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

Collisional Evolution of Galaxy Clusters: Fokker–Planck and N-body models

Koji Takahashi[1], Tomohiro Sensui[1], Yoko Funato[2], & Junichiro Makino[1]

[1]*Department of Astronomy, School of Science, University of Tokyo, Tokyo 113-0033, Japan*

[2]*General Systems Sciences, Graduate Division of International and Interdisciplinary Studies, University of Tokyo, Tokyo 153-8902, Japan*

Abstract. We investigate the dynamical evolution of clusters of galaxies in virial equilibrium by using Fokker–Planck models and self-consistent N-body models. In particular we focus on the growth of the common halos and the development of the central density cusps in the clusters. We find good agreement between the Fokker–Planck and N-body models. At the cluster center the cusp approximated by a power law, $\rho(r) \propto r^{-\alpha}$ ($\alpha \sim 1$), develops. We conclude that this shallow cusp results from the combined effects of two-body relaxation and tidal stripping. The cusp steepness α weakly depends on the relative importance of tidal stripping.

1. Introduction

Sensui et al. (1999, 2000) investigated the evolution of isolated galaxy clusters in dynamical equilibrium by using N-body simulations. Their main findings concerning the cluster evolution are summarized as follows: (1) The common halo of the cluster rapidly grows due to tidal stripping of mass from galaxies; (2) At the cluster center the density cusp approximated by $\rho \propto r^{-1 \sim -1.5}$ (for $r \lesssim R_{\rm h}$) develops. However, it was not very clear why such a cusp develops.

The main purpose of this paper is to investigate the physical mechanisms of the cluster evolution, especially of the development of the cusp found by Sensui et al. (1999, 2000). For that purpose, we perform Fokker–Planck (FP) simulations of idealized models of galaxy clusters, and compare them with N-body simulations. In the following we give only an outline of our study, and we refer to Takahashi et al. (2001) for further details.

2. Models

In FP models, a cluster is assumed to be spherically symmetric and in dynamical equilibrium. We use anisotropic orbit-averaged FP models (Takahashi 1995). The cluster is composed of "galaxy particles" and "background (common halo) particles" (the mass of an individual background particle $\rightarrow 0$). Our models are similar to Merritt's (1983) FP models. The effects of tidal stripping are included into FP models by using the mass loss rate given by Funato & Makino (1999).

We compare our FP models with N-body model PP of Sensui et al. (2000).

3. Results

Here we show an example of comparison between FP and N-body models.

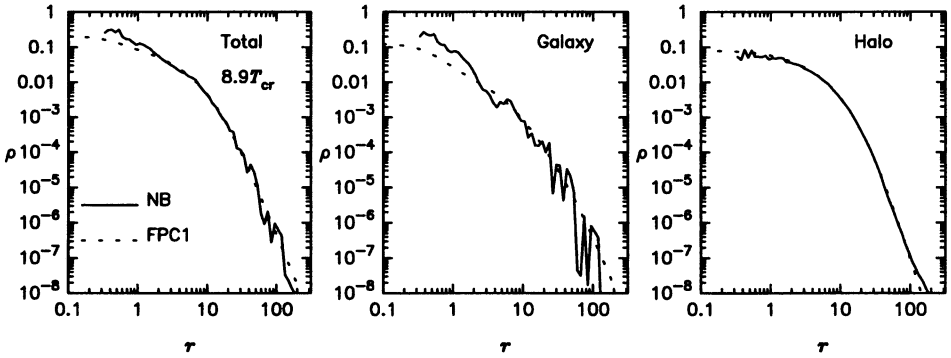

Figure 1. Comparison of the density profiles of models NB (N-body) and FPC1 (FP) at $t = 8.9T_{\rm cr}$. The three panels show the total density, the density of the galaxy component, and that of the common halo component. Note that the galaxies have the sizes $r_{\rm g} \lesssim 1$ in NB.

4. Conclusions

(1) The results of the FP and N-body simulations are in good agreement. (2) The cluster evolution is driven mainly by gravitational two-body encounters between galaxies and between galaxies and common halo particles, and by tidal stripping from galaxies. (3) At the cluster center the shallow density cusp approximated by $\rho \propto r^{-\alpha}$ with $\alpha \sim 1$ develops. (4) The shallow cusp develops, because tidal stripping is effective in galaxy clusters and thus "cool core collapse" occurs (Takahashi et al. 2001) as the consequence of collisional evolution.

This work was supported in part by the Research for the Future Program of Japan Society for the Promotion of Science (JSPS-RFTP97P01102).

References

Funato, Y., & Makino J. 1999, ApJ, 511, 625

Merritt, D. 1983, ApJ, 264, 24

Sensui, T., Funato, Y., & Makino, J. 1999, PASJ, 51, 943

Sensui, T., Funato, Y., & Makino, J. 2000, submitted to PASJ (astro-ph/0012092)

Takahashi, K. 1995, PASJ, 47, 561

Takahashi, K., Sensui, T., Funato, Y., & Makino, J. 2001, submitted to PASJ (astro-ph/0106521)