A Cluster Deficit in the ROSAT NEP Survey

Isabella M. Gioia\textsuperscript{1,2}

\textsuperscript{1}Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, Hawai‘i 96822, USA
\textsuperscript{2}Istituto di Radioastronomia del CNR, Via Gobetti 101, 40129 Bologna, Italy

Abstract. We have used data from the deepest region of the ROSAT All−Sky Survey, the North Ecliptic Pole (NEP) region, to produce a complete and unbiased X−ray selected sample of distant clusters to understand the nature of cluster evolution and determine implications for large scale structure models. In this contribution results are presented from a comparison between the number of the observed clusters in the NEP survey and the number of expected clusters assuming no−evolution models. There is a deficit by a factor of 2.5−4 of high luminosity, high redshift clusters with respect to the present. The evolution goes in the same direction as the original EMSS result, and the results from the CfA−IfA 160 deg\textsuperscript{2} survey by [17].

1 Introduction

The ROSAT North Ecliptic Pole (NEP) Survey began nine years ago right after the completion of the Einstein Medium Sensitivity Survey (EMSS) project (\textsuperscript{[5]}). The goal was to construct a statistically complete sample of galaxy clusters to

1. study the controversial issue of the cluster X−ray Luminosity Function (XLF) evolution (\textsuperscript{[6]}; \textsuperscript{[8]});
2. characterize the three−dimensional large scale structure of the universe.

The main difference between the NEP survey and the existing X−ray serendipitous ROSAT cluster surveys is that the NEP survey is carried out on a contiguous area of sky. Thus our database will allow to examine large scale structure in the cluster distribution. In addition, unlike existing X−ray cluster surveys, the NEP survey is completely optically identified. Specifically, all X−rays sources in the 81 deg\textsuperscript{2} region have been identified. Throughout this paper $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$ and $\Omega_0 = 1$ are used.

2 The NEP Survey

Our group at the Institute for Astronomy in Hawai‘i has been involved for many years in the optical identification of all the sources found in the NEP region of the ROSAT All−Sky Survey (RASS, [\textsuperscript{16}]; [\textsuperscript{18}]). The NEP region is the deepest area of the RASS where the ROSAT satellite scan circles overlap and the effective exposure time exceeds 35ks. The 9−year long identification program has been finally completed.
A total of 446 X-ray sources were detected at $>4\sigma$ in the 0.1 – 2.4 keV band using the RASS–II processing (described in detail in \cite{18}). We have spectroscopically identified all but three sources in the survey (see Fig. 1). Redshifts have been measured for the extragalactic population. We have extracted a complete and unbiased sample of 65 galaxy clusters. Twenty clusters have a redshift greater than 0.3 with the highest being at $z=0.81$.

3 Serendipitous discoveries

As it happens in the course of identifying a large number of X-ray sources, several serendipitous discoveries were made. Among them: the most distant X-ray selected QSO at the time of publication ($z=4.3$, \cite{9}); a distant cluster at 0.81 ($\ldots$, \cite{7,10}), the second most distant X-ray selected cluster so far published and the only one with a large number of spectroscopically determined cluster member velocities; a supercluster of 20 clusters at $z=0.0877$ which is reported in the contribution by C. Mullis to this meeting.
4 A Deficit of High Redshift, High Luminosity Clusters

The XLF evolution result of [6] inspired many EMSS−style cluster surveys all based on ROSAT archival deep pointing images. Among them: the RDCS (Rosat Deep Cluster Survey, [14]); the WARPS (Wide Angle Pointed Rosat Survey, [15], [11]); the SHARC (Serendipitous High−Redshift Archival Rosat Cluster survey, [2], [1], [13], [12]) and finally the largest area survey after the EMSS, the [17] CfA−IfA 160 deg$^2$ survey. Each one of these surveys covers an area of sky of less than 200 deg$^2$, much less than the $\sim$ 800 deg$^2$ of the original EMSS, but with sensitivities almost an order of magnitude deeper than the EMSS ($\sim 1.8 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ vs $\sim 1.3 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ in 0.3−3.5 keV [6]). Most of these surveys are still works in progress but a few preliminary results are available.

While all the existing surveys are in agreement for cluster with the $z < 0.3$ and $L_{(0.5−2)} < 3 \times 10^{44}$ erg s$^{-1}$, there is not a consensus yet for the brightest and most distant clusters known.

To compare the number of observed clusters with the number of expected clusters assuming no−evolution models, we proceeded as follows. In all calculations K−corrections have been applied to the NEP clusters by assuming for each cluster a temperature derived from the $L_X−T_X$ relation of [19]. A constant cluster core radius of 0.25 Mpc has been assumed.

The local ($z < 0.3$) luminosity functions derived from the Southern hemisphere RASS1 Bright Sample ([3]) and from the Northern hemisphere BCS ([4]) have been integrated in the appropriate redshift and luminosity ranges. First the two luminosity functions are integrated between $z=0.3$ and $z=0.85$ and between $L_{\text{min}} = 2 \times 10^{42}$ and $L_{\text{max}} = 10^{47}$ erg s$^{-1}$. A value of 59.9 (39.9) clusters are expected according to the RASS1 (BCS), and only 20 NEP clusters are observed. The result is a factor of 3 (2) less than predicted from the no−evolution models. This deviation is significant at 6.1σ (3.7σ). A similar integration is then performed in the same redshift range but at luminosities $L_{0.5−2.0} > 1 \times 10^{44}$ erg s$^{-1}$. For the no−evolution model, 47.6 clusters are expected from the RASS1 (30.0 from the BCS) while only 12 are observed, a factor 4 (2.5) less than predicted. Given the large uncertainties the significance of this result is at the 6.2σ (3.9σ) level. In agreement with the findings of [17] and with the recent results of the RDCS (Rosati et al., this volume), we confirm a deficit of high luminosity high redshift clusters by a factor 2.5−4 which goes in the same direction as the evolution of the EMSS survey. However the deficit appears at lower luminosities than in the EMSS ($> 1 \times 10^{44}$ vs $> 3 \times 10^{44}$ in the 0.5−2.0 keV band), a result that we are still investigating. At luminosities lower than $1 \times 10^{44}$ erg s$^{-1}$, no evidence for evolution is present, in agreement with the existing deep ROSAT cluster surveys.

---

1The conversion from 0.5−2.0 keV to 0.3−3.5 keV is a multiplicative factor of 1.8, assuming a Raymond−Smith with a $kT$=6.0 keV and the standard 0.3 solar abundance.
2As shown by [17] the distributions of core radii for nearby ($z < 0.2$) and distant ($z > 0.4$) clusters are very similar with a difference for the average radius at $z > 0.4$ by a factor of only 0.9±0.1.
Acknowledgements. Many people contributed to the construction and success of the NEP survey. I would like to acknowledge the continuous support and hard work of my colleagues at the IfA, Christopher Mullis and Patrick Henry. This work would not have been possible without the collaboration of several MPE scientists and John Huchra. Partial financial support comes from NSF grant AST95−00515 and from CNR−ASI grants. Finally, I wish to thank Manolis Plionis, Ioannis Georgantopoulos and the other LOC members for organizing a great meeting in a magnificent Mediterranean spot.

References

[1] Burke, D.J., Collins, C.A., Sharples, R.M., Romer, A.K., Holden, B.P. and Nichol, R.C., 1997, ApJ, 488, L83
[2] Collins, C.A., Burke, D.J., Romer, A.K., Sharples, R.M. and Nichol R.C., 1997, ApJ, 479, L117
[3] 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
[4] Ebeling, H., Edge, A.C., Böhringer, H., Allen, S.W., Crawford, C.S., Fabian, A.C., Voges, W. and Huchra, J.P., 1997, MNRAS, 301, 881
[5] Gioia, I.M., Maccacaro, T., Morris, S. L., Schild, R.E., Stocke, J.T., Wolter, A. and Henry, J.P., 1990a, ApJS, 72, 567
[6] Gioia, I.M., Henry, J.P., Maccacaro, T., Morris, S. L., Stocke, J.T. and Wolter, A., 1990b, ApJ, 356, L35
[7] Gioia, I.M., Henry, J.P., Mullis, C.R., Ebeling, H. and Wolter, A., 1999, AJ, 117, 2608
[8] Henry, J.P., Gioia, I.M., Maccacaro, T., Morris, S.L., Stocke, J.T. and Wolter, A., 1992, ApJ, 386, 408
[9] Henry, J.P., Gioia, I.M., Böhringer, H., Bower, R.G., Briel, U.G., Hasinger, H., Aragon-Salamanca, A., Castander, F.J., Ellis, R.S., Huchra J.P. and Burg, R.G., 1994, AJ, 107, 1270
[10] Henry, J.P., Gioia, I.M., Mullis, C.R., Clowe, D.I., Luppino, G.A., Böhringer, Briel, U.G., Voges, W. and Huchra J.P. 1997, AJ, 114, 1293
[11] Jones, L.R., Scharf, C., Ebeling, H., Perlman, E., Wegner, G., Malkan, M. and Horner, D., 1998, ApJ, 495, 100
[12] Nichol, R.C., Romer, A.K., Holden, B.P., Ulmer, M.P., Pildis, R.A., Adami, C., Merrelli, A.J., Burke, D.J. and Collins, C.A., 1999, ApJ, 521, L21
[13] Romer, A.K., Nichol, R.C., Holden, B.P., Ulmer, M.P., Pildis, R.A., Merrelli, A.J., Adami, C., Burke, D.J., Collins, C.A., Metevier, A.J., Kron, R.G. and Commons, K., astro-ph/9907401
[14] Rosati, P., Della Ceca, R., Norman, C. and Giacconi, R., 1998, ApJ, 492, L21
[15] Scharf, C., Jones, L.R., Ebeling, H., Perlman, E., Malkan, M. and Wegner, G., 1997, ApJ, 477, 79
[16] Trümper, J., et al. 1991, Nature, 349, 579
[17] Vikhlinin, A., McNamara, B.R., Forman, W., Jones, C., Quintana, H. and Hornstrup A., 1998, ApJL, 498, L21
[18] Voges, W., et al. 1999, A&A, 349, 89
[19] White, D.A., Jones, C. & Forman, W., 1997, MNRAS, 292, 419