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LARGE-SCALE STRUCTURE IN BIASED COLD DARK MATTER COSMOLOGIES

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ABSTRACT

We analyze statistical properties of the large-scale distribution of galaxies in numerical simulations of biased cold dark matter (CDM) cosmologies. We explore different schemes for biased galaxy formation assuming a local nature (0.5–3 h^{-2} Mpc) for the processes that segregate luminous and dark matter. We consider biased and antibiased models for galaxy formation, using simple prescriptions for the assignment of the galaxies from the mass distribution. We also analyze models where galaxy luminosities depend on local density.

For all the models where galaxies are more clustered than the dark matter we find that the angular two-point correlation function has not enough power on large angular separations as compared with APM measurements. We find that a luminosity-density dependence cannot modify these negative results. However, we find that antibiased models provide a fair agreement between the angular correlation function of simulations and the observations. Nevertheless, the peculiar velocities of the galaxies in the simulations exceed by a factor of 1.5–2 the observed peculiar velocities of galaxies. Similarly, velocity dispersions of clusters in the simulations are also a factor of 2 larger than the typical velocity dispersion of a rich cluster of galaxies.

Taking into account the recent results of *COBE* experiments, we have analyzed CDM models with $\delta M/M = 1$. In order to reproduce in these simulations the observed clustering and velocity distribution of galaxies, we develop a simple model that includes mergers of galaxy pairs in high-density regions. The angular correlation function of this model has more power than that obtained in the Lick catalog on large scales, although it provides only a marginal fit to APM measurements. The reduction of galaxy velocities by mergers generates a rich-cluster velocity dispersion, $\sigma \simeq 1000$–1500 km s^{-1}, consistent with observations.

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

1. INTRODUCTION

The standard cold dark matter (CDM) model (White et al. 1987 and references therein) has been a useful tool for understanding the formation of galaxies and structure in the universe. This model has successfully accounted for the number density of galactic halos and rich clusters, galaxy and cluster spatial correlations, etc. However, recent measurements of the angular galaxy correlation function on large scales (Maddox et al. 1990; Collins, Nichol, & Lumsden 1992) and counts in three-dimensional cells of *IRAS* galaxies (Saunders et al. 1990; Efstathiou et al. 1990) indicate an excess in the variance of galaxy counts on large scales when compared with the values predicted by the standard CDM model. These recent observations indicate that the angular correlation function of galaxies on large scales exceeds the measurements obtained by Groth & Peebles (1977, hereafter GP) in the Lick maps. The origin of the differences between Maddox et al. (1990) and GP could be explained taking into account the fact that gradients in the Lick maps might have been overcorrected by GP (Maddox et al. 1990).

The standard CDM model has several attractive features from the theoretical point of view. Nevertheless, as mentioned above, the biased CDM cosmogony is not able to reproduce the most recent observations of galaxy clustering on large scales. Taking into account that galaxy formation processes are not well understood, it is interesting to explore in more detail the ability of different bias scenarios to provide enough power in the correlation function on large scales. The bias CDM model of White et al. (1987) assumes that galaxies form in regions of high density, and the prescription for biasing selects particles in high-density peaks of the smoothed initial conditions of the numerical simulations.

Peacock (1991) has pointed out difficulties of the biased CDM cosmogony in reproducing the large-scale power of the observations. From his analysis he concludes that the shape of the CDM power spectrum is not consistent with observations. In effect, as we shall see in this paper, it is possible to reproduce the large-scale power of the angular two-point correlation function by biasing the distribution of galaxies. However, when a good fit to the observations is achieved on large scales, an excess on small scales is unavoidable.

Although it is not clear from the observations whether the luminosity function of galaxies depends on environment (see, for instance, Binggeli, Sandage, & Tammann 1988 and references therein), we have also considered this possibility in our models. We have studied in biased models the effects of local dependences of galaxy luminosities on the shape of the correlation function. These models fail in reproducing the observed angular correlation function on large scales, indicating that local variations in galaxy luminosities cannot reconcile CDM cosmology with observations.

In this paper we investigate different prescriptions for biased galaxy formation and the resulting correlation functions. We have analyzed both bias and antibias schemes for galaxy for-

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1993ApJ...414...30L

mation, studying the clustering and the dynamics of the models. The biasing prescriptions are based on local density criteria, and the models are confronted with observations through the angular correlation function, cluster velocity dispersion, etc. In § 2 we describe the general procedure adopted for the statistical treatment of the models. In § 3 we study bias models where the galaxy distribution is more strongly clustered than the dark matter. In this section is also included an analysis of the effects of a local-density–dependent luminosity function on the angular correlation function. In § 4 we consider antibiased models where the mass distribution is dynamically more evolved and the galaxies are less clustered than mass. In this section we also include an analysis of the velocity distribution. Section 5 deals with models where relative fluctuations in galaxies are comparable to those in mass, $\delta N/N \simeq \delta M/M \simeq 1$, on a sphere of 8 h^{-1} Mpc. This model, consistent with the results of *COBE* experiments, includes a simple prescription for the effects of mergers on both correlations and dynamics. Finally, in § 6 we present a brief discussion of the results.

2. ANALYSIS

We simulate the evolution of structure in a region of the universe using $N = 10^6$ particles in a 128 grid with a particle-mesh code (Hockney & Eastwood 1981). The particles were initially perturbed using the Zel'dovich (1970) approximation according to the CDM power spectrum with a random Gaussian density field in a universe with density parameter $\Omega = 1$, cosmological constant $\Lambda = 0$, and Hubble's constant $H = 100$ h km s^{-1} Mpc^{-1}. We adopted in the simulations a box of comoving size 100 h^{-2} Mpc, implying a mass per particle $m = 2.8 \times 10^{11}\, h^{-4}\, M_\odot$. Throughout this paper Hubble's constant is fixed by $h = 0.5$. The simulations were run on a Dec 5000/200 station, each one taking $\simeq 12$ CPU hours.

We performed a set of eight simulations evolved to different values of rms mass fluctuations $\delta M/M$ measured on a sphere of radius 8 h^{-1} Mpc. One of the simulations was expanded to $\delta M/M = 0.5$, others to $\delta M/M \simeq 1.2$–1.5, and a final set to $\delta M/M \simeq 1$. These values of $\delta M/M$ correspond to those extrapolated by linear theory from the initial conditions. Thus $\delta M/M = 1/b$, where b is the usual bias parameter.

All simulations require a statistical procedure to assign the galaxies from the distribution of particles. This procedure assigns a probability $P(\rho)$ to each particle of the simulation to be identified as a galaxy according to the density of neighboring particles ρ within a sphere of radius $r_s = 0.5\, h^{-2}$ Mpc. This scale is sufficiently small to ensure that the segregation between luminous and dark mass is determined only by local processes. In the case $P \equiv$ constant, galaxies trace the mass distribution. We have also analyzed the effects of other scales in the computation of ρ. We explored $r_s = 1$, 1.5, and 3 h^{-2} Mpc. We find that the results given in this analysis for $r_s = 0.5\, h^{-2}$ Mpc do not exhibit major changes for these other values of r_s.

This statistical procedure is consistent with the fact that the mass of each particle is of the order of the mass of a typical galaxy. In Table 1 we list the experiments performed and their main characteristics.

A direct comparison with observations is obtained by calculation of the two-point spatial correlation function $\xi(r)$ of the galaxies assigned from the particle distribution in the simulations. We derive the corresponding angular correlation function $\omega(\theta)$ for a projected catalog at Lick depth equivalent to the automatic plate measuring (APM) magnitude limit $b_j = 18.4$

TABLE 1

MODEL CHARACTERISTICS

Simulation	$\delta M/M$	$P(\rho)$	Notes
1.....	0.52	ρ^α	$1 < \alpha < 2$
		0 if $\rho \le 3\rho_b$ and 1 if $\rho \ge 3\rho_b$	
		0 if $\rho \le 3\rho_b$ and 1 if $\rho \ge 3\rho_b$	$L = f(\rho)$
2.....	1.50	ρ^α	
3.....	1.20	ρ^α	
4.....	1.30	ρ^α	$-1 < \alpha < 0$
5.....	1.35	ρ^α	
6.....	1.40	ρ^α	
7.....	1.03	0.5 if $2\rho_b \le \rho_m \le 50\rho_b$, 1 otherwise	Merger model
8.....	0.95	0.5 if $2\rho_b \le \rho_m \le 50\rho_b$, 1 otherwise	Merger model

(Maddox et al. 1990), using the Limber equation (Peebles 1980):

$$\omega(\theta) = D^{-1}\left\{\int_{-\infty}^{\infty} y^4\Psi^2(y)dy \int_{-\infty}^{\infty} \xi([u^2 + (y\theta D)^2]^{1/2})du\right\} \times \left[\int_0^{\infty} y^2\Psi(y)dy\right]^{-2}, \quad (1)$$

where

$$\Psi(y) = \int_{-\infty}^{\infty} \phi(M)F(M - M^* + 5\log y)dM \Big/ \int_{-\infty}^{\infty} \phi(M)dM\,, \quad (2)$$

and $F(M - M^* + 5\log y)$ is the observer selection function.

We have adopted a luminosity function $\Phi(M)$ for the galaxies in the simulations according to Maddox et al. (1990). We assume no dependence on redshift, since the mean depth of the Lick catalog corresponds to a low-redshift limit $z_l \simeq 0.1$; therefore,

$$\phi(x) = \phi^* x^\alpha \exp(-x)\,, \quad (3)$$

where $x = 10^{0.4(M^* - M)}$, $\phi^* = 1.875 \times 10^{-3}$ Mpc^{-3}, $M^* = -21.3$, and $\alpha = -1$.

3. BIASED MODELS

We have constructed different biased distributions of galaxies from simulation 1, which has $\delta M/M = 0.5$. A simple model may be constructed assuming that the probability $P(\rho)$ is a power law, $P(\rho) =$ constant $\times\, \rho^\alpha$, where the parameter $\alpha > 0$ favors galaxy formation in high-density environments.

Following equations (1)–(3), we have analyzed the angular correlation function for the resulting galaxy distribution. The results indicate that the shape of the angular correlation function of the models is not consistent with APM measurements. We have explored other simple biased models. A step function in $P(\rho)$ was analyzed, and we obtained similar results. Other functional dependences were also analyzed, with no satisfactory fit to the APM angular correlation function. Figure 1 shows the angular correlation function for a model with $\alpha = 0.5$ and for a model with a step function $P(\rho) = 1$ if $\rho \ge \rho_c$ and $P(\rho) = 0$ if $\rho < \rho_c$, where ρ_c is three times the background density ρ_b. This figure illustrates that local biased models are not successful in reproducing APM angular correlations. This behavior is caused by the local nature of the bias mechanisms. Since we have explored a suitable variety of local scales as well as functional dependences of $P(\rho)$, we conclude that locally

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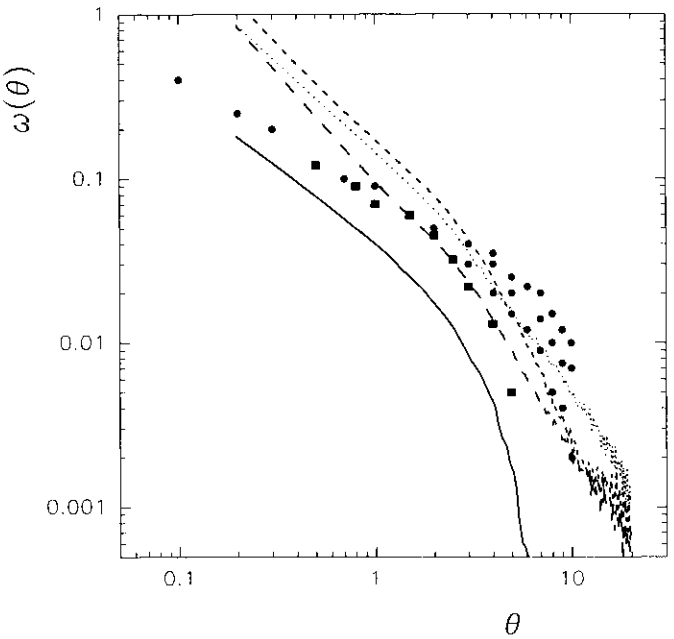

FIG. 1.—Angular correlation function of different biased models (simulation 1) scaled to Lick depth. The solid line shows the mass angular correlation function. The long-dashed line corresponds to a power-law biased model $\alpha = 0.5$. The dotted line corresponds to the same model with $r_s = 3\ h^{-2}$ Mpc. The short-dashed line corresponds to a step function. *Dots and squares*: APM and Lick angular correlation functions, respectively.

defined bias scenarios are not able to reproduce APM correlations at large angular scales. Large-scale biasing due to quasar activity (Babul & White 1991) might avoid these difficulties, although it is not clear whether this proposed mechanism may be astrophysically plausible.

3.1. *Effect of a Density-dependent Luminosity Function on the Angular Correlations of Biased CDM Models*

We have analyzed the effects of correlations between luminosities of galaxies and local densities on the angular correlation function. We note that differences in the absolute magnitudes of galaxies in different environments could sensibly modify the variance in the number of galaxies detected in a magnitude-limited catalog. We assume that the luminosity of a galaxy is affected by the presence of neighbor galaxies. We adopt the minimum radius $r_s = 0.5\ h^{-2}$ Mpc for the definition of the local density adopted in the bias prescriptions. We use a Monte Carlo method to assign the luminosities of the galaxies according to the luminosity function (3). The absolute magnitude M in the blue band of a galaxy is assigned in the range -24 to -16, taking into account the local galaxy density. For a given model we select the fraction f of the total number of galaxies in the highest density regions. We assign absolute magnitudes to these galaxies from the high-luminosity tail of equation (3), $M = -\infty$ to M_f, where M_f satisfies

$$f = \int_{-\infty}^{M_f} \phi(M)dM \Big/ \int_{-\infty}^{\infty} \phi(M)dM \ .$$

We note that $f = 0$ is equivalent to no dependence of galaxy luminosity on local density. We have considered f in the range 0.1–0.5 in the different models explored.

We note that the adopted procedure is a crude approximation for attempting a modeling of galaxy luminosities depending on environment. However, since we are interested only in analyzing variations in the angular correlation function of a magnitude-limited galaxy catalog, the results derived in this work should not be substantially affected by using more accurate procedures.

We have directly computed $\omega(\theta)$ for the projected distribution with a magnitude limit. Limber's equation cannot be used, since it does not permit us to consider the effect of the luminosity function depending on local spatial density. Angular correlation functions for models with $f = 0.5$ and without density-dependent luminosities ($f = 0$) for simulation 1 are displayed in Figure 2. Since the typical galaxies in a magnitude-limited catalog have M^*, we have adopted a limiting magnitude cut $m_l = 16.5$. An M^* galaxy will be observed at this limiting magnitude at a distance of 17,300 km s^{-1}, which is within the size 20,000 km s^{-1} of the simulated box.

We have applied the scaling relation to these correlation functions to the Lick depth of $m_l = 18.4$. We notice that this procedure gives a noisier estimate of $\omega(\theta)$ as compared with the estimate given by Limber's equation. The reason is that a large fraction of particles is not considered in the statistics due to the luminosity function. This fact accounts for the difference between the lower curve of Figure 1 and the one corresponding to the model with $f = 0$ (Fig. 2). Nevertheless, since we are interested in the differential effect of a luminosity-environment relation, the present calculation is valid for this purpose. It is seen in this figure that the correlation function at large angular scales shows small differences as compared with that measured in the density-independent luminosity models, in contrast to the significant differences found at small scales. Similar results

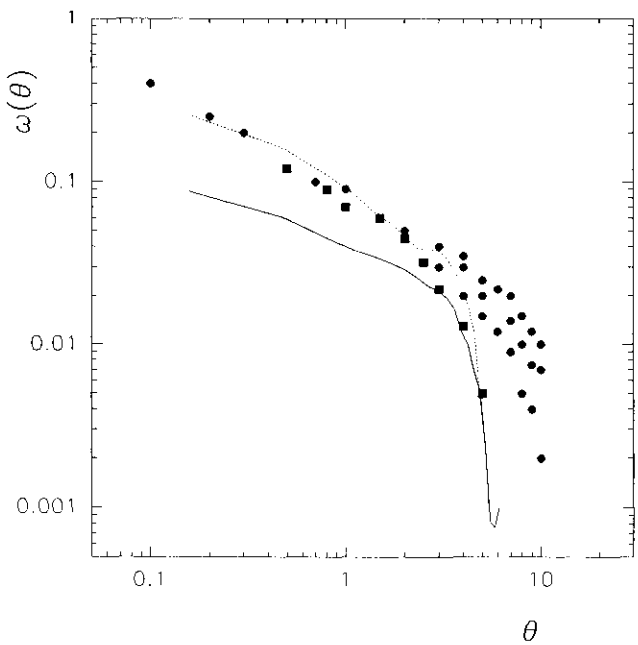

FIG. 2.—Effect of an environmental dependence of the luminosity function on $\omega(\theta)$. *Solid line*: Model with a luminosity function independent of environment, $f = 0$. *Dotted line*: Same model with no environment-dependent luminosity function, $f = 0.5$. *Dots and squares*: APM and Lick angular correlation functions, respectively. The angular correlation functions have been scaled to Lick depth. The model corresponds to all particles (mass) in simulation 1.

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1993ApJ...414...30L

are obtained for other values of f, and so we conclude that the local-density–dependent luminosities of galaxies in our model cannot account for the departures of CDM-biased cosmogony from APM large-scale angular correlations.

4. ANTIBIASING IN EVOLVED CDM MODELS

We have explored the possibility that the distribution of galaxies is less clustered than the mass distribution, owing to astrophysical mechanisms (see, for instance, Braun, Dekel, & Shapiro 1988). We consider that galaxy formation efficiency in high-density regions decreases as a function of local density. This fact might be related to galaxy merging processes, star winds, and the inhibition of massive formation of stars by gas reheating in regions of local high mass density. Another possibility is related to the ionization of the gas in the neighborhood of quasars or primeval supernova explosions (see Babul & White 1991). We remark that we have adopted the same scale for antibiasing as the scale of biased models (that is, a sphere of radius $r_s = 0.5$–$3\ h^{-2}$ Mpc). Thus, we assume that only local processes take place in regions of high density, and we exclude global-type phenomena such as those discussed by Babul & White (1991).

We have evolved several CDM models with $\delta M/M \simeq 1.2$–1.5 (simulations 2–6, Table 1). Therefore, the corresponding bias parameters b are in the range 0.6–0.8. In these evolved CDM models galaxy formation takes place much earlier than in the biased models with $b \geq 1$, such as the standard model of White et al. (1987). A typical redshift for the collapse of a galactic halo in a CDM model with $\delta M/M \simeq 1.5$ would be $z \simeq 5$ instead of the more recent epoch $z \simeq 1$ of the standard $\delta M/M \simeq 0.5$ biased CDM model. We note that estimates of the ages of stars and globular clusters would be in better agreement with an earlier development of structure as it occurs in these models.

As in the biased models, for reasons of simplicity we assumed a power law for the probability $P(\rho)$. Thus, we adopt $P(\rho) = \text{constant} \times \rho^{\alpha}$. A particular model that gives a good fit to observations is obtained for $\alpha = -\frac{1}{3}$ with $\delta M/M \simeq 1.3$. In this model roughly half the particles are identified as galaxies. We find large structures, filaments, and voids in the distribution of galaxies comparable to large-scale structures present in the observations. Figure 3 shows the angular correlation function of the mass and the galaxies for this model scaled to Lick depth. Lick and APM angular correlation functions are also shown for comparison. We see that this particular model successfully reproduces the APM two-point angular correlation function, and we conclude that evolved CDM models with suitable antibiasing mechanisms may provide reasonable fits to the observed correlation functions at large scales.

We note that in a biased CDM model with $\delta M/M = 0.5$, the most massive clump of the simulation has a velocity dispersion $\sigma \simeq 1200$ km s^{-1}. However, in an antibiased CDM model with $\delta M/M \simeq 1.3$, the greatest velocity dispersion is $\sigma \leq 3000$ km s^{-1}. Thus, the antibiased model implies deep potential wells in clusters and a mass-to-luminosity ratio increasing with local density. The observed velocity dispersions of rich clusters of galaxies are $\sigma \leq 1000$–1500 km s^{-1} (Struble & Rood 1987). We find that the virial masses of the clusters in the antibiased models are in excess when compared with the observations. Nevertheless, hydrodynamical effects could mitigate this problem, smoothing the velocity field in regions of high densities. This could have been particularly possible during the process of galaxy formation when the interaction of subclumps and the intracluster medium might have been important.

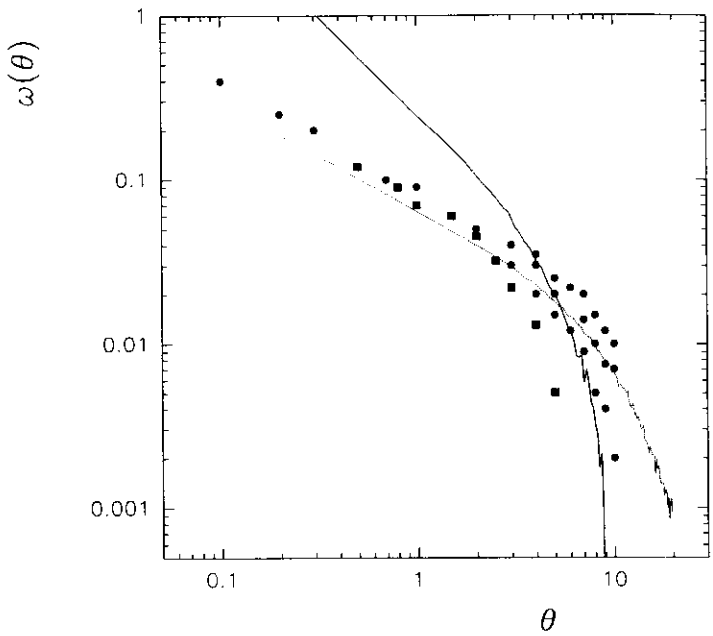

FIG. 3.—Angular correlation function for an antibiased model (simulation 5) scaled to Lick depth. *Solid line*: Mass angular correlation function. *Dotted line*: Antibiased model $\alpha = -\frac{1}{3}$. *Dots and squares*: APM and Lick angular correlation functions, respectively.

We have also analyzed in the antibiased model the peculiar velocities of galaxies. We find the probability $p(v)$ that an observer in the simulations measures its own peculiar velocity v as less than that of our Galaxy ($v_g \simeq 600$ km s^{-1} with respect to the microwave background) is only $p(v) \simeq 8\%$ for the $\delta M/M = 1.3$ model. By contrast, in the $\delta M/M = 0.5$ biased CDM model $p(v) \simeq 50\%$. Therefore, an observer with $v_p \leq v_g$ in the antibiased models has a low probability of occurrence, while most of the observers would detect $v \simeq 1000$ km s^{-1}.

As has been suggested by the referee, the depth of the potential wells of the clusters in these models implies large X-ray luminosities and temperatures. According to Henry & Arnaud (1991), X-ray data for clusters of galaxies indicate $\delta M/M \simeq 0.6$ for a power spectrum $P(k) \propto k^n$ with $n = -1.7$. We might argue that, in spite of the uncertainties in the models (see, for instance, Evrard 1991), it would be difficult to reconcile the CDM cosmology with $\delta M/M > 1$ and the X-ray observations of clusters of galaxies.

Another important property of the velocity field of the galaxies is the cosmic Mach number, defined as the ratio of systematic velocity to internal velocity dispersion, v/σ, in large volumes of space (Ostriker & Suto 1990). We have followed Park's (1990) calculations, and we find that the probability $p(v/\sigma)$ of occurrence of the observed $v/\sigma \simeq 1.3 \pm 0.4$, measured in a sphere of radius $18\ h^{-1}$ Mpc, in the $\delta M/M = 0.5$ biased model is $p(v/\sigma) = 0.07$ within the observed 1 σ error. On the other hand, for the antibiased model $\delta M/M = 1.3$ this probability is $p(v/\sigma) = 0.4$. Thus, large ratios of systematic to random motions are more likely to occur in antibiased models and are in better agreement with observations.

The observational lower limits of the fluctuations in temperature of the cosmic microwave background, $\Delta T/T$, require $b \geq 0.7$, ruling out very low-bias models (Bond et al. 1991;

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1993ApJ...414...30L

Vittorio et al. 1991; Wright et al. 1992); thus the antibiased models are marginally acceptable from these considerations.

5. MODELS WITH $\delta M/M \simeq 1$

The important measurements of $\Delta T/T$ by the *COBE* experiments provide a stringent normalization for hierarchical models (Wright et al. 1992). For CDM it implies $0.8 < \delta M/M < 1.2$. The *COBE* results were published after the first version of this paper. In the revised version we have also analyzed new simulations with $\delta M/M = 1$ (simulations 7 and 8). In these simulations the peculiar velocities of galaxies are still too high when compared with observations. We have followed the referee's suggestion that a complete bias model should take into account both dynamical and clustering properties. Therefore, a simple model was analyzed in order to account for the differences between the simulated and observed peculiar velocity distributions. The general idea of velocity bias was first proposed by Carlberg (1992). The author bases his conclusions on a model where the preferred sites for galaxy formation are identified at redshift $\simeq 3$. Our approach for velocity bias is based on the fact that galaxy encounters common in high-density environments would reduce the velocities of the resulting systems. We have considered a simple scheme where a merger of n particles in one single galaxy implies a probability $P = 1/n$ associated with each particle. We adopt a critical local density ρ_m beyond which mergers are effective. We assume the simplest case where all pairs of particles with $\rho > \rho_m$ undergo one single merger; thus $P = 0.5$. The velocities of the galaxies after mergers are computed assuming equal velocity moduli and random directions in the collision. Under this assumption the mean velocity of the galaxy after the collision equals 0.7 times the mean velocity of the colliders.

We computed the angular correlation function $\omega(\theta)$ for this simple model. The results are shown in Figure 4. We see that

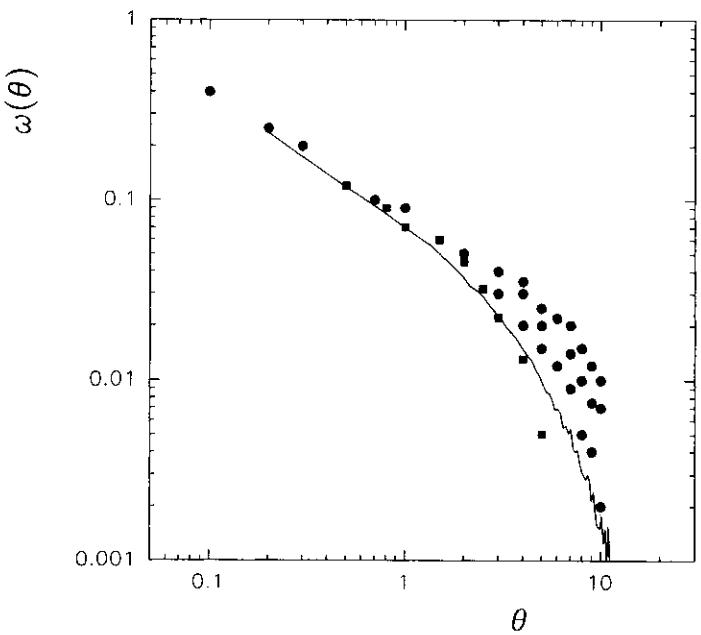

FIG. 4.—Angular correlation function for a merger model (simulation 8). *Solid line*: Angular correlation function for a merger model with $\delta M/M = 0.95$, $\rho_m = 25\rho_b$. *Dots and squares*: APM and Lick angular correlation functions, respectively.

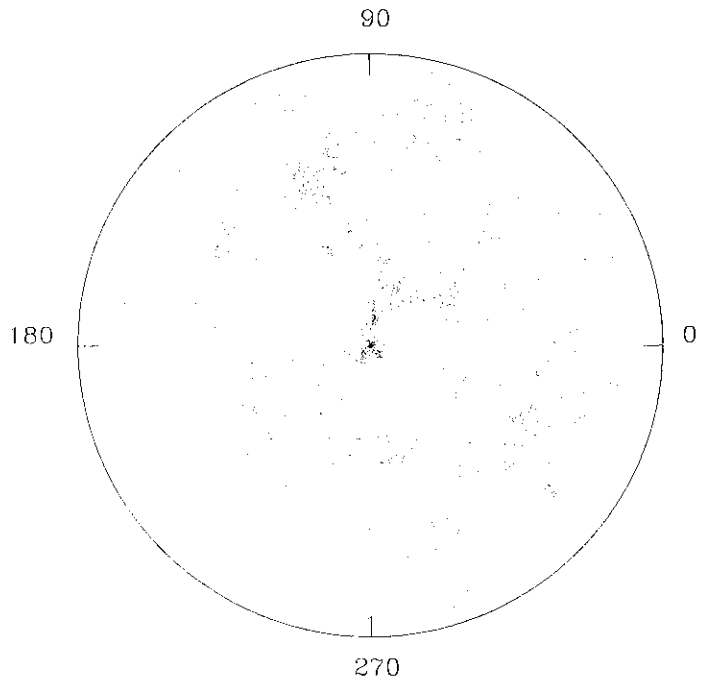

FIG. 5*a*

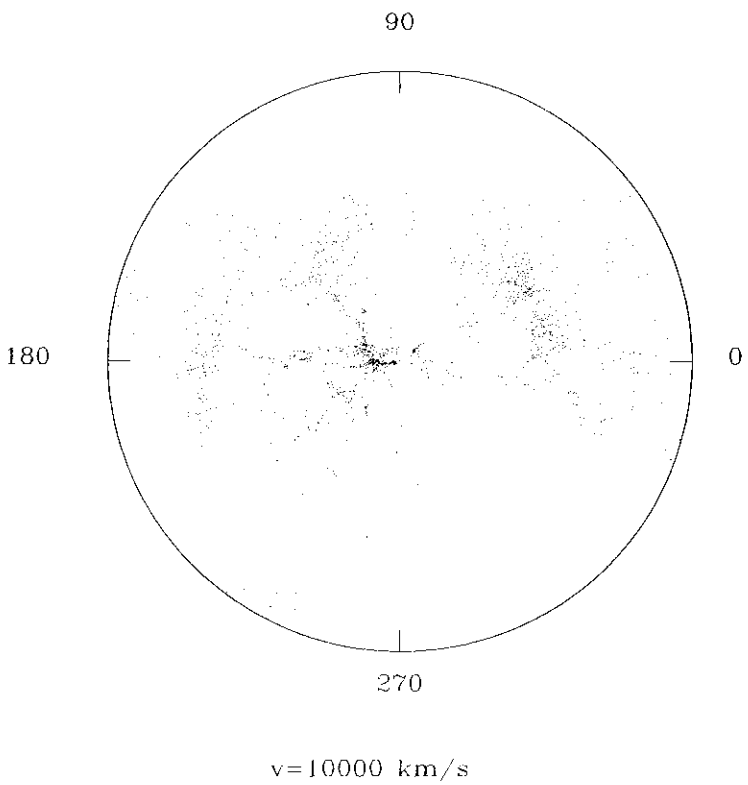

FIG. 5*b*

FIG. 5.—Wedge diagrams $v < 10{,}000$ km s^{-1} for the merger model and the observations. (*a*) Slice $15° < \delta < 55°$ for the merger model with $\delta M/M = 0.95$ (simulation 8). (*b*) CfA slice $15° < \delta < 55°$.

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1993ApJ...414...30L

only if APM correlations at large scales were slightly overestimated (Collins et al. 1992) would the fit of the model be acceptable. The velocities of the galaxies are in agreement with observations, since the average velocity dispersion of rich clusters is $\simeq 1200$ km s^{-1}.

We display in Figures 5*a* and 5*b* a slice $15° \leq \delta \leq 55°$ with $v \leq 10{,}000$ km s^{-1} for the simple merger model, and the observed distribution of galaxies from the CfA catalog. We have added an artificial radial gradient in the simulations, consistent with the CfA, in order to make the figures comparable. We can see from this figure that the model galaxies have a velocity and spatial distribution similar to those of the observations.

6. CONCLUSIONS

We have analyzed statistical properties of numerical simulations of CDM cosmology using different prescriptions for biased galaxy formation. The models studied in this work consider galaxy formation assuming local astrophysical processes. In our models galaxies are identified according to the density ρ of neighboring particles within a sphere of radius $r_s = 0.5$–3 h^{-2} Mpc.

From our analysis we conclude that CDM models where the galaxies are more clustered than the dark matter are not successful in reproducing the APM angular correlation function. There is a significant lack of power on large scales in these models when compared with observations. These results are similar to the conclusions of Maddox et al. (1990) for the "natural" bias CDM model of White et al. (1987).

The effects of a density-luminosity dependence in the angular correlation function were analyzed using a simple model. The results indicate that local variations in the absolute magnitudes of galaxies cannot account for the differences between the angular correlation function of the biased CDM cosmology and the observations.

We analyze CDM simulations with $\delta M/M > 1$. In these simulations we antibias the distribution of mass to generate the distribution of galaxies. We find that some of the models analyzed have correlation functions compatible with APM data. The potential wells of the clusters in these simulations are very deep. The mean cluster velocity dispersion is $\langle\sigma\rangle \simeq 2000$ km s^{-1}, a factor $\simeq 2$ greater than the observed mean velocity dispersion of rich clusters of galaxies $\langle\sigma\rangle \simeq 1000$ km s^{-1}. The typical peculiar velocity of a galaxy in the antibiased models is $\simeq 1200$ km s^{-1}, and the probability $p(v)$ that a galaxy in the model has a peculiar velocity v equal to or less than the velocity of our Galaxy with respect to the microwave background (600 km s^{-1}) is fairly low [$p(v) \simeq 0.08$]. For the standard CDM biased model $p(v) \simeq 0.5$. On the other hand, we find that the Mach number in the models with $\delta M/M \geq 1$ is in better agreement with observations than the standard CDM model.

A simple merger scheme in models with $\delta M/M \simeq 1$ has reasonable dynamical properties. The peculiar velocity dispersion of clusters of galaxies, significantly reduced by mergers, is consistent with observations. The clustering in this model is slightly weaker than that derived by Maddox et al. (1990) from APM angular correlation functions, although at large scales the model correlation function has more power than GP estimates. Only if the determination of $\omega(\theta)$ by Maddox et al. (1990) were partially affected by systematics, as Collins et al. (1992) have suggested, could the CDM cosmology account for the clustering and dynamics of the universe.

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