Astron. Nachr. 320 (1999)

The Empirical X-Ray Luminosity – Gravitational Mass Relation for Clusters of Galaxies

T.H. Reiprich and H. Böhringer

Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße 1, D-85740 Garching, Germany

1. Introduction

The ROSAT All-Sky Survey (RASS) is currently the best data base to construct X-ray flux-limited samples of nearby X-ray clusters (e. g., Ebeling et al. 1998, Böhringer et al. 1998). Fully exploiting the RASS, along with optical follow up, will yield X-ray luminosities ($L_{\rm X}$) for $\sim$ 2000 galaxy clusters in the near future. Assigning gravitational masses ($M_{\rm tot}$) to these clusters is of vital importance to probe cosmological models, e. g., by translating the cluster luminosity function to the mass function and comparison to numerical and analytical models (e. g., Press & Schechter 1974). Determining masses individually for this large number of clusters is not feasible at present. Alternatively one can test observationally if there is a correlation between $L_{\rm X}$ and $M_{\rm tot}$ using a smaller sample. In the course of constructing an X-ray flux-limited sample of the brightest galaxy clusters to determine the cluster mass function (Reiprich 1998; Reiprich & Böhringer 1999) we derived gravitational masses for 106 clusters. The mass estimates are based on the hydrostatic assumption and are carried out individually for each cluster but in a homogeneous way for the sample. We find a good correlation of $L_{\rm X}$ and $M_{\rm tot}$. We use $H_0 = 50\,\frac{\rm km}{\rm s\cdot Mpc}$ and $q_0 = 0.5$ throughout.

2. Data Reduction and Analysis

We used mainly high exposure ROSAT PSPC pointed observations to determine the physical parameters of the clusters. If clusters extend the PSPC's field of view or if no pointed PSPC observation was available, RASS data were used. We determined the intracluster gas density profile using the isothermal β-model (Cavaliere & Fusco-Femiano 1976). Using this gas density profile and assuming the gas to be isothermal we calculated $M_{\rm tot}(< r)$ by the hydrostatic equation. For the average gas temperature ($T_{\rm gas}$) mainly published ASCA values, but also values determined with previous satellites and for 24 clusters the observational $L_{\rm X} - T_{\rm gas}$ relation by Markevitch (1998) were used. There are currently contradictory measurements for average radial $T_{\rm gas}$ gradients (e. g., Markevitch et al. 1998, Irwin et al. 1999, Kikuchi et al. 1999), if the $T_{\rm gas}$ decrement towards outside is commonly present, the isothermal assumption leads to a slight systematic overestimation of $M_{\rm tot}$ inside our adopted outer radius. If confirmed, inclusion of an averaged $T_{\rm gas}$ profile will be performed. To be able to compare clusters of different size we determined $M_{\rm tot}$ inside the radius r_{500} where the gravitational mass density equals 500 times the critical density.

3. Results

In Fig. 1 the resulting $L_{\rm X} - M_{\rm tot}$ relation is shown. $L_{\rm X}$ is determined in the ROSAT energy band 0.1 – 2.4 keV. The lines represent linear regression fits to the logarithmically plotted data points. The preliminary result is $L_{\rm X} = 3.3 \cdot 10^{26}\, M_{\rm tot}^{1.23}(< r_{500})$; $L_{\rm X}$ in erg/s and $M_{\rm tot}$ in solar masses. Simple self-similar scaling laws for a constant gas mass fraction ($f_{\rm gas}$) predict $L_{\rm X} \propto M_{\rm tot}$. The slight dependence $f_{\rm gas} \propto M_{\rm tot}^{0.16}$ found by us yields $L_{\rm X} \propto M_{\rm tot}^{1.32}$, consistent with the above result. Schindler (1999) finds an exponent of 1.33 for a sample of high redshift clusters using bolometric luminosities.

The good correlation shows that the X-ray luminosity is a good measure of the mass of nearby clusters. Possible future applications include conversion of empirical cluster luminosity functions to mass functions and conversion of simulated mass functions to luminosity functions.

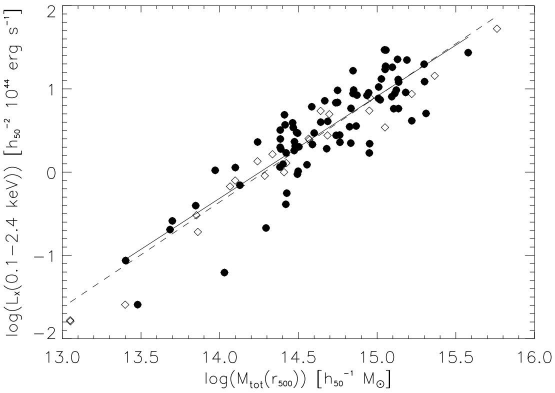

Fig. 1. $L_{\rm X} - M_{\rm tot}$ relation for 106 galaxy clusters (dashed line). Open diamonds indicate clusters where $T_{\rm gas}$ was determined using the $L_{\rm X} - T_{\rm gas}$ relation. These clusters were excluded for the relation given in section 3 (solid line).

References

Böhringer H. et al.: 1998, ESO Messenger 94, 21
Cavaliere, A. & Fusco-Femiano, R.: 1976, A&A 49, 137
Ebeling, H. et al.: 1998, MNRAS 301, 881
Irwin, J. et al.: 1999, astro-ph/9901406
Kikuchi, K. et al.: 1999, astro-ph/9903431
Markevitch, M.: 1998, Astrophys. J. 504, 27
Markevitch, M. et al.: 1998, Astrophys. J. 503, 77
Press, W.H. & Schechter, P.: 1974, Astrophys. J. 187, 425
Reiprich, T.H.: 1998, Diploma Thesis, LMU München
Reiprich, T.H. & Böhringer H.: 1999, in: Proceedings of the 19^{th} Texas Symposium on Relativistic Astrophysics
Schindler, S.: 1999, A&A, submitted