Mass determinations in the distant cluster of galaxies Cl0024+17

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ABSTRACT

I present in this poster a deep analysis of the mass distribution in the rich and distant cluster of galaxies Cl0024+17. The comparison between the mass derived from a standard X-ray analysis and from other methods such as the Virial theorem or the gravitational lensing effect lead to a mass discrepancy of a factor 3 to 5. I will give some indications on the way to reduce it with future data.

1. Introduction

Clusters of galaxies are the most massive gravitationnaly bound systems in the Universe. They are dynamically young as most of their timescales for evolution (virialization, cooling of the intra-cluster gas, dynamical friction, two-body relaxation, ...) are not small with respect to the age of the Universe. In addition, cluster evolution and the evolution of their content are strongly related to the global evolution of the Universe and to the physical conditions for the groth of primordial fluctuations. Another important cosmological issue is to understand the distribution and the physical properties of the different components inside clusters of galaxies Their mass content is separated in three main components: the galaxies, which represent only a few percents of the total mass, the intra-cluster gas which goes up to 20 % of the mass and the dark matter which is the dominant component. The study of each component can allow an estimate of the total mass and its distribution through 3 independant methods of mass determination: the Virial theorem is related to the galaxies distribution, the X-ray gas distribution traces the mass through the equation of hydrostatic equilibrium and finally, gravitational lensing of background galaxies is sensitive to all the mass in the clusters.

In this poster, I propose a combined analysis of the lensing cluster Cl0024+17 located at a redshift $z = 0.39$ for which this multiple approach on the mass determination is possible.

2. The cluster of galaxies Cl0024+17

This cluster was initially studied by Butcher and Oemler (1978) and was remarquable by its high content of blue cluster members. It is a rich cluster, highly concentrated in its center but not dominated by a cD galaxy. Dressler, Gunn and Schneider (1985) obtained a reasonable number of redshifts for cluster members, from which they measured a rest-frame velocity dispersion of 1300 km/s. From the analysis of the galaxy distribution they derive an estimate of the Virial mass (Schneider, Dressler and Gunn, 1986):

$$M_{viriel} = 1 \pm 0.4 \ 10^{15} \, h_{50}^{-1} M_{\odot}$$

Note that the application of the Virial theorem assumes that the cluster is in a stationary dynamical state and that "light traces mass" from the galaxy distribution. It does not take into account the existence of possible substrucutres or dynamical inhomogeneities.

A better understanding of the internal dynamics in this cluster will follow the spectroscopic survey we are performing in collaboration with O. Czoske and J.P. Kneib from the analysis of a sample of 400 cluster members.

3. Cl0024+17 as a gravitational lens

The spectacular system of giant arcs in the center of the cluster was initially mentionned by Koo (1988) and observed spectroscopically by Mellier et al. (1991). Unfortunately, no redshift istill available for this very blue multiple system. Deep HST images revealed that the arc system corresponds to the merging of three images (Figure 1), with the clear identification of an additional counter-image (Kassiola et al. 1992, Smail et al. 1996, Colley et al. 1996). Several arclets are also present in the same region.

Any lens model of the cluster center is strongly constrained by the multiple image system of the giant arc (5 images, including a faint one close to the center of the lens). In the model presented by Smail et al. (1996), the main ellipticity of the potential is 0.15, and the central mass is given by

$$M(r < r_{arc}) = 2 \pm 0.2 \ 10^{14} \, h_{50}^{-1} M_{\odot} \quad \text{and} \quad r_c = 40 \, \text{kpc}$$

knowing that $r_{arc} = 35'' = 225 h_{50}^{-1}$ kpc for a cosmological model with $H_0 = 50$ km/s/Mpc and $q_0 = 0.5$.

In addition to the strong lensing effect detected in the core of the cluster, a significant weak shear detection was measured by Bonnet et al. (1994) up to 3 h_{50}^{-1} Mpc from the center. This was indeed the first distortion map measured on a massive cluster and the shear was detected up to a 10% level at the periphery. The adjustment of the shear profile with a mass profile indicates that an isothermal profile is best suited to the measures, and gives a total mass up to the periphery of the cluster:

$$M(r < 3 h_{50}^{-1} Mpc) \simeq 3 \ 10^{15} \, h_{50}^{-1} M_{\odot}$$

or a mass about twice the virial mass.

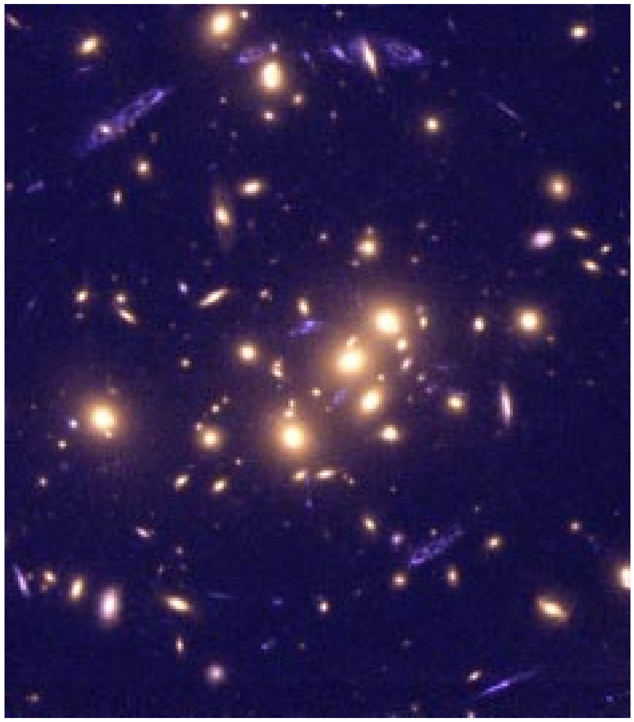

Fig. 1.— HST/WFPC2 multi-color image of Cl0024+17 displaying the multiple-imaged giant arc around the cluster centre.

4. X-ray observations of Cl0024+17

Cl 0024+17 was detected by the EINSTEIN observatory with an X-ray luminosity of about $3\,10^{44}$ erg/s (Fabricant et al., 1991). More recently a deep ROSAT/HRI image has been obtained in the cluster, with a total integration time of 116 ksec (Figure 2). From this image, we can perform a standard analysis of the X-ray cluster emission. But it is first necessary to identify the different contaminating sources and their optical counter-parts, in order to "clean" the cluster emission itself. The astrometry of the X-ray image, overlaid on a wide field optical image taken at the ESO NTT reveals several interesting points: first, there is a good coincidence between the X-ray and the optical centres for the cluster, although there may be a small but not significant shift. Second, the 4 additional sources identified in the X-ray map are coincident with individual objects, in most cases unresolved. In particular, the source S2 is identified with the quasar PC0023+1653 at $z = 0.959$ (Schmidt et al. 1986) and allows a secure centering of the X-ray image with the optical one. S1 may also correspond to a ponctual source, although it is difficult to assess wether the X-ray source is resolved or not, due to the small number of photons available. For S3 and S4, a ponctual object also lies close to the X-ray barycenter, but no redshift is available for a spectroscopic identification. With these sources removed from the X-ray image, it is possible to

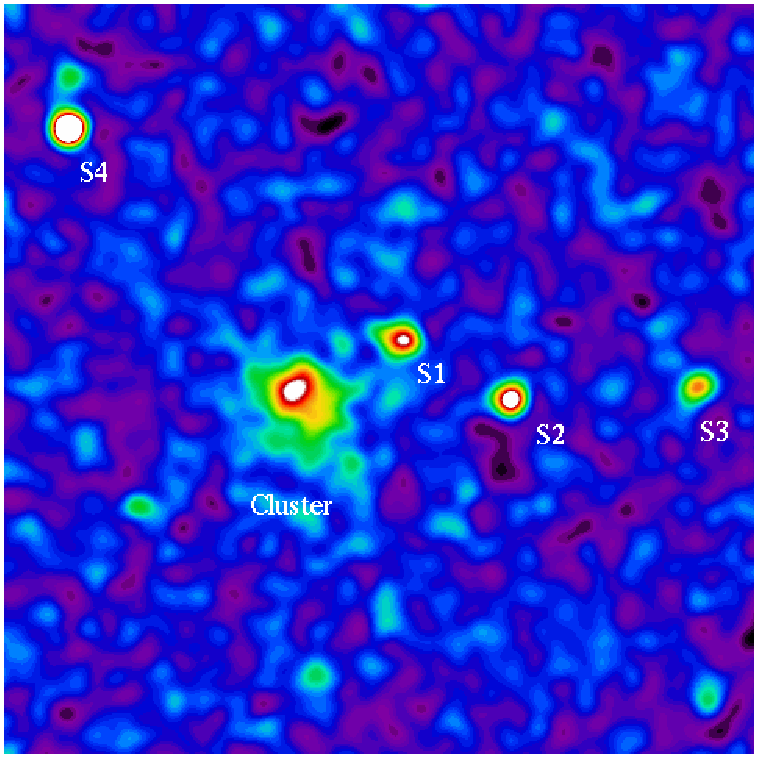

Fig. 2.— ROSAT/HRI deep image of the field of Cl0024+17 (field of view of $8' \times 8'$ approximatively. North is top and East is left). The contaminating sources are labelled S1 to S4.

analyse the extended X-ray emission from the cluster itself with an elliptical fit of the isophotes. With an ellipticity ranging from 0.1 to 0.2, we can neglect it as a first step, in order to build the intensity profile of the X-ray emission. The fit of the profile with a standard β-function give the values $\beta = 0.54$ and $r_c = 125 h_{50}^{-1}$ kpc. But as for many data coming from the HRI, the β value is underestimated because the high level of the background does not allow the detection of the flux far enough from the center, where the slope of the profile is better evaluated (see Bartelmann & Steinmetz 1996). Anyhow, with these values it is possible to reconstruct the total mass profile, provided a value of the gas temperature is fixed. We chose initially the value $T = 10$ keV which is compatible with the velocity dispersion of the cluster, following the scaling relations for nearby clusters (Edge and Steward 1991). In these conditions, the total mass we find from the X-ray analysis is

$$M_X(r < 1 h_{50}^{-1} Mpc) = 6\ 10^{14}\ h_{50}^{-1} M_\odot$$

$$M_X(r < r_{arc}) = 1\ 10^{14}\ h_{50}^{-1} M_\odot$$

which must be compared to the previous determinations

$$M_{viriel}(r < 1 h_{50}^{-1} Mpc) = 1\ 10^{15}\ h_{50}^{-1} M_\odot$$

$$M_{shear}(r < 1h_{50}^{-1}Mpc) = 1.3\ 10^{15}\,h_{50}^{-1}M_{\odot}$$
$$M_{lens}(r < r_{arc}) = 2\ 10^{14}\,h_{50}^{-1}M_{\odot}$$

Globally, there is a discrepancy of a factor 2 between the X-ray mass and the other determinations. More concerning is the recent results claimed by M. Hattori (private communication) about the measurement of the true X-ray temperature of the cluster with ACSA. His best fit of the spectrum gives a temperature of about 5.7 keV, which inevitably decreases the X-ray mass by another factor of 2. *Globally, in the cluster Cl0024+17, we are facing a global discrepancy of a factor 3 to 5 between X-ray mass and lensing or virial mass !*

How could we reconcile this paradox? There are some indications which could help to reconcile the problem:

- The β uncertainty due to the high background level of HRI data can underestimate the total mass by a factor 1.5 to 2 (Bartelmann & Steinmetz 1996).
- M_{shear} is probably overestimated and needs to be re-analysed with the new mass reconstruction techniques (Seitz et al. 1998). Anyway, $M(r < r_{arc})$ is strongly constrained by the lens configuration and would be difficult to change by a factor 2. Note however that the mass derived from lensing is integrated along the line of sight and may contain any contribution from additional mass concentrations.
- The QSO PC0023+1653, located $2'$ from the cluster centre may modify the full ASCA spectrum although it represents only 20% of the flux emitted by the cluster. In addition, QSO X-ray spectra are generally harder than clusters of galaxies so removing its contribution would still decrease the X-ray temperature of the cluster.
- Finally, if we assume $T_X \simeq 6$ keV and $\sigma_{los} = 1400$ km/s as definitive values, the cluster Cl0024+17 falls far away from the well-known correlation σ_{los}/T_X. So it is also necessary to study in more details the internal dynamics of this cluster. This work is in progress in our group.

5. Conclusions

Clusters of galaxies are complex structures which must be studied in details, in particular to raise the apparent contradiction between M_X and M_{lens}, already seen in many other clusters (Miralda-Escudé & Babul 1995, Allen 1998) and especially strong in the cluster presented here. More must be learned from the X-ray emission of clusters and in particular from the temperature distribution of the gas and the effects of sub-structures and mergings on the dynamics of the gas. Significant progresses are expected from the next generation of X-ray satellites XMM and AXAF. On the other hand, weak shear distortion must be quantified in the outer parts of clusters. Non-parametric methods of mass reconstruction are under evaluation and will give more quantitative results. Again, it is also important to stress the fact that the internal dynamics of the cluster galaxies may be more complex than usully admitted and must be analysed in more details than the crude Virial estimator. Finally another method of mass determination seems quite promising. Indeed the distribution of the Sunyaev-Zeldovich decrement which scan the outer parts of X-ray clusters with a better sensitivity than X-ray emission which scales as n_e^2 instead of n_e for SZ. So a combined analysis of X-ray and SZ maps should give a coherent view of the distribution of the intra-cluster gas and the potential well. But this also has to wait for the next generation of satellites such as Planck Surveyor.

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