Relating Galaxy Cluster X-Ray Luminosities to Gravitational Masses in Wide Angle Surveys

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1 Introduction

The cosmologically most important cluster parameter is its gravitational mass. In order to constrain cosmological models of structure formation by comparing simulations or analytic models with, e.g., observational mass functions of statistical cluster samples, cluster masses are needed. Precise cluster mass determinations for large cluster surveys, e.g. [3], however, require extensive observations and are currently not feasible. An alternative approach is to use established relations between more easily observed quantities and cluster mass. For optical cluster samples the observed number of cluster galaxies has sometimes been used to relate to cluster mass. For X-ray cluster samples a three component approach is commonly used. First, measured X-ray luminosities are converted to X-ray temperatures using an observational relation. Then, a slope for the X-ray temperature – gravitational mass relation is assumed on theoretical grounds. And finally, the X-ray temperatures are converted to masses by normalizing this relation with hydrodynamical simulations.

Here we show that cluster surveys selecting clusters by their X-ray luminosities effectively select by cluster mass. It is shown that a selection based solely on Abell galaxy richness is less efficient in terms of mass. Furthermore we quantify the empirical X-ray luminosity – gravitational mass relation and its scatter, offering the possibility to directly use this observed relation in wide angle X-ray cluster surveys for the luminosity – mass conversion. Throughout $H_0 = 50\,\mathrm{km/s/Mpc}$, $q_0 = 0.5$ and $\Lambda = 0$ is used.

2 Results and Discussion

In the course of constructing a highly complete X-ray flux-limited sample of the brightest galaxy clusters in the sky (*HIFLUGCS*, [9]) cluster masses for more than 100 clusters have been determined individually from X-ray data. In Fig. 1 the bolometric $(0.01 - 40\,\mathrm{keV})$ X-ray luminosity, L_{Bol}, is plottet versus the gravitational mass within an overdensity of 200 times the critical density, M_{200}. The solid line shows the best fit relation for 106 clusters, the triple-dot-dashed line is the best fit relation determined using the 63 clusters included in the strictly flux-limited sample (*HIFLUGCS*), the dot-dashed

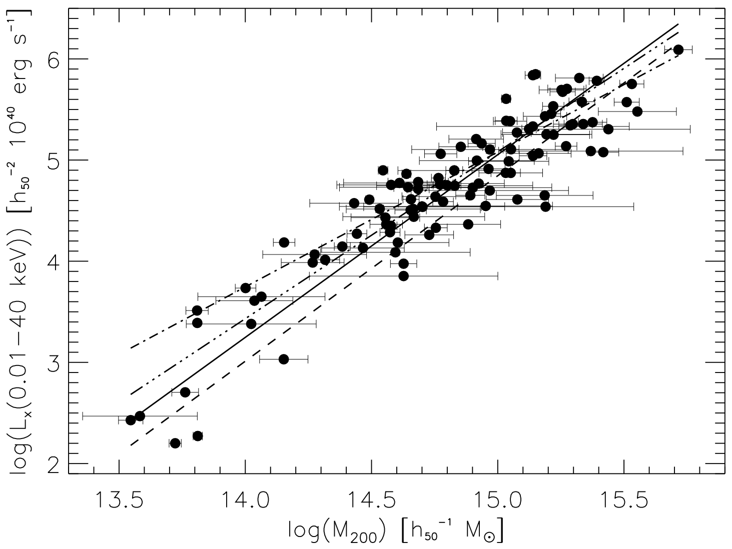

Fig. 1. Bolometric X-ray luminosity versus gravitational mass for 106 clusters.

line is the self-similar relation (slope = 4/3) normalized by the simulations of Navarro, Frenk & White [7], the dashed line is the 'pre-heated' relation given by Evrard & Henry [4] (slope = 11/6). The normalization given by Evrard & Henry, determined theoretically, agrees with the normalization found in the simulations of pre-heated clusters by Navarro, Frenk & White. The measured relations lie in between the relations with and without pre-heating. The physical implications will be discussed in Reiprich et al. (in prep.), here we emphasize that the plot shows measured and predicted $L_{\mathrm{Bol}} - M_{200}$ relation to be in rough agreement. Using a bisector linear regression fit routine in log–log space which takes into account errors in both variables and allows for intrinsic scatter [2], the following best fit relations are found using 106 clusters: $L_{\mathrm{Bol}} = 9.25 \times 10^{-23}\, M_{200}^{1.81\pm0.08}$ and for the luminosity in the ROSAT energy band $L_{\mathrm{X}}(0.1 - 2.4\,\mathrm{keV}) = 1.47 \times 10^{-19}\, M_{200}^{1.57\pm0.08}$ (L_{X} in units of 10^{40} erg/s and M_{200} in solar masses). Note that different best fit values are obtained when errors in the variables are neglected and only one variable is treated as dependent (e.g., for the latter relation then a slope of 1.33, in agreement with the slope of the preliminary $L_{\mathrm{X}} - M_{500}$ relation quantified by Reiprich & Böhringer [8], is found instead of 1.57). The bisector method used here ensures that variables are treated symmetrically [6]. The 1-σ scatter in log space for the mass around the $L_{\mathrm{Bol}} - M_{200}$ relation equals 0.19, corresponding to a relative mass error of +55% and −35% when converting L_{Bol} to M_{200}. This error includes intrinsic and measurement scatter.

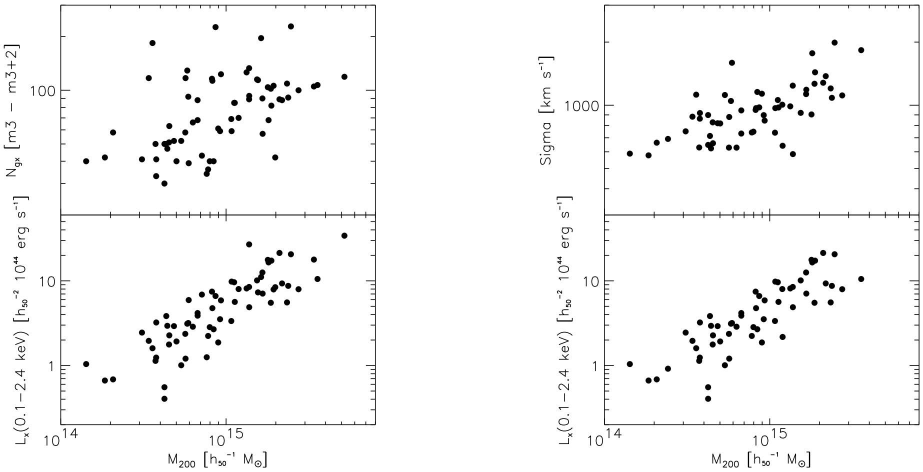

Fig. 2. Number of cluster galaxies for 66 clusters (left) and galaxy velocity dispersion for 58 clusters (right) versus mass as compared to X-ray luminosity versus X-ray mass for the same clusters.

In Fig. 2 the measured number of cluster galaxies, $N_{\rm gx}$, as taken from Abell, Corwin & Olowin [1] and the measured radial galaxy velocity dispersion, Sigma, as taken from Struble & Rood [10] are compared to $L_{\rm X}$ as gravitational mass tracers. It is clear from the plot on the left that, assuming M_{200} to be a good estimate of the true cluster mass, solely taking the Abell richness to select clusters is not a very effective way to select clusters by their mass. From the plot on the right one can see that the velocity dispersion correlates better with mass than the galaxy richness but also it confirms that careful analyses are required, e.g. [5], when determining the cluster mass from the velocity dispersion.

For further infos and more comprehensive articles please check http://www.xray.mpe.mpg.de/∼reiprich/

References

1. Abell, G. O., Corwin Jr., H. G., & Olowin, R. P. 1989, ApJS, 70, 1
2. Akritas, M. G. & Bershady, M. A. 1996, ApJ, 470, 706
3. Böhringer, H. & Schuecker, P., these proceedings
4. Evrard, A. E. & Henry, J. P. 1991, ApJ, 383, 95
5. Girardi, M., Giuricin, G., Mardirossian, F., Mezzetti, M., & Boschin, W. 1998, ApJ, 505, 74
6. Isobe, T., Feigelson, E. D., Akritas, M. G., & Babu, G. J. 1990, ApJ, 364, 104
7. Navarro, J. F., Frenk, C. S., & White, S. D. M. 1995, MNRAS, 275, 720
8. Reiprich, T. H. & Böhringer, H. 1999, Astron. Nachr., 320, 296
9. Reiprich, T. H. & Böhringer, H. 1999, in 19th Texas Symposium on Relativistic Astrophysics and Cosmology, ed. J. Paul, T. Montmerle, & E. Aubourg
10. Struble, M. F. & Rood, H. J. 1999, ApJS, 125, 35