CLUSTER ABUNDANCE AS TEST OF THE PRIMORDIAL PERTURBATION SPECTRUM

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ABSTRACT. The Press-Schechter formalism is used to derive the abundance of rich galaxy clusters in dependence on the cluster mass or the corresponding X-ray temperature of the hot gas confined in the cluster potential wells. We consider a characteristic double inflation spectrum in the standard CDM model leading to a hierarchical clustering scenario. Normalising the amplitude to the COBE-quadrupole, and supposing a biasing $b \approx 2$, we get a reasonable fit both to the amplitude and the slope of the X-ray temperature function of Edge et al. (1990) and Henry & Arnaud (1991). In the considered model the cluster abundance changes strongly with redshift.

1. Introduction

The COBE measurements of temperature fluctuations in the microwave-background (cf. Smoot et al. 1992) provide a first direct indication of the initial fluctuations responsible for the formation of large-scale structure in the universe. At the observed angular scales (corresponding to multipoles $l < 20$) the fluctuation spectrum is in agreement with the predictions of the inflationary model of the early cosmological evolution, but its amplitude exceeds the extrapolation of the observed galaxy clustering (cf. Fig. 1). Similarly, large galaxy surveys point to more power at large scales than predicted in the standard CDM-model.

We propose a model for these observations which decouples the clustering properties at large and small scales by taking into account more than one effective field responsible for inflation (Gottlöber et al. 1991). In Fig. 1, this spectrum is compared with the reconstructed galaxy power spectrum and corresponding model calculations. The non-flat initial spectrum leads to a good fit of the data in the wave-number range $10^{-3} < k\ h\mathrm{Mpc}^{-1} < 10$. Here we discuss the consequences of such non-flat primordial perturbation spectra for the abundance of bright X-ray clusters of galaxies.

2. Press-Schechter Analysis

It is well known that the abundance of rich clusters of galaxies represents a challenge to the standard CDM model. Both the Press-Schechter theory and the self-similar clustering model lead to an over-abundance and a steeper slope of the cumulative number density of clusters up to a

H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging, 664–666.

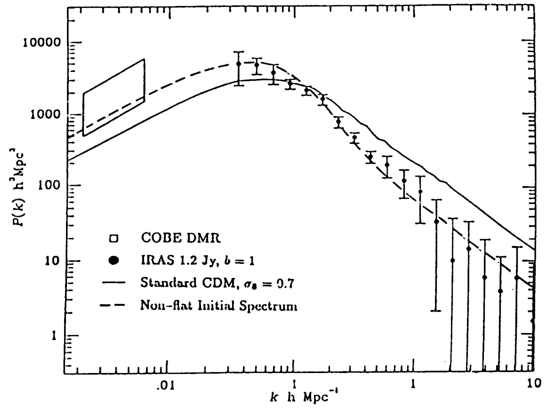

Figure 1. IRAS observations of the power spectrum of density fluctuations $P(k)$ as a function of the wave number k compared with the CDM model (Fisher et al. 1993). The dashed line represents a double inflation perturbation spectrum with a break of $\Delta = 4$ at a scale $k^{-1} = 3h^{-1}$Mpc.

certain mass, the mass function (cf. Kaiser 1991). For our analysis we employ a top-hat filter $W(kR) = (\sin(kR) - kR\cos(kR))/(kR)^3$ to derive the rms-mass fluctuations on scale R,

$$\sigma_{cl}^2(R) = b^2\sigma_{DM}^2(R) = \frac{1}{2\pi^2}\int_0^\infty k^2 P(k) W(kR)$$

where a biasing factor b is introduced for the ratio of dark matter to the galaxy fluctuations and M denotes the mass inside radius R. Then for Gaussian fluctuations the number density of collapsed objects with mass M is

$$n(M) = -\frac{\rho_0}{M}\sqrt{\frac{2}{M}}\frac{\delta_c}{\sigma_{cl}^2}\exp\left(-\frac{\delta_c^2}{\sigma_{cl}^2}\right)\frac{d\delta_c}{dM}$$

Here ρ_0 denotes the background density. Further we use the spherical collapse model to estimate the critical overdensity $\delta_c = 1.68$ required for the recollapse of a positive mass fluctuation.

Taking into account the condition of hydrostatic equilibrium for the hot gas gravitationally confined in the clusters to derive the mass to temperature relation, $T = 6.4h^{3/2}$ keV $M_{15}^{2/3}$, (Evrad 1990), we get the cluster X-ray temperature function. Our results are given in Fig. 2. For the exponential dependence of $n(M)$ we get a sensible dependence of the cluster number density on the amount of galaxy number fluctuations, σ_{cl}, while the differential strongly influences the slope of the temperature function.

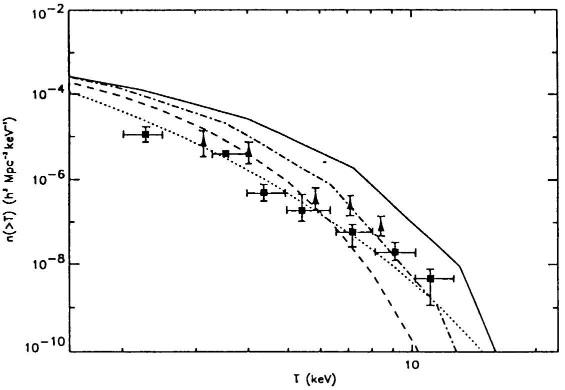

Figure 2. The temperature functions of rich galaxy clusters according to Edge et al. (1990, squares) and Henry & Arnaud (1991, triangles) compared with the standard CDM-model (full line), double inflation models with a break height $\Delta = 4$, $k^{-1} = 3h^{-1}$Mpc, $b = 2.4$ (dotted line), $\Delta = 3$, $k^{-1} = 7h^{-1}$Mpc, $b = 2.5$ (dash-dotted line), and $\Delta = 3$, $k^{-1} = 1h^{-1}$Mpc, $b = 1.5$ (dashed line).

3. Discussion

The fitting of the data of Edge et al. (1990) and Henry & Arnaud (1991) by the theoretical temperature function requires a biasing factor $b \approx 2$ and a break height $\Delta = 3 - 4$ at a scale $k^{-1} \leq 3h^{-1}$Mpc. These parameters are also preferred by the comparison of the perturbation spectrum with other characteristics of the large-scale matter distribution such as the angular correlation function of APM galaxies and the large scale streaming motions (Gottlöber et al. 1993). Taking the other way around, our results underline the usefulness of the Press-Schechter approach to the description of hierarchical clustering. It is especially sensitive to the form of the fluctuation spectrum at the scale of galaxy clusters. Similar analyses for models with a cosmological constant and for mixed dark matter models are due to Lilje (1992) and Bartlett & Silk (1993).

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