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XMM-Ω project : Cosmological implication from the high redshift $L-T$ relation of X-Ray clusters

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Abstract. The evolution of the temperature distribution function (TDF) of X-ray clusters is known to be a powerful cosmological test of the density parameter of the Universe. Recent XMM observations allows us to measure accurately the $L-T$ relation of high redshift X-ray clusters. In order to investigate cosmological implication of this recent results, we have derived theoretical number counts for different X-ray clusters samples, namely the RDCS, EMSS, SHARC, 160 deg^2 and MACS at $z > 0.3$ in different flat models. We show that a standard hierarchical modeling of cluster distribution in a flat low density universe, normalized to the local abundance, overproduces cluster abundance at high redshift ($z > 0.5$) by an order of magnitude. We conclude that presently existing data on X-ray clusters at high redshift strongly favor a universe with a high density of matter, insensitively to the details of the modeling.

Key words. Cosmology – Galaxies Clusters – Cosmological parameters

1. Introduction

In this work we examine the expected number counts of X-ray clusters as a function of redshift with different values for the density parameter and compare them to observed counts. The first model is the best flat model fitting the local Temperature Distribution Function (TDF) as well as the high redshift TDF (Henry 1997), see Blanchard et al. (2000). While the second model is a flat low density model normalized to the local TDF (the so-called concordance model).

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2. Ingredients of the modeling and results

As a first step, models are normalized using the local temperature distribution function, two fundamental ingredients are needed: the mass function and the mass-temperature relation, $M-T$. Here we use the expression of the mass function given by Sheth et al. (2001), SMT hereafter.

$$\frac{dN}{dm} = \sqrt{\frac{2a}{\pi}}\, c\, \frac{\bar{\rho}}{m} \frac{d\nu}{dm} \left(1 + \frac{1}{(a\nu^2)^p}\right) \times \exp\left(-\frac{a\nu^2}{2}\right) \quad (1)$$

with $a = 0.707$, $c = 0.3222$ and $p = 0.3$ and $\nu = \delta/\sigma(m)$.

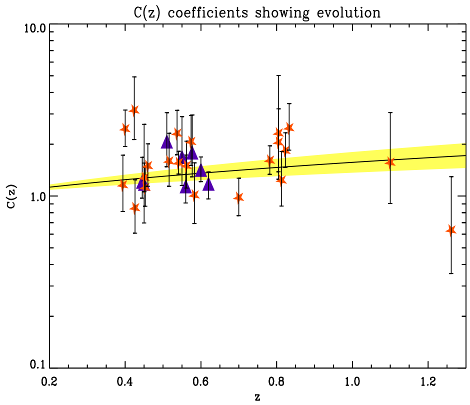

Fig. 1. XMM measurements of the evolution of clusters $L-T$ relation expressed by the $C(z)$ coefficient (Eq. 2). Triangles are our XMM data and error bars are derived from the 1σ error on the temperature measurement. Grey (yellow) area represents the 1σ error on the $C(z)$ fit and stars are the *Chandra* data.

The $M-T$ relation is written to be:

$$T = T_{15}(\Omega\Delta)^{1/3}M_{15}^{2/3}(1+z). \quad (2)$$

In this work we use different models of universe, including different $M-T$ normalizations, presented in Table 1.

A key-ingredient of the modelling is the $L-T$ relation and its evolution. The goal of the XMM-Omega project was to measure accurately this relation at redshift about 0.5 (Bartlett et al. 2001). We estimate the evolution from the recent XMM observations of high redshift clusters (Lumb et al. 2003), following the method of Sadat et al. (1996), by computing for each cluster :

$$C(z) = \frac{L}{AT^B}\frac{D_l(\Omega_M = 1, z)^2}{D_l(\Omega_M, z)^2} \quad (3)$$

We parametrize the evolution by $C(z) = (1+z)^\beta$ and we determine the best fitting $\beta = 0.65 \pm 0.21$, consistent with the *Chandra* result (Vikhlinin et al. 2002).
In order to compute number counts, one can notice that the observations actually provide z and f_x (rather than the actual L_x and T_x). For a flux limited sample with a flux limit f_x one has therefore to compute the following:

$$\begin{aligned} N(> f_x, z, \Delta z) &= \int_{z-\Delta z}^{z+\Delta z} \frac{\partial N}{\partial z}(L_x > 4\pi D_l^2 f_x)dz \\ &= \int_{z-\Delta z}^{z+\Delta z} N(> T(z))dV(z) \\ &= \int_{z-\Delta z}^{z+\Delta z}\int_{M(z)}^{+\infty} N(M,z)dMdV(z) \end{aligned}$$

where $T(z)$ is the temperature threshold corresponding to the flux f_x as given by the observations, being therefore independent of the cosmological model.

Results are presented in Figure 1. We conclude that *within the standard scenario of structure formation*, the predicted abundance of galaxy clusters points toward a high density universe. This result is insensitive to the local $L-T$ used, to the dispersion on its evolution nor to the different $M-T$ normalization, thanks to our local normalization (see Fig. 3).

3. Discussion

As we have seen a model which is normalized to the local as well as to the high redshift TDF, reproduces impressively well the redshift distribution of all the surveys we have investigated, without any adjustment and with little uncertainties arising from the modeling. This is a strong indication that existing samples of clusters (namely the Henry sample, the RDCS, the EMSS, the Bright SHARC, the 160deg^2 and the MACS sample) draw the same picture, consistently pointing out towards the fact that the cluster abundance is significantly evolving with redshift. Furthermore, in standard hierarchical picture of structure formation such evolution points towards a high matter density universe with Ω_M in the range [0.85-1.05], the precise value depending on the $M-T$ normalization.
This conclusion is clearly conflicting with the currently popular concordance model. However, it should be emphasized that this is entirely consistent with *all previous existing*

Table 1. Models and parameters used in the number counts calculations

T_{15} (keV)	Ω_M	σ_8	Γ	Cosmological model and ingredients
4	0.3	1.	0.2	B: Low Ω_M+ Bryan & Norman98+SMT
6.5	0.3	0.72	0.2	B: Low Ω_M+Markevitch98+SMT
4	1.	0.55	0.12	A: best model+Bryan & Norman98+SMT
6.5	0.85	0.45	0.1	A: best model+Markevitch98+SMT

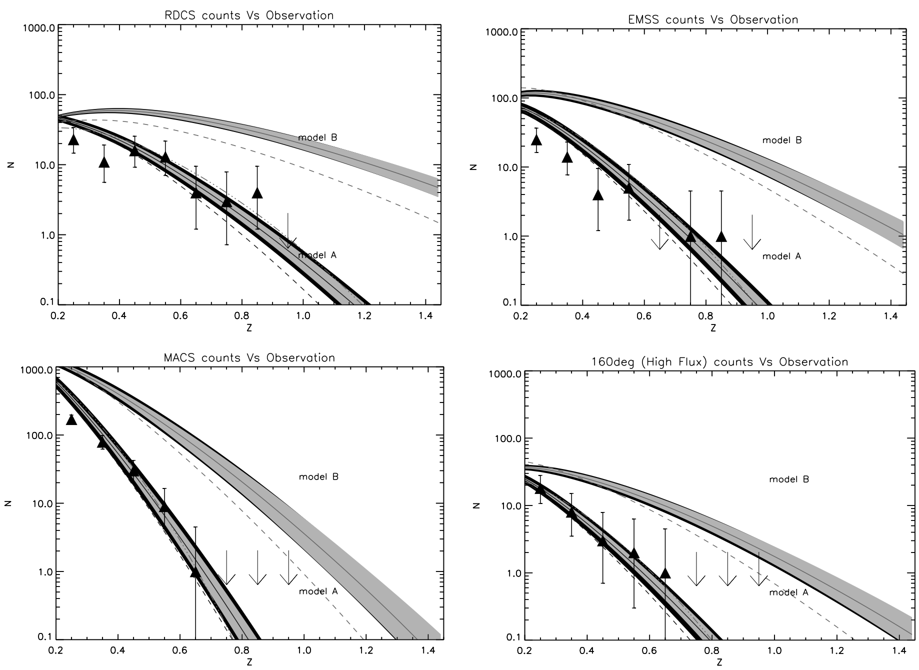

Fig. 2. Theoretical number counts in bins of redshift ($\Delta z = 0.1$) for the different surveys: RDCS, EMSS, MACS and 160deg^2. Observed numbers are triangles with 95% confidence interval on the density assuming poissonian statistics (arrows are 95% upper limits). For the 160deg^2 we show here only the brightest part ($f_x > 2\,10^{-13}$ erg/s/cm^2). The upper curves are the predictions in the concordance model. The continuous lines correspond to $T_{15} = 4$ (Bryan & Norman 1998) while the dashed lines are for $T_{15} = 6$ (Markevitch 1998). The grey area show the dispersion of the number counts due to the uncertainty in the evolution of the L-T relation and the dark area show the dispersion due the uncertainty on σ_8. The 3-dotted dashed line show the number counts in the concordance model using $M - T$ relation from Eq. 4 violating the standard scaling with redshift.

analyzes performed on the redshift distribution of X-ray selected samples of clusters performed with the same methodology (Reichart et al. 1999; Borgani et al. 1999).

We therefore conclude that the redshift distributions of present–day available X-ray clusters surveys, as well as the recent results on the $L - T$ relation of high redshift clusters, favor a high matter density universe unless the

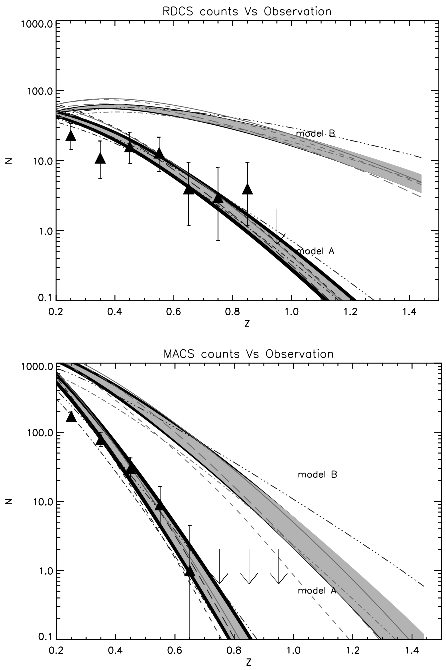

Fig. 3. This two last plots show the systematics effect: counts using the Press and Schechter mass function (solid line) and changing the local L-T (slope and normalization, dashed lines) from $0.04T^3$ to $0.08T^3$ and $L \propto T^{2.7}$ to $L \propto T^{3.3}$.

standard paradigm on clusters gas physics has to be deeply revised. For example, a possibility would be that the scaling in the redshift of the $M - T$ relation is completely wrong, violating the basic scaling scheme (Vauclair et al. 2003). In Fig. 2, we have plotted the predicted counts in a concordance model (3-dotted dashed lines), assuming

$$T = T_{15}(\Omega_M \Delta(z, \Omega_M)/178)^{1/3} M_{15}^{2/3} \quad (4)$$

instead of Eq. 2. As one can see, such a modification reestablishes agreement of the concordance model with observations.

It is well known that the $L - T$ relation cannot be explained from simple scaling arguments. One may therefore argue that the redshift evolution of the $M - T$ relation may suffer from more dramatic effect than usually assumed, although – to our knowledge – such a possibility has never been advocated and it is probably not obvious to find physical motivation leading to gas thermal energy in distant clusters ($z \sim 1$) to be reduced by a factor of two compared to clusters in the local universe.

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