The ROSAT Deep Cluster Survey: Constraints on Cosmology

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Abstract. We use the ROSAT Deep Cluster Survey (RDCS) with the purpose of tracing the evolution of the cluster abundance out to $z \simeq 0.8$ and constrain cosmological models. We resort to a phenomenological prescription to convert masses into X-ray fluxes and apply a maximum–likelihood approach to the RDCS redshift– and luminosity–distribution. As a main result we find that, even changing the shape and the evolution on the $L_{bol}$–$T_X$ relation within the observational uncertainties, a critical density Universe is always excluded at more than 3σ level. By assuming a non–evolving X–ray luminosity–temperature relation with shape $L_{bol} \propto T_X^3$, it is $\Omega_m = 0.35_{-0.25}^{+0.35}$ and $\sigma_8 = 0.76_{-0.14}^{+0.08} (\Omega_m = 0.42_{-0.27}^{+0.08} \text{ and } \sigma_8 = 0.68_{-0.12}^{+0.21})$ for flat (open) models, while no significant constraints are found for the power–spectrum shape parameter $\Gamma$. Uncertainties are 3σ confidence levels for three significant fitting parameters.

1 Introduction

The mass function of local ($z \lesssim 0.1$) galaxy clusters has been used as a stringent constraint for cosmological models. Independent analyses have shown that $\sigma_8 \Omega_m^{\gamma(\Omega_m)} \simeq 0.5$–0.6, where $\Omega_m$ is the density parameter, $\sigma_8$ the r.m.s. fluctuation amplitude within a sphere of $8h^{-1}$Mpc ($h = H_0/100$ km s$^{-1}$ Mpc$^{-1}$) radius and $\gamma(\Omega_m) \simeq 0.4$–0.6 [1, 2]. The increasing availability of X–ray temperatures for distant ($z \gtrsim 0.3$) clusters is providing a handle to estimate the density parameter which best reproduces the evolution of the cluster abundance [3, 4, 5] (see also Henry, this volume, for a review). A limitation of this approach comes from the small size of the current samples [6].

An alternative way to trace the evolution of the cluster abundance is to rely on the luminosity and redshift distribution of X-ray flux–limited cluster samples.
Figure 1: Confidence regions on the $\Omega_m - \sigma_8$ plane. In all the panels, solid contours and dashed contours are for flat and open models, respectively. Here $\alpha = 3.5$, $A = 0$ and $\beta = 1.15$ are assumed for the mass–luminosity conversion. Contours are $1\sigma$, $2\sigma$ and $3\sigma$ c.l. for two significant parameters.

The advantage of this approach lies in the availability of large samples, with well understood selection functions. As a limitation, however, one has to face with the uncertain relation between cluster masses and X-ray luminosities. The ROSAT Deep Cluster Survey (RDCS) provides a flux–limited complete sample of clusters identified in the ROSAT PSPC archive and including $\gtrsim 100$ spectroscopically confirmed systems. In the following we will outline the main results of a comparison between the RDCS sample and the predictions of cosmological models. The analysis of RDCS for constraining the evolution of the X-ray luminosity function is contained in a separate paper (Rosati et al., this volume).

2 X–ray cluster bias: from luminosity to mass

The Press-Schechter approach is used in our analysis, as it provides an accurate mass function in the range of masses probed by the RDCS. The conversion from masses to X-ray luminosities, which is required in analysis of any flux-limited sample is implemented as follows: (a) convert mass into temperature by assuming virialization, hydrostatic equilibrium and isothermal gas distribution; (b) convert temperature into bolometric luminosity according to $L_{\text{bol}} \propto T^\alpha (1 + z)^A$; (c) compute the bolometric correction to the 0.5-2.0 keV band.

The critical step is represented by the choice for the $L_{\text{bol}} - T_X$ relation. Low redshift data for $T \gtrsim 3$ keV indicates that $\alpha \approx 2.7-3.5$, depending on the sample and the data analysis technique, with a reduction of the scatter after account for the effect of cooling flows in central cluster regions. At lower temperatures, evidence has been found for a steepening of the $L_{\text{bol}} - T_X$ relation below 1 keV.
Figure 2: Effect of changing the $L_{\text{bol}}-T_X$ relation. Solid contours are from assuming $\Gamma = 0.2$, $\alpha = 3.5$, $A = 0$ and $\beta = 1.15$. Contours have the same meaning as in Fig. 1.

As for the evolution of the $L_{\text{bol}}-T_X$ relation, existent data out to $z \simeq 0.4$ and, possibly, out to $z \sim 0.8$ are consistent with no evolution (i.e., $A \simeq 0$). Instead of assuming a unique mass–luminosity conversion, in the following we will show how final constraints on cosmological parameters changes as the $L_{\text{bol}}-T_X$ and $M-T_X$ relations are varied.

3 Analysis and results

The RDCS subsample, that we will use in the following analysis, has a flux-limit of $S_{\text{lim}} = 3.5 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ and contains 81 clusters with measured redshifts out to $z = 0.85$ over a 33 sq. deg. area. In order to fully exploit the information provided by the RDCS, we resort to a maximum–likelihood approach, in which model predictions are compared to the RDCS cluster distribution on the $(L, z)$ plane. To this purpose, let $\phi(L, z)$ be the Press–Schechter based luminosity function, as predicted by a given model, so that $\phi(L, z) (dV/dz) dz dL$ is the expected number density of clusters in the comoving volume element $(dV/dz) dz$ and in the luminosity interval $dL$. Therefore, the expected number of clusters in RDCS lying in the $dz dL$ element of the $(L, z)$ plane is $\lambda(z, L) dL = \rho(z, L) f_{\text{sky}} S(z, L) (dV/dz) dz dL$. Here $f_{\text{sky}}$ is the flux-dependent RDCS sky–coverage.

The likelihood function $L$ is defined as the product of the probabilities of observing exactly one cluster in $dz dL$ at each of the $(z_i, L_i)$ positions occupied by the RDCS clusters, and of the probabilities of observing zero clusters in all the other differential elements of the $(z, L)$ plane which are accessible to RDCS. Assuming Poisson statistics for such probabilities and defining $S = -2 \ln L$, it is $S = -2 \sum_{i=1}^{N_{\text{occ}}} \ln[\rho(z_i, L_i)] + 2 \int dz \int dL \lambda(z, L)$, where the sum runs over the occupied elements of the $(z, L)$ plane. Model predictions are also convolved with sta-
statistical errors on measured fluxes, as well as with uncertainties in the luminosity–mass relation associated to a ≃ 30% scatter in the $L_{bol}$–$T_X$ relation and to a 20% uncertainty in the mass–temperature conversion. Best estimates of the model parameters are obtained by minimizing $S$.

In Figure 1 we show the resulting constraints on the $\sigma_8$–$\Omega_m$ plane for different values of the shape parameter $\Gamma$, based on assuming $\alpha = 3.5$ and $A = 0$ for the $L_{bol}$–$T_X$ relation. It is clear that low–density models are always preferred, quite independent of $\Gamma$. We find $\Omega_m = 0.35^{+0.32}_{-0.25}$ and $\sigma_8 = 0.76^{+0.38}_{-0.14}$ ($\Omega_m = 0.42^{+0.35}_{-0.27}$ and $\sigma_8 = 0.68^{+0.21}_{-0.11}$) for flat (open) models, where uncertainties correspond to 3$\sigma$ confidence level for three significant fitting parameter. No significant constraints are instead found for $\Gamma$. In order to verify under which circumstances a critical density model may still be viable, we show in Figure 2 the effect of changing the parameters of the $L_{bol}$–$T_X$ relation. Although best–fitting values of $\Omega_m$ and $\sigma_8$ move somewhat on the parameter space, neither a rather strong evolution nor a quite steep profile for the $L_{bol}$–$T_X$ relation can accommodate a critical density Universe: an $\Omega_m = 1$ Universe is always a $> 3\sigma$ event, even allowing for values of the $A$ and $\alpha$ parameters which are strongly disfavored by present data.

Based on these results, we point out that deep flux–limited X–ray cluster samples, like RDCS, which cover a large redshift baseline ($0.1 \lesssim z \lesssim 1.2$) and include a fairly large number of clusters ($\gtrsim 100$) do indeed place significant constraints on cosmological models. To this aim, some knowledge of the $L_{bol}$–$T_X$ evolution is needed from a (not necessarily complete) sample of distant clusters out to $z \sim 1$.

References

[1] Arnaud, K.A., & Evrard, A.E. 1999, MNRAS, 305, 631
[2] Bahcall, N.A., & Fan, X. 1998, ApJ, 504, 1
[3] Borgani, S., Rosati, P., Tozzi, P., & Norman, C. 1999, ApJ, 517, 40
[4] Della Ceca, R., et al. 1999, A&A, in press, astro-ph/9910489
[5] Donahue, M., & Voit, G.M. 1999, ApJ, 523, L127
[6] Eke, V.R., Cole, S., Frenk, C.S., & Henry, J.P. 1998, MNRAS, 298, 114
[7] Girardi, M., et al. 1998, ApJ, 506, 45
[8] Mushotzky, R.F., & Scharf, C.A. 1997, ApJ, 482, L13
[9] Ponman, T.J., et al. 1996, MNRAS, 283, 690
[10] Reichart, D.E., et al. 1998, ApJ, 518, 521
[11] Rosati, P. 1998, in Wide Field Surveys in Cosmology, 14th IAP Meeting (Paris, Publ.: Editions Frontieres) p.219
[12] Rosati, P., et al. 1998, ApJ, 492, L21
[13] Sadat, R., Blanchard, A., & Oukbir, J. 1998, A&A, 329, 21
[14] Viana, P.T.P., & Liddle, A.R. 1999, MNRAS, 303, 535
[15] White, D.A., Jones, C., & Forman, W. 1997, MNRAS, 292, 419