GAS DISTRIBUTIONS IN AN UNBIASED SAMPLE OF LOW-Z GALAXY CLUSTERS

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ABSTRACT

We present an improved technique for the deprojection and PSF-deconvolution of X-ray surface brightness profiles of galaxy clusters. Our method is tested using simulated profiles, *XMM-Newton* and *Chandra* data, and is shown to result in unbiased gas density profiles that retain full information about the gas distribution. We then apply the method to surface brightness profiles of an unbiased sample of nearby clusters from the XMM Legacy Project for the Study of Galaxy Cluster Structure, and discuss the scaling properties of the gas density profiles.

1. AN IMPROVED TECHIQUE FOR MEASURING GAS DENSITY PROFILES

We have developed a regularisation procedure for the direct deprojection and PSF-deconvolution of X-ray surface brightness profiles. Our technique allows us to obtain accurate gas density profiles in a straightforward manner from X-ray observations, avoiding *a priori* assumptions about the functional form of the density distribution and making full use of the information in the surface brightness profile, unlike the use of analytical models. Our regularisation procedure is adapted from the Philips-Towmey method used by Bouchet (1995) for the deconvolution of gamma-ray spectra. The effects of projection and PSF blurring can be expressed as a 2D redistribution matrix, determined from geometrical calculations and detector characteristics, which is multiplied by the emitted profile to produce an observed surface brightness profile. Since directly solving this equation for the emitted profile is an inverse problem, we minimise the amplification of errors in the derived emitted profile by constraining the solution to be smooth (minimising the sum of the squares of the 2nd derivatives about each point), using a cross-validation technique to systematically choose a regularisation coefficient based on distinguishing between smooth (i.e. physically plausible) variations and noise (e.g. Wahba 1978).

In Fig 1 we show the results of Monte Carlo simulations of profiles obtained by projection and PSF convolution of the simulated emission from model density distributions. We used the AB model of Pratt & Arnaud (2002), a modified β-model that can also fit central cusps:

$$n_e = A\left(\frac{r}{r_c}\right)^{-\alpha}\left[1+\left(\frac{r}{r_c}\right)^2\right]^{-3\frac{\beta}{2}+\frac{\alpha}{2}} \tag{1}$$

We varied the parameters to generate input profiles, which were each projected, then used to generate 100 simulated *XMM* profiles per model using Poisson statistics. These were convolved with an *XMM* response matrix. For each model, we then compared the mean output density profiles from our code with the input profiles. In all cases the input profile is recovered to a high degree of accuracy with no bias. More details and rigorous testing of our method are presented in Croston et al. (in prep).

We applied our deprojection code to three clusters for which both XMM and Chandra data exist: Abell 478, Abell 1413 and Abell 1991. We found very good agreement between our results and the deprojected Chandra profile of Sun et al (2003) for A478, and best-fitting analytical model of Vikhlinin et al. (2005) for A1413 (Figure 2). In the case of Abell 1991 (not shown), the shape of the XMM profiles (both deprojected and best-fit model)

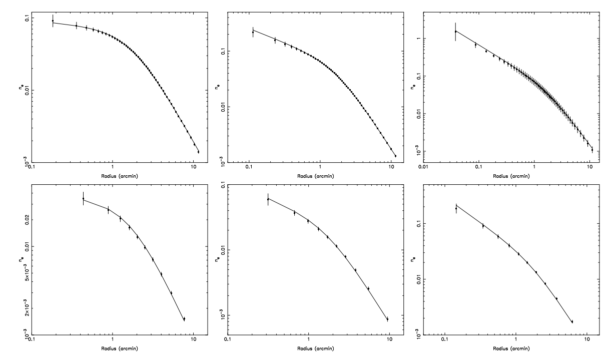

Figure 1. Simulation input density profiles (solid line) and output profiles (filled squares). L to r: AB models with $\beta = 0.67$ $r_c = 0.1R_{200}$, and $\alpha = 0.1$, 0.5 and 0.9. Top: high quality data, bottom: poor quality data.

was found to differ at about the 10% level from the best-fitting Chandra model (Vikhlinin et al. 2005) in the inner regions, but the profiles are consistent at large radii.

2. THE *XMM-NEWTON* LEGACY PROJECT FOR GALAXY CLUSTER STRUCTURE

A large, unbiased sample of clusters has been observed with XMM-Newton in order to allow a systematic investigation of: the scaling relations of observable cluster properties, such as X-ray luminosity, temperature, characteristic radius and cluster mass, and the source of scatter in these relations, e.g. non-thermal heating processes, merger activity; dynamical states of the clusters, the statistics of cluster mergers and the frequency of cooling cores as a function of cluster mass (important cosmological diagnostics); entropy profiles as a probe of thermal and star fomation history, metal abundances as a function of various observational parameters, and the variation of cluster mass and mass-to-light profiles. The REFLEX catalogue (Böhringer et al. 2004) was used to construct a sample based on the following criteria: $z < 0.2$; X-ray-luminosity-selected, to be unbiased to cluster type; close to homogeneous coverage of luminosity space; $T > 2$ keV; distances selected to optimally use photon collection power and field-of-view of XMM; and detectable with XMM to at least a radius of r_{500}. XMM-Newton has now carried out observations for the entire sample of 34 clusters. The results presented here are based on analysis of a subsample of 15 clusters, consisting of those for which the data were not significantly affected by high background periods.

X-ray surface brightness profiles were extracted for the subsample of 15 clusters, using standard techniques and double background subtraction. Profiles from the MOS1, MOS2 and pn cameras were summed. Density profiles were then obtained using the technique described in Section 1. Global temperatures (emission-weighted averages, excluding cooling regions) were used to calculate R_{200} using the relation of Arnaud et al. (2005); the densities were then scaled according to their expected evolution as a function of redshift. In Fig 3 (left) the scaled density profiles are shown for the entire subsample. We found a large scatter in the density profiles at large radii (σ_{ne}/n_e = 0.28 at $0.3R_{200}$). We tested whether this could be explained by a temperature-dependence of the density; however, rescaling the density profiles by $T^{0.525}$ (not plotted), the relation expected as a result of the departure from self-similarity in the $S-T$ relation (e.g. Ponman et al. 2003) does not reduce the scatter in n_e at $0.3R_{200}$. The mean slope for $R > 0.2R_{200}$ is $\alpha = 1.87 \pm 0.24$ ($\beta = 0.62$, consistent with the mean value of β for the sample of Vikhlinin et al. 2005). We find possible evidence of a relation between slope and global temperature; however, the temperature range is not sampled very well for our subsample, and so the full sample will be necessary to confirm this. We next investigated the scaling of the total gas mass with temperature (Fig 3, right), measuring the mass to a scaled radius of $0.7R_{200}$, and found a reasonably tight correlation, with a slope of 1.8 ± 0.3, consistent with the observed relation for total cluster mass (e.g. Arnaud et al. 2005). An investigation into the influence of cluster dynamical state on the gas density scaling properties is ongoing.

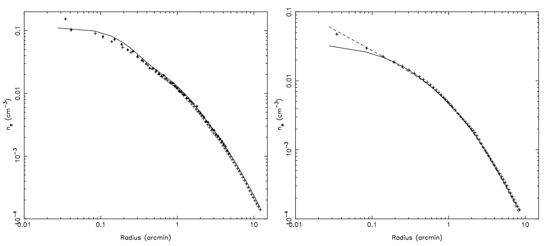

Figure 2. Comparison of XMM and Chandra profiles for Abell 478 (left) and Abell 1413 (right), with the XMM profile obtained with our method (+ symbols), the best-fitting XMM models of Pointecouteau et al. (2004) and Pratt & Arnaud (2002) (solid lines), respectively, and the Chandra profiles of Sun et al. (2003) (filles triangles) and Vikhlinin et al. (2005) (dashed line), respectively.

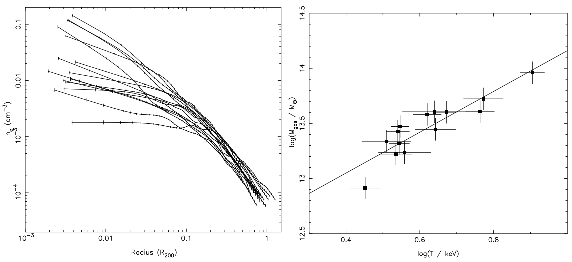

Figure 3. Left: The scaled gas density profiles for the cluster sample. Right: Total gas mass vs. global temperature.

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