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CLUSTER CORRELATIONS FAVOR COLD + HOT DARK MATTER

JOEL R. PRIMACK
Santa Cruz Institute for Particle Physics
University of California, Santa Cruz, CA 95064

Abstract

Old redshift data on correlations of ~ 100 rich clusters, including corrections for projection effects, did not significantly constrain theories, but newer data on a total of ~ 220 $R \geq 1$ Abell clusters now do (Olivier, Primack, Blumenthal and Dekel 1992, hereafter OPBD). "Standard" $\Omega = 1$ Cold Dark Matter (CDM) is now in $> 3\sigma$ conflict with this data. Holtzman and Primack (1992, hereafter HP) have calculated the autocorrelation function of rich clusters for several nonstandard variants of CDM that have an enhanced power spectrum on large scales compared to "standard" $\Omega = 1$ CDM. The models discussed here are (1) Cold + Hot dark matter (C+HDM) models with $\Omega_{CDM} + \Omega_\nu = 1$ (where Ω_ν, the fraction of critical density in one or three species of light neutrinos, is comparable to Ω_{CDM}) and (2) $\Omega_{CDM} + \Omega_b = 0.2$ or 1 (where Ω_b, the fraction of critical density in baryonic matter, is comparable to Ω_{CDM}). Several of the models considered here – in particular, C+HDM models with $\Omega_\nu \approx 0.3$ – are consistent with the available cluster correlation data as well as with other observations, including the COBE measurement of the microwave background quadrupole anisotropy. The C+HDM model warrants careful numerical simulations to treat properly the velocity of the neutrinos, which should inhibit their clustering on small scales and perhaps help explain how dynamical tests can give Ω increasing with scale size in an $\Omega = 1$ universe.

1. Cluster Data

"Standard" Cold Dark Matter (CDM) (Blumenthal *et al.* 1984; Davis *et al.* 1985) with $\Omega = 1$ and $h \equiv H_o/(100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}) \approx 0.5$ provides an attractive theory of structure formation from galaxy to cluster scales, but it probably does not have enough power on larger scales to account for observations. Among the data that challenge this theory, I focus attention here on correlations of rich clusters. Holtzman and I (HP) have considered several variations on "standard" CDM that are known to increase the power in the fluctuation power spectrum on large spatial scales, and for which other observational implications have already been calculated (e.g., Holtzman 1989; Schaefer, Shafi, and Stecker 1989). HP calculated the rich cluster correlations using the theory of linear Gaussian fluctuations (Bardeen *et al.* 1986, Bardeen, Bond, and Efstathiou 1987), and compared them to data on cluster correlations corrected for projection contamination. Our calculations assumed a bias factor of $b = 2$; however, the cluster correlations are rather insensitive to the bias parameter, while bulk velocities and microwave background anisotropies scale as b^{-1}.

Reanalyses of the Abell and the southern (Abell, Corwin, and Olowin 1989, hereafter ACO) cluster data correcting for projection effects lowered the cluster correlations (Sutherland 1988; Dekel *et al.* 1989; Olivier *et al.* 1990; Sutherland and Efstathiou 1991). The angular correlation functions (Sutherland, Maddox, and Efstathiou 1991) and spatial correlation functions (Dalton *et al.* 1992, Nichol *et al.* 1992) of moderately rich clusters identified by various procedures on machine-measured southern Schmidt plates are mostly smaller than the earlier uncorrected estimates from the Abell and ACO catalogs; also, this data shows clearly the strong dependence

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on cluster definition, in particular the richness and background subtraction, of the resulting correlation functions.

Recently two new data sets have been obtained: a deeper complete redshift survey in a small angular region at high northern galactic latitude containing 145 Abell clusters (Huchra *et al.* 1990), and an extension of the nearby complete redshift sample (Postman *et al.* 1992). OPBD recently reanalyzed this data, with results that are in reasonable agreement with other recent estimates based on new cluster redshifts by Cappi and Maurogordato (1992) and Peacock and West (1992). Although the Poisson errors on the OPBD points in the Figure ignore the fact that the clusters are clustered and therefore underestimate the true statistical errors, OPBD shows in some detail that data at $r \approx 30h^{-1}$ Mpc disagree with CDM at least at the 3σ level even when cluster clustering is taken into account. (There is also strong disagreement with the Texture model.) On these large scales projection effects are relatively unimportant.

2. Comparison with Models

Results of some of HP's calculations of the cluster–cluster correlation functions are presented in the Figure. (Similar calculations for C+HDM models have been done by van Dalen and Schaefer 1992.) Comparing the calculations with the OPBD $\xi_{cc}(r)$, concentrating especially on the region around $r \approx 30h^{-1}$ Mpc where $\xi_{cc} \approx 0.5$, it is evident that standard $\Omega = 1$ CDM is in fairly serious disagreement with the data. The disagreement with standard CDM becomes more severe for $h > 0.5$ or for a smaller filtering radius. Models with enhanced large scale power such as C+HDM are consistent with the ξ_{cc} data. The $\Omega = 1$ CDM + baryon models can fit the cluster correlation data for $\Omega_b \approx 0.3$. However, this is much larger than the baryonic density indicated by the comparison of the abundances of light nuclides with standard Big Bang nucleosynthesis calculations. CDM + baryon models with $\Omega = 0.2$ and Ω_b consistent with BBN constraints can fit the cluster autocorrelation data, and with $\Lambda \neq 0$ are consistent with CMB data. However, recent analyses of large scale galaxy peculiar velocity data and the IRAS data (Dekel *et al.* 1992; Yahil, these proceedings) suggest that $\Omega \approx 1$, and such a low value as 0.2 is certainly disfavored in Gaussian models (Nusser and Dekel 1992; Dekel, these proceedings).

CDM with $\Omega \approx 0.2$, or $\Omega = 1$ hybrid models with some massive neutrinos, could easily account for larger cluster correlations. Models with light neutrinos are particularly interesting since such models normalized to the microwave background quadrupole anisotropy observed by COBE are also able to produce large streaming velocities (Holtzman 1989, Wright *et al.* 1992, HP).

A potential problem with C+HDM and other models with a shallow power spectrum is that there is less small-scale power than with standard CDM, which might result in too little galaxy formation at early times to account for observations. However, it will be necessary to be rather careful in doing N-body simulations for H+CDM. The power spectra of the CDM and HDM (light neutrino) components are quite different on small scales, with the HDM fluctuations suppressed by their still-substantial velocities, especially at the intermediate redshifts $z \approx 10 - 20$ where N-body simulations are started. The neutrino velocities must also be taken into account in the N-body simulations. In addition to addressing on small scales the question of the era of galaxy formation and on large scales the nature of the large-scale structure that forms in such models, such nonlinear calculations must especially consider the galaxy correlations and velocities on scales of a few Mpc on which the overall amplitude in models is usually normalized. Because the neutrino velocities will to some extent impede their clustering on small scales, it is possible that C+HDM models, unlike standard CDM, will lead to small enough galaxy velocities on small scales without biasing. This would lead to more

power at both small and large scales, and could also explain why dynamical measurements (*e.g.* from infall or virial estimates) typically give $\Omega \approx 0.2-0.3$ on scales of a few Mpc but $\Omega \approx 1$ on large scales. To check this will require high-resolution N-body simulations and perhaps even calculations including gas dynamics in boxes of perhaps 30-40 h^{-1} Mpc. Davis *et al.* (1992) have reported encouraging results from a simplified C+HDM P^3M N-body calculation in a 14 Mpc box, neglecting the initial neutrino perturbations. Holtzman *et al.* (1992) are doing a more elaborate series of PM N-body calculations.

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References

Abell, G. O., Corwin, H.G., and Olowin, R.P., 1988, *Ap. J. Supp.* **70**, 1 (ACO).

Bardeen, W. A., Bond, J. R., and Efstathiou, G. 1987, *Ap. J.* **321**, 28.

Bardeen, W. A., Bond, J. R., Kaiser, N., and Szalay, A. S. 1986, *Ap. J.* **304**, 15.

Blumenthal, G. R., Faber, S., Primack, J. R., and Rees, M. J., *Nature*, **311**, 517.

Cappi, A, and Maurogordato, S. 1992, *Astron. Astrophys.* **259**, 423.

Dalton, G. B., Efstathiou, G., Maddox, S. J., and Sutherland, W. J. 1992, *Ap. J. (Letters)* **390**, L1.

Davis, M., Efstathiou, G., Frenk, C. S., and White, S. D. M. 1985, *Ap. J.* **292**, 371.

Davis, M., Summers, F. J., and Schlegel, D. 1992, Berkeley preprint.

Dekel, A., Blumenthal, G. R., Primack, J. R., and Olivier, S. 1989, *Ap. J. (Letters)* **338**, L5.

Dekel, A., Bertschinger, E., Yahil, A., Strauss, M., and Davis, M. 1992, *Ap. J.*, in press.

Dekel, A., and Nusser, A., *Ap. J.*, in press.

Holtzman, J.A. 1989, *Ap. J. Supp.* **71**, 1.

Holtzman, J.A. and Primack, J.R. 1992, *Ap. J.* in press (HP).

Holtzman, J., Klypin, A., Primack, J., and Regős, E. 1992, preprint in final preparation.

Huchra, J. P., Henry, J. P., Postman, M., and Geller, M. J. 1990, *Ap. J.* **365**, 66.

Nichol, R. C., Collins, C. A., Guzzo, L., and Lumsden, S. L. 1992, *M. N. R. A. S.* **255**, 21P.

Olivier, S., Blumenthal, G.R., Dekel, A., Primack, J.R., and Stanhill, D. 1990, *Ap. J.* **356**, 1.

Olivier, S., Primack, J.R., Blumenthal, G.R., and Dekel, A. 1992, submitted to *Ap. J.* (OPBD).

Park, C. 1990, Ph. D. dissertation, Princeton University.

Peacock, J. A. and West, M. J. 1992, Edinburgh preprint.

Postman, M., Huchra, J. P., and Geller, M. J. 1992, *Ap. J.* **384**, 404.

Schaefer, R.K., Shafi, Q., and Stecker, F.W., 1989, *Ap. J.* **347**, 575.

Sutherland, W. 1988, *M. N. R. A. S.* **234**, 159.

Sutherland, W, and Efstathiou, G. 1991, *M. N. R. A. S.* **248**, 159.

van Dalen, A. and Schaefer, R. K. 1992, preprint. Also Schaefer, R.K. and Shafi, Q. 1992, Bartol preprint.

Wright, E.L. *et al.* 1992, *Ap. J. (Letters)* **392**, L13.

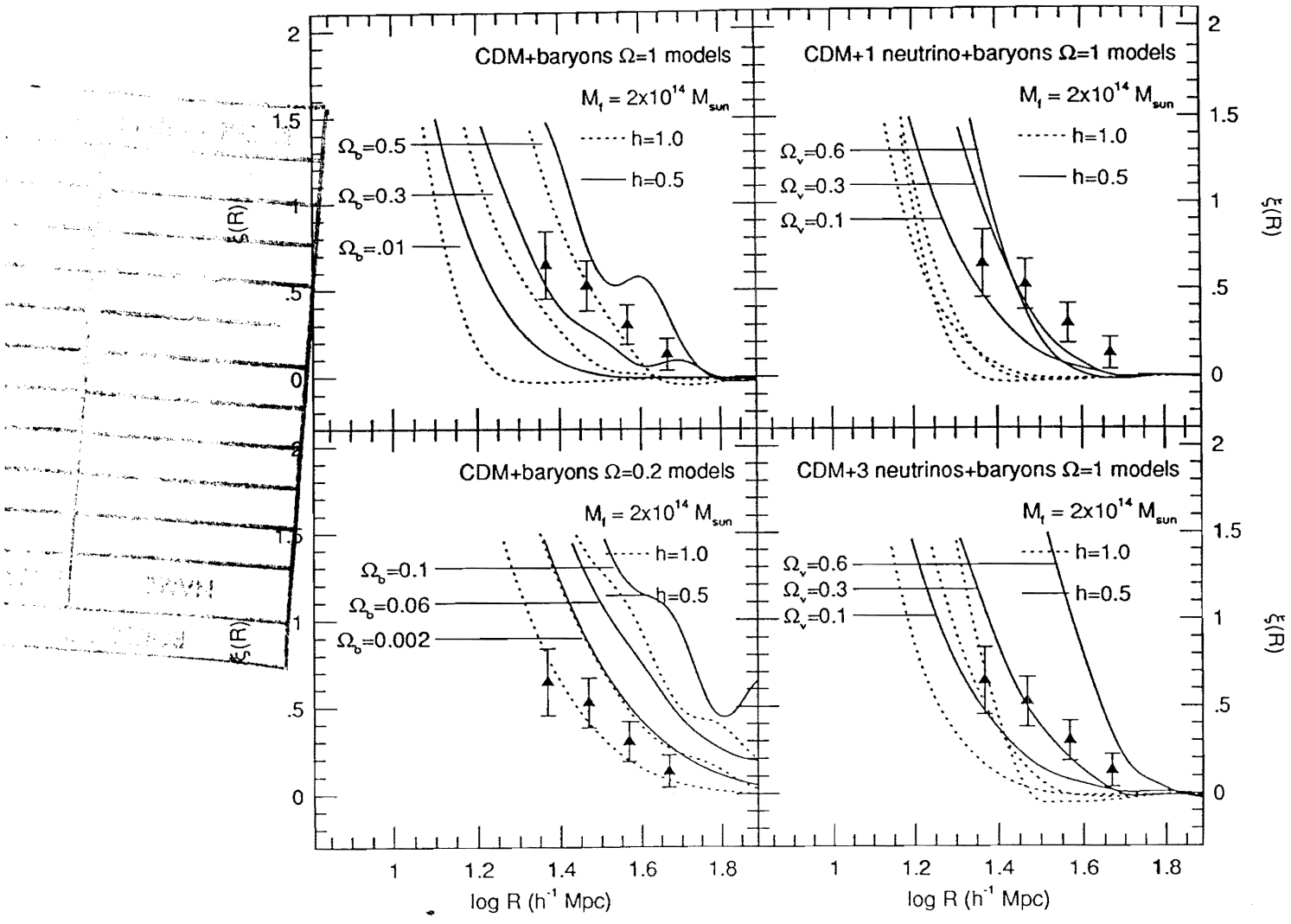

Figure Caption Two point cluster-cluster correlation functions vs. OPBD data. The left panels show models with CDM and baryons only; three different baryon fractions are shown, with $\Omega_b = 0.01, 0.3$, and 0.5. The right panels include massive neutrinos; in all cases $\Omega_b = 0.01$, with $\Omega_\nu = 0.1$, 0.3, and 0.8. All the models in the upper panels have $\Omega = 1$. The lower left panel gives results for the CDM+baryon models with $\Omega = 0.2$. The upper right panel gives results for massive neutrino models with the entire neutrino mass given to one neutrino species; the lower right panel has the neutrino mass divided evenly between the three species. Results for two values of the Hubble constant are shown with different line types.