THE EVOLUTION OF COOLING FLOW AND THE MASS DEPOSITION PROCESS

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ABSTRACT.

We perform the numerical hydrodynamical calculation of cluster cooling flow including the mass deposition process and examine evolution of cooling flow. We take two mass deposition models. In one model, mass deposition occurs in large extent. In other model, mass deposition occurs only in central region. In any model, diagnostics of X-ray surface brightness do not agree with observation in any evolutional phases.

1. INTRODUCTION

Studies of observational results of X-ray surface brightness of cluster cooling flows have indicated that mass flux of accretion flow has to decrease with decreasing radius from cluster center (Stewart *et al.* 1984; Thomas *et al.* 1987). Mass deposition from the cooling flow in large extent due to thermal instability have been discussed by many authors as one possible explanation for decreasing mass flux (Matthews and Bregman 1978; Nulsen 1986; Thomas *et al.* 1987). Effects of the mass deposition process on cluster cooling flow are studied by White & Sarazin (1987a, c) using steady state solutions. They proposed prescriptional mass deposition rate. Chevalier (1987) examines the calculation of cooling flow using self-similar solutions. The numerical calculation of evolution of cluster cooling flow is important subject for two main reasons. First, solutions of evolutional calculation could show the entire structure of cluster cooling flow. If one makes steady assumption, that study would be restricted to the inner parts of the cooling flow (Chevalier 1987). Second, numerical calculation could apply to more realistic situations. The approach taken self-similar solutions is restricted in the variety of physical paramaters and because of the mass distribution of cluster of galaxies have core radius self-similarity of the system is destroyed by this radius in the case of cluster cooling flows. In this paper, we perform numerical hydrodynamical calculation of the cluster cooling flow including mass deposition process and examine evolution of cooling flow.

2. MODELS

In this study, we use two mass deposition models. In one model, we assume that inside the cooling radius, where cooling time equals the age of cluster, mass is deposited from cooling flow in the White & Sarazin's (1987a) 'thermal instability' mass deposition rate. We call this the inhomogeneous model. In the other model, we assume that when the temperature is below 10^6 K and cooling time is below 10^8 yr, mass is deposited at the rate which equals the hot gas density divided by isobaric cooling time, where isobaric cooling time equals the thermal energy divided by cooling rate. We call this the homogeneous model. We construct mass distribution of cluster of galaxies, stellar component and dark halo of central galaxy corresponding to Virgo cental galaxy M87 and a total gravitational velocity potential of these models is consistent with the spectroscopical velocity dispersion (Sargent et al. 1978) and with the range of masses determined from the X-ray data (Fabricant & Gorenstein 1983) of Virgo central galaxy M87. We ignore self gravity of hot gas and gravity of deposited gas. We take the radiative cooling function given by Raymond, Cox and Smith (1976). Initially, isothermal gas with temperature of 3×10^7 K and central electron density of 1×10^{-3} cm is placed in hydrostratic equilibrium in the total gravitational field. Isobaric cooling time of initial gas is 2×10^7 yr at the centre of the cluster of galaxies. We consider the stellar mass loss (Gisler 1976), supernova heating (Tamman 1974; Macdonald & Bailey 1981; Hattori, Habe & Ikeuchi 1987) from central galaxy and heating by stellar random motions in central galaxy (Sarazin and White 1987). The numerical method is the spherical symmetric MacCormack scheme.

3. RESULTS OF EVOLUTIONAL CALCULATIONS

The entire cluster gas evolves to nearly steady inflow after time comparable to the isobar cooling time of initial intracluster medium at the centre of cluster of galaxies. We summarize our results at 2×10^{10} yr when cooling flow evolves to nearly steady state, below. In inhomogeneous model with $q_i = 0.5$, mass deposition occurs inside of 95 kpc and this radius expands very slowly. Total amount of deposited gas is 2.7×10^{11} $M_\odot$. Mass deposition rate is 30 $M_\odot yr^{-1}$. X-ray luminosity from inside of 100 kpc, between 0.5–8 keV band, is 2.5×10^{43} erg s^{-1}. In this case to calculate X-ray luminosity we assume the emissivity due to cooling condensations dropping out of cooling flows same as White & Sarazin (1987b). In homogeneous model, mass deposition occurs only inside 0.8 kpc and mass deposition rate is 36 $M_\odot yr^{-1}$. Total amount of deposited gas is 1.7×10^{11} $M_\odot$. X-ray luminosity is 3.27×10^{43} erg s^{-1}. In both models, until flow evolves to nearly steady state, mass accretion rate to central galaxy is larger than mass deposition rate and gas is stored as hot halo around central galaxy. Fig. 1 shows the flow structures of our results when cooling flow evolves to nearly steady state. The density distribution of inhomogeneous model with $q_i = 0.5$ is flatter than the results of homogeneous model. Temperature gradient is positive in all models and $q_i = 0.5$ model's result is smaller than the result of homogeneous model. These tendencies of flow structures of cluster gas inside of cooling radius are very similar to the steady solution of White and Sarazin (1987c). In each model, velocity is highly subsonic and has negative sign in most of the region. Especially in $q_i = 0.5$ model, in entire region mach number is less than 1. Because of our spatial resolution at the centre is 200 pc, if flow becomes transonic inside of 200 pc, we would not resolve the transonic region. Then we calculated evolution of cooling flow of $q_i = 0.5$ model using high resolution mesh system that spatial resolution at the centre is 20 pc, transonic region appeared inside 200 pc, but flow structure and properties of evolution did not change from previous calculation.

4. DISCUSSION

Fig. 2 shows the evolution of X-ray surface brightness in 0.5–8 keV band. Dotted circles are the observational results for M87 (Fabricant and Gorenstein 1983). The X-ray surface brightness of homogeneous model is centrally too peaked at the centre in the steady state. In the evolutional phase, X-ray emission from inner part of cooling flow is mainly originated from emission of stellar ejecta. If the spatial distribution of metallicity in cooling flow could be observed in detail, the possibility that cooling flow is unsteady could be checked. In inhomogeneous model, X-ray surface brightness becomes flatter distribution than homogeneous model and central peak is suppressed. There is enhancement in X-ray surface brightness, in the mass deposition occurring region which is inside of cooling radius. In both models, diagnostics of X-ray surface brightness do not agree with observation in any evolutional stages (Fig. 2). It is necessary to reexamine the standard cooling flow model.

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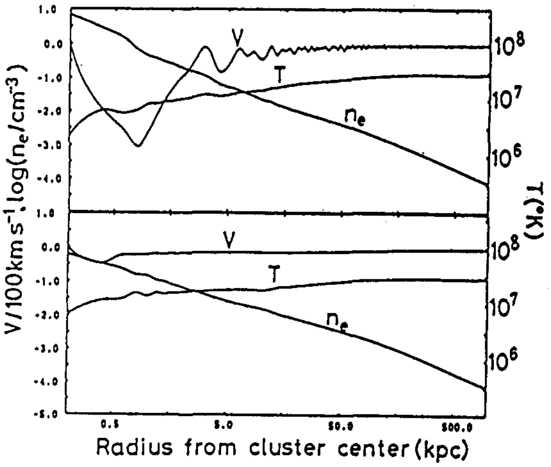

Fig. 1.-The distributions of temperature T, electron density n and velocity v of our results when cooling flow evolve to nearly steady state. Upper panel is the result of homogeneous cooling flow model at 2.03×10^{10} yr. Lower panel is the result of inhomogeneous cooling flow model with q_i=0.5 at 2.1×10^{10} yr.

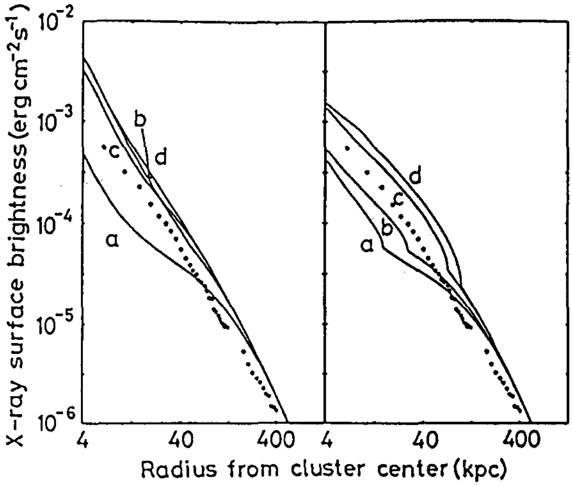

Fig. 2.-The evolution of X-ray surface brightness distributions of our results. Left panel is the results of homogeneous model and a, b c and d are results at 9.1×10^9 yr, 1.78×10^{10} yr, 2.03×10^{10} yr and 2.1×10^{10} yr, respectively. Right panel is the results of inhomogeneous model and a, b, c and d are results at 7.0×10^9 yr, 1.07×10^{10} yr, 1.67×10^{10} yr and 2.1×10^{10} yr, respectively. Dotted-circles are the observational results for M87 (Fabricant and Gorenstein 1983).