THE BRIGHT SHARC SURVEY: THE CLUSTER CATALOG

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INTRODUCTION

Clusters of galaxies play a key role in constraining cosmological models. It has been shown (e.g. Oukbir & Blanchard 1992; Carlberg et al. 1997; Henry et al. 1997; Sadat et al. 1997; Viana & Liddle 1999) that measurements of the cluster number density, and its evolution, play an important role in the derivation of the mean mass density of the Universe, \( \Omega_m \). At present, there is a large dispersion in the values of \( \Omega_m \) derived from measurements of the cluster number density; e.g. \( \Omega_m = 0.2^{+0.3}_{-0.1} \) (Bahcall & Fan 1998), \( \Omega_m = 0.4^{+0.3}_{-0.2} \) (Borgani et al. 1999), \( \Omega_m = 0.5^{+0.14}_{-0.05} \) (Henry et al. 1997), \( \Omega_m = 0.85^{+0.2}_{-0.1} \) (Sadat et al. 1998), \( \Omega_m = 0.96^{+0.36}_{-0.12} \) (Reichart et al. 1999).

To fully exploit clusters as cosmological tools one needs to have access to large, objectively selected, cluster cata-

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logs which cover a wide redshift range. Most cluster catalogs constructed prior to 1990 had a very limited redshift range and were not constructed in an objective manner (e.g. Abell 1958; Abell, Corwin & Olowin 1989). However, recent developments, such as CCD mosaic cameras, optical plate digitizers and imaging X-ray satellites, have resulted in a growing number of high quality cluster catalogs. These include optically selected cluster samples derived from digitized plate material, e.g. the EDCC (Lumsden et al. 1992) and the APM (Dalton et al. 1998) and the ESO Imaging Survey (Lobo et al. 1998). X-ray selected cluster samples derived from imaging X-ray satellite data include those from the Einstein mission, e.g. the EMSS cluster sample (Gioia et al. 1990), and those from the ROSAT (Trumper et al. 1993) mission.

The various ROSAT cluster catalogs divide into two categories; those based on ROSAT All-Sky Survey (RASS) data and those based on ROSAT pointing data. The former includes the SRCS (Romer 1993), XIBACS (Ebeling et al. 1991), BCS (Ebeling et al. 1991), RXFES (Bohringer et al. 1998), De Grandi et al. 1999) and NEP (Gioia et al. 1993, Henry 1997) surveys. Examples of surveys based on ROSAT pointing data are the SHARC (Collins et al. 1999), RIXOS (Castander et al. 1996), RDCS (Rosati et al. 1998), WARPS (Jones et al. 1998) and 160deg2 (Vikhlinin et al. 1998b) surveys. The ROSAT instrument of choice for cluster surveys has been the PSPC, which combines imaging capabilities with a large field of view (2° in diameter), low background contamination and some spectral resolution. The angular resolution of the ROSAT PSPC is better than that of Einstein, allowing one to take advantage of the extended nature of cluster emission to distinguish clusters from X-ray point sources, e.g. AGN and quasars. Moreover, the enhanced sensitivity of ROSAT over Einstein means that ROSAT cluster surveys can reach fainter flux limits than the EMSS.

The RASS surveys have yielded several important insights into the clustering properties (Romer et al. 1994) and evolution (Ebeling et al. 1997; De Grandi et al. 1999) of the z < 0.3 cluster population. At higher redshifts, the ROSAT pointing data surveys have shown that there is no evidence for evolution in the cluster population at luminosities fainter than Lx = 5 x 1044 erg s−1 [0.5-2.0 keV] and redshifts less than z ∼ 0.7 (Nichol et al. 1997; Burke et al. 1997; Collins et al. 1997; Vikhlinin et al. 1998b; Rosati et al. 1998; Jones et al. 1998; Nichol et al. 1999). At brighter luminosities, the 160deg2 and Bright SHARC surveys, have provided evidence for negative evolution (Nichol et al. 1999; Vikhlinin et al. 1998b) similar to that seen in the EMSS cluster sample (Henry et al. 1992; Reichart et al. 1994).

The SHARC (Serendipitous High-Redshift Archive ROSAT Cluster) survey was designed to optimize studies of X-ray cluster evolution and combines two complementary surveys; a narrow area deep survey and a wide area shallow survey. The former, known as the Southern SHARC, has been described elsewhere, (Collins et al. 1997; Burke et al. 1997). We introduce the latter survey, the Bright SHARC, here. Unlike the Southern SHARC, the philosophy of the Bright SHARC has been to achieve maximum areal coverage rather than maximum sensitiv-
include several pointings in the survey which had intrinsically extended central targets, e.g. galaxies and clusters – as long as those targets did not extend beyond 2.5. We discuss cases where Bright SHARC clusters are detected in pointings with cluster targets in Table 2 (see §3) and §4.

The 178 pointings listed in appendix B were not included in the Bright SHARC because either an extended X-ray (or optical) source covers most of the field of view, or the pointing is within < 6° of the Magellanic clouds. Extended X-ray and optical objects include low redshift Abell clusters and Galactic globular clusters. The pointings listed in Appendix B were removed after visual inspections of the reduced X-ray data and the Digitized Sky Survey. Despite its subjective nature, this procedure does not undermine the serendipitous nature of the SHARC survey, since it was performed before the cluster candidate list was constructed. We have indicated in column 7 of appendix B why each pointing was rejected from the survey.

3. SOURCE DETECTION

Our source detection algorithm was based on wavelet–transforms \(\text{Slezak et al. 1990}\). For our purposes, we required a detection algorithm which (i) was sensitive to both extended and point–like sources, (ii) worked in crowded fields and (iii) took into account a varying background level. Moreover, we wanted our method to be as simple as possible, so that we could define our selection function \textit{a posteriori} using simulations. With these concerns in mind, we chose to convolve the PSPC count rate maps with a spherically symmetric, “Mexican-hat” wavelet. This wavelet, in one dimension, is given by:

\[
w(x) = (1 - \frac{x^2}{a^2}) e^{-\frac{x^2}{a^2}},
\]

and is the second derivative of a Gaussian \(\text{Slezak et al. 1990}\) of width \(\sigma = a\). The radially averaged point–spread function of the ROSAT PSPC can be approximated to a Gaussian (Hasinger et al. 1992), so this wavelet is well suited to the detection of sources in PSPC images. An additional attraction of this wavelet is that it can be used to determine the extent of a source, since it has a width of \(2 \times a\) at its zero–crossing points. A wavelet transform of a PSPC count rate map will, therefore, produce a wavelet coefficient map in which all the sources are bounded by a ring of zero values. The diameter of these zero crossing rings provides a direct measure of the source’s extent in wavelet space.

Ideally, “a” should be scaled logarithmically to provide statistically independent wavelet images over the whole range of real and k-space. For any given source, the wavelet coefficient will have a maximum when the value of “a” matches the sigma of the best fit Gaussian. However, the use of multiple wavelets would make \textit{a posteriori} simulations of the selection function very complex and CPU intensive. We therefore decided to use only one wavelet convolution \(a = 3\) pixels or 45° in our source detection pipeline. This particular wavelet was found, empirically, to be the best compromise between smaller wavelets, which tended to fragment extended sources, and larger wavelets, which tended to blend neighboring sources. The penalty for this simplification was the inclusion of some blended sources in our extended candidate list (§3) and underestimated cluster count rates (§4).

Sources were identified in the wavelet coefficient map by selecting pixels with coefficients above a given threshold. This threshold was set, empirically, to be 7 sigma above the peak of the coefficient distribution. The thresholding technique only highlights the cores of each source, since that is where the wavelet coefficients are highest, so a “friends–of–friends” analysis was run to identify other associated pixels. This was done by growing the sources outwards in the wavelet coefficient map until they reached the zero crossing ring. Once the source boundaries were defined, best fit centroids and ellipses were computed. A filling factor was also derived for each source. This was defined as ratio of the area within the fitted ellipse to the area within the zero–crossing boundary. For \(f = 1\), the ellipse fits the source shape exactly, while \(f >> 1\) indicates the presence of blended sources (dumb-bell shapes) or percolation runaways (filamentary shapes).

In total, 10,277 sources were detected in the 460 pointings. To keep track of all of these sources, and their boundaries, a mask file was generated for each pointing so that pixels associated with sources could be distinguished from those that were not. For each source, a 51 × 51 pixel box, with the source at its center, was extracted from the count rate map. An average background for the box was calculated using all pixels not flagged as belonging to sources. The count rate for the central source was then derived by subtracting this background (appropriately scaled) from the sum of the pixels enclosed by the source boundary. We used this method because it was easy to apply to the thousands of sources detected in the Bright SHARC Survey. (We will refer to the count rates derived in this manner as “wavelet count rates”, \(cr_{w}\), hereafter.) However, the method has the disadvantage of underestimating the true count rate if the source is extended beyond the wavelet boundary (in §4 we describe an alternative method used to derive count rates for known clusters). An approximate signal-to-noise value for each source was also calculated using the count rate uncertainty maps produced by ESAS. It should be noted that certain pixels, those which received less than half the exposure time of the central pixel in the count rate maps, were not included in the “friends–of–friends” analysis. Such pixels included those in the shadow of the PSPC window support structure and those at the edge of the field of view. These regions, which are noisier than those that were well exposed, were not used to define source centers, shapes or wavelet count rates.

4. SELECTION OF CLUSTER CANDIDATES

The majority of X-ray sources can be considered point like in their spatial properties, e.g. stars and AGN. In the minority are objects with complex and extended X-ray profiles, such as supernova remnants, galaxies and clusters of galaxies. Of these, only clusters are large enough and bright enough to be detected as extended beyond \(z \simeq 0.1\). Therefore the strategy adopted by the SHARC has been to search for clusters only among those ROSAT sources that have a significant extent. This reduces the required optical follow-up significantly. The disadvantage of this approach, however, is that some clusters, e.g. those with compact surface brightness distributions, may be excluded from the survey.
Bright SHARC Cluster candidates were selected from the 10,277 sources found in the survey using the following six criteria: The source had to (i) have a signal-to-noise ratio greater than 8, (ii) its centroid had to fall within 90 pixels (22.4') of the pointing center, (iii) its centroid had to fall more than 10 pixels (2.5') from the pointing center, (iv) its filling factor had to be less than \( f = 1.3 \), (v) it had to be more than 3\( \sigma \) extended and (vi) it have to have a count rate higher than 0.01163 counts s\(^{-1}\). The imposition of these criteria cut down the source list from 10,277 (total) to 3,334 (criterion i) to 1,706 (criterion ii) to 374 (criterion iii) to 94 (criterion iv). Criterion (i) was imposed because it has been shown (Wirth & Ber-Ish, in preparation) that extent measures can only be derived with confidence for sources meeting a minimum signal-to-noise threshold. Criterion (iii) was applied to avoid including the intended target of the pointing in the candidate list. Criterion (iv) was set empirically with the aim of reducing the number of blended sources and per- culation runaways in the candidate list. The rationale for the other criteria is provided below.

The point-spread function of the PSPC degrades significantly as one moves out from the center of the detector (Hasinger et al. 1992). It therefore becomes increasingly difficult to distinguish extended sources from point sources as the off-axis angle increases. To overcome this, we used all 3334 of the S/N > 8 in our survey to study statistically how source size varies as a function of position on the PSPC. The method used has been described previously (Nichol et al. 1997), but we include an overview here for completeness. Figure 1 shows the distribution of source size (as defined by the lengths of the major and minor axes of the best fit ellipses) as a function of off-axis angle. After collecting these data into 10 pixel bins, we were able to determine how the mean and FWHM of the distribution varied with off-axis angle. (Beyond an off-axis angle of 90 pixels, the dispersion in source sizes became too large to define a reliable FWHM, hence the imposition of criterion ii.) Under the assumption of a Gaussian distribution, the FWHM values were converted into sigma values and a three sigma cut was determined by fitting a 4th order polynomial to the [mean+3\sigma] values. A source was defined to be extended if it had a major and/or a minor axis more than 3\( \sigma \) from the mean.

In total, 374 sources were found to meet criteria (i) through (vi). These are listed in Appendix E in right ascension order. Wavelet countrates (cr\( _W \)) are given for each source in units of \( 1 \times 10^{-2} \) counts s\(^{-1}\) (column 4). We note that duplicate entries, e.g. RX J0056.5-2730 – which was detected in two pointings, wp700528 and rp701225m00 – have not been excised from this list. The fluxes for these 374 sources (assuming thermal spectra see 12) range from 0.2 \( \leq \) \( f_{-3} \leq 40 \). In the interests of completing the optical follow-up in a timely fashion, it was decided to concentrate only on the brightest of these 374. An arbitrary count rate cut (cr\( _W > 0.01163 \)) was imposed to reduce the sample size to roughly 100 (criterion vi). At the redshift of the most distant cluster in the EMSS sample (\( z = 0.81 \)), this count rate corresponds to a luminosity of \( \sim 3.9L_{44} \), which is approximately equal to locally determined values of \( L_\ast \), e.g. \( L_\ast = 5.7L_{44} \) (Elbing et al. 1997), \( L_\ast = 3.8L_{44} \) (De Grandi et al. 1999a).

The total areal coverage of the Bright SHARC survey is 178.6 square degrees. This value was determined by calculating the area available for candidate detection in each of the 460 pointings in the survey. This area includes all pixels at radii greater than 2.5 and less than 22.4 which had exposure times more than half that of the central pixel and (ii) did not overlap pixels in a higher exposure pointing. (There were 21 pairs of pointings with some overlap between them.)

5. IDENTIFICATION OF EXTENDED SOURCES

We present the 94 unique\(^7\) extended sources in the Bright SHARC survey in Table 1 and Appendix C. For each candidate, we provide the source name (column 1), its J2000 position (columns 2 & 3), the wavelet count rate [0.4-2.0 keV] (cr\( _W \) in units of \( 1 \times 10^{-2} \) counts s\(^{-1}\) column 4), the pointing in which it was detected (column 5), the source type (column 6), and the method used to identify the source (column 7). Alternate source names and redshifts (where available) are listed in column 8. We note that Abell clusters (Abell 1958, Abell, Corwin & Olowin 1989) are denoted by ‘A’. Likewise for EMSS sources (MS, Stocks et al. 1991), 160 deg\(^2\) clusters (‘V’, Vikhlinin et al. 1998a, V98 hereafter), Hickson groups (‘HCG’, Hickson 1982) and Zwicky clusters (‘Z’, Zwicky et al. 1968). When an object is listed in more than one catalog, we have defaulted to the name given in the older catalog, e.g. for RX J0237.9 we have listed the Abell number (A3038), not the V98 number (V28).

In Appendix C, we present small (6’.6 x 6’.6) Digitized Sky Survey (DSS) images of each of the 94 extended sources listed in Table 1. The source outlines, as defined by our friends-of-friends analysis are overlaid on these images. We note that the source centroids were defined in a weighted fashion and do not necessarily coincide with the geometric center of the source outline. No external astrometric solution was applied before making these DSS images, because the expected pointing offset is much smaller (\( \lesssim 6'' \)) than the typical size of one of our extended sources.

In some cases it was possible to identify the source using the DSS images alone. For example, the X-ray emission from source RX J0324.6-5103 is clearly associated with a bright star (HD21360). This source was flagged as extended because emission from the star was blended by the friends-of-friends analysis with the (fainter) emission from a neighboring point source. (The X-ray surface brightness contours for this source show a secondary peak centered on the faint DSS object to the lower left of the source outline.) In other cases, the source outline, and/or the surface brightness contours, are indicative of blended emission but no obvious counterpart could be found on the DSS images, e.g. RX J0947.8+0741. When the DSS (or X-ray) images played a role in the identification of a source, a ‘D’ (or ‘X’) is listed in column 7 of Table 1.

A search of the NASA/IPAC Extragalactic Database (NED) has also provided useful information for several of the Bright SHARC extended sources, including some cluster redshifts e.g. for RX J1204.0+2807 (MS1201.5, Gioia et al. 1999b). When NED yielded information was used during the source identification, an ‘N’ is listed in column 7.

\(^7\)Duplicate entries for RX J0237.9-5224 and RX J1211.2+3911 have been removed.
of Table.

Optical follow-up of Bright SHARC extended sources has been carried out at a number of telescopes; the 3.5m ARC telescope at Apache Point Observatory, the Danish 1.5-m and 3.6-m telescopes at the ESO Southern Observatories, the 1.5-m telescope at the Cerro Tololo Inter-American Observatory, the 3.6-m Canada France Hawaii Telescope on Mauna Kea and the 4-m Mayall telescope at Kitt Peak National Observatory. Optical follow-up includes CCD imaging, long slit spectroscopy and multi-object spectroscopy. Of the 94 extended sources, to date 57 have CCD images and 51 have been the target of spectroscopic follow-up. A ‘C’ in column 7 of Table indicates that a CCD image is available, whereas an ‘S’ indicates spectroscopic follow-up by the SHARC collaboration and an ‘O’ indicates that spectroscopy came from private communications. To date, 91 of the 94 Bright SHARC extended sources have been identified: 37 clusters, 41 blends, 9 galaxies and 3 galaxy groups. The symbols ‘+’? in column 8 indicate that the identification of one of the components of a blended source is unknown. We note that the distinctions between galaxies and groups (see §4), and between groups and clusters, are not absolute at the low luminosity end. For the 12 extended objects (9 galaxies and 3 groups) at redshifts less than z = 0.07, we based our classifications on the information provided by NED.

6. THE BRIGHT SHARC CLUSTER SAMPLE

The thirty-seven clusters in the Bright SHARC are listed in Table 2. For each cluster, we list the source number (column 1), the cluster redshift (column 2), the hydrogen column density (in units of 1×10^{20} cm^{-2}, column 3), the major and minor axes (in units of 14.947 pixels, columns 4 & 5), the offset angle of the cluster centroid (in units of 14.947 pixels, column 6), the wavelet ($\delta_{cr}$) and total ($\delta_{TT}$) count rates [0.4-2.0 keV] (in units of $1 \times 10^{-2}$ counts s^{-1}, columns 7 & 8), the percentage error on $\delta_{TT}$ ($\delta_{cr}$, column 9), the aperture containing 80% of the flux from a model cluster profile ($r_{80}$, column 10, see §6.1), the fraction of that aperture used to measure the cluster count rate ($f_{80}$, column 11), the total flux [0.5-2.0 keV] ($f_{13}$, in units of $1 \times 10^{-15}$ erg s^{-1} cm^{-2}, column 12), the corresponding luminosity ($L_{44}$, in units of $1 \times 10^{44}$ erg s^{-1}, column 13), and the temperature used to derive the flux and luminosity (T, in units of keV, column [14]). Various notes, including alternative cluster names and pointers to the information on the pointing target (if that target was a cluster) are given in column (15).

The redshift distribution ($z=0.266$) for the 37 Bright SHARC clusters is shown in Figure 3. The highest redshift, and most luminous, cluster in the sample is RX J0152.7 ($z=0.83$). The lowest redshift cluster in the sample is RX J0232.1 ($z=0.0696$). Twenty-one of the redshifts in Table 2 are presented here for the first time. These 21 include 17 clusters which have not been listed before in any published catalog and 4 clusters from the 160 deg^2 survey (V98). We describe below how the count rates ($\delta_{TT}$) and fluxes/luminosities ($\delta_{TT}$) were derived.

6.1. Total Cluster Count rate Derivation

The method described in §4, to measure wavelet count rates for all 10,277 sources in the Bright SHARC survey, was adopted because it was easy to apply to large numbers of sources. However, the method is not optimal for measuring cluster fluxes. This is because no correction is made for cluster flux falling outside the zero crossing boundary. Moreover, when a portion of a cluster overlaps a masked out region (e.g. regions in the shadow of the support struts), the flux from that region will not be included in the count rate. Therefore, for the 37 sources identified with clusters of galaxies, we have performed a second count rate determination based on the method adopted by Holden et al. (1997). For each of the clusters, we derived an aperture for the flux measurement using a cluster model based on a modified isothermal sphere:

$$I = \frac{I_0}{[1 + (r/r_c)^2]^{\beta - 1/2}},$$

where I is the surface brightness at radius r. We used values for the slope ($\beta = 0.67$) and core radius ($r_c = 250$ kpc) which are typical for rich clusters (Jones & Forman 1992) and then converted the model from physical units to angular units using the cluster redshift. The cluster models were convolved with the appropriate off-axis PSF (Nichol et al. 1994a) so that the radius of a circular aperture, $r_{80}$, which contained $\approx 80\%$ of the total model flux could be defined (for $\beta = \frac{3}{2}$, $r_{80} = \sqrt{241}r_c$). The choice of $r_{80}$ for the aperture represents a compromise between including a high fraction of the cluster flux and keeping down the number of contaminating sources within the region.

The 80% radii, $r_{80}$, are listed in column 10 of Table 2 in units of 14.947 pixels. Since these radii could be quite large, up to 40 pixels, some of them overlapped other sources. If any $r < r_{80}$ pixels lay within the wavelet-defined boundary of another source, they were masked out from the cluster aperture. Also masked were any pixels that received less than half the exposure time of the central pixel in the count rate map. By reference to the cluster model, it was possible to correct for the fraction of cluster flux lying in these masked regions. In column 11 of Table 2, we list the fraction of the 80% aperture available for flux determination, $f_{80}$. The raw aperture count rates for each of the 37 clusters were measured by summing the flux in the unmasked $r < r_{80}$ pixels.

The corresponding background count rates were measured inside 120 × 120 pixel boxes centered on the cluster position. The background levels were measured in annuli with minimum radii of $1 \times r_{80}$ and maximum radii $3 \times r_{80}$. If these annuli overlapped any source boundaries, any low exposure pixels, or the edges of the 120 × 120 pixel box, the pixels in those regions were excluded from the background calculations. In Appendix D we illustrate the masked out regions for the source and background apertures for each of the 37 Bright SHARC clusters. After subtraction of the appropriately scaled background, the total cluster count rates were derived by dividing by ($0.8 \times f_{80}$). The background subtracted, aperture corrected, total cluster count rates ($\delta_{cr}$) are listed in column 8 of Table 2. The one sigma errors on the total cluster count rates are listed in column 9 of Table 2. These errors were calculated by adding in quadrature the counting errors on the cluster count rates and the background count rates. We draw attention to three SHARC clusters with anomalously high (>15%) count rates errors; RX J0250.0, RX J1524.6, RX...
J1222.1. These clusters have much lower signal to noise values inside the \(cr_T\) apertures than in the \(cr_W\) apertures, demonstrating that the adopted cluster model (equation 2) significantly over estimates the size of the aperture which encircles 80% of the source flux. The count rate errors are quoted as percentages since, in the absence of systematic errors in the count rate to flux/luminosity conversions (8.1-2), they should also reflect the percentage errors on the flux \((f)\). The count rate errors of less than 10% it is worth making the exception. In order to sample the observed distribution of cluster redshifts and column densities, and the expected distribution of cluster temperatures, we derived conversion factors over the following ranges; \((i)\) 0.06 \(< z < 0.86\) (in increments of \(\delta z = 0.05\)), \((ii)\) 0\(<H<20\times10^{20}\) cm\(^{-2}\) (in increments of 1 \(\times10^{20}\) cm\(^{-2}\)), and \((iii)\) 1\(<T<12\) keV (in increments of 1 keV). (When a cluster redshift or column density was not exactly matched by one of the matrix entries, linear interpolation was used.) As expected, the count rate to flux conversion varied most rapidly along the column density axis of this matrix, however changing the redshift also had a measurable effect (by a factor of \(\approx 2\) over the range 0.08 \(< z < 0.8\)). Estimates of the bolometric and k-corrections were also derived, as a function of temperature, using XSPEC.

The luminosity derivation included an iteration to obtain an estimate of the X-ray temperature for each cluster, using the luminosity–temperature (L-T) relation presented in Arnaud & Evrard (1999). From a starting point of \(T=6\) keV an initial \([0.5-2.0]\) keV luminosity was derived. This luminosity was then converted into a pseudo bolometric luminosity, so that a temperature estimate (to the nearest integer in keV) could be derived. The new temperature was used to select a second count rate to flux conversion from the matrix and the process was repeated until convergence was reached. The temperature used in the final luminosity calculation is listed in column 14 of Table 2. In the past, the luminosity-temperature (L-T) relation was not so well known and other groups have adopted a single temperature, usually 6 keV, for their luminosity calculations. Using the Arnaud & Evrard (1999) L-T relation, 6 keV corresponds to a cluster of \(L_{44} \approx 6\). Most of the clusters in Table 2 are significantly fainter than this, meaning that the use of a canonical temperature will yield inaccurate results, especially for the lowest luminosity clusters. This is illustrated by the faintest (and hence, coolest) cluster in our sample (RX J1524.6) which has a luminosity of \(L_{44}=0.065\) when a temperature of \(T=1\) keV is assumed and a luminosity of \(L_{44}=0.072\) when a temperature of \(T=6\) keV is assumed (an 11% effect). By contrast the effect is smaller (5%) for the hottest cluster in our sample; RX J0152.7 has a luminosity of \(L_{44} = 8.26\) when a temperature of \(T=9\) keV is assumed and a luminosity of \(L_{44}=8.65\) when a temperature of \(T=6\) keV is assumed. It is worth mentioning that the L-T relation we use (Arnaud & Evrard 1999) was constructed from clusters known not to contain cooling flows. Another recent work (Allen & Fabian 1998) combines both non-cooling flow and cooling flow clusters and fits a flatter slope to the L-T relation (2.4 compared to 2.9). Unfortunately, the poor photon statistics of the Bright SHARC cluster sample do not allow us to test for the presence of cooling flows and so our choice of L-T relation will be inappropriate in some cases. Finally, we note that the conversion between cluster count rate and cluster luminosity is a function of the adopted Hydrogen column densities adopted for each cluster are listed in column 3 of Table 2. These values were derived using the AT&T Bell Laboratories 21 cm survey (Stark et al. 1993), for clusters north of \(\approx 40^\circ\), and the values presented in Dickey & Lockman (1990) for clusters at lower declinations. We have constructed a matrix of count rate to flux conversions of Raymond and Smith (Raymond & Smith 1977). The integrated emission from a Raymond-Smith spectrum typical in X-ray cluster analyses, we adopted an emission model for each cluster to make the conversion between measured cluster count rate and unabsorbed flux. As is usual in X-ray cluster analyses, we used an emission spectrum from hot, diffuse gas based on the model calculations of Raymond and Smith (Raymond & Smith 1977). The integrated emission from a Raymond-Smith spectrum in the SHARC energy band (observer’s rest frame) depends on several factors; the metallicity and temperature of the gas, the redshift of the cluster, and the absorption column along the line of sight. This means that the conversion between measured aperture count rate and cluster luminosity is non trivial and must take into account the specific properties of each cluster. We note that, in most cases, the dominant source of error in the derived luminosities comes from the count rate uncertainty, which rises to 30% in the case of RX J1524.6. However, for those clusters with well determined count rates (30 clusters have count rate errors of less than 10%) it is worth making the extra effort to reduce the systematic errors in the conversion between count rates, fluxes and luminosities.

\[\text{We have constructed a matrix of count rate to flux conversion factors as a function of temperature, redshift and absorbing column. (A single, canonical, value for the metallicity – one third the Solar value – was used throughout.)} \]

The conversion factors were derived using the \texttt{fakeit} command in XSPEC (version 10.00, Arnaud et al. 1996) together with the appropriate ROSAT PSPC response function. Photo-electric absorption was included via the XSPEC \texttt{wabs} model, which is based on cross sections presented in Morrison & McCammon (1983). The neutral

\[\text{8An energy range of 0.01-50 keV was used to calculate the (pseudo) bolometric corrections, which were found to be in excellent agreement with those presented in Figure 2 of Borgani et al. 1999.} \]
values of Hubble’s Constant and the deceleration parameter and that we have used $H_0=50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0=0.5$ throughout.

7. DISCUSSION

In a companion paper (Nichol et al. 1999, N99 hereafter) we use the Bright SHARC sample to examine evolution in the X-ray cluster luminosity function (XCLF). Future papers will go on to use these evolution results to constrain the density parameter $\Omega_m$. It is appropriate, therefore, to discuss here some of the observational issues relevant to $\Omega_m$ analyses. These issues include systematic biases in the derived luminosities (§6.1) of the Bright SHARC clusters and any possible contamination (§6.2), or incompleteness (§6.3) in the Bright SHARC catalog. We also discuss the possible discovery of three “fossil groups” (§6.4) and our overlap with the 160 deg$^2$ survey of V98 (§6.5).

7.1. Luminosity Bias in the Bright SHARC Cluster Sample

A systematic bias in our luminosities would result in an over (or under) estimate of the number density of high luminosity systems. To investigate whether such a systematic bias exists, we have compared the luminosities quoted in column 13 of Table 2 with published values for the six clusters we have in common with the EMSS (Gioia et al. 1993): RX J1024.3 (MS1020.7 or A981), RX J1204.0 (MS1201.5), RX J1211.2 (MS1208.7), RX J1222.1 (MS1219.9), RX J1311.2 (MS1308.5), RX J2258.1 (MS2255.7 or Z2255.5). We have chosen to compare our luminosities for these clusters with those presented in the N97 study used the SHARC pipeline to produce count rate maps. A comparison of the two sets of luminosities will, therefore, show if the methodology outlined in sections 6.1 & 6.2 since they will allow us to (i) more accurately excise contaminating sources in the cluster aperture, (ii) use fitted, rather than canonical, values for $\beta$, $r_c$, and the ellipticity, (iii) be less sensitive to errors in the background calculation and (iv) improve our spectral dependent count rate to flux conversions.

7.2. Contamination of the Bright SHARC Cluster Sample

The thorough, multi-object, spectroscopic follow-up of the Bright SHARC extended source list means that it is highly unlikely that any of the entries in Table 2 are mis-identified contaminants. However, we stress that there are two clusters in that table which should not be used for studies of the cluster XCLF because their detections are not truly serendipitous: RX J1024.3 and RX J1541.1 were found in cluster pointings and lie at redshift separations from the pointing target of $\delta z < 0.002$, or $cz < 600$ km s$^{-1}$. These clusters are probably associated with the pointing target via the cluster correlation function (Komer et al. 1994; Nichol et al. 1994b). In addition, we find that RX J1222.1 (MS1219.9) warrants further study: This object is very compact, has a large count rate uncertainty (§6.1) and Gioia & Luppino (1994) note that its central galaxy has emission lines. It is possible, therefore, that the luminosity quoted in Table 2 is an overestimate due to AGN contamination. (Although, it should be noted that the presence of emission lines in the central galaxy could be attributed to cooling flow nebulosity or star formation. Crawford et al. 1999). We note that the three clusters highlighted here (RX J1024.3, RX J1222.1 & RX J1541.1) have redshifts in the range $0.2 < z < 0.25$ and so were not used in the N99 analysis (which concentrated only on those clusters at $z > 0.3$).

7.3. Incompleteness of the Bright SHARC Cluster Sample

There are three possible ways in which the Bright SHARC cluster sample might be incomplete. First there are those clusters that did not meet our selection criteria. Second, there is a possibility that some clusters were misidentified as contaminants. Third, there are the three extended sources which have yet to be identified. We are using simulations to understand how the adopted selection criteria (§6.3) effects the completeness of the Bright SHARC cluster sample. We are in the process of carrying out a very thorough investigation of our selection function by adding many thousands of fake clusters (one at a time) to the pointings in our survey and then determining the fraction of these fake clusters that would have been selected as Bright SHARC cluster candidates. These simulations will provide us with the efficiency of cluster detection as a function of cluster parameters (e.g. redshift, luminos-
ity, ellipticity, core radius etc.) and operational parameters (e.g. exposure time, off-axis angle, Hydrogen column density, central target etc.). The results of these simulations will be presented elsewhere (Adami et al. 1999), but our preliminary findings are described in N99.

Let us now address possible cases where clusters might be misidentified as contaminants. We discuss first the two objects listed in Table as blends of a cluster with another source, RX J0318.2 & RX J2314.7. The former, RX J0318.2, is a blend of a cluster with a QSO. (The cluster has the same redshift as the neighboring cluster RX J0318.8, z=0.37). The surface brightness contours of RX J0318.2 are clearly dumb-bell shaped and so it has been possible to remove the QSO contribution from the total count rate. This object was also discovered as part of the Southern SHARC and Burke (1998) has determined the total count rate and luminosity of this cluster to be $c r_W = 0.01362$ count $s^{-1}$ and $L_{44} = 1.11$ respectively. Therefore, this cluster would not have made it into the Bright SHARC sample had it not been blended with the QSO and its exclusion for Table 2 is justified. By contrast, the boundary between the cluster and M-star emission for RX J2314.7 is blurred. Hence it is not possible to excise the M-star flux to see if the cluster alone has a high enough count rate (and extent) to qualify as a Bright SHARC candidate. If the M-star makes only a minimal contribution, less that 20%, to the total flux, then the cluster should have been included in Table 2. Assuming that all the RX J2314.7 flux comes from the cluster, the cluster would have a luminosity of $L_{44} = 1.31$.

As stated above, three of the 94 Bright SHARC extended sources remain unidentified. If all three were high redshift, high luminosity clusters, then there would be important implications for cluster evolution. In N99, we predict that the Bright SHARC survey should include 4.9 clusters with luminosities $L_{44} \geq 5$ in the redshift range $0.3 < z < 0.7$ (based on a simple extrapolation of the De Grandi et al. 19990 local XCLF). Since only 1 such cluster has been confirmed to exist in the Bright SHARC (RX J1210.1), we conclude in N99 that there may be evidence for evolution at luminosities brighter than $L_{44} = 5$. This evidence would effectively disappear if another 3 Bright SHARC clusters were added in this luminosity range. We stress, however, that it is very unlikely all these objects are clusters with luminosities brighter than $L_{44} = 5$; the CCD images of RX J0340.1 & RX J1705.6 are not consistent with the presence of distant clusters and RX J1838.8 is in a crowded star field (and so is most likely associated with a stellar X-ray source). We conservatively estimate that one these objects may be a cluster, given that the ratio of clusters to non-clusters among the other 91 identified sources is roughly 1:3. We have calculated that this cluster would have to reside at $z > 0.62$, $z > 0.57$ or $z > 0.51$, for RX J0340.1, RX J1705.6 and RX J1838.8 respectively, to have a luminosity greater than $L_{44} = 5$.

We also highlight candidate RX J1210.4. This object contains a QSO and has a compact X-ray surface brightness profile. Even though most of the flux from this source is probably coming the QSO, this object merits further study since a CCD image highlights a clustering of faint galaxies around the bright central object. The redshift of this source ($z=0.615$) and its high count rate ($c r_W = 0.1430$) mean that if more than 18% of the count rate from this source was coming from an associated cluster, then this cluster would have a luminosity greater than $L_{44} = 5$.

For the various reasons outlined above, we have decided to continue the follow-up of the Bright SHARC in a variety of ways. As a first priority, we plan to identify the three remaining unidentified Bright SHARC extended sources (RX J0340.1, RX J1705.6 and RX J1838.8). We also plan to obtain identifications for at least one portion of the seven “id-pending” blends listed in Table and to continue our campaign to obtain velocity dispersions for the Bright SHARC clusters. Moreover, we hope to obtain higher resolution X-ray images of complex sources such as RX J1210.4, RX J1222.1 and RX J2314.7, to help determine the contamination level.

7.4. Fossil Groups and Dark Clusters in the Bright SHARC Survey

We present evidence for the discovery of three new “fossil groups” (Ponman et al. 1994) or X-ray Over-Luminous Elliptical Galaxies (OLEGs, Vikhlinin et al. 1999). These objects are predicted to occur when a galaxy group relaxes to form a single elliptical galaxy. They are interesting because they provide invaluable insight into the processes of elliptical galaxy evolution, metal enrichment in the intra cluster medium, and the dynamics of extended dark halos (Mulchaey & Zabludoff 1998). Their observational signatures would be an isolated cD or giant elliptical galaxy surrounded by a cool ($T \approx 1$ keV), extended, X-ray halo. Two galaxies detected in the Bright SHARC survey appear to share these properties; RX J1730.6 (NGC6414, $z=0.05$) and RX J0327.9 (UGC2748, $z=0.03$). Applying the same method used to obtain total cluster count rates (8.2), we have measured their luminosities to be $L_{44} = 0.158$ and $L_{44} = 0.056$ respectively. In addition to these two galaxies, one of the Bright SHARC clusters, RX J0321.9 (A3120, z=0.0696, $L_{44} = 0.43$), also appears to display “fossil group” characteristics. We highlight these objects here since they are ideal targets for follow-up studies at X-ray and optical wavelengths. We have estimated the “fossil group” space density to be $\sim 2 \times 10^{-6}$ Mpc$^{-3}$ under the assumption that the Bright SHARC is 100% efficient in detecting extended sources in the redshift range $0.02 < z < 0.08$ and at luminosities of $L_{44} > 0.1$.

In addition to estimating the space density of “fossil groups”, we can comment on the space density of “dark clusters” or “failed clusters”. These objects are theorized to have cluster-like masses, and to radiate in the X-rays but to have an under luminous galactic component (Tucker et al. 1995, Hattori et al. 1997). We have successfully identified 91 of the 94 Bright SHARC extended sources and have found no evidence for “dark clusters”. To avoid detection in the Bright SHARC, these objects either must have a lower space density than rich clusters and “fossil groups”, or they must be intrinsically faint and evolve rapidly (to avoid detection at low redshift). In either case, “dark clusters” are unlikely to be a significant contribution to the mass of the universe.

7.5. Comparison with the 160 deg$^2$ Survey

10Assuming an absorbed Raymond Smith spectrum with an electron temperature of $T=1$ keV.
As pointed out by N99, it may be possible to combine the Bright SHARC with the 160 deg$^2$ survey (V98), to maximize the area available for high redshift cluster searches. The motivation for this is demonstrated by Figure 3, which shows several gaps in the redshift coverage of our survey. Even though we are able to find high luminosity clusters out to at least $z = 0.83$, we find none at $z \approx 0.5$ or $z \approx 0.7$. The only way to guarantee more $L_{44} > 3$ cluster detections would be to search over a wider area. The combination of the two surveys would yield a search area of $\approx 260$ deg$^2$, since only 44% (or $\approx 78$ deg$^2$) of the Bright SHARC Survey overlaps with the 160 deg$^2$ survey. (There are 201 pointings in common between the 160 deg$^2$ and Bright SHARC Surveys; Alexey Vikhlinin, private communication).

There are 13 sources in common between the Bright SHARC and the 160 deg$^2$ surveys. Of these 13, five clusters have not been followed up spectroscopically by either survey but rely on literature redshifts (RX J1010.2$^{11}$, RX J1204.0, RX J1211.2, RX J1311.2, RX J2258.1). An additional three clusters have both Bright SHARC and V98 redshifts (RX J0849.1, RX J1406.9, RX J1701.3); with the two redshifts being in agreement in all cases. We have also been able to provide spectroscopic information for five 160 deg$^2$ sources which previously relied on photometric redshifts; RX J0237.9 (V28), RX J0947.8 (V75), RX J1418.5 (V159), RX J1524.6 (V170), RX J1641.2 (V183). We have identified RX J0947.8 as a blend, the main component of which is a QSO$^{12}$ at $z = 0.63$ (Burke 1998). We confirm that the other four sources are clusters and we find that the photometric redshifts listed in V98 are good estimates of the true redshift, with the largest error being $\delta z = 0.065$ for RX J1641.2. This cluster has been shown to be at $z = 0.195$, giving it a luminosity of $L_{44} = 1.355$. It is not, therefore, a high redshift, high luminosity, cluster, as previously suggested by Vikhlinin et al. (1998$^{13}$), based on the upper limit of the estimated redshift ($z_{est} = 0.26^{+0.04}_{-0.07}$). In addition to the 13 sources described above, 77 other V98 clusters were detected in the 201 pointings common to the two surveys. Most of these clusters are too faint to have been included in the Bright SHARC sample, only 9 have wavelet count rates greater than the Bright SHARC threshold ($cr_w = 0.01163$). Of these 9, seven were not included in the Bright SHARC because they did not meet our filling factor criterion ($f < 1.3$), one was detected at an offaxis distance less than our threshold of 2.5 and one did not meet our extent criterion. Conversely, two clusters (RX J0256.5 and RX J1311.8) in Table 2 are not listed in V98, despite falling in common pointings, because they lie beyond the V98 offaxis limit of 17.5. These examples demonstrate how differing survey selection criteria produce differing cluster samples and that detailed simulations are required to determine a survey’s selection function.

There are eight confirmed $L_{44} > 3$ clusters in the Bright SHARC; RX J0152.7, RX J0256.5, RX J0318.5, RX J0426.1, RX J1241.5, RX J1120.1, RX J1334.3, RX J1701.3. The presence of so many clusters in the Bright SHARC has allowed us to show that the XCLF is non-evolving up to $L_{44} \approx 5$ (N99). It is important to note that, even after the combination of Bright SHARC and 160 deg$^2$ surveys, the areal coverage available for high redshift cluster searches will still be only about one third that of the EMSS at the bright end (Henry et al. 1992). This means that we will probably have to wait until larger area surveys are made available, e.g., from the XMM satellite (Romer et al. 2000), to make definitive statements about XCLF evolution at $L_{44} > 5$.

Appendices A through E have been ommitted from the astro-ph submission.$^{13}$

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$^{11}$RX J1010.2 was not included in Table 2 because its redshift ($z = 0.045$) is too low, i.e. $z < 0.07$.

$^{12}$Subsequent observations by Vikhlinin et al. have shown that this QSO most likely resides on the outskirts of a cluster at the same redshift (Alexey Vikhlinin, private communication).

$^{13}$The appendices are accessible from http://www.journals.uchicago.edu/ApJ/journal/issues/ApJS/v126n2/40418/40418.html.
Fig. 1.— The distribution of major and minor axes for the 3,334 S/N>8 sources in the Bright SHARC survey as a function of off-axis angle. The solid lines correspond to the fitted three-sigma extent curves; any sources falling above these lines are classified as extended. For illustration purposes, we have plotted, as open diamonds, the points corresponding to the thirty-seven Bright SHARC clusters on the major axis plot (the numerical values for these points can be found in Table [1]).
Fig. 2.— The wavelet count rate versus the total count rate for each of the thirty-seven clusters in the Bright SHARC sample. The low redshift \( (z < 0.15) \) clusters are indicated by circles. A least squares fit to the \( z > 0.15 \) clusters (diamonds) is shown by the dotted line (slope=2.1).

Fig. 3.— Redshift distribution of the thirty-seven clusters in the Bright SHARC.
Table 1
extended sources in the Bright SHARC survey

| Source RA (J2000) Dec | crw | Pointing ID | ID code | Notes |
|-----------------------|-----|-------------|---------|-------|
| RX J0031.0–3547 00 31 03.0 | -35 47 21.8 | 1.26 | wp800387n00 | Blend X S N C AGN, z=0.25 + ? |
| RX J0031.9–3556 00 31 59.5 | -35 56 12.1 | 1.19 | wp800387n00 | Blend X S C id pending |
| RX J0058.0–2721 00 58 00.5 | -27 21 29.3 | 1.18 | rp701223n00 | Blend S N C Mstar + ? |
| RX J0117.6–2338 01 17 36.5 | -23 38 13.5 | 1.25 | rp100376n00 | Cluster S N C A2894, z=0.207 |
| RX J0121.4+0932 01 21 08.4 | +09 58 25.9 | 1.54 | wp900147 | Cluster S C |
| RX J0124.9–1800 01 27 16.1 | -18 00 05.7 | 1.38 | rp900352n00 | Blend S C AGN, z=0.97 + ? |
| RX J0152.7–1357 01 52 42.0 | -13 57 52.9 | 1.79 | rp600005n00 | Cluster S O C |
| RX J0209.4–1008 02 09 58.1 | -10 08 04.2 | 1.34 | rp800114n00 | Cluster S N C |
| RX J0217.4–1800 02 17 26.1 | 1.18 | rp800016n00 | Cluster S O N C |
| RX J0223.4–0852 02 23 28.1 | -08 52 14.3 | 1.20 | rp800114n00 | Cluster S O N C |
| RX J0237.9–5224 02 37 59.1 | -52 24 45.7 | 2.32 | rp900352n00 | Cluster S C A3038, z=0.133 |
| RX J0318.2–0301 03 18 17.3 | -03 01 21.1 | 1.33 | wp800555n00 | Cluster, z=0.37 + AGN, z=0.233 |
| RX J0318.5–0302 03 18 33.3 | -03 02 46.7 | 2.76 | wp800555n00 | Cluster S C |
| RX J0321.9–5119 03 21 57.0 | -51 19 33.1 | 6.18 | wp800371n00 | Cluster N A3120, z=0.0696 |
| RX J0324.6–5103 03 24 37.9 | -51 03 52.1 | 1.32 | rp800016n00 | Cluster S O N C |
| RX J0327.9+0233 03 27 54.3 | +02 33 43.2 | 3.23 | rp700099m01 | Galaxy N UGC2748, cz=2421 km/s |
| RX J0337.5–2518 03 37 34.2 | -25 18 01.5 | 2.13 | rp700099m01 | Blend S C |
| RX J0340.1–4458 03 40 09.0 | -44 58 42.1 | 1.24 | rp800114n00 | Cluster S C |
| RX J0359.1–5300 03 59 11.9 | -53 00 56.2 | 1.51 | rp900308 | Blend X D 2 stars |
| RX J0414.0–1224 04 14 05.7 | -12 24 21.0 | 2.50 | rp900495n00 | Blend S N AGN, z=0.572 + ? |
| RX J0415.7–5355 04 15 45.4 | -53 35 10.1 | 1.20 | wp600623n00 | Galaxy N NGC1549, cz=1197 km/s |
| RX J0416.1–5546 04 16 10.3 | -55 46 43.3 | 3.65 | wp600623n00 | Galaxy N NGC1553, cz=1080 km/s |
| RX J0420.9+1444 04 20 58.7 | +14 44 07.7 | 2.83 | wp200441 | Blend S C A GN + ? |
| RX J0421.2+1340 04 21 16.8 | +13 40 14.8 | 1.32 | rp200776n00 | Blend X S C star + ? |
| RX J0426.1+1655 04 26 07.3 | +16 55 12.1 | 1.79 | rp201369n00 | Cluster S C |
| RX J0454.3–0329 04 54 19.6 | -03 39 50.0 | 1.59 | rp800229n00 | Cluster S C |
| RX J0514.2–4826 05 14 16.7 | -48 26 53.4 | 1.58 | wp800368n00 | Blend X S C AGN, z=0.230 + ? |
| RX J0609.1–4854 06 09 06.5 | -48 54 50.4 | 2.15 | rp300111 | Blend D star + ? |
| RX J0849.1+3731 08 49 08.9 | +37 31 47.9 | 1.29 | rp700546n00 | Cluster S N C A708, z=0.23 |
| RX J0853.6+1349 08 53 41.1 | +13 49 29.5 | 1.17 | rp700887n00 | Blend X D N Star + Galaxy:MS0850.8, z=0.194 |
| RX J0945.6–1434 09 45 40.4 | -14 34 5.0 | 2.30 | wp701458n00 | Blend X D S AGN, z=1.2 + star |
| RX J0947.8+0741 09 47 50.5 | +07 41 43.0 | 1.51 | wp701587n00 | Blend S C QSO, z=0.63 + ? |
| RX J1010.2+5430 10 10 12.9 | +54 30 09.6 | 1.41 | wp900213 | Group N V84 z ~ 0.045 |
| RX J1020.0+3915 10 20 02.4 | +39 15 50.8 | 1.18 | wp800528n00 | Blend X C id pending |
| RX J1024.3+6805 10 24 20.1 | +68 05 05.1 | 2.60 | wp800061n00 | Cluster N A981, z=0.201 |
| RX J1031.3–1433 10 31 23.3 | -14 33 40.6 | 1.18 | rp700461n00 | Blend D S Star + ? |
| RX J1118.8+0417 11 13 48.5 | +04 17 18.3 | 1.44 | rp700855n00 | Cluster N A1203, z=0.0795 |
| RX J1120.1+4318 11 20 07.5 | +43 18 04.9 | 2.11 | rp900383n00 | Cluster S C z=0.60 |
| RX J1122.2+1026 11 42 16.7 | +10 26 46.9 | 1.27 | wp600420 | Cluster N A1356, z=0.0698 |
| RX J1143.7+5520 11 43 46.5 | +55 20 13.6 | 1.98 | rp600230n00 | Blend X D C id pending |
| Source | RA (J2000) | Dec | $\sigma_{\mu}$ | Pointing | ID | ID code | Notes | Ref |
|--------|------------|-----|--------------|----------|----|---------|-------|-----|
| RX J1204.0+2807 | 12 04 03.6 | +28 07 03.6 | 4.49 | wp700232 | Cluster | N | MS1201.5, z=0.167 | 17 |
| RX J1204.1+2020 | 12 04 09.7 | +20 20 40.5 | 2.04 | rp800039 | Galaxy | N | NGC4066, z=0.024 | 18 |
| RX J1210.4+3929 | 12 10 25.9 | +39 29 07.6 | 14.30 | wp700277 | Blend | N | QSO: MS1207.9, z=0.615 + ? | 19 |
| RX J1211.1+3907 | 12 11 09.5 | +39 07 44.4 | 2.14 | rp600625n00 | Blend | X D | Star + ? | |
| RX J1211.2+3911 | 12 11 14.5 | +39 11 41.1 | 1.52 | wp700277 | Cluster | N | MS1208.7, z=0.34 | 20 |
| RX J1220.3+7522 | 12 20 18.0 | +75 22 10.2 | 4.65 | rp700434 | Galaxy | N | NGC4291, z=0.059 | 21 |
| RX J1222.1+7526 | 12 22 06.9 | +75 26 16.8 | 1.17 | rp700434 | Cluster | N | MS1219.9, z=0.24 | 22 |
| RX J1222.5+2550 | 12 22 30.8 | +25 50 26.7 | 36.93 | wp200307 | Blend | X D | 2 Stars | |
| RX J1227.4+0849 | 12 27 27.6 | +08 49 53.1 | 5.87 | wp600587n00 | Cluster | N | A1541, z=0.0895 | 23 |
| RX J1232.8+2605 | 12 32 48.3 | +26 05 39.0 | 1.82 | rp600162 | Cluster | S C | z=0.22 | |
| RX J1241.5+3250 | 12 41 33.1 | +32 50 22.9 | 2.38 | rp600129a00 | Cluster | S C | z=0.39 | |
| RX J1244.1+1134 | 12 44 08.2 | +11 34 16.8 | 1.16 | rp600017 | Blend | X C | id pending | |
| RX J1250.4+2530 | 12 50 26.1 | +25 30 17.6 | 1.71 | wp900212 | Galaxy | N | NGC4725, z=0.00402 | 24 |
| RX J1259.7–3236 | 12 59 45.4 | −32 36 59.9 | 1.19 | rp800384n00 | Cluster | S C | z=0.076 | |
| RX J1308.5+5342 | 13 08 22.6 | +53 42 19.3 | 1.25 | wp300394n00 | Cluster | S C | z=0.33 | |
| RX J1311.2+3228 | 13 11 12.3 | +32 28 52.2 | 2.53 | wp700216 | Cluster | N C | MS1308.8, z=0.245 | 25 |
| RX J1311.8+3227 | 13 11 49.8 | +32 27 40.4 | 1.47 | wp600219 | Cluster | S C | z=0.44 | |
| RX J1313.6–3250 | 13 13 41.0 | −32 50 45.9 | 1.28 | wp300219 | Cluster | X D | id pending | |
| RX J1334.3+5030 | 13 34 20.0 | +50 30 54.2 | 1.36 | rp800047 | Cluster | S C | z=0.62 | |
| RX J1334.7+5538 | 13 43 45.2 | +55 38 20.3 | 1.80 | rp700922n00 | Cluster | N | A1783, z=0.0766 | 26 |
| RX J1349.2–0712 | 13 49 12.3 | −07 12 41.2 | 1.51 | rp800637n00 | Gal. pair | N | part of HCG67, z=0.02406 | 27 |
| RX J1406.9+2834 | 14 06 55.1 | +28 34 15.7 | 1.30 | rp700061 | Cluster | N S C | V154, z=0.117 | |
| RX J1412.4+4355 | 14 12 29.8 | +43 55 31.2 | 2.32 | wp700248 | Blend | X S N C | AGN, z=0.095 + ? | 28 |
| RX J1416.4+2315 | 14 16 26.6 | +23 15 32.8 | 4.80 | rp800401a01 | Cluster | S C | z=0.138 | |
| RX J1417.9+5417 | 14 17 57.5 | +54 17 51.3 | 1.26 | wp150046 | Blend | O C | AGN + Mstar | 29 |
| RX J1418.5+2510 | 14 18 31.4 | +25 10 45.8 | 3.78 | wp150071 | Cluster | S C | V159, z=0.29 | |
| RX J1508.4+5537 | 15 08 24.6 | +55 37 05.3 | 1.16 | rp600119n00 | Blend | D S C | Star + ? | |
| RX J1517.1+3140 | 15 17 08.4 | +31 40 58.4 | 1.29 | rp201018 | Blend | X D S C | V170, z=0.078 | 30 |
| RX J1524.6+0957 | 15 24 39.6 | +09 57 44.8 | 1.64 | rp701001n00 | Cluster | S O C | Star + ? | |
| RX J1525.3+4201 | 15 25 23.3 | +42 01 00.0 | 1.26 | rp701405n00 | Blend | N C | QSO, z=1.189 + ? | 31 |
| RX J1541.1+6626 | 15 41 10.3 | +66 26 25.0 | 1.51 | rp800511n00 | Cluster | S C | z=0.245 | |
| RX J1543.7+6627 | 15 43 42.7 | +66 27 42.3 | 1.25 | rp800511n00 | Blend | S C | QSO, z=1.4562 + ? | 32 |
| RX J1641.2+8233 | 16 41 13.9 | +82 33 01.7 | 3.55 | rp700998 | Cluster | S N C | V183, z=0.195 | 32 |


| Source RA (J2000) Dec | Pointing | RA | Dec | ID code | Notes | Ref |
|---------------------|----------|----|-----|---------|-------|-----|
| RX J1701.3+6414 17 01 22.5 +64 14 08.3 1.98 wp01457n00 Cluster N S C V190, z=0.435 33 |
| RX J1705.6+6024 17 05 37.5 +60 24 11.0 1.46 rp01439n00 Pending C |
| RX J1726.2+0414 17 26 14.4 +04 10 23.8 1.98 rp00522n00 Blend X D Star + ? |
| RX J1730.6+7422 17 30 37.6 +74 22 23.8 3.20 wp01200n00 Galaxy N S C NGC6414, z=0.054 |
| RX J1845.6+7956 18 45 41.3 +79 56 34.5 2.23 rp00058n00 Blend X D Star:HD175938 + ? |
| RX J2109.7–1332 21 09 47.8 –13 32 24.2 1.38 rp01007n00 Blend X D Star + ? |
| RX J2202.8–5636 22 02 52.9 –56 36 08.3 1.63 rp00559n00 Blend X D id pending |
| RX J2215.2–2944 22 15 16.4 –29 44 29.2 1.95 rp01390n00 Blend N QSO: HB89:2212–299, z=2.7 + ? 35 |
| RX J2223.8–0206 22 23 48.8 –02 06 13.0 2.19 rp01018n00 Blend S AGN, z=0.0558 + ? |
| RX J2236.0+3358 22 36 00.3 +33 58 24.0 3.18 wp00066 N Group N Stef.Quintet, z=0.0215 36 |
| RX J2237.0–1516 22 37 06.6 –15 16 08.0 1.68 wp01723n00 Cluster S C z=0.299 |
| RX J2258.1+2055 22 58 08.4 +20 55 15.0 2.26 rp01282n00 Cluster S N C Z2255.5, z=0.288 37 |
| RX J2309.4–2713 23 09 27.9 –27 13 20.1 1.19 rp00023n00 Blend S C AGN, z=0.25 + ? |
| RX J2311.4+1035 23 11 25.9 +10 35 06.7 3.52 rp010057n00 Blend S C AGN, z=0.127 + ? |
| RX J2314.7+1915 23 14 44.0 +19 15 23.3 1.39 rp00488n00 Blend S C Cluster, z=0.28 + Mstar |
| RX J2353.5–1524 23 53 31.5 –15 24 51.2 1.18 wp01501n00 Blend S C QSO + Mstar |

Notes — Count rates (column 4) are quoted in units of $10^{-2}$ counts s$^{-1}$. 1Redshift taken from De Vaucouleurs et al. (1991, D91 hereafter). 2Confirmation of redshift provided by Piero Rosati (private communication) and Ebeling et al. (1999). 3Redshift taken from D91. 4Redshift taken from Stocke et al. (1991, S91 hereafter). 5Redshift taken from S91. 6Redshift information available in Perlman et al. (1998). 7Redshift taken from Longhetti et al. (1989). 8Redshift taken from D91. 9Redshift taken from S91. 10Additional redshift information provided by Ian Del Antonio. 11Redshift taken from Abell, Corwin & Olowin (1989). 12Redshift taken from S91. 13Redshift taken from Carballo et al. (1995). 14Redshift taken from Huchra et al. (1989). 15Redshift taken from Slinglend et al. (1998). 16Redshift taken from Struble et al. (1987). 17Redshift taken from S91. 18Redshift taken from S91. 19Redshift taken from S91. 20Redshift taken from S91. 21Redshift taken from S91. 22Redshift taken from S91. 23Redshift taken from Zabludoff et al. (1993). 24Redshift taken from S91. 25Redshift taken from S91. 26Redshift taken from Struble et al. (1987). 27Redshift taken from Fairall et al. (1992). 28Additional redshift information available in Boyle et al. (1995). 29Spectroscopy provided by Dave Turnshek and Eric Monier. 30Spectroscopy provided by Ian Del Antonio. 31Redshift taken from Perlman et al. (1998). 32Also known as EXXS 1646.5+8248 (Tucker et al. 1995). 33Also known as “Cluster B” (Reimers et al. 1997). 34,35Redshift taken from Hewitt & Burbidge (1993). 36Redshift taken from Hickson et al. (1992). 37Redshift taken from S91.
## Table 2
Bright SHARC Cluster Catalog

| Source               | Redshift | nH     | Major   | Minor   | Offaxis | crW | crP | δcrP | r90   | f90   | f1.13 | L44  | T   | Notes   |
|----------------------|----------|--------|---------|---------|---------|------|-----|------|-------|-------|-------|------|-----|---------|
| RX J0117.6-2238      | 0.20     | 1.51   | 8.82    | 6.32    | 86.91   | 1.254| 2.283| 9.2%  | 18.36 | 0.943 | 2.094 | 0.4951| 3    | A29894 |
| RX J0152.7-1357      | 0.83     | 1.42   | 11.4   | 4.99    | 57.22   | 1.716| 2.440| 5.6%  | 9.900 | 1.000 | 2.930 | 8.2604| 9    |         |
| RX J0221.1+1958      | 0.45     | 0.93   | 6.70    | 5.47    | 73.58   | 1.545| 2.211| 6.2%  | 12.03 | 0.969 | 3.296 | 2.8681| 6    |         |
| RX J0233.4-0852      | 0.163    | 3.18   | 8.86    | 4.98    | 43.25   | 1.202| 3.036| 7.7%  | 21.09 | 0.994 | 3.706 | 0.4350| 3    | (1)     |
| RX J0379.9-5224      | 0.133    | 3.08   | 8.56    | 5.53    | 69.94   | 2.324| 6.107| 5.3%  | 24.63 | 0.906 | 7.495 | 0.5824| 3    | A3038   |
| RX J0500.9+1908      | 0.12     | 9.40   | 13.5    | 5.92    | 57.00   | 1.426| 1.576| 15.3% | 26.49 | 0.997 | 2.242 | 0.1443| 2    |         |
| RX J0526.5+6.00      | 0.36     | 5.33   | 7.40    | 6.82    | 83.87   | 3.614| 5.692| 4.9%  | 13.44 | 0.998 | 7.549 | 4.1597| 7    |         |
| RX J0318.5-0302      | 0.37     | 5.09   | 6.79    | 5.08    | 43.35   | 2.763| 4.191| 5.5%  | 12.85 | 1.000 | 5.587 | 3.2819| 6    | (2)     |
| RX J0321.9-5119      | 0.0696   | 2.46   | 6.93    | 5.36    | 73.91   | 6.180| 17.10| 24.0% | 40.23 | 0.916 | 20.72 | 0.4355| 3    | A3120   |
| RX J0426.1+1655      | 0.38     | 16.4   | 5.23    | 4.55    | 22.54   | 1.797| 2.948| 6.3%  | 12.62 | 1.000 | 5.159 | 3.1969| 6    |         |
| RX J0435.3-0239      | 0.26     | 5.24   | 10.4    | 5.92    | 85.65   | 1.594| 2.732| 8.0%  | 16.01 | 0.914 | 3.564 | 1.0634| 4    |         |
| RX J0849.1+3732      | 0.30     | 8.07   | 8.72    | 7.17    | 52.64   | 1.392| 2.052| 9.4%  | 12.32 | 0.991 | 2.525 | 0.9796| 2    | A708    |
| RX J1024.3+0605      | 0.201    | 2.13   | 6.33    | 5.51    | 53.89   | 2.602| 4.787| 5.8%  | 18.38 | 0.991 | 5.699 | 1.0100| 4    | A981    |
| RX J1138.8+0404      | 0.0795   | 1.85   | 12.6    | 4.36    | 88.73   | 1.440| 5.879| 6.1%  | 36.39 | 0.913 | 6.696 | 0.1866| 2    | A1203   |
| RX J1210.1+3418      | 0.60     | 2.15   | 5.33    | 4.88    | 48.43   | 2.117| 2.728| 8.1%  | 10.63 | 1.000 | 3.285 | 5.0100| 7    |         |
| RX J1406.9+2834      | 0.117    | 1.40   | 6.68    | 5.01    | 28.69   | 1.304| 3.625| 7.3%  | 2  | 6.93 | 0.987 | 4.085 | 0.2497| 2    | V154    |
| RX J1524.6+0957      | 0.078    | 2.88   | 5.53    | 5.14    | 16.07   | 1.927| 2.052| 9.4%  | 12.32 | 0.991 | 2.525 | 0.9796| 2    |         |

Notes — Count rates (columns 4 & 5) are quoted in units of $10^{−2}$ counts s$^{−1}$. RX J0223.4 $(z=0.163)$ was detected in pointing rp080016n00, the central target of which was a wide angle radio (WAR) source. The cluster hosting this WAR source has a redshift of $z=0.41$ (Nichol et al. 1994a). The redshift separation of the two clusters is $\delta z=0.247$. RX J0318.5 $(z=0.37)$ was detected in wp0555n00 which was pointed, accidentally, $\sim 40''$ away in declination away from the listed target, A3112, which lies at 03:17:56–44:14:17 (Ebeling et al. 1996). RX J0321.9 $(z=0.0696)$ was detected in wp08037n00, the central target of which was a Couch et al. (1991) cluster at $z=0.49$. The redshift separation of the two clusters is $\delta z=0.42$. RX J0454.3 $(z=0.26)$ was detected in rp080229n00, the central target of which was cluster MS0545.6 $(z=0.55$, Gioia & Luppino 1994). The redshift separation of the two clusters is $\delta z=0.29$. RX J1024.3 $(z=0.201)$ was detected in wp0609n00, the central target of which was cluster A998 $(z=0.202$, Huchra et al. 1989). The redshift separation of the two clusters is $\delta z=0.001$. RX J1209.7 $(z=0.076)$ was detected in rp08038n00, the central target of which was cluster A3537 $(z=5007$ km/s, Abell, Corwin & Olowin 1989). The redshift separation of the two clusters is $\delta z=0.059$. RX J1334.3 $(z=0.62)$ was detected in rp080047, the central target of which was cluster A1758 $(z=0.2792$, Allen et al. 1992). The redshift separation of the two clusters is $\delta z=0.34$. RX J1416.4 $(z=0.138)$ was detected in rp08041a01, the central target of which was galaxy 4C23.37 $(z=154$ km/s, De Vaucouleurs et al. 1991). The redshift separation of the two clusters is $\delta z=0.137$. RX J1541.1 $(z=0.245)$ was detected in rp08051n00, the central target of which was A2125 $(z=0.2465$, Struble et al. 1987). The redshift separation of the two clusters is $\delta z=0.0015$. **
### Table 3

**Comparison of Bright SHARC and V98 Flux Measurements**

| Bright SHARC ID. | V98 ID. | Redshift | $f_{-13}$ | Ratio$^1$ | Ratio$^2$ |
|------------------|---------|----------|-----------|-----------|-----------|
| RX J0237.9–5224  | V28     | 0.1330   | 7.495     | 1.16      | 1.06      |
| RX J0849.1+3731  | V62     | 0.2300   | 2.525     | 1.72      | 1.48      |
| RX J1204.0+2807  | V112    | 0.1670   | 12.38     | 1.21      | 0.91      |
| RX J1211.2+3911  | V115    | 0.3400   | 3.163     | 1.19      | 0.83      |
| RX J1308.5+5342  | V132    | 0.3300   | 1.978     | 1.15      | 0.91      |
| RX J1406.9+2834  | V154    | 0.1170   | 4.085     | 1.58      | 1.22      |
| RX J1418.5+2510  | V159    | 0.2000   | 7.655     | 1.01      | 0.95      |
| RX J1524.6+0957  | V170    | 0.0780   | 2.371     | 0.78      | 0.83      |
| RX J1641.2+8233  | V183    | 0.1950   | 8.128     | 1.01      | 1.04      |
| RX J1701.3+6414  | V190    | 0.4530   | 3.965     | 1.03      | 0.92      |
| RX J2258.1+2055  | V213    | 0.2880   | 5.694     | 1.13      | 0.93      |
| **Average**      |         |          |           | 1.18      | 1.01      |

**Notes** — $^1$Ratios of the Bright SHARC fluxes (column 4) to the Vikhlinin *et al.* (1998a V98) fluxes. $^2$Ratios of the re-calculated Bright SHARC fluxes to the V98 fluxes, see §7.1 for details.