THE LUMINOSITY DEPENDENCE OF CLUSTERING

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Abstract. The PSCz redshift survey and the ongoing Two-Degree Field Galaxy Redshift Survey (2dFGRS) are used to look for luminosity dependence of galaxy clustering by measuring the two point correlation functions for sub-samples of the surveys.

An analysis of the PSCz survey finds that galaxies with cooler colours are more strongly clustered than warmer galaxies. Between 1 and 10 h^{-1}Mpc it is found that the redshift-space correlation function, $\xi(s)$, is a factor of ~ 1.5 larger for the cooler galaxies. This is consistent with the suggestion that hotter galaxies have higher star formation rates and correspond to later type galaxies which are known to be less clustered than earlier types. There is a very weak luminosity dependence of clustering with the more luminous galaxies being less clustered than fainter galaxies, but the trend has a low statistical significance.

Results from the 2dFGRS reveal a strong dependence of clustering on intrinsic galaxy luminosity. The most luminous galaxies are more strongly clustered by a factor ~ 2.5 than L^* galaxies, in qualitative agreement with analytic models of galaxy formation.

1 Introduction

Ever since the first galaxy surveys it has been clear that the galaxy distribution is not uniform and that the measured clustering is dependent on the properties of the sample in question. Differential clustering as a function of morphological type, colour, luminosity and wavelength probed have all been measured and imply the existence of biases between the distribution of galaxies and mass. It is this complex distribution of galaxies which galaxy formation models have tried to reproduce. In the era of new large redshift surveys it is now possible to test to much higher accuracy the large scale structure predictions of these models. This talk concentrates on the luminosity dependence of clustering which is perhaps the most controversial of these measurements.

Typical galaxy formation models start with a smoothed random density field, which is left to evolve. It is assumed that galaxies will form at the peaks of this density field and that the mass of the galaxy is related to the peak height. If we then assume that galaxy luminosity is related to galaxy mass we come to the conclusion that brighter galaxies are found at the higher peaks. As higher peaks are more strongly clustered [1], more luminous galaxies should also be more strongly clustered. Hence these galaxy formation models predict the amount of variation in galaxy clustering as a function of absolute magnitude that we should observe. They all show a strong variation over a wide range of magnitudes with a large increase of clustering strength for the very bright galaxies [2]. Although the models do disagree on the exact amount of variation, this effect should be large enough to be observable and the observations may allow us to select the more realistic models.

Many previous studies have claimed to have observed this effect (e.g. [2]) but there have also been plenty of non-detections (e.g. [3]). This controversy is likely due to the limited sizes and small number of galaxies in past surveys which have restricted the accuracy of the measurements. I use two recent, large, but very different redshift surveys to try and resolve this controversy.

2 Using the Infra-Red: The PSCz survey

The publicly available PSCz survey [4] was selected from the *IRAS* Point Source Catalogue and contains nearly 15000 galaxy redshifts to a limiting 60μm flux (f_{60}) of 0.6Jy. The median redshift is $z \sim 0.03$ and the survey covers about 84% of the sky (Figure 1). The main incompleteness is at low galactic latitudes and is due to galactic extinction which is masked out in the analysis. The

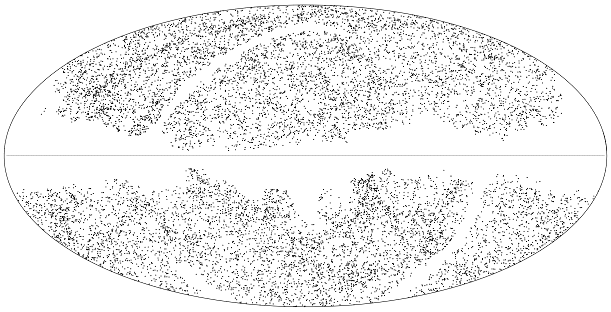

Figure 1: The sky distribution of the PSCz galaxies. The line across the middle is the galactic equator.

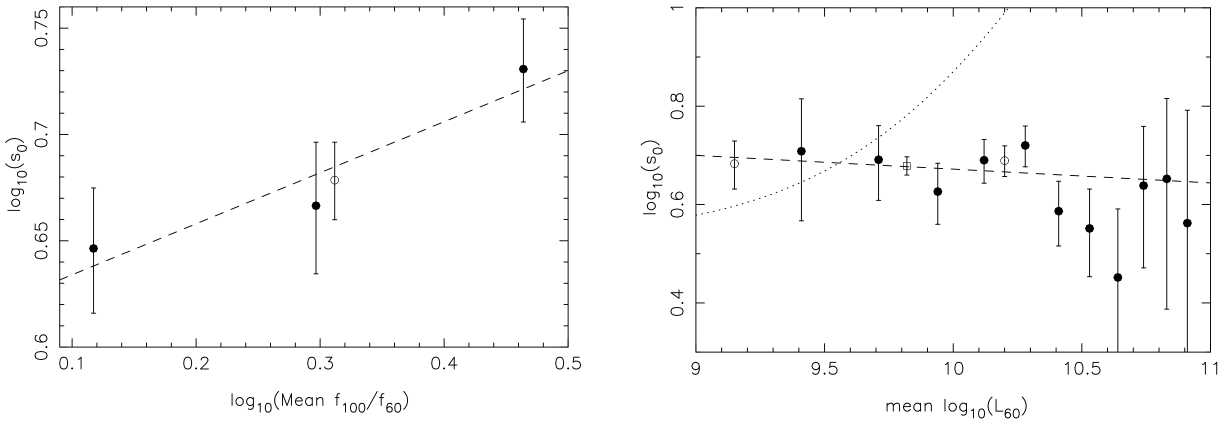

Figure 2: (a) The colour sub-sample results: The filled points are for the three colour sub-samples and the unfilled point is the result for the whole survey. The dashed line is a best fit to the data. (b) The luminosity sub-sample results: The filled points are the volume limited samples, the two circles are the bright and faint sub-samples and the square point is the result for the whole survey. The dashed line is the fit to the colour points converted to luminosity. The dotted line is a model prediction.

redshift-space correlation length, s_0, is measured using standard methods for the whole survey and for various sub-samples of the catalogue.

Galaxies with a high star formation rate (SFR) tend to be bright in the far infra-red (FIR) because of the thermal emission from dust heated by young stars. They will hence have warmer FIR colours and so splitting the survey by colour will test the dependence of clustering on star formation rate.

Figure 2a shows the results for three sub-samples selected on their f_{100}/f_{60} colour. The dashed line is a best fit to these results and it is clear that the clustering amplitude is less for the galaxies with a lower f_{100}/f_{60} ratio, and hence warmer colour. This implies that these warmer, more star-forming galaxies are found outside the dense regions of clusters which is confirmed by the observations that later type optical galaxies are found less clustered than earlier galaxy types.

The results for two luminosity selected samples and a range of volume-limited samples are plotted in Figure 2b. The best fit to the colour sample results is converted to a luminosity prediction via the observed PSCz colour-luminosity relation. This is the dashed line in Figure 2b and it can be seen that it is consistent with the data points. The dotted line is the prediction of a typical galaxy formation model described above and is clearly inconsistent with the data. The conclusion is that the assumption made in the galaxy formation models that galaxy luminosity is related to galaxy mass is not valid in the far infra-red, and that a galaxy's far infra-red luminosity is dominated by its SFR [5].

3 Using the Optical: The 2dF Galaxy Redshift Survey

The 2dF Galaxy Redshift Survey was selected in the b_J band from the APM survey and has a limiting apparent magnitude of $b_J = 19.45$. The survey covers approximately 2000 square degrees and is split

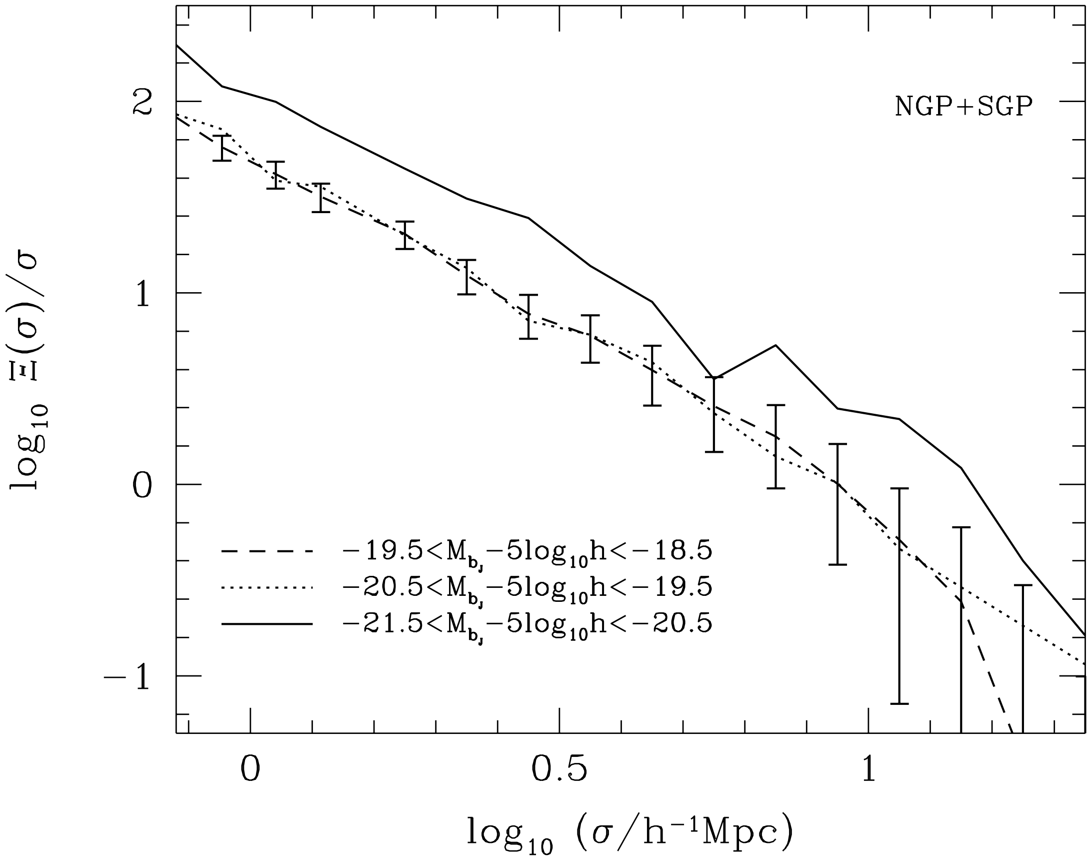

Figure 3: The projected correlation function for a single volume limited sample split into 3 disjoint magnitude slices. The brightest bin shows a clear increase in clustering but all have a similar slope.

into two broad strips, one in the South Galactic Pole region (SGP) and the other in the direction of the North Galactic Pole (NGP). The aim of the survey is to observe a total of 250,000 galaxies and as the survey is still on-going, the results that follow are from an interim study. To date over 170,000 unique galaxy redshifts have been measured, with a median redshift of $z \sim 0.1$. The survey is described in detail in [6], and the preliminary data release is available at `http://www.mso.anu.edu.au/2dFGRS/`. The large number of galaxies, over a large area of the sky, makes the survey ideal for measuring the large scale structure of the Universe. It is also large enough to allow accurate estimates of the clustering to be measured for sub-samples of the data, adding extra dimensions to the output of the survey. It is this fact which makes it ideal for looking for the dependence of clustering on galaxy properties.

The clustering is measured [7] using the projected correlation function, $\Xi(\sigma)$, which is obtained by projecting $\xi(\sigma,\pi)$ onto the σ axis, giving a correlation function measurement free from redshift-space distortions. The real-space correlation length, r_0, can then be measured from $\Xi(\sigma)$.

Figure 3 shows the projected correlation function results for a single volume limited sample defined to include all galaxies with $-21.5 < M_{b_J} - 5\log h < -18.5$. This sample is further split into three disjoint one magnitude slices. The brightest bin (solid line) clearly shows stronger clustering than the fainter two bins over a wide range of scales. The error bars come from the scatter between mock catalogues. Another feature of this plot is that the slopes of the measured correlation functions are very similar. Using a single volume is an important robustness test as the volume probed is the same for each sample and hence the cosmic variance is the same for each line. The disadvantage is that the brighter bins contain a lot fewer galaxies.

To overcome the lack of galaxies in the brighter bins of a single volume, a series of half-magnitude wide volume limited samples are used. They are created by changing the absolute magnitude limits to maximise the number of the very bright galaxies in the brightest bins. Thus the clustering can be measured as a function of median absolute magnitude. The disadvantage here is that different volumes are then being analysed and so could introduce cosmic variance.

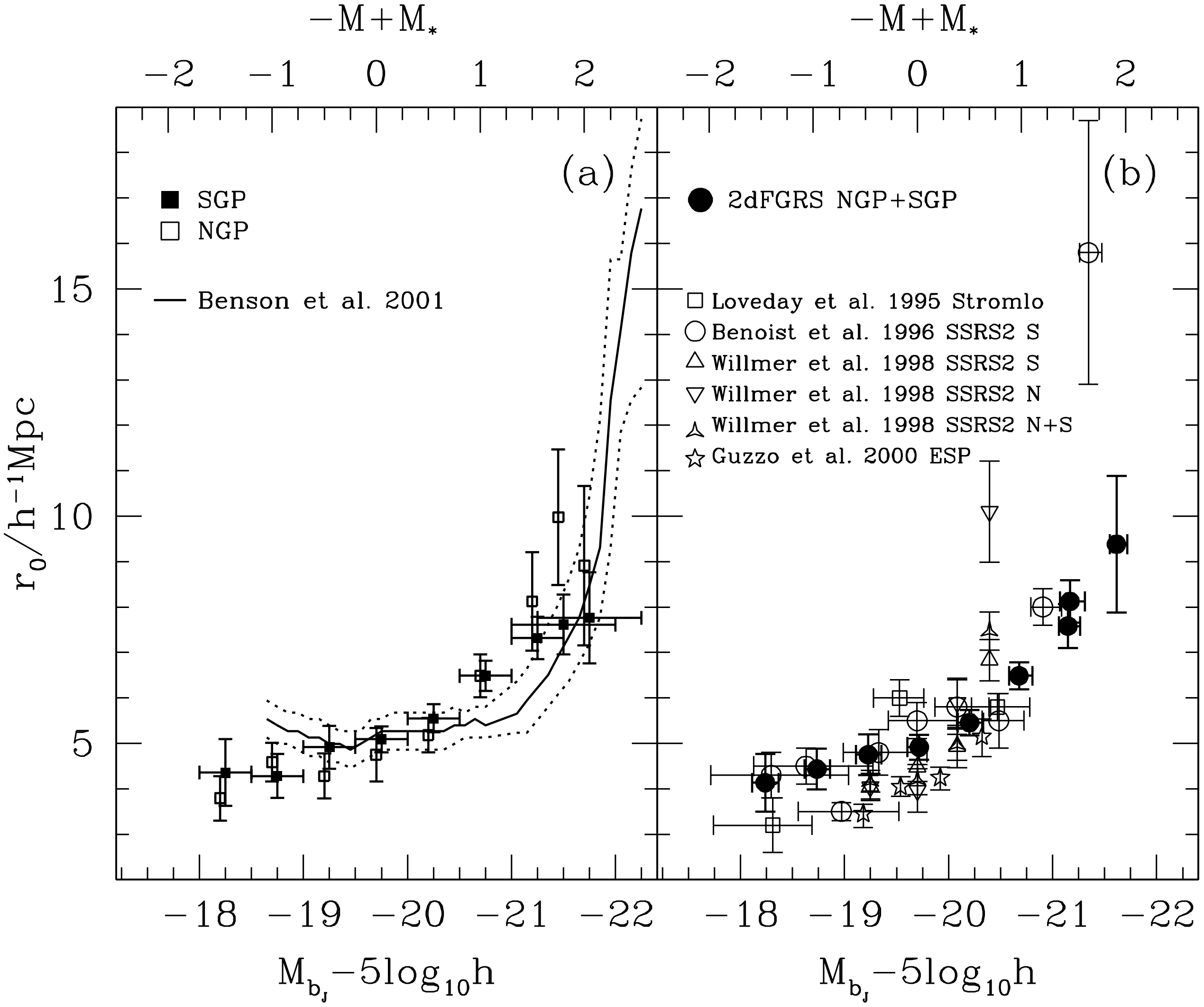

Figure 4: (a) The r_0 measurements for the two independent parts of the survey compared with a semi-analytical model. They are consistent within the errors. (b) The 2dFGRS results compared with the results from other surveys. The error bars are from the scatter between mock catalogues.

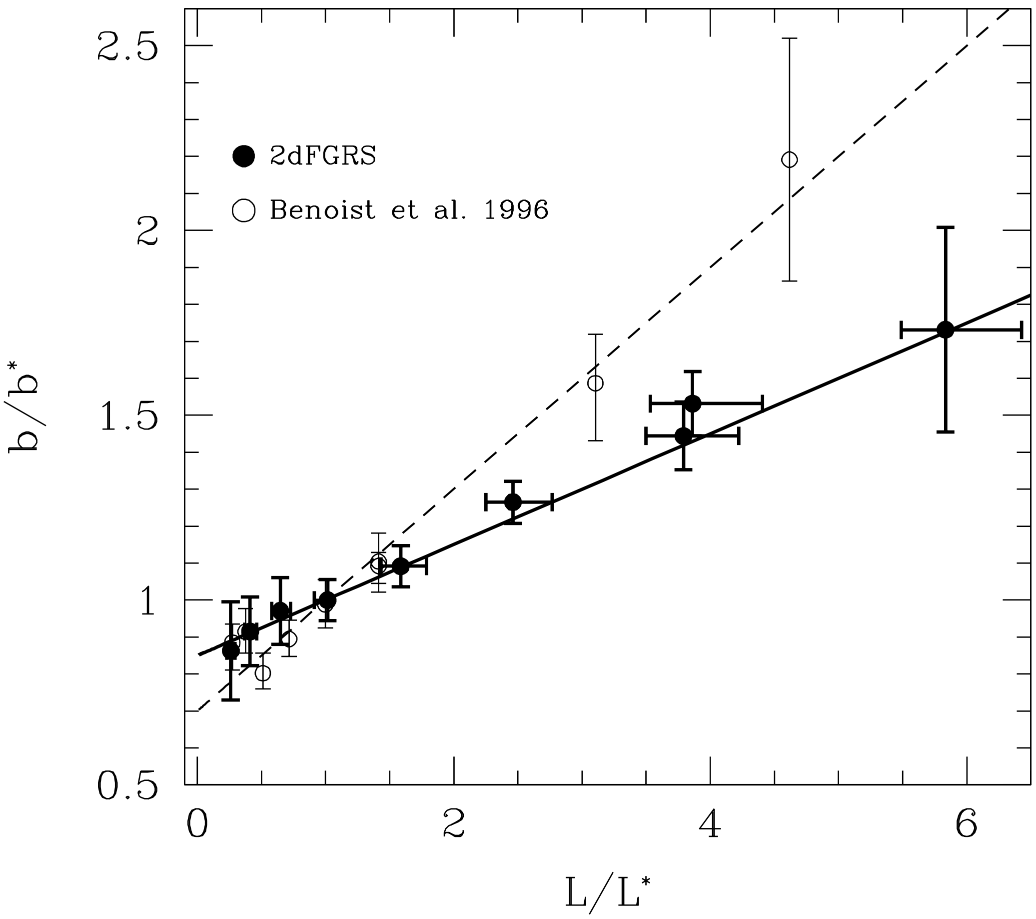

Figure 5: The relative bias as a function of relative luminosity for the 2dFGRS (solid points) compared with the results of [2] (unfilled points), which have been fit by the dashed line. The 2dFGRS results have a shallower slope and are fit by the solid line. The error bars are from mock catalogues.

Figure 4a shows the estimates of r_0 measured independently in the NGP and the SGP for the range of volume limited samples. The results are consistent within the errors and is another important test of the robustness of the clustering effect. In Figure 4b the NGP and SGP measurements have been combined to give the overall 2dFGRS results and these are compared to the results from other surveys. The results confirm the rapid increase of clustering for samples with M brighter than M^*. The error bars are smaller than previous measurements even though the scatter between mock catalogues is used. The Poisson and bootstrap re-sampling methods of previous surveys will tend to underestimate the errors.

Although the increase in clustering appears sharp in Figure 4, Figure 5 shows the relative bias, $b/b^* = (r_0/r_0^*)^{0.5}$, which is measured as a function of luminosity and compared to the results of [2]. The 2dFGRS results are actually well fit by the linear relation, [7]

$$b/b^* = 0.85 + 0.15L/L^*. \tag{1}$$

4 Summary

- Cold *IRAS* galaxies are found to be more clustered than hot *IRAS* galaxies.
- Bright and faint *IRAS* galaxies are found similarly clustered, consistent with the colour relation.
- Bright optical galaxies are found to be significantly more clustered than faint optical galaxies and the measurement presented is the most accurate yet made.

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