Suzaku observations of the metallicity in the intra-cluster medium of groups and clusters of galaxies

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Abstract

Suzaku enable us to investigate not only type Ia supernovae products (Si, S, and Fe) but also type II products (O and Mg) in the intra-cluster medium (ICM) to $\sim 0.3\ r_{180}$ region of clusters and groups of galaxies. We measured the metal abundances of the ICM of the clusters and groups between ∼1 and ∼4 keV and also calculated the Fe, O and Mg mass-to-light ratios (IMLR, OMLR, MMLR) with both B-band and K-band luminosities. The OMLR and MMLR were measured to $0.3\ r_{180}$ region in the ICM for the first time with Suzaku, while the resultant IMLR were consistent with those with ASCA. The MLRs of many groups seem to be lower than those of clusters. In addition, the values with K-band seem to be smooth for each cluster compared with those with B-band. Observed spatial metal distribution hint that type II products seem to have wider distribution than type Ia products. These suggest that metal enrichment process in the ICM seem to be similar for different clusters, while the MLRs of groups seem to have some scatter.

Key words: cluster: metal abundance

1. Observations and Spectral analysis

We selected four groups, NGC 5044, Fornax cluster, NGC 507 and HCG 62 below ~ 2 keV, and three clusters Abell 262 (hereafter A 262) , Abell 1060 (hereafter A 1060) and AWM 7 between 2 and 4 keV, to study the metallicity distribution in the ICM with Suzaku. These objects are nearby, bright systems observed with Suzaku. Detail analysis methods for each group and cluster were shown in Matsushita et al. (2007), Sato et al. (2007a, 2008, 2009a,b), Tokoi et al. (2008), and Komiyama et al. (2009).

In the observed spectra, the ionized O, Mg, Si, S, Fe lines are clearly seen for all objects. Although the ionized O lines are prominent in the outer regions of the groups and clusters, most of the emission is supposed to come from the local Galactic emission. Note that the the O abundance of the ICM is sensitive to the assumed Galactic component models as mentioned in Sato et al. (2007). We use $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 1 - \Omega_M = 0.73$ in this paper. The solar abundance table is given by Anders & Grevesse (1989), and errors are 90% confidence region for a single interesting parameter.

2. Results and Discussion

2.1. Abundance profiles

For all objects, the Fe abundances at the central region are a subsolar abundance, and decrease to ~ 0.2 of solar abundance around $\sim 0.3\ r_{180}$. We measured not only Si, S, and Fe but also O and Mg abundance profiles up to a radius of $\sim 0.3\ r_{180}$ for the first time with Suzaku. Because the Fe abundance was well determined in the metal abundances with the smaller uncertainties, we compared the distributions of the metal abundances with that of the Fe abundance. In order to compare the relative variation in the abundance profiles, we show abundance ratios of O, Mg, Si, and S divided by Fe as a function of projected radius. The projected radius is scaled by the virial radius for each object. As a result, the Si and S to Fe abundance ratios are close to ~ 1.5 from the central to the outer region, while the gradients of the O and Mg to Fe ratios seem to be milder increasing than those of the Si and S to Fe ratios. In addition, O/Fe solar abundance ratios at the central region are about ~ 0.6, while the other elements to Fe ratios at the central region are almost a solar abundance.

In order to investigate whether the gradient of the ra-

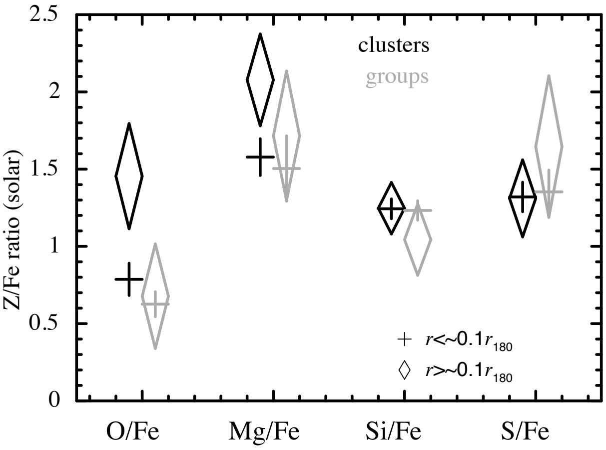

Fig. 1. Average of the radial Z/Fe ratio profiles for groups and clusters in $r <\sim 0.1\ r_{180}$ and $r >\sim 0.1\ r_{180}$ region.

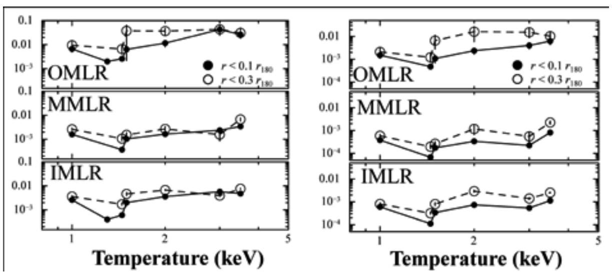

Fig. 2. Temperature dependence of the MLRs with B-band (left and K-band (right) for each group and cluster.

dial O, Mg, Si, and S to Fe ratios had different distributions or not, we calculated the average of each ratio in $r <\sim 0.1\ r_{180}$ and $r >\sim 0.1\ r_{180}$ regions. This was because the metals within $0.1\ r_{180}$ might be affected by the contributions from the central galaxy. The resultant averages are shown in figure 1. For the groups, the Mg, Si, and S to Fe ratios are about 1–1.5 solar within $r <\sim 0.1\ r_{180}$, while the O/Fe ratio is about ~ 0.6 solar. The ratios of groups have no spatial difference in/out $r \sim 0.1\ r_{180}$. For clusters, the ratios within $r <\sim 0.1\ r_{180}$ are similar to the case of the groups. On the other hand, in $r >\sim 0.1\ r_{180}$ region, the O and Mg to Fe ratios seem to increase compared to those within $r <\sim 0.1\ r_{180}$, although the Si and S ratios are almost equal between the regions.

2.2. IMLR and OMLR with B-band and K-band

We introduce the parameter of the metal mass-to-light ratio and estimate its value for the groups and clusters. Combining the X-ray luminous gas mass profile of the groups and clusters and the abundance profiles obtained with Suzaku, we calculated the cumulative metal mass profiles. Using the integrated optical (B-band) luminosity, we calculated the oxygen mass-to-light ratio (OMLR), magnesium mass-to-light ratio (MMLR), and iron mass-to-light ratio (IMLR) in unit of $M_{\odot}/L_{\odot}$. All the integrated OMLR, MMLR, and IMLR with B-band show a steep increase up to a radius of $\sim 0.1\ r_{180}$, and seem to reach almost the maximum at 0.1-0.2 r_{180}. The steep increase in the $r < 0.1\ r_{180}$ region suggests that the gas with O, Mg, and Fe ions which were synthesized in the central regions have been distributed to a wide region in the intra-cluster space, and/or that the member galaxies have been more concentrated than the ICM.

We also calculated OMLR, MMLR, and MMLR with K-band luminosity based on the Two Micron All Sky Survey. Detail analysis methods of K-band luminosity are mentioned in Sato et al. (2009a) and Komiyama et al. (2009). While the increase of MLRs with B-band luminosity seem to stop up to a radius of $\sim$ 0.1–0.2 r_{180}, the MLRs with K-band continue to increase in our observation region with Suzaku. Comparing to the tendency of MLRs with B-band, that with K-band seems to be similar to each object, and MLRs with K-band show a milder dispersion. These suggest that metal enrichment process in the ICM seem to be similar for each group and cluster.

Makishima et al. (2001) shows the larger and richer system have higher value of IMLR with B-band luminosity with ASCA. As mentioned in Sato et al. (2009a), Suzaku observations show that not only IMLR, but also OMLR and MMLR have the same tendency as ASCA observations. In order to investigate the temperature dependence of the OMLR, MMLR, and IMLR with K-band, we plotted the MLRs within $\sim$0.1 and 0.25 r_{180} in figure 2. As shown the tendency with B-band, the MLRs with K-band of lager and richer system have lager value within 0.1 and 0.25 r_{180}. In addition, the tendency of the IMLRs have a flatter distribution compared with that of the OMLRs in $r <\sim r_{180}$ region. This suggests that the metal distributions in $r <\sim 0.1\ r_{180}$ region are affected by the central galaxies.

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