Slow relative motion of IRAS galaxies at small separations: implications for galaxy formation models

Y.P. Jing

Shanghai Astronomical Observatory, the Partner Group of MPI für Astrophysik, Nandan Road 80, Shanghai 200030, China

Gerhard Börner

Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 85748 Garching, Germany

Yasushi Suto

Department of Physics and Research Center for the Early Universe, School of Science, University of Tokyo, Tokyo 113-0033, Japan.

Abstract. We report on the measurement of the two-point correlation function and the pairwise peculiar velocity of galaxies in the IRAS PSCz survey. The real space two-point correlation function can be fitted to a power law $\xi(r) = (r_0/r)^\gamma$ with $\gamma = 1.69$ and $r_0 = 3.70h^{-1}\text{Mpc}$. The pairwise peculiar velocity dispersion $\sigma_{12}(r_p)$ is close to $400\text{km s}^{-1}$ at $r_p = 3h^{-1}\text{Mpc}$ and decreases to about $150\text{km s}^{-1}$ at $r_p \approx 0.2h^{-1}\text{Mpc}$. These values are significantly lower than those obtained from the Las Campanas Redshift Survey, but agree very well with the results of blue galaxies reported by the SDSS team later on. We have constructed mock samples from N-body simulations with a cluster-weighted bias and from the theoretically constructed GIF catalog. We find that the two-point correlation function of the mock galaxies can be brought into agreement with the observed result, but the model does not reduce the velocity dispersions of galaxies to the level measured in the PSCz data. Thus we conclude that the peculiar velocity dispersions of the PSCz galaxies require a biasing model which substantially reduces the peculiar velocity dispersion on small scales relative to their spatial clustering. The results imply that either the cosmogony model needs to be revised or the velocity bias is important for the velocity dispersion of the IRAS galaxies.

1. Introduction

Large catalogs of galaxies with their redshift and angular positions are the major astronomical data sets which provide quantitative information on the distribution and formation of the universe. To properly decipher this information requires the use of statistical tools, and to assess their importance heavily relies on a quantitative comparison with theoretical models.
In a recent series of papers (Jing, Mo, & Börner 1998, hereafter JMB98; Jing & Börner 1998; Jing & Börner 2001), various statistical quantities from the Las Campanas Redshift Survey (LCRS) have been determined including the two-point correlation function (2PCF), $\xi(r)$, the power spectrum, $P(k)$, the pairwise peculiar velocity dispersion (PVD), $\sigma_{12}(r)$, and the three-point correlation function (3PCF), $\zeta(r_{12}, r_{23}, r_{31})$. In addition, a detailed comparison between these observational results and the predictions of current cold dark matter (CDM) models has been carried out with the help of mock samples constructed from N-body simulations. It has been found that both the real-space 2PCF and the PVD can be measured reliably from the LCRS, and that the observed 2PCF for LCRS is significantly flatter than the mass 2PCF in CDM models on scales $< \sim 1 h^{-1}$Mpc. The observed PVD also turned out to be lower than that of the dark matter particles in these models. JMB98 introduced a cluster-underweight (CLW) biasing model to account for these discrepancies; CLW essentially assumes that the number of galaxies per unit dark matter mass in a massive halo of mass $M$ decreases as $\propto M^{-\alpha}$. If $\alpha = 0.08$, the 2PCF and the PVD of the LCRS are well reproduced in a spatially-flat CDM model with $\Omega_0^0 \approx 0.4$, where $\Omega_0$ is the density parameter of the model and $\sigma_8$ is the current rms linear density fluctuation within a sphere of radius $8 h^{-1}$Mpc.

In this contribution, we report on the measurements of the 2PCF and PVD of galaxies in another large redshift survey, the PSCz catalog, which has become publicly available recently (Saunders et al. 2000). Since galaxies in the PSCz survey are selected from the IRAS point source catalog, they are supposed to be preferentially dominated by late types in contrast to the LCRS galaxies. Thus the difference of those clustering statistics between LCRS and PSCz should be interpreted as an indication for the morphology-dependent biasing of galaxies, and we will focus on the implications of the observed quantities for galaxy formation theories. For the details of this work, we refer the readers to our recent paper (Jing, Börner, & Suto 2002).

2. Clustering of PSCz galaxies and a comparison with the CDM predictions

We measure the two-point correlation function and the pairwise velocity dispersion for the PSCz galaxies following exactly the procedure of JMB98. The projected 2PCF $w(r_p)$ are presented in Figure 1 with the filled triangles. The data can be well fitted by a power law of $\xi(r) = (r_0/r)^{\gamma}$ with $r_0 = 3.70 h^{-1}$Mpc and $\gamma = 1.69$. The slope is shallower and the amplitude is lower than those for the LCRS (JMB98), reflecting the fact that the PSCz galaxies are preferentially in the field environments. The error bars are not plotted for clarity but are very close to the error bars predicted by the mock samples of the LCDM model with $\Omega_0 = 0.3$, $\lambda_0 = 0.7$ and $\sigma_8 = 1.0$ (the dotted lines). For the mock samples, we have applied the CLW bias with $\alpha = -0.25$, which is found to be in good agreement with the PSCz data (the solid line); even the wiggly structure of the PSCz $w(r_p)$ below $0.8 h^{-1}$Mpc is recovered.

To follow up this point a bit more, we have also constructed mock catalogs from the GIF simulation data (Kauffmann et al. 1999a,b). From the simulated catalogue, we select those galaxies with $\Delta V_{bg} \equiv V_b - V_g \geq 1$, where $V_b$ and
Figure 1. The predictions of CDM models vs the observation for the projected two-point correlation function (left) and the pairwise velocity dispersion (right). Triangles show the observational results. The mean value and the 1σ limits predicted by the cluster-weighted bias model are shown by the thick and thin lines respectively, and the mean values of the GIF simulation and the SCDM CLW model by the dot-dashed and dashed lines (without error bars). The SCDM curve of the correlation function is shifted vertically by a factor of $1/\sigma_8^2$ to account for the necessary linear bias in this model.

$V_g$ denote the V-band magnitudes of the bulge and the whole galaxy. This encompasses about 80 percent of the galaxies in the GIF catalog. The resulting $w(r_p)$ again fits the observations quite well (Fig. 1) for $r_p \gtrsim 1 \ h^{-1}\text{Mpc}$. While the amplitude of $w(r_p)$ for the GIF simulation is a bit larger than the PSCz data for $r_p \lesssim 1 \ h^{-1}\text{Mpc}$, it still lies close to the $+1\sigma$ error line of our CLW mock samples. So these semi-analytic models of galaxy formation which incorporate physical processes like star formation and supernova explosions in some global way have a similar effect of reducing the number of galaxies per unit dark matter mass as our simple bias prescription.

Figure 1 also displays the pairwise velocity dispersion for the self-similar infall model. The PVD is much lower than that for the LCRS: $\sigma_{12}$ just reaches 300 km s$^{-1}$ at $r_p = 1 \ h^{-1}\text{Mpc}$, whereas $\sigma_{12}(1 \ h^{-1}\text{Mpc}) = 570 \pm 80 \text{km s}^{-1}$ for the LCRS (JMB98). This is again qualitatively consistent with the fact that spirals have smaller random motions than the galaxies that reside in big clusters. Comparing with the PVD for the CLW and GIF mock samples, we find that the model predictions in all cases significantly exceed the estimate for the PSCz. Only around $r_p \approx 3 \ h^{-1}\text{Mpc}$ the disagreement is not serious, especially if the large error bars are taken into account. In fact, we may speculate that a CDM model with $\Omega_0 = 0.2$ may even produce quite a good fit to the data at larger $r_p$, since the amplitude of the PVD scales with $\sigma_8 \Omega_0^{0.6}$. Reducing the values of $\sigma_{12}$ accordingly, brings agreement on scales larger than $3 \ h^{-1}\text{Mpc}$. There is, however, no way to reproduce the steep decrease towards small values ($\sim 150 \text{km s}^{-1}$) at
$r_p = 0.2 \, h^{-1}\text{Mpc}$ of the PSCz data. The pairwise velocity dispersions are rather similar in the SCDM ($\Omega_0 = 1$ and $\sigma_8 = 0.6$) and in the LCDM models.

3. Discussion and conclusions

We have analyzed the data set of the IRAS PSCz galaxies (Saunders et al. 2000), and computed the two-point correlation functions and the pairwise peculiar velocity dispersion for these galaxies. A power-law fit to the real-space 2PCF $\xi(r) = (r_0/r)^\gamma$ gives an exponent $\gamma = 1.69$, and a amplitude $r_0 = 3.70 \, h^{-1}\text{Mpc}$. We show that these results can be very well reproduced from mock samples constructed for the LCDM model with the CLW bias of $\alpha = 0.25$. The bias needed for the PSCz galaxies is stronger than the LCRS galaxies, since IRAS galaxies tend to avoid high-density cluster regions. Mock samples from the GIF simulation with an appropriate choice of galaxies give similar 2PCF.

The pairwise peculiar velocity dispersion measured from the PSCz has a much lower value, about 300 km s$^{-1}$ at $r_p = 1 \, h^{-1}\text{Mpc}$, than the LCRS result at that separation of $570 \pm 80\,\text{km\,s}^{-1}$. All the simulation models which are consistent with the 2PCF of the PSCz predict significantly larger values for PVD, although the CLW bias reduces the PVD to within the $1\sigma$ limit of this value, at least near $3 \, h^{-1}\text{Mpc}$ (if $\Omega_0 = 0.2$). As discussed in the last section, the decrease of $\sigma_{12}(r_p)$ for $r_p \lesssim 1 \, h^{-1}\text{Mpc}$ for the PSCz data is significant, and cannot be reproduced by the current simple models. After our paper was submitted to the journal, we noted that the steep decline of the PVD at the small separation was also found in a recent work of the SDSS team on clustering of blue galaxies (Zehavi et al. 2002). Thus, our results indicate that either the cosmogony model needs to be revised or the velocity bias is important for the velocity dispersion of the IRAS galaxies. We are investigating this issue with high-resolution SPH/N-body simulations.

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