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CLUSTER EVOLUTION AS A PROBE OF PRIMORDIAL DENSITY FLUCTUATIONS

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ABSTRACT. *Although COBE's detection of large angle microwave background anisotropies*[1] *fixes the amplitude of density fluctuations on length scales* $k^{-1} \sim (300-6000)\,\mathrm{h^{-1}Mpc}$, *what is crucial for the level of large scale clustering is the amplitude of density fluctuations on scales* $(5-50)\,\mathrm{h^{-1}Mpc}$. *The level of dynamical clustering is usually parameterized by the size of the mass fluctuations in* $8\,\mathrm{h^{-1}Mpc}$ *spheres,* σ_8. *For the cold dark matter model, COBE gives* $\sigma_8 \sim 1$, *while models with extra large scale power give* $\sigma_8 \sim 1/2$. *The most massive clusters of galaxies* ($\gtrsim 10^{15}\,\mathrm{M_\odot}$) *form from rare 'peak patches' found in the initial mass density distribution. Their abundance as a function of redshift is a sensitive probe of the wavenumber band* $k^{-1} \sim (3-8)\,\mathrm{h^{-1}Mpc}$, *hence of* σ_8, *and so cluster evolution can discriminate among models allowed by the COBE results. We use our Hierarchical Peaks Method*[2], *which accurately reproduces the results of* P^3M *N-body simulations, to calculate the evolution of cluster X-ray flux counts, luminosity and temperature functions as a function of* σ_8 *for CDM models and those with more large scale power. We find that the EMSS and Edge et al. cluster samples support* σ_8 *in the range from* $\sim 0.6-0.9$, *and that models with more large scale power (and hence flatter fluctuation spectra in the cluster regime) fit the X-ray bright end better.*

It has long been recognized that the abundances of clusters can be used to constrain the 'biasing factor' $1/\sigma_8$. However, it was unclear how accurate the theoretical estimates of the mass functions of such rare events were. Although the Press-Schechter (PS) mass function for Gaussian hierarchical theories is widely used for estimating the distribution of cluster properties and accords reasonably well with N-body mass functions,[2,4] it has little theoretical support[4] and gives no information on spatial fluctuations. Hydrodynamical studies probe 3D volumes too small to use for a complete statistical description. Pure N-body calculations can now approach the large volumes required for a useful cluster sample at the expense of resolution. We find the peaks associated with a hierarchy of filter scales and calculate the virial masses, velocities v_{3D} and gas temperatures T_X using the local properties of the density field about the peaks. Subclustering within peaks, the influence of tidal forces on peak collapses, the merging of peaks and the motion of the surviving peaks using the Zeldovich approximation are included. We also have an accurate analytic counterpart to the Monte Carlo method. We have calibrated our peaks catalogues with those constructed from N-body simulations of the CDM model[3] and find excellent agreement. An important issue for PS and peak approaches is the relationship between the mass, T_X and the dark matter velocity dispersion v_{3D}. We have found that N-body velocity dispersions are about 16% higher than the N-body binding energy values, which would be appropriate if isolated virial equilibrium prevails in the clusters. High resolution hydrodynamical calculations are required to settle which is the appropriate T_X estimator to use. A further uncertainty arises in our estimates of cluster luminosity L_X and flux S_X through their (squared) dependence upon the gas density, which in turn depends upon the primordial density of baryons and the fraction of them which remain as hot intracluster gas. For the graphs we have taken $\Omega_B = 0.05$, and the X-ray core radius to be $0.15\,\mathrm{h^{-1}Mpc}$.

We have compared our results for CDM-like models with the available X-Ray data[5,6] and find that the luminosities and fluxes support a fluctuation amplitude σ_8 between 0.7 and 0.9 using the binding energy measure for T_X, while slightly smaller values are indicated if we use the N-body velocity dispersions. The key feature, generic to a wide class of extra power models, is the flattening of the power law index of the density fluctuations on the wavelengths that cluster counts probe, which gives more clusters with large values of L_X than the CDM slope gives and fits the data reasonably well for σ_8 in the 0.6-0.9 range. However, matching such models to COBE[1,7] gives $\sigma_8 \lesssim 0.5$, which would give too few clusters at moderate redshifts to match the Gioia *et al.* data. We have also made predictions for the ROSAT and microwave background sky for these models.[2] The non-standard models [C–F] were chosen to reproduce the large scale galaxy clustering data with linear biasing (which the CDM model does not). Model [F] is an example of a class of models with extra large-scale power, parameterised by the factor Γ,[7] which ranges from 0.15–0.3 to explain the large scale clustering, to 0.5 for standard CDM. Models with $\Lambda \neq 0$ can give $\Gamma \sim 0.2$, though for this paper we assume a flat cosmology. If the EMSS data at $z = 0.2$–0.4 is used, no CDM-like models in the $\Omega = 1$ cosmology are viable. Our conclusions are strongly dependent upon the details of the gas dynamics within the clusters, but it is highly unlikely that $b_8 > 1.5$ models can survive. Flat cosmologies with $\Lambda \neq 0$ provide good fits to the galaxy clustering data for $\Omega_\Lambda \approx 0.75$ (h=0.8), and COBE then gives $\sigma_8 \sim 1$.

References

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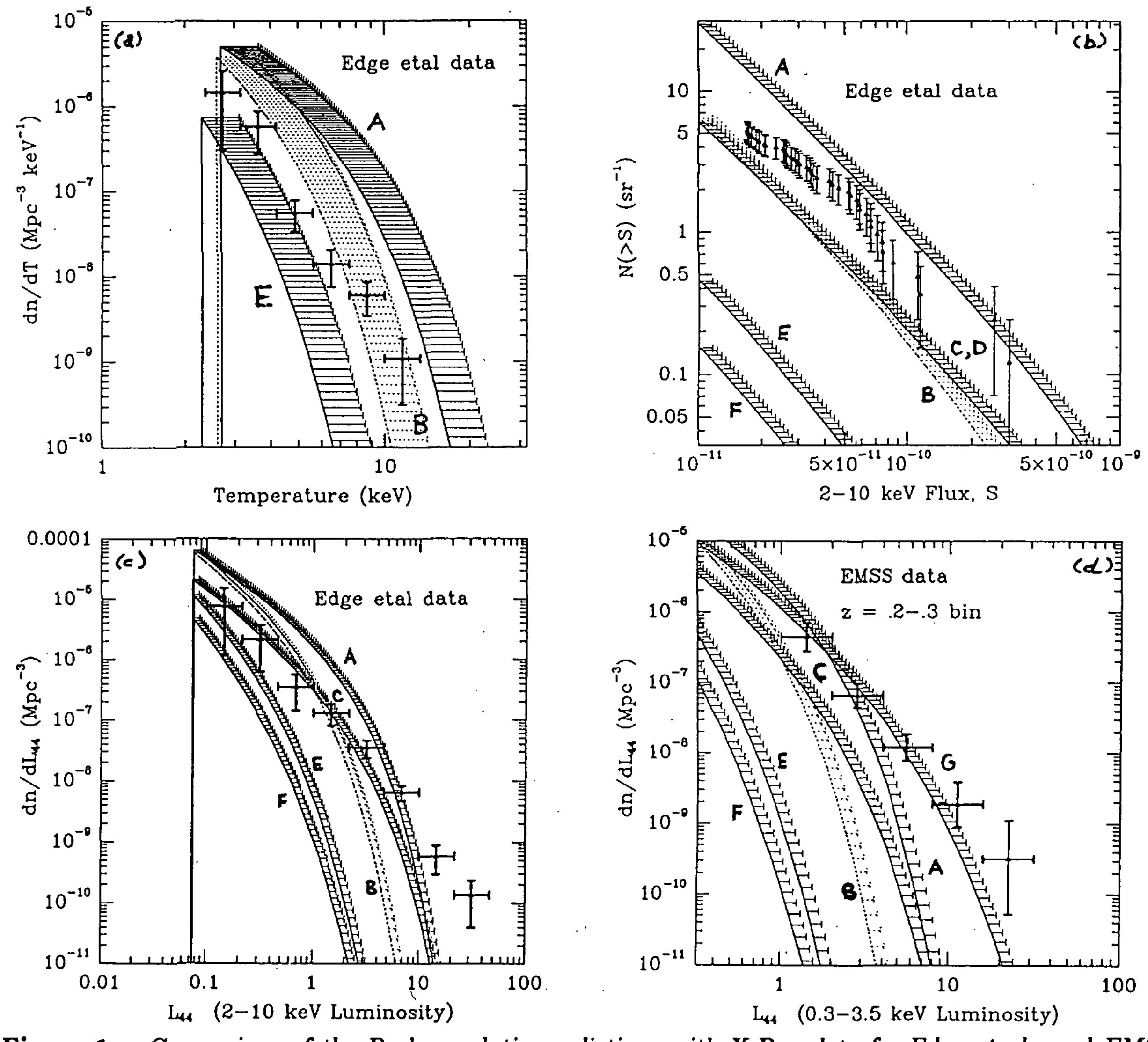

Figure 1. *Comparison of the Peaks analytic predictions with X-Ray data for Edge et al. and EMSS. The models are:* $b_8 = 1$ *[A] and* $b_8 = 1.4$ *[B] standard CDM models,* $b_8 = 1.4$ *HDM-CDM hybrid models* ($\Omega_\nu = 0.3, \Omega_{cdm} = 0.7, m_\nu = 7\,\mathrm{eV}$) *[C] and* ($\Omega_\nu = 0.13, \Omega_{cdm} = 0.87, m_\nu = 3\,\mathrm{eV}$) *[D], a* $b_8 = 2.0$ *CDM model with non-Zeldovich spectral index* $n = 0.6$ *[E], and an extra-power model* ($b_8 = 2.2, \Gamma = 0.2$) *[F]. For the peaks model curves, the spread represents the 16% uncertainty assumed for the velocity dispersion only. Panels (a–c) show the X-ray temperature, flux counts, and 2–10 keV luminosity function for the Edge data. The best-fit model appears to be the* $b = 1.4$ *hot-cold hybrid [C], though all models show a deficiency on the high end. In panel (d), the models are compared with the EMSS* $z = 0.2$*–0.3 luminosity function (0.3–3.5 keV). All our models fall short of reproducing the flat luminosity function in the EMSS data. To demonstrate what is required to obtain agreement, we have included another extra-power model* ($b_8 = 1, \Gamma = 0.1$) *[G], which does NOT match the COBE or low-redshift X-Ray data. High bias models fail miserably on all counts.*

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