Temperature and Metallicity in the Central Region of Cooling Flow Clusters of Galaxies

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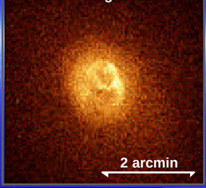
Abstract

We present the central temperature and metallicity structures in the cooling flow clusters of galaxies with Chandra. The temperature of the intracluster medium (ICM) evidently show a universal trend: it is constant at the outer regions and decrease toward the center. The consistency between the cooling radius and the radius where the temperature decline begins, support the idea that radiative cooling has surely occurred. However, the temperature at the center is so high that it is difficult to explain such profiles only with radiative cooling and therefore some heating should take place. The hierarchical evolution with mergers seems to play an important role for heating the ICM because it is most agreeable to our results. On the other hand, the iron abundance increases in the central ~100 kpc which is almost the same scale as that of the cD galaxy. The mass of iron within the abundance excess region is also comparable to that of the stars of the cD galaxy, and is capable of being supplied by the cD galaxy, considering that the Type Ia supernova explosion and the stellar mass loss work as the transport process of heavy metals. Thus, the cD galaxy can largely contribute to the metals in the ICM.

Sample Clusters

Chandra image of A2052



We select 18 clusters and 4 groups of galaxies.
The selection condition is as follows:

- typical cooling flow clusters
- nearby and bright for good photon statistics
- wide temperature range (0.6~9.8 keV)

Chandra's high resolution imaging allow us to study the detail structure of ICM. It is much more complex than expected before in many galaxy clusters.

	z	Lx (erg/s)	$\dot{M}$ ($M_\odot$/yr)		z	Lx (erg/s)	$\dot{M}$ ($M_\odot$/yr)
A1835	0.2532	2.7×10^{45}	1106	A2199	0.0302	2.7×10^{44}	208
A478	0.0773	2.1×10^{45}	990	A4059	0.0475	1.8×10^{44}	173
A2029	0.0881	2.0×10^{45}	449	A2052	0.0350	1.4×10^{44}	114
Ophiuchus	0.0280	1.5×10^{45}	159	Centaurus	0.0114	5.1×10^{43}	25
Perseus	0.0179	1.3×10^{45}	208	A262	0.0163	4.3×10^{43}	62
A1795	0.0631	1.1×10^{45}	523	Sersic159-03	0.0580	3.2×10^{43}	—
A3112	0.0750	4.8×10^{44}	565	MKW4	0.0200	7.9×10^{43}	20
A3558	0.0480	4.3×10^{44}	25	NGC507	0.0190	1.4×10^{43}	40
Hydra A	0.0538	4.0×10^{44}	489	NGC5044	0.0082	1.3×10^{43}	25
2A0335+096	0.0349	3.3×10^{44}	181	NGC533	0.0174	9.0×10^{42}	—
A496	0.0329	3.0×10^{44}	136	HCG62	0.0137	7.8×10^{42}	—

Origin of the Metal

The profiles of iron abundance exhibit the central excess above the cluster's typical abundance of 0.3 solar for all sample clusters as shown in figure 5. The excess occurs within 100~200 kpc.

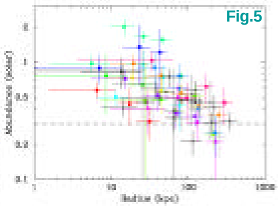


Fig.5

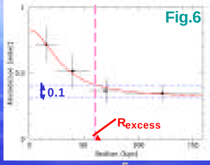


Fig.6

We define the excess radius (R_{excess}), where the abundance is 0.1 solar larger than the outer constant value, and compared it with the size of the cD galaxy ($2R_{eff}$ *). R_{excess} roughly has a good agreement with the size of cD galaxy (figure 7).

[* R_{eff} is the effective radius from the optical observations.]

We also estimate the iron mass within R_{excess} contained in the ICM and the stars of cD galaxy, respectively. We here assumed that the mass-to-light ratio is 8 and the abundance of iron is 1 solar. The iron mass in ICM is not largely different from that in cD galaxy (figure 8). This is consistent with the theoretically predicted ratio of iron mass. Thus, the iron excess in the central region of galaxy clusters seems to relate strongly with the cD galaxy.

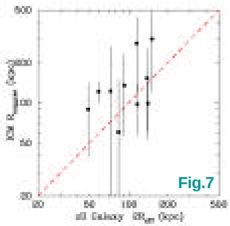


Fig.7

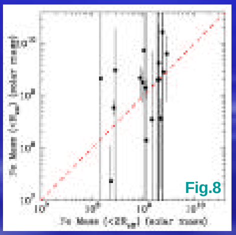


Fig.8

Can the excess metals from the elliptical galaxy be transported into ICM only by the Type Ia supernova explosion (SNe Ia) and the stellar mass loss ?

We calculate the iron mass ejected by these processes during Hubble time by using the experimental law (Bohringer et al., 2005).

[illegible]

[L_B : optical luminosity, SR : rate of SNe Ia (here [illegible]), η_{Fe} : iron mass ejected by one SNe Ia, γ_{Fe} : mass ratio of Fe/H]

In almost all clusters, the iron supply from the cD galaxy is enough to provide it in ICM.

It is highly possible that the cD galaxy is the origin of the metals in the ICM.

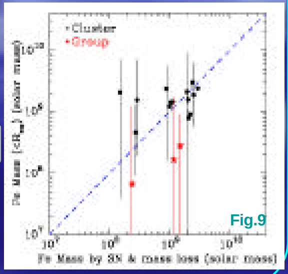


Fig.9

ICM Temperature distribution

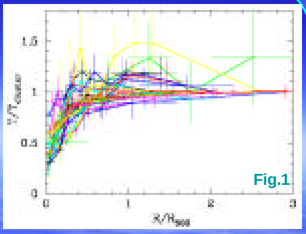


Fig.1

The radial profiles of temperature (figure 1) include some important matters when the vertical and horizontal axis are normalized with the outer temperature ($T_{cluster}$) and the virial radius (R_{500}).

- All clusters have very similar trend that the temperature decline within ~0.05 R_{500}.
- The central temperature is about a half of the outer one and widely scatters in the range of 0.6~4.7 keV.

We parameterize the scale of the cool region (R_{start}) as shown in figure 2. Compared with the cooling radius (figure 3), they are well correlate with each other. This indicates that the radiative cooling has surely occurred in the central region of the galaxy clusters though the high temperature at the center (>1 keV) cannot be explained simply by the standard radiaiive cooling.

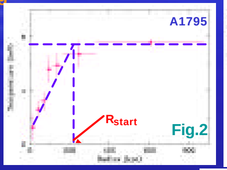


Fig.2

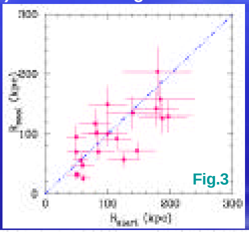


Fig.3

The ICM mass within R_{start} is much larger than the ISM mass of elliptical galaxies (figure 4). In contrast, it is smaller than the prediction of the cooling flow by an order of magnitude.

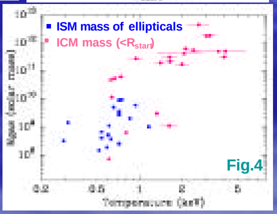


Fig.4

Thus the high central temperature and smaller mass imply that radiative cooling should be suppressed by a certain heating effect.

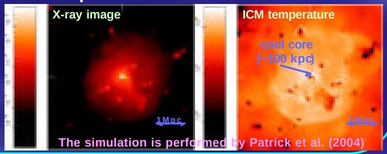
What is the heating mechanism ?

The heating by the AGN jet is difficult to deliver both the observed high central temperature and the Isotropic abundance profile at once. To explain the ICM conditions with thermal conduction, an unrealistic conductivity is necessary.

Then, we focus on the N-body simulation of hierarchical evolution with the repeating mergers. This yields the results same as ours in many point.

- The central temperature is higher than 1 keV at least.
- The large cool core of ~100 kpc is built up.
- The cold front or filament structure appears as well as the observations.

The hierarchical evolution with repeating mergers should play an important role to the ICM heating.



The simulation is performed by Patrick et al. (2004)

Summary

Temperature : It is natural to consider that radiative cooling and some heating are coexisting. As the heating mechanism, the hierarchical evolution with mergers is the most preferable from the aspect of agreement with observation.

Metallicity : The region and mass of the iron excess in ICM is closely related to that of the cD galaxy. The iron in the ICM can be sufficiently supplied by the SNe Ia and stellar mass loss which are the main transport process in the cD galaxy.

For more advanced discussion, SUZAKU should be fully utilized because...

- it will provide a capital key to the ICM heating by detecting the diffuse hard X-ray emission from the ICM for the first time.
- it become possible to measure the metallicity especially around Oxygen line (~0.6 keV) with better accuracy which is one of the primary element to examine the origin of metals.