Non-uniform scatter in the galaxy cluster L-T relation and its implication for cosmological studies

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Abstract:

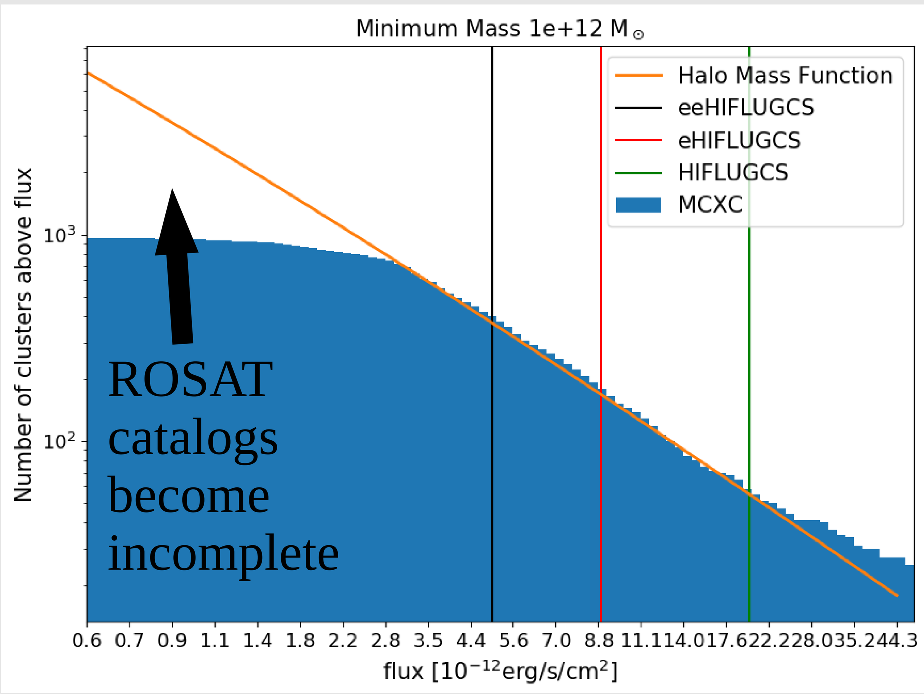
Hydrostatic cluster masses together with the halo mass function have been shown to be a competitive cosmological tool, since they can be derived from X-ray observations alone for large samples and with high precision. Biases from non-thermal pressure can be quantified and corrected for high mass objects. However, cosmological studies including galaxy groups suffer from unknown selection effects.
We investigate those biases using the largest complete X-ray sample of the brightest clusters and groups available. We quantify the luminosity-temperature scaling relation with more than 300 objects over a large range of masses, out to redshift 0.4, and find that the intrinsic scatter has a non-uniform distribution with respect to the temperature or mass.
We select a subset of the most relaxed and most disturbed objects and show that the non-uniform distribution remains. Although selection effects will not have a significant impact on the dependencies of the scatter itself, they have to be accounted for when deriving cosmological parameters. This is of particular interest also for eROSITA, since the first survey catalog will be dominated by the brightest objects already analyzed here.
Besides the temperature dependence of the scatter, we also find a spatial dependence: An anisotropy of underluminous clusters exists in a certain direction on the sky, which cannot be explained by any systematic.

eeHIFLUGCS: Sample properties

X-ray flux limited sample

Final sample consists of 376 Clusters with fluxes of at least 5×10^{-12} erg/s/cm^2

Selection:
- ROSAT clusters in MCXC catalog with flux > 4.5×10^{-12} erg/s/cm^2
- Reprocessed fluxes through growth curve analysis based on ROSAT All-Sky survey data (Pacaud et al., in prep.)
- For most clusters original fluxes from MCXC agree well with new fluxes
- Remove objects in the Galactic plane, Virgo area, LMC/SMC, double clusters or objects dominated by AGN emission
- Sample is complete (no missing clusters wrt to mass function)



Mostly nearby clusters (median z~0.08)

Wide range of temperatures

Includes relaxed, cool-core clusters and mergers

340 Clusters have sufficient X-ray data – Chandra data is used where available (266 Clusters), otherwise XMM-Newton (84 clusters)

Luminosity-Temperature Galaxy Cluster Scaling Relation

It has been shown that clusters of galaxies follow scaling relations between global quantities, such as the cluster mass, temperature or X-ray luminosity. These scaling relations facilitate the use of simple observables as traces for the cluster mass, which is needed for cosmological studies. The luminosity can be derived from very short observations, and it will be the only X-ray quantity available for most of the eROSITA detected clusters (Borm et al. 2015). The cluster temperature in turn is the only quantity that does not (or only weakly and indirectly) depend on the cosmological parameters. Here we study the effects of the intrinsic scatter in the luminosity-temperature relation.

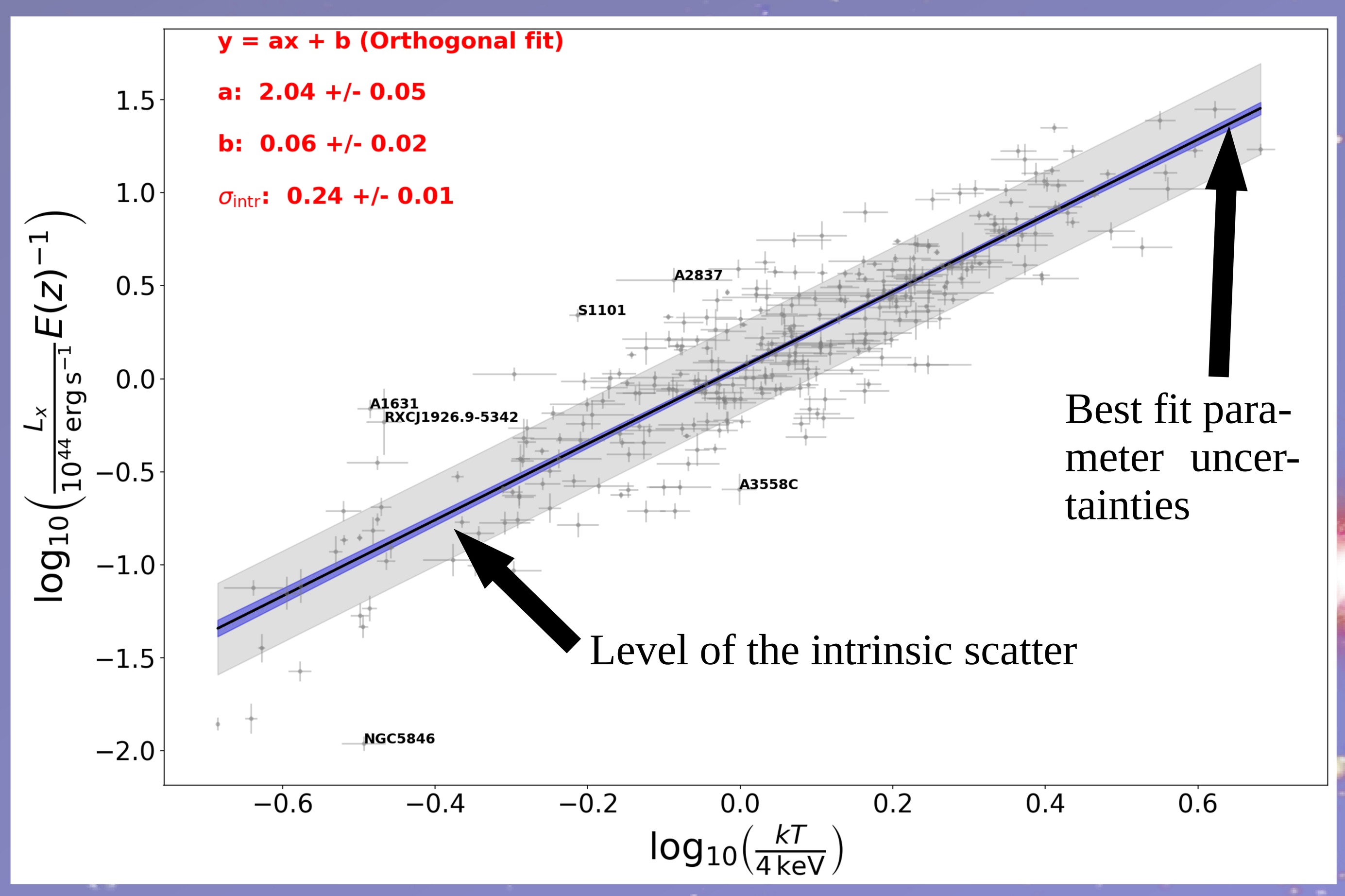
X-ray luminosity in the 0.1-2.4 keV band as measured by ROSAT, corrected from Galactic absorption and redshift (K-correction). Measurements depend on cosmology.

Gas temperature measured within 0.2-0.5 R_{500} (core excised). XMM-Newton measured temperatures are rescaled to Chandra (see Schellenberger et al., 2015). Temperature measurements are almost independent of cosmology.

$$\log_{10}\left(\frac{L_x}{10^{44}}\right)E(z)^{-1}=A+B\log_{10}\left(\frac{T}{4\,\mathrm{keV}}\right)+\sigma$$

Self similar evolution with redshift. Redshifts have been checked through NED and X-ray spectral redshifts.

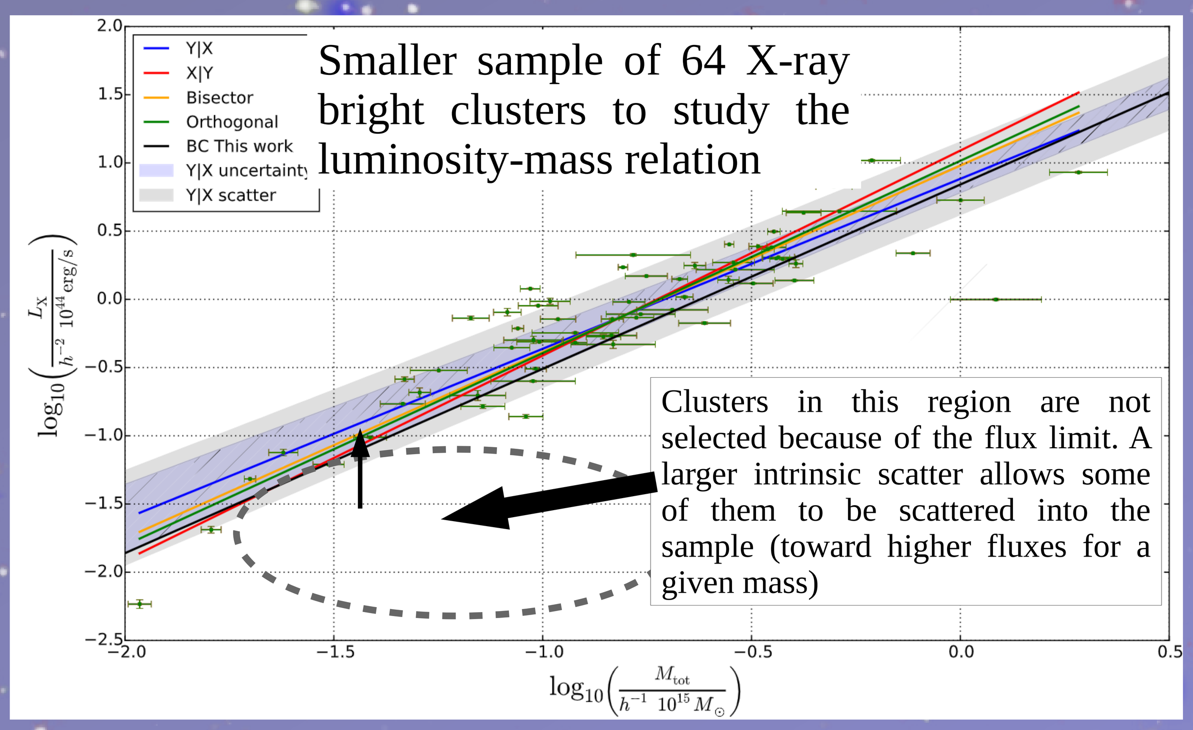
Intrinsic scatter, which might depend on temperature (or cluster mass), or sky position, or redshift.



Best fit scaling relation between X-ray luminosity and temperature (L-T) shows a tight correlation with small scatter. The relation is biased because of the selection (flux limit). To estimate the effects of the scatter the apparent scaling relation is used. The fitting is implemented in an MCMC algorithm, with a likelihood function where the scatter has a temperature dependence.

The L-T relation is relatively easy to derive for a large sample of clusters, and is ideal to study the uniformity of the intrinsic scatter and anisotropies, which are essential for cosmological studies.

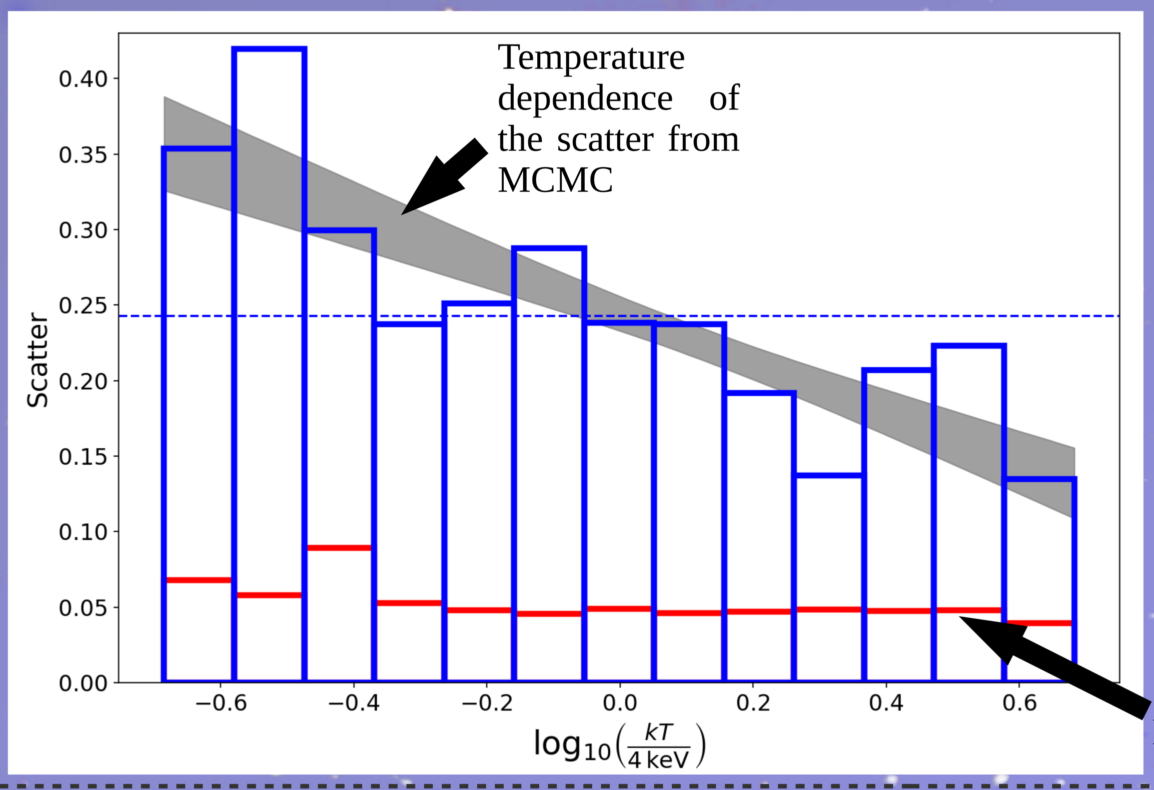
Scatter in the L-T relation



Mass – luminosity scaling relation for an X-ray flux limited sample (from Schellenberger & Reiprich 2017a)

To use clusters for cosmology (e.g., comparing the number density per mass interval with predictions from the halo mass function) one needs unbiased scaling relations (without selection effects). X-ray flux limited samples are generally biased, but follow a simple selection function which makes it possible to correct for these effects (see e.g., Vikhlinin et al. 2009, Mantz et al., 2010, Schellenberger & Reiprich 2017b). Selection effects become more and more dominant the larger the intrinsic scatter is. Generally the scatter is assumed to be normally distributed with a constant variance.

A non-uniform scatter (for example) with a temperature or mass dependence will make results inconsistent, since selection effects won't be accounted for correctly.



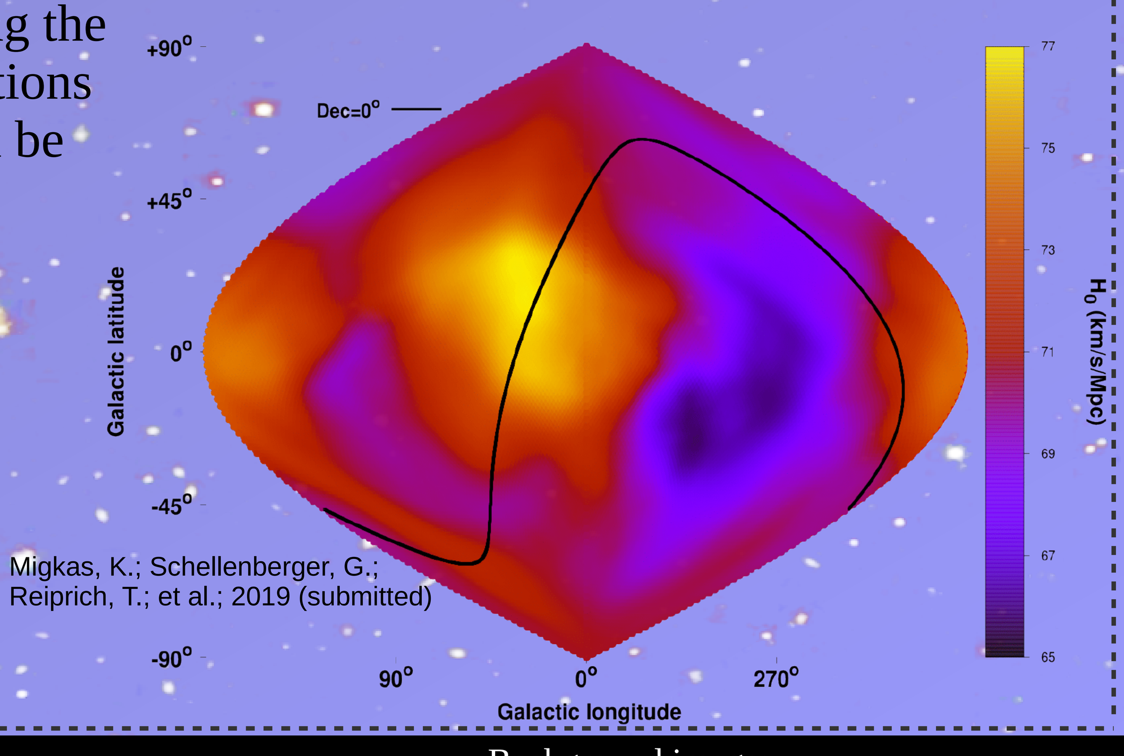
We find that the intrinsic scatter of the luminosity is significantly higher for low temperature clusters (and galaxy groups), while at the high mass end it is as low as 0.15dex. The statistical scatter, i.e. the uncertainties from the measurements of temperature and luminosity are constant over the same range of temperatures. This trend persists for the most relaxed and most disturbed objects (selected through central metallicity excess, see Lovisari & Reiprich, 2019).

Level of statistical scatter (red)

Direction dependence of the scatter

Migkas, K.; Schellenberger, G.; Reiprich, T.; et al.; 2019 (submitted)

We scan the sky by moving a cone across. For clusters within the cone a new normalization is calculated assuming the L-T slope of the full sample. Deviations from the overall normalizations can be visualized in terms of the Hubble constant H_0.



Migkas, K.; Schellenberger, G.; Reiprich, T.; et al.; 2019 (submitted)

Two most extreme regions in Galactic coordinates:

(l,b) = (302º, -26º) → H_0 = 65 km/s/Mpc and (l,b) = (30º, +16º) → H_0 = 77 km/s/Mpc

→ 5.4σ anisotropy between the two regions

This behavior persists across subsets, and is not sensitive to mass (groups vs. clusters), ICM metallicity, N_H value of the sky region (soft band absorption). It is possible to explain this effect as an non-isotropic expansion of the Universe, regions of unexpectedly large absorption, etc.

References

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Schellenberger & Reiprich 2017a. MNRAS, 469, 3738
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Background image:
Abell 1758 (Schellenberger et al., 2019)
X-ray: NASA/CXC/SAO; Optical:SDSS