The Astrophysical Journal, 624:L69–L72, 2005 May 10

CONFIRMATION OF THE PRESENCE OF NONTHERMAL HARD X-RAY EXCESS IN THE CLUSTER A2256 FROM TWO EPOCH OBSERVATIONS

Roberto Fusco-Femiano,[1] Raffaella Landi,[2,3] and Mauro Orlandini[2]
Received 2004 November 22; accepted 2005 April 5; published 2005 April 19

ABSTRACT

After confirmation of the presence of a nonthermal hard X-ray excess with respect to the thermal emission in the Coma Cluster from two independent observations, obtained using the Phoswich Detection System on board *BeppoSAX*, we also present in this Letter the results of two observations of A2256 performed with a time interval of about 2.5 yr. In both spectra a nonthermal excess is present at a confidence level of ∼3.3 σ and ∼3.7 σ, respectively. The combined spectrum obtained by adding up the two spectra allows us to measure an excess at the level of ∼4.8 σ in the 20–80 keV energy range. The nonthermal X-ray flux is in agreement with the published value of the first observation (Fusco-Femiano et al.) and with that measured by a *Rossi X-Ray Timing Explorer* observation (Rephaeli & Gruber).

Subject headings: cosmic microwave background — galaxies: clusters: individual (A2256) — magnetic fields — radiation mechanisms: nonthermal — X-rays: galaxies

1. INTRODUCTION

The formation of diffuse radio regions (radio halos or relics) detected so far in a limited number of clusters of galaxies seems due to large-scale shocks and turbulence associated with gravitational mergers of subclusters and groups that are able to provide the necessary ingredients, namely, magnetic field amplification and particle reacceleration (Tribble 1993; Brunetti et al. 2001; Fujita et al. 2003). In particular, the megaparsec scale of radio halos or relics combined with the relatively short radiative lifetimes of the electrons (∼10^8 yr) suggests an in situ electron reacceleration induced by very recent or current merger events whose link with diffuse radio emission seems to be evidenced by X-ray observations (Markevitch & Vikhlinin 2001; Govoni et al. 2004). The existence of these radio regions could be related to the origin of nonthermal hard X-ray (HXR) emission that has been detected in a few clusters thanks to the sensitivity and wide spectral coverage of *BeppoSAX* and the *Rossi X-Ray Timing Explorer* (*RXTE*).

A nonthermal HXR excess has been measured in the Coma Cluster by *BeppoSAX* and *RXTE* (Fusco-Femiano et al. 1999; Rephaeli et al. 1999) and was recently confirmed by combining the spectrum of the first *BeppoSAX*/Phoswich Detection System (PDS; Frontera et al. 1997) observation with the spectrum obtained with a second deeper observation (Fusco-Femiano et al. 2004). The results of these detections have been challenged by the data analysis of Rossetti & Molendi (2004, hereafter RM04). The origin of this difference is currently under investigation. However, in § 2 we examine the systematic effects reported in their paper and the possible systematic error in the net count rates, discussed in Nevalainen et al. (2004, hereafter NE04), due to unresolved point sources present in the field of view (FOV) of the PDS.

The nonthermal flux derived from the combined spectrum of the Coma Cluster, $(1.5 \pm 0.5) \times 10^{-11}$ ergs cm^{-2} s^{-1} in the 20–80 keV energy range, is consistent with the value of $(1.2 \pm 0.3) \times 10^{-11}$ ergs cm^{-2} s^{-1} measured by *RXTE* in the same energy band and confirmed by a second deeper observation (Rephaeli & Gruber 2002). Nonthermal radiation has been detected also in A2256 by *BeppoSAX* and *RXTE* (Fusco-Femiano et al. 2000; Rephaeli & Gruber 2003) and in A2319 by *RXTE* (Gruber & Rephaeli 2002). At a lower confidence level, with respect to Coma and A2256, nonthermal HXR radiation has been detected by *BeppoSAX* in A754 (Fusco-Femiano et al. 2003b). An upper nonthermal flux limit has been reported in A3667 (Fusco-Femiano et al. 2001), A119 (Fusco-Femiano et al. 2003a), and A2163 (Feretti et al. 2001). A nonthermal component is detected at an ∼2 σ level in ∼50% of the nonsignificantly active galactic nucleus–contaminated clusters observed by *BeppoSAX* (NE04).

The most likely interpretation of the nonthermal HXR radiation is inverse Compton (IC) emission by the same radio synchrotron electrons responsible for the extended radio emission present in all of the mentioned clusters, scattering the cosmic microwave background photons. It is well know that the alternative interpretation based on nonthermal bremsstrahlung emission from suprathermal electrons (Kaastra et al. 1998; Ensslin et al. 1999; Sarazin & Kempner 2000) has remarkable energetic problems (Petrosian 2003). Another possible explanation for the detected nonthermal emission may be due to a significant contamination by obscured active galactic nuclei (AGNs; Matt et al. 1999; Hasinger et al. 2001). However, the *Chandra X-Ray Observatory*, which is sensitive enough to probe a significant fraction of the obscured AGN, has not detected such sources in several clusters (e.g., Molnar et al. 2002). Besides, the co-added spectrum of the sample of clusters in NE04 gives indication for an extended distribution of the nonthermal emission against a significant contamination from an obscured AGN.

In this Letter, we present the combined PDS spectrum of A2256 obtained by summing the spectrum of a second long *BeppoSAX* observation of ∼300 ks with that of the previous shorter observation of ∼130 ks. The two observations both confirm the presence of nonthermal HXR radiation from the cluster in excess of the thermal emission measured by the Medium-Energy Concentrator/Spectrometer (MECS) in the energy range ∼2–10 keV. Throughout this Letter we assume a Hubble constant of $H_0 = 70$ km s^{-1} Mpc^{-1} h_{70} and $q_0 = \frac{1}{2}$, so that an angular distance of 1′ corresponds to 65.7 kpc

[1] Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF/Roma), INAF, via del Fosso del Cavaliere, I-00133 Rome, Italy; dario@rm.iasf.cnr.it.
[2] IASF/Bologna, INAF, via Gobetti 101, I-40129 Bologna, Italy; landi@bo.iasf.cnr.it, orlandini@bo.iasf.cnr.it.
[3] Dipartimento di Fisica, Università di Bologna, Viale C. Berti Pichat 6/2, I-40127 Bologna, Italy.

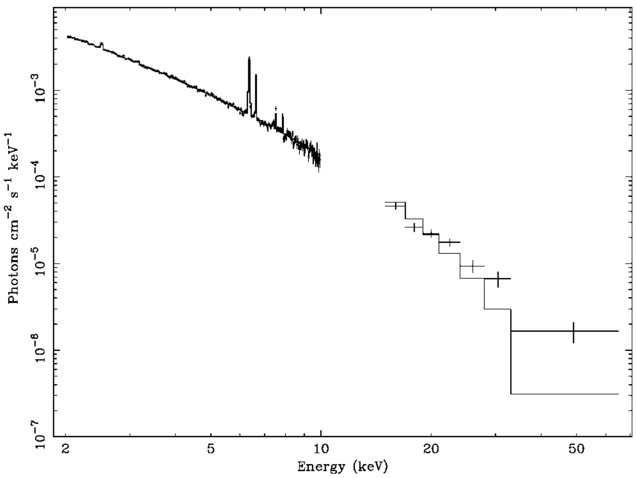

FIG. 1.—MECS and PDS data of A2256. The solid line represents a thermal component (MEKAL code) at the average cluster gas temperature of 7.65 ± 0.17 keV in the central circular region of 8′ in radius. The errors bars are quoted at the 1 σ level.

($z_{\rm A2256} = 0.0581$; Strubble & Rood 1991). Quoted confidence intervals are at 90% confidence level (c.l.), if not otherwise specified.

2. PDS DATA REDUCTION AND RESULTS

A2256 was observed for the first time in 1998 February and then in 1999 February for a total of ∼130 ks (observation 1 [OBS1]) and reobserved in 2001 July for ∼300 ks (observation 2 [OBS2]). The pointing coordinates of *BeppoSAX* are at $\alpha = 17^{\rm h}03^{\rm m}58\overset{\rm s}{.}3$, $\delta = +78°38'31''$ (J2000). The total effective exposure times of the PDS in the two observations were 70.1 and 190.3 ks, respectively. The PDS spectra of both the observations were extracted using the XAS version 2.1 package (Chiappetti & dal Fiume 1997). The background sampling was performed by making use of the default rocking law of the two PDS collimators that samples ON/+OFF, ON/−OFF fields for each collimator with a dwell time of 96 s (Frontera et al. 1997). When one collimator is pointing on-source, the other collimator is pointing toward one of the two off positions. We used the standard procedure to obtain PDS spectra (dal Fiume et al. 1997).

For both OBS1 and OBS2 the +OFF and −OFF count rate spectra are consistent with each other, with differences equal to $(2.7 \pm 3.3) \times 10^{-2}$ and $(3.3 \pm 1.8) \times 10^{-2}$ counts s^{-1} in the two observations, respectively. The marginal evidence (below 2 σ) for the presence of contaminating sources in the +OFF field in OBS2 implies that we consider the average of the two background measurements in order to have a more conservative determination of the confidence level of the excess with respect to the thermal emission. The background level for OBS1 is 19.50 ± 0.03 counts s^{-1} in the 15–100 keV energy range, and that for OBS2 is 16.68 ± 0.01 counts s^{-1}.[4] We have examined the presence of the instrumental background residual reported in RM04, obtained by these authors analyzing the spectra of 15 "blank fields." This residual is instead not found by NE04. We started from the complete sample of 868 PDS pointings with galactic latitude $|b| > 15°$ and selected the 15–100 keV net count spectra for which there is source detection below 1 σ (i.e., blank fields). We summed together these spectra (with a total exposure of ∼2.4 Ms), imposing a net exposure greater than 10 ks, and found a net count rate of $(0.66 \pm 3.29) \times 10^{-3}$ counts s^{-1}, consistent with the definition of blank field (see details in Landi 2005). We have then investigated the possible systematic differences between the two background fields ±OFF. RM04 analyze 69 observations chosen only on the base of a long exposure and high galactic latitude. They find that the mean value $\langle(-{\rm OFF}) - (+{\rm OFF})\rangle$ is significantly different from zero. Analyzing a larger sample, NE04 report evidence of a systematic instrumental residual that cancels out in the standard usage of both offsets. In agreement with NE04, our analysis on the *whole* sample of PDS observations gives a value of $(5.3 \pm 6.3) \times 10^{-3}$ counts s^{-1}, consistent with no contamination at all. Finally, using our PDS blank field sample, we examined the possibility of a point-source fluctuation ($\sigma_{\rm fluc}$) that is not significantly detected between the offsets. The resulting value $\sigma^2_{\rm fluc} = (9.5 \pm 10.3) \times 10^{-4}$ (counts s^{-1})^2 is consistent with that in NE04. Since the value is also consistent with zero, we assume in the following that this background component is absent in A2256 observations.

[4] The ∼20% variation in the PDS background is due to the *BeppoSAX* orbital decay: the lower orbit for OBS2 increased the shielding to ambient particles, therefore lowering the diffuse background.

2.1. *Spectral analysis*

In Figure 1 we report the PDS and MECS spectra obtained by summing the spectra of the two observations. The PDS background-subtracted combined count rate is 0.154 ± 0.011 counts s^{-1} in the 15–100 keV energy range at the confidence level of ∼14 σ. The PDS data of the first observation has been reanalyzed using the same procedure utilized for the second longer observation. The MECS spectrum is in the range ∼2–10 keV obtained from a circular region of 8′ corresponding to about 0.5 Mpc centered on the primary emission peak. The *ROSAT* PSPC radial profile indicates that ∼70% of the total cluster emission falls within this radius (see Fusco-Femiano et al. 2000 for details regarding MECS data reduction, the cross-correlation between MECS and PDS, and results for only OBS1). The total exposure time is 386.4 ks. The spectral analysis of the MECS data alone gives a temperature of $kT = 7.57^{+0.19}_{-0.14}$ keV using the MEKAL code on the XSPEC package, while the simultaneous fit to the MECS and PDS data gives 7.65 ± 0.17 keV (the MECS and PDS normalizations are treated as free parameters). This value of the temperature is consistent with the measurements of *Ginga* (7.32–7.70 keV; Hatsukade 1989) with a field of view comparable to that of the PDS, *Einstein* MPC (6.7–8.1 keV; David et al. 1993), *ASCA* GIS (6.78–7.44 keV; Henriksen 1999), and with the more recent joint analysis of *ASCA* and *RXTE* (PCA and HEXTE) data (7.66 ± 0.12 keV; Rephaeli & Gruber 2003). *Chandra* has reported several emission regions giving evidence of the presence of a merger event (Sun et al. 2002). These detections show temperature variations with a mean value of 6.7 ± 0.2 keV in the central $8\overset{\prime}{.}3$ square. Also, the flux of ∼5.4×10^{-11} ergs cm^{-2} s^{-1} in the 2–10 keV energy range measured by *BeppoSAX* is consistent with previous observations. The iron abundance is $0.29^{+0.01}_{-0.03}$, in agreement with the *ASCA* results (Markevitch & Vikhlinin 1997).

The presence of an excess with respect to the thermal emission in the spectrum of A2256 is evidenced (1) by the fit to the PDS data alone in the 15–80 keV energy range with a thermal component that determines a temperature of $14.6^{+4.3}_{-3.2}$ keV well above the average gas temperature given by *Ginga* in the interval 7.32–7.70 keV (David et al. 1993); (2) by the fit to the PDS data alone with a bremsstrahlung component at the fixed temperature of 7.6 keV, derived by the MECS data alone, that gives an

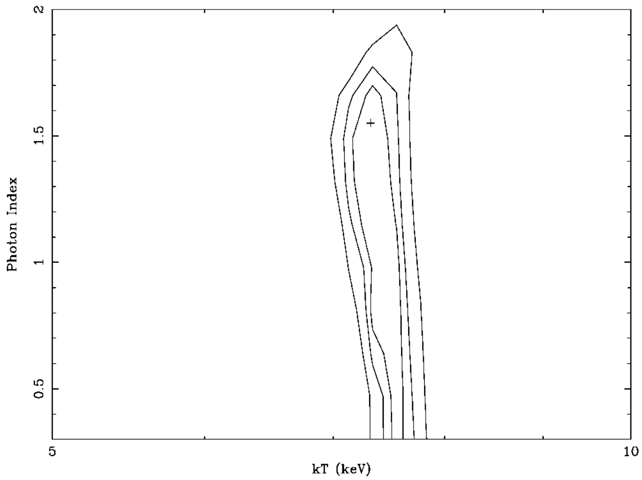

Fig. 2.—Confidence contours of a thermal and a nonthermal component (MEKAL and POW codes in XSPEC) at the 68%, 90%, and 99% confidence levels using the MECS and PDS data.

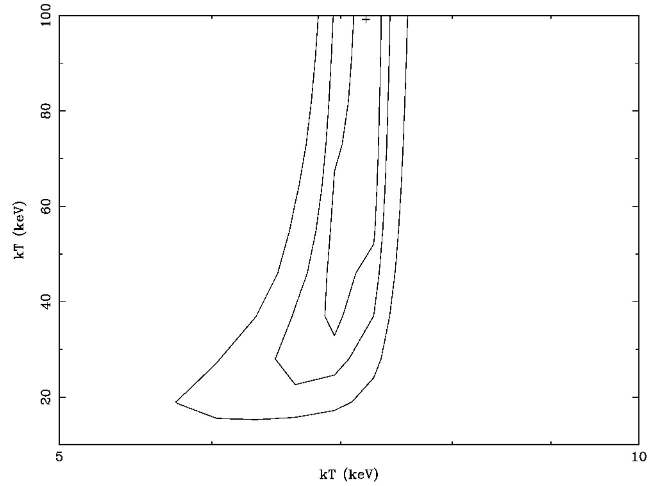

Fig. 3.—Confidence contours of two thermal components (MEKAL and BREM codes in XSPEC) at the 68%, 90%, and 99% confidences level using the MECS and PDS data.

unacceptable χ^2-value of 3.96 ($=$31.69/8 degrees of freedom [dof]). The nonthermal nature of this excess results from fitting the PDS data with two thermal components, one of these at the fixed temperature of 7.6 keV. For the second component we obtain an unrealistic temperature greater than ~30 keV. In the joint MECS and PDS data analysis the introduction of a second nonthermal component, modeled as a power law, allows us to obtain an improvement of the χ^2-value that is significant at more than the 99.99% confidence level, according to the *F*-test (198.51/175 dof vs. 176.96/173 dof). The presence of the nonthermal component has the effect of slightly decreasing the best-fit value of the temperature (7.32 ± 0.18 keV) with respect to the temperature obtained by considering only the MECS data. The confidence contours of the parameter *kT* and photon spectral index (α_X) show that, at a 90% confidence level, the temperature is well determined, 7.1–7.7 keV, while α_X describes a large interval of 0.3–1.8 (see Fig. 2). The contribution of the nonthermal component to the thermal flux in the 2–10 keV energy range is $\lesssim$10% for $\alpha_X \leq 1.8$. In the 20–80 keV energy band the excess with respect to the thermal component derived from the MECS and PDS data is at a level of ~4.8 σ (see Table 1) considering the average of the two background measurements. The uncertainties in the thermal flux prediction, reported in Table 1, are obtained considering the variations of the gas temperature in the 90% c.l. range that imply variations of ~0.1 σ for the level of the nonthermal excess. The flux of the nonthermal component, $8.9^{+4.0}_{-3.6} \times 10^{-12}$ ergs cm^{-2} s^{-1} in the 20–80 keV energy range, is obtained by fixing the photon spectral index (α_X) at the best-fit value of ~1.5. The flux error is derived by varying the PDS normalization within the 90% c.l. range. The two separate observations OBS1 and OBS2 show a hard excess of ~3.3 σ and ~3.7 σ, respectively, and the nonthermal fluxes are consistent with each other (see Table 1). The difference in the confidence level of the excess between that shown here for OBS1 and the one presented in Fusco-Femiano et al. (2000) is mainly due to a more conservative procedure for the background subtraction and for the bad events' rejection of the PDS data (details in Landi 2005).

3. DISCUSSION

The combined spectrum of two *BeppoSAX* observations performed with a time interval of ~2.5 yr confirms the presence in A2256 of a nonthermal HXR component in excess of the thermal emission at an ~4.8 σ confidence level. The nonthermal flux of ~9×10^{-12} ergs cm^{-2} s^{-1} in the energy range 20–80 keV is consistent with the published value of the first *BeppoSAX* observation, ~1.2×10^{-11} ergs cm^{-2} s^{-1} (Fusco-Femiano et al. 2000). The joint data analysis of *RXTE*/PCA and HEXTE and *ASCA*/GIS and SIS observations (Rephaeli & Gruber 2003) yields evidence of two components in the spectrum. The secondary component can be either thermal with a low gas temperature, *kT* ~ 1.5 keV, or a power law with a photon index of ~2.2 with a nonthermal flux in the 90% confidence error interval of (0.3–10) $\times 10^{-12}$ ergs cm^{-2} s^{-1} consistent with our detection. The confidence contours of two thermal components performed using the MECS and PDS data (see Fig. 3) confirm the nonthermal origin for the second component in the spectrum of A2256. At the 90% c.l. the temperature value of the secondary feature must be greater than ~20 keV. The hottest regions of the

TABLE 1
Nonthermal HXR Excess in the 20–80 keV Energy Range

Observation	Epoch	PDS Exposure (ks)	T[a] (keV)	Observed Rate (10^{-2} counts s^{-1})	Predicted Rate (10^{-2} counts s^{-1})	Excess (c.l.)	Flux[b] (10^{-12} ergs cm^{-2} s^{-1})
1	1998/1999 Feb	70.1	$7.43^{+0.27}_{-0.21}$	10.630 ± 1.854[c]	$4.485^{+0.195}_{-0.083}$[c]	3.3 σ	$9.5^{+7.8}_{-5.9}$
2	2001 Jul	190.3	7.67 ± 0.21	8.324 ± 1.004	$4.649^{+0.170}_{-0.146}$	3.7 σ	$8.0^{+4.4}_{-4.1}$
Combined		260.4	7.65 ± 0.17	8.944 ± 0.888	$4.628^{+0.154}_{-0.126}$	4.8 σ	$8.9^{+4.0}_{-3.6}$

Note.—Quoted errors for the observed count rates are at 1 σ.
[a] Derived from the joint analysis of the MECS and PDS data.
[b] A photon index of 1.5 was used to derive the flux (see text for details).
[c] In agreement with the value derived by NE04.

cluster shown by the *Chandra* temperature map are at the level of ∼9 keV (Sun et al. 2002). The combined spectrum also confirms the upper limit of 1.8 for the HXR photon index reported in the first data analysis of OBS1 (Fusco-Femiano et al. 2000).

As stated in § 1, we cannot exclude a significant contamination by obscured sources located in the PDS FOV able to simulate the nonthermal flux detected in Coma and A2256, but so far the observations do not seem to support this interpretation. The most likely interpretation is IC emission by the relativistic electrons responsible for the radio diffuse emission present in both the clusters. An extended radio emission (halo) permeates the center of A2256 with a steep radio spectral index of ∼1.8–2.0 (Bridle & Fomalont 1976; Rengelink et al. 1997). This region could be responsible for the second component that was noted by Markevitch & Vikhlinin (1997) in their spectral analysis of the *ASCA* data in the central $r = 3'$ spherical bin. Their best-fit favors a power-law model with a photon index of 2.4 ± 0.3, and therefore a nonthermal component may be present in the soft region of the X-ray spectrum (for details, see Fusco-Femiano et al. 2000). Instead, the probable source of the nonthermal HXR emission detected by *BeppoSAX*, in the framework of the IC model, may be the large and bright relic in the northwest region of the cluster at a distance of ∼7′ from the cluster center. The extent of this relic is estimated to be ∼1.0 × 0.6 Mpc with a rather uniform spectral index of 0.8 ± 0.1. This low value of the radio spectral index indicates a broad reacceleration region, probably the result of the ongoing merger event that is due to a subcluster shown by the X-ray observations. In particular, the *Chandra* X-ray image reported in Figure 1 of Sun et al. (2002) shows that the connection of the northwest radio relic with the ongoing merger event seems to be very likely. The merger is probably still at the early stage (Briel & Henry 1994) and seems to be confirmed by the temperature variations across the cluster, which are not as strong as those expected in a major merger. This phase of the merger event may explain the nonthermal HXR and radio synchrotron emissions that are expected only in clusters with a recent or current injection of relativistic electrons because of their rather short lifetimes due to radiative losses. In the hypothesis that the northwest relic is the source of the nonthermal HXR flux, the *BeppoSAX* observations allow us to derive a uniform magnetic field of ∼0.05 μG ($\alpha_R = 0.8$) in the radio region. Instead, in the central radio halo a uniform magnetic field of ∼0.5 μG ($\alpha_R = 1.8$) is derived, assuming a reasonable contribution of ∼5%–10% by the power-law component detected by *ASCA* to the total X-ray flux in the 2–10 keV energy range (Markevitch & Vikhlinin 1997). Further evidence that the origin of the nonthermal HXR radiation detected by *BeppoSAX* is probably not due to the central radio halo seems to be given by the inconsistency between the observed radio index ($\alpha_R = 1.8$), which implies a photon index $\alpha_X = 1 + \alpha_R = 2.8$, and the upper limit of the nonthermal HXR slope of 1.8 (see Fig. 2).

We wish to thank L. Feretti for her critical reading of the Letter, F. Frontera for his contribution to the PDS data analysis, and the referee J. Nevalainen for very useful suggestions.

REFERENCES

Bridle, A. H., & Fomalont, E. B. 1976, A&AS, 52, 107
Briel, U. G., & Henry, J. P. 1994, Nature, 372, 439
Brunetti, G., Setti, G., Feretti, L., & Giovannini, G. 2001, MNRAS, 320, 365
Chiappetti, L., & dal Fiume, D. 1997, in Proc. Fifth Workshop, Data Analysis in Astronomy, ed. V. Di Gesu et al. (Singapore: World Scientific), 101
dal Fiume, D., Frontera, F., Nicastro, L., Orlandini, M., Palazzi, E., Costa, E., Feroci, M., & Zavattini, G. 1997, in Proc. Fifth Workshop, Data Analysis in Astronomy, ed. V. Di Gesu et al. (Singapore: World Scientific), 111
David, L. P., Slyz, A., Jones, C., Forman, W., & Vrtilek, S. D. 1993, ApJ, 412, 479
Ensslin, T., Lieu, R., & Biermann, P. L. 1999, A&A, 344, 409
Feretti, L., Fusco-Femiano, R., Giovannini, G., & Govoni, F. 2001, A&A, 373, 106
Frontera, F., Costa, E., dal Fiume, D., Feroci, M., Nicastro, L., Orlandini, M., Palazzi, E., & Zavattini, G. 1997, A&AS, 122, 357
Fujita, Y., Takizawa, M., & Sarazin, C. L. 2003, ApJ, 584, 190
Fusco-Femiano, R., et al. 2000, ApJ, 534, L7
Fusco-Femiano, R., dal Fiume, D., Feretti, L., Giovannini, G., Grandi, P., Matt, G., Molendi, S., & Santangelo, A. 1999, ApJ, 513, L21
Fusco-Femiano, R., Dal Fiume, D., Orlandini, M., Brunetti, G., Feretti, L., & Giovannini, G. 2001, ApJ, 552, L97
Fusco-Femiano, R., dal Fiume, D., Orlandini, M., de Grandi, S., Molendi, S., Feretti, L., Grandi, P., & Giovannini, G. 2003a, in ASP Conf. Ser. 301, Matter and Energy in Clusters of Galaxies, ed. S. Bowyer & C.-Y. Hwang (San Francisco: ASP), 109
Fusco-Femiano, R., Orlandini, M., Brunetti, G., Feretti, L., Giovannini, G., Grandi, P., & Setti, G. 2004, ApJ, 602, L73
Fusco-Femiano, R., Orlandini, M., De Grandi, S., Molendi, S., Feretti, L., Giovannini, G., Bacchi, M., & Govoni, F. 2003b, A&A, 398, 441
Govoni, F., Markevitch, M., Vikhlinin, A., VanSpeybroeck, L., Feretti, L., & Giovannini, G. 2004, ApJ, 605, 695
Gruber, D. E., & Rephaeli, Y. 2002, ApJ, 565, 877
Hasinger, G., et al. 2001, A&A, 365, L45
Hatsukade, I. 1989, Ph.D. thesis, Osaka Univ.
Henriksen, M. 1999, ApJ, 511, 666
Kaastra, J. S., Bleeker, J. A. M., & Mewe, R. 1998, Nucl. Phys. B, 69, 567
Landi, R. 2005, Ph.D. thesis, Bologna Univ.
Molnar, S. M., Hughes, J. P., Donahue, M., & Joy, M. 2002, ApJ, 573, L91
Markevitch, M., & Vikhlinin, A. 1997, ApJ, 474, 84
———. 2001, ApJ, 563, 95
Matt, G., et al. 1999, A&A, 341, L39
Nevalainen, J., Oosterbroek, T., Bonamente, M., & Colafrancesco, S. 2004, ApJ, 608, 166 (NE04)
Petrosian, V. 2003, in ASP Conf. Ser. 301, Matter and Energy in Clusters of Galaxies, ed. S. Bowyer & C.-Y. Hwang (San Francisco: ASP), 337
Rephaeli, Y., & Gruber, D. E. 2002, ApJ, 579, 587
———. 2003, ApJ, 595, 137
Rephaeli, Y., Gruber, D. E., & Blanco, P. 1999, ApJ, 511, L21
Rengelink, R. B., Tang, Y., de Bruyn, A. G., Miley, G. K., Bremer, M. N., Röttgering, H. J. A., & Bremer, M. A. R. 1997, A&AS, 124, 259
Rossetti, M., & Molendi, S. 2004, A&A, 414, L41 (RM04)
Sarazin, C. L., & Kempner, J. C. 2000, ApJ, 533, 73
Strubble, M. F., & Rood, H. J. 1991, ApJS, 77, 363
Sun, M., Murray, S. S., Markevitch, M., & Vikhlinin, A. 2002, ApJ, 565, 867
Tribble, P. C. 1993, MNRAS, 261, 57