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Inner Structure of Dark Matter Halos

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Abstract. We investigate the structure of the dark matter halo formed in the cold dark matter scenarios by N-body simulations with parallel treecode on GRAPE cluster systems (Fukushige, Kawai, Makino 2003). We simulated 8 halos with the mass of $4.4 \times 10^{14} M_\odot$ to $1.6 \times 10^{15} M_\odot$ in the SCDM and LCDM model using up to 30 million particles. With the resolution of our simulations, the density profile is reliable down to 0.2 percent of the virial radius. Our results show that the slope of inner cusp within 1 percent virial radius is shallower than -1.5, and the radius where the shallowing starts exhibits run-to-run variation, which means the innermost profile is not universal.

We simulate the formation of the dark matter halos using the "re-simulation" method, which has been a standard method for the simulation of halo formation. We consider two cosmological models, SCDM model ($\Omega_0 = 1.0$, $h = 0.5$, $\sigma_8 = 0.6$) and LCDM model ($\Omega_0 = 0.3$, $\lambda_0 = 0.7$, $h = 0.7$, $\sigma_8 = 1.0$). We first performed large scale cosmological simulations with 3.7×10^6 particles in a sphere of $300h^{-1}$Mpc co-moving radius. We regard spherical overdensity regions around local potential minima within $r_{\rm v}$ as candidate halos.

We selected 8 halos from the catalog of candidate halos. We express a region within $5r_v$ from the centre of the halo at $z = 0$ in the cosmological simulation with larger number of particles. We place particles whose mass is as same as that in the cosmological simulation in a sphere of $\sim 100h^{-1}$Mpc co-moving radius surrounding the high resolution region, in order to express the external tidal field.

Figure 1 shows the density profiles of all runs at $z = 0$ for LCDM model. The numbers of particles within $r_{\rm v}$ are 25.2, 26.0, 7.2, and 7.8 million for Run L1, L2, L3, L4, respectively. The position of the centre of the halo was determined using the potential minimum and the density was averaged over each spherical shell. For the illustrative purpose, the densities are shifted vertically. We plot the densities by the thick lines only if the criteria (Fukushige & Makino 2001)

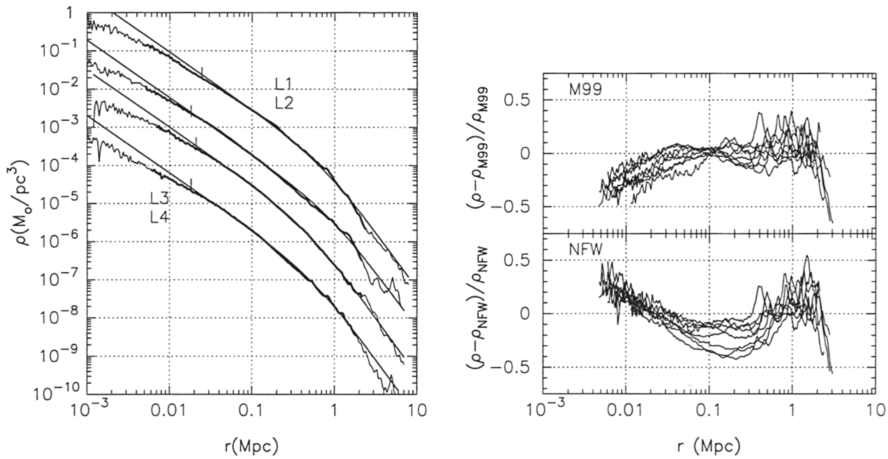

Figure 1. (left) Density profile of the halos for all runs of the LCDM model at z=0. Only the densities plotted in the thick lines satisfy the accuracy criterion. The vertical bar above the profiles indicate $0.01r_{\rm v}$. The solid curves indicate the M99 profile. (right) Residuals $(\rho - \rho_{\rm M99})/\rho_{\rm M99}$ and $(\rho - \rho_{\rm NFW})/\rho_{\rm NFW}$ as a function of radius.

for two-body relaxation. $t_{\rm rel}(r)/t > 3$, is satisfied, where $t_{\rm rel}(r)$ is the local two-body relaxation time

At $r > 0.02$ Mpc or $r > 0.01r_{\rm v}$, the density profiles are in good agreement to the profile given by equation: $\rho_{\rm M99} = \rho_0(r/r_0)^{-1.5}[1 + (r/r_0)^{1.5}]^{-1}$ (Moore et al. 1999; the M99 profile) in all runs. This result is consistent with the previous simulations performed with a few million particles. The fitting here was done using $M_{\rm v}$ and the least square fit of $(\rho - \rho_{\rm M99})/\rho_{\rm M99}$ at $0.03 < r < 0.5$ Mpc. On the other hand, at $r < 0.01r_{\rm v}$, we can see the shallowing of the cusp from the power -1.5 for all runs. The degree of the shallowing seems to increase as the radius decreases, which seemingly suggests that the inner cusp profile does not converge to a single slope. Moreover, the point where the profile starts to depart from the $r^{-1.5}$ cusp is different for different runs. Figure 1 also shows the residual, $(\rho - \rho_{\rm NFW})/\rho_{\rm NFW}$, where $\rho_{\rm NFW} = \rho_0(r/r_0)^{-1}(1 + r/r_0)^{-2}$ (Navarro, Frenk, White 1996; the NFW profile), together with that for the M99 profile. The agreement with the NFW profile is not good at all radii, while that with the M99 profile is not good only in the inner region ($r < 0.03$Mpc). Moreover, we can see that the sign of the residuals for NFW profile systematically change, which means the central slope of the NFW profile is too shallow.

References

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