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The 2dF Galaxy Redshift Survey: Luminosity dependence of galaxy clustering

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ABSTRACT

We investigate the dependence of the strength of galaxy clustering on intrinsic luminosity using the Anglo-Australian two degree field galaxy redshift survey (2dFGRS). The 2dFGRS is over an order of magnitude larger than previous redshift surveys used to address this issue. We measure the projected two-point correlation function of galaxies in a series of volume-limited samples. The projected correlation function is free from any distortion of the clustering pattern arising from peculiar motions and is well described by a power law in pair separation over the range $0.1 < (r/\,h^{-1}\,\mathrm{Mpc}) < 10$. The clustering of L^* ($M_{b_J} - 5\log_{10} h = -19.7$) galaxies in real space is well fit by a correlation length $r_0 = 4.9 \pm 0.3\,h^{-1}\,\mathrm{Mpc}$ and power law slope $\gamma = 1.71 \pm 0.06$. The clustering amplitude increases slowly with luminosity for galaxies fainter than L^*, but rises more strongly at higher luminosities. At low luminosities, our results agree with measurements from the SSRS2 by Benoist et al. However, we find a weaker dependence of clustering strength on luminosity at the highest luminosities. The correlation function amplitude increases by a factor of 3.2 between $M_{b_J} - 5\log_{10} h = -18$ and -21.5, and the most luminous galaxies are 2.4 times more strongly clustered than L^* galaxies. The power law slope of the correlation function shows remarkably little variation for samples spanning a factor of 40 in luminosity. Our measurements are in excellent agreement with the predictions of the hierarchical galaxy formation models of Benson et al.

Key words: methods: statistical - methods: numerical - large-scale structure of Universe - galaxies: formation

1 INTRODUCTION

A major obstacle to be overcome by any successful theory of the formation of large scale structure is the problem of how galaxies trace the distribution of matter in the Universe. Measurements of differential galaxy clustering as a function of colour (Willmer et al. 1998), morphological type (Davis & Geller 1976; Iovino et al. 1993) and selection passband (Peacock 1997; Hoyle et al. 1999) imply the existence of biases between the distribution of galaxies and of mass.

A generic prediction of hierarchical structure formation models is that rarer objects should be more strongly clustered than average (Davis et al. 1985; White et al. 1987).

Correspondingly, if more luminous galaxies are associated with more massive haloes, then these galaxies are expected to exhibit stronger clustering than the galaxy population as a whole (for the special case of bright galaxies at high redshift, see for example Baugh et al. 1998; Governato et al. 1998). However, the form of the dependence of the amplitude of galaxy clustering on luminosity remains controversial even after more than twenty years of constructing and analysing redshift surveys of the local Universe. In the literature, claims of a dependence of galaxy clustering on luminosity (e.g. Davis et al. 1988; Hamilton 1988; Maurogordato & Lachieze-Rey 1991; Benoist et al. 1996; Willmer et al. 1998; Guzzo et al. 2000) have been made with similar regularity to claims of non-detections (e.g. Phillips & Shanks 1987; Hasegawa & Umemura 1993; Loveday et al. 1995; Szapudi et al. 2000; Hawkins et al. 2001). Part of the reason for this disagreement is a mismatch in the range of luminosities studied. However, the main problem with earlier work is the small size of the redshift surveys analysed, both in terms of volume and number of galaxies. With previous surveys, the dynamic range in luminosity for which clustering can be measured reliably is limited, particularly when volume-limited samples are used. Due to the small volumes probed, it has generally not been possible to compare the clustering of galaxies of different luminosity measured within the same volume. Therefore, it is not clear how sensitive the results are to sampling fluctuations. This problem is compounded by underestimation of the errors on the measured correlation functions.

In this paper, we use the largest extant local survey, the Anglo-Australian two degree field galaxy redshift survey (hereafter 2dFGRS), to resolve the issue of how clustering depends upon galaxy luminosity. We describe the 2dFGRS and the construction of volume-limited samples in Section 2, and our estimation of the correlation function is described in Section 3. Our results for the real space correlation function are given in Section 4. We compare our results with those from previous studies and with the predictions of simulations of hierarchical galaxy formation in Section 5.

2 THE DATA

2.1 The 2dFGRS sample

The 2dFGRS is selected in the photometric b_J band from the APM galaxy survey (Maddox et al. 1990a,b; 1996) and its subsequent extensions (Maddox et al. in preparation). The survey is divided into two regions and covers approximately 2000 square degrees. The bulk of the solid angle of the survey is made up of two broad strips, one in the South Galactic Pole region (SGP) covering approximatively $-37^{\circ}.5 < \delta < -22^{\circ}.5$, $21^{\rm h}40^{\rm m} < \alpha < 3^{\rm h}30^{\rm m}$ and the other in the direction of the North Galactic Pole (NGP), spanning $-7^{\circ}.5 < \delta < 2^{\circ}.5$, $9^{\rm h}50^{\rm m} < \alpha < 14^{\rm h}50^{\rm m}$. In addition to these contiguous regions, there are a number of circular 2-degree fields scattered randomly over the full extent of the low extinction regions of the southern APM galaxy survey. In this paper, we use the redshifts obtained prior to January 2001, over 160 000 in total. As we are mainly interested in measuring clustering out to separations of order $20\,h^{-1}$ Mpc, we do not include galaxies that lie in the random fields in our analysis.

In order to select an optimal sample for the measurement of the two point correlation function, we apply a weighting scheme to objects in the 2dFGRS. A weight is assigned to each measured redshift based upon the redshift completeness mask, the construction of which is explained in Colless et al. (2001; see also Norberg et al. 2001, in preparation). We require a relatively high completeness in a given direction on the sky, so that, in practice, our results are fairly insensitive to the precise details of the weighting scheme. Excluding areas below our completeness threshold (which arise mainly as a result of the tiling strategy adopted to make optimal use of telescope time, coupled with the fact that the survey is not yet finished), we estimate the effective solid angle used in the SGP region is $\sim 420\ \square^{\circ}$, and in the NGP $\sim 190\ \square^{\circ}$.

2.2 Constructing a volume-limited sample

In this paper, we analyse a series of volume-limited subsamples drawn from the 2dFGRS. The advantage of this approach is that the radial selection function is uniform, and the only variation in the space density of galaxies with radial distance is due to clustering. On the other hand, in a flux limited survey, the galaxy number density is a strong function of radial distance and this effect needs to be corrected for when measuring the clustering. The disadvantage of using a volume-limited sample is that a large number of galaxies in the flux limited survey do *not* satisfy the selection cuts (which are explained below). This is a serious problem for previous surveys, but not for the 2dFGRS. As we demonstrate in Section 4, the volume-limited samples we analyse give robust clustering measurements and contain over an order of magnitude more galaxies than similar samples constructed from previous surveys (see Table 1).

The construction of a volume-limited sample drawn from a flux limited redshift survey first requires a range of absolute magnitudes to be specified for consideration. Following this, because a flux limited survey has a bright and a faint apparent magnitude limit, the range of absolute magnitudes chosen implies that both a minimum ($z_{\rm min}$) and a maximum redshift ($z_{\rm max}$) cut have to be applied to the volume-limited sample. Thus in principle, a galaxy that is included in the volume-limited sample could be displaced to any redshift between $z_{\rm min}$ and $z_{\rm max}$ and would still remain within the bright and faint *apparent* magnitude limits of the flux limited survey.

In order to estimate the absolute magnitude of 2dFGRS galaxies at redshift zero, it is necessary to apply corrections for band shifting ($k-$correction) and evolution in the stellar populations ($e-$correction). We adopt a global $k+e$ correction given by $k+e = 0.03z/\left(0.01+z^4\right)$, which is a good fit to the correction calculated for the b_J selected ESO Slice Project survey using population synthesis models (see Fig. 1 of Zucca et al. 1997). This form for the $k+e$ correction gives consistent luminosity functions for the 2dFGRS when the survey is divided into bins of redshift, indicating that it adequately accounts for the degree of evolution in galaxy luminosity over the lookback time spanned by the survey (Norberg et al. 2001, in preparation). Our results are unchanged if we use the mean of the k corrections for different spectral types given by Madgwick et al. (2001, in preparation). The values of $z_{\rm min}$ and $z_{\rm max}$ that define a volume-limited sample

Table 1. Properties of the combined NGP & SGP volume-limited samples analysed. Columns 5 and 6 list the best fitting correlation length, r_0, and power-law slope γ for the correlation function in real space, fitted over the range $0.5 \leq \sigma/(h^{-1}\,\mathrm{Mpc}) \leq 10$. Column 7 gives the value of $A(\gamma)$, defined by equation 4, evaluated for the best fitting value of γ.

Mag. range $M_{b_J} - 5\log h$		N_{gal}	$z_{\min}$	$z_{\max}$	r_0 (h^{-1} Mpc)	γ	$A(\gamma) = \frac{\Gamma(1/2)\Gamma([\gamma-1]/2)}{\Gamma(\gamma/2)}$
−18.5	−18.0	7061	0.010	0.086	4.1 ± 0.6	1.78 ± 0.10	3.75
−19.0	−18.5	9382	0.013	0.104	4.4 ± 0.4	1.75 ± 0.08	3.80
−19.5	−19.0	13690	0.016	0.126	4.7 ± 0.4	1.68 ± 0.08	4.14
−20.0	−19.5	15123	0.020	0.152	4.9 ± 0.3	1.71 ± 0.06	4.01
−20.5	−20.0	13029	0.025	0.182	5.5 ± 0.3	1.68 ± 0.06	4.14
−21.0	−20.5	9114	0.031	0.220	6.5 ± 0.3	1.63 ± 0.06	4.39
−21.5	−21.0	3644	0.039	0.270	7.6 ± 0.5	1.76 ± 0.09	3.82
−19.0	−18.0	12594	0.013	0.086	4.1 ± 0.5	1.79 ± 0.09	3.72
−20.0	−19.0	21874	0.020	0.126	4.7 ± 0.4	1.70 ± 0.08	4.06
−21.0	−20.0	17383	0.031	0.182	5.6 ± 0.3	1.69 ± 0.06	4.10
−22.0	−21.0	4013	0.048	0.270	8.1 ± 0.5	1.78 ± 0.12	3.75

drawn from the 2dFGRS vary slightly with position on the sky. This is due to revisions made to the map of galactic extinction (Schlegel, Finkbeiner & Davis 1998) and to the CCD calibration of APM plate zero points since the definition of the original input catalogue. Throughout the paper, we adopt an $\Omega_0 = 0.3$, $\Lambda_0 = 0.7$ cosmology to convert redshift into comoving distance.

3 ESTIMATING THE TWO-POINT CORRELATION FUNCTION

The galaxy correlation function is estimated on a two dimensional grid of pair separation parallel (π) and perpendicular (σ) to the line of sight. To estimate the mean density of pairs, a catalogue of unclustered points is generated that has the same angular selection and the same $z_{\min}$ and $z_{\max}$ as the data. The correlation function is estimated using

$$\xi = \frac{DD - 2DR + RR}{RR}, \tag{1}$$

where DD, DR and RR are the suitably normalised number of weighted data-data, data-random and random-random pairs respectively in each bin (Landy & Szalay 1993).

Contours of constant clustering amplitude in the redshift space correlation function $\xi(\sigma,\pi)$ are distorted as a result of the peculiar motions of galaxies, as demonstrated for the 2dFGRS by Peacock et al. (2001). On small scales, random motions inside virialised structures elongate the constant-ξ contours in the π direction, whereas on large scales, coherent flows flatten the contours. The latter effect was measured clearly for the first time for galaxies using the 2dFGRS (Peacock et al. 2001). The dependence of the redshift space correlation function on galaxy luminosity is dealt with in a separate paper (Hawkins et al. 2001, in preparation). In this paper, to simplify the interpretation of our results, we consider clustering in real space, which we infer by projecting the measured correlation function along the line of sight. We compute a dimensionless quantity, $\Xi(\sigma)/\sigma$ by integrating over the measured $\xi(\sigma,\pi)$ grid (note that $\Xi(\sigma)$ is sometimes referred to as $w(r_p)$ in the literature):

$$\frac{\Xi(\sigma)}{\sigma} = \frac{1}{\sigma}\int_{-\infty}^{\infty} \xi(\sigma,\pi)\mathrm{d}\pi. \tag{2}$$

In practice, the integral converges by a pair separation of $\pi = 75\,h^{-1}$ Mpc. The projected correlation function can, in turn, be written as an integral over the spherically averaged real space correlation function, $\xi(r)$,

$$\frac{\Xi(\sigma)}{\sigma} = \frac{2}{\sigma}\int_{\sigma}^{\infty} \xi(r)\frac{r\mathrm{d}r}{(r^2-\sigma^2)^{1/2}}, \tag{3}$$

(Davis & Peebles 1983). If the real space correlation function is a power law (which is a reasonable approximation for APM galaxies out to separations around $r \sim 10\,h^{-1}$ Mpc, see e.g. Baugh 1996), then

$$\frac{\Xi(\sigma)}{\sigma} = \left(\frac{r_0}{\sigma}\right)^{\gamma} \frac{\Gamma(1/2)\Gamma([\gamma-1]/2)}{\Gamma(\gamma/2)} = \left(\frac{r_0}{\sigma}\right)^{\gamma} A(\gamma), \tag{4}$$

where $\xi(r) = (r_0/r)^{\gamma}$ and r_0 is the correlation length.

Previous studies have estimated the error on the measured correlation function using Poisson errors on the pair counts in each bin (Peebles 1980) or bootstrap resampling of the data (e.g. Benoist et al. 1996). Since we study a range of samples corresponding to different luminosity bins and also compare samples from different volumes, it is important to include an estimate of the sampling fluctuations in the error on the correlation function. To achieve this goal, we analyse a sample of 22 mock 2dFGRS catalogues drawn from the ΛCDM Hubble Volume simulation, whose construction is explained in Baugh et al. (2001, in preparation; see also Cole et al. 1998). The mock catalogues have the same clustering amplitude measured for galaxies in the flux limited 2dFGRS and the same selection criteria that are applied to the data are used in the construction of the mock surveys. The clustering amplitude in the mocks is independent of luminosity. The error bars that we plot on correlation functions measured from the 2dFGRS are the *rms* found by averaging over the 22 mock catalogues.

4 RESULTS

We first demonstrate the robustness of the approach of measuring the correlation function in volume-limited samples. Unless stated otherwise, we have added the pair counts in the NGP and SGP regions to compute correlation functions.

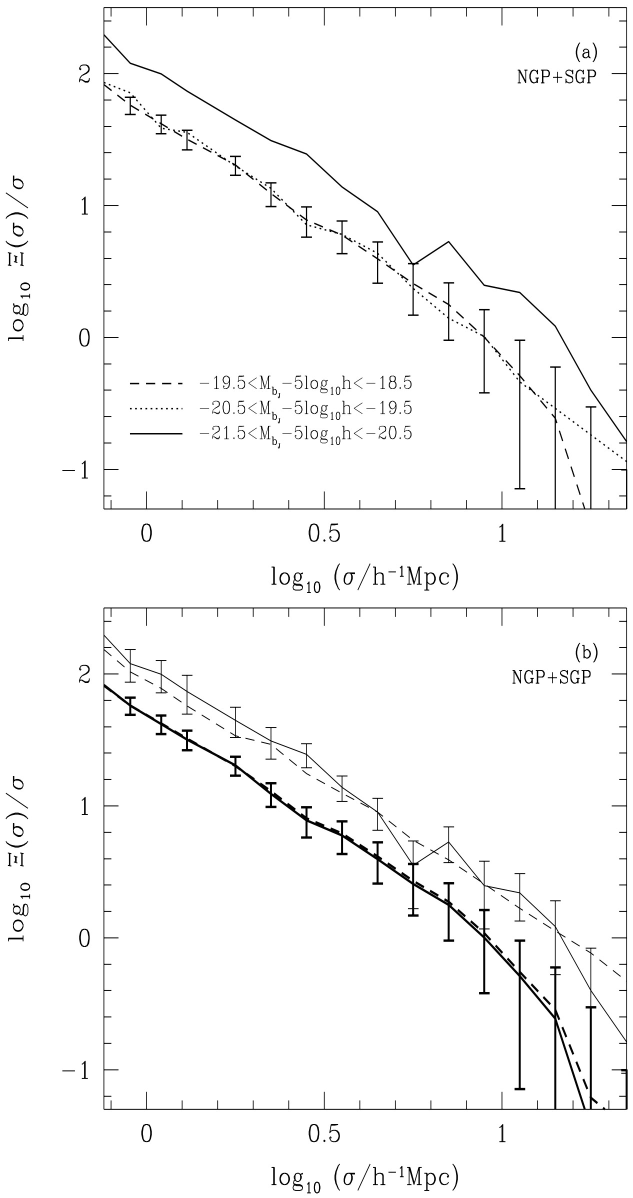

Figure 1. (a) The projected correlation function measured for galaxies in three different absolute magnitude bins in the *same* volume. The faintest sample contains 16 134 galaxies, the middle sample contains 6 186 galaxies and the brightest contains 985 galaxies. For clarity, error bars are plotted only on the correlation function of galaxies with $-19.5 \leq M_{b_J} - 5\log_{10} h \leq -18.5$. (b) A comparison of the correlation function of galaxies in the same absolute magnitude bins but measured in different (but not completely independent) volumes. The heavy lines show results for galaxies with $-19.5 \leq M_{b_J} - 5\log_{10} h \leq -18.5$ and the light lines show results for a brighter bin with $-21.5 \leq M_{b_J} - 5\log_{10} h \leq -20.5$. In each case, the dashed line shows the estimate from the optimal sample (see text) for the stated magnitude bin, whilst the solid line shows an estimate of the correlation function taken from the volume analysed in Fig. 1(a). For the $-21.5 \leq M_{b_J} - 5\log_{10} h \leq -20.5$ magnitude bin, the optimal estmate is measured using 10 962 galaxies, which should be contrasted with the 985 galaxies used to make the measurement shown by the light solid line, in a volume defined by a broader magnitude bin.

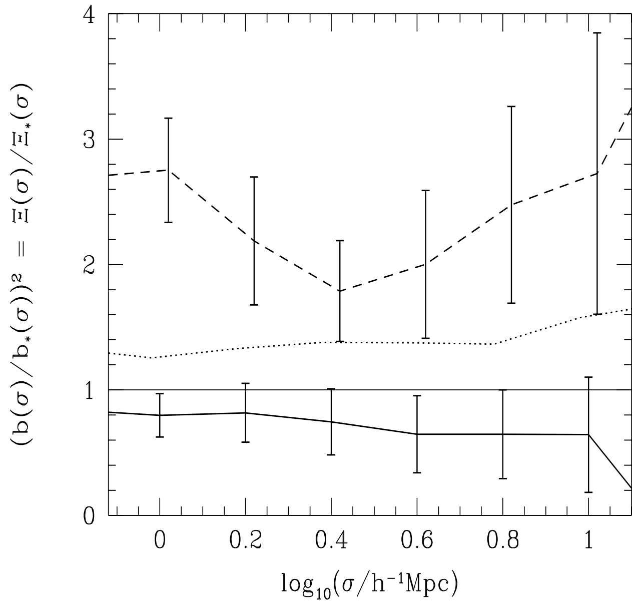

Figure 2. The ratio of the projected correlation function of galaxies in different magnitude slices to the projected correlation function of galaxies with $-20 \leq M_{b_J} - 5\log_{10} h \leq -19$. Note the ratio is plotted on a linear scale, whilst the pair separation is on a log scale. The solid line shows the ratio for galaxies with absolute magnitudes in the range $-19 \leq M_{b_J} - 5\log_{10} h \leq -18$, the dotted line for $-21 \leq M_{b_J} - 5\log_{10} h \leq -20$ and the dashed line for galaxies with $-22 \leq M_{b_J} - 5\log_{10} h \leq -21$. For clarity, error bars have been omitted from the dotted line but are comparable in magnitude to those plotted on the solid line.

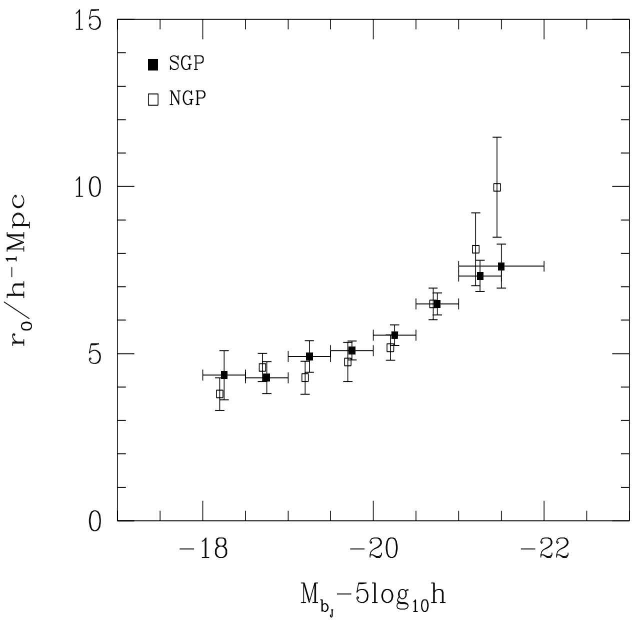

Figure 3. The best fitting correlation length in real space for the projected correlation function measured as a function of absolute magnitude. In this Fig., results are shown for the SGP and NGP regions analysed separately. The NGP points are plotted with an offset set of 0.05 mag for clarity. Horizontal error bars on the SGP points indicate the absolute magnitude range of each bin. In each case, the brightest data point is for galaxies in a one magnitude wide bin.

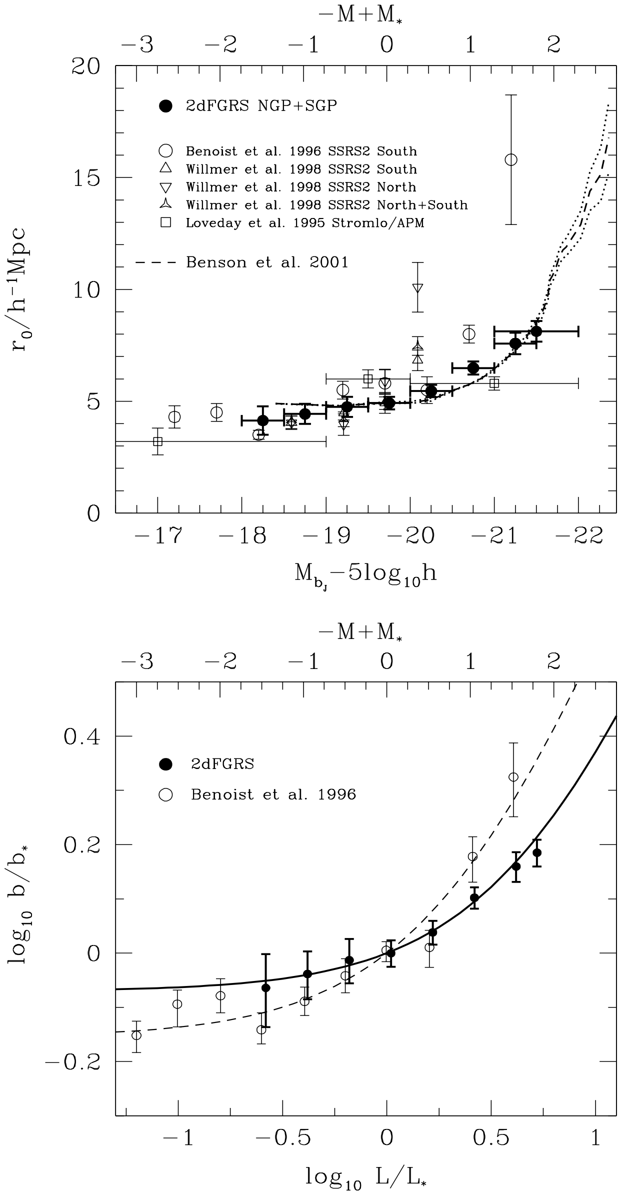

Figure 4. (a) The best fitting real space correlation length for the projected correlation function estimated combining pairs counts in the NGP and SGP (filled circles). The open symbols show a selection of recent data from other studies. The data for surveys selected in the B-band have been corrected to the $b_J$band using the approximate relation $M_{b_J} = M_B - 0.2$. The dashed line shows the prediction of the semi-analytic model of Benson et al. (2001). The dotted curves show an estimate of the errors on this prediction based upon pair counts. The upper axis gives the magnitude relative to M_* where $M_* = M_{b_J} - 5\log_{10} h = -19.7$. (b) The variation of the relative bias as a function of luminosity, using the clustering of L^* galaxies as a reference point (see text for definition). The Benoist et al. (1996) points are taken directly from their Fig. 5. Note that the error bars on the Benoist et al. points are obtained by averaging over correlated bins in pair separation. The curves shows parametric fits: the Benoist et al. measurements are well fitted by $b/b^* = 0.7 + 0.3L/L^*$ (dashed line), whereas the 2dFGRS results suggest a more modest dependence on luminosity: $b/b^* = 0.85 + 0.15L/L^*$ (solid line).

In Fig. 1(a), we show the correlation function of galaxies in three disjoint absolute magnitude bins measured in the same volume. The sampling fluctuations are therefore the same for each sub-sample, though the number of galaxies varies between the samples. There is a clear difference in the clustering amplitude of galaxies in the brightest absolute magnitude bin. Next, we demonstrate that sampling fluctuations are not important in a survey of the volume of the 2dFGRS. We show, in Fig. 1(b), the correlation function in two fixed absolute magnitude bins measured in different volume-limited samples. Specifically, the dashed lines show the correlation function measured in an optimal volume-limited sample, defined by the absolute magnitude bin for which the correlation function is measured. Such a sample contains the maximum number of galaxies for the stated magnitude bin. The different estimates of the correlation function agree within the errors.

We now focus our attention on a series of volume-limited subsamples covering the range $-18 \leq M_{b_J} - 5\log_{10} h \leq -22$. The characteristics of the samples are listed in Table 1. The shape and amplitude of the projected correlation function in a selection of these samples is compared with the correlation function of galaxies in the magnitude range $-20 \leq M_{b_J} - 5\log_{10} h \leq -19$ in Fig. 2. The shape of the correlation function varies relatively little as the absolute magnitude defining the sample is varied, though the amplitude of the correlation function changes significantly for the brightest magnitude slice considered. Another view of this trend is given in Fig. 3 in which we plot the real space correlation length as a function of absolute magnitude. The best fitting values of the correlation length, r_0, and power-law slope γ, are obtained by applying equation 4 to the measured correlation function over the pair separation range $0.5 \leq \sigma/(h^{-1}\,\mathrm{Mpc}) \leq 10$. Errors on the fitted quantities are derived from the 2dFGRS mock catalogues and therefore take into account sample variance. In Fig. 3, we plot the correlation lengths for the NGP and SGP regions separately. These independent estimates are in excellent agreement. Note that the slope of the best fitting power law correlation function, as shown by the results listed in Table 1, is essentially the same for the volume-limited samples considered. The clustering amplitude increases slowly with luminosity for galaxies fainter than M^* (where we adopt $M^* = M_{b_J} - 5\log_{10} h = -19.7$, as found by Folkes et al. 1999), but rises more strongly at higher luminosities. The correlation function amplitude increases by a factor of 3.2 between $M_{b_J} - 5\log_{10} h = -18$ and -21.5, and the most luminous galaxies are 2.4 times more strongly clustered than M^* galaxies.

5 DISCUSSION

The 2dFGRS represents the current state of the art in surveys of large scale structure in the local Universe. The volume-limited samples analysed in this paper contain over an order of magnitude more galaxies than in previous studies of the dependence of clustering on galaxy luminosity. The sheer volume of the samples considered, $10^6 - 2 \times 10^7\,h^{-3}\,\mathrm{Mpc}^3$, ensures that sampling fluctuations have little impact upon our results.

We compare the 2dFGRS results with a selection of recent measurements taken from the literature since 1995 in Fig. 4(a). Benoist et al. (1996) analysed quasi volume-limited samples in the South Galactic Pole region of the Southern Sky Redshift Survey 2 (SSRS2), and find a sharp increase in the correlation length for galaxies brighter than $M_B - 5\log_{10} h = -20.5$. The Benoist et al. correlation lengths are measured in redshift space, though the authors report that a similar trend with luminosity is seen in real space. Willmer et al. (1998) reanalysed the SSRS2 South using different volume limits and also measured clustering in the SSRS2 North, presenting fits for the correlation length in real and redshift space. Intriguingly, Willmer et al. find a larger correlation length in real space for galaxies with $M_B - 5\log_{10} h \sim -20$ than Benoist et al. find in redshift space. Moreover, the clear disagreement between the results for the brightest galaxies analysed in SSRS2 North and South suggests that sampling fluctuations are significant in a survey of this size and that the errors on these points have been underestimated (as demonstrated in Fig. 4 of Benson et al. 2001). Loveday et al. (1995) measured the clustering in real space by cross correlating galaxies in the sparsely-sampled Stromlo/APM redshift survey with galaxies in the parent catalogue. Galaxies were considered in three absolute magnitude bins. No difference was found between the clustering amplitude of L^* galaxies and galaxies brighter than L^*. However, the bright bin is two magnitudes wide and we find that the correlation length changes significantly across this bin.

Our clustering results can be characterised in a concise way in terms of a relative bias parameter, b/b^*, that gives the amplitude of the correlation function relative to that of L^* galaxies (where $M_* = M_{b_J} - 5\log_{10} h = -19.7$). The *relative* bias between the correlation functions of galaxies of different luminosity is assumed to be constant for pair separations in the range of the r_0 values listed in Table 1. The relative bias is then defined by $b/b_* = (r_0/r_0^*)^{\gamma/2}$, where we take $r_0^* = 4.9 \pm 0.3\,h^{-1}$ Mpc from Table 1 and use $\gamma = 1.7$. The 2dFGRS results are shown by the filled symbols in Fig. 4(b) and are well fitted by the relation $b/b^* = 0.85 + 0.15L/L^*$. The 2dFGRS data suggest a significantly weaker dependence of the relative bias on luminosity than the Benoist et al. data, which follow the relation $b/b^* = 0.7 + 0.3L/L^*$ (Peacock et al. 2001). However, there would be quite good agreement between the two datasets if the last point in the Benoist et al. data, with a large error bar, was ignored. (We note that the parametric fit to the Benoist et al. measurements was used by Peacock et al. 2001 to estimate the parameter $\beta = \Omega^{0.6}/b$ for L^* galaxies in the 2dFGRS. Using the above fit to the 2dFGRS measurements changes the inferred value for β by less than 1σ to $\beta = 0.49 \pm 0.08$.)

Hierarchical models of galaxy formation predict that bright galaxies should be more strongly clustered than faint galaxies (e.g. White et al. 1987; Kauffmann, Nusser & Steinmetz 1997). This generic prediction arises because bright galaxies are expected to occupy more massive dark matter haloes and these haloes are more strongly clustered than the overall distribution of dark matter. The trend of clustering amplitude with luminosity measured for 2dFGRS galaxies is in excellent agreement with the predictions of a simulation of hierarchical galaxy formation taken from Fig. 4 of Benson et al. (2001), reproduced as the dashed line in Fig. 4(a). In the Benson et al. semi-analytic model, the input parameters are set in order to reproduce a subset of local galaxy data, with most emphasis given to the field galaxy luminosity function (see Cole et al. 2000). No reference is made to clustering data in setting the model parameters. In a ΛCDM cosmology, Benson et al. (2000a,b) find excellent agreement with the real space correlation function measured for galaxies in the APM survey by Baugh (1996). It is remarkable that the same model, without any readjustment of parameters, also reproduces the dependence of clustering amplitude on luminosity found for 2dFGRS galaxies in Fig. 4(a).

The increase in clustering amplitude with luminosity will be connected with a change in the mix of morphological types with increasing luminosity. The mix of spectral types at the brightest absolute magnitudes is dominated by spectra characteristic of elliptical galaxies, whereas spiral galaxies are more numerous around L^* (Folkes et al. 1999; Cole et al. 2001; Madgwick et al. in preparation). The clustering of galaxies as a function of spectral type will be analysed by Norberg et al. (2001, in preparation).

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