Extended X-ray emission at high redshifts: radio galaxies versus clusters

A. Celotti\textsuperscript{1} and A.C. Fabian\textsuperscript{2}

\textsuperscript{1}SISSA, via Beirut, 2-4, 34014 Trieste, Italy
\textsuperscript{2}Institute of Astronomy, Madingley Road, Cambridge CB3 0HA

\textbf{Abstract}

Most old distant radio galaxies should be extended X-ray sources due to inverse Compton scattering of Cosmic Microwave Background (CMB) photons. Such sources can be an important component in X-ray surveys for high redshift clusters, due to the increase with redshift of both the CMB energy density and the radio source number density. We estimate a lower limit to the space density of such sources and show that inverse Compton scattered emission may dominate above redshifts of one and X-ray luminosities of $10^{44} \text{erg s}^{-1}$, with a space density of radio galaxies $> 10^{-8} \text{Mpc}^{-3}$. The X-ray sources may last longer than the radio emission and so need not be associated with what is seen to be a currently active radio galaxy.

\textbf{Key words:} galaxies: active - galaxies: clusters - X-ray: galaxies - clusters

1 INTRODUCTION

\textit{Chandra} has revealed extended X-ray emission from a wide range of radio sources out to high redshifts. Jets and the lobes and cocoons of radio quasars and galaxies have been imaged with unprecedented resolution (e.g. Chartas et al 2000, Schwarz et al 2001, Harris & Krawczynski 2002, Kataoka et al 2003, Comastri et al 2003, Wilson, Young & Shopbell 2001, Kraft et al 2002). At low redshifts, extended emission directly associated with the radio lobes is seen through its inverse Compton emission in some objects (e.g. Fornax A; Feigelson et al 1995, Kaneda et al 1995; 3C219, Comastri et al 2003). In the powerful radio source Cygnus A, diffuse X-ray emission is also detected from the radio cocoon, i.e. the reservoirs of shocked material associated with the radio expansion (Wilson, Young & Smith 2003). When however a modest radio source lies in a rich cluster, the surface brightness of the inverse Compton emission in soft X-rays can be so low that it cannot be separated from thermal emission and the lobes appear as holes in the X-ray emission due to displacement of the hot gas by the lobes (e.g. the Perseus cluster, Fabian et al 2000, Sanders et al 2004; Hydra A, McNamara et al 2000; A2052, Blanton et al 2001).

Extended X-ray emission is also associated with an increasing number of radio sources at cosmological distances, for example 3C 294 (Fabian et al 2003), 3C 9 (Fabian, Celotti & Johnstone 2003), PKS 1138-262 (Carilli et al 2002), 4C 41.17 (Scharf et al 2003), GB 1508+5714 (Yuan et al 2003, Siemiginowska et al 2003), although often the low photon count rate makes it hard to disentangle the different X-ray components. In general however, much of the emission can be interpreted as due to inverse Compton scattering of non-thermal radio emitting electrons on CMB photons (Felten & Rees 1967, Schwartz 2002), thereby making them detectable.

Independently of the spatial distribution, the presence of extended radio synchrotron emission is a direct indication of the presence of a non-thermal population of relativistic particles. These particles, at least, must produce high energy emission via inverse Compton scattering of CMB photons (direct measurements and upper limits for such emission are used to estimate the intracluster magnetic field). Here, we consider the effective number density of extended X-ray emitting sources due to this process as a function of X-ray luminosity and show that they can be a serious contaminant to X-ray surveys searching for clusters and protoclusters at high redshift.

The outline of the paper is as follows: in Section 2 we estimate the ratio of (synchrotron) radio to (inverse Compton) X-ray emission, while in Section 3 we estimate the corresponding X-ray luminosity functions of radio sources as a function of $z$ and compare them with those of X-ray clusters. A discussion in Section 4 concludes this Letter. A cosmology
2 X-RAY EMISSION FROM SCATTERING ON THE CMB

We now attempt to estimate the X-ray luminosity associated with each extended radio source and the number density of X-ray emitting objects using radio emission as a direct tracer of the relativistic electron population. Although based on well known classical arguments (Felten & Morrison 1966), we explicitly re-derive the limits on the inverse Compton emission as these are the basis for the robustness of the inferred X-ray emission from radio sources. A simplified approach restricts us to lower limits, but bypasses the need for determining particle life-times (due to acceleration/injection history and radiative and adiabatic cooling, see Sarazin 1999) and consideration of the (uncertain) conversion of radio luminosity into source power. It should be noted that for typical gas densities associated with radio emitting regions, inverse Compton largely dominates over non-thermal bremsstrahlung emission (Sarazin 1999, Peterson 2001).

In order to include only radio emission arising as synchrotron radiation from a non-thermal (power-law) distribution of electrons on extended scales we use low frequency radio luminosities, $L_R$, at 151 MHz. The major uncertainty in the estimate of the X-ray luminosity is the magnetic field in the radio-emitting region. Depending on its intensity the same electrons can give both the observed radio emission and the X-ray emission, or some extrapolation of the electron spectrum is required.

Let us consider the monochromatic X-ray luminosity $L_X$ at a reference frequency of 1 keV (in the observer frame), and define $\gamma_X = 3\nu_X / 4\nu_{CMB} \approx 10^3$ as the Lorentz factor of the electrons which could emit at (the observed) 1 keV photon frequency $\nu_X$ via inverse Compton on the CMB (peaked at the frequency $\nu_{CMB}$) and $B_X \sim \text{few} \times 10^{-5}$ as the magnetic field intensity for which these same electrons radiate at $\nu_R$ (151 MHz) via synchrotron (i.e. $B_X \approx 5.4 \times 10^{-5} \nu_R (1+z)\gamma_X^{-2}$ G for $z=0$). In other words, for any magnetic field $B < B_X$, the Lorentz factor of the radio (151 MHz) emitting particles $\gamma_R > \gamma_X$, and vice-versa.

The relative luminosity in the synchrotron and inverse Compton components is given by the ratio of the magnetic $U_B$ vs radiation $U_{CMB}$ energy densities. More specifically, the relative luminosities at the two fixed observed frequencies in the radio and X-ray bands scale as

$$\frac{\nu_X L_X}{\nu_R L_R} = \frac{U_{CMB}}{U_B} \left( \frac{\nu_X}{\nu_{CMB}} \nu_R \right)^{1-\alpha} (1+z)^{(3+\alpha)-k(1+\alpha)},$$

(1)

where $U_B$ and $U_{CMB}$ are the energy densities at redshift $z=0$ and $k$ accounts for a possible dependence of the magnetic energy density on $z$, parametrized as $B(z) = B(0)(1+z)^k$. The non-thermal particle distribution has been assumed to be a power-law whose slope $p$ is related to the luminosity spectral index $\alpha = (p-1)/2 \left( L(\nu) \propto \nu^{-\alpha} \right)$.

Figs. 1a and 2a show the ratio of the expected X-ray (inverse Compton) and radio (synchrotron) luminosities at the (observed) frequencies of 1 keV and 151 MHz, at different redshifts and for two representative power-law parti-

![Figure 1](image-url)

**Figure 1.** In both panels $B_{eq}$ is the value of the field in equipartition with $U_{CMB}$ (at redshifts $z=0,1,2$, - solid, dotted and dashed lines, respectively). The solid vertical line labeled $B_R$ represents the value of $B$ for which electrons emitting at 1 keV via inverse Compton radiate at 151 MHz via synchrotron. Top panel: ratio of the expected X-ray (inverse Compton) and the radio (synchrotron) luminosities at the observed frequencies of 1 keV and 151 MHz for a single power-law particle distributions with $p=2.6$, and one flattening to $p=1$ at $\gamma < \gamma_R$. The luminosity ratio is represented by the oblique lines (solid, dotted and dashed for $z = 0,1,2$, respectively). Bottom panel: the Lorentz factors of the emitting electrons (for the assumed B field). The horizontal lines indicate $\gamma_R$, i.e. the Lorentz factor of the electrons which could emit at (the observed) 1 keV energy via inverse Compton on the CMB, while the oblique lines (labeled $\gamma_\nu$) show the Lorentz factors of electrons emitting at 151 MHz (for $z=0,1,2$ - solid, dotted and dashed lines, respectively). The lines labeled $\gamma_7$ indicate instead the synchrotron self-absorption frequency for different (Thomson) optical depths ($\tau = 10^{-3}, 10^{-2}, 10^{-1}, 1$). It is assumed a homogeneous region and constant $B$ as a function of redshift.
High redshift extended X-ray emission: radio galaxies vs. clusters

2.0.1 Caveats

There are two main caveats to be considered before adopting the above estimates.

Firstly, the actual value of the magnetic field. Estimates for nearby clusters based on equipartition (minimum energy) arguments from the non-thermal emitting component lead typically to $B \sim 0.1 - 1 \mu$G for unit volume filling factor and equal electron and proton energies. Similar estimates are derived for the few clusters where there is a detection of hard X-ray emission $^*$, assumed to be inverse Compton scattering on CMB photons. Fields inferred from Faraday rotation measures are instead about one order of magnitude higher (including cooling flow clusters), in the range $1 - 10 \mu$G (Carilli & Taylor 2002, Feretti 2003 for reviews). These values can be reconciled with the former ones by taking into account the dependence on radial distance, field substructures, different electron spectra, etc. (see e.g. Feretti 2003). In any case, typical fields appear to be in the range considered above, up to $\sim 10 \mu$G, i.e. $\lesssim B_\bullet$, and thus not dynamically important in clusters. Although the origin of such fields is not known, it appears likely that seed fields (primordial or produced from galactic winds, AGN, shocks associated to large scale structure formation) could be amplified following cluster mergers up to $\sim \mu$G values (e.g. Roettiger, Stone & Burns 1999). Therefore, it seems plausible that, despite a higher (thermal) gas pressure at higher cluster luminosities/redshift, the actual field might be a decreasing function of $z$, leading to even higher $L_x/\nu_x/L_{\nu_R}$ values. We conclude that the above estimates for $B \sim 1 - 10 \mu < B_\bullet$ G fields are a reasonably robust lower limit to such ratio.

The second critical assumption in the above estimates is that the shape of the particle distribution, considered as a single power-law. As this might well not be the case, let us thus consider the uncertainties related to this assumption, which depend on which energy range of the particle distribution is actually responsible for the X-ray emission. Figs. 1b and 2b show the Lorentz factors of the emitting electrons as a function of $B$. The horizontal line indicates $\gamma_x$ while the oblique lines (labeled $\gamma_R$) show the Lorentz factors of electrons emitting at 151 MHz at different redshifts.

For any $B < B_\bullet$ (as discussed above), corresponding to $\gamma_R > \gamma_x$, it is therefore necessary to assess whether the extrapolation on the particle number density at energy $m_e c^2 \gamma_x$ from the corresponding intensity at 151 MHz provides a robust lower limit, as the particle distribution might flatten or cut off at a Lorentz factor $\gamma^*$, with $\gamma_x < \gamma^* < \gamma_R$. Indeed such a flattening/cutoff could be expected if:

- a) relativistic particles have been injected with energies $> \gamma_x$ and had not (yet) cooled down to $\gamma_x$; the observed spectral slope would then correspond to the slope of a cooled particle distribution, i.e. above a cooling break $\gamma_b$ with $\gamma_R > \gamma_b > \gamma_x$; the low energy particles lose energy non-radiatively, namely via Coulomb losses – indeed for typical (cluster) densities this process dominates at $\gamma < 100$ (e.g. Petrosian 2001);
- b) self-absorption is effective in re-heating the low energy particles, causing the particle distribution to (quasi-) thermalize around a self-absorption Lorentz factor $\gamma_t > \gamma_x$ (Ghisellini, Guilbert & Svensson 1988). The ‘flattest’ oblique lines in Figs. 1b, 2b represent $\gamma_t$ for increasing values of the (Thomson) optical depth (for $\tau = 10^{-3}, 10^{-2}, 10^{-1}, 1$), showing that indeed self-absorption might cause the particle spectrum to flatten at energies higher than $\gamma_x$, although only for significantly large optical depths in relativistic particles.

The radiative cooling timescales of the X-ray emitting electrons

$$t_{\text{rad}} \simeq 2.4 \times 10^9 \gamma_x^{-1} (1 + z)^{-4} \left(1 + \frac{U_B}{U_{\text{CMB}}} (1 + z)^{k-4}\right) \text{ yr} \tag{2}$$

would be typically much larger than the adiabatic one

$$t_{\text{ad}} \simeq 3.2 \times 10^6 R_2 (R_2/\lambda_{\text{acc}}, 1) \text{ yr} \tag{3}$$

where $R_2 = R/100$ kpc is a typical size of extended radio emission, and $\lambda_{\text{acc}} = 10$ kpc is considered as the typical ‘scattering’ length for field coherence cells of $\sim 10$ kpc (Carilli & Taylor 2002). Furthermore expansion – and thus cooling – would likely start from the injection/acceleration site, i.e. on presumably smaller scales. Thus it appears unlikely that particles with $\gamma > \gamma_x$ have not cooled or that particle thermalisation could be effective (also inverse Compton cooling should prevent the quasi-thermalization of the non-thermal particles below $\sim \gamma_t$). Note also that Coulomb losses start to dominate over radiative ones for $\gamma < 100$, not affecting the shape of the particle distribution above $\gamma_x$.

In order to estimate the effect on the X-ray-to-radio luminosity ratio of a break in the particle distribution we considered an ‘extreme’ case where the particle spectrum flattens to $p = 1$ (i.e. as expected from adiabatic cooling and flatter than for radiative cooling) just below $\sim \gamma_R$. The corresponding luminosity ratio is shown in Fig. 1a: for $B < 10 \mu$G the ratio is $\gtrsim 0.3$ at $z \gtrsim 1$.

It is worth noticing that these considerations also account for an inhomogeneous radio emitting volume (equivalent to the added contributions from different regions), as the above results would refer to the X-ray luminosity expected from the region dominating the radiative output at 151 MHz. In this case however the observed spectrum would not be indicative of the shape of the emitting particle distribution: if the latter is steeper than $p = 2.6$ the above estimates (for $p = 2.6$) provide a lower limit to $\nu_x L_x/\nu_R L_R$.

The reported estimates for $p = 1$ provide instead a lower limit for any flat distribution with $p \gtrsim 1$.

We conclude that radio sources constitute a potentially significant population of extended X-ray emitting objects.

$^*$ see however the recent results by Rossetti & Molendi (2003) on the Coma cluster.
3 HIGH REDSHIFT EXTENDED X-RAY EMITTERS

In order to estimate the number density and thus the possible contribution of radio sources to X-ray surveys (see also Schwartz 2002), we consider the luminosity function of steep radio sources, as determined from surveys at 151 MHz. This has a twofold advantage: it avoids or at least reduces contamination from compact components (with respect to the extended lobe/cocoon emission) and it takes advantage of the most recent and deeper radio surveys.

In particular we adopt the luminosity function and its evolution as due to two (distinct) populations: FR I plus low excitation line (LEG) FR II sources and high excitation line (HEG) FR II, representing low and high radio power sources, respectively (Fanaroff & Riley 1974, see Laing et al 1994, Jackson & Wall 1999). We associate an extended X-ray luminosity with each 151 MHz radio sources as determined above: Fig. 3 shows the corresponding number density of the two populations of X-ray sources at different redshifts assuming a conservative (and constant) radio-to-X-ray (151 MHz and 1 keV) conversion factor $L_x \nu_x / L_R \nu_R = 1$.

For comparison, Fig. 3 also reports the luminosity function and evolution of X-ray clusters in the (0.5-2) keV band following the parametrization by Rosati et al (2000) – although the evolution at luminosities $< \text{few} \times 10^{44} \text{erg s}^{-1}$ is currently not robustly determined by the data. It is apparent that at redshift $z \gtrsim 1$ the radio source population starts becoming comparable to or even exceeding the expected cluster number density at the high X-ray luminosity end, $L_x > 10^{44} \text{erg s}^{-1}$. Because of the weaker cosmological evolution and intrinsic lower luminosity of the FR I+FR II/LEG population, the major contribution is provided by the high radio luminosity, high excitation line, FR II radio galaxies.

4 DISCUSSION

The above estimates indicate that powerful radio galaxies are expected to be found in significant numbers at redshift $z \gtrsim 1$ as extended X-ray sources. Indeed, we expect that most old distant radio galaxies are also extended X-ray sources.

It should be stressed that for any $B < B_x$ the above

\[ \text{Figure 2. Same as Fig. 1, for a particle distribution with } p = 2. \]

\[ \text{Figure 3. X–ray luminosity functions of X-ray clusters (CL) and radio galaxies (low and high radio power populations, labeled for simplicity FR I and FR II, respectively). Continuous, dotted and dashed lines refer to redshifts } z=0, 1, 2, \text{ respectively. The radio } 151 \text{ MHz luminosity has been 'converted' into an X-ray (1 keV) one assuming } \nu_R L_R = \nu_X L_X \text{ and the number density is per } 10^{44} \text{erg s}^{-1}. \]
estimates provide a lower limit on both the individual luminosity and the number density of extended X-ray emitting radio sources for the following reasons. Firstly, extended X-ray emission can also be produced by non-thermal particles which do not contribute to the 151 MHz emission, further increasing the actual X-ray luminosity with respect to the estimates given above: lobes, cocoons, relics and jets can emit not only as inverse Compton emission on the CMB, but also via other emission processes such as synchrotron self-Compton, bremsstrahlung and inverse Compton on other photon fields, such as far-infrared photons in the vicinity of the massive, extremely luminous galaxies detected in the sub-mm at high redshifts. Secondly, the radio-emitting electrons cool faster than the X-ray emitting ones (for $B < B_{\text{c}}$). Thus the radio luminosity function might significantly underestimate, by a factor corresponding to the relative cooling times $t_{\text{cool}}(\gamma R)/t_{\text{cool}}(\gamma x)$, the number density of sources and the volume pervaded by non-thermal electrons with energy $\sim \gamma x$ contributing to the X-ray emission. In other words the estimates above refer to 'prompt' X-ray emission only over the cooling timescale due to radio emission. Taking into account this ratio effectively increases the normalization of the luminosity function of radio sources by factors $\sim 3 - 10$ (see Fig. 1b). In this respect it is interesting to notice that indeed in the case of 3C294 (Fabian et al 2001) the X-ray emission extends much further than the radio structure (visible at 5 GHz), indicating that $B < B_{\text{c}}$ there. Consequently, extended non-thermal X-ray emission is not necessarily associated with a currently active radio source, instead providing information on the past radio behaviour of a galaxy.

We conclude that deep X-ray surveys should detect a significant population of extended X-ray sources associated with both 'live and dead' radio sources. At redshift $z > 1$ their space density should be at least comparable to or possibly larger than that of high X-ray luminosity, high redshift clusters. Caution in the interpretation of the origin of extended X-ray emission of course applies to that associated with high redshift radio sources, treated as beacons for clusters. While the presence of a radio source could still by itself be a cluster tracer (the radio-emitting plasma is probably confined by some intracluster or intragroup gas), the inferred luminosities could lead to misleading results on the cluster luminosity function and thus evolution. Particularly ambiguous situations for disentangling X-ray emission from cluster gas or a present/past AGN activity can arise when only inverse Compton emission can be detected at the location of a cluster, or when the surface brightness of inverse Compton emission corresponds to that of the surrounding intracluster medium.‡

Spectral information, including evidence for a thermal component and/or an iron line feature, such as detected in the cluster RDCS 1252.9-2927 at $z = 1.24$ (Rosati et al 2004) and RXJ1053.7+5735 at $z = 1.14$ (Hashimoto et al 2004), will be a key to disentangling the thermal and non-thermal contributions. The search for extended X-ray sources in deep Chandra fields (Bauer et al 2002) indicates a surface density of about 150 deg$^{-2}$ at soft X-ray fluxes $> 3 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$. A potential diagnostic of non-thermal emission is emission at energies $\gtrsim 1$ keV is also expected. Although a study of the effective extension of the particle distribution requires a knowledge of the acceleration processes at work as well as its history (see Sarazin 1999), if a source is radio emitting at 151 MHz, for any given $B$ the spectrum produced via the scattering of CMB photons extends at least up to $\sim 40(1+z)B_{\gamma}^{-1}$ keV; possibly to a few hundreds MeV $(for \gamma \sim 10^5)$. Because of photon redshifting, detection of any emission above a few keV at high $z$ would be a clear signature of a non-thermal component, presumably due to inverse Compton emission. Interestingly, one of the six extended X-ray sources detected by Bauer et al. (2002) has a high temperature with respect to the $L_x - T$ cluster correlation.

The inverse Compton emission is a direct result, and also a probe, of the major non-gravitational energy injection phase of the present day intracluster medium. In fact, the radio luminosity of radio galaxies grossly underestimates the intrinsic power of their jets which can be 1000 or more times greater. The radio-emitting plasma is likely to be confined by some intracluster or intragroup gas, which is displaced outward. The energy dumped into the immediate surroundings of such sources can be considerable and thereby influence the gaseous properties of clusters and groups (Eastrand et al 1997, Valageas & Silk 1999; Wu, Fabian & Nulsen 2000). Integrating the radio galaxy luminosity function over time leads to a comoving energy input of about $10^{47}$ erg Mpc$^{-1}$ (Inoue & Sasaki 2001) which can (pre)heat – although the precise mechanism is not yet clear – the intracluster medium by 1–2 keV per particle, so explaining much of the non-gravitational scaling behavior of groups and clusters (e.g. Lloyd-Davies et al 2000). The intracluster or intragroup medium will be highly disturbed during the energy injection phase and for up to a core crossing time (about a Gyr) after. This means that the detection and interpretation of Sunyaev-Zeldovich signals from high redshift clusters (Carlstrom, Holder & Reese 2003) may be complicated. Alternatively, the lack of detection of a large population of non-thermal extended X-ray emitters would provide interesting information about the radio source/cluster magnetic field evolution. This would suggest that the radio emitting particles have lower energy than the radio emitting ones, indicating $B > B_{\text{c}}$, and thus point to positive evolution in the magnetic field associated with the diffuse radio emission at higher redshifts, although it would be difficult to precisely quantify and interpret such result.

5 ACKNOWLEDGMENTS

We thank the anonymous referee for helpful criticisms. The Italian MIUR and INAF (AC) and the Royal Society (ACF) are thanked for financial support.

REFERENCES

Bauer F.E., et al. 2002, AJ, 123, 1163
Blanton E., Sarazin C.L., McNamara B.R., Wise M.W., 2001, ApJ, 558, L15
Carilli C.L., Harris D.E., Pentericci L., Röttgering H.J.A., Miley G.K., Kurk J.D., van Breugel W., 2002, ApJ, 567, 781
Carilli C.L., Taylor G.B., 2002, ARA&A, 40, 319
Carlstrom, J., Holder G.P., Reese E.D., 2003, ARAA, 40, 643
Celotti A., Ghisellini G., Chiaberge M., 2001, MNRAS, 321, L1
Chartas G., et al, 2000, ApJ, 542, 655
Cooke B.A., Lawrence A., Perola G.C., 1978, MNRAS 182, 661
Comastri A., Brunetti G., Dallacasa D., Bondi M., Pedani M., Setti G., 2003, MNRAS, 340, L52
Crawford C.S., Fabian A.C., 2003, MNRAS, 339, 1163
Einslenn T.A., Biermann P.L., Kronberg P.P., Wu X.-P., 1997, ApJ, 477, 560
Fabian A.C., et al, 2000, MNRAS, 318, L65
Fabian A.C., Crawford C.S., Ettore S., Sanders J.S., 2001, MNRAS, 322, L11
Fabian A.C., Sanders J.S., Crawford C.S., Ettori S., 2003, MNRAS, 341, 729 (astro-ph/0301468)
Fabian A.C., Celotti A., Johnstone R.M., 2003, MNRAS, 338, L7
Feltre J.E., Rees M.J., 1967, Nature, 221, 924
Feretti L., 2003, proc. XXI Texas Symposium on Relativistic Astrophysics, Florence Dec. 9-13 2002 (astro-ph/0309221)
Ghisellini G., Guilbert P.W., Svensson R., 1988, ApJ, 334, L5
Harris D.E., Krawczynski H., 2002, ApJ, 565, 244
Inoue S., Sasaki S., 2001, ApJ, 562, 618
Jackson C.A., Wall J.V., 1999, MNRAS, 304, 160
Kaneda H., et al., 1995, ApJ, 453, L13
Kataoka J., Leahy J.P., Edwards P.G., Kino M., Takahara F., Serino Y., Kawai N., Martel A.R., 2003, A&A, 410, 833
Kraft R.P., et al, 2000, ApJ, 531, L9
Laing R.A., Jenkins C.R., Wall J.V., Unger S.W., 1994, in The First Stromlo Symposium: The Physics of Active Galaxies. ASP Conference Series, Vol. 54, G.V. Bicknell, M.A. Dopita, and P.J. Quinn Eds., 201M.J., Worrall D.M., 2002, ApJ 569, 54
Lloyd-Davies E.J., Ponman T.J., Cannon D.B., 2000, MNRAS, 315, 689
McNamara B.R., et al, 2000, ApJ, 534, L135
Petrosian V., 2001, ApJ, 557, 560
Rosati P., Borgani S., Della Ceca R., Stanford A., Eisenhardt P., Lidman C., 2000, Large Scale Structure in the X-ray Universe, Atlantiscences, eds. M. Plionis, I. Georgantopoulos, 13
Rosati P., et al, 2004, AJ, in press (astro-ph/0309546)
Sarazin C.L., 1999, ApJ, 520, 529
Scharf C., Smail I., Ivison R., Bower R., van Breugel W., Reuland M., 2003, ApJ, 596, 105
Schwartz D.A., 2002, ApJ, 569, L23
Schwartz D.A., et al, 2000, ApJ, 540, L69
Siemiginowska A., Smith R.K., Aldcroft T., Schwartz D.A., Paerels F., Petric A.O., 2003, ApJ, 598, L15
Tavecchio F., Maraschi L., Sambruna R.M., Urry C.M., 2000, ApJ, 544, L23
Valageas P., Silk J., 1999, A&A, 350, 725
Willott C.J., Rawlings S., Blundell K.M., Lacy M., Eales S.A., 2001, MNRAS, 322, 536
Wilson A.S., Young A.J., Shopbell P.L., 2001, ApJ, 547, 740
Wilson A.S., Young A.J., Smith D.A., 2003, Active Galactic Nuclei: from Central Engine to Host Galaxy, ASP Conf. Series, eds S. Collin, F. Combes, I. Shlosman, in press (astro-ph/0211541)
Worrall D.M., 2002, New Astron. Rev, 46, 121
Wu K.K.S., Fabian A.C., Nulsen P.E.J., 2000, MNRAS, 318, 889
Yuan W., Fabian A.C., Celotti A., Jonker P.G., 2003, MNRAS, 346, L7