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CONSTRAINING OMEGA AND BIAS FROM THE STROMLO-APM SURVEY

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Abstract

Galaxy redshift surveys provide a distorted picture of the universe due to the non-Hubble component of galaxy motions. By measuring such distortions in the linear regime one can constrain the quantity $\beta = \Omega^{0.6}/b$ where Ω is the cosmological density parameter and b is the (linear) bias factor for optically-selected galaxies. In this paper we estimate β from the Stromlo-APM redshift survey by comparing the amplitude of the direction-averaged redshift space correlation function to the real space correlation function. We find a 95% confidence upper limit of $\beta = 0.75$, with a 'best estimate' of $\beta \approx 0.48$. A bias parameter $b \approx 2$ is thus required if $\Omega \equiv 1$. However, higher-order correlations measured from the APM galaxy survey [9] indicate a low value for the bias parameter $b \approx 1$, requiring that $\Omega \lesssim 0.6$.

1 Introduction

Galaxy redshift surveys can provide some of the most important constraints on theories of large-scale structure, but they must be analysed with care. For pure, unperturbed Hubble flow, galaxy clustering measured in both real space and redshift space would be identical and isotropic. However, in practice, peculiar velocities distort the redshift space correlation function. Since the amplitude of peculiar velocities depends on the cosmological density parameter Ω, by measuring this distortion we can hope to constrain the value of Ω. On small scales, the effect of peculiar velocities is to elongate clusters of galaxies along the line of sight in redshift space, leading to the well known 'fingers of God'. However, on large scales, coherent bulk flows dominate the peculiar velocity field resulting in a *compression* in the clustering pattern along the line of sight. This is illustrated for Stromlo-APM Survey galaxies in Figure 1, where we show a contour plot of the full redshift space correlation function $\xi(\sigma, \pi)$ as a function of separation

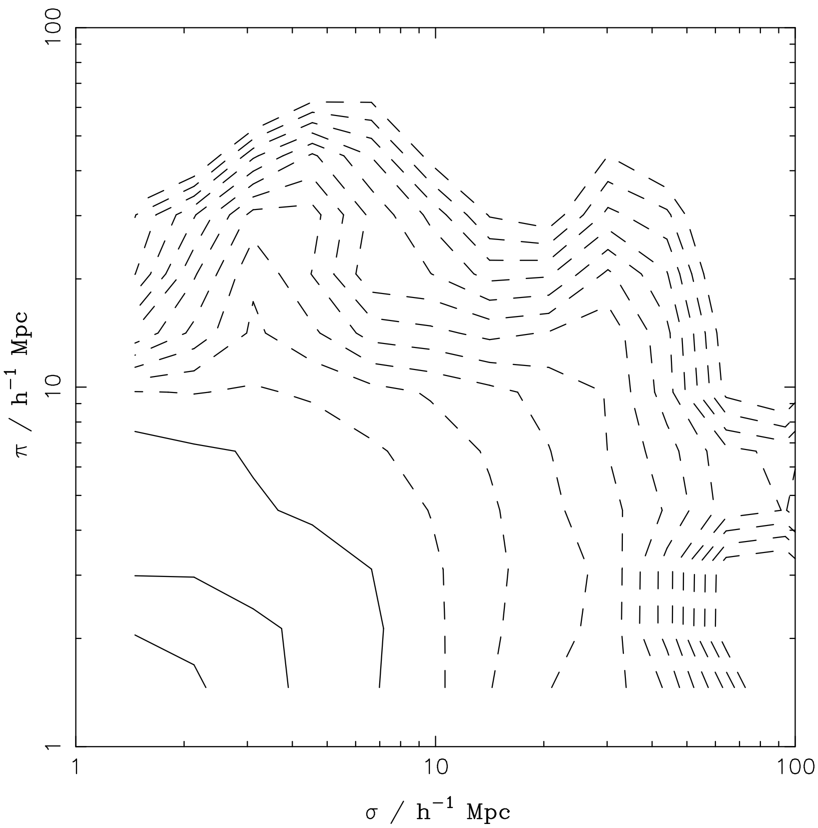

Figure 1: A smoothed contour plot of the full redshift space correlation function $\xi(\sigma, \pi)$ measured from the Stromlo-APM Redshift Survey as a function of separation parallel (π) and perpendicular (σ) to the line of sight. The contours are plotted in fixed steps in $\log \xi$ from -3 to 1. Solid contours show values $\xi \geq 1$, dashed contours show values $\xi < 1$ (*i.e.* in the linear regime).

parallel (π) and perpendicular (σ) to the line of sight. A compression of the low-amplitude ξ contours in the π direction compared with the σ direction is clearly visible for $\pi \gtrsim 10h^{-1}$Mpc.

This large-scale anisotropy in redshift space clustering is most naturally expressed in terms of the power spectrum. Kaiser [14] has shown that in the linear regime of gravitational instability models, the power spectra in redshift space, $P_s(\mathbf{k})$ and real space $P_r(\mathbf{k})$ are simply related by

$$P_s(\mathbf{k}) = (1 + \beta\mu_{\mathbf{k}}^2)^2 P_r(\mathbf{k}), \tag{1}$$

where $\mu_{\mathbf{k}}$ is the cosine of the angle between the wavevector $\mathbf{k}$ and the line of sight. The amplitude of the distortion is determined by the parameter $\beta = f(\Omega)/b$, where $f(\Omega) \approx \Omega^{0.6}$

is the dimensionless growth rate of growing modes in linear theory. The bias parameter b relates the fluctuations in galaxy density to the underlying mass density in the linear regime, $\delta_g = b\delta_\rho$ for linear bias. Several practical methods for measuring β have recently been applied: measuring the anisotropy of the correlation function [10, 11, 7, 18], the anisotropy of the power spectrum [2, 3, 22] and spherical harmonics of the density field [8, 12]. Unfortunately, measured anisotropies in redshift space clustering are strongly perturbed by non-linear effects on scales up to $r \sim 30h^{-1}$Mpc [2, 18], and so one needs to be able to measure anisotropies reliably on scales $r \gtrsim 30h^{-1}$Mpc in order for equation (1) to be valid.

As well as causing anisotropy in redshift space, large-scale streaming motions also produce an amplification in the direction-averaged redshift space correlation function. Fortunately, the direction-averaged correlation function is only affected by non-linearities on scales $r \lesssim 5h^{-1}$Mpc [18]. For fluctuations in the linear regime, the direction-averaged redshift space correlation function $\xi(s)$ and the real space correlation function $\xi(r)$ are related by [14],

$$\xi(s) \approx \left(1 + \frac{2}{3}\beta + \frac{1}{5}\beta^2\right)\xi(r). \tag{2}$$

The large uncertainty in the value of β hinders comparison of $\xi(s)$ with real space predictions of galaxy clustering from various models [15]. In a recent paper [17], we estimated the real-space correlation function of optically-selected galaxies by cross-correlating galaxies in the sparse-sampled Stromlo-APM Redshift Survey with the fully-sampled, parent APM Galaxy Survey. This projected cross-correlation function is unaffected by redshift-space distortions and may be stably inverted to give the real-space correlation function $\xi(r)$. Moreover, the large number of cross-pairs enables clustering to be measured to smaller scales than using the redshift survey data alone. If both $\xi(r)$ and $\xi(s)$ can be reliably measured in the linear regime then the value of β can be constrained using equation (2).

The above formula assumes a plane-parallel approximation for peculiar displacements. In order to approximate this ideal in our analysis, we use only those pairs of galaxies separated by less than 50 degrees on the sky. This rejects about 20% of galaxy pairs, and, as shown in [2], will limit deviations from the plane-parallel approximation to cause no more than a 5% bias in the estimated value of β.

Equation (2) also assumes that linear theory is valid on scales on which ξ can be reliably measured. In order to check the validity of this assumption, we have analyzed an ensemble of CDM-like N-body simulations [4]. See [18] for a description and analysis of the simulations.

2 Stromlo-APM Survey Data

The Stromlo-APM redshift survey consists of 1787 galaxies with $b_J \leq 17.15$ selected randomly at a rate of 1 in 20 from the APM (Automated Plate Measuring) galaxy survey [19, 20]. The survey covers a solid angle of 1.3 sr (4300 square degrees) in the south galactic cap. The APM magnitudes have been calibrated and corrected for photographic saturation using CCD photometry as described in [16]. An approximate morphological type was assigned to each galaxy by visually inspecting the images on the United Kingdom Schmidt Telescope (UKST) survey plates. Redshifts were obtained with the Mount Stromlo-Siding Spring Observatory (MSSSO) 2.3m telescope at Siding Spring. Measured radial velocities were transformed to the local group frame using $v = v + 300\sin(l)\cos(b)$ and we assumed $\Lambda = 0$, $q_0 = 0.5$ and $H_0 = 100$ km s^{-1}Mpc^{-1} with uniform Hubble flow in calculating distances and absolute magnitudes. We adopt k-corrections for different morphological types in the b_J system [6]. More details about the survey are given in ref [16]. Error bars on measurements from survey data are estimated using the bootstrap resampling technique [1] with nine bootstrap resamplings of the survey.

3 Results

3.1 Constraints on β

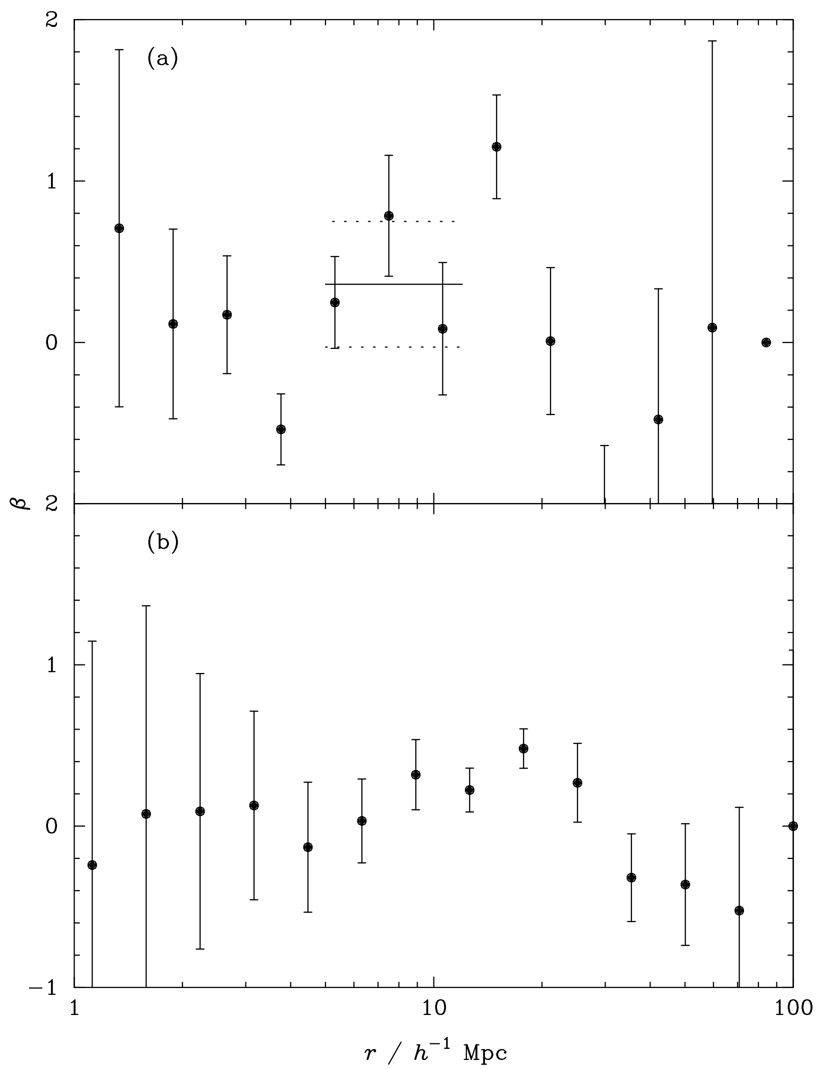

Figure 2: (a) Estimates of β as a function of separation for the Stromlo-APM survey data using $\xi(s)$ and $\xi(r)$ in equation (2). The horizontal line shows the maximum-likelihood fit to β over the range indicated and the dotted lines show 95% confidence limits on β. (b) Same as (a), but using the volume integrals J_3 in place of ξ.

In Figure 2a, we plot our estimates of β from the redshift survey, as determined from the ratio $\xi(s)/\xi(r)$. The redshift space correlation function $\xi(s)$ has been calculated in the usual way, directly from the redshift survey data. The real space correlation function $\xi(r)$ has been calculated via inversion of the projected cross-correlation function with the parent APM galaxy catalogue [17]. Although there is quite a wide scatter in the β estimates on different scales, there is no obvious systematic trend with separation, and so we have calculated the maximum-likelihood value of β using the three data points in the range 5–12 h^{-1}Mpc, since analysis of the N-body simulations [18] shows that $\xi(s)$ and $\xi(r)$ are essentially unaffected by non-linearity on scales $r \gtrsim 5h^{-1}$Mpc. We find $\beta = 0.36$ with 95% confidence limits -0.03–0.75.

One may obtain a less noisy estimate of β by replacing the correlation functions $\xi(s)$ and $\xi(r)$ in equation (2) with the integrated quantities $J_3(s)$ and $J_3(r)$, where $J_3(r) = \int_0^r x^2\xi(x)dx$. Analysis of the N-body simulations [18] shows that the J_3 integrals are unaffected by non-linear effects on scales $r \gtrsim 15h^{-1}$Mpc. Using the $J_3(s)/J_3(r)$ ratio (Fig. 2*b*), we find a value of $\beta = 0.48 \pm 0.12$ at $r = 17.8h^{-1}$Mpc. Our measurements of $\xi(r)$ and hence $J_3(r)$ are not expected to be reliable on scales $r \gtrsim 20h^{-1}$Mpc [17], and hence we do not regard the downturn in β on these scales as being significant.

Both $\xi(s)/\xi(r)$ and $J_3(s)/J_3(r)$ estimates of β give consistent results and exclude the possibility of $\beta \gtrsim 0.75$ at very high confidence.

3.2 Disentangling Ω and b

Ideally, of course, one would like to know the values of the density parameter Ω and the bias parameter b individually. Dekel (these proceedings) describes how peculiar velocity maps can be used to estimate Ω independently of b, and Cole *et al.* [2] have discussed how it may be possible with future redshift surveys to separate the determination of Ω and b by studying the scaling of non-linear effects. An alternative approach is the study of high order correlations to constrain the (possibly non-linear) biasing model using weakly non-linear perturbation theory. Gaztañaga and Frieman [9] have used high order moments of APM galaxies to constrain biasing models. To be consistent with non-linear perturbation theory, one should allow the possibility of *non-linear* bias, in which case second- and third-order non-linear bias coefficients can be chosen which match the observed high order correlations. However, the observations are very well fit by an *unbiased*, low-density CDM model with $b \approx 1$. Applying Occam's razor, this seems the more natural solution.

4 Conclusions

Measuring the projected cross-correlation function of Stromlo-APM galaxies with the parent APM galaxy survey enables a reliable determination of $\xi(r)$ on linear scales $r \gtrsim 5h^{-1}$Mpc. The ratio $\xi(s)/\xi(r)$ on scales 5–12 h^{-1}Mpc yields a value $\beta \approx 0.36$. The integral J_3 is less noisy than $\xi(r)$ and on a scale $r \approx 17.8h^{-1}$Mpc $J_3(s)/J_3(r)$ provides the estimate $\beta = 0.48 \pm 0.12$. Although a little lower than estimates of β from peculiar velocity analyses (eg. Hudson *et al.* [13], who find $\beta = 0.74 \pm 0.13$), the large errors on *all* current estimates of β means they are all consistent. See [5, 21] for reviews of recent measurements of β.

The Stromlo-APM survey is a powerful sample for constraining β since the large volume probed allows us to reliably measure redshift space galaxy clustering in the linear regime, whereas many previous analyses have been limited to measuring $\xi(s)$ in the non-linear regime. Cross-correlation with the fully-sampled APM galaxy survey enables us to measure $\xi(r)$ much more accurately than using the angular correlation function $w(\theta)$, and thus the technique of using the ratio $\xi(s)/\xi(r)$ [or $J_3(s)/J_3(r)$] comes into its own for this survey.

With linear theory and 2-point clustering statistics alone one cannot separate the contributions of Ω and b to β. However, as discussed by Gaztañaga and Frieman [9], higher order correlations may be used to constrain biasing models. Their analysis of APM galaxies favours a linear bias parameter $b \approx 1$, although to be strictly self-consistent, one should allow for a non-linear bias model in non-linear perturbation theory, in which case one can always match the observed skewness of APM galaxy counts in cells by adjusting the non-linear bias parameters. Further work is clearly required in constraining possible biasing models.

In conclusion, we find that a relatively low value of β is favoured by the Stromlo-APM data; we can certainly exclude an unbiased, $\Omega = 1$ model at more than 95% confidence. If galaxies are indeed unbiased tracers of the mass distribution, then $\Omega \lesssim 0.6$.

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References

[1] Barrow, J.D., Bhavsar, S.P. and Sonoda, D.M., 1984, MNRAS, 210, 19p

[2] Cole, S., Fisher, K.B. and Weinberg, D.H., 1994, MNRAS, 267, 785

[3] Cole, S., Fisher, K.B. and Weinberg, D.H., 1995, submitted to MNRAS

[4] Croft, R.A.C. and Efstathiou, G., 1994, MNRAS, 267, 390

[5] Dekel, A., 1994, ARA&A, 32, 371

[6] Efstathiou, G., Ellis, R.S. and Peterson, B.A., 1988, MNRAS, 232, 431

[7] Fisher, K.B., Davis, M., Strauss, M.A., Yahil, A. and Huchra, J.P., 1994, MNRAS, 267, 927

[8] Fisher, K.B., Scharf, C.A. and Lahav, O., 1994, MNRAS, 266, 219

[9] Gaztañaga, E. and Frieman, J.A., 1994, ApJ, 437, L13

[10] Hamilton, A.J.S., 1992, ApJ, 385, L5

[11] Hamilton, A.J.S., 1993, ApJ, 406, L47

[12] Heavens, A.F. and Taylor, A.N., 1994, submitted to MNRAS

[13] Hudson, M., Dekel, A., Courteau, S., Faber, S.M. and Willick, J.A., 1995, MNRAS, in press

[14] Kaiser, N., 1987, MNRAS, 227, 1

[15] Loveday, J., Efstathiou, G., Peterson, B.A. and Maddox, S.J., 1992, ApJ, 400, L43

[16] Loveday, J., Peterson, B.A., Efstathiou, G. and Maddox, S.J., 1992, ApJ, 390, 338

[17] Loveday, J., Maddox, S.J., Efstathiou, G. and Peterson, B.A., 1995, ApJ, 442, 457

[18] Loveday, J., Efstathiou, G., Maddox, S.J. and Peterson, B.A., 1995, submitted to ApJ

[19] Maddox, S.J., Sutherland, W.J. Efstathiou, G. and Loveday, J., 1990, MNRAS, 243, 692

[20] Maddox, S.J., Efstathiou, G. and Sutherland, W.J., 1990, MNRAS, 246, 433

[21] Strauss, M.A. and Willick, J.A., 1995, submitted to Phys. Rep.

[22] Tadros, H., Efstathiou, G., Loveday, J. and Peterson, B.A., 1995, in preparation