X-ray active galactic nuclei in the core of the Perseus cluster

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ABSTRACT
We present a study of the X-ray emission from the nuclei of galaxies observed in the core of the Perseus cluster in a deep exposure with Chandra. Point sources are found coincident with the nuclei of 13 early-type galaxies, as well as the central galaxy NGC 1275. This corresponds to all galaxies brighter than $M_B > -18$ in the Chandra field. All of these sources have a steep power-law spectral component and four have an additional thermal component. The unabsorbed power-law luminosities in the 0.5–7.0 keV band range from $8 \times 10^{38}$ to $5 \times 10^{40}$ erg s$^{-1}$. We find no simple correlations between the $K$-band luminosity, or the FUV and NUV AB magnitudes of these galaxies and their X-ray properties. We have estimated the black hole masses of the nuclei using the $K$-band $M_{BH} - L_{K bol}$ relation and again find no correlation between black hole mass and the X-ray luminosity. Bondi accretion on to the black holes in the galaxies with minihaloes should make them much more luminous than observed.

Key words: galaxies: clusters: individual: Perseus – X-rays: galaxies.

1 INTRODUCTION
X-ray observations with the Chandra observatory have enabled detailed studies to be made of the X-ray emission of early-type galaxies. The results show hot diffuse gas and low-mass X-ray binaries (LMXBs), many of which are associated with globular clusters (Sarazin, Irwin & Bregman 2001; Fabbiano & White 2003; Kim & Fabbiano 2004). The hot gas has a temperature of $10^7$ K and is not expected to survive in the cores of rich clusters of galaxies, where it should be rapidly depleted by stripping and/or conduction (Gunn & Gott 1972). However, small confined regions, of radius a few kpc, do survive in some early-type galaxies near the centres of rich clusters, as discovered in Chandra observations of the Coma cluster by Vikhlinin et al. (2001). Yamasaki, Ohashi & Furusho (2002) later found two small galaxy coronae in the centre of the A1060 cluster. Sun et al. (2005a) and Sun, Jerius & Jones (2005b) found four such X-ray minicoronae in A1367 and one in the Perseus cluster, respectively, and Fujita, Sarazin & Sivakoff (2006) found one in A2670. A systematic search for X-ray minihaloes in 157 early-type galaxies and 22 late-type galaxies in 25 hot, rich nearby clusters by Sun et al. (2007) yielded many more examples. From all these observations, the authors have concluded that the diffuse hot coronae are stripped off the galaxies in the cores of rich clusters of galaxies, but minihaloes remain at the centres of some galaxies. Such minihaloes have typical sizes of 1–3 kpc, gas densities of 0.1 cm$^{-3}$ or more and temperatures of about $10^7$ K.

Other studies include Finoguenov et al. (2004) who measured the X-ray luminosity function of galaxies in the Coma cluster using XMM–Newton, and Finoguenov & Miniati (2004) who studied the impact of high-pressure cluster environment on the X-ray luminosity of Coma galaxies. Chandra X-ray observations of galaxies in an off-centre region of the Coma cluster were done by Hornschemeier et al. (2006) to explore the X-ray properties and luminosity function of normal galaxies. They detected 13 galaxies. The X-ray activity is suppressed with respect to that of the field, indicating a lower level of X-ray emission for a given stellar mass.

Some nuclei of nearby early-type galaxies are active but often at a level well below that expected from Bondi accretion of the hot coronal gas (Fabian & Canizares 1988; Di Matteo et al. 2000, 2001, 2003; Pellegrini 2005). There are two possible explanations for the low luminosities of nearby black holes: (i) any accretion proceeds at extremely low rates or (ii) the accretion occurs at low radiative efficiencies as predicted, for example, by advection-dominated accretion flow (ADAF) models (e.g. Rees et al. 1982; Abramowicz et al. 1995; Narayan & Yi 1995) and by jet models (e.g. Allen et al. 2006).

Here, we study the X-ray point sources coincident with member galaxies in the Perseus cluster using a very deep, 900-ks, Chandra image. The Perseus cluster is the brightest cluster in the Sky in X-rays, which makes looking for faint or diffuse emission difficult, particularly in the core where our observations are best. In this paper, we have looked at X-ray point sources coincident with bright galaxies. We are interested here in the unresolved point sources with power-law spectra, coincident with the galactic nuclei, in order to assess the level of nuclear activity. Sun et al. (2007) have previously used the same Chandra image of the Perseus cluster, and Chandra images of several other clusters, to explore the incidence and general properties of minihaloes in cluster galaxies. Martini et al. (2006) found that 5 per cent of the galaxies brighter than $M_B < -20$ in rich clusters are active, with X-ray luminosity $L_X > 10^{41}$ erg s$^{-1}$. This is five times more than that found in optical spectroscopic studies by
Dressler, Thompson & Shectman (1985). Our results are consistent with all galaxies above that optical magnitude limit having detected central X-ray sources, albeit at lower luminosities.

This paper is organized as follows. In Section 2, we describe the data preparation, source detection and the X-ray spectral analysis. We compare the X-ray properties with the K-band luminosity, UV AB magnitude, radio and black hole mass in Section 3. In Section 4, we discuss our results and summarize them in Section 5.

2 DATA ANALYSIS

2.1 Observations

The 13 Chandra observations analysed here are detailed in Fabian et al. (2006). Each observation used the ACIS-S3 detector as the aim-point. The total maximum effective exposure time was 890 ks, after flares were removed. The level 2 event files were reprocessed with ACIS˙PROCESS˙EVENTS using the acisD2000-01-29gain˙ctiN0003.fits gain file, and reprojected to match the coordinate system of the 04952 observation.

The regions of the sky with the highest effective Chandra exposure time are shown in Fig. 1. The off-axis effective exposure decreases away from the centre of the ACIS-S3 CCD (which is the south-western part of the right-hand side region, with a total exposure time of 890 ks). In the north-eastern and north-western parts of the right-hand chip, the exposure times are 75 and 50 per cent of the maximum, respectively. The exposure time declines to 13 per cent of the maximum in the region indicated by source 13.

2.2 X-ray source detection

We found 49 X-ray sources by eye in the total Chandra 0.3–7 keV image. Of those sources, 13 have optical counterparts. The positions of these 13 sources and the nearest galaxy are listed in Table 1. The sources are split into six close to the central galaxy (detected on the central CCD) and seven farther away (detected by other CCDs). The remaining 36 sources without optical counterparts are shown in Table 2. We exclude these sources from the remainder of our analysis.

![Figure 1](https://example.com/chandra_sources.png)

**Figure 1.** Optical images of the detected X-ray sources from SDSS (numbered according to Table 1). The two regions with greater than 25 per cent of the maximum Chandra exposure time are shown by the black contour (each region measures 8 arcmin across).

| N  | RA       | Dec.     | Nearest galaxy name from NED (J2000) |
|----|----------|----------|--------------------------------------|
| 1  | 03°19′26″73 | +41°32′26″0 | NGC 1273                             |
| 2  | 03°19′40″57 | +41°32′55″2 | NGC 1274                             |
| 3  | 03°19′51″50 | +41°34′24″8 | NGC 1277                             |
| 4  | 03°19′54″13 | +41°33′48″4 | NGC 1278                             |
| 5  | 03°19′59″05 | +41°28′46″5 | NGC 1279                             |
| 6  | 03°20′00″91 | +41°33′13″8 | Vzw 339                              |
| 7  | 03°19′17″68 | +41°38′37″8 | 2MASX J03191772+4138391               |
| 8  | 03°19′34″22 | +41°34′50″0 | CGCG 540–101                          |
| 9  | 03°19′37″38 | +41°37′58″9 | 2MASX J03193743+4137580               |
| 10 | 03°20′06″19 | +41°37′46″3 | NGC 1281                              |
| 11 | 03°20′21″42 | +41°38′23″9 | MCG+07–07–070                         |
| 12 | 03°20′56″60 | +41°35′57″7 | 2MASX J032050744+4136015              |
| 13 | 03°20′57″71 | +41°30′20″4 | 2MASX J032057764+4130229              |

We detected X-ray sources for all the galaxies brighter than $M_B < -18$. In this deep observation, one might expect to detect galaxies fainter than $M_B > -18$, but the diffuse cluster emission makes the background too high for such work.

The red Digitized Sky Survey (DSS2) was first used to identify possible optical counterparts for the X-ray sources. We then examined archival images from the Sloan Digital Sky Survey (SDSS) and the catalogue of Perseus cluster galaxies by Brunzendorf & Meusinger (1999). Fig. 1 shows the SDSS I-band image, indicating the detected X-ray sources with optical counterparts. They are all listed as early-type galaxies in the work of Brunzendorf & Meusinger (1999). We do not detect a three-armed spiral galaxy (UGC 2665, listed in Brunzendorf & Meusinger 1999), which lies between sources 7 and 9 (Fig. 1). This morphology excludes it being an early-type galaxy. Moreover, the velocity of this galaxy is 2800 km s$^{-1}$ higher than that for the Perseus cluster core, so it is likely an outlier.

In Fig. 2, we show the X-ray contours for each of the detected sources (from a 0.3–7 keV image), overlaid on optical images of the galaxies from SDSS. The first six sources are nearer to NGC 1275.
than the others. It is seen that in each of these cases the contours coincide with the nucleus of the galaxy, so the X-ray sources match the optical sources. They are also consistent with being point sources. The remaining seven sources are farther from the central galaxy. Some of these distant sources appear off-centred with respect to the galaxy are given in Table 3.

Some of these distant sources appear off-centred with respect to the central galaxy. The remaining seven sources are farther from the central galaxy.

| RA          | Dec.     | Flux         |
|-------------|----------|--------------|
| 03h19m09.52 | +11°34′29.2″ | 1.1 × 10^{-14} |
| 03h19m11.97 | +11°33′53.1″ | 4.5 × 10^{-15} |
| 03h19m18.76 | +11°34′38.3″ | 3.2 × 10^{-15} |
| 03h19m15.95 | +11°34′07.9″ | 7.8 × 10^{-16} |
| 03h19m19.93 | +11°31′56.2″ | 5.0 × 10^{-15} |
| 03h20m00.10 | +11°37′46.4″ | 2.1 × 10^{-14} |
| 03h21m12.04 | +11°31′19.4″ | 6.2 × 10^{-14} |
| 03h22m26.64 | +11°39′37.3″ | 4.4 × 10^{-15} |
| 03h23m50.80 | +11°37′08.7″ | 3.6 × 10^{-14} |
| 03h25m13.13 | +11°40′26.5″ | 1.3 × 10^{-14} |
| 03h28m11.98 | +11°34′25.4″ | 3.0 × 10^{-15} |
| 03h30m02.64 | +11°40′12.3″ | 2.3 × 10^{-15} |
| 03h30m09.69 | +11°35′04.1″ | 9.5 × 10^{-15} |
| 03h33m38.11 | +11°29′55.9″ | 3.3 × 10^{-15} |
| 03h33m56.77 | +11°27′49.9″ | 1.7 × 10^{-15} |
| 03h37m49.49 | +11°38′44.2″ | 2.0 × 10^{-14} |
| 03h38m37.33 | +11°27′53.5″ | 1.3 × 10^{-15} |
| 03h43m36.81 | +11°27′25.1″ | 2.2 × 10^{-15} |
| 03h43m59.11 | +11°33′04.7″ | 5.2 × 10^{-15} |
| 03h44m10.44 | +11°25′53.2″ | 1.6 × 10^{-14} |
| 03h45m47.47 | +11°42′19.5″ | 6.0 × 10^{-15} |
| 03h46m27.27 | +11°37′35.7″ | 7.4 × 10^{-15} |
| 03h47m75.75 | +11°27′23.5″ | 7.7 × 10^{-16} |
| 03h48m24.82 | +11°32′49.7″ | 9.6 × 10^{-16} |
| 03h51m44.14 | +11°31′51.0″ | 3.7 × 10^{-15} |
| 03h56m09.80 | +11°33′15.4″ | 1.3 × 10^{-14} |
| 03h59m91.83 | +11°39′36.1″ | 5.1 × 10^{-15} |
| 04h00m15.50 | +11°31′27.5″ | 2.5 × 10^{-14} |
| 04h02m71.27 | +11°30′33.3″ | 9.0 × 10^{-16} |
| 04h04m47.54 | +11°38′39.5″ | 5.1 × 10^{-15} |
| 04h05m34.78 | +11°30′54.5″ | 4.3 × 10^{-15} |
| 04h11m52.00 | +11°36′59.4″ | 6.1 × 10^{-15} |
| 04h14m31.54 | +11°36′05.8″ | 4.8 × 10^{-15} |
| 04h18m24.89 | +11°37′24.0″ | 2.8 × 10^{-15} |
| 04h19m59.10 | +11°30′30.8″ | 5.8 × 10^{-15} |

2.3 X-ray spectral analysis

We extracted and modelled the X-ray spectra of those sources identified as Perseus core galaxies. For those sources on the central CCD, we used an extraction region of 3 arcsec. This increased to 5–10 arcsec on the other chips. Spectra for each source were extracted from each of the separate observations and added together. The local backgrounds were extracted from annuli with outer radii of 5 arcsec on the central CCD, increasing to 10–20 arcsec on the other chips. Response matrix files (RMFs) and ancillary response files (ARFs) were created for each of the sources by averaging the RMFs and ARFs from the individual observations (created using MKACISRMF and MKWARF).

The xspec fitting was performed using xspec v11.3.2. The spectra were grouped to have a minimum of 20 counts in each spectral bin before background subtraction in order to use the χ^2 statistic. Model fitting was carried out in the 0.5–7.0 keV band.

Each X-ray spectrum was fitted by a power law with possible intrinsic absorption and then, separately, by a MEKAL thermal spectrum. Most were best fitted by the power-law spectrum. We let the power-law slope (Γ) and the absorbing column density (N_H) vary freely. In some cases, the column density was less than 1.3 × 10^{23} cm^{-2} (the Galactic absorption value) which was unphysical, so we fixed it at this minimum. The photon indices of sources 5, 8 and 9 were fixed at 2.0. In the cases where a single-component power-law did not give a satisfactory fit, a MEKAL component with a temperature fixed at 0.6 keV was added to improve the fit. We assume that this is a minihalo component, although it is not spatially resolved.

The results of the spectral fitting of all the galaxies are given in Table 3. The values of N_H and Γ vary between (1.3–3.7) × 10^{21} cm^{-2} and (2.0–3.77), respectively. The values of the column density was fixed at the minimum for sources 1, 2, 6, 9, 10, 11, 12 and 13. The Γ values are much steeper than that for LMXBs (Irwin, Athey & Bregman 2003).

A typical spectral fit (for source 3) is shown in Fig. 4. The spectrum was fitted using an absorbed power-law and MEKAL model.

In Table 4, the 0.5–7.0 keV flux and the absorption-corrected luminosities of the individual sources based on the best-fitting absorbed power-law model, and in some cases MEKAL + absorbed power-law model, are presented. Luminosities were determined assuming a redshift of 0.018 and cosmological model with H_0 = 70 km s^{-1} Mpc^{-1}. The distances of all of these galaxies are assumed to be the same as that of NGC 1275, as they are in the same cluster (Brunzendorf & Meusinger 1999). The uncertainties on the X-ray luminosities were determined by generating a Monte Carlo Markov Chain using the built-in xspec functionality. After the chain had converged, we calculated the luminosity (without absorption) from each set of values in the chain. The quoted luminosity is the median luminosity from the chain, and the uncertainties were calculated using the 16.85 and 84.15 percentiles. The rest-frame 0.5–2 keV luminosities of thermal minihaloes of Perseus core galaxies from Sun et al. (2007) are also given in Table 4. These are the total (power-law + MEKAL) luminosities. Sun et al. (2007) give no data for sources 6, 7, 9, 11, 12 and 13 and found only two minihalo objects. We found two more. The absolute total B-band magnitudes of the galaxies are also shown in Table 4, calculated using the luminosity distance and the total B-band flux density from the NASA/IPAC Extragalactic Data base (NED). There are no reported B-band fluxes for sources 5, 6, 11, 12 and 13.

As the first 200 ks of the observations occurred around 2 yr before the remainder, we investigated whether the detected sources were time-variable. We determined the X-ray flux of the sources for
Figure 2. X-ray contours for each of the sources with optical counterparts, overlaid on the SDSS I-band optical images. The first six sources are nearer to the central galaxy and the rest are farther away. The first six images are $27.8 \times 16.5$ arcsec$^2$ in size, while the next seven are $55.2 \times 23$ arcsec$^2$.

the two epochs of observations and found that the fluxes were the same within the uncertainties. Therefore, no significant variability was found.

3 PROPERTIES OF THE EARLY-TYPE GALAXIES

We now make a systematic investigation of the properties of the detected 13 early-type galaxies.

3.1 K-band luminosity and X-ray luminosity

In Fig. 5, we plot for each source the unabsorbed power-law X-ray luminosity versus the $K$-band luminosity. $L_K$ was derived from $K_{20}$ measured within the 20 mag arcsec$^{-2}$ isophote [taken from Two-Micron All-Sky Survey (2MASS)], using $M_K = 3.33$ mag. We also plot a straight line showing the linear relation between the X-ray luminosity of LMXBs in a galaxy and the galaxy $K$-band luminosity (from Kim & Fabbiano 2004). Kim & Fabbiano (2004) find a range in $K$-band luminosity of $7-40 \times 10^{10} L_K \odot$, which is a similar range to our galaxies. All but two of our sources lie below the relation. Therefore, the galaxies appear superficially underluminous in point sources.

To assess the effect of instrumental effects and projection of intracluster medium on the detectability of point sources, we compared from Perseus NGC 1278 ($L_K = 40.55 \times 10^{10} L_K \odot$), the optically brightest galaxy detected here, against the publicly-available Chandra observation of NGC 720 ($L_K = 18.58 \times 10^{10} L_K \odot$). NGC 720
lies at a distance of 28 Mpc, is not in a cluster and has a Chandra observation of 40 ks length (OBSID 492). To account for the effect of distance on the spatial scale, we binned the image of NGC 720 by a factor of 3, and smoothed it by 1 arcsec to account for the background component to account for the projected intracluster medium in Perseus. Finally, we generated an image by making a Poisson realization of our model, to account for counting statistics. We show an image of NGC 1278 and NGC 720 before processing, and the final simulated NGC 720 image in Fig. 6.

It is clear that most of the haloes of point sources (LMXBs) spread after the higher absorption to the Perseus cluster is included. We only detect in NGC 1278 a point source coincident with the nucleus and a possible LMXB to the south-west. It would be interesting to see whether this last source coincides with a globular cluster there but we have found no published information of globular clusters in our 13 galaxies. We conclude that the low X-ray luminosity of most of the 13 galaxies, when compared with nearby ones, is due to our inability to resolve the expected, spatially distributed, population of point sources.

### 3.2 UV band magnitudes, radio emission, black hole mass and X-ray luminosity

GALEX FUV and NUV photometry of the centres of the detected Perseus cluster galaxies was taken from O’Connell et al. (in preparation). We plot FUV and NUV AB magnitudes against the unabsorbed power-law X-ray luminosity in Fig. 7. We see that there is no obvious correlation between UV and X-ray fluxes. The FUV and NUV magnitudes vary from 19 to 21.5 and 18 to 20.5, respectively, whereas the X-ray luminosity ranges by almost a factor of 100.

We found only four published values of radio power for the 13 galaxies. These are at 1.4-GHz data and from Miller & Owen (2001) and Sijbring (1993). The values of the logarithm of radio power in W Hz^{-1} are 21.9, 21.2, 21.5 and 21.2 for CGCG 540-101, NGC 1277, NGC 1278 and NGC 1281, respectively.

The black hole mass of each galaxy was calculated using the relation from Marconi & Hunt (2003), relating black hole mass to the X-ray luminosity

\[ \log M_{\text{BH}}(M_\odot) = (8.21 \pm 0.07) + (1.13 \pm 0.012)(\log L_{K,\text{bul}} - 10.9) \]  

\[ \log L_{K,\text{bul}} \text{ in units of } L_{K,\odot} \]

where \( L_{K,\text{bul}} \) is in units of \( L_{K,\odot} \). We show in Table 5 the total 2MASS K-band luminosities (taken from NED) and the derived black hole mass. The masses vary from \( 2.4 \times 10^7 \) to \( 1.1 \times 10^8 M_\odot \).

The unabsorbed power-law X-ray luminosity was plotted against the black hole mass of the galaxies in Fig. 8. The open diamonds show those sources with a minihalo. The distances between the galaxies and the central galaxy, NGC 1275, are also given. We see that all the sources are within 250 kpc radius from NGC 1275. No correlation is found between the X-ray luminosity and the black hole mass.
4 DISCUSSION

All of the bright early-type galaxies in the region studied are detected in X-rays. The X-ray luminosities range from just below $10^{39}$ to $\sim 5 \times 10^{40}$ erg s$^{-1}$ in an unresolved component. The sources are spatially coincident, or consistent within uncertainties, with the centres of the galaxies. The LMXBs expected in these galaxies are barely detectable owing to the high background due to the dense intracluster gas.

All 13 sources have a power-law spectral component and four have an additional thermal component, suggestive of a minihalo (as also found by Sun et al. 2007). The photon index of the power law is steeper than typically expected from LMXBs ($\Gamma \sim 1.6$; Irwin et al. 2003), indicating that the sources are unlikely to be central, unresolved, concentrations of LMXBs.

The bolometric accretion luminosity expected from Bondi accretion of the intracluster medium in the cluster core, assuming that the galaxy motion is subsonic, is $6 \times 10^{39} \left( \frac{\dot{M}_{\odot}}{10^{-5} \odot \text{yr}^{-1}} \right)^2$ erg s$^{-1}$ (e.g. Allen et al. 2006). We assume that the gas has a density of $0.02$ cm$^{-3}$ and velocity/sound speed of $10^3$ km s$^{-1}$. With a typical bolometric correction of 10 in the 0.5–7 keV band for sources at low Eddington rate (Vasudevan & Fabian 2007), most of our sources have X-ray luminosities close to that expected from Bondi accretion (Fig. 8), especially when variations in velocity, etc., are considered. Where there are minihaloes, and it is plausible that they all have some form of minihaloes due to central stellar mass loss, then the expected accretion luminosity should be up to $10^4$ times higher owing to

| $N$ | Total flux (0.5–7.0 keV) (erg cm$^{-2}$ s$^{-1}$) | Velocity (from NED) (km s$^{-1}$) | Absorption-corrected luminosity (0.5–7.0 keV) (erg s$^{-1}$ MEKAL) | Power law | Rest-frame luminosities (0.5–2 keV) (erg s$^{-1}$) (from Sun et al. 2007) | Total B-band luminosity (mag) |
|-----|---------------------------------------------|-------------------------------|--------------------------|-------------|-----------------------------------|------------------|
| 1   | $7.66 \times 10^{-15}$                     | 5387                          | $7.29^{+0.58}_{-0.57} \times 10^{39}$ | $<3.80 \times 10^{39}$ | $-20.04$                         |
| 2   | $1.90 \times 10^{-15}$                     | 6413                          | $1.83^{+0.30}_{-0.27} \times 10^{39}$ | $<3.16 \times 10^{39}$ | $-19.58$                         |
| 3   | $1.57 \times 10^{-14}$                     | 5066                          | $1.69^{+0.23}_{-0.18} \times 10^{40}$ | $4.47 \times 10^{39}$ | $-19.51$                         |
| 4   | $4.26 \times 10^{-15}$                     | 6090                          | $4.53^{+0.79}_{-1.42} \times 10^{39}$ | $<2.75 \times 10^{39}$ | $-21.01$                         |
| 5   | $2.19 \times 10^{-15}$                     | 7285                          | $1.22^{+0.07}_{-0.04} \times 10^{39}$ | $<3.09 \times 10^{39}$ | -                                 |
| 6   | $3.36 \times 10^{-15}$                     | 5186                          | $3.10^{+0.40}_{-0.38} \times 10^{39}$ | -           | -                                 |
| 7   | $3.95 \times 10^{-15}$                     | 6211                          | $6.17^{+0.56}_{-0.54} \times 10^{39}$ | -           | -                                 |
| 8   | $3.49 \times 10^{-15}$                     | 4500                          | $4.06^{+1.97}_{-1.33} \times 10^{39}$ | $1.09^{+0.70}_{-0.59} \times 10^{39}$ | $3.16 \times 10^{39}$ | $-18.68$                        |
| 9   | $9.09 \times 10^{-16}$                     | 8574                          | $8.07^{+3.42}_{-1.26} \times 10^{38}$ | -           | -                                 |
| 10  | $6.55 \times 10^{-15}$                     | 4300                          | $5.83^{+0.57}_{-0.53} \times 10^{39}$ | $<4.37 \times 10^{39}$ | $-19.29$                         |
| 11  | $7.8 \times 10^{-15}$                      | 3749                          | $5.50^{+1.36}_{-1.60} \times 10^{39}$ | $3.66^{+0.70}_{-0.21} \times 10^{39}$ | -                                 |
| 12  | $4.45 \times 10^{-15}$                     | 5306                          | $5.6^{+0.79}_{-0.77} \times 10^{38}$ | $5.6^{+0.79}_{-0.77} \times 10^{38}$ | -                                 |
| 13  | $4.82 \times 10^{-14}$                     | 4965                          | $4.68^{+0.31}_{-0.31} \times 10^{39}$ | -           | -                                 |
Figure 6. Left-hand panel: NGC 1278 in the Perseus cluster. Middle panel: NGC 720 at the same physical scale as NGC 1278. Right-hand panel: simulated image of NGC 720 accounting for projected cluster emission, PSF and Poisson noise.

Figure 7. Source FUV (left-hand panel) and NUV (right-hand panel) AB magnitudes plotted against X-ray luminosity. Note that all sources are essentially at the same distance.

| N | K-band flux density (10^{-28} W m^{-2} Hz^{-1}) | Black hole mass (10^8 M_\odot) |
|---|---------------------------------|-------------------------------|
| 1 | 7.79 | 5.58 |
| 2 | 4.21 | 2.77 |
| 3 | 7.92 | 5.69 |
| 4 | 14.4 | 11.2 |
| 5 | 3.44 | 2.22 |
| 6 | 2.15 | 1.30 |
| 7 | 3.36 | 2.16 |
| 8 | 6.61 | 4.66 |
| 9 | 1.61 | 0.94 |
| 10 | 6.29 | 4.31 |
| 11 | 0.48 | 0.24 |
| 12 | 4.03 | 2.95 |
| 13 | 3.80 | 2.48 |

Table 5. Total K-band flux density and black hole mass of the galaxies.

The solution may lie in ADAFs (Narayan & Yi 1995) or other radiatively inefficient flows or with outflows so that little matter reaches the centre (Blandford & Begelman 1999). The luminosity of the sources may also act back on the accreting gas (Ostriker et al. 1976; Di Matteo et al. 2003). Alternatively, the matter may accrete to the centre and power relativistic jets (e.g. Allen et al. 2006), which can be very radiatively inefficient. We do not, however, see any disturbance in the surrounding hot gas, nor radio emission, which would be expected to accompany such powerful jets.

Our results do not distinguish which solution is the more correct, but underline the widespread nature of the problem.

5 CONCLUSION

We have made a detailed analysis of X-ray point sources detected with a deep Chandra ACIS-S observation of the core of the Perseus cluster. The main observational results and conclusions of our study are as follows.

(i) We have found a total of 13 X-ray sources coincident with the nuclei of early-type galaxies projected near the centre of Perseus cluster (excluding NGC 1275).

(ii) All 13 sources have a power-law spectra component and four have an additional thermal component.

(iii) No obvious correlations are found between X-ray luminosities and the K-band luminosities, UV AB magnitudes and black hole masses of the galaxies.

the gas being much denser and cooler. If these galaxies do contain minihaloes, then they are further extreme examples of the general problem found for the supermassive black holes in early-type galaxies (Fabian & Canizares 1988; Pellegrini 2005). On simple grounds, they should all be much more luminous than observed if the black hole accretes in a radiatively efficient manner. None is as faint as our own Galactic Centre, Sgr A*, but there is the fuel at hand for them to be much brighter.
(iv) Our results are consistent with the nuclei of all early-type galaxies in rich clusters being active, albeit at a low level.

(v) There is no apparent difference between the X-ray luminosity of nuclei in a minihalo and of those with no detected minihalo. Bondi accretion, for those nuclei with a minihalo, should make them much more luminous.

(vi) Some form of radiatively inefficient accretion is likely operating in these sources.

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