Structural analysis of galaxy clusters

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Substructure estimators and applications

Alexandra Weißmann[1], R. Šuhada[1], H. Böhringer[1], S. Borgani[2]

[1] Max Planck Institute for Extraterrestrial Physics, Garching, Germany [2] Dipartimento di Fisica dell'Università di Trieste, Trieste, Italy

X-ray observations of galaxy clusters reveal a large range of morphologies. The determination of cluster masses from X-ray data rely on the assumption of hydrostatic equilibrium and spherical shape, which are not satisfied in clusters showing substructure. The effect of substructure on global cluster properties is expected to manifest itself for example in the scatter of the X-ray scaling relations. It is therefore important for the understanding of cluster properties as well as for cosmological applications to mark disturbed galaxy clusters.

Structure measurements, however, can be heavily biased by Poisson noise. We performed an extensive analysis of the effect of Poisson noise and X-ray background on substructure measures (power ratios and center shifts) using > 120 simulated X-ray observations (Borgani et al. 2004, Ameglio et al. 2007). We quantify the bias in detail, make corrections and give ranges where morphological analysis is feasible. This will enable us to study the evolution of substructure over a large redshift range where photon statistics varies substantially and investigate its impact on cluster scaling relations.

Shot noise correction

Power ratios (Buote&Tsai 1995) and center shifts (Mohr et al. 1993, O'Hara et al. 2006) trace the gravitational potential of the ICM and quantify the amount of substructure. *P3/P0* represents the normalized hexapole of the X-ray surface brightness and is sensible to asymmetries in the ICM on scales of the aperture radius (e.g. r_{500}). Center shift *w* measures the variance of the offset between the X-ray peak and the center of mass of the surface brightness for different apertures (e.g. 0.1-1 r_{500}).

Observations, in particular those with low photon statistics, suffer from shot noise which produces artificial structure (bias). After an extensive analysis of the bias as a function of structure and photon statistics and the influence of the X-ray background, we present a method to **correct the effects of photon noise**. Motivated by previous works (e.g. Böhringer et al. 2010, Jeltema et al. 2005), we use 100 poissonised simulations of the X-ray image to estimate and correct the bias. Fig. 1 shows the decrease of the bias after applying the correction. Especially in the significant range (*P3/P0* > 5×10^{-7}) the bias drops well below 10% of the obtained value. The bias of *w* behaves similar to that of *P3/P0* but is always very low.

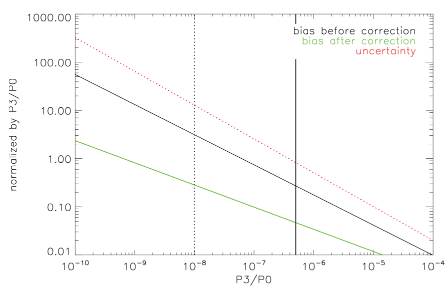

Fig. 1: Mean bias as a function of structure before (black line) and after applying the correction method (green line) for 1000 source counts and an aperture of r_{500}. The uncertainties of the corrected measurements are marked by the red line. In addition, we show the threshold at 5×10^{-7} below which most clusters are relaxed and 10^{-8} below which all clusters are relaxed.

Structure of Sample

We analyzed > 120 simulated X-ray cluster images and found significant substructure for ***w* > 0.01** and ***P3/P0* > 5×10^{-7}**, which is in agreement with observations.

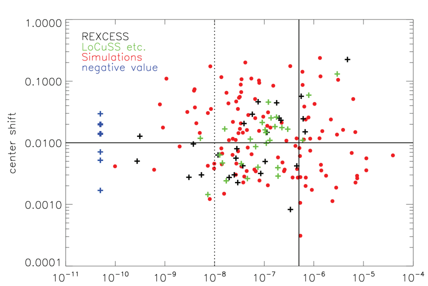

Fig. 2: Power ratio and center shift parameter for > 120 simulated X-ray cluster images, 31 REXCESS clusters and 49 clusters from different samples (e.g. LoCuSS). Clusters with a negative *P3/P0* after the bias correction are marked as blue crosses and are set to 5×10^{-11}. The *P3/P0* thresholds are as described in Fig. 1.

Scaling relations

With a well understood substructure estimation method at hand, we investigate scaling relations, in particular the LT-relation. Cool-core (CC) clusters appear overluminous at a given temperature because their bright core boosts the luminosity (e.g. Markevitch et al. 1998). This is shown for the REXCESS CC clusters (red crosses) in Fig. 3, which are also mostly found to be relaxed (*w* < 0.01).

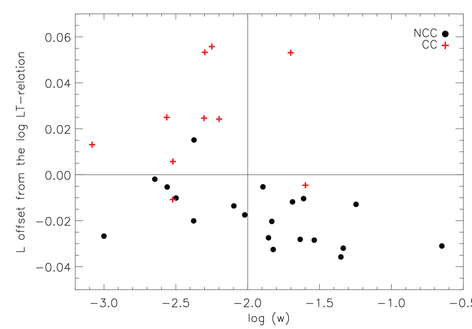

Fig.3: Luminosity offset from the logarithmic LT-relation as a function of structure for 31 REXCESS clusters. Cool-core (CC) clusters are marked as red crosses and non-cool core (NCC) clusters as black points. Cool cores were classified according to Pratt et al. 2009. In addition we show the substructure threshold at *w*=0.01 and a horizontal line for an offset of 0.

NCC clusters seem underluminous which is shown by their negative luminosity offset. In contrast to CC clusters, they populate the full *w* range. In addition, we see a trend that for **REXCESS NCC clusters the offset from the LT-relation is correlated with the substructure measure *w***. A Spearman rank test confirms a weak, but very significant anti-correlation (-0.53), with a probability of 0.2% for no correlation.

Outlook

We have developed a **reliable method** to estimate power ratios and center shifts **down to very low counts**. This opens a window of opportunity to study the structure of clusters which have only low photon statistics (in particular at high-z) with good accuracy. In addition, we plan to establish a large sample of low and high-z clusters to improve the statistics and study the evolution of structure. Different substructure measures trace structures at various scales (e.g. central region, global cluster scale etc.) and it is especially interesting to study their impact on scaling relations, morphological classification schemes, but also correlations with optical properties.

References:

Ameglio, S., Borgani, S., Pierpaoli, E., & Dolag, K. 2007, MNRAS, 382, 397
Borgani, S., Murante, G., Springel, V., et al. 2004, MNRAS, 348, 1078
Böhringer, H., Pratt, G., Arnaud, M., et al. 2010, A&A, 514, A32+
Buote, D. & Tsai, J. 1995, ApJ, 452, 522
Jeltema, T., Canizares, C., Bautz, M., & Buote, D. 2005, ApJ, 624, 606
Markevitch, M. 1998, ApJ, 504, 27
Mohr, J., Fabricant, D., & Geller, M. 1993, ApJ, 413, 492
O'Hara, T. B., Mohr, J. J., Bialek, J. J., & Evrard, A. E. 2006, ApJ, 639, 64
Pratt, G., Croston, J., Arnaud, M., & Böhringer, H. 2009, A&A, 498, 361

For further information, please contact: weissman@mpe.mpg.de