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# THE DYNAMICAL STATE OF MASSIVE GALAXY CLUSTERS

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RESUMEN

Se evalúa la distribución de masa para 24 cúmulos de Abell brillantes en rayos-X usando el efecto débil de los lentes gravitacionales. Este método es independiente del estado dinámico del cúmulo, y por lo tanto la comparación con masas "dinámicas" posibilita una determinación del estado dinámico de los cúmulos. Los cúmulos con temperaturas ICM mayores que 8 keV presentan desviaciones con respecto a los cúmulos dinámicamente relajados, como también presentan sub-estructuras significativas. Los distintos indicadores de masa dan valores consistentes entre si para los demás (la mayoría de los cúmulos de la muestra), lo cual es indicativo de estados cercanos al equilibrio dinámico.

ABSTRACT

We study the mass distribution of a sample of 24 X-ray bright Abell clusters through weak gravitational lensing. This method is independent of the dynamical state of the galaxy cluster. Hence, by comparing dynamical and lensing mass estimators, we can access the dynamical state of these clusters. We have found that clusters with ICM temperatures above 8 keV show strong deviations from the relaxation, as well as the presence of prominent sub-structures. For the remaining clusters (the majority of the sample) we have found agreement among the several mass estimators, which indicates that most of the clusters are in or close to a state of dynamical equilibrium.

*Key Words:* **GALAXY: CLUSTERS: GENERAL — GRAVITATIONAL LENSING**



## 1. INTRODUCTION

There are several ways to measure the masses of galaxy clusters but the most widely used methods are the dynamical ones, for instance the study of the line-of-sight velocity distribution of the member galaxies and the X-ray measurements of the temperature and distribution of the intra-cluster gas. They relay on the assumption that galaxies and/or the intra-cluster gas are reliable tracers of the potential well or that all cluster components are in a state dynamical equilibrium. Gravitational lensing methods, on the other hand, are completely independent of the cluster dynamical state.

The goal of this study is to take advantage of both kind of methods to identify whether a cluster is in dynamical equilibrium or not by comparing indicators of the dynamical mass: the velocity dispersion of the galaxies ($\sigma_v$) and the X-ray measured gas temperature ($T_X$) with weak-lensing equivalent indicators. Disagreement between dynamical and non-dynamical mass indicators can be interpreted as an indication that the assumption of dynamical equilibrium is not valid.

## 2. RESULTS

In Cypriano et al. (2004) we have fitted the weak-shear data with singular isothermal profiles (spherical and elliptical) from a sample of 24 Abell clusters with X-ray luminosities higher than $5 \times 10^{44}$ $h_{50}^{-2}$ erg $s^{-1}$. Here we will present the results of the sample members with independent measurements of either $T_X$ or $\sigma_v$. The mass related parameter that came out from these fits is an equivalent of the line of sight velocity dispersion ($\sigma_{SIS}$ or $\sigma_{SIE}$, respectively for spherical and elliptical profiles). Assuming energy equipartition between cluster galaxies and gas, we obtain $T_{SIS}$ (or $T_{SIE}$) through the relation: $\sigma^2 = kT/\mu m_H$, where $\mu = 0.61$ is the mean molecular weight of the gas, $m_H$ is the hydrogen mass, and $k$ is the Boltzmann constant. In Figure 1 we compare the actually measured dynamical mass indicators with their weak-lensing counterparts.

It can be noted in Figure 1 that for most clusters the weak-lensing results agree with the dynamical

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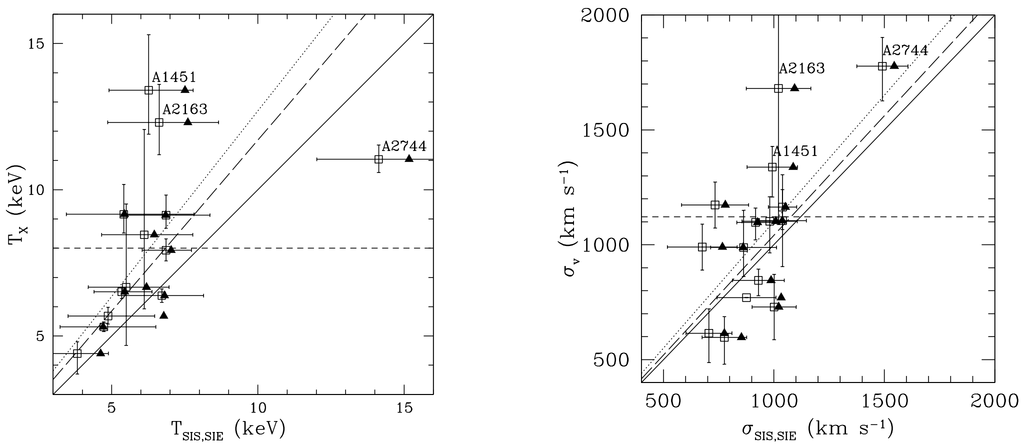


Fig. 1. Comparison between the actually measured ICM temperatures (left panel) and velocity dispersions (right panel) with those inferred by the fitting of isothermal profiles (spheric–SIS and elliptical–SIE) to the shear data. The squares correspond to the spherical model and triangles to the elliptical. The error bars of the latter were suppressed for clarity. The solid line is defined by $T_{SIS,SIE} = T_X$ or $\sigma_{SIS,SIE} = \sigma_v$. The dotted and long dashed lines show the best-fit obtained with the SIS and SIE models, respectively, when the origin is kept constant. The short dashed line indicates $T_X = 8$ keV. Clusters with higher temperatures show signals of dynamic activity.

data within 1.5 $\sigma$. However, this is not true for the entire sample. For clusters with $T_X < 8$ keV (or equivalently $\sigma_v < 1122$ km s$^{-1}$) the ratio between the dynamical estimator and its weak-lensing equivalent is consistent with the expected value of 1.

Nonetheless, for clusters with $T_X > 8$ keV strong disagreements can be found. Among these cases three clusters stands out: A2744, A1451 and A2163 (all labeled in the plots). These clusters show temperatures and velocity dispersions significantly different from the lensing estimations, suggesting that they should be dynamically active. Actually, detailed individual analysis of these clusters provide support for this conclusion.

The study of the A2163 temperature map made by Markevitch & Vikhlinin (2001) with Chandra data shows at least two shocked regions and other evidences that the central region of this cluster is in a state of violent motion. In the same way, Valtchanov et al. (2002) describes A1451 as being in the final stage of establishing equilibrium after a merger event, whereas its high X-ray temperature (13.4 keV) would be probably due to a shock occurred recently.

A2744 seems to be an exception, since, contrarily to A1451 and A2163, which have both dynamical indicators in excess compared to the lensing estimates, this cluster has a temperature significantly lower than that inferred from weak-lensing, but a higher velocity dispersion.

The case of A2744 can be understood if, as suggested by the dynamical analysis of Girardi & Mezzeti (2001), there are two structures along the line-of-sight. In this case $\sigma_v$ is artificially increased upwards, since it has been measured over two superimposed galaxy velocity distributions. Gravitational lensing is sensitive to the mass projected on the plane of the sky, therefore its result is a weighted sum of the mass of both structures. Finally, $T_X$, which is obtained through X-ray spectroscopy, will be biased in favour of just one of the components, the brightest in X-rays, giving a mass estimation lower than that obtained with the other two methods.

In the hierarchical scenario, where most massive structures are formed through the merger and accretion of less massive ones, massive galaxy clusters should be forming at the present epoch. The results presented here reinforces this idea by detecting dynamical activity among such systems, but not in the less massive ones. One of the many consequences of this result is that massive clusters can be used as cosmological tools only if extra care is taken. Otherwise the presence of non-relaxed structures can bias the results.

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