Searching for Galaxy Clusters in the ROSAT All-Sky Survey: The ROSAT ESO Flux-Limited X-Ray (REFLEX) Cluster Survey

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ABSTRACT

The construction of a new sample of 476 ROSAT clusters of galaxies obtained in the southern hemisphere using the ROSAT All-Sky Survey is described. Preliminary results illustrate the homogeneous sampling of the clusters out to redshifts $z \approx 0.3$. The sample is used for statistical studies giving observational constraints on different cosmological structure formation scenarios.

1. Introduction

Thousands of mostly unknown clusters of galaxies are expected to be found among the 145,060 X-ray sources detected during the ROSAT All-Sky Survey (RASS, Trümper 1993, Voges et al. 1998, these proceedings). Since most of the X-ray sources in the RASS are detected with only few photons the X-ray clusters cannot be identified on the basis of the X-ray source properties alone, and further optical information is required. Concentrating on a flux-limited sample of X-ray sources in the southern sky outside the galactic plane we have made a first identification of galaxy cluster candidates using the COSMOS galaxy catalog.

In addition we have started an extensive optical follow-up survey (ESO key programme, Böhringer et al. 1994, 1998, Guzzo et al. 1995) to firmly identify the cluster sources and to obtain their redshifts. These X-ray clusters constitute important probes of the large-scale structure and of the evolution of the universe. Thus cluster population statistics as the X-ray luminosity function and the cluster density fluctuation power spectrum give important constraints on cosmological models.

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2. Important Steps in the Sample Construction

A primary source list (see Fig. 1) down to a very low significance (compiled by the ROSAT team) is reanalysed by a novel source analysis technique which especially reduces the bias in the flux measurement of extended sources (Böhringer et al., 1999, in preparation). Starting with the determination of the source center and the X-ray background in a ring around the source (Fig. 2) the integrated background-subtracted source count rate profile is calculated (Fig. 3). The total count rate is determined from the height of the plateau of this curve.

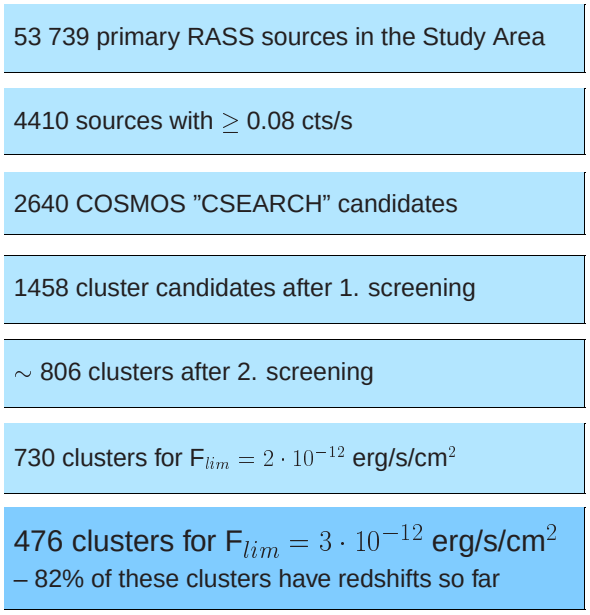

Fig. 1.— Illustration of the construction of the REFLEX cluster catalog.

In a second step cluster candidates were identified by correlating the positions of a count rate limited ($\geq 0.08\,\mathrm{cts\,s^{-1}}$) sample of sources ($N = 4,410$) with galaxy overdensities in the COSMOS galaxy catalog. Taking a low threshold in the galaxy overdensity a large fraction of non-cluster sources are flagged. This large contamination is readily reduced by obvious non-cluster sources, e.g., stars with diffraction spikes and obvious known AGNs. A second screening of the cluster candidates involves a detailed evaluation of the X-ray and optical properties and literature information. The residual contamination is recognized during the follow-up observations, where of the order of 10% of the cluster candidates are found to be active galaxies often located in galaxy groupings.

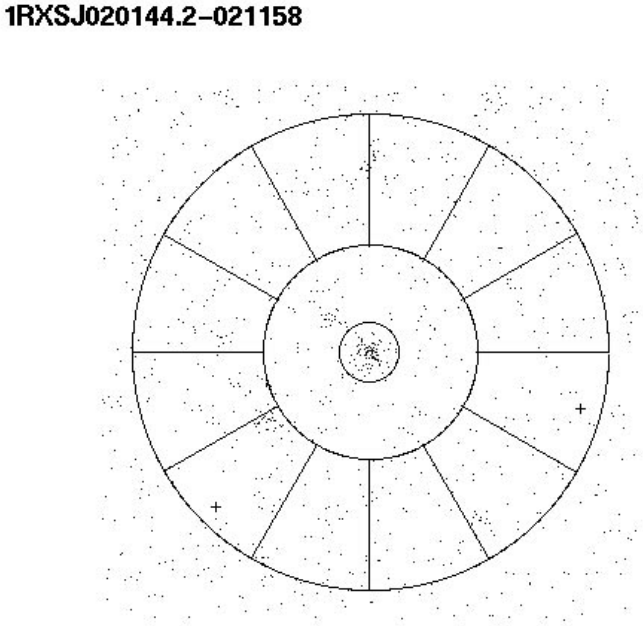

Fig. 2.— Distribution of X-ray photons located in a region of 1.0 square degree around RXSJ020144.2-021158, and the areas used to estimate the local background (outer segments) and to estimate the count rate of the central source (innermost circle). Segments marked with crosses show significant deviations from the average and are not used for the determination of the local background count rate.

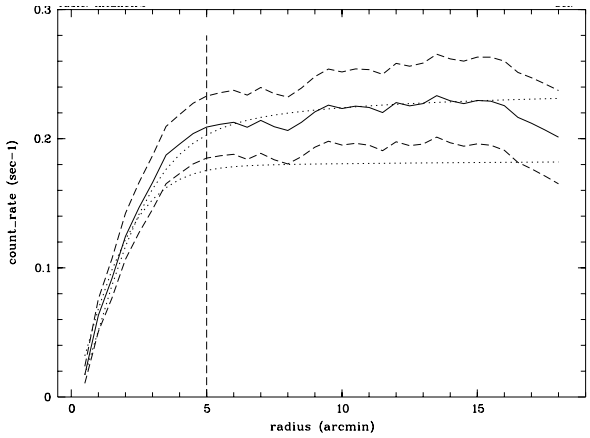

Fig. 3.— Cumulative background-subtracted count rates as a function of radial distance from the expected source center (continuous line) and the formal 1σ error envelope (long dashed lines) including the uncertainty of the signal and background determination. The distance where the cumulative count rate approaches a plateau-like distribution (vertical dashed line) determines the outer radius and the count rate of the source. Also shown are numerical fits of a point source (lower dotted line) and of a King model (upper dotted line).

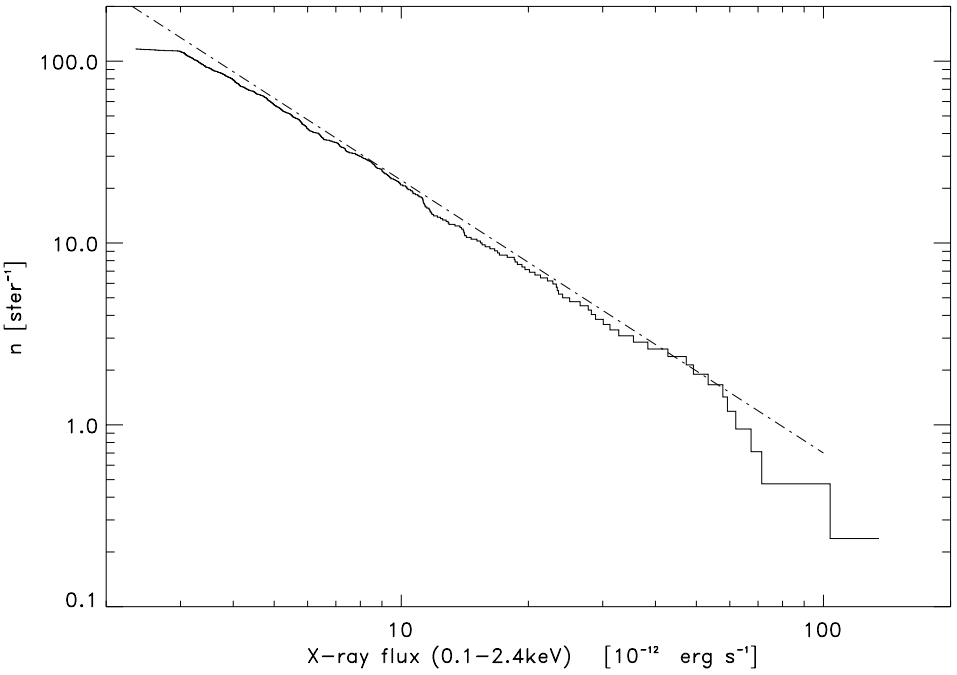

Fig. 4.— Cumulative flux-number counts of 476 REFLEX clusters of galaxies with $F \geq 3.0 \times 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ in the energy range $0.1 - 2.4\,\mathrm{keV}$ (continuous line). For comparison, the short-dashed line has the logarithmic slope -1.5 as expected for an Euclidian survey volume.

3. Preliminary Results

The survey covers an area of 13,924 square degrees (Dec $\leq 2.5\,\mathrm{deg}$, galactic latitude $|b| \geq 20\,\mathrm{deg}$) and includes 476 galaxy clusters with fluxes $F \geq 3 \times 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$, from which 75% are clearly extended. The sample consists of 254 Abell Corwin Olowin (ACO) clusters (53%), 47 ACO supplementary clusters (10%), and 175 non-ACO clusters (37%).

The flux-number counts ($\log(N) - \log(F)$) are basic not only for their relation to the luminosity function and cluster evolution (for nearby X-ray cluster samples cosmological K- and curvature effects are of minor importance) but also for the understanding of possible selection effects introduced by the complex survey process. The cumulative counts obtained with the REFLEX cluster sample (Fig. 4) suggest an almost Euclidean slope (dashed line) as expected for our cluster sample with the median redshift $z = 0.085$.

In spite of the present redshift incompleteness (20%) the luminosity function already recovers

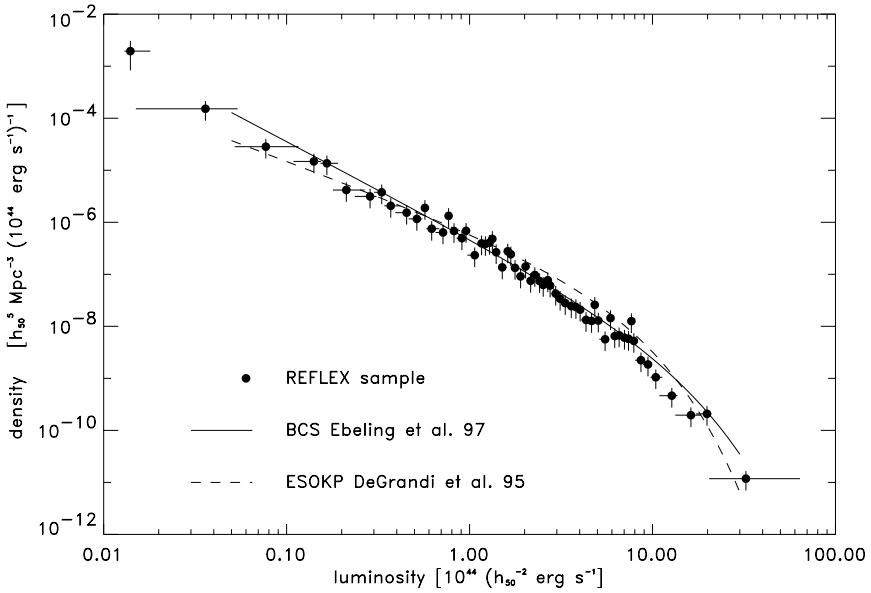

Fig. 5.— X-ray cluster luminosity function of the REFLEX sample (dots) and their formal 1σ Poisson error bars in vertical direction. For comparison, the luminosity functions obtained by Ebeling et al. (1997) and De Grandi et al. (1995) are shown.

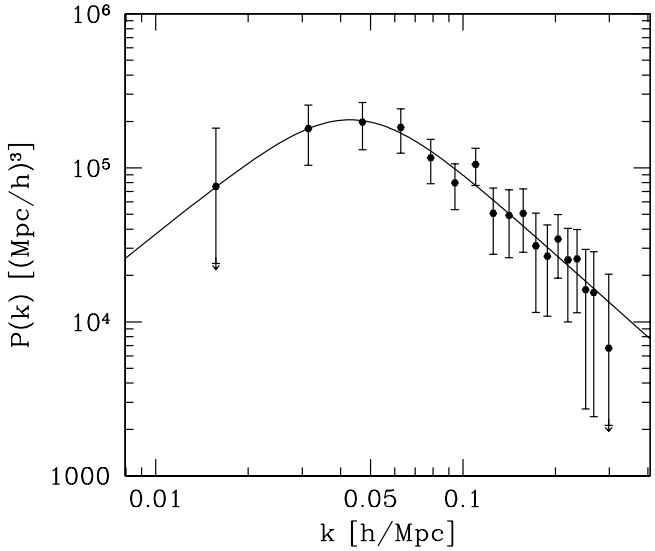

Fig. 6.— Power spectrum of the fluctuations of the comoving REFLEX cluster number densities (dots). The 1σ error bars are obtained from Bootstrap resampling. The continuous line is a phenomenological model used to describe the data.

the densities reached in previous surveys (Fig. 5). The overall shape of the curve is well-fitted by a Schechter-type function. Comoving number densities of clusters with similar X-ray luminosities are almost redshift-independent, consistent with no serious selection effects and no significant evolution of clusters with redshifts $z \leq 0.3$.

The power spectrum of the comoving number density fluctuations is an important summary statistic to discriminate between different cosmological structure formation scenarios. The power spectral analysis of a subsample of 188 X-ray clusters located within a cubic volume of $(400\,h^{-1}\,\mathrm{Mpc})^3$ indicates a maximum of the fluctuation power per mode at the comoving wavelength $120\,h^{-1}\,\mathrm{Mpc}$ and seems to be consistent with optical cluster surveys (Fig. 6).

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REFERENCES

Böhringer, H., et al., 1998, ESO Messenger (submitted)

Böhringer, H., 1994, MPE-Rep. 256, Proc. Studying the Universe with Clusters of Galaxies, eds. H. Böhringer and S. Schindler, (München: MPE), 93

De Grandi, S., 1996, MPE-Rep. 263, Proc. Röntgenstrahlung from the Universe, ed. H.U. Zimmermann, J. Trümper and H. Yorke (München: MPE), 577

Ebeling, H., Edge, A.C., Fabian, A.C., Allen, S.W., Crawford, C.S., & Böhringer, H., 1997, ApJ, 479, L101

Guzzo, L., et al. 1995, Proc. Wide-Field Spectroscopy and the Distant Universe, ed. S.J. Maddox and A. Aragon-Salamanca (Singapore: World Scientific), 205

Trümper, J., 1993, Science, 260, 1769