The REFLEX Galaxy Cluster Survey IV: The X-ray Luminosity Function

H. Böhringer\textsuperscript{2}, C.A. Collins\textsuperscript{3}, L. Guzzo\textsuperscript{4}, P. Schuecker\textsuperscript{2}, W. Voges\textsuperscript{2}, D.M. Neumann\textsuperscript{5}, S. Schindler\textsuperscript{3}, G. Chincarini\textsuperscript{4}, S. De Grandi\textsuperscript{4}, R.G. Cruddace\textsuperscript{6}, A.C. Edge\textsuperscript{7}, T.H. Reiprich\textsuperscript{2}, P. Shaver\textsuperscript{8}

Received \_______________; accepted \_______________

\textsuperscript{1}Based on observations at the European Southern Observatory La Silla, Chile
\textsuperscript{2}Max-Planck-Institut für extraterrestrische Physik, D-85740 Garching, Germany
\textsuperscript{3}Liverpool John Moores University, Liverpool, U.K.
\textsuperscript{4}Osservatorio Astronomico di Brera, Merate, Italy
\textsuperscript{5}CEA Saclay, Service d’Astrophysique, Gif-sur-Yvette, France
\textsuperscript{6}Naval Research Laboratory, Washington, USA
\textsuperscript{7}Physics Department, University of Durham, U.K.
\textsuperscript{8}European Southern Observatory, Garching, Germany
ABSTRACT

The X-ray galaxy cluster sample from the REFLEX Cluster Survey, which covers the X-ray brightest galaxy clusters detected in the ROSAT All-Sky Survey in the southern sky, is used to construct the X-ray luminosity function of clusters in the local Universe. With 452 clusters detected above an X-ray flux-limit of $3 \cdot 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ in 4.24 sr of the sky, this sample is the most comprehensive X-ray cluster sample with a well documented selection function, providing the best current census of the local X-ray galaxy cluster population. In this paper we discuss the construction of the luminosity function, the effects of flux measurement errors and of variations with sample region and we compare the results to those from previous surveys.

Subject headings: Cosmology – Galaxies: clusters – Xrays: galaxies
1. Introduction

Since the X-ray luminosity of galaxy clusters is closely related to the cluster mass (Reiprich & Böhringer 1999) and can be measured for a large sample of galaxy clusters, the X-ray luminosity function provides a good estimate of the mass function of galaxy clusters. Therefore the X-ray luminosity function has been widely used as a census of the galaxy cluster population in the Universe (e.g. Picinotti et al. 1982, Kowalski 1984, Gioia et al. 1984, Edge et al. 1990, Henry et al. 1992, Burns et al. 1996, Ebeling et al. 1997, Collins et al. 1997, Rosati et al. 1998, Vikhlinin et al. 1998, De Grandi et al. 1999, Ledlow et al. 1999, Nichol et al. 2000, Gioia et al. 2001). The close connection of cluster formation with the evolution of the large-scale structure of the Universe makes the cluster mass function - and its observational substitute, the X-ray luminosity function - very important for the statistics of large-scale structure and for tests of cosmological models. The cluster luminosity function constrains in particular the normalization of the amplitude of the primordial density fluctuation power spectrum on scales of about $5 - 10 \, h^{-1}_{100} \, \text{Mpc}$ (e.g. Henry & Arnaud 1991, Bahcall & Cen 1992, White et al. 1993), and the evolution of the X-ray luminosity function provides a sensitive test of the mean density of the Universe (e.g. Perrenod 1980, Oukbir & Blanchard 1992, Eke et al. 1996, Viana & Liddle 1996, Borgani et al. 1998).

A precise measurement of this function had to await two improvements: the availability of cluster samples large enough to reduce the statistical scatter and effects of cosmic variance and homogeneous enough to minimize uncertainties and corrections of selection effects. The ROSAT All-Sky Survey (RASS, Trümper 1992, 1993), its improved processing (Voges et al. 1999), and a comprehensive optical follow-up observing program provided the basis for such improvements. In this paper we use the ROSAT-ESO Flux-Limited X-ray (REFLEX) cluster survey (Böhringer et al. 1998, 2001 (paper I), Guzzo et al. 1999, Collins
et al. 2000 (paper II), Schuecker et al. 2001 (paper III)) comprising 452 southern clusters in total and 449 with measured redshifts above a nominal X-ray flux limit of $3 \cdot 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ in the ROSAT band (0.1 - 2.4 keV) to construct the X-ray luminosity function of galaxy clusters in the local Universe. Compared to previous cluster samples based on the RASS and used for the construction of the X-ray luminosity function, the present sample is more than a factor of two larger and features a well understood selection function. It provides a good measure of the local luminosity function for studies of cluster evolution by comparison with distant X-ray cluster samples (e.g. in Gioia et al. 2001).

This paper is organized as follows. Section 2 gives a short description of the REFLEX cluster sample. The flux and luminosity determination is summarized in section 3. In section 4 the X-ray luminosity function is derived and comparison to previous results is made in section 5. Section 6 provides a summary. For the calculation of luminosities and volumina we use the cosmological parameters: $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_0 = 1$ and $\Lambda = 0$.

2. The REFLEX cluster sample

The construction of the REFLEX cluster sample is described in detail by Böhringer et al. (2001). The survey area covers the southern sky up to the declination $\delta = +2.5^\circ$, avoiding the band of the Milky Way ($|b_{II}| \leq 20^\circ$) and the regions of the Magellanic clouds. The total survey area is 13924 deg$^2$ or 4.24 sr.

The X-ray detection of the clusters is based on the second processing of the RASS (Voges et al. 1999), providing 54076 sources in the REFLEX area. All sources were reanalysed by means of the growth curve analysis (GCA) method (Böhringer et al. 2000) and the results are used to produce a flux-limited sample of RASS sources with a nominal flux of $F_n \geq 3 \cdot 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ (with $F_n$ as defined below). Cluster candidates
were found using a machine based correlation of these X-ray sources with galaxy density enhancements in the COSMOS optical data base (derived from digital scans of the UK Schmidt survey plates by COSMOS at the Royal Observatory Edinburgh, MacGillivray & Stobie 1984). The resulting candidate list was carefully screened based on X-ray and optical information, literature data, and results from the optical follow-up observation program. The selection process was designed to provide a completeness in the final cluster catalogue in excess of 90% and several further completeness tests support this claim. The final cluster sample includes 452 clusters and there are three objects left in the list with uncertain identifications and redshifts. These three objects are excluded from the further analysis. The sample has already been used to analyse the statistics of the spatial cluster distribution by the two-point correlation function (Collins et al. 2000) and by the density fluctuation power spectrum (Schuecker et al. 2001).

3. Luminosity and survey volume determination

The X-ray luminosities of the REFLEX clusters are determined from the count rate measurements provided by the GCA (Böhringer et al. 2000). For the first analysis these count rates are not corrected by means of a model estimate of the total flux. Such modifications are discussed in a second step. To determine the cluster X-ray luminosity we convert the measured count rate into a “nominal” X-ray flux for the ROSAT band (0.1 to 2.4 keV), $F_n$, by assuming a Raymond-Smith type spectrum (Raymond & Smith 1977) for a temperature of 5 keV, a metallicity of 0.3 of the solar value (Anders & Grevesse 1989), a redshift of zero, and an interstellar hydrogen column density as found for the line-of-sight in the compilation by Dickey & Lockman (1990) as given within EXSAS (Zimmermann et al. 1994). The value of $F_n$ is used to make the flux cut independent of any redshift information (since this information is not available for all objects at the start of the survey). With
the redshift value at hand, the X-ray flux is redetermined \((F_x)\) with an improved spectral model, where the temperature is now estimated (iteratively) from the preliminarily derived X-ray luminosity and the luminosity-temperature relation derived by Markevitch (1998). The redshift of the spectrum is now taken into account, which corresponds to a \(k\)-correction in optical astronomy with \(k(T,z,N_H)\) and provides luminosities for the cluster rest frame energy band 0.1 to 2.4 keV.

For the construction of the luminosity function of a flux-limited sample the survey volume, \(V_{\text{max}}\), as a function of X-ray luminosity has to be known. The survey volume is given by the volume of the cone defined by the survey area and the luminosity distance at which a cluster with a given luminosity is just observed at the flux limit. Since we have used the flux parameter \(F_n\) for the flux cut \(F_{n \text{ lim}}\) and since we have calculated the luminosity, \(L_x\), iteratively from \(F_n\), we have to reverse these steps, where the limiting luminosity distance, \(D_{L \text{ lim}}\), is now iteratively calculated from \(F_{n \text{ lim}}\) and \(L_x\) involving the two steps:

\[
\text{corr} = \frac{F_{x \text{ lim}}}{F_{n \text{ lim}}} = f(L_x, D_{L \text{ lim}}) \quad \text{and} \quad D_{L \text{ lim}}^2 = \frac{L_x}{4\pi F_{n \text{ lim}} \text{ corr} \left( L_x, D_{L \text{ lim}} \right) k(T,z,N_H)}.
\]

These equations establish a unique relation between \(L_x\) and \(V_{\text{max}}\) for given \(F_{n \text{ lim}}\). The two correction factors are small with typical values quoted by Böhringer et al. (2000). (Note, that no new flux cut has been introduced after the correction of the flux values. Therefore the sample does not change and the selection volume depends on \(F_{n \text{ lim}}\).

The second correction applied in the \(V_{\text{max}}\) calculation concerns the sensitivity function derived in paper I providing the sky coverage as a function of flux (Böhringer et al. 2001, Figs. 22 and 23). The sensitivity function is defined by two limiting parameters, the flux limit, \(F_{n \text{ lim}}\), and the minimum number of photons required for a safe detection and flux measurement. We use a soft coding of the photon number cut, such that the effect of using different cut values can easily be explored. For a minimum value of 10 photons, for example, the nominal flux limit is reached in 97% of the REFLEX area, while for a value
of 30 photons this fraction 78%. For the remaining part of the sky with higher flux limit the corresponding survey volume has to be reduced accordingly. The large sample size of REFLEX allows us to be selective and to use the very safe, higher cut of 30 photons for the standard derivation of the luminosity function.

As shown in paper I, a complete removal of the photon number cut leads to an estimated deficit of only about $14(\pm 7)$ clusters (3.8%). Thus the assumption of a homogeneous selection function without source count limit and inclusion of all clusters leads to results insignificantly different from the results obtained with the conservative approach below. For a minimal photon number of 30, the sample contains 423 clusters with redshifts. For luminosities lower than $L_x = 10^{42}$ erg s$^{-1}$ the counterparts to the extended X-ray sources very often appear as single elliptical galaxies with no optically bright companions and therefore these objects may be incompletely represented in our sample. We therefore exclude three objects with lower luminosity from the parametric fit to the luminosity function described below.

4. Results

The binned luminosity function calculated for this sample is shown in Fig. 1 (with 20 clusters per bin). The 3 objects with the lowest luminosity are grouped here into the first bin. The calculation for each bin is performed using the formula

$$n(L) = \frac{1}{\Delta L} \sum_{i=1}^{N} \frac{1}{V_{\text{max}}(L_i)}$$

where the sum is over all $N$ clusters falling into the luminosity interval of the bin. Note, that with this approach we determine the mean luminosity function in the survey volume averaging over large-scale structure density fluctuations. Also, no major redshift
Fig. 1.— X-ray luminosity function for the REFLEX sample. The solid data points give the results for the detected luminosities while the open diamonds indicate the results including a model dependent correction for the missing flux. The data points are plotted at the density weighted mean luminosity per bin. The line gives the maximum likelihood fit including the correction for missing flux and the individual uncertainties in the flux measurement.
dependence of the cluster density has been detected. An alternative determination of a density independent luminosity function and the redshift dependence of the cluster density is planned for a future paper. The error bars shown are Poissonian errors based on the number of clusters per bins. The function shown in Fig. 1 by solid data points concerns the observed fluxes only. To explore the effect of the flux missed by the GCA algorithm in the outskirts of the clusters we correct the fluxes and luminosities based on a self-similar cluster model as described in Böhringer et al. (2000): a $\beta$-model (Cavaliere & Fusco-Femiano 1976) with a $\beta$-value of 2/3, a core radius that scales with mass, and an assumed extent of the X-ray halo out to 12 times the core radius. The correction procedure has been successfully tested by simulations based on the same cluster model. The resulting corrected luminosity function is also shown in Fig. 1. As expected from the typical mean correction factor of about 8% (Böhringer et al. 2000) the main effect is a shift of the curve to higher luminosity of this order. A larger shift is only observed for the lowest redshift bins (for the groups with extended, low surface brightness emission).

As a first consistency check we compared luminosity functions derived for flux limits of $3 \cdot 10^{-12}$ and $5 \cdot 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ finding excellent agreement. This indicates that there is no significant incompleteness effect at low fluxes. We also derived an unbinned, parametric representation of the luminosity function by means of a maximum likelihood fit (by the method described by e.g. Murdoch et al. 1973 and by an alternative Poisson formulation of the ML method, with both giving identical results) of a Schechter function

$$n(L) dL = n_0 \exp \left( -\frac{L}{L_*} \right) \left( \frac{L}{L_*} \right)^{-\alpha} \frac{dL}{L_*}$$

(Schechter 1976) over the luminosity range $10^{42}$ erg s$^{-1}$ to infinity. The resulting best fit parameters are given in Table 1. The normalization parameter $n_0$ is derived from the requirement that the total number obtained by integration of $n(L)$ equals the observed
number of clusters. The constraints obtained from the maximum likelihood analysis for the shape parameters are shown in Fig. 2. We have also performed a $\chi^2$ fit to the binned data to test for the quality of the fit and obtained a $\chi^2$ value of 18 (for 19 dof, 22 bins), 39 (for 40 dof, 43 bins), and 64 (for 68 dof, 71 bins). Thus the Schechter function provides a good representation of the data within the current uncertainty limits. The $\chi^2$ method is also used for the error estimation for $n_0$.

In the next step of the analysis we consider the effect of the uncertainties in the flux measurement on the results. For this purpose we extend the maximum likelihood approach of Murdoch et al. to include the effect of errors on the expected luminosity distribution as well as on the uncertainty of the survey volume (the Eddington (1940) bias). The log-likelihood, $\mathcal{L}$, is then given by:

$$\mathcal{L} = \sum_i -\ln K(\sigma_i) + \ln \int_{L_{\min}}^{\infty} V_{\text{max}}(L') n(L') G(L_i, L', \sigma_i) dL'$$

with

$$K(\sigma_i) = \int_{L_{\min}}^{\infty} dL \int_{L_{\min}}^{\infty} dL' V_{\text{max}}(L') n(L') G(L, L', \sigma_i)$$

where $G(L, L', \sigma_i)$ is a normalized Gaussian function containing the photon noise error of the flux measurement, $\sigma_i$, for each cluster and the sum is over all clusters in the sample. While the previous correction for missing flux leads essentially to an increase in $L_\star$ of about 8%, the inclusion of the flux errors results in a decrease by about 4%. Both effects are relatively small, yielding overlapping parameter constraints (Fig. 2).

As another test of the stability of the results we compare in Fig. 3 and Table 1 the results obtained for the luminosity function, if the REFLEX sample is split into the part above and below the galactic disk. There is good agreement within the error bars at intermediate luminosities where most of the clusters were found. The deviations
Table 1. Results of the fitting of a Schechter function to REFLEX X-ray luminosity function and results from previous work

| sample                      | \(L_\star^{(a)}\)   | \(\alpha\) | \(n_0^{(b)}\) |
|-----------------------------|----------------------|------------|---------------|
| REFLEX uncorrected          | 6.26 \((^{+0.6}_{-0.53})\) | 1.63(±0.06) | 1.75 \((^{+0.5}_{-0.4})\) \cdot 10^{-7} \((d)\) |
| corr. for miss. flux        | 6.79 \((^{+0.6}_{-0.55})\) | 1.63(±0.06) | 1.80 \((^{+0.5}_{-0.4})\) \cdot 10^{-7} |
| corr. for flux error        | 6.00 \((^{+0.6}_{-0.5})\) | 1.63(±0.06) | 1.58 \((^{+0.5}_{-0.4})\) \cdot 10^{-7} |
| corr. for both effects      | 6.47 \((^{+0.6}_{-0.54})\) | 1.63(±0.06) | 1.68 \((^{+0.5}_{-0.4})\) \cdot 10^{-7} |
| High flux sample uncorr.*   | 6.85(±0.7)           | 1.68(±0.07) | 1.5 \((^{+0.6}_{-0.5})\) \cdot 10^{-7} |
| BCS                         | 9.1 \((^{+2.0}_{-1.5})\) | 1.85(±0.09) | 7.74 \((^{+0.76}_{-0.70})\) \cdot 10^{-8} |
| Bright RASS1                | 6.08 \((^{+1.1}_{-1.0})\) | 1.52(±0.11) | 2.53(±0.23) \cdot 10^{-7} |
| Ledlow and others           | 8.78(±0.62)          | 1.77(±0.01) | 7.9(±0.38) \cdot 10^{-8} |

* sample with a flux-limit of \(5 \cdot 10^{-12}\) erg s\(^{-1}\) cm\(^{-2}\)

\(^{a})\) \(L_\star\) is in units of \(10^{44} h_{50}^{-2}\) erg s\(^{-1}\) cm\(^{-2}\) in the 0.1 to 2.4 keV band

\(^{b})\) \(n_0\) is in units of \(h_{50}^{3}\) Mpc\(^{-3}\)

\(^{c})\) errors are quoted for 68% limits

\(^{d})\) the errors quoted for the normalization for the REFLEX samples were evaluated by a \(\chi^2\) method with two free parameters \((L_\star, \alpha)\), which differs from the approach for the other samples. For one free parameter the error reduces to \(±0.1\) – \(±0.2\) and to \(±0.08\) for fixed \((L_\star, \alpha)\) and Poissonian errors.
Fig. 2.— Constraints on the parameters of the shape of the Schechter function derived from maximum likelihood fits to the total sample including corrections for missing flux and flux errors (solid lines), uncorrected for missing flux (thin lines), no correction for missing flux and flux error (broken line). The contour lines encircle the best fitting value and indicate the 1σ- and 2σ-limits, respectively.
at low luminosities are consistent with the cosmic variance estimated for the respective survey volume (approximated to be spherical) and the power spectrum determined for the REFLEX cluster distribution (Schuecker et al. 2001). Details of this calculation will be given in a further publication in this series. The differences at the highest luminosity are due to small number statistics.

5. Comparison to previous results

In Fig. 4 we compare the results for REFLEX with the largest previous samples from the first processing of the RASS, our RASS1 Bright Sample in the South (De Grandi et al. 1999), BCS in the North (Ebeling et al. 1997) and the work by Ledlow et al. (1999) based on X-ray detections of Abell clusters. We note that even though the results agree within the combined individual errors in this binned representation there are global differences. At low luminosities the differences are approximately within the expected cosmic variance (e.g. Fig. 3). The low density at low luminosities in the Ledlow et al. sample is due to the fact that the Abell catalogue does not well sample the X-ray emitting galaxy groups. At medium luminosity, where the data sets are most accurate, the result for the RASS Bright Sample are systematically higher and the BCS and Ledlow et al. samples are lower by about 20-30%. The De Grandi et al. results predict a cluster density for the most interesting part of the luminosity function which is about 50% higher than that of the BCS (noted also by Gioia et al. 2001). Therefore this comparison shows where an improvement in the precision of the luminosity function is achieved – in particular as reference for the local Universe in the study of cluster evolution.
Fig. 3.— Comparison of the X-ray luminosity function derived for the subsamples in the southern and northern galactic caps with the result of the total REFLEX sample. All results are normalized by the luminosity function for the total sample (solid line). All functions are given in the observed, uncorrected form.
Fig. 4.— Comparison of the REFLEX X-ray luminosity function to those of the BCS (Ebeling et al. 1997), the Bright RASS1 sample (De Grandi et al. 1999), and X-ray detected Abell clusters (Ledlow et al. 1999). All results are normalized by the luminosity function for the REFLEX sample (solid line). The REFLEX function is used in the form corrected for missing flux but uncorrected for the flux errors, to conform with the treatment of the other surveys. The REFLEX data points without missing flux correction are also shown.
6. Summary and conclusions

The REFLEX sample has allowed us to determine the X-ray luminosity function with an accuracy of for example better than 20% for 22 independent data bins over three orders of magnitude in luminosity (better than 12% for 8 independent e-folding intervals). This accuracy will provide the basis for a precise comparison with luminosity functions determined for high redshift samples in search for evolutionary effects. The size of the REFLEX sample has also allowed us to determine the luminosity function of subsamples for different flux-limits and different survey regions to demonstrate the stability of the result. In our following work we will use the X-ray luminosity function derived here to obtain constraints on cosmological models.

We thank Joachim Trümper and the ROSAT team providing the RASS data fields and the EXSAS software as well as H.T. Mac Gillivray, Daryl Yentis, and the COSMOS team for the digitized optical data. P.S. acknowledge the support by the Verbundforschung under the grant No. 50 OR 9708 35, H.B. the Verbundforschung under the grand No. 50 OR 93065.
REFERENCES

Anders, E. & Grevesse, N., 1989, Geochimica et Cosmochimica Acta, 53, 197

Bahcall, N.A. & Cen, R., 1992, ApJ, 407, L49

Böhringer, H., Guzzo, L., Collins, C.A., Neumann, D.M., Schindler, Schuecker, P.,
    Cruddace, R.G., DeGrandi, S., Chincarini, G., Edge, A.C., MacGillivray, H.T.,
    Shaver, P., Vettolani, G., & Voges, W., 1998, The Messenger, No. 94, 21 - 25

Böhringer, H., Voges, W., Huchra, J.P., McLean, B., Giacconi, R., Rosati, P., Burg,
    R., Mader, J., Schuecker, P., Simić, D., Komossa, S., Reiprich, T.H., Retzlaff, J.,
    Trümper, J., 2000, ApJS, 129, 435

Böhringer, H., Schuecker, P., Guzzo, L., Collins, C.A., Voges, W., Schindler, S., Neumann,
    D.M., Cruddace, R.G., De Grandi, S., Chincarini, G., Edge, A.C., MacGillivray,
    H.T., Shaver, P., 2001, A&A, 369, 826, paper I

Borgani, S., Rosati, P., Tozzi, P., & Noman, C., 1998, ApJ, 517, 40

Burns, J.O., Ledlow, M.J., Loken, C., Klypin, A., Voges, W., Bryan, G.L., Norman, M.L.,
    White, R.A., ApJ, 1996, 467, L49

Cavaliere, A. & Fusco-Femiano, R., 1976, A&A, 49, 137

Collins, C.A., Burke, D.J., Romer, A.K., Sharples, R.M., Nichol, R. C., 1997, ApJ, 479, 117

Collins, C.A., Guzzo, L., Böhringer, H., Schuecker, P., Chincarini, G., Cruddace, R.,
    DeGrandi, S., Neumann, D., Schindler, S., & Voges, W., 2000, MNRAS, 319, 939,
    (paper II)

De Grandi, S., Guzzo, L., Böhringer, H., Molendi, S., Chincarini, G., Collins, C., Cruddace,
    R., Neumann, D., Schindler, S., Schuecker, P., Voges, W., 1999, ApJ, 513, L17

Dickey, J.M. & Lockman, F.J., 1990, ARAA, 28, 215
Ebeling, H., Edge, A.C., Fabian, A.C., Allen, S.W., Crawford, C.S., Böhringer, H., 1997, ApJ, 479, L101
Eddington, A. S., 1940, MNRAS, 100, 354
Edge, A.C., Stewart, G.C., Fabian, A.C., & Arnaud, K.A., 1990, MNRAS, 245, 559
Eke, V., Cole, S., & Frenk, C.S., 1996, MNRAS, 282, 263
Gioia, I.M., Maccacaro, T., Schild, R.E., Stocke, J.T., Liebert, J.W., Danziger, I.J., Kunth, D., & Lub, J., 1984, ApJ, 283, 495
Gioia, I.M., Henry, J.P., Mullis, C.R., Voges, W., Briel, U.G., Böhringer, H., Huchra, J.P., 2001, ApJ, 553, L105
Guzzo, L., Böhringer, H., Schuecker, P., Collins, C.A., Schindler, S., Neumann, D.M., DeGrandi, S., Cruddace, R.G., Chincarini, G., Edge, A.C., Shaver, P., & Voges, W., 1999, The Messenger, No. 95, 27
Henry, J.P. & Arnaud, K.A., 1991, ApJ, 372, 410
Henry, J.P., Gioia, I.M., Maccacaro, T., Morris, S.L., Stocke, J.T., & Wolter, A., 1992, ApJ, 386, 408
Kowalski, M., Cruddace, R.G., Wood, K.S., & Ulmer, M., 1984, ApJS, 56, 403
Markevitch, M., 1998, ApJ, 504, 27
MacGillivray, H.T. & Stobie, R.S., 1984, Vistas Astr., 27, 433
Murdoch, H.S., Crawford, D.F. & Jauncey, D.L., 1973, ApJ, 183, 1
Nichol, R.C., Romer, A.K., Holden, B.P., Ulmer, M.P., Pildis, R.A., Adami, C., Merrelli, A.J., Burke, D.J., Collins, C.A., 1999, ApJ, 521, 21
Oukbir, J. & Blanchard, A., 1992, A&A, 262, L21
Perrenod, S.C., 1980, ApJ, 236, 373
Piccinotti, G., Mushotzky, R.F, Boldt, E.A., Holt, S.S., Marshall, F.E., Sermelitosos, P.J., & Shafer, R.A., 1982, ApJ, 253, 485

Ledlow, M. J., Loken, C., Burns, J. O., Owen, F.N., Voges, W., 1999, ApJ, 516, L53

Schechter, P., 1976, ApJ, 203, 297

Raymond, J.C. & Smith, B.W., 1977, ApJS, 35, 419

Reiprich T.H. & Böhringer, H., 1999, Astron. Nachr., 320, 296

Rosati, P., Della Ceca, R., Norman, C., & Giacconi, R., 1998, ApJ, 492, L21

Schuecker, P., Böhringer, H., Guzzo, L., Collins, C.A., Neumann, D.M., Schindler, S., Voges, W., Chincarini, G., Crudace, R.G., De Grandi, S., Edge, A.C., Müller, V., Reiprich, T.H., Retzlaff, J., & Shaver, P., 2001, A&A,368, 86, paper III

Trümper, J., 1992, Royal Astron. Soc. Quart. J., 33, 165

Trümper, J., 1993, Science, 260, 1769

Viana, P.T.P. & Liddle, 1996, MNRAS, 281, 323

Vikhlinin, A., McNamara, B.R., Forman, W., Jones, C., Quintana, H., Hornstrup, A., 1998, ApJ, 498, L21

Voges, W., Aschenbach, B., Boller, et al., 1999, A&A, 349, 389

White, S.D.M., Efstathiou, G., Frenk, C.S., 1993, MNRAS, 262, 1023

Zimmermann, H.U., Becker, W., Belloni, T., et al., 1994, EXSAS User's Guide, MPE Report No. 257

This manuscript was prepared with the AAS TeX macros v4.0.