Max Planck Institute for Extraterrestrial Physics

Studying the properties of galaxy cluster morphology estimators

Alexandra Weißmann[1], H. Böhringer[1], R. Šuhada[2], A. Ameglio[3]

[1] Max Planck Institute for Extraterrestrial Physics, Garching, Germany
[2] Department of Physics, Ludwig-Maximilians-Universität, Munich, Germany
[3] Dipartimento di Astronomia dell'Universität di Trieste, Italy

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X-ray observations of galaxy clusters reveal a **large range of morphologies with various degrees of disturbance**, showing that the assumptions of hydrostatic equilibrium and spherical shape which are generally used to determine the cluster mass from X-ray data are not always satisfied. It is therefore important for the understanding of cluster properties as well as for cosmological applications to identify and mark disturbed clusters. We use *power ratios* and *center shifts* to detect and quantify substructure in their X-ray images. Since these measurements can be heavily affected by **Poisson noise** and **X-ray background**, we performed an extensive analysis of statistical properties of these parameters and present a **method to correct for these effects**. We studied the morphology of simulated cluster images and established **structure boundaries** to divide samples into relaxed, mildly disturbed, and disturbed clusters. We present a new morphology estimator to better identify merging clusters and show results for 80 galaxy clusters observed with XMM-Newton.

Correction method

Power ratios and **center shifts** characterize the morphology of the cluster X-ray surface brightness which traces the gravitational potential of the cluster. *P3/P0 is* the normalized hexapole of the X-ray surface brightness and is sensible to asymmetries 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 the surface brightness for different apertures (e.g. 0.1-1 r_{500}).

Observations suffer from shot noise which produces **artificial structure (bias),** especially at low photon counts. We performed an extensive analysis of the bias as a function of structure and photon statistics and studied the influence of the X-ray background. We add Poisson noise to X-ray images and background to estimate and **correct the bias**. Calibration and testing was done using a set of simulated cluster images. Fig. 1 shows the remaining absolute bias after applying the correction. In the significant range (*P3/P0*>10^{-7}, *w*>0.01), the remaining bias of both estimators is below 10%. *w* can recover the signal to much lower counts and is less sensible to noise than *P3/P0*.

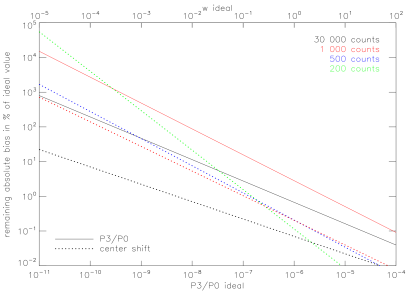

Fig. 1: Remaining absolute bias in units of % of the ideal value after applying the correction as a function of *P3/P0* (solid lines) and *w* (dashed lines) for different net counts (color coded). The upper x-axis shows the *w* range, the lower x-axis the *P3/P0* range.

Structure boundaries

After establishing a method to correct the bias, we studied how certain parameter ranges can be related to different visually classified morphologies. We visually classified a set of simulated X-ray cluster images as relaxed or disturbed and give **substructure boundaries** (see Fig. 2).

For **low photon statistics**, the boundary at *P3/P0*=10^{-7} or *w*=0.01 divides samples into rather relaxed and rather disturbed clusters. In the case of **high photon counts**, a more detailed analysis using two *P3/P0* boundaries at 10^{-8} and 5×10^{-7}, to distinguish between relaxed, mildly disturbed and disturbed objects is possible.

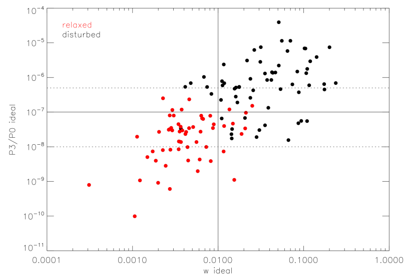

Fig. 2: Motivation for the different boundaries for *P3/P0* and *w*. We show the *P3/P0-w* plane for ideal simulated cluster images. The classification into relaxed (red) and disturbed (black) was done visually. The boundaries are displayed as horizontal and vertical lines.

Power ratios are typically calculated in a large aperture like r_{500} and only sensitive on these scales. This leads to very low *P3/P0* values for e.g. the Bullet cluster, where the merging component is well within the aperture radius of r_{500}. We studied the *P3/P0* profile, which picks up in all aperture sizes. We propose to use the **maximum of the *P3/P0* profile** because it finds clusters with structure on all scales and is **better in identifying merging clusters**.

Morphological results

Applying the *P3/P0* (*w*) boundary, we find 41% (47%) of our observed clusters to be disturbed. The two *P3/P0* boundaries yield 10% disturbed, 65% mildly disturbed and 25% relaxed objects. This large difference in the number of disturbed objects using the **different boundaries** shows that most objects are not significantly but only mildly disturbed and do not show a clear second component.

We **visually classified** all clusters into 4 groups to further test the strength of the structure estimators and find 7.5% double, 15% complex, 37.5% intermediate and 40% relaxed objects. Fig. 3 shows the relation between *w* and *P3/P0* calculated in the single aperture r_{500} on the left side. In order to demonstrate the **strength of the new morphology estimator** in detecting merging clusters (double), we show the relation between *w* and the maximum of the *P3/P0* profile on the right side.

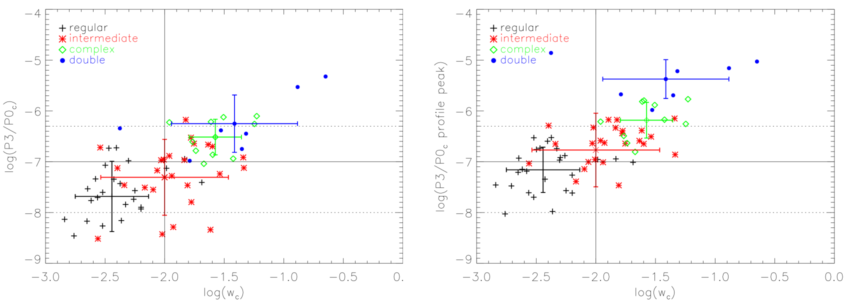

Fig. 3: Relation between the corrected center shift and power ratios - *P3/P0* (left) and the maximum of the *P3/P0* profile (right). Color coded are the four visually classified morphologies including their log-mean and 1-σ errors. The black lines show the *P3/P0* and *w* boundaries.

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