OBSERVATIONS OF GALAXY AND QSO CLUSTERING

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ABSTRACT

We present correlation function results from galaxy and QSO redshift surveys. The galaxy correlation function shows evidence for a possible 'shoulder' feature in $\xi(s)$ at $s = 2h^{-1}$ Mpc. At scales between 10 and $100h^{-1}$Mpc the correlation function remains close to zero and shows no evidence for any large scale galaxy clustering. The QSO correlation function detects strong QSO clustering for scales $s < 10h^{-1}$ Mpc. At larger scales ($10 < s < 1000h^{-1}$ Mpc) no evidence of significant QSO clustering is seen.

1. INTRODUCTION

The aim of this paper is to address the main issue of this conference; to determine the extent of the Universe's large scale structure. We do this firstly by reporting preliminary correlation analysis results from a redshift survey of $\sim$ 700 B $\lesssim$ 16.75 mag galaxies. Then we go on to discuss similar results from a redshift survey of $\sim$ 400 B $\lesssim$ 21mag QSOs.

2. GALAXY REDSHIFT SURVEY RESULTS

The galaxy redshift survey is the Durham/SAAO survey of Metcalfe et al. (1987). This survey is an extension of the Durham/AAT Redshift Survey of Peterson et al. (1986) and made in a similar way except that a one-third sampling procedure was adopted so that a bigger area of sky (nine 3.75 x 3.75 deg^2) fields could be observed in the given observing time. The B $\lesssim$ 16.75 mag limit means that our average survey redshift is $\bar{z} \sim$ 0.05 ($150h^{-1}$ Mpc). Redshifts for 263 galaxies were obtained using a Reticon detector on the SAAO 74" telescope and the velocity accuracy is $\pm$ 120 kms^{-1}. We include in our analyses the fully sampled Durham/AAT redshift survey and also the fully sampled survey of $\sim$ 100 galaxies in a single 5.4 x 5.4 deg^2 field of Parker et al. (1986)

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which was made in very similar fashion to our own.

The 2-point velocity correlation function ($\xi(s)$) results for this 15 field ($\sim$ 700 galaxy) redshift survey are shown in figures 1a and 1b.

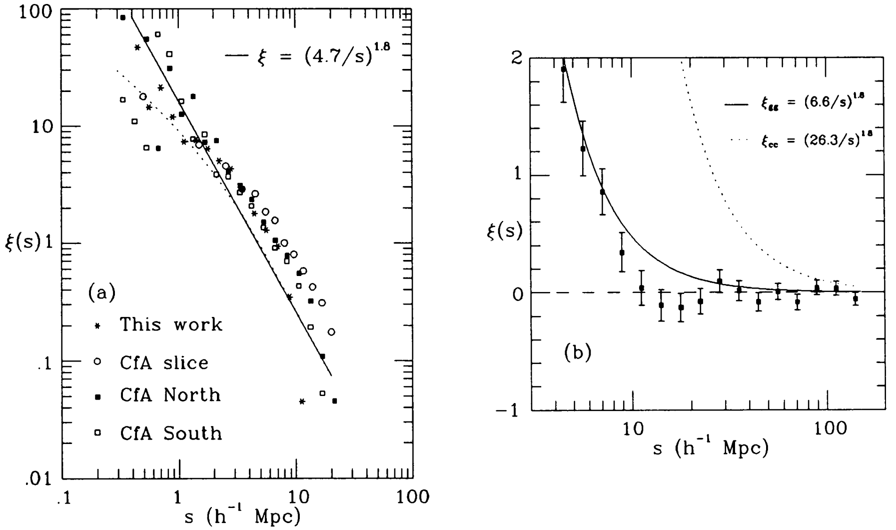

Figure 1(a). The galaxy correlation function at small separations compared to other results and to simple models (see text).
(b) The galaxy correlation function at large separations. The solid line represents $\xi(s)$ extrapolated from the range $2<s<7h^{-1}$ Mpc. The dashed line represents the Abell cluster $\xi(s)$.

The results include the contribution from the cross-field correlation function which improves our estimate at scales larger than $40h^{-1}$ Mpc. The error bars come from simulations; field-to-field errors give very similar results. The correlation function is normalised using the average space density of galaxies in the sample; here as elsewhere the assumption is that the sample is "fair".

From the small scale results in Figure 1a we see that $\xi(s)$ does not resemble a -1.8 power-law with clustering length, $r_o = 4.7h^{-1}$ Mpc (the solid line in Figure 1a) as expected from $\xi_v(\sigma,\pi)$ (Peebles, 1979) analysis of the small scale correlations in this redshift survey (Hale-Sutton et al. 1987) and from analyses of angular surveys (e.g. Groth and Peebles, 1977). For $s < 2h^{-1}$ Mpc this result is expected since the effect of the known 300 kms^{-1} rms galaxy velocity dispersion is to smooth out small-scale correlations. The dashed line shows a model where this smoothing has been taken into account. Although this model reasonably explains the small-scale behaviour of $\xi(s)$ it still seriously under-estimates the observed $\xi(s)$ at scales between $2 < s < 7$ h^{-1} Mpc. The observed excess correlation represents a 3.8σ effect over this model (Hale-Sutton et al. 1987). Such an effect was noted by Bean (1983) and Shanks et al. (1983) in the Durham/AAT

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redshift survey and it is also seen in the new surveys. Also marked in Figure 1a are the results from the Northern and Southern CfA surveys (Davis and Peebles, 1983, Davis, 1987) and also from the "slice" survey of de Lapparent et al. (1987). It is apparent that all these surveys show a similarly enhanced $\xi(s)$ amplitude ($r_o \sim 7h^{-1}$ Mpc) in the range $2 < s < 7h^{-1}$ Mpc. As noted by Bean (1983) such an enhancement could exist in $\xi(r)$ as a real spatial feature and still be consistent with the power-law form of the projected correlation function; projection effects in the presence of a "break" at larger separations can efficiently smooth out such a "shoulder" feature (see also Soneira & Peebles 1978). If the observed behaviour indicated a non-power law feature in the spatial correlation function then its importance would be immense since, previously, the smooth behaviour of $\xi(s)$ has always been taken as a strong argument for scale-free galaxy clustering (but see Shanks 1979). However, it is also possible that such a feature may only appear in the velocity correlation function, being caused by the effects of infall or streaming velocities. The detection of such infall would also have important consequences for cosmology and it will be important to discriminate between these alternative explanations. At present we confine ourselves to the conclusion that the observational case for the "shoulder" feature is becoming increasingly compelling at least in the case of the velocity 2-point correlation function, $\xi(s)$.

At larger scales ($s > 7h^{-1}$ Mpc) our $\xi(s)$ breaks away to zero more quickly than a -1.8 power-law (see Figure 1b). As can be seen the observations lie $\sim 2\sigma$ below the model with $r_o \simeq 7h^{-1}$ Mpc in Figure 1b. For $s > 10h^{-1}$ Mpc the correlation function is essentially zero with no deviation which is significant at more than the 2σ level. Thus if any large scale structure exists at these separations it must contrive to produce a galaxy correlation function which has $\xi(s>10h^{-1}$ Mpc) $\lesssim 10\%$ as a 1σ upper-limit. This result is in disagreement with the strong positive clustering shown at large scales by the Abell clusters (Hauser & Peebles, 1973, Bahcall & Soneira, 1983) whose $\xi(s)$ result is shown as the dashed line in Figure 1b. One possible doubt about using clusters to trace the mass distribution is that their correlation function amplitude may be very prone to enhancement by statistical biasing of the type described by Kaiser (1984). Of course it is still possible that very long wavelength fluctuations have been filtered out of the galaxy result by our use of a "local" (i.e. depth $\sim 150h^{-1}$ Mpc) background galaxy density to normalise $\xi(s)$. If so then such fluctuations can only exist on scales larger than $150h^{-1}$ Mpc. In any case the existence of such large scale fluctuations will be tested using the QSO survey as described next.

3. THE QSO REDSHIFT SURVEY

The QSO redshift survey was made using the fibre optic coupler FOCAP (Gray, 1984) at the Anglo-Australian Telescope. Spectroscopically surveying 50 ultra-violet excess QSO candidates in a single 9000 sec

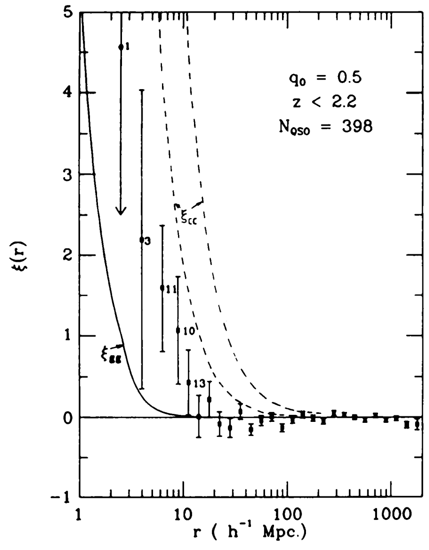

Figure 2. The QSO correlation function. The solid line represents the galaxy correlation function at z∿1.5 predicted from a 'stable' evolutionary model. the dashed lines similarly represent the Abell cluster ξ(s) under 'stable' and 'comoving' evolutionary models.

exposure, Boyle et al. (1987a) have identified ∿ 400 $0 < z < 2.2$ QSOs in 32 40' diameter fibre fields situated in 7 randomly chosen UK Schmidt telescope fields in the Southern and Northern Galactic Caps. Unambiguous redshifts were obtained for 85% of the QSOs. Results on the QSO luminosity function and the clustering correlation function have already been presented (Boyle et al. 1987b, Shanks et al. 1987a). Here we discuss the preliminary clustering results from the extended survey of 400 QSOs.

At small scales ($s < 10h^{-1}$ comoving Mpc, $q_o = 0.5$) we find evidence for strong QSO clustering. Whereas on a random hypothesis we expect to find 10.4 QSO pairs in this separation range, we actually observe 25 (independent) QSO pairs representing a 4.5σ detection of QSO clustering. A model where clusters are stable below a present day ξ(s) break scale of $5h^{-1}$ Mpc predicts 11.5 QSO pairs and even a comoving evolutionary model predicts only 15.6 QSO pairs in this range. Thus the QSO clustering seems significantly stronger than would be predicted by these simple models. On the other hand as can be seen in Figure 2 the QSOs seem less clustered than would be predicted by reasonable evolutionary models for the Abell cluster ξ(s) at our average redshift of 1.5 (with 60 and 159 QSO pairs predicted with $s < 10h^{-1}$ Mpc in stable and comoving evolutionary models). One interpretation of this result is that the preferred QSO environment may be richer than average galaxy groups i.e. an intermediate environment

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between the field and rich cluster populations. Some support for this interpretation comes from the work of Yee & Green 1984 who found this result from CCD imaging observations around low redshift QSOs (see also paper by Boyle et al. 1987, this volume). However, it could still be that QSOs are randomly sampling a galaxy distribution which is evolving differently from the simple models considered above. The extended survey should allow some discrimination between the various models from direct observation of the evolution of $\xi(s)$ with redshift. The preliminary result is that, in contrast to the claim by Shaver et al. (1987, this volume) who used a different dataset, a non-evolving comoving $\xi(s)$ of larger amplitude than $\xi_{gg}(s)$ is still consistent with our data but the statistics may still be too poor to rule out any model. A full discussion of the constraints on the evolution of the QSO correlation function will be given elsewhere (Shanks et al. 1987b).

At larger scales Figure 2 shows that there is no significant evidence of QSO clustering at any separation larger than $10h^{-1}$ Mpc. The amount of large scale clustering shown by the QSOs is again much smaller than shown by the Abell clusters and is much more in line with the result given by the galaxies. The QSO data have the advantage of sampling structure over a huge redshift range ($0 < z < 2.2$) and is therefore even less likely than the galaxy data to be biased by 'local' features. It is this large redshift range which enables us to reliably estimate $\xi(s)$ in the range $100 < s < 1000h^{-1}$ Mpc; only QSOs are capable of directly probing the homogeneity of the Universe at these scales. It should be noted that the average redshift of the QSO survey is $\bar{z} \sim 1.5$ and there may have been significant amounts of evolution in $\xi(s > 10h^{-1}$ Mpc) before the present day especially in the $\Omega_o = 1$ model. Again the extended survey will allow us to directly inspect the amount of evolution at large scales as a function of redshift and this work is also currently in progress.

4. CONCLUSIONS

Our galaxy redshift survey data (Metcalfe et al. 1987) has given evidence for a non power-law "shoulder" feature in the velocity correlation function, $\xi(s)$ for $2 < s < 7h^{-1}$ Mpc. If a real spatial feature then this would be evidence that the galaxy distribution is not scale-free. If the feature is caused by peculiar velocities then it could be taken as a detection of infall of galaxies into clusters. At $s > 7h^{-1}$ Mpc the galaxy correlation function breaks away to zero and for $10 < s < 100h^{-1}$ Mpc no significant evidence for galaxy clustering is seen.

The QSO redshift survey (Boyle et al. 1987a) gives a 4.5σ detection of QSO clustering at $s < 10h^{-1}$ Mpc (comoving) at a level stronger than that expected for galaxies on simple assumptions about galaxy clustering evolution. In the range $10 < s < 1000h^{-1}$ Mpc no significant evidence for any clustering in the QSO spatial distribution is detected. Thus at large scales both the galaxy and QSO correlation functions detect no new evidence for large scale structure. Although these results do not rule out the existence of large scale structure they do suggest that the power in the large scale fluctuations may be smaller if galaxies and QSOs prove to be better tracers of the Universal mass distribution than Abell clusters.

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