Metal distributions out to $0.5 \ r_{180}$ in the intracluster medium of four galaxy groups

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ABSTRACT

We first studied the distributions of metal abundances in the intracluster medium (ICM) of four galaxy groups, MKW 4, HCG 62, the NGC 1550 group, and the NGC 5044 group, out to $0.5 \ r_{180}$ observed with Suzaku. The Mg/Fe and Si/Fe ratios in the ICM are nearly constant at the solar ratio out to $0.5 \ r_{180}$. Since the metals have been synthesized in galaxies, we compared the Fe mass in the ICM and the galaxy luminosity profiles, as integrated iron-mass-to-light-ratios (IMLRs). The groups with smaller gas-mass-to-light ratios have smaller IMLR values and the IMLR is inversely correlated with the entropy excess. Based on these abundance features, we discussed the history of metal enrichment processes in galaxy groups.

KEY WORDS: galaxies: groups: individual (MKW 4, HCG 62, NGC 1550 group, NGC 5044 group) — X-rays: galaxies: clusters

1. Introduction

Clusters and groups of galaxies are the best laboratories for studying their thermal and chemical evolution history governed by baryons. The observations of metals in the intracluster medium (ICM), synthesized by supernovae (SNe) in galaxies, provide an important clue in studying the evolution of galaxies. The ratio of the iron mass in the ICM to the total light from galaxies in clusters, the iron-mass-to-light-ratio (IMLR), is a key parameter in investigating the star formation history in these systems.

We studied the distributions of metal abundances and IMLRs in the ICM of four galaxy groups, MKW 4, HCG 62, the NGC 1550 group, and the NGC 5044 group, observed out to $\sim 0.5 \ r_{180}$ with Suzaku.

2. Analysis

It is important to estimate the Galactic and CXB emissions accurately, because the spectra, particularly in the outer regions of groups, suffer from the Galactic and CXB emissions strongly. We simultaneously fitted the spectra for the outermost and other annulus regions, and obtained the metal abundances of the ICM.

We derived K-band luminosity profiles, which trace the stellar (galaxy) mass distribution well (Nagino et al. 2009), from the Two Micron All Sky Survey (2MASS) catalog. We derived three-dimensional radial profiles of the integrated K-band luminosity up to $r_{180}$.

$r_{180}$ is the radius within which the mean density of a galaxy cluster is 180 times the critical density of the universe, and corresponds to the cluster size defined as the "virial radius".

3. Si/Fe and Mg/Fe ratios

Both of Si/Fe and Mg/Fe ratios in our sample are almost consistent with the solar ratio out to $\sim 0.5 \ r_{180}$. In figure 1, we compared the Si/Fe ratio between the groups and several clusters observed Suzaku and XMM. The Si/Fe ratios in these clusters and the flat radial profiles at the solar ratio agree well with those of our sample groups of galaxies. This result indicates the contributions from the SNe Ia and core-collapse SNe to the metals enriched in the ICM are universal.

![Fig. 1. Radial profiles of Si/Fe ratio.](image.png)

We compared the radial profiles of the integrated IMLRs of the galaxy groups with those of several other clusters observed with Suzaku and XMM. The IMLRs of the groups were significantly smaller than those of the other clusters at a given radius in units of $r_{180}$.

In Figure 2 (a), we plotted the integrated gas mass out to 0.5 $r_{180}$, $M_{\text{gas}}(<0.5 \, r_{180})$, of the four groups of galaxies in our sample with those of the other clusters as a function of $L_K(<r_{180})$. The $M_{\text{gas}}(<0.5 \, r_{180})$ of these clusters of galaxies are mostly proportional to $L_K(<r_{180})$. In contrast, the other groups and the Abell 262 cluster have smaller $M_{\text{gas}}(<0.5 \, r_{180})$ to $L_K(<r_{180})$ ratios by a factor of ~5. The bottom panel of figure 2 shows the integrated Fe mass out to 0.5 $r_{180}$, $M_{\text{Fe}}(<0.5 \, r_{180})$, against $L_K(<r_{180})$. The groups with a lower $M_{\text{gas}}(<0.5 \, r_{180})$ for a given $L_K(<r_{180})$ have lower $M_{\text{Fe}}(<0.5 \, r_{180})$ values.

5. Entropy vs. IMLRs of groups and clusters

Entropy profiles of the ICM is more expressive characterization of the thermodynamical history than the temperature. The entropy parameter is defined as $K = kT(r) n_e(r)^{-2/3}$ where $kT(r)$ and $n_e(r)$ are temperature and deprojected electron density, respectively, at a radius $r$ from the cluster center. Based on the simple gravitational heating model, the entropy scaled by the mean temperature of the ICM would have a similar number.

In order to investigate the correlation between entropy and IMLR profiles, we plotted IMLR profiles as a function of entropy profiles scaled by the ICM temperature in 0.1-0.3 $r_{180}$. In Figure 3, we plotted the IMLR within 0.5 $r_{180}$ against the scaled entropy at 0.1-0.3 $r_{180}$. The IMLR profiles correlate inversely well with the scaled entropy at each radius.

The increase of IMLR with radius and the relationship between the scaled entropy and IMLR indicate early metal enrichments in clusters and groups of galaxies as already suggested by Matsushita (2011). If these systems synthesized Fe in an early phase of cluster evolution, the ICM is polluted in the same way. Then the relative importance of the non-gravitational energy inputs in poor systems causes the difference in the gas distribution.

References

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Fig. 3. Integrated IMLRs within 0.5 $r_{180}$ as a function of the scaled entropy profiles at 0.1-0.3 $r_{180}$. The dashed lines indicate the best-fit power-law model for the Coma, the Perseus, and the AWM 7 cluster.