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Editors: Vladimir Avila-Reese, Claudio Firmani, Carlos S. Frenk & Christine Allen

DYNAMICAL EVOLUTION OF CLUSTERS OF GALAXIES

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RESUMEN

Se presenta evidencia en favor de una evolución reciente de los procesos de relajamiento en cúmulos de galaxias. Los criterios usados para el relajamiento del cúmulo son la elipticidad del mismo, la temperatura del medio ICM y la luminosidad del cúmulo en rayos X. Encontramos evidencia de que los tres indicadores evolucionan con el corrimiento al rojo para $z \lesssim 0.15$. Este resutado apoya la idea de que los cúmulos ya han prácticamente cesado de coalescer y de acrecer materia, como se espera en un Universo con pequeña Ω_m, y que se encuentran ahora en proceso de relajamiento gravitacional, el cual reduce su achatamiento, su temperatura ICM (que aumentó por choques durante la fase de coalescencia), y su luminosidad en rayos X.

ABSTRACT

Evidence is presented for a recent evolution of the relaxation processes in clusters of galaxies. The criteria of the cluster relaxation used are the cluster ellipticity, the ICM temperature and X-ray cluster luminosity. We find evidence of all three indicators evolving with redshift for $z \lesssim 0.15$. This result supports the view that clusters have mostly stopped undergoing mergers and accreting matter, as expected in a low-Ω_m Universe, and are now in the process of gravitational relaxation, which reduces their flattening, their ICM temperature (shock heated during the merging phase), and their X-ray luminosity.

Key Words: **COSMOLOGY — GALAXIES: CLUSTERS**

1. GENERAL

The present dynamical state of clusters of galaxies should contain interesting cosmological information since the rate of growth of perturbations is different in universes with different matter content. It is well known that in an $\Omega_m = 1$ universe the perturbations grow proportionally to the scale factor; $\delta \propto (1+z)^{-1}$ (cf. Peebles 1980). It is also known that $\Omega_m < 1$ universes behave dynamically as an $\Omega = 1$ universe at large redshifts, while at some redshift $1 + z \sim 1/\Omega_m - 1$ perturbations stop evolving, allowing clusters to relax up to the present epoch much more than in an $\Omega_m = 1$ model, in which clusters are still forming and thus should show evidence of dynamical youth (cf. Richstone et al 1992; Beisbart et al 2002)

Therefore one should be able to put cosmological constraints from the evolution of the cluster dynamical state. One such indicator is the cluster ellipticity (cf. Melott et al 2001; Kolokotronis et al 2001). In a low-Ω_m universe and in the hierarchical clustering scenario, one expects that merging and anisotropic accretion of matter along filaments will have stopped long ago and thus the clusters should be relatively isolated and gravitational relaxation will tend to isotropize the clusters reducing their ellipticity, more so in recent times. One could also expect an evolution of the temperature and luminosity of the cluster X-ray emitting gas which should follow the same trend as the cluster ellipticity, decreasing in recent times, since the violent merging events, at relatively higher redshifts, will compress and shock heat the diffuse ICM gas (cf. Ritchie & Thomas 2002)

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2. ANALYSIS

We analyse the 900 APM clusters (Dalton et al 1997), the shape parameters of which were estimated in Basilakos et al (2000), using the moments of inertia method on the Gaussianly smoothed galaxy distribution, the angular smoothing scale of which depends on the distance of each cluster. An optimum grid size was selected based on an extensive Monte-Carlo procedure. In order not to bias the ellipticity measurements no circular aperture was used, but rather all cells above a selected density threshold were fed into the inertia tensor.

Figure 1 shows the distribution of APM cluster ellipticities as a function of redshift. There is a weak but definite trend of ellipticity with redshift (with correlation coefficient ~ 0.2) in the direction expected from an evolution of the dynamical status of clusters, supporting the claims of Melott et al (2001). A detailed and extensive Monte-Carlo procedure was devised in order to test the significance of this trend, taking into account the ellipticity determination procedure, background galaxy projections, the APM se-

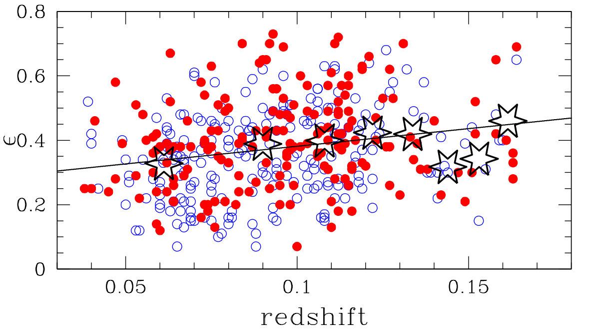

Fig. 1. Ellipticity-redshift evolution for the APM clusters. The straight line represented the best least-square fit to the data and the large star symbols represent the mean ellipticity in equal volume shells. The filled circles represent APM clusters that are also Abell/ACO ones.

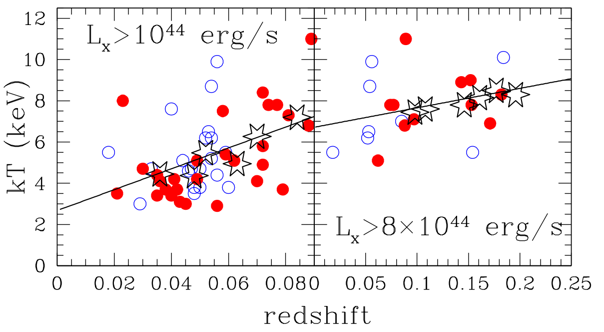

Fig. 2. The ICM $kT - z$ correlation for those clusters with measured temperatures. Filled and open points represent volume limited subsamples of the BCS and XBAC clusters, respectively (with L_x limits are indicated). The solid line is the best least-square fit to the data, while the stars represent the mean ICM temperature in equal volume shells.

lection function and shot-noise increase as a function of distance. We find that the the ellipticity-redshift correlation has a high significance: $\mathcal{P}_{\epsilon-z} \simeq 10^{-4}$. This result is robust to changes of the sample size by factors of two or three, depending on whether we use clusters with observed redshifts or different cluster richness.

We also use two volume limited subsamples of the XBAC and BCS ROSAT X-ray cluster samples (Ebeling et al 1996, 1998) to test whether there is any indications of a recent evolution of the ICM temperature.

Most of the ICM temperatures are estimated from the $L_x - T$ relation of White et al (1997), but a reasonable number of clusters have measured temperatures.

As can be seen in Fig.2 there is such a $kT - z$ correlation. Using clusters with measured temperatures, which reduces our samples considerably, we find for the low-L_x sample ($N = 48$) a correlation coefficient of 0.45 with random correlation probability of $\sim 10^{-3}$, while for the high-L_x subsample ($N = 19$) the corresponding values are 0.3 and $\sim 10^{-2}$. If we include in our analysis the rest of the clusters (with estimated kT's) then the samples increase to $N = 106$ and 55 with corresponding probabilities of $\sim 10^{-3}$ and 10^{-4}, respectively for the low and high L_x samples. Similar results are obtained also for the X-ray luminosity redshift correlation. The frequency shift due to the expanding Universe implies a temperature evolution according to $T_z = T_0(1+z)$, which could explain the $kT - z$ relation of the right panel of Fig. 2 but by no means that of the left panel.

3. CONCLUSIONS

We have presented indications of recent dynamical evolution of clusters of galaxies, a fact to be expected if in clusters the merging and anisotropic accretion of matter along filaments have stopped and relaxation processes are now in effect. Gravitational relaxation will tend to isotropize the clusters reducing their ellipticity and their ICM temperature (shock heated during the violent merging phase of their formation). We have found indications of varying strength and significance for these effects.

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