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Metal distribution in the center of the Virgo cluster

N. Iijima[1], I. Mitsuishi[1], T. Ohashi[1], K. Matsushita[2] and K. Sato[2]

[1] Department of Physics, Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji, Tokyo 192-0397, Japan, e-mail: noriko@phys.se.tmu.ac.jp
[2] Department of Physics, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan

Abstract. We analyzed SUZAKU data around M87 and derived metal abundances of various elements to a radius of about 70 kpc. PSF effect and ambiguity of spectral index of the central AGN were considered. The abundances show generally positive correlation, but we do not see a significant metallicity enhancement along the extension of the NE and SW arms. This suggests that the metal lifting by radio jets may slow down around the radius of 30 kpc.

Key words. Galaxies: abundances – Galaxies: individual: M87 – Galaxies: ISM – X-rays: galaxies: clusters

1. Introduction

Metal abundances in X-ray halos of early-type galaxies provide us with the opportunity of looking into the past history of star formations. While hot intracluster medium (ICM) generally holds almost all the metals which have been produced in the evolutionary history, its metal abundance are diluted in the primeval matter and effects of clumpiness and non-thermal processes make estimation of the metal production process not easy. The hot interstellar medium (ISM) in early-type galaxies reflects the recent metal production process and very useful to understand how star formation and metal production took place in the past.

M87 is a unique object in studying the metal production in a cD galaxy and its effect to the surrounding ICM. This is the brighter cD galaxy in the X-ray sky, and its closeness allows us to look into detailed structures in the temperature and metallicity distribution. The first report on the central iron concentration in the Virgo cluster was given by Koyama et al. (1991), and subsequent imaging studies of the metallicity distribution in M87 showed that all the metals including O, Mg, Si, and Fe have radial abundance gradient with a peak value of around 1.5 solar in the center. The two radio arms in the E and SW directions exhibit cooler gas with $kT \sim 1$ keV (Belsole et al. 2001), and these regions also show enhanced metal abundance. It is suggested that radio jet has lifted up metal-rich gas from the M87 center along the radio arms (Simionescu et al. 2008).

There is also a metallicity jump seen at 90 kpc north of M87, possibly caused by sloshing caused by M87 in the Virgo cluster. These fine scale studies of the metallicity distribution in and around M87, mostly carried out

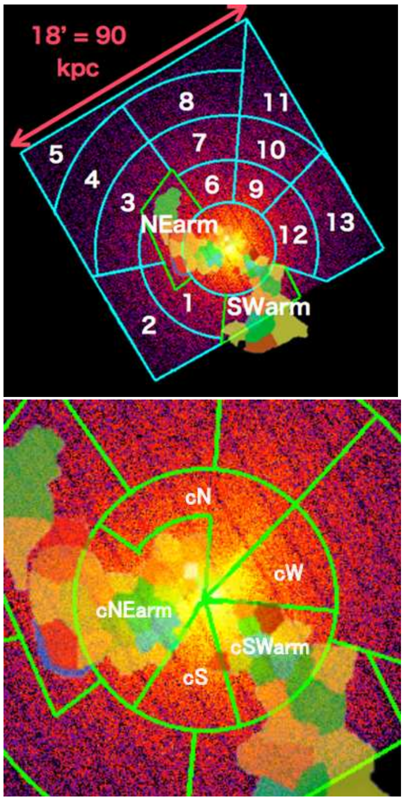

Fig. 1. Regions for the spectral analysis are shown, overlaid on the map of low temperature emission by Simionescu et al. (2008). Four regions, cNEarm, cSWarm, NEarm and SWarm, are along the arms. Left: outer 15 regions. Radius of the innermost circle is 3.12'. Right: a close-up view of the central region, showing the inner 5 regions.

by XMM-Newton, have been limited to very bright regions. Further studies with better sensitivity would be needed to see how the fresh metals produced in the cD galaxy diffuses into the ICM.

X-ray morphologies and metallicity distribution in M87 indicate that there are dynamical processes going on in this rather young system. Dynamical evolution of clusters of galaxies will be studied more directly with future high resolution X-ray spectroscopy such as with microcalorimeters. These dynamical process may carry significant amount of the pressure in the form of turbulence, for example, and its understanding is important to use clusters the probe of cosmological studies. The detailed X-ray spectral study of the gas dynamics with the present energy resolution with CCD would give us a constraint about the role of non-thermal processes around the cD galaxy.

This paper reports results from Suzaku observation of M87. We use solar abundance by Anders & Grevesse (1989).

2. Observations and analysis

The data we analyze here are contained in a single field observed by the XIS instrument of Suzaku. The observation was carried out in 29 Nov. - 2 Dec. 2006 for 98 ks, with the field center at (RA, DEC) = (187.7366, 12.4456) in J2000. The resultant image in the all energy range is shown in Fig. 1. For further spectral analysis, we divided the image into 20 regions with radial (every 3' steps) and azimuthal cuts as indicated in the figure. We call region in and out of radius 3.12' "inner region" and "outer region" respectively. In this radius, excess of radiation from ISM over from ICM was found in terms of mass-to-light ratio (Matsushita et al. 2002).

As for the background, we used the data taken in the Lockman Hole for which the total observation time is 80 ks. We first carried out a spectral fit for the Lockman data with a 3-component model, consisting of a power-law model (CXB: cosmic X-ray background) and an apec model (MWH: milky-way halo), both with the Galactic absorption, and an unabsorbed apec model (LHB: local hot bubble). The parameters were 3 normalization, one power-law photon index, two temperatures, and one $N_{\rm H}$. These parameters were fixed when we performed spectral fits to the M87 spectra.

In fitting the M 87 spectra, we applied 3 models, one temperature plasma model (ICM) for outer non-arm regions, two temperature plasma model (mixed ISM and ICM) for outer arm regions and two temperature plasma plus power-law model (ISM, ICM and central AGN) for inner regions, to extract the abun-

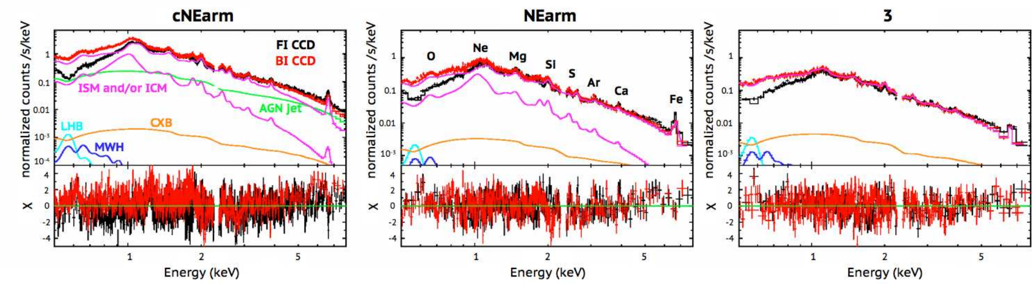

Fig. 2. Examples of SUZAKU spectra for inner arm (left), outer arm (middle) and outer non-arm region (right) regions. Black and red data are for front-side illuminated (FI) CCD and back-side illuminated (BI) CCD, respectively. The best fit models only for the BI CCD are shown with solid curves.

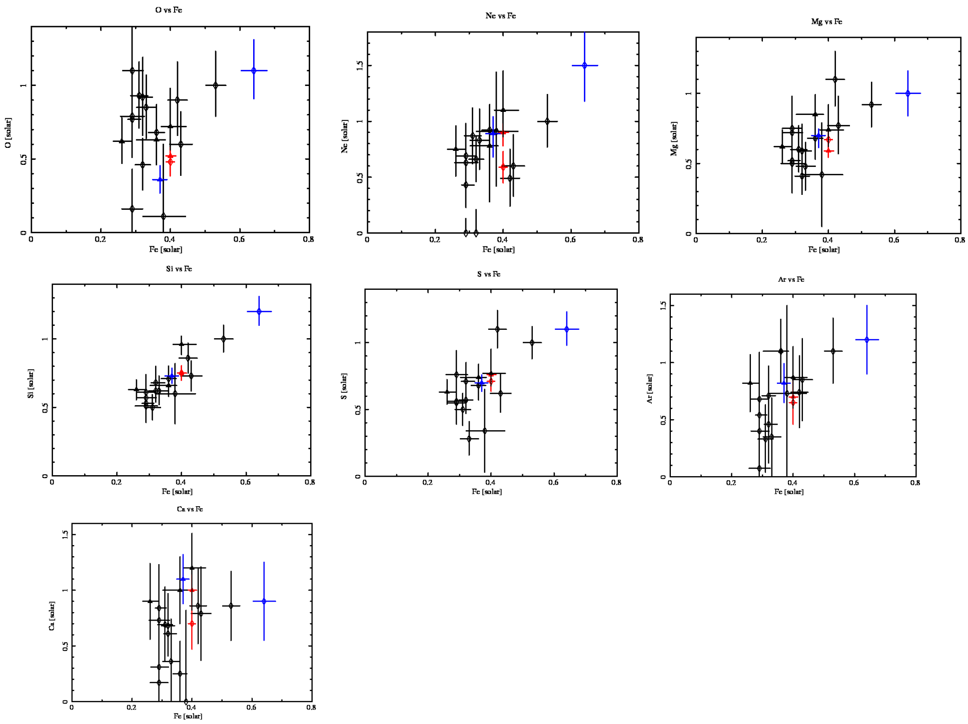

Fig. 3. Abundances of various elements against Fe are shown. Red crosses are for cNEarm and NEarm regions, and blue ones are for cSWarm and SWarm (higher Fe abundance), respectively.

dance in the hot gas. These models were based on the necessity of the second and third component implied by an F test.

We also estimated spectral contamination caused by the SUZAKU PSF (HPD ~ 1.8') and subtracted the contribution from other region. These spectral contamination were calculated by ray tracing simulation with XMM-Newton spectral distribution. These XMM temperature and abundance used here are consistent with previous results (Matsushita et al. 2002).

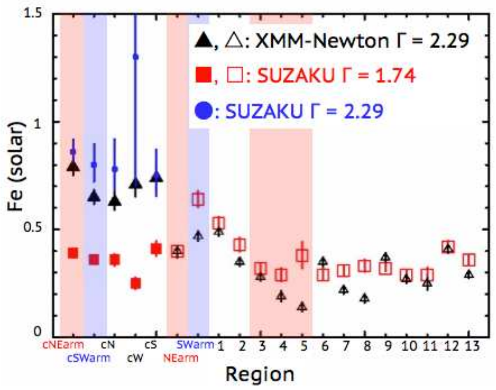

Fig. 4. The best fit Fe abundance against the region name (NOT in order of radius) for both XMM and SUZAKU data. Red and blue shaded areas correspond to the NEarm and its extension and the SWarm regions, respectively.

3. Result

Examples of the observed SUZAKU spectra are shown in Fig. 2. Emission lines of O, Ne, Mg, Si, S, Ar, Ca and Fe are seen. We derived abundances of these elements and plotted against Fe abundance in Fig. 3. Si shows strong correlation with Fe, and other elements excluding Ca also seem to show positive correlations. The abundance pattern is almost the same for all regions including garmh, gnon-armh, ginnerh and gouterh ones. It is not clear that the abundance enhancement along the arms continues to the outer regions (Fig. 4).

For the inner region data, the abundance parameters strongly depend on the photon index of the power-law component. We assumed 1.74 (Chandra value) for the Fig. 3 results. However, XMM data indicates an index of 2.29, and Fe abundance for this case is shown in Fig. 4. Note that the outer regions are not affected by AGN, and our abundance results are reliable.

4. Conclusions

SUZAKU data around M87 show metal abundance of various elements to a radius of about 70 kpc. Most of the elements show positive correlations, but we do not see a marked metallicity enhancement along the extension of the NE and SW arms. This may suggest that the metal lifting slows down around 30 kpc from the center and metals would diffuse out to ICM.

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