THE SHARC SURVEY: AN UPDATE

M ULMER[a], C ADAMI[a], R PILDIS[a], A ROMER[b], R NICHOL[b], B HOLDEN[c], R KRON[c]
[a] *Dept. of Physics & Astronomy, Northwestern University, Evanston, IL 60208-2900, USA,* [b] *Dept. of Physics, Carnegie Mellon University, Pittsburgh, PA 15213,* [c] *Dept. of Astronomy & Astrophysics, University of Chicago, Chicago, IL 60637*

We summarize the results of the Bright SHARC (Serendipitous High-redshift Archival ROSAT Cluster) survey (http://www.astro.nwu.edu/sharc). This is a search for distant X-ray bright clusters, which must be corrected for completeness in order to convert these results into a luminosity function. We have completed a thorough simulation of the SHARC survey. We show that our new improved results have produced no major change to the results of the recently published paper of Nichol *et al.* on cluster luminosity evolution. Besides statistics, the uncertainty in the luminosity function derived from X-ray surveys is large, because we do not know the distribution of X-ray cluster morphologies at high redshift. Our simulations show that to fully understand the completeness of deep surveys, the distribution of the shapes of the clusters must be understood. For, sharply peaked or highly elliptical clusters are the easiest to detect. Beyond the Bright SHARC, we have initiated a search for more distant X-ray luminous clusters. We have found preliminary evidence for the detection of up to four high-redshift X-ray luminous cluster.

1 Introduction

We are motivated to make surveys of clusters of galaxies to understand how they form and evolve and to use the evolution of clusters to discriminate amount various proposed cosmology models[1,2,3]. Cluster formation may be complex enough, however, that using clusters alone to determine the mass density of the universe may be too optimistic. However, when we combine the implied value of Ω_0 with other independent determinations of Ω_0 we can hope that the search for agreement with other methods will eventually lead us to the correct answer. We acknowledge that besides the SHARC, there have been several other surveys made[4,5,6,7], but our simulations to measure completeness have been the most thorough. Details of the SHARC work, thorough simulations that show the uncertainties that are inherent in any current survey, and the application of these results to an inference of the value of Ω_0 are given elsewhere[8,9,10].

There are four points we would like to make here: (1) The derived luminosity function is not sensitive to the assumed value of Ω_0. (2) The inferred luminosity function at high redshift depends critically on the assumed shape of the surface brightness profile of the clusters and, hence, the completeness of the survey; (3) The apparent paucity of clusters in the $L_x \sim 5 \times 10^{44} - 10^{45}$ ergs / sec luminosity in the z = 0.3–0.7 range[10] suggests a negative redshift evolution and, hence, a high value of Omega matter today (called Ω_m, hereafter, = Ω_0 if $\Lambda = 0$). (4) While, contrary-wise, the evidence for the existence of redshift z = 1 cluster candidates with luminosities as high as $L_x = 10^{45}$ ergs / sec argues for no evolution out to z = 1 and a low value of Ω_m. So the value of Ω_m as inferred by the cluster X-ray luminosity function (CXLF) at high redshift is an *open question*. This is regardless of possible uncertainties in the predictions based on theory.

2 Results

2.1 The CXLF And Effects of Ω_0

Using a standard shape and core radius for clusters we have refined and updated the result presented in our previous work[10]. This is shown in Figure 1 (left), where we see no statistically significant evidence for evolution of the CXLF. In our previous work[10], however, we argued, that when combined with other work[3], that a lack of $> 5 \times 10^{45}$ ergs / sec clusters in the z = 0.3–0.7 range is suggestive of negative evolution[10]. We have displayed the *approximate* location of this combined survey data point from our previous work in Figure 1 (the associated error bar is also *approximate* and is to show the result is about 3σ ignoring uncertainties in the completeness due to a lack of knowledge of the surface brightness profiles of the typical distant cluster. We have not had time to calculate this point based on our refined simulations. As we will see below, the completeness of the high redshift surveys is *very uncertain*, though, because of the lack of knowledge of the shapes of the clusters. Furthermore, we now have some high-redshift high X-ray luminosity cluster candidates. We also see in the figure that the derived luminosity function is relatively insensitive to the assumed cosmology. On the right side of Figure 1, we show the effective area as function of luminosity and redshift which can be used to gauge how much of a relative correction factor was applied to the luminosity function for a redshift and luminosity range.

2.2 The Simulations and the Effect of Shape

The simulations were carried out by putting artificial clusters into real data. This was done over and over again and in different places within the ROSAT fields to provide a statistically significant result. The details are given in our recently submitted work[9]. We found that very sharply peaked cluster profiles such as the NFW[11] profile are much more easily detected than the standard β = 0.67 King model. And, if β were 0.55 rather than 0.67, the cluster would be much harder to detect. The effect on the derived luminosity function of a given surface brightness profile can be seen in Figure 2. We also see in this figure that other profiles do not produce such dramatic effects. The error bars shown include both the statistical errors of the data and the uncertainty in the derived completeness as based on our simulations. The similar uncertainties from our previous work[10] are shown in Figure 1 (left) as the dotted envelope and are slightly different from what is shown here, because of the rebinding as well as some refinement of the simulations.

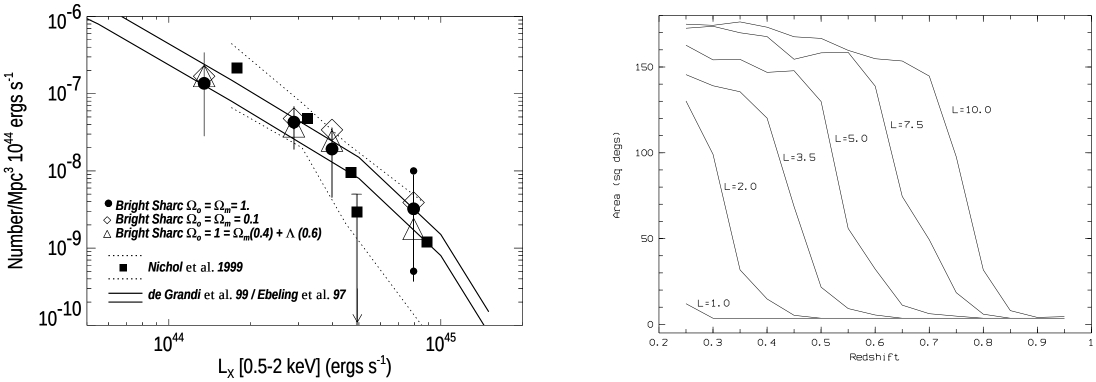

Figure 1: Left: The current Bright SHARC CXLF for the z = 0.3 to 0.7 is shown by the symbols except as noted. The small filled circles show the range of values that can be derived depending on the assumed shape of the cluster surface brightness profile. The filled squares (and dotted line error envelope) are from our previous work[10]. The filled square with an error bar is the *approximate* value[10] derived by including another survey[3]. The highest square data point is for the $0.3 \leq z \leq 1.0$ range. For clarity, we only show the error bars for the $\Omega_0 = 1$ case. Right: the effective areal coverage of the survey as function of redshift and luminosity.

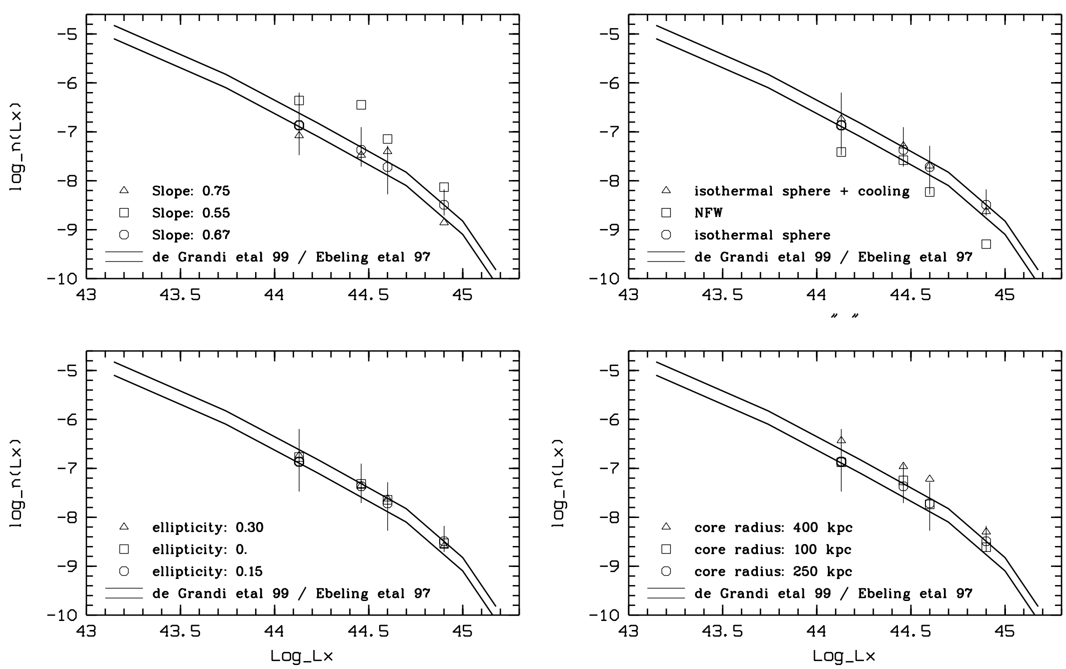

Figure 2: This shows the effect on the CXLF based on the completeness of the survey derived from different assumptions about the surface brightness profiles.

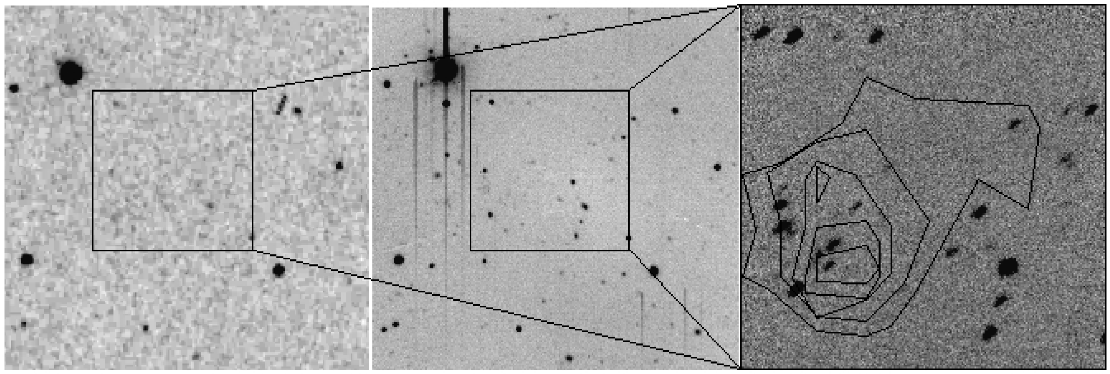

Figure 3: Three images of an extended X-ray source field. From left to right: the DSS image; a twenty minute R-band exposure on the 3.6 m ARC telescope; a 2 hour K-band exposure on 3.6 m ARC telescope. The field of view of the K-band image is $1.'.7 \times 1.'7$.

2.3 Evidence for High Redshift

We have found four cluster candidates that could be at high redshift (z ~ 1). We found these by using our initial search technique to pick out extended objects and then we searched these position of optical counterparts. Next we made K-band observations of these fields. We have yet to reduce all of these data, but the best case is most tantalizing and is shown in Figure 3. We suggest that this object and (the other 3 candidates as well) might indeed be a high redshift, high X-ray luminosity clusters because: (1) they are extended X-ray sources; (2) assuming that the brightest cluster member has a V magnitude of -22 and putting in a k-correction, that we see no galaxy visible in V down to m = 24, which implies a z = 1.15. ; (3) a 2 hour K-band image on the 3.6m ARC telescope shows a concentration of galaxies at the X-ray position; (4) assuming a kT of 8–11 keV and H_0 of 50 and $\Omega_0 = 1, \Lambda = 0$, we find the $L_x \simeq 1 \times 10^{45}$ ergs/sec (k-corrected, 0.5–2 keV range) and this is self consistent with the L_x Temperature relation.

3 Conclusions

As yet we have conflicting evidence for and against a high value of Ω_m. Although it is tempting to assume there is evolution in the CXLF and that Ω_m is high, the possible existence of high redshift clusters high X-ray luminosity clusters suggest Ω_m might indeed be low. Recent studies of how evolution of the CXLF is affected by a non-zero Λ have been done and the effect of Λ seems to be relatively negligible for z less than 1. Therefore a low Ω_m (about 0.3) plus a high Ω_Λ (about 0.7) model could be consistent with our cluster data as well as the values tentatively derived from both the CMB[14] and the distant supernova searches[15]. Over the next few years, followup observations on our cluster candidates and other Chandra and XMM observations will lead to a much clearer picture of the evolution of the CXLF and the inferred value of Ω_0

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