X-RAY CONSTRAINTS ON THE DARK MATTER PROFILE OF A VERY RELAXED CLUSTER OF GALAXIES

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ABSTRACT

We have analyzed an XMM-Newton observation of the cluster Abell 2589. Apart from a low-level asymmetry in the central region, the cluster appears very relaxed and does not show presence of a central AGN. We derived constraints for the radial temperature, density and, assuming hydrostatic equilibrium, mass profiles. We find that the best fit to the dark matter profile is given by the Sersic-like profile proposed by Navarro et al. (2004). The NFW model does not provide a good fit. We also tested whether the central stellar component could affect the profile through the adiabatic contraction model but were unable to distinguish it from a simple dark matter + stars modeling.

Key words: X-rays: galaxies: clusters; dark matter; galaxies: clusters.

1. INTRODUCTION

Clusters of galaxies, being the largest bound and dark matter dominated objects in the universe, are an optimal place to test the predictions of cosmological simulations regarding the mass profile of their dark halos. In this regard their X-ray emission can be successfully used to constrain the mass profile as long as the emitting plasma is in hydrostatic equilibrium. For this reason, to compare with theoretical predictions, we need to study very relaxed systems that do not show any sign of disturbance in their morphology. Clusters like these are very rare since they often show signs of interactions with other objects and, especially the more relaxed ones, almost always show a central radio galaxy whose influence on the hot plasma can easily invalidate the assumption of hydrostatic equilibrium. Here we show the results of an XMM-Newton analysis of Abell 2589 (z=0.0414), a very relaxed cluster with no presence of central radio emission.

2. DATA REDUCTION

The data reduction was performed using SAS 6.0. We excluded the point sources by first looking at the PPS source list and then through a visual inspection. The $50\,\mathrm{ksec}$ observation we have analysed was affected by frequent periods of strong flaring. Having screened the data, based on light curves from a “source-free” region in different energy bands, the final exposure times were 17 ksec and 13 ksec respectively for the MOS and PN detectors. We modeled the background by performing a simultaneous fit of the spectra of the outermost 4 annuli we have chosen for the spectral analysis.

3. SPATIAL ANALYSIS

In Fig. 1 we show the XMM-MOS and Chandra X-ray images[1] of the cluster and their unsharp mask images obtained by differencing images smoothed by gaussian kernels of $5''$ and $40''$. The images show very regular isophotes with ellipticities of ~ 0.3. The only disturbance in the morphology is a southward centroid offset very well shown in the unsharped mask images. This offset region has an emission only 30% higher than the mean cluster emission at $\sim 60\,\mathrm{kpc}$ from the center corresponding to $\sim 15\%$ variation in the gas density. We also produced an hardness ratio map and could not find any significant non radial variation in temperature. The cluster has a central dominant bright galaxy centered at the X-ray peak. Beers et al. (1991) measured its relative velocity finding that is unusually high for a dominant galaxy. The distribution of galaxies shows a preferential north-south alignment (2.5 degrees to the south there is Abell 2593) and a big subclump to the north (in the opposite side of the X-ray offset) off-centered by $3'$ from the X-ray peak. The well relaxed gas phase appearance and the particular galaxy distribution may be revealing a mild process of accretion through the large-scale structure (Plionis & Basilakos, 2002) that does not greatly disturb the gas properties.

4. SPECTRAL ANALYSIS

We extracted spectra from 7 concentric annuli centered on the X-ray peak and obtained gas density and tem-

[1]The Chandra images are from a 14 ksec observation previously analized by Buote & Lewis (2004).

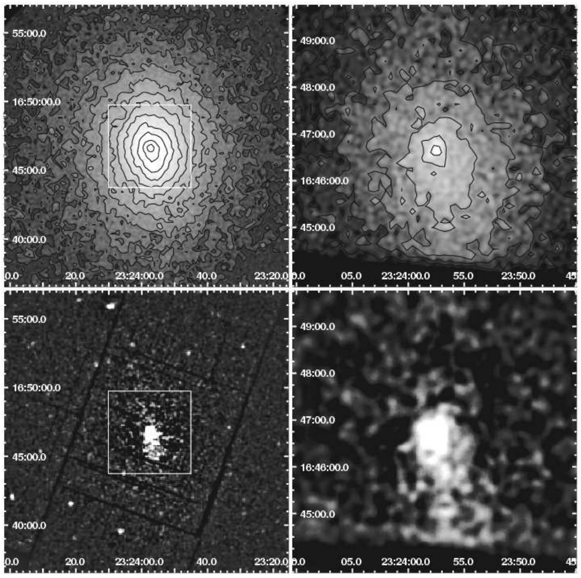

Figure 1. Upper panels: XMM-MOS and Chandra images. Lower panels: XMM-MOS1 and Chandra unsharp mask images. The XMM images report the Chandra field of view.

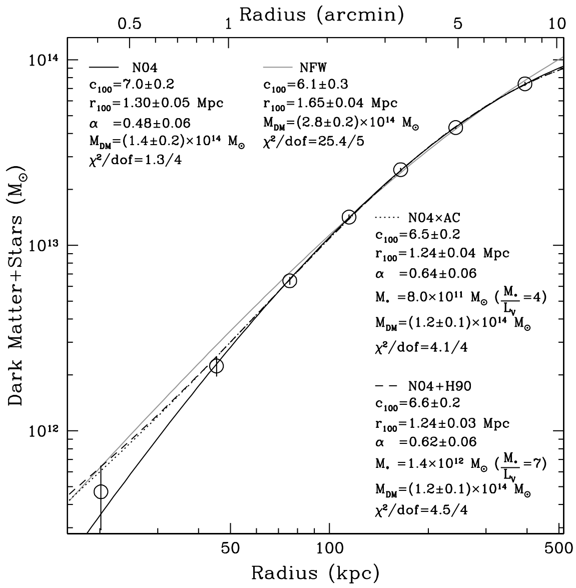

Figure 2. Dark matter+stars *profile. The models discussed in Sect. 5 are reported. The virial quantities refer to a halo whose mean density is* $100\,\rho_c$.

perature[2] profiles. We have analyzed only the projected quantities that with the quality of our data give us the best constraints. The best fit to the projected gas density is obtained using a cusped β model with core radius $r_c = 110 \pm 12\,\mathrm{kpc}$, cusp slope $\alpha = 0.3 \pm 0.1$ and $\beta = 0.57 \pm 0.01$. A single β model does not fit the inner two data points. The temperature profile of Abell 2589 is almost isothermal as already shown by the Chandra analysis of this object by Buote & Lewis (2004). The important deviations from isothermality are in the inner and outer data points that have lower temperatures. The resulting profile has been parametrized using two power-laws joined smoothly by exponential cut-offs.

5. DARK MATTER PROFILE

Given the parametrized quantities we can calculate the *total gravitating mass* profile (assuming hydrostatic equilibrium) and infer constraints on the dark matter profile. The *dark matter+stars* profile ($total\ mass - gas\ mass$) and the fitted models are shown in Fig. 2. The NFW profile (solid grey line; Navarro et al., 1997) is a good fit except for $\mathrm{r} < 80\,\mathrm{kpc}$. The updated Sersic-like CDM profile proposed by Navarro et al. (2004) (hereafter N04) is able to provide a good fit to the entire *dark matter+stars* profile. We tried to assess the level of importance of the stellar component due to the central bright galaxy, modeled with an Hernquist profile (Hernquist, 1990, hereafter H90), using parameters from Malumuth & Kirshner (1985). We also tested the influence of baryonic condensation into stars by using the adiabatic contraction model (AC) of Gnedin et al. (2004). If we let the total mass in stars M_* be free to vary, the data do not require any stellar component. If we fix $\mathrm{M}_*/\mathrm{L}_\mathrm{v}$ we can still obtain a reasonable fit allowing for $\mathrm{M}_*/\mathrm{L}_\mathrm{v} = 7$ in case of a N04+H90 profile (dashed black line) and $\mathrm{M}_*/\mathrm{L}_\mathrm{v} = 5$ in case of a N04 with adiabatic contraction ($\mathrm{N04} \times \mathrm{AC}$; dotted black line). In general we are not able to discriminate between models with and without adiabatic contraction.

[2]We fitted APEC models modified by the Galactic absorption using XSPEC.

ACKNOWLEDGMENTS

We thank O. Gnedin for providing us the code for the adiabatic contraction.

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