Search for gas bulk motions in eight nearby clusters with Suzaku

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Abstract

To search for bulk motions of the intracluster medium, we analyzed X-ray spectra taken with Suzaku and measured the Doppler shift of Fe-K line emission from eight nearby clusters of galaxies with various X-ray morphologies. In the core of the Centaurus cluster and the Perseus cluster, the gas bulk velocity does not exceed the sound velocity, which confirmed the previous results. For the Cen45 subcluster, the radial velocity relative to the cluster center is found to be smaller than that reported in the optical band. In A2142, A3667, and A133, no significant bulk motion was detected. On the other hand, we discovered the sign of Doppler shift in excess of the XIS calibration uncertainty near the center of cool-core clusters, A2029 and A2199, and in the subcluster of the merging cluster A2255. The large bulk velocity (∼2000 km s⁻¹) in A2255 is comparable to the radial velocity of galaxies in the subcluster, suggesting that the gas bulk motion is associated with a minor merger. The present study also provides a pilot survey prior to the future high-resolution spectroscopy with ASTRO-H, which is expected to play a critical role in revealing the cluster evolution.

Key words: galaxies: clusters – galaxies: intracluster medium – X-rays: galaxies: clusters – cosmology: observations

1. Introduction

How mass distributions of gas and galaxies (and dark matter) in galaxy clusters evolve? Clusters are believed to have grown into the present shape via merging and numerical simulations predict that a large-scale motions of intracluster medium (ICM) with velocity ~1000 km s⁻¹ are generated and last for several Giga years. If the ICM kinetic velocity is larger than its sound velocity, non-thermal pressure cannot be neglected in estimating the total gravitational mass (e.g., Lau et al. 2009).

The kinetic gas motions can be directly measured by the Doppler shift of emission lines (e.g., Tamura et al. 2014; Ota 2012). Early results from the Suzaku mission reported the absence of bulk motions in the center of the Centaurus cluster (the 90% limit on line-of-sight velocity ∆V ≪ 1400 km s⁻¹; Ota et al. 2007). Suzaku has measured the ICM motions in about eight nearby clusters, however, the significant Doppler shift was detected only in A2256 (Tamura et al. 2011). They suggest that the gas and galaxies are moving together as a single subcluster inside the cluster potential.

In this paper, aiming at exploring the dynamical evolution of clusters, we searched for the gas bulk motions in nearby clusters with Suzaku.

2. Analysis and results

To study the ICM velocity structure and its possible relationship with the X-ray morphology, we have analyzed the Suzaku archive data of both regular and irregular clusters. Because the Doppler shift measurement requires a good photon statistics, the sample was limited to eight nearby clusters with z < 0.1 (Table 1).

We utilized X-ray spectral data obtained with Suzaku XIS because it has an excellent sensitivity at the Fe-K line energies and the lowest background. The XIS field of view was divided into smaller cells and the Fe line energy in each cell was determined from the spectral fitting (Figure 1). The model consists of the APEC model with metallicity reset to 0 and three Gaussian lines.

The ICM radial velocity relative to the optical redshift was calculated by ∆v = c(z_{cell} − z_{optical}), where z_{cell} is the redshift measured by XIS and z_{optical} is the optical redshift. Table 1 lists the line-of-sight bulk velocity obtained in each cluster. The present results show that the bulk velocity does not largely exceed the sound velocity of ICM in the Centaurus and Perseus clusters. No significant gas motion was detected in A3667, A133, and A2142, indicating an upper limit on the radial velocity of 3000–4000 km s⁻¹. On the other hand, we found the sign of the Doppler shift to be in excess of instrumental calibration uncertainty in the core of three clusters. If both statistical and systematic errors are considered,
Table 1. Cluster sample and line-of-sight bulk velocity measured by XIS

<table>
<thead>
<tr>
<th>Cluster</th>
<th>$z_{\text{optical}}$</th>
<th>Exposure (ks)</th>
<th>Morphology</th>
<th>$\Delta v \pm \sigma_{\text{stat}} \pm \sigma_{\text{sys}}$ (km s$^{-1}$)</th>
<th>Sound velocity (km s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centaurus</td>
<td>0.0104</td>
<td>36.5</td>
<td>Regular</td>
<td>$210 \pm 120 \pm 310 (&lt;550)$</td>
<td>870</td>
</tr>
<tr>
<td>Perseus</td>
<td>0.0183</td>
<td>48.8</td>
<td>Regular</td>
<td>$-260 \pm 350 \pm 315 (&lt;830)$</td>
<td>1160</td>
</tr>
<tr>
<td>A2199</td>
<td>0.0302</td>
<td>25.0</td>
<td>Regular</td>
<td>$1110 \pm 580 \pm 320 (1.9\sigma)$</td>
<td>1030</td>
</tr>
<tr>
<td>A2029</td>
<td>0.0773</td>
<td>7.6</td>
<td>Regular</td>
<td>$-1540 \pm 600 \pm 300 (2.7\sigma)$</td>
<td>1400</td>
</tr>
<tr>
<td>A3667</td>
<td>0.0556</td>
<td>20.9</td>
<td>Irregular</td>
<td>$730 \pm 1260 \pm 340 (&lt;4000)$</td>
<td>870</td>
</tr>
<tr>
<td>A133</td>
<td>0.0566</td>
<td>48.5</td>
<td>Irregular</td>
<td>$-60 \pm 2220 \pm 340 (&lt;3700)$</td>
<td>1250</td>
</tr>
<tr>
<td>A2255</td>
<td>0.0806</td>
<td>44.1</td>
<td>Irregular</td>
<td>$-2340 \pm 1450 \pm 350 (1.6\sigma)$</td>
<td>1470</td>
</tr>
<tr>
<td>A2142</td>
<td>0.0909</td>
<td>50.8</td>
<td>Irregular</td>
<td>$-1080 \pm 1150 \pm 360 (&lt;4000)$</td>
<td>1320</td>
</tr>
</tbody>
</table>

Fig. 1. Top: XIS image of the A3667 center (18$''$ x 18$''$). The cells used for spectral extraction are shown with the green boxes. Bottom: Example of Gaussian fitting to the Fe-K line spectra in A3667 cell No. 6 (the crosses in the upper panel). The solid line shows the best-fit model and the three Gaussian lines are indicated with dashed lines. In the bottom panel, the residuals of fit are shown.

The significance of the bulk velocity is 1.9$\sigma$ for A2199, 2.7$\sigma$ for A2029, and 1.6$\sigma$ for A2255, respectively. The standard deviation $\sigma$ is given by a quadrature sum of the 1$\sigma$ statistical and systematic errors, $\sigma = (\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2)^{1/2}$. The systematic error of the XIS energy scale is estimated to be 0.1% based on the analysis of the Mn Kα line from the onboard calibration sources. The sign of large bulk motion is found in the regular clusters for the first time.

3. Discussion
From the XIS analysis, a signature of gas bulk motion on the order of 1000 – 2000 km s$^{-1}$ was discovered in A2199, A2029, and A2255. On the contrary, no significant bulk motion was detected in five clusters. We compare the velocity distributions of ICM with those of member galaxies for the Centaurus cluster and A2255 below. Discussions on individual targets as well as the impact of the bulk motions on the cluster mass estimate are presented in Yoshida & Ota submitted.

For the Centaurus cluster, the ICM velocity difference between the main cluster and the Cen45 subcluster is found to be significantly smaller than that of galaxies (+1500 km s$^{-1}$; Lucey et al. 1986), suggesting there is an offset between the gas and galaxy distributions along the line of sight. A spatial segregation between a dissipationless component and fluid-like X-ray gas has been found in on-going mergers. Thus the above results supports that the cluster has experienced a line-of-sight subcluster merger and gas near Cen45 has been heated by the strong shock (Walker et al. 2013).

For A2255, the ICM radial velocity is comparable to that of member galaxies (Yuan et al. 2003). The results support that the gas is moving along with the infalling subcluster in the cluster potential. Due to the large measurement uncertainty, however, a further examination by the follow-up observations is needed.

We expect that the ASTRO-H SXS microcalorimeter (Mitsuda et al. 2010) will determine the ICM velocity structure more accurately and clarify the contribution of non-thermal pressure in the cluster mass estimation.

References
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