A New Method to Quantify X-ray Substructures in Clusters of Galaxies

Felipe Andrade-Santos, Gastão B. Lima Neto & Tatiana Ferraz Laganá

Instituto de Astronomia, Geofísica e Ciências Atmosféricas - Universidade de São Paulo - Brasil

fsantos@astro.iag.usp.br

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Abstract

We present a new method to quantify substructures in clusters of galaxies, based on the analysis of the intensity of structures detected in a residual image, which is the result of the subtraction of a surface brightness model, obtained by fitting a two-dimensional analytical model (β-model or Sérsic profile) with elliptical symmetry, from the X-ray image. Our method was applied to 36 clusters observed by the *Chandra* Space Telescope that are in the redshift range $z \in [0.02, 0.2]$ and present a signal to noise ratio greater than 100. We present the calibration of the method and a preliminary result on the scaling between the substructure level and the cluster total mass. Our method is instrument independent and could also be applied on XMM-Newton and future X-ray space missions data such as IXO.

Introduction

Clusters of galaxies are the largest virialized objects in the Universe, the superior limit of collapsed halo mass function. In this hierarchical scenario of structures formation, clusters are thus dynamically young objects and contain evidence of their recent past merging history (e.g. Kauffmann & White 1993). We can relate substructures with the cluster dynamical age (e.g. Richstone et al. 1992; Suwa et al. 2003): the more substructures a cluster presents, the younger (dynamically speaking) it is.

Sample

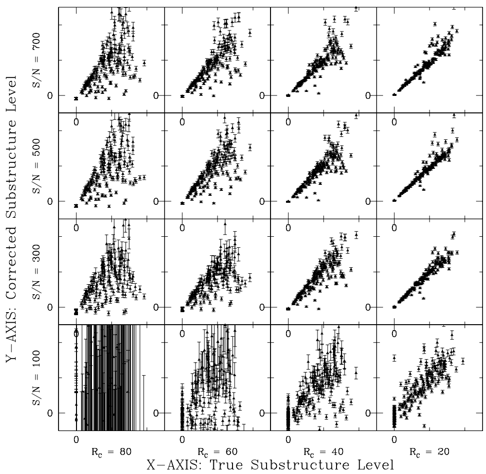
Our method was applied to 36 clusters observed by the *Chandra* X-ray Telescope ACIS-I detector, with signal-to-noise ratios greater than 100, and that are in the redshift range $z \in [0.02, 0.2]$.

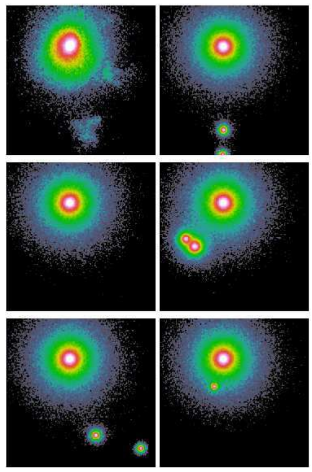
Method

We quantify the substructure level by computing the ratio between the total number of counts of the residual (taking the absolute value of the negative counts, and treating them exactly as the counts in the positive regions) and the original images. By construction, the substructure level, S, is defined as:

$$S \equiv \frac{\sum_{i=1}^{n} |C_i^r|}{\sum_{i=1}^{n} C_i^t}, \tag{1}$$

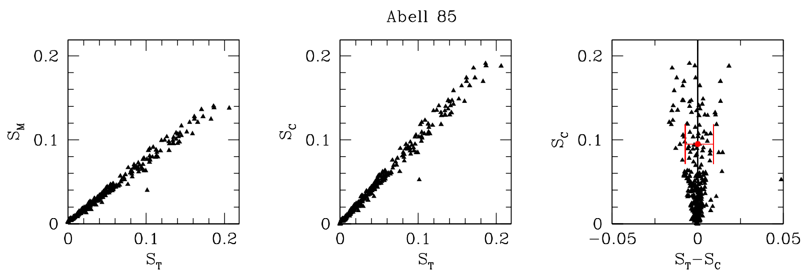
where C_i^r is the number of counts of the i-th residual image pixel, C_i^t is the number of counts of the i-th image pixel and n is the number of pixels of the image. We defined the substructure level this way because it has a direct physical interpretation: it reflects the fraction of the total X-ray luminosity provided by substructures. The statistical uncertainties in the substructure level were computed using Monte Carlo simulations. **The plot on the center of this panel** shows the quality of quantification as a function of the S/N and core radius of the simulated clusters, whereas the **the figure on the right** shows the X-ray image of Abell 85 on the top left corner and its simulated images containing arbitrary substructure.





Monte Carlo for Abell 85

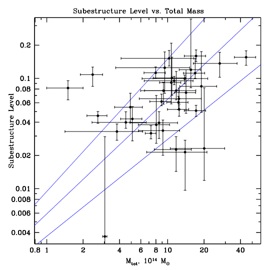
Here we present the Monte Carlo simulation for Abell 85:



Left: Measured Substructure, S_M, vs. the True Substructure Level, S_T, for all 400 Monte Carlo simulations. *Center:* Substructure Corrected, S_C, vs. True Substructure Level for all simulations. *Right:* Substructure corrected vs. (True Substructure Level − Substructure Corrected) for the simulations.

Main Result

Here we present the main result, which is the substructure level dependency on cluster total mass.



The figure shows the substructure level as a function of the cluster total mass. We see that more massive clusters show the tendency to present more substructures.

Conclusions

We have developed a new method to quantify X-ray substructures in clusters of galaxies based on the ratio between the number of counts in the residual and original X-ray images. We applied our new method to 36 clusters of galaxies in order to obtain the substructure level dependence with physical parameters, such as total mass, temperature, metallicity and redshift. We calibrated the method using Monte Carlo simulations, which showed that the method recuperates very well the true amount of substructure for small angular core radii (with respect to the whole image size) and good signal-to-noise clusters.

Non-gravitational processes such as AGN and star formation may produce surface brightness subestructures. We verified that the substructure level scaled almost linearly with mass, suggesting that it is an indicator of halo accretion history and that subtructures in the gas distribution should be caused mainly by mergers.

References

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[3] Suwa, T., Habe, A., Yoshikawa, K., & Okamoto, T. 2003, ApJ, 588, 7