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THE PAIRWISE PECULIAR VELOCITY DISPERSION OF GALAXIES: EFFECTS OF THE INFALL

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ABSTRACT

We study the reliability of the reconstruction method that uses a modeling of the redshift distortions of the two-point correlation function to estimate the pairwise peculiar velocity dispersion of galaxies. In particular, the dependence of this quantity on different models for the infall velocity is examined for the Las Campanas Redshift Survey. We make extensive use of numerical simulations and of mock catalogs derived from them to discuss the effect of a self-similar infall model, of zero infall, and of the real infall taken from the simulation. The implications for two recent, discrepant determinations of the pairwise velocity dispersion for this survey are discussed.

Subject headings: galaxies: formation — cosmology: observations — dark matter — large-scale structure of universe

1. INTRODUCTION

The pairwise peculiar velocity dispersion (PVD) of galaxies is, in principle, a well-defined statistical quantity that can give interesting information on the cosmic matter distribution in addition to the two-point correlation function. The peculiar velocities of galaxies are determined by the action of the local gravitational fields, and thus they directly mirror the gravitational potentials caused by dark and luminous matter. The PVD is measured by modeling the distortions in the observed redshift-space correlation function $\xi_z(r_p, \pi)$, which, in general, is not just a function of the distance $s^2 = r_p^2 + \pi^2$, but depends anisotropically on the separations of a galaxy pair perpendicular to (r_p) and along (π) the line of sight. This is the information that can be obtained from a redshift survey. The basic step in modeling is to write $\xi_z(r_p, \pi)$ as a folding integral of the real-space correlation function $\xi(r)$ and the distribution function $f(v_{12})$ of the relative velocity v_{12} of galaxy pairs along the line of sight

$$1 + \xi_z(r_p, \pi) = \int f(v_{12})[1 + \xi(\sqrt{r_p^2 + (\pi - v_{12}/H_0)^2})]dv_{12} \tag{1}$$

(see, e.g., Davis & Peebles 1983). The real space correlation function $\xi(r)$ must be estimated from the redshift catalog through the relation

$$w(r_p) = \int_0^\infty \xi_z(r_p, \pi)d\pi = \int_0^\infty \xi(\sqrt{r_p^2 + y^2})dy \ , \tag{2}$$

where $w(r_p)$ is the "projected" two-point correlation function. In most previous works, a power-law form is assumed for $\xi(r)$. Based on observational (Davis & Peebles 1983; Fisher et al. 1994) and theoretical (Diaferio & Geller 1996; Sheth 1996; Seto & Yokoyama 1998) considerations, an exponential form is usually adopted for $f(v_{12})$:

$$f(v_{12}) = \frac{1}{\sqrt{2}\sigma_{12}} \exp\left(-\frac{\sqrt{2}}{\sigma_{12}}|v_{12} - \overline{v_{12}}|\right), \tag{3}$$

where $\overline{v_{12}}$ is the mean and σ_{12} is the dispersion of the one-dimensional pairwise peculiar velocities along the line of sight. It is worth pointing out that every step in the above modeling (eqs. [1]–[3]) is only an approximation, and the infall $\overline{v_{12}}$ is unknown. As demonstrated by Jing, Mo, & Börner (1998, hereafter JMB; also, see below) with mock samples of the Las Campanas Redshift Survey (LCRS; Shectman et al. 1996), however, the above procedure can give an accurate estimate of σ_{12} (within 20% accuracy) if the infall is known.

The distribution function $f(v_{12})$ is determined by its first and second moments: the infall ($\overline{v_{12}}$) and the dispersion $\sigma_{12}(r)$. Both distort the two-point correlation function but in opposite ways. The infall velocity must also be modeled in some detail to allow a precise measurement of the dispersion $\sigma_{12}(r)$. The situation seems somewhat complex: $\overline{v_{12}}$ in the real universe is not known at present. One might think that on small scales $\overline{v_{12}}$ is negligible, but this is true only for very small scales indeed. As has been shown by Mo, Jing, & Börner (1997), the function $\overline{v_{12}}$ rises quite sharply around $1h^{-1}$Mpc, reaching twice the Hubble velocity just beyond $1h^{-1}$Mpc. Therefore it is necessary to model the infall carefully when measuring $\sigma_{12}(r)$.

In JMB we have determined the PVD for the LCRS using this reconstruction method. Recently, an attempt to measure the PVD for the same survey directly from a Fourier deconvolution of the anisotropies of the redshift space two-point correlation function (Landy, Szalay, & Broadhurst 1998) has resulted in a much lower value for the PVD (363 ± 44 km s^{-1} vs. 570 ± 80 km s^{-1}). We think it is important to identify the causes for the discrepancy, since the PVD is a very powerful test for the theories of the structure formation. We shall show that the different infall models used in the two studies can explain the discrepancy. But in addition to this immediate aspect, there is the general question of how reliable these methods to measure the PVD really are. In this paper we want to address this question.

2. *N*-BODY SIMULATION AND MOCK SAMPLES

The true PVD can be easily determined from the three-dimensional velocities of particles in numerical simulations. Writing the three-dimensional velocity difference of particle pairs at points $\boldsymbol{x}$ and $\boldsymbol{x} + \boldsymbol{r}$, i.e., at separation $\boldsymbol{r}$, as

$$\boldsymbol{v}_{12}(\boldsymbol{r}) = \boldsymbol{v}(\boldsymbol{x}) - \boldsymbol{v}(\boldsymbol{x} + \boldsymbol{r}) \ , \tag{4}$$

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the true PVD is defined as

$$\sigma_{12}(r) = \langle [\boldsymbol{v}_{12}(\boldsymbol{r}) - \langle \boldsymbol{v}_{12}(\boldsymbol{r})\rangle]/3\rangle^{1/2} , \quad (5)$$

where $\langle \cdots \rangle$ denotes the average over all pairs at separation r. In JMB we considered three spatially flat cosmological models. Here we make use of one simulation of the model with density parameter $\Omega_0 = 0.2$, cosmological constant $\lambda_0 = 0.8$, shape parameter $\Gamma = 0.2$, and normalization $\sigma_8 = 1$. This N-body simulation was generated with a P^3M code (Jing & Fang 1994) with 128^3 particles. Twenty mock samples without the fiber collisions are generated from the simulation to mimic the LCRS. We use these mock samples to determine the PVD in the way outlined above and compare the results to the true PVD obtained from the simulations. Further details about the simulation, the mock samples, and our statistical method were given in JMB.

3. DEPENDENCE ON INFALL MODELS

In JMB we determined the PVD for the LCRS and found a best estimate of

$$\sigma_{12}(1\ h^{-1}\ \mathrm{Mpc}) = 570 \pm 80\ \mathrm{km\ s^{-1}} \quad (6)$$

at a separation of 1 h^{-1} Mpc. Figure 1 gives an indication of the reliability of the result: accepting the exponential shape of the distribution function $f(v_{12})$ as a reasonable *Ansatz*, there remains the mean value $v_{12}(r)$ to be modeled. The filled squares in Figure 1 represent the results from the modeling process, when a self-similar infall model is used for $\overline{v_{12}}$:

$$\overline{v_{12}}(\boldsymbol{r}) = -\frac{yH_0}{1 + (r/r_*)^2} , \quad r_* = 5\ h^{-1}\ \mathrm{Mpc} , \quad (7)$$

and y is the radial separation in real space. This form for $\overline{v_{12}}$ has been widely used in previous work. It also is a good approximation the real infall pattern in some cold dark matter (CDM) models. The circles in Figure 1 denote the PVD reconstructed when the infall is set to zero. In Figure 2, we have plotted the true PVD, read off directly from the simulation, as the solid line. Circles are the result from the

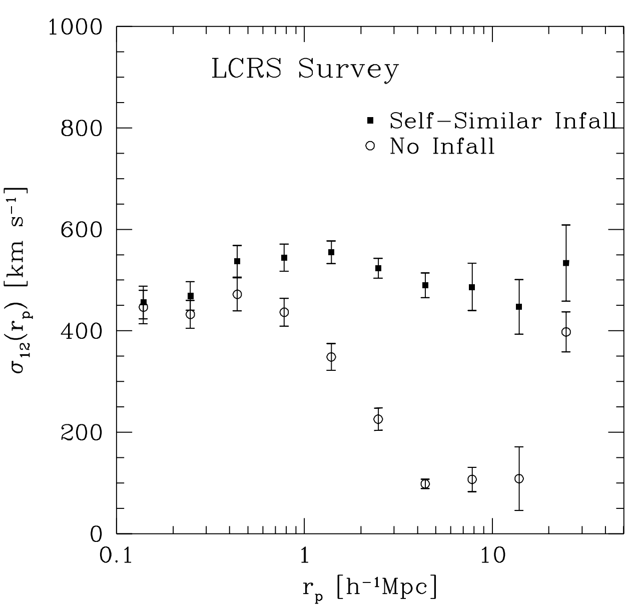

FIG. 1.—PVD of the LCRS: self-similar infall (*filled squares*) and zero infall (*circles*). Error bars are 1σ deviations given by bootstrap resampling.

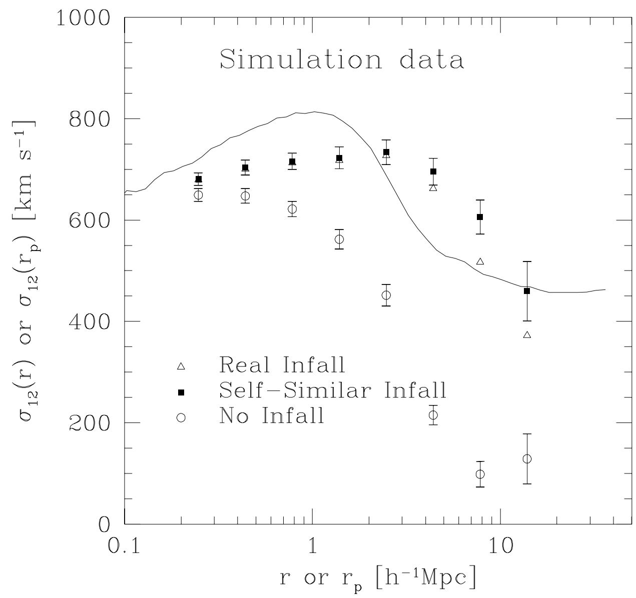

FIG. 2.—PVD of 20 mock samples without fiber collisions. Three infall models are adopted for $\overline{v_{12}}(r)$: the self-similar infall model (*filled squares*), the zero-infall model (*circles*), and the infall derived directly from the simulations (*open triangles*). The true pairwise velocity dispersion given by the three-dimensional velocities in the simulations is shown as the solid line. Error bars are the (1σ) standard deviations of the mean from the mock samples.

mock catalogs with zero-infall, triangles depict the result from the modeling process when the real infall from the simulation is used, and filled squares are again the reconstruction for a self-similar infall. The two different infall models give very similar results on scales $r_p < 10\ h^{-1}$ Mpc. We may conclude that the reconstruction of the PVD does not depend very sensitively on the model for $\overline{v_{12}}$. The PVD reconstructed from the redshift distortions agrees qualitatively with the true value. There are, however, differences of some significance, even if the real infall pattern is used, which reflect the approximate features of the modeling (eqs. [1]–[3]). In contrast, the model, where the infall is completely neglected, does not even qualitatively correspond to the true value. Although the infall velocity becomes negligible on small scales, it still has a strong influence on the PVD: at 1 h^{-1} Mpc, we find a reduction from 570 to 400kms^{-1} if $\overline{v_{12}} = 0$, and at larger scales the no-infall model lets the PVD go down quite rapidly. The same behavior of a rapid drop of the no-infall models can be seen in the simulation results (Fig. 2). (The simulation results are higher, because we have not yet applied the bias necessary to achieve agreement with the observation.) It is probably due to the shape of the infall velocity (Mo et al. 1997) around 1 h^{-1} Mpc, with a steep rise and a maximum at a few h^{-1}Mpc for all CDM models considered in Mo et al. (1997). The Fourier deconvolution method as applied by Landy et al. (1998) appears simpler, because it does not seem to have to model the infall $\overline{v_{12}}$. In fact, however, they use the model $\overline{v_{12}} = 0$, which can, as we have seen from our simulations, lead to an underestimation of the true value. To obtain the true PVD, therefore, the Fourier deconvolution method also needs to model the infall, and thus it meets the same difficulties as the usual approach.

The influence on the PVD estimate at $\sim 1\ h^{-1}$ Mpc of the infall models we found here is in qualitative agreement with many previous works (e.g., Davis & Peebles 1983; Marzke et al. 1995). Quantitatively, the influence may depend on the sample used, which is particularly true for small samples, since the infall effect depends on which regions (clusters or fields) the sample has surveyed. Certainly, the infall effect should be universal for *fair* samples, but it is not known that any observational sample available to date could be considered "fair" for the infall effect. Therefore it is necessary to quantify this effect individually for each sample, as we have done for the LCRS here.

4. DISCUSSION

The modeling of the redshift distortions of the two-point correlation function gives a reasonable estimate—certainly within 20% of the true PVD, despite the complex reconstruction method involved. The differences are due to the fact that the form of $f(v_{12})$ is only approximately an exponential, and that the PVD estimated from the redshift distortions is some kind of average of the true PVD along the line of sight. Since the true PVD depends on the separation of galaxy pairs in real space, these two quantities are different by definition. Whether we use the self-similar or the true infall model has little effect on the results. It is very important, however, to use both the first and second moments of the velocity distribution function in the modeling process, since they lead to distortions of the redshift space correlations in opposing directions. Thus, for instance, setting $\overline{v_{12}} = 0$ leads to drastic changes. The value σ_{12} at 1 h^{-1} Mpc drops from 570 s^{-1} to about 400 s^{-1}, and it becomes very small even for $\gtrsim 1$ h^{-1} Mpc. We suspect that this behavior is responsible for the result of a recent work (Landy et al. 1998), where σ_{12} from the LCRS is estimated to be 363 ± 44 km s^{-1} at scale ~ 1 h^{-1} Mpc. Their reconstruction method makes use of a Fourier deconvolution of $\xi_z(r_p, \pi)$, but the effects of infall are neglected. We can reproduce their result if we set $\overline{v_{12}} = 0$, but from our comparison between simulations and mock catalogs we can draw the conclusion that this approach may have underestimated the true PVD and that the analysis incorporating a reasonable infall, like that of JMB, gives a much more reliable result.

Considering the fact that the two works have used rather different methods to measure the PVD, we would stress that one should remain open-minded with respect to both values, even though we have quantitatively explained the discrepancy with the different infall models. However, the PVD is a very important quantity in cosmology. Since the procedure of JMB has been extensively tested with mock samples, it is important and necessary to make a similar test of the procedure of Landy et al. (1998).

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