



HAL
open science

Cosmological Interpretation from High Redshift Clusters Observed Within the XMM-Newton Ω -Project

Alain Blanchard

► **To cite this version:**

Alain Blanchard. Cosmological Interpretation from High Redshift Clusters Observed Within the XMM-Newton Ω -Project. 2005. hal-00004228

HAL Id: hal-00004228

<https://hal.science/hal-00004228>

Preprint submitted on 10 Feb 2005

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Cosmological Interpretation from High Redshift Clusters Observed Within the XMM-Newton Ω -Project

Blanchard Alain¹

¹LATT, UPS, CNRS, UMR 5572, 14 Av Ed.Belin, 31 400 Toulouse, France
alain.blanchard@ast.obs-mip.fr

Summary. During the last ten years astrophysical cosmology has brought three remarkable results of deep impact for fundamental physics: the existence of non-baryonic dark matter, the (nearly) flatness of space, the domination of the density of the universe by some gravitationally repulsive fluid. This last result is probably the most revolutionizing one: the scientific review *Sciences* has considered twice results on this question as *Breakthrough of the Year* (for 1998 and 2003). However, direct evidence of dark energy are still rather weak, and the strength of the standard scenario relies more on the “concordance” argument rather than on the robustness of direct evidences. Furthermore, a scenario can be build in an Einstein–de Sitter universe, which reproduces as well as the concordance model the following various data relevant to cosmology: WMAP results, large scale structure of the universe, local abundance of massive clusters, weak lensing measurements, most Hubble constant measurements not based on stellar indicators. Furthermore, recent data on distant x-ray clusters obtained from XMM and Chandra indicates that the observed abundances of clusters at high redshift taken at face value favors an Einstein de Sitter model and are hard to reconcile with the concordance model. It seems wise therefore to consider that the actual existence of the dark energy is still an open question.

1 Introduction

1.1 On the determination of cosmological parameters

The determination of cosmological parameters has always been a central question in cosmology. However, this problem has become more and more important in recent years due to the deep implications it can lead to. One of the most spectacular results established in recent years are for instance the existence of a dominant form of non-baryonic matter in the clustered content of the universe. After a very long debate on whether evidence for non baryonic dark matter universe were sufficiently robust, it is nowadays almost unanimously admitted that there are enough evidences to consider it as an established fact

(such a conclusion has strongly contributed to emphasize the deep couplings that exist between astrophysical cosmology and fundamental physics). As long as no direct evidence is found (from laboratory experiments) doubts are still possible and indeed few researchers still maintain the point of view that modified theories of gravitation could do the job as well.

A second essential result in recent modern cosmology is the evidence for the (nearly) flatness of the Universe which comes from the C_l curve of the CMB. The Saskatoon experiment was probably the first one to provide evidence for the presence of a peak around $l \sim 200$ [34], which was shown to provide a statistically significant indication for the flatness of the universe, a conclusion drawn as early as 1997: [28] see also [22]. This conclusion has been firmly established by second generation experiments, including those of Boomerang [14], Maxima [21], DASI [20], Archeops [2], allowing tight cosmological constraints [3]. Of course all these results have been superseded by WMAP measurements [26, 4]. It should be realized that these CMB measurements provide an observation (basically the position of the Doppler peak) which is predicted by models, involving standard physics, consistent with flat models. It is not a direct measurement of curvature of space (as could be obtained from a triangulation measurement for instance). The two above results are therefore the unavoidable consequences of the existing observations, if they have to be interpreted within standard physics as we know it by now. Rejecting these conclusions is possible, but only at the expense of modifying fundamental laws of physics as we know them by now.

The third result which has emerged in recent years, and which is revolutionizing for fundamental physics : the dominance of the density of the universe by some “dark energy”, i.e. a fluid with very exotic equation of state: $p = w\rho c^2$ with $w \sim -1$ [16, 49]. There is a large consensus around this so-called concordance model, which leads to the idea that the determination of cosmological parameters has been achieved with a rather good precision, may be of the order of 10%. Indeed this model does fit an impressive set of independent data, the most impressive been: local estimation of the density of the universe, CMB C_l curve, most current matter density estimations, Hubble constant estimation from HST, apparent acceleration of the Universe, good matching of the power spectrum of matter fluctuations. However, the necessary introduction of a non zero cosmological constant is an extraordinary new mystery for physics, or more exactly the come back of one of the ghost of modern physics since its introduction by Einstein. Here the situation is slightly different from the two previous cases: the introduction of a non-vanishing cosmological constant is a major modification of a fundamental law of physics (gravity). Although the cosmological constant certainly allows one to fit easily the Hubble diagram of distant SNIa, its introduction is not unavoidable, given the data. Rather, trusting fundamental physical laws as we know them lead to the conclusion that distant SNIa are, for some unknown

reason, intrinsically fainter than local ones. There is no argument that dismiss this “fact”. Therefore, in order for the SNIa Hubble diagram to be regarded as a convincing evidence for a cosmological constant, one should provide a convincing independent evidence that the luminosity of a distant SNIa is directly comparable to a local one without any correction. It is therefore the opinion of the author, that in order to consider SNIa as an argument in favor a cosmological constant, evidence for the absence of astrophysical corrections to SNIa luminosity has to be demonstrated (and one should remember there that the “absence of evidence “ is not “an evidence of absence”...).

The possible detection of a cosmological constant from distant supernovae has brought the first direct piece of evidence largely comforting the so-called concordance model: the apparent luminosity of distant supernovae now appears fainter, i.e. at larger distance, than expected in any decelerating universe [42, 39] and can therefore be explained only within an accelerating universe. There is a set of fundamental assumptions in this reasoning, that is that SNIa are standard candles which are not affected by any bias, any evolution, any obscuration. Although the data are well consistent with this hypothesis, it is almost impossible to demonstrate that it is actually right, i.e. that data are not biased by some astrophysical process. A more problematic point is that astrophysical processes in an Einstein de Sitter universe, if roughly proportional to the look back time may mimic rather well an apparent cosmological constant, producing an Hubble diagram that is almost indistinguishable from the standard diagram of the concordance model (see figure1). This means that SNIa argument is relatively weak by itself. For instance would the SNIa Hubble diagram points toward a negative matter content, $\Omega_m < 0.$, it would probably be interpreted by everybody as an evidence for some astrophysical process affecting SNIa luminosity...

I have already discussed in some detail the various arguments that may raise doubts on the validity of the concordance model [6, 5] (before WMAP results): for most observations which match the concordance model, there is some other evidences which go in a different direction (for instance different upper limits on the cosmological constant uncomfortably below the present preferred value were published in the past, including one coming from the SNIa in the SCP! [38]. I would like to add one recent example: the Hubble constant. Several measurements based on non stellar distance indicators lead to a lower value for Hubble constant than that has been derived from HST key-Project [19]. A recent analysis of the Cepheid distances suggests that one bias exist which when corrected would lead to a value 20% lower for the Hubble constant [37]. Such a value would imply, in combination with CMB a matter density parameter close to 0.5, ruining the nice concordance of the standard paradigm.

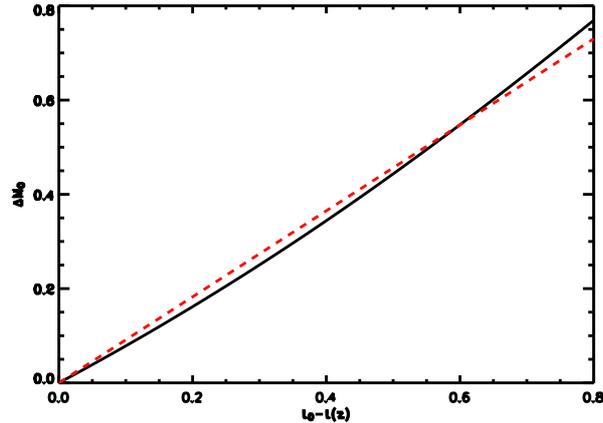


Fig. 1. Difference of magnitude between an Einstein de Sitter Universe and the concordance (full line) versus look back time. Any process which would produce an apparent dimming proportional to this look back time may mimic the presence of a cosmological constant (dashed line).

1.2 What the CMB does actually tell us?

Since the discovery of the CMB fluctuations by COBE [48] the idea that early universe physics has left imprints revealed by these fluctuations has gained an enormous attention. In this respect, DMR results have played a fundamental role in modern cosmology comparable to the discovery of the expansion of the universe or the discovery of the microwave background by Penzias and Wilson. The remarkable results of the WMAP experiment, are often quoted as providing a direct evidence for an accelerating universe. This is incorrect: cosmological constraints as established by the WMAP team [49] entirely rely on the powerlaw spectrum assumption. Therefore these conclusions could be erroneous [27, 23]. Indeed, relaxing this hypothesis, i.e; assuming non power law power spectrum allows to produce C_l curve which as good as the concordance model. This is illustrated by figure 2 on which 3 models are compared to the WMAP data, two being Einstein de Sitter models. Such models not only reproduce the TT spectrum, but are also extremely close in term of ET and EE spectra. Furthermore the matter power spectrum are similar on scales probed by current galaxies surveys. An un-clustered component of matter like a neutrino contribution or a quintessence field with $w \sim 0$ is necessary to obtain an acceptable amplitude of matter fluctuations on clusters scales [9]. Such models require a low Hubble constant ~ 46 km/s/Mpc. Such a value might be look as terribly at odd with central HST key program value (~ 72 km/s/Mpc) but is actually only $\sim 3\sigma$ away from this value. Given the above mentioned uncertainties (which raised the preferred value to lie $\sim 1.75\sigma$ away, this can certainly not be considered as a fatal problem for an Einstein-de Sitter

universe. The introduction of non-power law power spectrum might appear as unnatural. This is a somewhat subjective question. However, present measurement of C_l curve is testing the initial spectrum over 3 order of magnitude in length. The existence of distinct features in the primordial spectrum are suggested by present WMAP data [50], which could be the consequences of early physics on super-Planck scales [32], as scales which are now accessible to the observations are very likely to be sub-planckian before inflation. This argument could be regarded as an argument for which non-power-law models are to be preferred (although this is not giving any support to our –specific– model, given our poor knowledge of the relevant physics). This argument is strengthened by the global value of the χ^2 from the WMAP C_l : a point that is not much emphasized, is that the global value of the χ^2 is not good. In fact, the χ^2 for TT data has only a probability of 3% [49]. The conclusion in such a situation is that the hypotheses in the model are probably to be abandoned! An other option is that the data are still suffering from unsubtracted systematics (which is the proposed explanation given by the WMAP team).

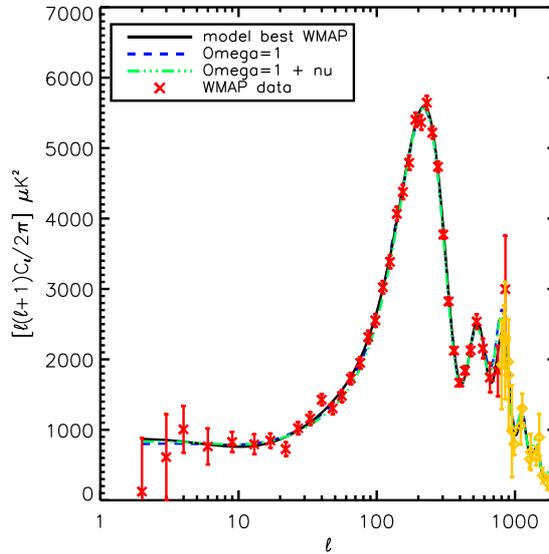


Fig. 2. The TT spectrum of the WMAP data compared to three different models: one is the concordance, the two others are Einstein de Sitter models, one of which comprises neutrino contribution of $\sim 10\%$ corresponding to three degenerate families with $m_\nu \sim 0.7\text{eV}$. Courtesy of M.Douspis.

1.3 Motivation for the XMM- Ω project

If one keeps an open mind, one should consider that the existence of a cosmological constant is not yet a scientific fact established beyond reasonable doubt or to be more precise, that the case for its actual existence is not as strong as the case for non-baryonic dark matter (furthermore it is always healthy to have an alternative model to the dominant paradigm). It is therefore of high interest to have a reliable measurement of the matter content of the universe, which in conjunction with the CMB data provides a case for or against a non-vanishing cosmological constant, depending on the value obtained for Ω_M . Most of existing measurements are local in nature, i.e. they actually provide mass to light ratio (M/L) from finite and relatively small entities, like clusters, which occupy a tiny fraction of the universe: massive clusters cover only 10^{-5} of the total volume of space! Therefore using the M/L argument relies on an extrapolation over five orders of magnitude... The baryon fraction has been argued as favoring a low density universe. However, this relies on some specific value of the estimation of mass of x-ray clusters which is uncertain. Consequently, given this uncertainty the baryon fraction is actually consistent as well as with a high density universe [44].

The evolution of the number of clusters of a given mass is a sensitive function of the cosmological density of the Universe, very weakly depending on other quantities when properly normalized [7], therefore offering a powerful cosmological test [35]. The XMM- Ω project [1] was designed in order to provide an accurate estimation of the possible evolution of the luminosity-temperature relation at high redshift for clusters of medium luminosity which constitutes the bulk of X-ray selected samples, in order to remove a major source of degeneracy in the determination of Ω_M from cluster number counts in flux limited number counts.

2 Observed evolution of the $L - T$ relation of X-ray clusters

For the first time a measurement of the $L - T$ evolution with XMM has been obtained. D.Lumb et al. (2004) [30] present the results of the X-ray measurements of 8 distant clusters with redshifts between 0.45 and 0.62. By comparing to various local $L - T$ relations, clear evidence for evolution in the $L - T$ relation has been found. The possible evolution has been modeled in the following way:

$$L_x = L_6(0) \left(\frac{T}{6\text{keV}} \right)^\alpha (1+z)^\beta \quad (1)$$

where $L_6(0) \left(\frac{T}{6\text{keV}} \right)^\alpha$ is the local $L - T$ relation. β is found to be of the order of 0.6 ± 0.3 in an Einstein-de Sitter cosmology [30, 52]. This result is entirely consistent with previous analyzes [45, 56] and others XMM data (see figure 3).

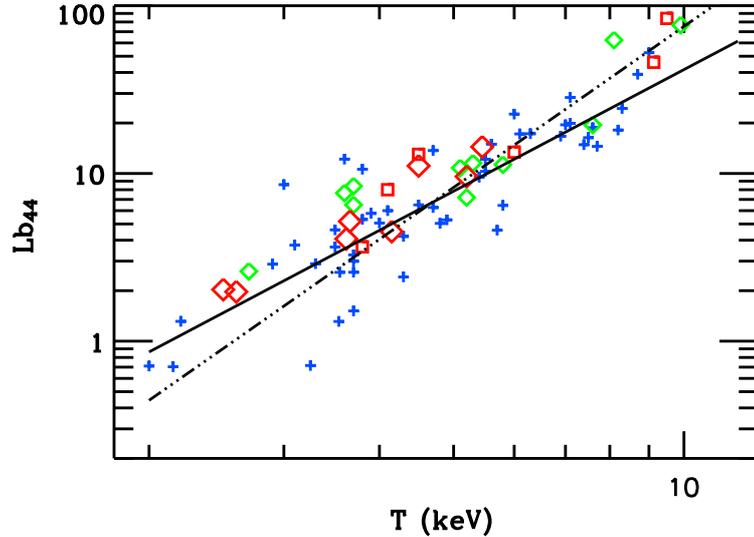


Fig. 3. Temperature–luminosity of X-ray clusters: crosses are local clusters from a flux selected sample [10], grey diamonds are distant clusters from Chandra [56] in the redshift range $0.4 \leq z \leq 0.625$, large dark diamonds are clusters from the XMM Ω project, squares are other XMM clusters within the same redshift range.

3 Cosmological interpretation

Attempts to apply directly the test of the evolution of the abundance of clusters have been performed but still from a very limited number of clusters (typically 10 at redshift 0.35) [25, 18, 51, 10]. In [10] it was found that $\Omega_M = 0.86 \pm 0.25$ (1σ), so that a concordance model is away at only a $2\text{-}\sigma$ level, while systematic differences explain the values obtained from the various authors. On the other hand, number counts allow one to use samples comprising much more clusters. Indeed using simultaneously different existing surveys: EMSS, SHARC, RDCS, MACS NEP and 160 deg² [24, 43, 41, 17, 33, 55] one can use information provided by more than 300 clusters with $z > 0.3$ (not necessarily independent). In order to model clusters number counts, for which temperatures are not known, it is necessary to have a good knowledge of the $L - T$ relation over the redshift range which is investigated, which information has been provided by XMM and Chandra. Number counts can then be computed:

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

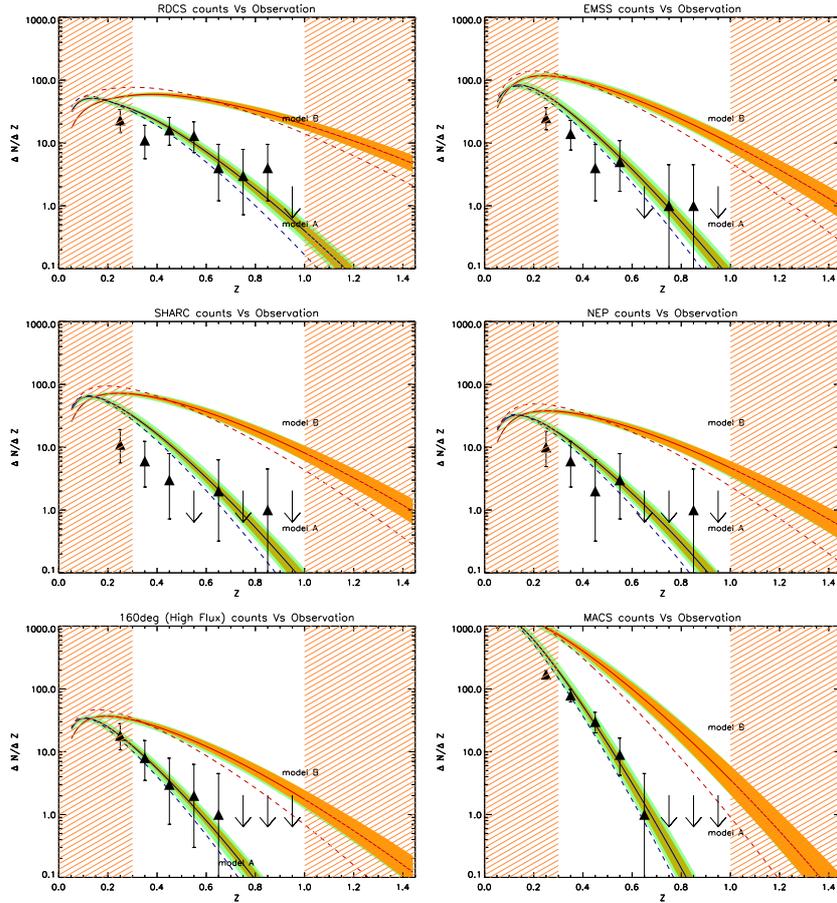


Fig. 4. Theoretical number counts in bins of redshift ($\Delta z = 0.1$) for the different surveys: RDCS, EMSS, MACS and 160deg²-high flux (corresponding to fluxes $f_x > 2 \cdot 10^{-13}$ erg/s/cm²). Observed numbers are triangles with 95% confidence interval on the density assuming poissonian statistics (arrows are 95% upper limits). The upper curves are the predictions in the concordance model (model B). The lower curves are for critical universe (model A). Uncertainties on σ_8 and on $L - T$ evolution lead to the grey area (see [53]).

$$= \Omega \int_{z-\Delta z}^{z+\Delta z} \int_{M(z)}^{+\infty} N(M, z) dM dV(z) \quad (2)$$

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. For most surveys the above formula has to be adapted to the fact that the area varies with the flux limit, and eventually with redshift. Several ingredients are needed: the local abundance of clusters as given by the temperature distribution function ($N(T)$), the mass-temperature relation and its evolution,

the mass function and the knowledge of the dispersion. Uncertainties in these quantities result in -systematics- uncertainties in the modeling which have been found to be comparable to statistical uncertainties. Figure 4 illustrates [53] the counts obtained with a standard mass temperature relation:

$$T = 4\text{keV}M_{15}^{2/3}(1+z) \quad (3)$$

the SMT mass function [47], and the $L - T$ relation observed by XMM with its uncertainty. These counts were computed for different existing surveys to which they can be compared. Several likelihood analyzes have been performed. Among the various conclusions that were found are: all existing x-ray clusters surveys systematically point toward high Ω_M , statistical uncertainties allow a determination of Ω_M with a 10% precision: $0.9 < \Omega_M < 1.07(1\sigma)$. During this analysis numerous possible source of systematics were investigated with great detail (local samples, normalization of the $M - T$ relation, local $L - T$ relation, dispersion in the various relations). The dominant source of systematic uncertainty is coming from the uncertain calibration of the mass temperature relation. This uncertainty can be greatly removed using the method based on a self consistent adjustment to the baryon fraction [8]. With this method the likelihood obtained is wider and the precision is decreased down to 15% (see figure 5). In addition the distribution is non-Gaussian: with the above prescription, although one conclude that $\Omega_M \sim 0.975 \pm 0.15$, the concordance model is still ruled out at 7σ level. Remaining systematics have been added in quadrature and are also representing roughly an additional 15% uncertainty. This means that global uncertainty is roughly 20%. We have also check that the local luminosity in our models is in good agreement with local surveys (without requesting it explicitly).

4 Looking for loopholes

4.1 Systematics

I have mentioned above that the source of various systematics have been investigated and lead to a $\sim 17\%$ uncertainty. This value is larger than the statistical uncertainty $\sim 10\%$. It is therefore very important to investigate one by one this systematics and what typical amplitude may restore the concordance. Special attention has been paid to selection functions. For instance if flux limit, or identically flux calibration in faint surveys, is erroneous by a factor of 2–3 the concordance would be much closer to existing surveys. However typical uncertainty is considered to be of the order of 20%. This provides a typical number: if the value of one of the systematic effects is ten times larger than estimated amplitude, then the concordance would accommodate the data.

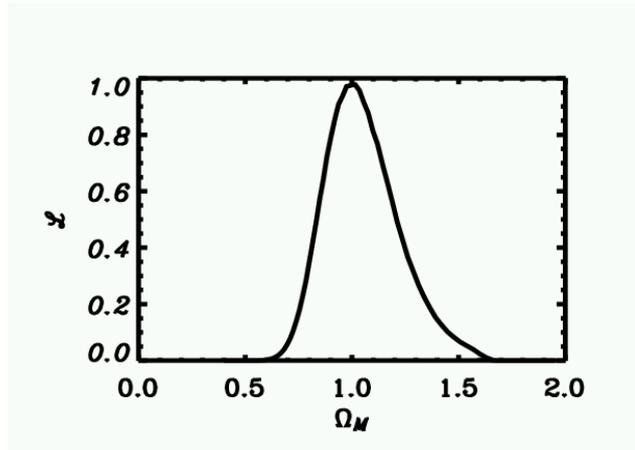


Fig. 5. Final likelihood from x-ray cluster number counts obtained with independent samples: MACS, EMSS, NEP, 160 deg^2 . The $M - T$ relation was treated self consistently as in [8].

4.2 Comparison with previous works

A comment that is heard sometimes in conferences, is that we are the only group who find such a high value for Ω_M . This an incorrect statement: when dealing with the $N(T)$ evolution, [51] did found a high central value, close to our best one. Major differences with previous analyzes to [10] were explained in term of systematics. As those results lie within the 2σ range found in [10], one can conclude that the problem is yet open. However, the redshift distribution of X-ray clusters using normalization from the local temperature distribution has been investigated in the past. With the analysis presented in [36, 45], there has been three different independent analyzes [11, 40], each leading to consistent results with EMSS as well as with ROSAT. All these analyzes indicate that redshift number counts are consistent with a high Ω_M and at odd with value of the order of 0.3 (note that [12] have obtained an acceptable fit to RDCS distribution, but at the price of unacceptable local abundance).

Our new analyzes basically recover identical results to the one mentioned above. However, the statistical significance is now much better: these samples contains ~ 300 clusters. Each sample is individually well fitted, this is a very important point: any large unidentified systematics affecting data, would have to affect the different surveys (from different groups and different methodology, on both ROSAT and EMSS data) in different way to mimic the Einstein de Sitter case, a somewhat tricky coincidence. I conclude that this new analysis is much mores robust than previous one, both in term of statistic and in term of control on systematics.

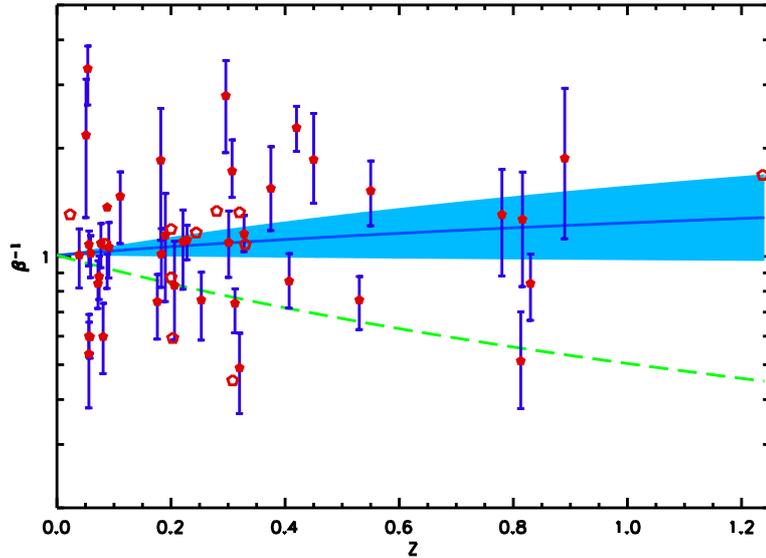


Fig. 6. The ratio between thermal energy of the gas measured by T_x and the kinetic energy of galaxies measured by their velocity dispersion for a sample of clusters with $T_x \geq 6$ keV with redshift spanning from 0 to 1.2. No sign of evolution is found. The best fit is the continuous line, grey area is the formal one σ region, dashed line is the level necessary to make the concordance in agreement with the x-ray clusters counts.

4.3 Is cluster gas physics essentially non-gravitational?

We have identified only one possible realistic way to reproduce number counts in a concordance model, that is by assuming that the redshift evolution of the $M - T$ relation is not standard:

$$T \propto M_{15}^{2/3} \quad (4)$$

(i.e. removing the standard $1 + z$ factor appearing in equation 3). This is conceivably possible if a large fraction of the thermal energy of the gas in present day clusters originates from other processes than the gravitational collapse and has been continuously injected during recent past (although it remains to be shown that this is actually possible in a realistic way). It is possible to test observationally this latter possibility: heating processes of the gas will obviously heat the gas but not galaxies. The quantity:

$$\beta^{-1} \propto \frac{T_x}{\sigma^2}$$

should therefore evolve with redshift accordingly to $(1 + z)^{-1}$ if the $M - T$ relation evolved accordingly to the above non-standard scheme while it should

remains constant in the standard case. Note that this conclusion persists even if galaxies velocity dispersion are a biased version of the dark matter one [15]. In order to test whether existing data do provide some indication on such a possible evolution, we have collected some existing measurements of velocity dispersion σ for massive clusters using BAX cluster data base [46] with further recent measurements: we selected clusters with temperature greater than 6 keV for which velocity dispersion was available. The result is shown on figure 6. We found no sign of such a non-standard behavior which is in principle ruled out at the $3\text{-}\sigma$ level at least.

5 Conclusions

The major results obtained with the Ω project are the first XMM measurement of the evolution of the luminosity-temperature with redshift. A positive evolution has been detected, in agreement with previous results including those obtained by Chandra [56]. The second important result is that this evolving $L - T$ produced counts in the concordance model which are inconsistent with the observed counts in all existing published surveys. This is in principle the signature of a high density universe, but might be as well due to a deviation of the expected scaling of the $M - T$ relation with redshift. Our investigation of the ratio $\frac{T_x}{\sigma^2}$ shows no sign of such deviation. Therefore, the distribution of x-ray selected clusters as known at present day favors a high density universe, alleviating the need for a cosmological constant.

References

1. J. Bartlett et al: proceedings of the XXIth rencontres de Moriond, astro-ph/0106098 (2001)
2. A. Benoît et al: astro-ph/0210305, A&A **399**, L19 (2003)
3. A. Benoît et al: astro-ph/0210306, A&A **399**, L25 (2003)
4. C. L. Bennett et al: ApJS **148**, 97 (2003)
5. A. Blanchard: Ap&SS **290**, 135 (2004)
6. A. Blanchard: proceedings of the Faro Conference "New Worlds in Astroparticle Physics", 2002, astro-ph/0301137, World Scientific ed, pp 50–69. (2003)
7. A. Blanchard, J. Bartlett: A&A **332**, 49L (1998)
8. A. Blanchard, M. Douspis: astro-ph/0405489 A&A submitted (2005)
9. A. Blanchard, M. Douspis, M. Rowan-Robinson, S. Sarkar: A&A **412**, 35 (2003)
10. A. Blanchard, R. Sadat, J. Bartlett., M. Le Dour: A&A **362**, 809 (2000)
11. S. Borgani et al.: ApJ **517**, 40 (1999)
12. S. Borgani et al.: ApJ **561**, 13 (2001)
13. S. Boughn, R. Crittenden: Nature **427**, 45 (2004)
14. P. de Bernardis et al: Nature **404**, 955 (2000)
15. J. Diemand, B. Moore, J. Stadel: MNRAS **352**, 535 (2004)

16. M. Douspis, A. Riazuelo, Y. Zolnierowski, A. Blanchard: *A&A* **405**, 409 (2003)
17. H. Ebeling, A. C. Edge, J. P. Henry: *ApJ* **553**, 668 (2001)
18. V. R. Eke, S. Cole, C. Frenk, J. P. Henry: *MNRAS* **298**, 1145 (1998)
19. W. L. Freedman, et al: *ApJ* **553**, 47 (2001)
20. N. W. Halverson et al: *ApJ* **568**, 38 (2002)
21. S. Hanany, et al: *ApJ* **545**, L5 (2000)
22. S. Hancock, G. Rocha, A. N. Lasenby, C. M. Gutierrez: *MNRAS* **294**, L1 (1998)
23. S. Hannestad: *PRD* **63**, 043009 (2001)
24. J. P. Henry, I. M. Gioia, T. Maccacaro et al: *ApJ* **386**, 408 (1992)
25. J. P. Henry: *ApJ* **489**, L1 (1997)
26. G. Hinshaw et al: *ApJS* **148**, 135 (2003)
27. W. H. Kinney: *PRD* **63**, 043001 (2001)
28. C. Lineweaver, D. Barbosa, A. Blanchard, J. Bartlett: *A&A* **322**, 365 (1997)
29. C. Lineweaver, D. Barbosa, *ApJ* **496**, 624 (1998)
30. D. H. Lumb et al: *A&A* **420**, 853 (2004)
31. A. Markevitch: *ApJ* **504**, 27 (1998)
32. J. Martin, R. H. Brandenberger: *PRD* **63**, 123501 (2001)
33. C. R. Mullis et al: *ApJ* **594**, 154 (2003)
34. C. B. Netterfield et al: *ApJ* **445**, L69 (1995)
35. J. Oukbir, A. Blanchard: *A&A* **262**, L21 (1992)
36. J. Oukbir, A. Blanchard: *A&A* **317**, 10 (1997)
37. G. Paturel, P. Teerikorpi: *A&A* **413**, L31 (2004)
38. S. Perlmutter et al: *ApJ* **483**, 565 (1997)
39. S. Perlmutter et al: *ApJ* **517**, 565 (1999)
40. Reichart, D. E. et al: *ApJ* **518**, 521 (1999)
41. P. Rosati et al.: *ApJ* **492**, L21 (1998)
42. D. Reiss et al: *AJ* **116**, 1009 (1998)
43. A. K. Romer et al: *ApJS* **126**, 209 (2000)
44. R. Sadat, A. Blanchard: *A&A* **371**, 19 (2001)
45. R. Sadat, A. Blanchard, J. Oukbir: *A&A* **329**, 21 (1998)
46. R. Sadat, A. Blanchard, J.-P. Kneib, G. Mathez, B. Madore, J. M. Mazzarella:
<http://bax.ast.obs-mip.fr/> *A&A* **424**, 1097 (2004)
47. R. K. Sheth, H. J. Mo, G. Tormen: *MNRAS* **323**, 1 (2001)
48. G. F. Smoot et al: *ApJL* **396**, L1 (1992)
49. D. N. Spergel et al: *ApJS* **148**, 175 (2003)
50. D. Tocchini-Valentini, M. Douspis, J. Silk: astro-ph/0402583, *MNRAS* to be published (2005)
51. T. P. Viana, A. R. Liddle: *MNRAS* **303**, 535 (1999)
52. S. C. Vauclair et al: *A&A* **412**, L37 (2003)
53. S. C. Vauclair et al: in preparation (2005)
54. P. T. P. Viana, A. R. Liddle: *MNRAS* **303**, 535 (1999)
55. A. Vikhlinin et al: *ApJ* **502**, 558 (1998)
56. A. Vikhlinin et al: *ApJL* **578**, 107 (2002)