Astrophysical Supercomputing Using Particles
IAU Symposium, Vol. 208, 2003
J. Makino and P. Hut, eds.

Substructure of Galaxy Clusters and Cosmological Constant

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Abstract. We calculate some indicators, which are closely related with galaxy clusters' substructure, for each cluster obtained in numerical simulations in OCDM and ΛCDM, and make a statistical comparison between two models. In ΛCDM the indicators, multipole moment power ratios and center shifts, are larger than those in OCDM. This result is consistent with the analytical prediction; galaxy clusters' formation epoch in ΛCDM is later than in OCDM and then clusters in OCDM are more relaxed than those in ΛCDM. We show that these indicators for X-ray surface brightness are useful tools to distinguish between OCDM and ΛCDM.

1. Introduction

Richstone, Loeb, & Turner (1992) proposed that structures of clusters are closely related to a cosmological model, since the recently formed clusters have substructure and fraction of the clusters is strongly depends on a cosmological model. According to their result, in flat cold dark matter (CDM) universe ($\Omega_0 = 0.3,\ \lambda_0 = 0.7$, ΛCDM), formation of clusters proceeds in later epoch than in open CDM universe ($\Omega_0 = 0.3,\ \lambda_0 = 0$, OCDM).

We study possibility to distinguish between ΛCDM and OCDM by statistical indicator, which quantifies irregularity of the structure of clusters.

2. Method

For simulated clusters in ΛCDM and those in OCDM (Yoshikawa, Jing, & Suto 2000), we obtain two indicators, multipole moment power ratios (hereafter power ratios), P_m/P_0, and center shifts, C. These indicators are calculated for X-ray surface brightness, Σ_X, and column density, σ. The power ratios quantify the shape of projected cluster's potentials and are derived from their multipole expansion. The center shift is defined as dispersion of centers of contours in

https://doi.org/10.1017/S0074180900207699 Published online by Cambridge University Press

Table 1. Logarithm of mean values of indicators

Model	$\log(P_2/P_0)_{\Sigma_X}$	$\log(P_2/P_0)_\sigma$	$\log(C_{\Sigma_X})$	$\log(C_\sigma)$
ΛCDM	-3.92	-2.90	-3.20	-2.33
OCDM	-4.40	-3.03	-3.64	-2.54

each cluster. For a well-relaxed cluster, these indicators are small. Detailed definitions of these are described in Suwa et al.(2001). The Kolmogorov-Smirnov test (hereafter KS-test) is performed on these indicators in ΛCDM and OCDM. The KS-test gives the probability of null-hypothesis that the two distributions of the indicator are generated from the same population. If the result of the KS-test is under 0.05, we can distinguish two cosmological models by this indicator.

3. Results and discussion

Logarithm of the mean values of the center shifts and the second order power ratios are shown in Table 1.

All of mean values of these indicators in ΛCDM are larger than those in OCDM. These large values of the indicators implies a recent formation of the cluster. This can be explained by the fact that the typical formation epoch of galaxy clusters in ΛCDM is later than in OCDM. Our results are consistent with the analytical prediction (Richstone et al. 1992).

The indicators for Σ_X are smaller than those for σ. This implies that the dark matter distribution of a cluster, which dominates the structure of σ, is harder to relax than the gas distribution which is closely related with the structure of Σ_X.

We use the KS-test to estimate the ability of the indicators to distinguish between two cosmological models. The results of the KS-test for power ratios, $(P_2/P_0)_{\Sigma_X}$ and $(P_2/P_0)_\sigma$, are 4.19×10^{-8} and 2.43×10^{-2}, and for center shifts, C_{Σ_X} and C_σ, are 8.53×10^{-3} and 1.02×10^{-2}, respectively. Since all of these are under 0.05, we can distinguish two cosmological models by these indicators.

Using the power ratio for Σ_X we can distinguish between ΛCDM and OCDM better than using that for σ. One explanation for this difference is that the relaxation time scale of structure for σ is longer than that for Σ_X. The structure of dark matter is harder to relax than that of gas, hence the indicators for σ, which reflects the distribution of dark matter, remains a large value after the formation of cluster. Since the power ratios for σ tend to show the trail of early formation of clusters, the power ratios for Σ_X is more suitable to distinguish between ΛCDM and OCDM than that for σ.

References

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