black holes at the present time. Although this mass range is in good agreement with the inferred mass of the black hole in the galaxy NGC 4151 (Ulrich et al. 1984) it could still be that the simplest pure luminosity evolution model will turn out to be too naive an interpretation of our results. The future theoretical challenge is, therefore, to make luminosity function predictions for alternative physical models where the birth and death rates of short lived QSO's <u>are</u> significant to evaluate the real strength of the present evidence for a pure luminosity evolution model.

4. THE SPATIAL CLUSTERING OF QSO's.

We finally used our redshift survey to estimate the spatial correlation function, $\xi_{qq}(r)$, for QSO's and this is shown in Figure 3. At small scales (< $10h^{-1}$ comoving Mpc) the statistics are poor but since we observe 11 QSO pairs in this range of separations whereas on a random hypothesis we expect only 4, there is tentative (3σ) evidence for QSO clustering. Even on a model where we assume QSO's cluster like galaxies and that the clustering pattern is stable at scales below $10h^{-1}$Mpc to z = 2.2 we expect to see only ∿ 5 QSO's and so there is also tentative evidence that QSO's may cluster more strongly than galaxies. It would be interesting if the QSO correlation function proved to be as high as the correlation function of rich galaxy clusters because this might indicate that QSO's are associated more with superclusters rather than clusters of galaxies. However, a larger QSO redshift survey will be required before any detailed conclusion can be drawn on the small scale clustering of QSO's.

At larger scales the QSO correlation function produces new limits on the homogeneity of the Universe to $1000h^{-1}$ Mpc. At present the results are consistent with a Poisson distribution for QSO's at all scales above $10h^{-1}$ Mpc. However, from other considerations the

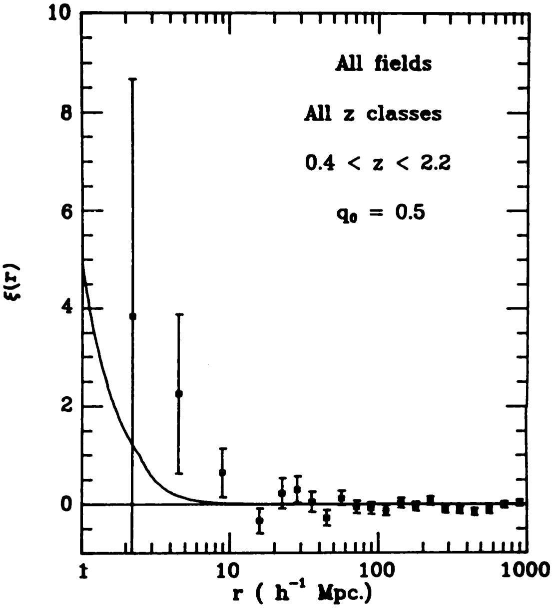

Fig. 3. QSO 2-point correlation function, $\xi_{qq}(r)$. r is a comoving coordinate computed assuming $q_o = 0.5$. The solid line is the expected galaxy correlation function at z = 1.5.

expected amplitude of any inhomogeneity in $\xi_{qq}(r)$ is still of the order of the error bars in Figure 3. In a larger QSO survey it would be interesting to see if there exist any weak features in ξ_{qq} which are also detected in the galaxy correlation function at low redshift. If so then it will not only be very important for theories of galaxy formation but it could also afford a powerful test for q_o; at z = 1.5 any feature in ξ_{qq} moves by 50% in comoving separation between models which assume $q_o = 0.1$ and $q_o = 0.5$ and so comparison between a feature's location at high and low redshift produces a q_o test. The determination of the form of the QSO correlation function at both large and small scales therefore forms a primary motivation for making further faint QSO redshift surveys in the manner described here.

5. CONCLUSIONS

Using our COSMOS/UKST UVX QSO surveys we have found evidence for dust absorption of high redshift QSO's by low redshift galaxy groups and clusters. Consideration of the number counts and luminosity functions of our spectroscopially confirmed QSO's suggest a pure luminosity evolution model which could imply that QSO's are long-lived. Finally correlation analysis of the clustering of QSO's in our redshift survey has shown tentative evidence for QSO clustering at scales up to $10h^{-1}$ Mpc but a reasonably homogeneous QSO distribution at larger scales.

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DISCUSSION

Segal : The luminosity evolution estimated by Marshall et. al., which you cite, as well as that for the X-ray sample of AGNs of Maccacaro et. al., is closely similar to the simple difference between the non-evolutionary Friedman prediction and the Chronometric prediction, - though the latter has a smaller rms deviation in its magnitude-redshift residuals. Do you have any explanation for this ?

Shanks : I thought that Marshall found that the Chronometric model was inconsistent with V/V_{max} results obtained from the bright quasar samples.

Canizares : There appear to be statistically significant deviations from a powerlaw in the luminosity functions at the high luminosity end. Would you please comment on this ?

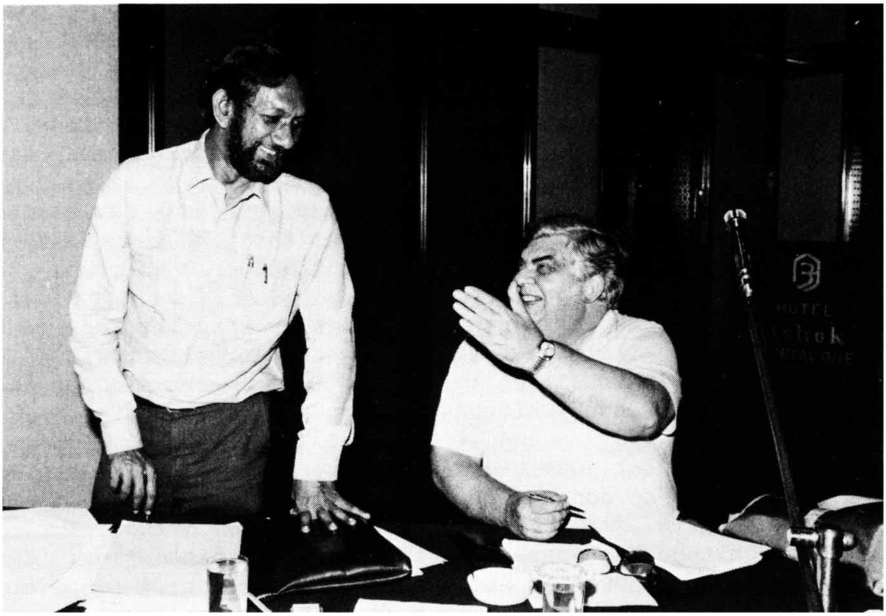
Shanks : In the magnitude range up to 3^m brighter than the knee in the luminosity function a single powerlaw provides an excellent fit at all redshifts. At higher luminosities the statistical errors are too large to allow any meaningful conclusions to be drawn.

Wampler : Did you correct your broad-band blue magnitudes for the emission lines. This could be done using your spectra.

Shanks : The magnitudes are corrected to the rest B band using a K-correction based only on a powerlaw continuum. In the redshift range of interest here I expect the contribution of the emission lines to the B magnitude to be small especially since our photometry is based on the very broad IIIaJ photographic blue band.

Rees : I would like to ask what inferences you think can be drawn from the clustering your data show. As you know, this is a potentially important discriminant among different cosmogonic schemes. In the "pancake" picture, quasars would be highly clustered at formation (though the clusters should become few and far between as one looks back to the highest z, when only the rare "high-σ" pancakes have collapsed); in a simple heirarchical clustering scheme, there would be less clustering, on a given comoving scale, at higher z; in schemes involving "biasing", the clustering may be enhanced and less sensitive to z.

Shanks : At small scales it is important to see whether the QSOs cluster as strongly as Abell galaxy clusters for this could imply that QSO's are associated with superclusters. At present the data are not inconsistent with this idea, although the errors are large and more data are needed. In bigger samples it will also be possible to divide the data by redshift to directly study the evolution of the QSO clustering which might also constrain Ω_o.



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