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CORRELATIONS OF FAINT GALAXIES: A MONTE CARLO APPROACH

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ABSTRACT

Monte Carlo methods are employed to study the angular correlations arising from simulated galaxy clusters in flux-limited samples. In particular, we show that the models of Chokshi and coworkers that best reproduce the general characteristics of the observed deep blue photometric counts and redshift distributions also satisfy the observed angular correlation constraints of faint galaxies, under a stable clustering hypothesis. In particular, the diminished clustering of faint simulated galaxies ($24 < b_j < 26$) in the blue band arises from a extended high-redshift tail of simulated galaxies, in agreement with the models of Roche and coworkers.

Subject headings: galaxies: clusters: general — large-scale structure of universe — methods: numerical

1. INTRODUCTION

The origin and nature of the excess faint blue galaxy counts $b_j \geq 24$ has been a topic of intense debate over the last several years. While the steep rise in blue counts exceeds the nonevolutionary and some evolutionary model predictions, their redshift distribution is consistent with nonevolving galaxy models. Several scenarios have been suggested to explain such discrepant photometric versus spectroscopic behavior; these include galaxy luminosity and/or density evolution, invoking of starbursts, mergers, or a missing population of galaxies.

One constraint on the nature and evolutionary behavior of faint galaxies arises from their angular correlation function. Several studies of faint galaxy correlations now exist in the literature (Koo & Szalay 1984; Efstathiou et al. 1991; Couch, Jurcevic, & Boyle 1993; Roche et al. 1996a, 1996b; Neuschaefer et al. 1995) with a consensus that the observed faint galaxy correlations are consistently lower than those of nonevolving galaxy models in stably clustered environments. This paper is part of a series designed to study in a systematic fashion the nature of deep multiwavelength galaxy properties using simulations. The essential premise of the approach is to rely on the known properties of local galaxy samples and to extend them to high redshifts using passively evolving stellar populations in galaxies and an assumed set of cosmological parameters that define the spacetime geometry.

The Monte Carlo method that we use for our simulations was originally designed by Chokshi (1986) (see Chokshi & Wright 1988) to study the properties of galaxies extending to large look-back times in terms of both the changes in their physical parameters, such as color and surface brightness evolution, and their observability—for example, the behavior of confusion as a function of flux limit. This program was updated for comparison with the recent optical and near-infrared data by Chokshi et al. (1994). It was found that, unlike the previous models, a quiescently evolving galaxy-population model with formation redshift $z_f \simeq 5$ in a low-Ω_0 cosmology was sufficient to explain the observed number counts, redshift, and color distributions of galaxies in the blue and the near-infrared bands. Here we attempt to carry the success of this quiescent model further by making a comparison between the derived and the observed two-point correlations of galaxies. In particular, we examine the issue of faint blue galaxy clustering in our simulated sample in a reverse order—i.e., given that the simulations are based on the pure luminosity evolution of galaxies (and effects of K-correction) as a function of galaxy type and stable clustering of the associated large-scale structure with redshift, we investigate whether the derived angular correlations at faint magnitude levels ($b_j > 24$) are consistent with the observed values. In § 2 we briefly describe the simulation method; § 3 details the angular correlation analyses; its results are discussed in § 4.

2. SIMULATION APPROACH

As described in Chokshi & Wright (1988), simulations are carried out in a conical field of a given angular size extending to a maximum redshift of 5. The shape of the cone is determined by the cosmological parameters that determine how the angular size distance varies with redshift. All galaxies belong to clusters, and the number of galaxies per cluster varies according to a power law from 10^2 to 10^4 with a mean of 1000 members per cluster. The number of clusters within a field is then determined by the overall galaxy number density, set by the integral of the adopted local luminosity function, and the size of the simulated volume.

Three scale lengths enter the placement of galaxies within a cluster—the primary clump size is derived from the empirical normalization of the two-point correlation function $\xi(r)$, which equals unity at 5 h^{-1} Mpc. This is held constant for all redshifts and corresponds to the stable ($\epsilon = 0$) clustering model discussed in the literature. The amplitude or the clustering scale length of the individual clusters is allowed to vary on this primary scale in a power-law fashion such that there is a distribution in cluster richness from rich Abell class I clusters to those where the scale length is large enough to mimic the separation of galaxies in a field population. Thus there are no bona fide field galaxies within these simulations. Finally, the galaxy members of a particular cluster are placed using a Rayleigh-Levy random-walk process using Mandlebrot's prescription (see Peebles 1980) starting from an initial and random cluster seed position placed in a field that is twice the required field of view. The member galaxies of a cluster are thus allowed to random-walk their way into the simulation field and also out of it. All the galaxies of each cluster are assigned the same redshift as the initial cluster seed, so that the cluster

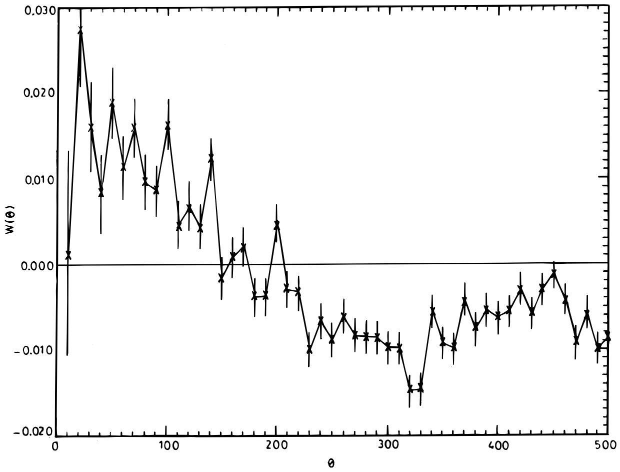

FIG. 1*a*

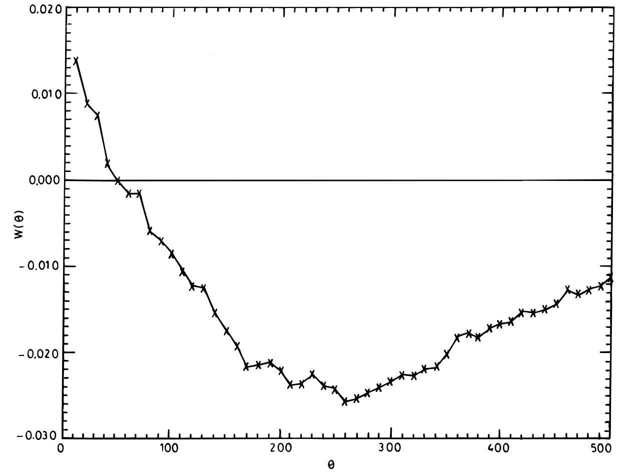

FIG. 1*b*

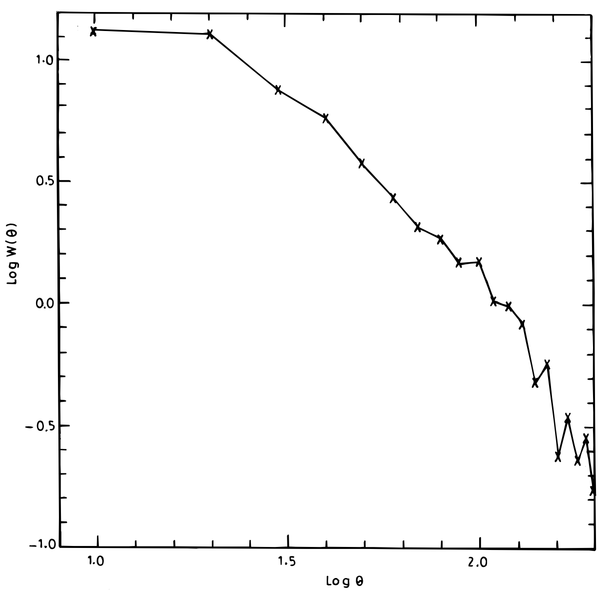

FIG. 1*c*

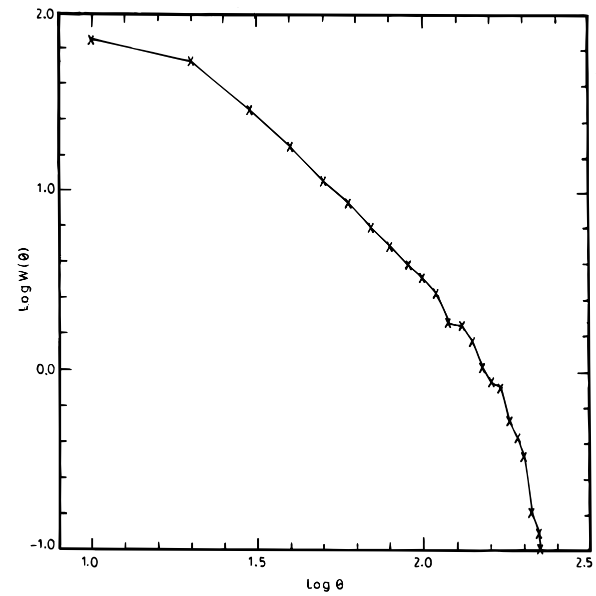

FIG. 1*d*

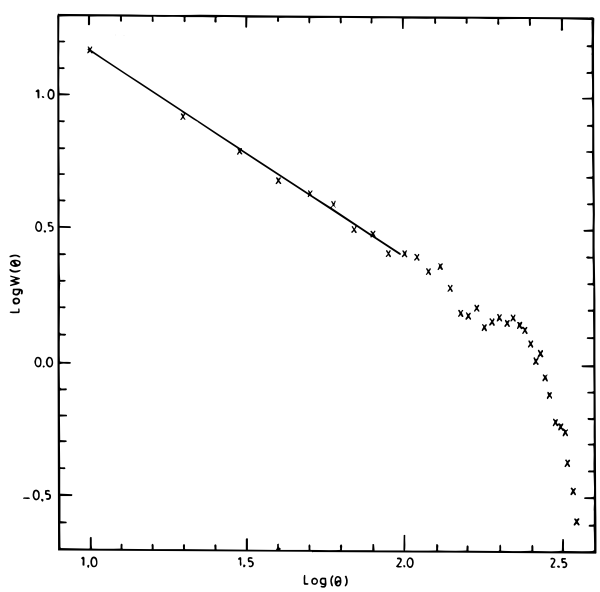

FIG. 1*e*

FIG. 1.—Angular correlation $w(\theta)$ vs. θ, (*a*) for the $\Omega = 0$ model with $24 < b_j < 26$; (*b*) for the $\Omega = 0$ model and the entire sample; (*c*) averaged over identified galaxy clusters in the simulations for the $\Omega = 0$ model with $24 < b_j < 26$; (*d*) averaged over identified galaxy clusters in the entire $\Omega = 0$ simulation; and (*e*) for a single cluster in the $\Omega = 0$ model (the line represents an arbitrarily normalized power law of slope -0.77).

velocity dispersion is ignored here. For further details on the clustering process and simulations refer to Chokshi & Wright (1988).

Given the position of galaxies, each galaxy is assigned a realistic set of parameters necessary to describe its observed light distribution. These include the galaxy luminosity; the de Vaucouleur or exponential scale size associated with the bulge or disk component; and the rest-frame spectral energy distribution, which is decided for a galaxy type by its age, which is extracted from the evolutionary code of Mazzei (1988) and described in Chokshi et al. (1994). These parameters allow artificial images of galaxies to be created with any chosen resolution on a field of a given size. Examples of such images are shown in Chokshi et al. (1994). Here we chose the $H_0 = 50$, $\Omega_0 = 0$, and $z_{\rm form} = 5$ model for analyzing the two-dimensional distribution of galaxies in a simulated field that is 15′ on side and extends to a maximum redshift of 5. This model comes closest to explaining both the observed number count and the redshift distribution of galaxies.

3. ANGULAR CORRELATIONS

The data we analyze are extracted from simulations *before* imaging processing and consist of a list of galaxy positions, redshifts, and fluxes in the b_j band that were used to create two-dimensional photometric galaxy "fields." Chokshi, Majewski, & Lonsdale (1996) show that under realistic observing conditions of a sky background, seeing blurring, instrumental noise, and finite integration times, the image analysis package FOCAS (Valdes 1982) is able to extract photometric properties of galaxies to a fair degree of accuracy, at the flux levels of interest ($b_j < 26$) in the present study.

The angular correlation of galaxies is defined as

$$1 + W(\theta_i) = \frac{n_{\rm pg}(\theta_i)}{n_{\rm Pp}(\theta_i)} \left(\frac{N_{\rm P}}{N_g}\right)^2 ,$$

where $n_{\rm pg}(\theta_i)$ and $n_{\rm Pp}(\theta_i)$ are the number of galaxy pairs and Poisson pairs, respectively, with a separation of θ_i, where θ_i is the mean angular separation of the ith bin of width 10″ in the present analysis. N_g and $N_{\rm P}$ are the total numbers of simulated galaxies and Poisson points used in the analysis. For the Poisson distribution we use a random number generator to create a set of 5000 random (θ_x, θ_y) positions distributed uniformly in our field, the pairwise separation of which yielded $n_{\rm Pp}(\theta)$. The angular correlation for a $\Omega = 0$, 15′ field simulation in the $24 < b_j < 26$ magnitude bin, as a function of separation, was calculated using equation (1) and is shown in Figure 1*a*. In the present analyses where we study a single simulated field, the only error in a bin θ_i is in the Poisson statistics and is equal to $[n_{\rm pg}(\theta_i)]^{-1/2}$. These correspond to the error bars shown in Figure 1*a*. We find a weak positive correlation at $\theta < 100''$ with a mean of 0.014 ± 0.005 for $10'' < \theta < 50''$. Figure 1*b* shows the angular correlation for all the galaxies in our field. The total number of galaxies in this sample is 145,885, and we used 20,000 random points for normalizing the distribution. The error bars in the analysis are small compared to the size of the symbols on the plot. We find that the overall amplitude of the correlation remains weak and positive for $\theta < 50''$, in the volume-limited experiment to $z_{\rm max} = 5$.

We use the simulation technique to our advantage by calculating the average two-dimensional angular correlations of the physically correlated galaxies from a priori knowledge of their cluster membership. Figures 1*c* and 1*d* show the average angular correlation derived for the known cluster galaxies in $24 < b_j < 26$ and the entire sample, respectively. We find that the correlation function is identical in shape in the two samples and is large and positive for all $\theta \geq 220''$, being as large as $\simeq 15$ and $\simeq 70$, respectively, at $\theta = 10''$, in contrast to what was found from the angular position studies without the redshift information. However, the shape of the angular correlation averaged over the input cluster galaxies in the field departs significantly from a simple power law predicted for a cluster (see eq. [52.8] of Peebles 1980), being flatter compared to the expected -0.77 power law at small separations but falling faster at large θ. This deviation arises because of averaging over different fractions of cluster members of different correlation amplitude that contribute to the samples, and then averaging over the redshift distribution within the flux bin under consideration. For example, our entire sample consists of 145,885 galaxies belonging to 3556 clusters, so that the average number of members per cluster is $\simeq 41$, although with a large dispersion about this value. The flux-limited $24 \leq b_j \leq 26$ sample consists of a total of 6110 members belonging to 1720 different clusters with an average of three members per cluster! Taking one large cluster that happens to fall in our field with more than 500 members, we find that the angular correlation of this single cluster is well represented by the expected power law based on the input spatial correlation of galaxies. This is shown in Figure 1*e*, where the straight line represents a -0.77 slope and provides a good fit to the data.

4. DISCUSSION

The cluster simulations that we have carried out here allow us to make direct comparison with the observed correlation from the deep b_j band samples of Efstathiou et al. (1991), and Roche et al. (1996a, 1996b). We have found that the average correlation at small angular separation $10'' < \theta < 50''$ with $\langle\theta\rangle = 30''$ is 0.014 ± 0.005 for the $\Omega = 0$ model in the $24 < b_j < 26$ magnitude limit. This is consistent with the observed values of 0.022 ± 0.006 and

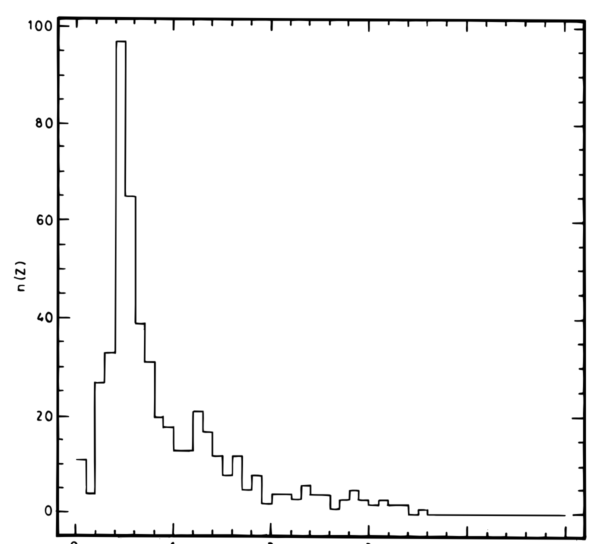

FIG. 2.—Redshift distribution for the $\Omega = 0$ simulation for the $24 < b_j < 26$ sample.

0.009 ± 0.006 in the SA68 and TS12 samples for $15'' < \theta < 45''$ within the same flux limit (Efstathiou et al. 1991) and a mean of $\sim 0.02 \pm 0.02$ observed for similar angular separation range and $b < 25.5$ in Figure 8 of Roche et al. (1996b).

Figure 2 shows the redshift distribution for the simulations in the $24 < b_j < 26$ range. While the simulated galaxies were distributed uniformly in the redshift space to $z_{\rm max} = 5$, the $24 < b_j < 26$ range shows a broad humped distribution extending over the entire redshift interval with a small fraction of systems lying at the maximum redshift limit of simulations. This is identified as the principal reason for the severe diminishing of the angular correlation in the simulated data set. Roche et al. (1996b) reach a similar conclusion after detailed modeling of their observed correlation functions with a combination of pure luminosity evolution galaxy model and a stably clustered correlation function with redshift.

Note that important constraints have been derived by Roche et al. (1996b) by comparing the observed correlations of their faint blue galaxy sample against the systems with red colors. Such an exercise is beyond the scope of the present simulations, which treat the photometric behavior of galaxies as independent of their environment, i.e., the observed morphology/color–density relation is explicitly ignored in the Monte Carlo models used here.

In conclusion, it appears that the simulations of galaxies in a simple open universe geometry with quiescent photometric evolution driven by their younger stellar content with look-back times suffice in reproducing most of the observed properties of the faint galaxy samples and, in particular, their diminished correlation, as is explicitly demonstrated in this paper. This conclusion further validates the use of these simulations to study the expected characteristics of passively evolving galaxies, and galaxy ensembles, at large look-back times, particularly for data extraction and study of selection effects that become increasingly important for a high-redshift universe.

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