DISTRIBUTION OF BARYONIC AND NON BARYONIC MATTER IN CLUSTERS OF GALAXIES

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We present the analysis of baryonic and non-baryonic matter distributions in a sample of eleven nearby clusters (0.03 < z < 0.09) with temperatures between 4.4 and 9.4 keV. These galaxy clusters have been studied in detail using X-ray data and global physical properties have been determined. Correlations between these quantities have been analysed and compared with the results for distant clusters. We found an interesting dependence between the relative gas extent (expressed as the ratio of gas mass fractions at r_{500} and $0.5 \times r_{500}$) and the total cluster mass. The extent of the gas relative to the extent of the dark matter tends to be larger in less massive clusters. This dependence might give us some hints about non-gravitational processes in clusters.

1 Introduction

Clusters of galaxies are fascinating objects. They represent important structures in the universe and the understanding of the physical processes during their formation is an attractive task. The study of correlations between different physical properties as X-ray luminosity, temperature, total mass, gas mass and relative gas extent enable us to draw conclusions about their formation processes, about the thermal history of clusters and hence about cosmological parameters. Some authors have studied cluster samples to search for these fundamental relations (e.g., Fukazawa 1997 [1]; Allen & Fabian 1998 [2]; Arnaud & Evrard 1999 [3]; Ettori & Fabian 1999 [4]; Horner et al. 1999 [5]; Jones & Forman 1999 [6]; Mohr et al. 1999 [7]; Schindler 1999 [8]; Neumann & Arnaud 1999 [10]).

We selected a sample of nearby clusters of galaxies in which an accurate total mass determination is possible, i.e with relaxed and symmetric morphologies, good temperatures measurements and good surface brightness profiles. All the masses have been calculated in a consistent way and within equivalent volumes for all the clusters. We analyse relations between different properties and compare them with the relations in the more distant sample (0.3 < z < 1.0) by Schindler 1999 [8]. We included in the comparison two more distant clusters: RBS797 (z=0.35) analysed with a Chandra observation by Schindler et al. 2001 [9] and the cluster RXJ0849+4452 (z=1.26) where we have calculated the total and gas mass using the parameters from the Chandra data analysis by Stanford et al. 2000 [11]. Our preliminary results are presented here. The cosmology used is: $H_0 = 50$ km/s/Mpc and $q_0 = 0.5$.

2 Data Reduction and Analysis

X-ray imaging data retrieved from the ROSAT archive is used[a] to determine the surface brightness profiles of the clusters. For each cluster a ROSAT PSPC image was reduced using the standard analysis with EXSAS software. In order to maximize the signal-to-noise ratio, we use the hard energy band (0.5-2.0 keV). The images were corrected for exposure variations and telescope vignetting using exposure maps generated with MIDAS/EXSAS software.

To calculate the gas density profiles the standard β-model (Cavaliere & Fusco-Fermiano 1976 [12]) has been used.

$$\rho_{gas}(r) = \rho_0 \left[1 + \frac{r^2}{r_c^2}\right]^{-\frac{3}{2}\beta} \tag{1}$$

We generated radial surface brightness profiles in concentric annuli (centred on the emission maximum in the cluster) excluding obvious point sources manually. The observed profiles are fitted with a β-model plus background:

$$S(b) = S_0 \left[1 + \frac{b^2}{r_c^2}\right]^{-3\beta+\frac{1}{2}} + B. \tag{2}$$

As the overall β-model fit is a poor description of the central region of some clusters where excess emission is observed (due to a cooling flow or a central point source) we minimised the reduced χ^2 by excluding the central bins from the fit. The best fit β-model was determined by excluding the profile within the cooling radius (Peres et al. 1998 [13], Allen & Fabian 1997 [14], White et al. 1997 [15]), taking into account the errors due to the uncertainty of the cooling radius in the errors of the fit parameters.

With the assumption of hydrostatic equilibrium and spherical symmetry cluster masses can be derived directly from X-ray observations through the gas density gradient, the gas temperature gradient and the gas temperature itself:

$$M(<r) = -\frac{kr}{\mu m_p G} T_{gas}(r) \left(\frac{d\ln\rho_{gas}(r)}{d\ln r} + \frac{d\ln T_{gas}(r)}{d\ln r}\right). \tag{3}$$

Weighted ASCA temperatures for our targets were taken from (Markevitch, et al. 1998 [16], White 2000 [17]). We choose the temperatures obtained when the central cluster regions are excluded to avoid the complication due to the additional cool emission component. In this way we determine the spatial distributions of gas mass and total mass from X-ray surface brightness and ASCA temperatures assuming isothermality (Irwin & Bregman 2000 [18]). This provides also estimates for quantities like e.g the baryonic fraction and the gas extent relative to the dark matter distribution.

3 Results and discussion

Having acquired the gravitational mass profiles for the clusters sample, it is now important to determine the radius within which to calculate the cluster mass. As the mass of a cluster is increasing with radius, masses can only be compared when derived within equivalent volumes. Simulations by Evrard et al. 1996 [19] have shown that the assumption of hydrostatic equilibrium is generally valid within a radius r_{500}, where the mean gravitational mass density is equal to 500 times the critical density $\rho_c(z) = 3H_0^2(1+z)^3/8\pi G$. We calculated M_{tot} and M_{gas} at r_{500}. Some of the preliminary results in the analysis of the nearby cluster sample are presented here.

[a] http://www.xray.mpe.mpg.de/rosat/archive

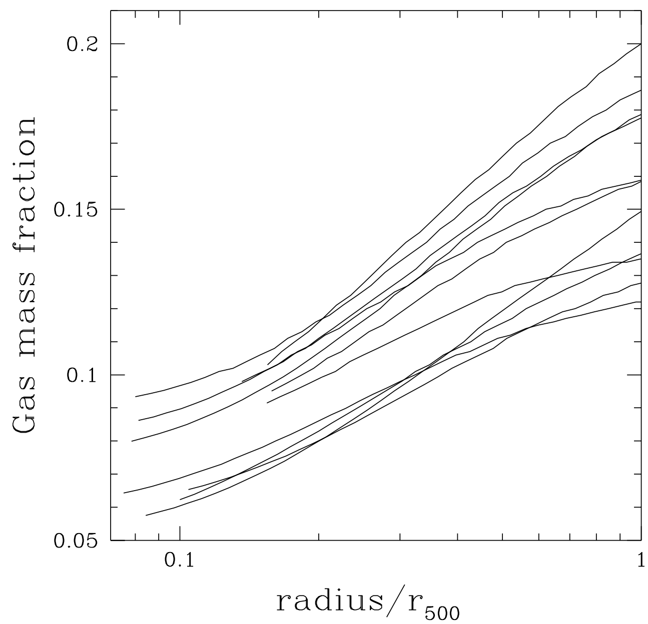

Figure 1: Gas mass fraction profiles derived for the nearby cluster sample. Profiles are plotted from the minimum radius fitted in the $\beta-$model.

3.1 Gas mass fraction

We find that inside each cluster the gas mass fraction increases outwards (see figure 1) implying that the gas distribution is more extended than dark matter (see section 3.2 for a detailed discussion). A low Ω is required to explain the high gas mass fraction of $< f_{gas} >_{r_{500}} = 0.16 \pm 0.02$, when compared to the baryon fraction predicted by primordial nucleosynthesis. From cluster to cluster we find large variations in the gas mass fraction as Ettori & Fabian 1999 [4] found. The gas mass fraction at r_{500} ranges from $0.121^{+0.014}_{-0.015}$ for cluster A644 to $0.20^{+0.04}_{-0.03}$ for cluster A3112. These variations have some implications on cluster formation because it probably reflects the distribution of baryonic and non-baryonic matter in the early universe. If all the clusters had originally the same gas mass fraction and all the differences came later by different amounts of gas released by the cluster galaxies, larger metallicities in clusters with high gas mass fraction would be expected. But this not observed (Schindler 1999 [8]). Therefore the difference must be caused at least partially by the primordial distribution or baryonic and non-baryonic matter.

To test whether there is any dependence on redshift with the gas mass fraction we plot this quantity versus redshift including the results from Schindler 1999 [8] for distant clusters in red circles and the other two distant clusters: RBS797 (blue circle) and RXJ0849+4452 (green circle) (see figure 3). The mean value for the nearby sample is $< f_{gas} >_{r_{500}} = 0.16 \pm 0.02$ being similar within the errors to the mean value for the distant sample $< f_{gas} >_{r_{500}} = 0.18$. Hence we see no clear trend in the gas mass fraction with redshift in these data implying an early gas presence in the cluster (only the most distant cluster RXJ0849+4452 shows a lower value of 0.11). This contradicts the results by Ettori&Fabian 1999 [4] where evolution of the gas mass fraction is found in a nearby sample. Matsumoto et al. 2000 [20] found no clear evidence of evolution for the clusters at z < 1.0.

We have also looked for trends of f_{gas} with the total cluster mass $M_{tot}(r_{500})$, see figure 4. The gas mass fraction does not show a clear correlation with the total mass at radius r_{500}.

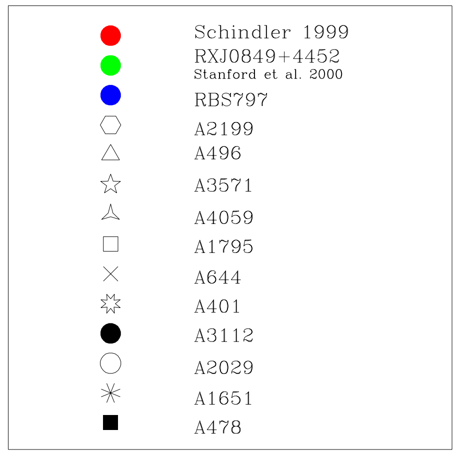

Figure 2: Symbols used for various clusters in the figures.

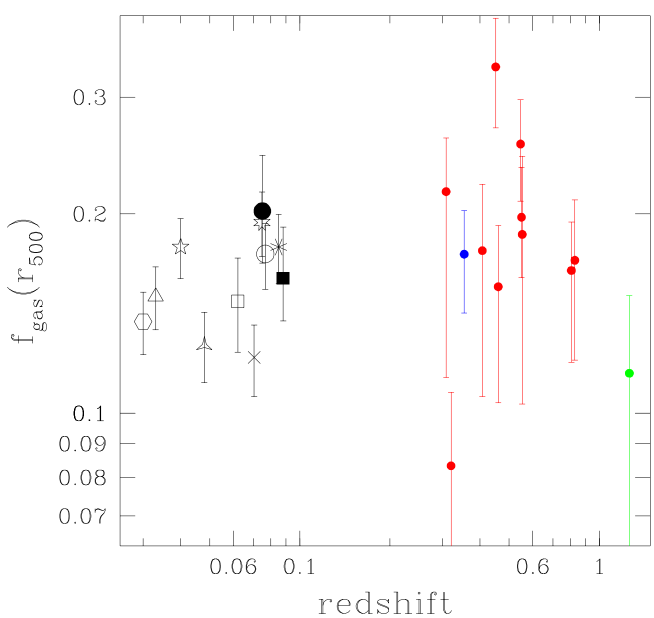

Figure 3: Gas mass fraction at radius r_{500} versus redshift.

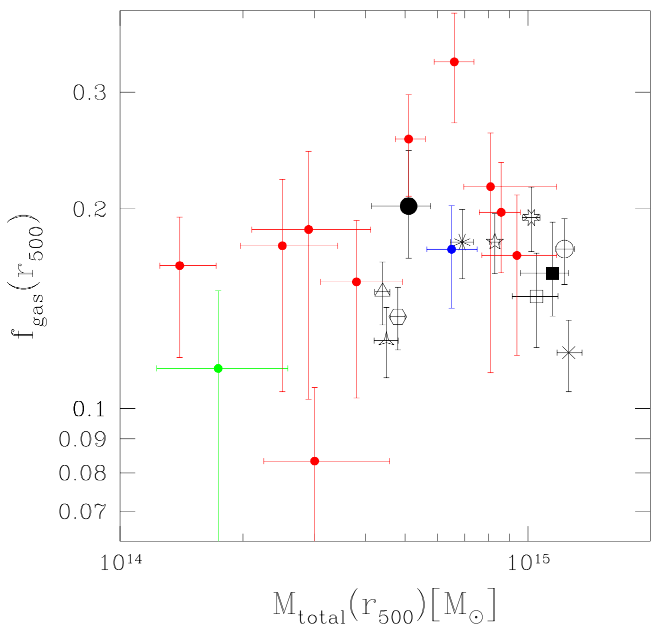

Figure 4: Gas mass fraction versus total mass at radius r_{500}.

Instead we find the similar trends as found by Reiprich & Böhringer 1999 [21]: for cluster masses greater than $5 \times 10^{14} M_{\odot}$ the $f_{gas}(r_{500})$ seems to decrease with the total cluster mass and for masses lower than the above limit $f_{gas}(r_{500})$ tends to increase with total cluster mass.

3.2 Gas extent

As mentioned before the gas mass fraction is not constant with radius. We compare the gas mass fraction at radius r_{500} with the gas mass fraction at $0.5 \times r_{500}$ in each cluster. The mean gas mass fraction at $0.5 \times r_{500}$ is 0.13, i.e. smaller than the mean of 0.16 at r_{500}. The ratio of these fractions is a measure of how fast the gas mass fraction is increasing with radius and as such a measure for the extent of the gas distribution with respect to the dark mater distribution.

For all the clusters in our sample the relative gas extent E is larger than 1 (see figure 5). This means that in general the gas distribution is more extended than the dark matter in agreement with results from other authors for nearby and distant cluster. The distant sample by Schindler 1999 [8] is also shown in figure 6 for comparison.

In the nearby sample this relative gas extent E shows a mild dependence on the total mass (see figure 5). Clusters with larger masses tend to have smaller relative gas extents (similar dependence confirmed by Reiprich & Böhringer 1999 [21]).

The distant and low mass cluster RX J0849+4452 seems to follow the same trend as the nearby sample showing a higher value for the relative gas extent. The cluster RBS797 lies in the trend as well.

This trend can be explained by the physical processes in the gas, which are assumed to be responsible for the increase of gas mass fraction with radius like e.g. energy input by supernovae driven galactic winds. If gas is placed artificially into a model cluster potential in hydrostatic equilibrium the distributions of gas and dark matter have the same slope at radii larger than the core radius, therefore one would expect a priori a ratio $E \approx 1$. It might be that this additional

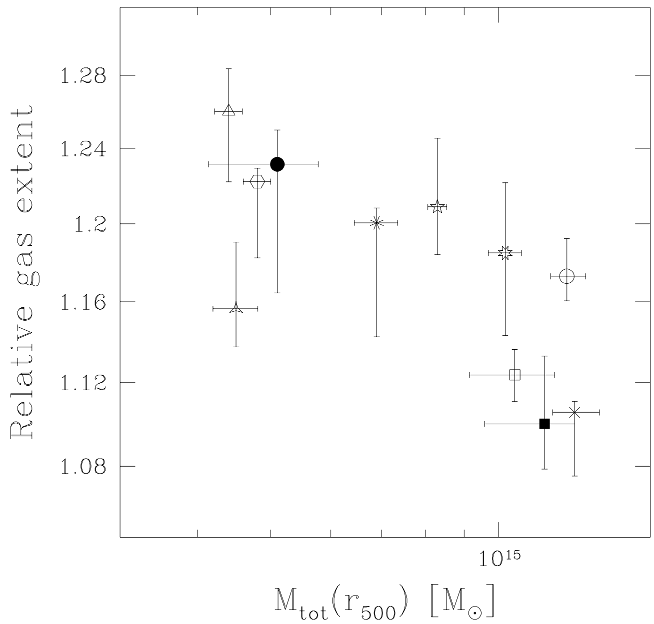

Figure 5: Ratio of gas mass fraction at r_{500} and $r_{500}/2$ as a measure for the relative gas extent of the gas distribution versus total cluster mass at r_{500} for the nearby sample.

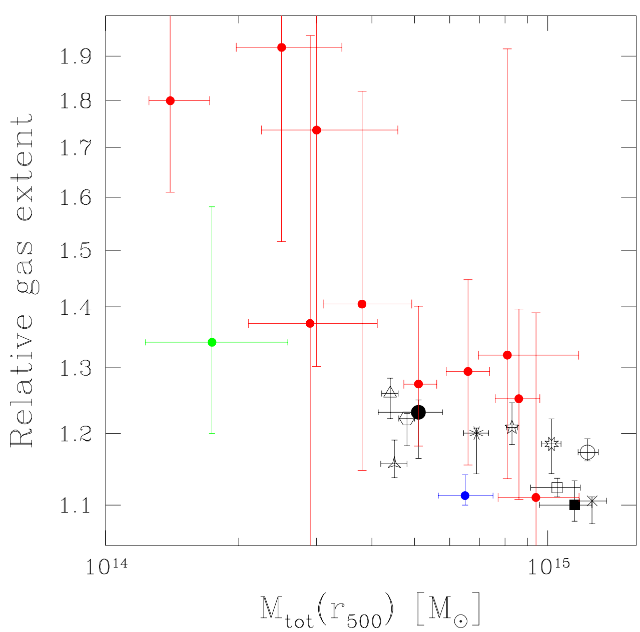

Figure 6: Ratio of gas mass fraction at r_{500} and $r_{500}/2$ as a measure for the relative gas extent of the gas distribution versus total cluster mass at r_{500}.

heat input affects low mass clusters more that massive clusters, so that a massive cluster can maintain a ratio E = 1 while in the smaller clusters the gas is becoming more and more extended.

4 Further work

The nearby sample of clusters need to be extended to lower temperature clusters to confirm the trend of more extended gas distribution in low mass clusters. At the same time the sample is going to be more complemented by CHANDRA and XMM data.

Acknowledgments

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