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STRUCTURAL ANALYSIS OF A2034 CLUSTERS OF GALAXIES

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Abstract. We present the analysis of X-ray and optical observations of Abell 2034. It is located at the moderate redshift of z=0.113. X-ray data are taken from the XMM-Newton archive. The best-fit single temperature of 7.6 keV model well defines the diffuse hot plasma. The cluster is observed by ground based optical Turkish National Observatory RTT-150 telescope. X-ray spectra of the individual sources from the cluster outskirts are studied. The intra cluster medium (ICM) temperature and metal distributions are constructed using wavelet algorithms. We explore the morphology and dynamical history of the cluster based on our multi-wavelength analysis results.

1. INTRODUCTION

Clusters of galaxies are bright X-ray sources, with typical bolometric luminosities in the range of $10^{43} < L_X < 10^{45}$ ergs s^{-1}. In the standard hierarchical model of structure formation, larger clusters are formed by accretion of smaller clusters. This type of relaxed systems are expected to be in the nearby universe. The clusters also merge and occasionally, two clusters collide. These major mergers are expected to have significant effects on the intracluster medium (ICM). Mergers will drive shocks which can significantly heat the ICM. While strong, centrally condensed cooling flows are anticorrelated with major mergers, merger shocks are too weak to completely disrupt cooling flows at the centers of clusters. Consequently, cold cores of gas have been observed to be moving at high velocities through the ICM of several clusters (e.g., A2142, A3667; Markevitch et al. 2000; Vikhlinin, Markevitch and Murray 2001). In principle, these thermal effects should all be visible in the X-rays: the shocks as abrupt increases in the entropy of the X-ray emitting gas, and cold cores as regions of high-density, cold gas.

2. ABELL 2034

A2034 is a moderate-redshift, high X-ray luminosity cluster at z=0.113. Previous observations of the cluster with ASCA and ROSAT have found, respectively, a cooling-flow corrected temperature of 9.6 keV (White 2000) and a bolometric luminosity of

2.2×10^{45} ergs s^{-1} (David, Forman and Jones 1999). White (2000) found a best-fit single temperature of 7.6 keV. Optically, it is quite rich with ACO richness class 2. It has a cD galaxy that is offset $1'$ from the X-ray centroid and $2'.5$ from the optical centroid of the cluster. The relative displacements of the cD galaxy, average galaxy position, and center of the X-ray gas distribution suggest that the cluster is out of equilibrium. Indeed, non-equilibrium features were seen in the cluster in a pointed ROSAT observation. Recently, a detailed analysis of the cluster with *Chandra* data is reported by Kempner (2003). Fig. 1 shows the images from *Chandra* analysis. It showed an excess of emission to the south of the cluster center that was suspected to be a merger shock. The detection of a radio relic near the position of the northern discontinuity (Kempner and Sarazin 2003) strengthens the case for the cluster being out of equilibrium because of a recent or ongoing merger.

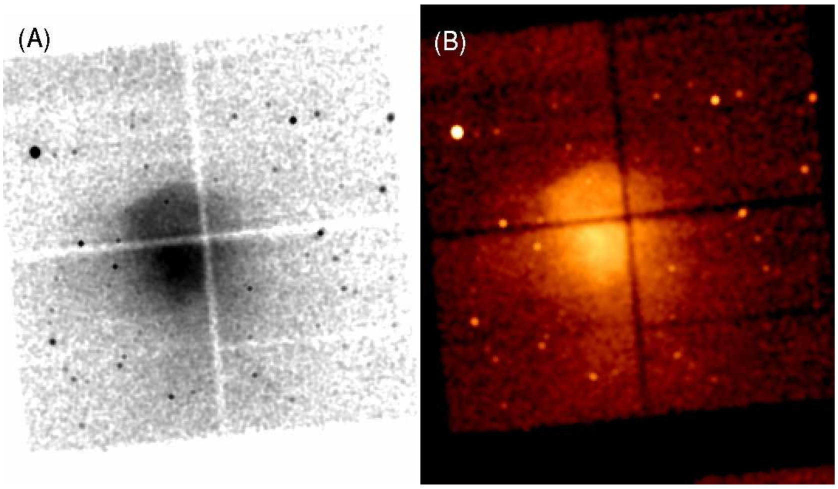

Figure 1: Abell 2034 *Chandra* raw (A) and smoothed (B) 0.3-10 keV image.

In this study, we present the results for Abell 2034. All errors are quoted at 90% confidence unless otherwise stated. We assume the Hubble constant H_0=75 km s^{-1} Mpc^{-1} and the cosmological deceleration parameter of q_0=0.5 throughout this paper. At the redshift of A2034, $1' \simeq 100$ kpc.

3. DATA AND ANALYSIS

We analyzed archival X-ray data obtained by using three XMM-*Newton* observations (Table 1). The three EPIC instruments, the two MOSs and the PN were used. The cameras were operated in the Prime Full Window mode for MOS and Prime Full Window Extended mode for PN. The medium filter was used for all EPIC cameras. We processed the observation data files and created calibrated event files using the SAS version 7.0.0. The event lists were generated from the observation data files (ODF) by the tasks EMCHAIN and EPCHAIN. The data were cleaned for soft proton flares. Gaussian smoothed soft X-ray image, uncorrected for background or exposure, is shown in Fig. 2 left panel.

Table 1: Log of X-Ray (XMM-*Newton*) observations for A2034.

Source	Date	α (2000)	δ (2000)	Exp. (sec)
Abell 2034	2003.08.01	15:10:06.38	+33:30:19.50	26413
	2006.01.07	15:10:16.89	+33:30:18.80	17006
	2006.01.02	15:10:16.90	+33:30:18.30	32009

The properties of X-ray extend emission are studied by extracting source counts from $5'$ circular region centered at the X-ray peak. The required response and auxiliary files for spectra were produced by rmfgen-1.53.5 and arfgen-1.66.4, respectively. We fitted the spectrum with a single MEKAL model. It is an emission spectrum from hot diffuse gas based on the model calculations of Mewe (1995) with Fe-L calculations by Liedahl et al. (1995). The absorption is fixed to the Galactic value. The temperature value is $kT = 7.6 \pm 0.3$ keV and metal abundance value is $Z = 0.27 \pm 0.06$ solar, which is consistent with the previous studies. We also spectrally studied X-ray point sources from the cluster field. Power-law model is added to MEKA thermal plasma for point source spectral fitting. The power-law indices of the best-fit values were in the physically tolerable range ($1 < \Gamma < 3.5$), clustering around the $\Gamma = 2.08$. Some sources have too few counts (~ 110) for a spectral fit. Fig. 2 (ii) displays the spectrum of the brightest source located at top-left of the X-ray peak. Three colors are the data from two MOSs and PN, respectively. The source has a Γ=1.7 and it's halo has a temperature value of 0.49 keV.

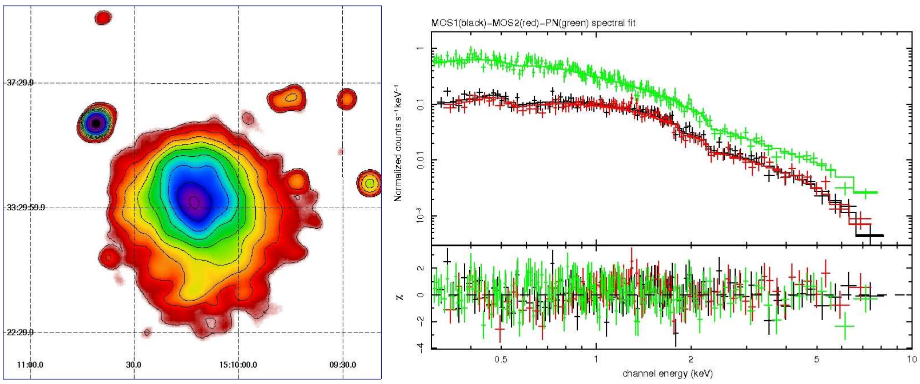

Figure 2: Abell 2034 (i) XMM-*Newton* soft image (ii) The best fit x-ray spectra.

Fig. 3 (i) shows RTT150 R-filtered observation of the cluster central region. The contours are derived from XMM-*Newton* soft 0.3-2 keV emission. The shift between X-ray peak and cD elliptical location is evident. The brightest point source with its optical counterpart can also be seen at the top-right. The right panel in the same figure is the temperature map from *Chandra* data. Our temperature map of XMM-*Newton* data has no peculiarity. The temperature gradually drops from the core to the outskirts. Although the system is relaxed on a cluster scale, small scale temperature variations are evident.

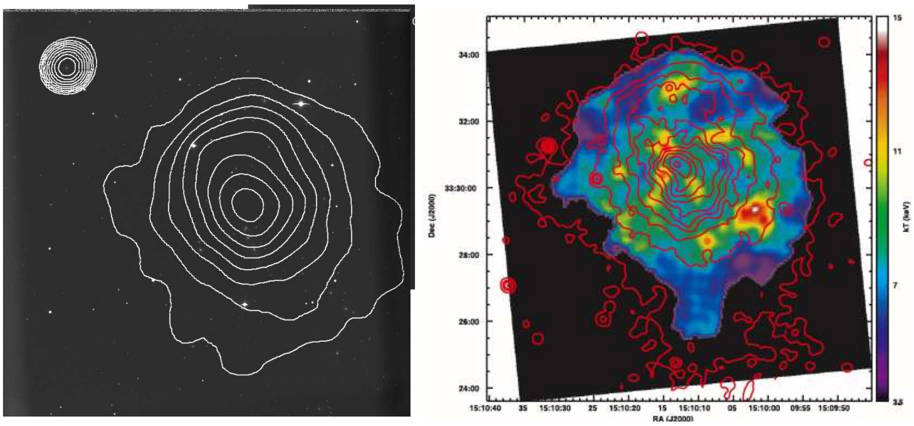

Figure 3: Abell 2034, (i) RTT150 R-filtered optical image overlaid by 0.3-10 keV contours. (ii) Temperature map by Kempner (2003) with *Chandra* data.

4. DISCUSSION

Our analysis of the XMM-*Newton* observation of the massive, moderate-redshift cluster A2034 has revealed a number of interesting features. We have determined that (i) the temperature of the cluster is fairly constant out to a radius of at least about 800 kpc. (ii) Temperature map shows small scale variations (100 kpc). This indicates that A2034 is not relaxed but dynamically active. Other major evidence for the cluster being out of equilibrium includes (iii) the significant offset of the central cD galaxy from the center of the X-ray emission.

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