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The differential energy distribution of the universal density profile of dark halo

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Abstract. We study the differential energy distribution of dark matter halos, carrying out cosmological N-body simulation. From our simulation, we give an analytical formula of the differential energy distribution of dark matter in the halos. Density distribution from the analytical formula is consistent with the Navarro, Frenk, and White (NFW) profile. We find that a parameter in our analytical formula of differential energy distribution is related with the slope of inner cusp of dark halo. We discuss physical reason of form of the analytical formula.

1. Introduction

Numerical studies of CDM scenarios show that dark matter distributions in galaxies and cluster of galaxies in numerical simulations are self-similar (Navarro, Frenk and White 1995, 1996, 1997 It is intersting to study physical origin of NFW profile,

$$\rho(r) = \frac{\rho_c}{(r/r_c)(1 + r/r_c)^2}.$$

Recently, non-extensive statistics makes success in its application to study self-gravitating system, e.g. peculiar velocity distribution of clusters of galaxies (Tsallis 1999). We compare statistical property of NFW profile with non-extensive statistics.

2. Tsallis statistics

Tsallis statistics is proposed as a generalized statistics for long range force systems (Tsallis 1988, 1999, Boghosian 1996). Tsallis statistics has successfully been applied in many physics fields, e.g. pure-electron plasma, turbulence, solar neutrino fluxes, self-gravitating stellar system, and peculiar velocities of clusters of galaxies.

3. Numerical simulation of clusters of galaxies

We simulate cluster formation in SCDM scenario with $\Omega = 1, h = 0.5, \sigma = 0.68$. We use a Grape SPH code with particle numbers, $N_{dm} = N_{sph} = 29855$ and particle masses, $m_{DM} = 6 \times 10^{11} \mathrm{M}_\odot$ and $m_{sph} = 3 \times 10^{10} \mathrm{M}_\odot$.

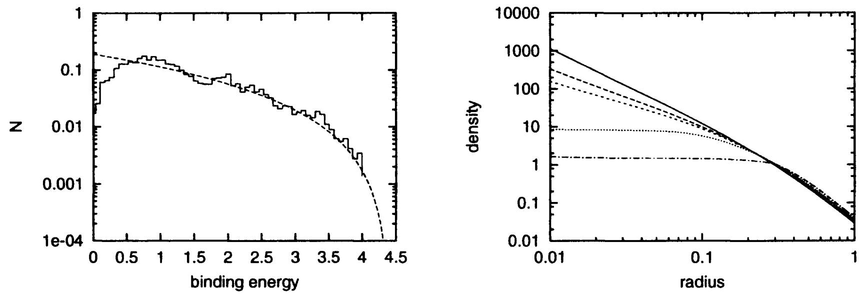

Figure 1. Left panel shows the fractional mass distribution (solid line) of the cluster and $N(e)$ (dashed line) defined in the text. Right panel shows density profiles for different $q = 0.25, 0.5, 0.65, 0.75$ and 1 but $e = 1.4$. Smaller q ($q < 0.5$) results in shallower core in the inner region. On the other hand, larger q ($q > 0.67$) makes a cusp steeper than the NFW profile, density profile approaches $\rho \propto r^{-2}$ in the inner part, for $q \longrightarrow 1$.

4. results

(1) Dark matter distribution in a cluster in our numerical simulation agrees with NFW profile.
(2) Differential energy distribution, N(e), of dark matter in a cluster in our simulation can be approximated by

$$N(e) = N_0(1 - (1 - q)(e/e_0))^{\frac{q}{1-q}}.$$

This is same function form of a probability function in Tsallis statistics.
(3) Density profiles given by N(e) of our formula with $q = 0.25 - 1$ are shown in Figure 1.

5. Summary

We obtain $N(e)$ from the NFW profile and show that N(e) agrees with the probability function in Tsallis statistics which is non-extensive statistics. We obtain density profile from $N(e)$ and show that density profile changes with q value. ρ in inner part ($r < 0.2r_{200}$) becomes steep with increasing of q. These results suggest that increase of q relates with relaxation of the system. Physical process which determines q value is open qustion.

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