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GALACTIC HALO FORMATION AND THE EVOLUTION OF BIAS

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RESUMEN

Estudiamos la evolución del sesgo galáctico en cuatro modelos cosmológicos (ΛCDM, OCDM, τCDM y SCDM). El uso de simulaciones numéricas de alta resolución, obtenidos con el código AP^{3}M, produce docenas de halos galácticos dentro de halos más masivos. Estos grupos de halos galácticos tienen una apariencia muy similar a la que se observa en grupos de galaxias en el universo real. Encontramos que el sesgo disminuye monotonicamente con el tiempo en todos los modelos y que varía de 2–3 a $z = 3.0$ (1 Mpc/h) para halos con una densidad numérica de $0.02h^3$Mpc^{-3}. Todos los modelos están anti-sesgados ($b < 1$) a $z < 1$.

ABSTRACT

We study the evolution of bias in four cosmological models (ΛCDM, OCDM, τCDM, and SCDM). The use of very high-resolution simulations, achieved with the AP^{3}M code, produces dozens of galaxy-size halos inside groups. The groups look like real groups of galaxies. The bias decreases monotonically with redshift for all models and varies from 2 to 3 at $z = 3.0$ on 1 Mpc/h scale for halos with a number density of $0.02h^3$Mpc^{-3}. All models are anti-biased ($b < 1$) at $z < 1$.

Key Words: **COSMOLOGY: THEORY — LARGE-SCALE STRUCTURE OF THE UNIVERSE — METHODS: NUMERICAL**

1. INTRODUCTION

In the hierarchical cosmological model for structure formation low mass objects collapse first; for example, the top-hat spherical collapse model predict that galaxy-size halos of $10^{11}h^{-1}$ $M_\odot$ collapse at around $z \sim 3.3$ in an $\Omega_0 = 1.0$ CDM COBE-normalized model. Galactic halos of this mass start forming at even higher redshifts in rarer, higher density, peaks. Their mean redshift formation depend on the cosmological parameters Ω_0 (the mean density of the universe in units of the critical density $\rho_c = 1.879$ $h^2 \times 10^{-29}$g cm^{-3}), Ω_Λ (the energy density provided by the cosmological constant in units of ρ_c) , h (the Hubble constant in units of 100 km s^{-1} Mpc^{-1}), n (spectral index of the primordial power spectrum), and σ_8, the rms mass fluctuation at $8h^{-1}$Mpc, which measures the power spectrum amplitude. On the contrary, cluster-size halos are still very young objects.

The notion of bias, the difference between the spatial distribution of galaxies and that of the dark matter (DM), was introduced by Kaiser (1984) to explain the large difference in the clustering amplitude between galaxies and Abell clusters. Davis et al. (1985) showed that if galaxies were distributed like DM, both the shape and correct amplitude of the observed galaxy 2-point correlation function, ξ_{gg}, could not be reproduced simultaneously in a CDM model. They adopted then a biased galaxy formation scenario that could fit well ξ_{gg}.

Here, the *bias function*, b^2, is defined as the ratio of the two-point correlation function of galaxy-tracers

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(halos), $\xi_{hh}(r,z)$, and dark matter, $\xi_{dm}(r,z)$: $b^2(r,z) = \xi_{hh}(r,z)/\xi_{dm}(r,z)$.

2. COSMOLOGICAL MODELS

We have choose four models for the evolution of bias: (1) A 2-year COBE- normalized CDM model (SCDM); (2) a variant of the $\Omega_0 = 1.0$ CDM model (τCDM), with a different shape of the power spectrum; (3) a flat low-density model with $\Omega_0 = 1 - \Omega_\Lambda = 0.3$ (ΛCDM); and (4) an open model with $\Omega_0 = 0.3$ (OCDM). We used two approximations for the power spectrum: for OCDM and ΛCDM we used the fit by Bardeen et al. (1986), with corrections by Sugiyama (1995), while for SCDM and τCDM we used the formula by Efstathiou, Bond, & White (1992). The SCDM and ΛCDM models were normalized to the 2-year COBE-DMR data, $\sigma_8 = 1.1$ and 1.2, respectively. Moreover, our normalizations for OCDM and τCDM are $\sigma_8 = 0.9$ and 1.0, respectively.

3. NUMERICAL SIMULATIONS

We used the AP^{3}M code (Couchman 1991) to run our simulations. A box size $L_{box} = 30h^{-1}$Mpc was chosen as a compromise between requirements of high force resolution ($\sim 3h^{-1}$kpc) and good statistics. The mass per particle is $m_p = 3.5 \times 10^9 h^{-1}\ M_\odot \Omega_0$. All simulations were started very early: $z_{init} \sim 50 - 100$. The intention of this paper (see Colín et al. 1999) was to follow the evolution of the 2-point correlation function for galactic halos until present time. For this purpose, it was very important to assure that our halos would survive even in very extreme conditions like the ones they encounter in the centers of groups and clusters. Studies like Klypin et al. (1999), indicated the need for a mass resolution of $\lesssim 10^9 h^{-1}\ M_\odot$ (galactic halos could be resolved by more than 30 particles) and a spatial resolution of $1 - 3h^{-1}$kpc. Halos were identified using an algorithm called Bound Density Maxima (BDM, Klypin et al. 1999). This algorithm finds positions of local maxima in the density field, smoothed at the scale of interest, and applies physically motivated criteria to test whether the group of DM particles, halo, is gravitationally bound.

4. RESULTS

Halos with a maximum circular velocity, V_{max}, greater than 200 km s^{-1} (SCDM and τCDM) or 120 km s^{-1} (ΛCDM and OCDM) were included in the computation of the halo-halo correlation function. It is seen that ξ_{hh} remains approximatly constant with time in comoving units. On the other hand, ξ_{dm} is a function that always increases with time. These dependencies of ξ_{hh} and ξ_{dm} on time produces a typical behavior of the bias in all models: the bias is a monotonically decreasing function of time. Models can be distinguished from each other by the different amount of bias they present at a given redshift; for example, the τCDM model show a bias at $z \sim 4$ that is almost a factor 2 higher than the one of the SCDM model.

Halos form near high density peaks (Frenk et al. 1988) and are thus much more clustered than the background dark matter. With time, numerous new halos start forming in lower density (less rare) regions and are thus less clustered (meanwhile the background clustering continue to grow). At the same time, at high-redshift, mergers (quite frequent at those epochs) act against the halo gravitational clustering growth. The halo-halo correlation function increases just slightly. On the other hand, mergers at low-redshift are no longer important (except in the central parts of clusters) and thus a sustained increase in ξ_{hh} is expected at late times.

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