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The 160 deg^2 *ROSAT* Survey Revised Catalog and Cluster Evolution

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1.1 Overview of the Survey

We have constructed a large, statistically complete sample of galaxy clusters serendipitously detected as extended X-ray sources in 647 *ROSAT* PSPC pointed observations (Vikhlinin et al. 1998a, hereafter V98). The survey covers 158 square degrees with a median sample flux limit of 1.2×10^{-13} erg cm^{-2} s^{-1} (0.5–2.0 keV). Our sample consists of 201 clusters of galaxies characterized by a median redshift of z=0.25 and a maximum of z=1.26. With 22 clusters at $z > 0.5$, the 160 Square Degree *ROSAT* Survey (hereafter 160SD) is the largest high-redshift sample of X-ray-selected clusters published to date.

The galaxy clusters of our survey were initially confirmed in a comprehensive program of optical imaging of all the candidates (e.g., CCD image in Figure 1.1) and optical spectroscopy for a limited subsample. Two-thirds of the cluster redshifts in the original catalog (V98) were photometric estimates and the remaining third were spectroscopic measurements. We recently completed spectroscopy of the entire sample, and we now have spectroscopic redshifts for 99.5% of the clusters (e.g., spectra in Figure 1.1; Mullis et al. 2004a). Details of the revised cluster sample are discussed in the next section.

The 160SD clusters have been used to study the evolution of cluster X-ray luminosities and radii (Vikhlinin et al. 1998b), to present evidence for a new class of X-ray overluminous elliptical galaxies or "fossil groups" (Vikhlinin et al. 1999), to analyze the correlation of optical cluster richness with redshift and X-ray luminosity (McNamara et al. 2001), and to discover a wide-angle gravitational lens (Munoz et al. 2001). Chandra observations of high-redshift 160SD clusters have been used to make an accurate determination of the evolution of the scaling relations between X-ray luminosity, temperature, and gas mass (Vikhlinin et al. 2002), and to derive cosmological constraints from the evolution of the cluster baryon mass function (Vikhlinin et al. 2003). Subsequently we will describe the most recent results of our survey which concern the evolution of the number density of clusters.

We assume an Einstein-de Sitter cosmological model with $H_0 = 50\ h_{50}$ km s^{-1} Mpc^{-1} and $\Omega_M = 1$ ($\Omega_\Lambda = 0$), and quote X-ray fluxes and luminosities in the 0.5–2.0 keV energy band.

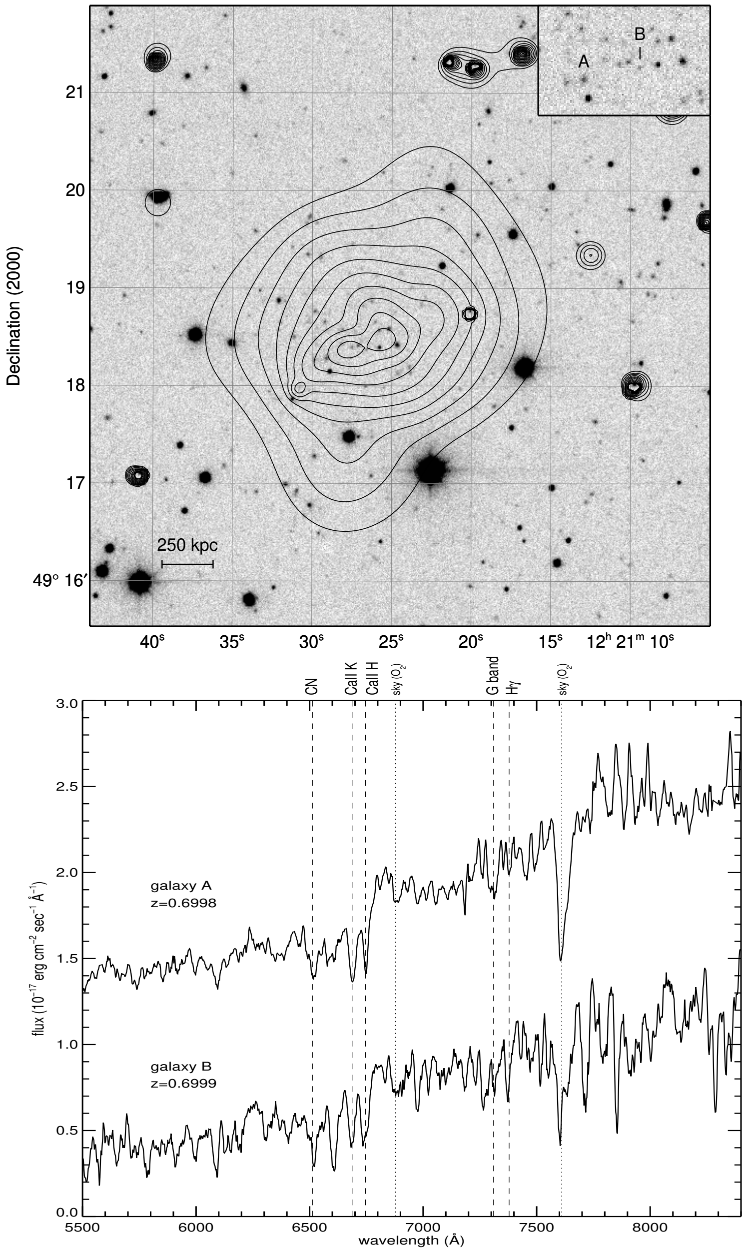

Fig. 1.1. RX J1221.4+4918 (#119): a distant cluster at $z = 0.700$. A 5 minute *R*-band image (upper panel) taken with the FLWO 1.2m is overlaid with adaptively smoothed X-ray flux contours in the 0.7–2.0 keV band from an 80 ks observation with the *Chandra* ACIS-I. Contours are logarithmically spaced by factors of 1.4 with the lowest contour a factor of 2 above the background (5.5×10^{-4} counts s^{-1} arcmin^{2}). The inset indicates the cluster galaxies for which redshifts were measured using longslit spectra from Keck-II LRIS (lower panel).

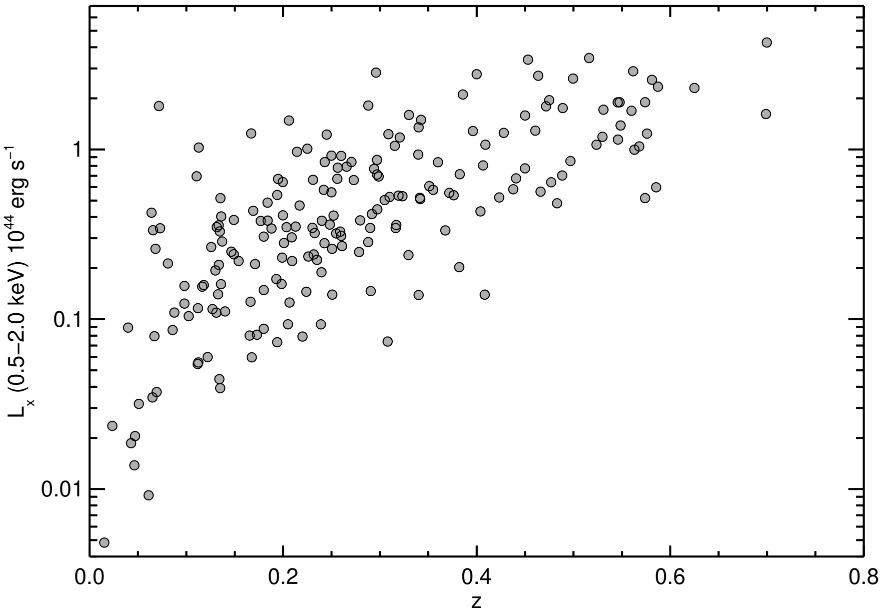

Fig. 1.2. X-ray luminosity and redshift distribution of the 160SD cluster sample. The median redshift is $z_{\mathrm{median}} = 0.25$ and the median X-ray luminosity is $L_{\mathrm{X,median}} = 4.2 \times 10^{43}$ erg s^{-1}.

1.2 Revised Cluster Sample with Spectroscopic Redshifts

Since the initial follow-up observations we have gone on to measure spectroscopic redshifts for 110 additional clusters from our 160SD survey using the Keck-II 10m and the University of Hawai‘i (UH) 2.2m telescopes at the Mauna Kea Observatories, and the ESO 3.6m telescope at La Silla Observatory. Combining these new redshifts with 76 measurements reported by V98 and 14 redshifts from the literature and private communications results in essentially complete (200 of 201 clusters) spectroscopic coverage for our entire sample. In general the photometric redshifts were quite reliable. The membership of the 160SD cluster sample has proven to be remarkably stable since first presented by V98. The revised sample consists of 201 confirmed clusters, 21 false detections, and one source obscured by Arcturus.

1.3 Cluster Evolution

We have the three requirements for testing evolution in the number density of clusters. First we have a statistically complete sample which probes sufficiently high luminosity and redshift (Figure 1.2) where differential evolution should be strongest. Second we have accurately measured the survey selection function via extensive Monte Carlo simulations (Figure 1.3) which permits us to compute reliable search volumes necessary for constructing volume-normalized diagnostics. And finally, the local X-ray luminosity function (XLF), which forms the baseline for the no-evolution scenario, is well determined.

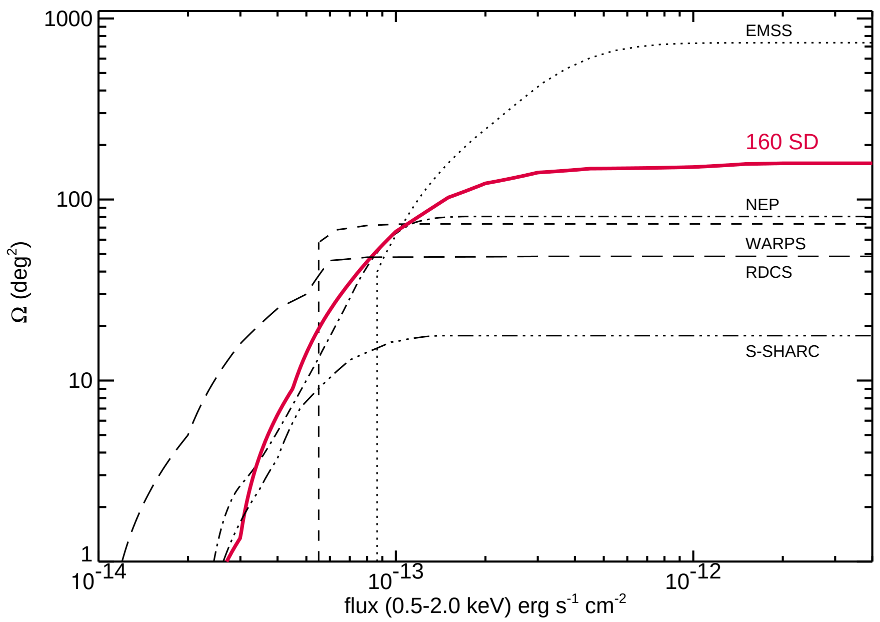

Fig. 1.3. The sky coverage of various *ROSAT* cluster surveys along with the EMSS. The survey selection of the 160SD survey is highlighted. References for the surveys: EMSS, Henry et al. 1992; NEP, Mullis 2001; WARPS, H. Ebeling 2000, private comm.; RDCS, Rosati et al. 1995; S-SHARC, Burke et al. 1997.

We present the high-redshift XLF in Figure 1.4. At lower luminosities the abundance is in good agreement with the local value. However, at higher luminosities ($>3 \times 10^{44}$ erg s^{-1}) there is a systematic departure from the no-evolution curve. We can quantify this cluster deficit by comparing the number of detected clusters versus the expected number computed by folding the local XLF through our selection function. Between $0.3 < z < 0.8$ and above 3×10^{44}, we find 3 clusters where 15 (20, 25) clusters are predicted using the BCS (REFLEX, RASS1BS) XLF as the no-evolution baseline. This deficit is significant at the 3.5 (4.5, 5.2) sigma level. In Figure 1.5 we show that the false detections can not resolve this mismatch because the implied luminosities are too low.

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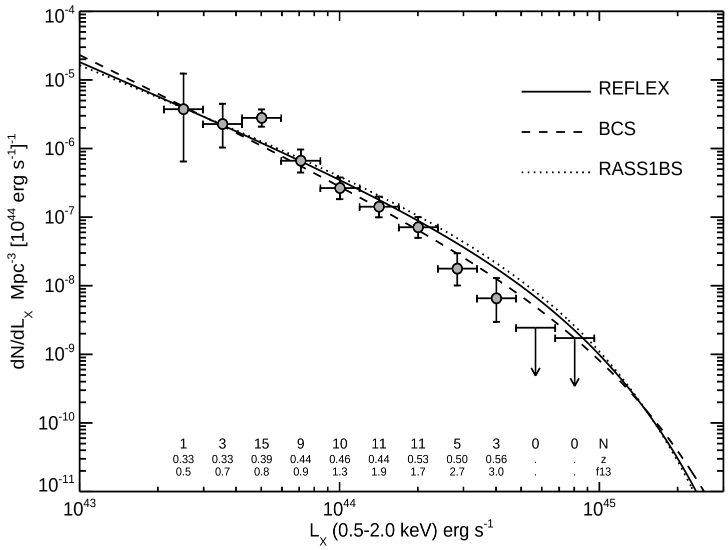

Fig. 1.4. High-redshift 160SD cluster XLF ($z = 0.3$–0.8). Note the deficit of clusters above 3×10^{44} erg s^{-1}. In this luminosity-redshift interval 3 clusters are detected where 15 (20, 24) clusters are predicted using the BCS (REFLEX, RASS1BS) XLF as the no-evolution baseline.

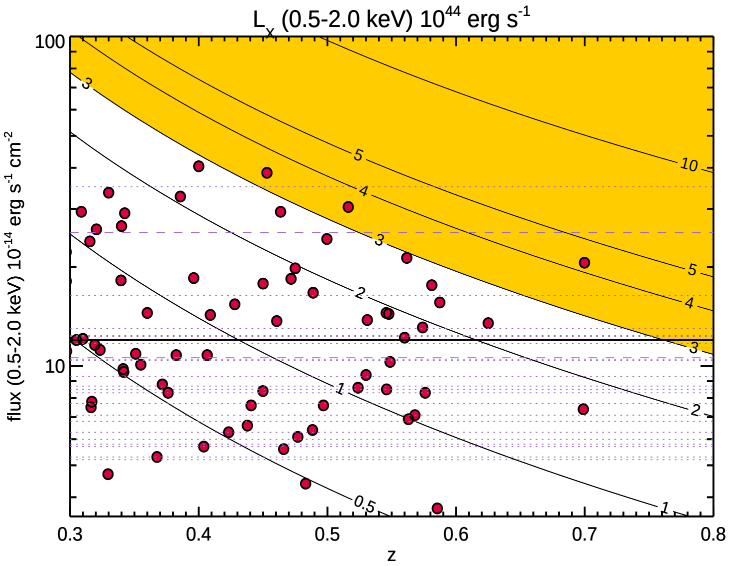

Fig. 1.5. X-ray flux versus redshift for the 73 clusters of the 160SD sample at $z > 0.3$. Isocontours of X-ray luminosity (10^{44} erg s^{-1}) are overplotted. The luminosity regime of the observed cluster deficit is shaded. The "missing" clusters would be high-flux sources. The flux of the 21 false detections of the 160SD survey are represented by the dotted horizontal lines.

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