The Impact of AXAF & XMM on Measurements of $\Omega_0$ from Cluster Abundances

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Abstract. Two major X-ray satellites, AXAF & XMM, will be launched in 1998/1999. Both satellites have spectral and imaging capabilities, and are several times more sensitive than either ROSAT or ASCA. AXAF & XMM will yield significant scientific returns in many fields of astrophysics. We concentrate here on how AXAF & XMM will improve constraints on the density parameter, $\Omega_0$, via measurements of the cluster abundance at high redshift.

1 Biasing $\Omega_0$ Using Observed Cluster Abundances

In a high $\Omega_0$ universe, the density of the most massive clusters will be vanishingly small at high redshift. This density rises rapidly as $\Omega_0$ decreases, meaning that the discovery of only one or two massive clusters at a redshift of $z\sim1$ has the potential to rule out $\Omega_0=1$ to high significance [1]. This sensitivity has meant that measurements of cluster abundances have become a popular means by which to constrain $\Omega_0$. However, one has to be extremely cautious when making cluster abundance measurements, since any observational bias which mimics an under (or over) abundance of massive clusters will lead to an over (or under) estimate of $\Omega_0$.

For example, one could mimic an under abundance of massive clusters in an X-ray selected survey, such as the EMSS, if the optical follow-up was incomplete: Optical follow-up becomes increasingly difficult as redshift increases and so there is a finite probability that some high $z$ clusters will be missed and that other clusters will be assigned incorrect redshifts. The optical follow-up of the EMSS cluster sample is now complete, but in an earlier version of the catalog, one high redshift ($z>0.5$) cluster was missed (MS1610.4) and two more had underestimated redshifts (MS1054.4 & MS1137.5). Small errors like these have a significant effect on measured parameters, such as the significance of measured luminosity evolution [14] and on the value of $\Omega_0$ [16].

To date, the analysis of cluster abundances has been made in the context of the Press-Schechter formalism, which gives an analytical relation for the number density of virialized dark matter halos as a function of mass and redshift [15]. When even a small fraction of the high redshift clusters in a given catalog have artificially high masses, then the Press-Schechter derived value of $\Omega_0$ will

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2By “abundances” we mean the number density of clusters as a function of mass and $z$.

3This formalism has been shown to be very accurate but will, no doubt, be replaced in coming years as larger and more accurate n-body simulations become available.
be too low. This situation could easily occur in an X-ray selected survey, if one has to rely on global X-ray luminosity or temperature measurements to derive the cluster masses: If a cluster has significant subclustering, e.g. MS1054.4 [5], then the derived mass can be higher than the virial mass.

Viana & Liddle conclude that, “at present the observational data and the theoretical modelling carry sufficiently large associated uncertainties to prevent an unambiguous determination of $\Omega_0$” [18]. This is illustrated by the fact that the EMSS yields best fit values that range from $\Omega_0=0.2$ [1] to $\Omega_0=1$ [2].

2 The Impact of AXAF and XMM

The two main observational issues that need to be addressed when attempting to measure $\Omega_0$ from cluster abundances are; (i) the completeness of the cluster catalog under study and (ii) the accuracy of the cluster mass estimates. We describe the positive impact that AXAF & XMM will have in both areas below.

**Improving cluster mass estimates:** It has been shown that there is a tight relationship between cluster mass and X-ray temperature ($T_x$) in a virialized system [7]. Existing $T_x$ data, derived from ASCA and GINGA observations [11], provide only weak constraints on $\Omega_0$ [18], but we can expect these constraints to tighten dramatically after the launch of AXAF and XMM. These satellites will provide $T_x$ values more accurately, and more efficiently, than ever before. As an illustration, let us compare the expected countrates for the most luminous cluster in the EMSS (MS0015.9, $z=0.54$) in the AXAF ACIS-I camera ($0.15$ s$^{-1}$), the XMM EPIC pn-camera ($0.57$ s$^{-1}$) and an ASCA SIS camera ($0.05$ s$^{-1}$). With $\sim2000$ photons, or a 13 ks ACIS-I observation, one can measure $T_x$ for this cluster to a reasonable accuracy ($\delta T_x/T_x < 0.2$) [11].

It is likely, given the excellent spatial resolution of AXAF & XMM (0.5$''$ and 10$''$ respectively) that many guest observers will request exposure times long enough to make spatially resolved temperature maps of high redshift clusters. (With ASCA, these sorts of maps have only been feasible for high flux, low redshift, clusters [13].) These efforts should be encouraged, since temperature maps allow one to correct $T_x$ for the influence of shock fronts at subcluster boundaries and of cooling flows in the cluster core. The exposure times required will be high, but over the lifetime of the satellites ($\sim 10$ years), we can expect temperature maps to become available for a significant fraction of known X-ray clusters at $z > 0.3$. For example, to measure a $T_x$ value in 4 independent radial apertures for MS0015.9, one would require $\sim 50$ ks with AXAF or $\sim 14$ ks with XMM.

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4These countrates were derived using HEASARC W3PIMMS webpage and assuming an 8keV Raymond-Smith spectrum and the total [0.3-3.5 keV] flux quoted in [1].
Towards new cluster samples: In addition to the EMSS, which was produced from Einstein-IPC data, there are now several samples of X-ray selected, high redshift, clusters based on ROSAT PSPC data e.g. [3] [14] [19]. These ROSAT surveys cover smaller areas (17 - 200°) than the EMSS (40 - 730°), which is a distinct disadvantage, since it is areal coverage, not flux limit, that determines the number of high z, high mass, clusters in a given survey. For example, in only a 1 ks XMM observation one could detect a massive cluster at z=1 to a signal-to-noise greater than 10. (Here we define a “massive cluster” to be one with a luminosity greater than L*, where L* ≃ 3e44 erg/s [6].) But, since these clusters are so rare beyond z=0.3, one would need to make ≃420, non-overlapping, XMM pointings to guarantee a single detection. (This estimate was based on the number of 0.3<z<1, Lx>L* clusters in the EMSS [9].)

Apart from a possible “XMM Slew Survey”, which would have an effective exposure time of less than 100 seconds (David Lumb, private communication), there are no plans to use either XMM or AXAF as survey instruments. Any new cluster catalogs would, therefore, have to be based on serendipitous detections. Given the growing number of ROSAT derived cluster catalogs, and the huge areal coverage of the EMSS, would yet another serendipitous cluster survey be worthwhile? We suggest that is not only worthwhile, but imperative. This is because all surveys to date have been based on less than ideal X-ray data, meaning one cannot fully define their selection functions, and hence completeness, using simulations. For example, (i) several of the EMSS clusters were detected at only the 5σ level [14] and (ii) ROSAT-PSPC cluster surveys which rely on source extent have problems with blended emission (blends make up ≃ 50% of the cluster candidates in the Bright SHARC sample [17]). The only way to remove observational biases like these is to create a new cluster sample based on higher quality X-ray data.

If the XMM-EPIC camera remains in service during the whole lifetime of the satellite, then one could use it to build up an X-ray cluster survey with the same areal coverage as the EMSS. Under the conservative assumption of only 3 pointings per day, then XMM would be able to cover a total area of 2200° in 10 years. (The XMM field of view is 0.2° compared to 1.6° for the Einstein-IPC.) Not all of the available area will be of use to a cluster survey, however, since some will fall in the galactic plane and some will be in the field of diffuse X-ray sources, such as low z clusters and supernova remnants. Using the ROSAT archive as a guide, one can expect that only ≃1/3 of the XMM pointings will be suitable for a serendipitous cluster survey, but this would still yield ≃ 700° over the lifetime of the satellite. Such a survey will be aided both by the planned pipeline processing at the XMM Survey Science

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5ROSAT-PSPC surveys based on pointing data will never cover more than ∼ 200° because the PSPC instrument was retired after only 4 years in service.

6It is not practical to carry out a serendipitous cluster survey with AXAF because its FOV for imaging is even smaller (0.08°) than that of XMM. In addition, unlike XMM, AXAF is not able to produce imaging data when the diffraction gratings are in place.
Center and by the spatial resolution of the EPIC cameras: The XMM spatial resolution is better, even at the edges of the FOV, than the on-axis resolution of the ROSAT-PSPC. This means that far fewer blended point sources will be falsely flagged as cluster candidates, which in turn eases optical follow-up. In addition, a new XMM cluster sample will require much less X-ray follow-up than the EMSS or the ROSAT-PSPC samples. This is because the majority of XMM exposures are expected to be at least ten times longer than the 1 ks required for a 10σ detection of a z=1, L⋆ cluster. Therefore, most serendipitous cluster observations will yield sufficient counts to allow cluster profiles and global T_x values to be measured directly.

3 Summary

Measurements of cluster abundances allow one to place strict constraints on the value of Ω_0 which are independent from those derived from high redshift supernovae or from Cosmic Microwave Background fluctuations. After the launch of AXAF & XMM, it will be possible to remove several observational biases that have dogged previous attempts to measure Ω_0 from cluster abundances. Progress will come via the derivation of accurate virial temperatures for a large number of clusters and via the development of a new, large area, cluster survey.

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