Study on Spatial Distribution of Metals and the Other Cluster Components

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§ 1. Objective and method

Metals in the ICM should have been synthesized in stars and supernovae, spread to the intra galactic space, and transported to the vast intra cluster space as,

Star、Supernova ⇨ Intra-galactic space ⇨ ICM
～10pc 3 orders ～10kpc 2 orders ～1Mpc

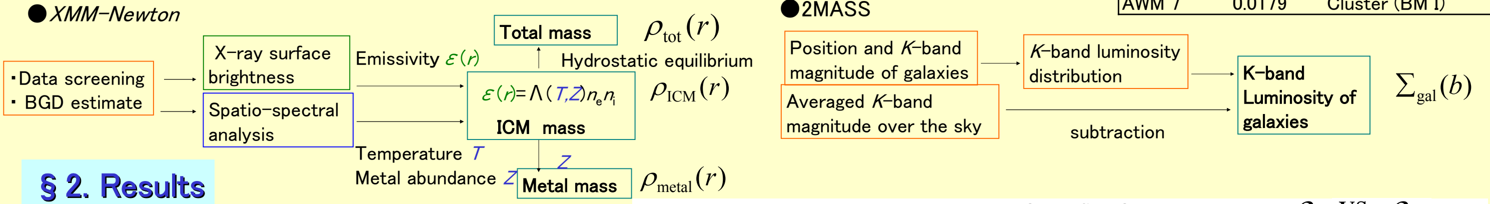
Then, (Metal distribution in the ICM) ∝ ∫(distribution of galaxies) × (activity of supernovae) dt.

Therefore, the spatial metal distribution in the ICM reflects evolution of distribution of galaxies and supernova activities.

We study 12 nearby clusters of galaxies shown Table 1which were archived in the *XMM-Newton* database. The sample includes various types of clusters with X-ray luminosities scattering 2 orders of magnitude. We compare the distributions of metals in the ICM with galaxies, along with ICM and total mass. As for the distribution of galaxies, we utilized archival data of Two Micron All Sky Survey (2MASS). Below is the flow chart of the analysis.

Table 1: Analyzed Targets

Target	Redshift	Type
NGC 1132	0.02323	IXEG(E)
NGC 1550	0.01239	IXEG(S0)
HCG 62	0.01370	Compact group
NGC 5044	0.00902	group(E)
NGC 4325	0.02571	group(E)
NGC 507	0.01645	group(E)
MKW 4	0.02000	Poor cluster (BM I)
Abell 3581	0.02300	Poor cluster (BM I)
Abell 262	0.01630	Poor cluster (BM III)
Centaurus	0.01140	Cluster (BM I-II)
Abell 1060	0.01260	Cluster (BM III)
AWM 7	0.0179	Cluster (BM I)



§ 2. Results

2-1. Density-Density Plot (DDP)

We devised a new plot to compare two cluster components, named Density-Density Plot (DDP). By omitting spatial information, the DDP clarifies direct relations of two densities concerned.

Figure 1 shows DDPs we derived for the 12 clusters. The ICM is spatially more extended than the iron, reflecting increase of iron abundance to the center. Interestingly, we found that the distribution of iron is rather similar to that of the total mass. This would be reasonable from a viewpoint that galaxies have distributed along dark matter, then the iron has similarly distributed. The silicon (and sulfur) distribution is not different from the iron distribution within errors.

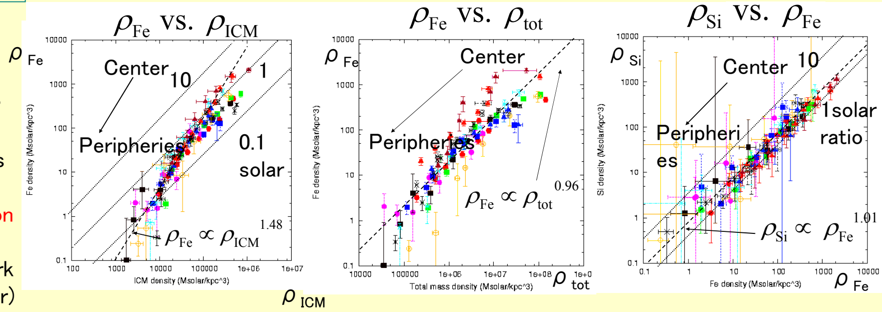


Figure 1: DDP between iron and ICM (left), iron and total mass (middle), and iron and silicon (right).

2-2. Iron-mass-to-light ratio (IMLR)

When we compare the radial profile of iron with that of galaxies as shown in Figure 2, the iron distributes along the galaxies in the peripheries. In the central regions within ～100 kpc, however, the IMLR decreases more than a order of magnitude toward the center. This means that the iron in the ICM is deficient relative to the central galaxies. This behavior of IMLR supports the results of *ASCA* (Makishima et al. 2001; Ezawa et al. 1997) with larger sample and more accuracy.

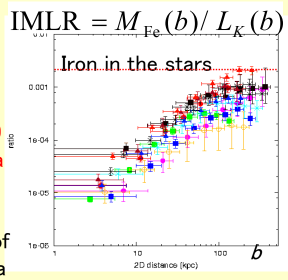


Figure 2: Iron-mass-to-light ratio profiles.

2-3. total iron mass in the 12 clusters

In order to study relations of total iron mass in the 12 systems with other mass components, we made several scatter plots, and found that the total iron mass is nearly proportional to total ICM mass multiplied by total K-band luminosity as shown in Figure 3. This result indicates that the interaction between the ICM and the galaxies affects the iron enrichment to the ICM.

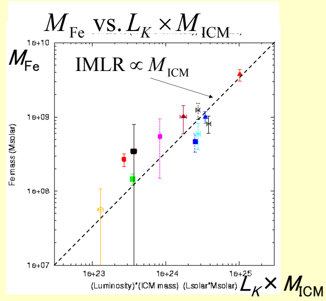


Figure 3: Total iron mass vs. (total ICM mass) x (total K-band luminosity).

§ 3. Discussion

We analyzed the 12 clusters of galaxies, and compared the metal distribution with the other cluster components. The results, as summarized in Figure 4, cast a mystery that the iron in the ICM is deficient at the center relative to the galaxies there.

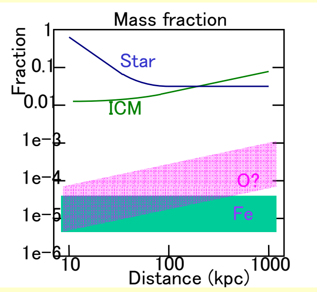


Figure 4: Schematic radial profiles of cluster components normalized to the total mass.

3-1. Scenarios for the iron deficiency at the centre

Two scenarios would be possible to the iron deficiency at the center;

(I) The distribution of galaxies has not changed from the cluster formation age, and the iron in the central region has transported to the peripheries.

(II) The galaxies have fallen toward the center along the gravitational potential made by dark matter, with supplying the iron the ICM.

When we adopt the scenario (I), some difficulties arise. The diffusion of iron in the ICM is at most ～10 kpc even in the Hubble time (Rephaeri et al. 1978). Then, if the iron has been transported outward with the ICM, the rate of bulk outflow becomes higher than 1 x 10^2 M_{solar} yr^{-1}. Moreover, the iron must have been re-distributed along the total mass distribution in all the 12 clusters. Therefore, the scenario (II) would be more favorable.

In the scenario (II), galaxies must have lost their kinetic energies. From our result of §2-3, the most plausible mechanism is the ICM-galaxy interaction. Actually, this kind of interaction has found by *Chandra* (Wang et al. 2004; Sun et al. 2005). We hypothesize that magneto-hydrodynamic interactions between the ICM and galaxies can be strong enough to decelerate galaxies (Makishima et al. 2001).

§ 4. Future works

4-1. Evolution of distribution of galaxies

In order to verify the scenario (II), we need to directly detect the evolution of distribution of galaxies by comparing distant and nearby clusters. We have already had a sign of the evolution as shown in Figure 5 that the distribution of galaxies are flatter in the distant cluster (Kitaguchi et al. 2005). We are now undertaking a systematic study using larger sample.

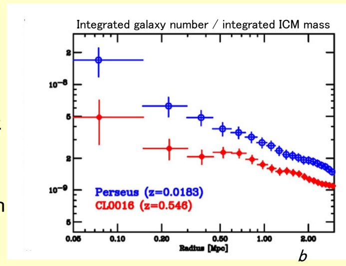


Figure 5: Encircled galactic number divided by encircled ICM mass in Perseus and CL0016

4-2. Oxygen distribution

Products of type-II supernova may have different distribution from those of type-Ia such as iron. In this point, oxygen is very important because it is considered to have been created mostly via type-II supernova. Recently *Suzaku* has revealed that the oxygen abundance profile is flatter than iron in several clusters (e.g. Matsushita et al. 2006; Sato et al. 2006) as exemplified in Figure 6. This means that the oxygen distribution is more extended than iron, and suggests the different history of supernova activities between the type-Ia and the type-II. In the contest of our scenario (II), oxygen might be supplied to the ICM mainly in the cluster formation age when starburst (and type-II supernovae) were far more active than the present.

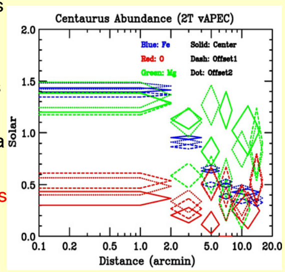


Figure 6: Metal abundance profiles in Centaurus.