Chapter 7

Conclusions

Our aim in this thesis has been to use the clustering of QSOs as a probe of cosmology. We are particularly interested in making new estimates of the parameters which govern the form and evolution of large-scale structure in the Universe. We have used QSO catalogues that are already available to obtain initial results, and we have then begun the process of constructing a new, large, QSO catalogue which will allow more definitive answers to our questions.

7.1 QSO Environments

A first important question to be answered before we make cosmological inferences is: how do QSOs trace the mass distribution? In Chapter 2 we address this question by cross-correlating a sample of ~ 150 QSOs from optically and X-ray selected catalogues with faint, $b_J < 23$, galaxies. These data allow us to probe the galaxy clustering environment of QSOs out to $z \sim 1.5$. Far from giving a positive correlation, the QSO-galaxy cross-correlation function is marginally negative even at $z < 1.5$ (-0.027 ± 0.020 at $< 120''$). Colour information shows that the anti-correlation is most significant between the QSOs and the red galaxy population.

We have therefore constructed a model to predict the QSO-galaxy cross-correlation. To do this we need to know the form of the $N(z)$ distribution of $b_J < 23$ galaxies; fortunately this is now well constrained from Keck data (Cowie et al., 1995). Clustering evolution is also included in the model. A case in which QSOs exist in rich cluster environments is comfortably ruled out by comparing our model to the data. The cross-correlation function is more consistent with a 'normal' galaxy environment. If the small anti-correlation is interpreted as an effect of gravitational lensing, then this conclusion is not altered. In this case, the data are only $\sim 1\sigma$ below the low clustering amplitude models, while the high amplitude models are still comfortably rejected. We therefore conclude that QSOs do not trace a highly biased distribution, such as galaxy clusters. The results are in line with previous observations of radio-quiet QSOs at lower redshift (Ellingson et al., 1991; Boyle & Couch, 1993; Smith et al., 1995) which suggest that QSOs tend to exist in *average* galaxy environments and are not highly biased.

7.2 Evolution of QSO Clustering

In Chapter 3, several presently available QSO surveys were combined to place constraints on cosmology from the evolution of their clustering properties. We used the LBQS, Durham/AAT, CFHT and ESO/AAT QSO surveys, a total of > 1500 QSOs over the redshift range $0.3 < z < 2.2$. This combined data set has a clustering amplitude $\bar{\xi}(10\ h^{-1}\ \mathrm{Mpc}) = 0.83 \pm 0.29$ for $\Omega_0 = 1$ at $\bar{z} = 1.27$. On larger scales, from $\sim 100 - 1000\ h^{-1}$ Mpc, the limit on a detected signal in ξ is ± 0.025.

A model of clustering evolution which includes the effect of bias was used to estimate the expected QSO clustering amplitude at the present day. The measured clustering amplitude at high redshift could then be compared to present day galaxy clustering and the clustering of low redshift Seyfert galaxies. The maximum present day QSO correlation length is $r_0 = 9.23 \pm 1.11$ (for $\gamma = -1.8$), assuming $\Omega_0 \leq 1$ and that galaxies are not anti-biased on $\sim 10\ h^{-1}$ Mpc scales. If the low redshift Seyferts and high redshift QSOs are from a similarly clustered population, the best fit is a slowly evolving model, which implies low Ω_0 and/or high bias for both galaxies and QSOs. By contrast, comparisons of QSO clustering to the CMB measurements of *COBE*, using CDM-type power spectra suggest relatively low bias. Although this might be taken as evidence for a low Ω_0 model, the statistics still allow an $\Omega_0 = 1$ world model with $b_{q\rho} \simeq b_{g\rho} \simeq 2$. The 2dF QSO Redshift survey will be needed to make further progress on these questions.

7.3 Lensing of QSOs by Galaxy Clusters

Various authors have noted the apparent correlation between nearby galaxies and distant QSOs. This is most easily interpreted in terms of gravitational lensing. We consider the anti-correlation found by Boyle et al., (1988) in terms of gravitational lensing in Chapter 5. Using an isothermal sphere lens model, the required velocity dispersion is $\sigma = 1286^{+72}_{-91}\mathrm{kms}^{-1}$. With an isothermal sphere plus uniform density plane, the velocity dispersion is $\sigma = 1205^{+85}_{-108}\mathrm{kms}^{-1}$, while the plane density is $\Sigma_c = 0.0779 \pm 0.0232h\ \mathrm{g\ cm}^{-2}$. Both these values are considerably larger than expected for the poor clusters and groups used by BFS88. We extend this investigation to the UVX catalogue prepared for the 2dF QSO redshift survey, in combination with the ACO (Abell et al., 1989) and APM (Dalton et al., 1997) cluster catalogues. Due to the small number of clusters available, no significant result was found. We find that the anti-correlation between QSOs and faint, $b_J < 23$, galaxies in Chapter 2 can also be interpreted as due to gravitational lensing. Similarly, in this case, an extreme model is required to account completely for the anti-correlation. The existence of a small amount of dust in clusters could reduce estimated masses, bringing them into line with other cluster mass estimates.

A more convincing test will be possible, given the full 2dF QSO catalogue (without contamination) and a complete galaxy catalogue across the survey area. This should allow us to test whether the large masses found from statistical lensing investigations are indeed correct.

7.4 The 2-degree Field QSO Redshift Survey

Chapters 4 and 6 are concerned with preparing a new QSO redshift survey which is currently being undertaken using the 2dF facility at the AAT. This survey is expected to obtain redshifts for ~ 25000 QSOs, over an order of magnitude larger than current QSO surveys. Chapter 4 discusses the production of the UVX catalogue which forms the basis of the candidate selection in the Southern portion of the survey. The survey is based on UKST photographic plates in b_J and u, scanned by APM. These have been corrected for field effects and calibrated using CCD sequences obtained in each UKST field. Several tests have been carried out in order to determine the photometric accuracy of the catalogue. Estimates of completeness, based on previously known QSOs in our survey area, suggest that the survey will be $\sim 80\%$ complete over the redshift range $0.3 < z < 2.2$. This corresponds to a QSO surface density of ~ 34 deg^{-2} at a magnitude limit of $b_J = 21$.

In Chapter 6 we analyse the first spectroscopic observations of the UVX catalogue. Observations of bright candidates, with $17 \leq b_J < 18.25$, have been made using the FLAIR instrument on the UKST. The fainter candidates have been observed using the 2dF facility at the AAT. The combined data set contains 167 QSOs. In particular, the Southern 2dF observations contain 114 QSOs, that is, 50% of the candidates observed. The estimated completeness of this data is $71.1 \pm 7.1\%$, lower, although not significantly, than predicted in Chapter 4. A possible solution to the general problem of incompleteness is to include UKST r plates in our candidate selection process. We demonstrate that in one field, which contains a number of previously known QSOs, selection based on $b_J - r$ and $u - b_J$ colours increases the completeness from 80% to 93%. This is obviously a significant improvement and observations to test the new UBR catalogue are currently underway.

7.5 The Future: Science from the 2dF QSO Redshift Survey

The 2dF QSO Redshift Survey will allow a wide ranging and detailed investigation of the Universe at high redshift. The primary scientific aims are:

- To measure the power spectrum of density fluctuations from small scales (a few Mpc) to the large scales sampled by *COBE*, $\sim 1000\ h^{-1}$ Mpc.

- To measure the rate of QSO clustering evolution, in order to constrain Ω_0 and QSO bias.

- To apply geometric tests to measure the cosmological constant, Λ.

As described in Chapter 1, we expect the power spectrum to turn over to $P(k) \sim k$ on the largest scales. On the scales probed we should see this effect in the 2dF QSO Survey. We will be able to compare the shape of the QSO power spectrum to a wide range of theoretical models. Matching the QSO power spectrum to CMB measurements on large scales should also allow a *direct* measurement of QSO bias. Chapter 3 shows how Ω_0 and bias can be constrained from clustering evolution using a relatively small sample of QSOs. The 2dF sample will allow accurate measurements of these parameters. The measurement of the cosmological constant uses a geometric test (Alcock & Pacynski, 1979; Phillipps, 1994; Ballinger et al., 1996) similar to that outlined in Chapter 3, which uses the fact that when the wrong cosmology is assumed, clustering is distorted from its average spherical distribution. The distortion is particularly sensitive to the value of the cosmological constant.

The 2dF QSO Redshift Survey will supply us with a picture of the Universe to a fraction of its current age. The ability to *look back in time* over great distances gives us new opportunities to further our understanding of the Universe and the physical processes which control its evolution.