**CHANDRA REVEALS GALAXY CLUSTER WITH THE MOST MASSIVE NEARBY COOLING CORE: RXC J1504.1–0248**

H. Böhringer, V. Burwitz, Y.-Y. Zhang, P. Schuecker, and N. Nowak  
Max-Planck-Institut für extraterrestrische Physik, D-85741 Garching, Germany

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**ABSTRACT**

A *Chandra* follow-up observation of an X-ray–luminous galaxy cluster with a compact appearance, RXC J1504.1–0248, discovered in our REFLEX Cluster Survey, reveals an object with one of the most prominent cluster cooling cores. A β-model fit to the X-ray surface brightness profile gives a core radius of ~30 h_70^{-1} kpc, which is much smaller than the cooling radius with ~140 kpc. As a consequence, more than 70% of the high X-ray luminosity of L_xbol = 4.3 × 10^{45} h_70^{-1} ergs s^{-1} of this cluster is radiated inside the cooling radius. A simple modeling of the X-ray morphology of the cluster leads to a formal mass deposition rate within the classical cooling flow model of 1500–1900 \( M_\odot \) yr\(^{-1} \) (for \( h_{100} = 0.7 \); 2300–3000 \( M_\odot \) yr\(^{-1} \) for \( h_{100} = 0.5 \)). The center of the cluster is marked by a giant elliptical galaxy, which is also a known radio source. Thus, it is very likely that we are observing one of the interaction systems where the central cluster active galactic nucleus (AGN) is heating the cooling core region in a self-regulated way to prevent a massive cooling of the gas, similar to several such cases studied in detail in more nearby clusters. The interest raised by this system is then due to the high power recycled in RXC J1504–0248 over cooling timescales, which is about 1 order of magnitude higher than what occurs in the studied, nearby cooling core clusters. The assumption that cooling is exactly balanced by the AGN heating implies a central black hole mass growth rate of the order of 0.5 \( M_\odot \) yr\(^{-1} \). This cluster is therefore a prime target for the study of AGN–intracluster medium interaction at very extreme conditions. Further features common to cooling cores found in this cluster are a strong temperature drop toward the center and narrow, low-ionization emission lines in the central cluster galaxy. The cluster is also found to be very massive, with a global X-ray temperature of about 10.5 keV and a total mass of about 1.7 × 10^{15} h_70^{-1} M_\odot inside 3 h_70^{-1} Mpc.

**Subject headings:** cooling flows — galaxies: clusters: general — galaxies: clusters: individual (RXC J1504.1–0248) — X-rays: galaxies: clusters

1. INTRODUCTION

One of the currently most debated questions concerning the structure of the X-ray–luminous, hot intracluster plasma of clusters of galaxies is the consequence of the small cooling time of this plasma in those clusters with dense central cores (e.g., Fabian 1994). *XMM-Newton* X-ray spectroscopy has shown that, in spite of its short cooling time, the gas is not cooling at the high expected rates in the absence of heating processes (e.g., Peterson et al. 2001, 2003; Matsushita et al. 2002; Böhringer et al. 2002; Molendi 2002). The most popular scenario that allows for a self-regulated heating of the hot plasma in cluster cooling cores and prevents massive cooling is the heating of the intracluster medium (ICM) by the jets and radio lobes of the active galactic nucleus (AGN) in the central cluster galaxies (e.g., Churazov et al. 2000, 2001; McNamara et al. 2000; David et al. 2001; Fabian 2003; Forman et al. 2005). It was shown that this interaction provides enough power in many nearby cooling flows to at least balance cooling. For example, the current kinetic energy output of the inner radio lobes in M87 in the Virgo Cluster and NGC 1275 in the Perseus Cluster has estimated values of ~10^{44} and ~10^{45} ergs s^{-1}, respectively, in both these cases about an order of magnitude higher than the cooling power in the cooling core (Churazov et al. 2000, 2004; Birzan et al. 2004). Recently, further very deep and detailed X-ray observations have given some insight into the details of the heating process, which is proposed to occur through the dissipation of sound waves set off by the interaction of the radio lobes with the ICM (Fabian 2003) or by shock fronts (Forman et al. 2005; Nulsen et al. 2005a, 2005b; McNamara et al. 2005). A promising picture seems to be emerging in which the recycling of AGN energy with powers of the order of 10^{44}–10^{45} ergs s^{-1} in cluster cooling cores of nearby clusters could explain the observed phenomena.

Searching through larger volumes of our universe, more extreme cases of cluster cooling cores can be found where the rate of AGN energy recycling is even higher by up to an order of magnitude. The cluster with the largest cooling core detected so far, RXC J1347.5–1144 at \( z = 0.4516 \), was discovered in the ROSAT-ESO Flux-Limited X-Ray (REFLEX) survey (Schindler et al. 1995; Böhringer et al. 2004b), with a formally derived cooling flow mass deposition rate of the order of 3000 \( M_\odot \) yr\(^{-1} \) (for a Hubble constant of \( H_0 = 50 \) km s\(^{-1} \) Mpc\(^{-1} \)). Schindler et al. 1997; Allen 2000), which corresponds to an energy dissipation of \( \sim 10^{46} \) ergs s\(^{-1} \). This cluster is unfortunately much more distant than the well-studied nearby clusters and does not lend itself easily to a detailed observational study. We have now discovered a more nearby, similarly striking, massive cooling core cluster in the REFLEX Survey, RXC J1504.1–0248, at a redshift of \( z = 0.2153 \). This cluster was flagged as a cluster candidate due to a galaxy overdensity detected in the COSMOS database (MacGillivray & Stobie 1984), and six concordant galaxy redshifts found in our subsequent follow-up observations confirmed the existence of a cluster. Three of these cluster galaxies show AGN-like spectra.

Serious doubts remained about the cluster identification of this X-ray emitter, because the X-ray source appeared much too compact for its high luminosity, compared to the other clusters in the REFLEX sample in the same distance and luminosity range. This could possibly be attributed to a contaminating central AGN. The certain identification clearly required a higher resolution
X-ray observation, which could recently be made through a Chandra snapshot exposure yielding a perfect cluster image without significant contamination by point sources (Fig. 1). With these source properties, it becomes immediately clear that RXC J1504.1–0248 must have an extremely bright core and is potentially a very interesting cooling core cluster.

In this paper we study the structure of this cluster in more detail. In §§ 2 and 3 we present the observational results. Section 4 is devoted to the modeling of the mass profile and the determination of the parameters in the frame of a classical cooling flow model. In § 5 we discuss further phenomenological features related to the cooling core of the cluster, and § 6 provides the conclusion. We adopt a cosmological model with \( \Omega_m = 0.3, \Omega_{\Lambda} = 0.7, \) and \( H_0 = 70 \) km s\(^{-1}\) Mpc\(^{-1}\), unless noted otherwise. Thus, 1' at the distance of RXC J1504–0248 corresponds to 209 kpc.

### 2. OBSERVATION AND DATA PREPARATION

RXC J1504.1–0248 was observed with the Chandra ACIS-I on 2004 January 7 for 13,463 s. The observation was hardly disturbed by times of high background, and the net exposure after standard cleaning procedures is 13,298 s. Figure 2 shows an image of the cluster in the 0.5–2 keV energy band superposed on an optical R-band image taken as a 5 minute exposure in our REFLEX redshift survey at the European Southern Observatory (ESO) La Silla 3.6 m telescope. The total ACIS-I count rate in the region \( r \leq 6' \) in the 0.5–2 keV band is 2.03 counts s\(^{-1}\), implying an unabsorbed flux of about 1.18 and 1.9 \( \times 10^{-11} \) ergs s\(^{-1}\) cm\(^{-2}\) in the 0.5–2 and 0.1–2.4 keV energy bands, respectively. In the Röntgensatellit (ROSAT) All-Sky Survey we found a flux of 2.2 \( \pm 0.11 \) \( \times 10^{-11} \) ergs s\(^{-1}\) cm\(^{-2}\) in the 0.1–2.4 keV band within an aperture of 12' radius, in reasonable agreement with the new results from the much deeper image.

The X-ray cluster center coincides well with a central dominant galaxy that can be identified with LCRS B150131.5–023636 at the J2000.0 position R.A. = 15°04′07″, decl. = −02°48′16″ at \( z = 0.216917 \) (Shechtman et al. 1996). The optical image of the cluster and the spectrum of the galaxy B150131.5–023636 described in § 5 have been obtained with EFOSC2 at the 3.6 m telescope of ESO La Silla on 2001 August 14 and 20, respectively.

### 3. ANALYSIS AND RESULTS

The above noted fluxes imply an X-ray luminosity of \( L_X = 2.3 \times 10^{45} \) \( h_{70}^{-1} \) ergs s\(^{-1}\) in the 0.1–2.4 keV band and a bolometric X-ray luminosity of \( L_X = 4.3 \times 10^{55} \) \( h_{70}^{-1} \) ergs s\(^{-1}\). This makes this cluster the most prominent X-ray–luminous cluster in the southern sky at redshifts below \( z = 0.34 \), with only two galaxy clusters at larger distances in the REFLEX catalog having a higher X-ray luminosity. The X-ray image in Figure 1 shows a high degree of regularity, with a slightly elliptical shape and a major axis approximately along a position angle of about 40° (north to east). As seen in Figure 2, the center of the X-ray emission is marked by a dominant giant galaxy in the optical.

The azimuthally averaged X-ray surface brightness profile from which the background was subtracted is well described by a \( \beta \)-model out to a radius of about 300″, outside of which the background subtraction uncertainties become significant (Fig. 3). The background was estimated either from the outer region of the CCD or from an external background field. Remarkable is the small core radius of \( r_c \sim 30 h_{70}^{-1} \) kpc and the high central gas density of \( n_{e0} \sim 0.16 h_{70}^{1/2} \) cm\(^{-3}\). The slope parameter, \( \beta \), has the very typical value of 0.6.

The temperature profile was determined by fitting a spectral Mewe-Kaastra-Liedahl (MEKAL) model with fixed Galactic absorption with a column density of 6 \( \times 10^{20} \) cm\(^{-2}\) (as measured from 21 cm observations;Dickey & Lockman 1990) to the spectra obtained from the photons extracted from concentric rings around the cluster center. The background for subtraction was taken either from a background region at the outer parts of the...
detector (radial zone 3′/8–5′7) or from a background field in the same rings as taken for the target spectral extraction. Since there is some faint X-ray emission from the cluster almost throughout the entire detector, the on-target background subtraction prevents an accurate temperature determination at larger radii. Figure 4 provides a comparison of both methods, showing that the two approaches yield practically identical results out to a radius of 1′, but the analysis based on an external background field can be extended to a radius of 3′. While the bulk temperature of the cluster is about 10.5 keV, we note a strong temperature drop toward the center to a value below 5 keV. Such a temperature drop by a factor of 2 or 3 is observed in many cooling core clusters (e.g., De Grandi & Molendi 2002; Fabian 2003; Ikebe et al. 2004). A possible temperature drop to larger radii indicated by the data cannot be established with the present photon statistics. Figure 5 shows the spectrum of the innermost circle (0′0–1′5′5). For the given photon statistics the spectrum is well fitted by a one-temperature MEKAL model. We do not note any features that could indicate the Fe L line complex observed at lower temperatures, which would indicate the presence of cooler temperature phases.

In Figure 4 we show three rough fits of analytic expressions to the temperature profile that were chosen to approximately bracket the inner and outer gradients of the temperature profile. The analytical expressions are

\[ T_1(\text{keV}) = \begin{cases} 
3.5 +0.44r^{0.9} - 0.044r^{1.4} + 0.007r^2 & \text{for } r < 150, \\
11.076 - 0.00544r & \text{for } r > 150,
\end{cases} \]

\[ T_2(\text{keV}) = \begin{cases} 
3.0 +0.305r^{0.9} - 0.0192r^{1.4} & \text{for } r < 100, \\
9.80 + 0.003322r & \text{for } r > 100,
\end{cases} \]

\[ T_3(\text{keV}) = \begin{cases} 
3.5 +0.52r^{0.9} - 0.0526r^{1.4} + 0.00083r^2 & \text{for } r < 150, \\
12.932 - 0.001364r & \text{for } r > 150,
\end{cases} \]

where the radius, \( r \), is in units of arcseconds.

The spectral fits also indicate abundances of heavy elements (dominated by the fit to the Fe K line) of about 0.3–0.4 solar with large errors of about 0.1–0.2 in solar units (abundances based on Anders & Grevesse 1989). To our surprise we do not find a strong increase of the iron abundance toward the center, as seen in many cooling flow clusters (De Grandi & Molendi 2001; Böhringer et al. 2004a), but a deeper observation is necessary to draw a firm conclusion.

4. MODELING THE CLUSTER STRUCTURE

4.1. Mass Profile

From an analytical deprojection of the \( \beta \)-model fit to the X-ray surface brightness profile of the cluster and the temperature profile, we can obtain the cluster mass profile under the assumption of hydrostatic equilibrium and spherical symmetry. The resulting mass profile is shown in Figure 6 together with the profile of the gas mass, as derived from the \( \beta \)-model fit. For the gravitational mass profile we also indicate the typical uncertainties determined from the local minima and maxima of the mass profile for the different analytical temperature fits shown in Figure 4. An additional scaling uncertainty of 15% for \( T_1 \) and \( T_2 \) and 5% for \( T_3 \) is included. At a radius of 3 \( h_70^{-1} \) Mpc the total mass is \( 1.8\times10^{15} h_70^{-1} \) M\(_\odot\). For the radius \( r_{200} = 2.3 \) Mpc we find a mass of \( 1.5\times10^{15} h_70^{-1} \) M\(_\odot\). Thus, RXC J1504–0248 is among the most massive clusters known. The gas-to-total
Fig. 6.—Gravitational mass profile of RXC J1504.1−0248 calculated for the three bracketing gas temperature profiles adopting a Λ-cosmological model with a Hubble constant of $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. The two dotted lines indicate the uncertainties determined from the local minima and maxima in the mass profiles from the three analytic fits to the temperature profile and their scaling uncertainties (see text). The dashed line is the gas mass profile calculated from the β-model.

mass ratio for the two fiducial radii is $0.17^{+0.03}_{-0.07}$ and $0.15^{+0.03}_{-0.05}$, respectively.

4.2. Cooling Flow Analysis

To gain an understanding of the processes occurring in the central ICM of this cluster we start with a classical cooling flow analysis (e.g., Fabian et al. 1984; Thomas et al. 1987). We take two approaches. For the more simple model A we equate the energy loss by radiation inside a given radius, $r$, with the enthalpy influx from outside through the sphere with radius $r$. In model B we formulate the energy balance in a local differential way and include the gain of gravitational energy of the material flowing in from the outer regions,

$$\dot{M}(r) = 4\pi r^2 \frac{\kappa^2 \Lambda(T) + [M(r + \Delta r)/\Delta r] \frac{T}{\Delta T} \frac{dM}{dr}}{T\Delta r + dT/dr} + \frac{M(r)G/r + \Phi/\Delta r}{},$$

where $\Lambda(T)$ is the cooling function normalized to the electron density squared, $\Delta r$ is the shell width in the numerical calcu-

Fig. 7.—Cooling time profile for the ICM in RXC J1504.1−0248 calculated for the three bracketing gas temperature profiles adopting an Einstein–de Sitter cosmological model with a Hubble constant of $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$.

Fig. 8.—Inferred mass flow rates assuming a conventional cooling flow model (solid curve: model A; dashed curve: model B, including gravitational energy gain) as a function of radius for an Einstein–de Sitter cosmological model with a Hubble constant of $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$. The vertical lines indicate the radius with a cooling time of $10^{10}$ yr and its uncertainty.

lation, $\Phi$ is the gravitational potential, and the other symbols have their usual meaning.

Figure 7 shows the cooling time as a function of the cluster radius. If we take the often used fiducial value of $10^{10}$ yr, we find a cooling radius of $140(\pm 5)$ kpc [for a Hubble constant of $h_{100} = H_0/(100$ km s$^{-1}$ Mpc$^{-1}) = 0.7$] and $165(\pm 5)$ kpc [for $h_{100} = 0.5$]. Here the uncertainty is determined from the minima and maxima for the different adopted fits to the temperature profile. Figure 8 then shows the mass flow rates determined for models A and B, and the cooling radius is indicated by vertical lines. For this adopted cooling radius we find mass flow rates of 1400 and 1900 $M_\odot$ yr$^{-1}$ (for $h_{100} = 0.7$) and 2300 and $2930 M_\odot$ yr$^{-1}$ (for $h_{100} = 0.5$) for models B and A, respectively.

These high formal cooling flow mass deposition rates make RXC J1504−0248 the most prominent cooling flow cluster next to the most luminous cluster known, RXC J1347−1144 at $z = 0.45$, for which a mass deposition rate of the order of $3000 M_\odot$ yr$^{-1}$ (for $h_{100} = 0.5$) was also deduced (Schindler et al. 1997; Allen 2000). This makes RXC J1504−0248 a very interesting target to study the cooling core phenomenon under the most extreme conditions.

5. DISCUSSION

In the new scenario of the physics of cooling core clusters, the large radiative cooling rates are compensated by the energy released from a central AGN (e.g., Churazov et al. 2000, 2001; McNamara et al. 2000; David et al. 2001; Böhringer et al. 2002; Fabian 2003; Forman et al. 2005). To keep the balance such that neither massive mass condensation nor a dispersion of the dense gaseous core occurs, the heating has to be fine-tuned. This is achieved by a self-regulation system in which large mass deposition rates in the center lead to an increased feedback from the AGN, which limits the cooling rate. Seen from the perspective of the central AGN, its accretion rate is limited by the amount of cooling that can occur, that is, the energy that can be dissipated by the ICM in the cooling core region (Churazov et al. 2002). In this cooling core scenario, a high radiative power of the central ICM indicates a fast accretion of the interacting AGN.

The case of RXC J1504−0248 is an extreme case in this scenario. Since the core radius is so small, actually much smaller than the cooling radius by a factor of about 4, the major part of
the total X-ray luminosity (about 72%) originates from inside the cooling radius. This corresponds to a total radiation power of $\sim 3 \times 10^{45}$ ergs s$^{-1}$. So far we have no direct indication that this cooling rate is balanced by AGN heating in this system. Some support for this scenario is discussed below. Assuming that the above-sketched cooling core scenario applies and that the observed cooling power inside the cooling radius is balanced by the energy output from the AGN, we can calculate further interesting system parameters. If the radiation power is replenished by accretion power from the AGN, and if we assume an energy return efficiency, $\eta = 0.1$, from accretion onto the AGN black hole, then we can imply an accretion rate of the order of $0.5 M_\odot$ yr$^{-1}$. Thus, in this mode the central black hole can gain a considerable mass of the order of the most massive black holes known over cosmic times.

Therefore it is very interesting to see if this scenario actually applies to RXC J1504—0248. So far the observational evidence is far less detailed, as the best observed nearby cooling core clusters and the implications indicated above remain very speculative. But the few additional features known point in the right direction. The central dominant galaxy is known to harbor a radio source with a brightness of 62 mJy at 1.4 GHz (Bauer et al. 2000), and thus it presumably contains a massive black hole. The radio source image obtained from the NRAO Very Large Array (VLA) Sky Survey is, however, unresolved and featureless. A zoom into the central region of the Chandra image (Fig. 9) shows indications of an asymmetric distortion that could be due to the interaction of the AGN jets with the ICM. Better photon statistics is needed to draw a more firm conclusion. Therefore deeper X-ray observations have been scheduled for Chandra, and a detailed VLA radio study has been proposed for this cluster.

The central dominant galaxy is extremely large. The Gunn $r$ magnitude of 16.4 determined in the Las Campanas Redshift Survey (Shectman et al. 1996) translates into an absolute magnitude of $M_r \sim -24$, which corresponds to about $3 \times 10^{11} L_\odot$ in this band. It places this galaxy in the upper few percent of the luminosity distribution of cluster central galaxies as found, for example, by comparison to the survey by Lauer & Postman (1994).

The optical spectrum of the central galaxy, shown in Figure 10, shows narrow, low-excitation emission lines, notably strong [O ii], [O iii] weaker than [O ii], and bright H$\alpha$/[N ii] lines, similar to what has been observed for many massive cooling flows (e.g., Hu et al. 1985; Johnstone et al. 1987; Heckman et al. 1989; Donahue et al. 1992; McNamara & O'Connell 1993; Crawford et al. 1999). This provides another hint that this cluster resembles a scaled-up version of the known nearby cooling core clusters.

A very similar spectrum has been observed and studied in detail in the central galaxy of the cooling core galaxy cluster A2597 by Voit & Donahue (1997). In the spectrum of A2597 the [O ii] line is even more dominant compared to the other lines. Voit & Donahue provide a very comprehensive discussion on the origin of this spectrum. They conclude that hot stars constitute the best-fitting source of ionization, but in order to match the spectral properties with a photoionization nebular model, an additional heat source has to be assumed that may well be the heating source of the cooling core. The same discussion most probably applies to this object also, but to perform the same analysis, a deeper spectroscopic observation is required in order to get accurate line fluxes for more diagnostic lines. Very similar spectra can also be found among the spectra compiled from central cluster galaxies by Crawford et al. (1999). It is very striking that the spectra that best match the spectrum of RXC J1504—0248 are those from the prominent well-known cooling flow clusters such as Z3146, A1835, A2204, and A2390. Overall these spectra show some variation in the degree of ionization, with [O ii] and [O i] lines being more prominent compared to [O iii] in Z3146 and [O iii] being relatively more prominent in A2390 than in the present case. But the close resemblance is very obvious. Within the classification scheme of AGN, the present observation features a low-ionization nuclear emission-line region (LINER) spectrum.

The equivalent width of the [O ii] line is about 151 $\pm$ 2.43 $\AA$, corresponding to a line flux of about $9 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$. Together with the total luminosity of the galaxy and the relation of [O ii] luminosity and star formation rate as given by Kennicutt (1992), we get formally a star formation rate of the order of about $50 M_\odot$ yr$^{-1}$. This is not untypical for a massive cooling core cluster (e.g., McNamara 1997). Since there are surely other ionization sources present, this simple modeling is certainly an oversimplification.
6. CONCLUSION

The Chandra observation reveals the X-ray source RXC J1504−0248 as a galaxy cluster that has extreme and surprising properties in two respects. It is found to be a very massive cluster and the most luminous cluster known in the southern sky at redshifts lower than $z \leq 0.3$. Second, the cluster appears extremely compact, with a very dense central region. Thus, the high X-ray luminosity is the result of both the large cluster mass and the high central density.

These properties would make the cluster a cooling flow with one of the largest mass deposition rates ever inferred. But the observation of a radio AGN in the cluster center and the absence of low-temperature signatures in the central X-ray spectrum leads us to suspect that the dense central ICM region is heated by the AGN, as is implied from the X-ray observations for nearby clusters. The heating source required in RXC J1504−0248 needs to have a power about an order of magnitude larger than that of the nearby well-studied cooling core clusters. This extreme energy recycling will surely make RXC J1504−0248 a very interesting object of study for many future investigations. This X-ray source has been accepted for observations with Astro-E2, which should, for example, provide insight into the degree of turbulence prevailing in the cooling core region.

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REFERENCES

Allen, S. W. 2000, MNRAS, 315, 269
Anders, E., & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Bauer, F. E., Condon, J. J., Thuan, T. X., & Broderick, J. J. 2000, ApJS, 129, 547
Birzan, L., Rafferty, D. A., McNamara, B. R., Wise, M. W., & Nulsen, P. E. J. 2004, ApJ, 607, 800
Böhringer, H., Matsushita, K., Churazov, E., Finoguenov, A., & Ikebe, Y. 2004a, A&A, 416, L21
Böhringer, H., Matsushita, K., Churazov, E., Ikebe, Y., & Chen, Y. 2002, A&A, 382, 804
Böhringer, H., et al. 2004b, A&A, 425, 367
Churazov, E., Brüggen, M., Kaiser, C. R., Böhringer, H., & Forman, W. 2001, ApJ, 554, 261
Churazov, E., Forman, W., Jones, C., & Böhringer, H. 2000, A&A, 356, 788
Churazov, E., Forman, W., Jones, C., Sunyaev, R., & Böhringer, H. 2004, MNRAS, 347, 29
Churazov, E., Sunyaev, R., Forman, W., & Böhringer, H. 2002, MNRAS, 332, 729
Crawford, C. S., Allen, S. W., Ebeling, H., Edge, A. C., & Fabian, A. C. 1999, MNRAS, 306, 857
David, L. P., Nulsen, P. E. J., McNamara, B. R., Forman, W., Jones, C., Ponman, T., Robertson, B., & Wise, M. 2001, ApJ, 557, 546
De Grandi, S., & Molendi, S. 2001, ApJ, 551, 153
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Donahue, M. E., Stocke, J. T., & Gioia, I. M. 1992, ApJ, 385, 49
Fabian, A. C. 1994, ARA&A, 32, 277
———. 2003, Rev. Mex. AA Ser. Conf., 17, 303
Fabian, A. C., Nulsen, P. E. J., & Canizares, C. R. 1984, Nature, 310, 733
Forman, W., et al. 2005, ApJ, in press (astro-ph/0312576)
Heckman, T. M., Baum, S. A., van Breugel, W. J. M., & McCarthy, P. 1989, ApJ, 338, 48
Hu, E. M., Cowie, L. L., & Wang, Z. 1985, ApJS, 59, 447
Ikebe, Y., Böhringer, H., & Kitayama, T. 2004, ApJ, 611, 175
Johnstone, R. M., Fabian, A. C., & Nulsen, P. E. J. 1987, MNRAS, 224, 75
Kennicutt, R. C. 1992, ApJ, 388, 310
Lauer, T. R., & Postman, M. 1994, ApJ, 425, 418
MacGillivray, H. T., & Stobie, R. S. 1984, Vistas Astron., 27, 433
Matsushita, K., Belsole, E., Finoguenov, A., & Böhringer, H. 2002, A&A, 386, 77
McNamara, B. R. 1997, in ASP Conf. Ser. 115, Galactic Cluster Cooling Flows, ed. N. Soker (San Francisco: ASP), 109
McNamara, B. R., Nulsen, P. E. J., Wise, M. W., Rafferty, D., Carilli, C., Sarazin, C. L., & Blanton, E. L. 2005, Nature, 433, 45
McNamara, B. R., & O’Connell, R. W. 1993, AJ, 105, 417
McNamara, B. R., et al. 2000, ApJ, 534, L135
Molendi, S. 2002, ApJ, 580, 815
Nulsen, P. E. J., Hambrick, D. C., McNamara, B. R., Rafferty, D., Birzan, L., Wise, M. W., & David, L. P. 2005a, ApJ, 625, L9
Nulsen, P. E. J., McNamara, B. R., Wise, M. W., & David, L. P. 2005b, ApJ, 628, 629
Peterson, J. R., Kahn, S. M., Paerels, F. B. S., Kaastra, J. S., Tamura, T., Bleeker, J. A. M., Ferrigno, C., & Jernigan, J. G. 2003, ApJ, 590, 207
Peterson, J. R., et al. 2001, A&A, 365, L104
Sanders, J. S., Fabian, A. C., Allen, S. W., & Schmidt, R. W. 2004, MNRAS, 349, 952
Schindler, S., Hattori, M., Neumann, D. M., & Böhringer, H. 1997, A&A, 317, 646
Schindler, S., et al. 1995, A&A, 299, L9
Shectman, S. A., Landy, S. D., Oemler, A., Tucker, D. L., Lin, H., Kirschner, R. P., & Schechter, P. L. 1996, ApJ, 470, 172
Thomas, P. A., Fabian, A. C., & Nulsen, P. E. J. 1997, MNRAS, 228, 973
Voit, G. M., & Donahue, M. 1997, ApJ, 486, 242