Exploring the Temperature Dependence of Intrinsic Scatter in the Galaxy Cluster X-ray $L_X - T$ Relation

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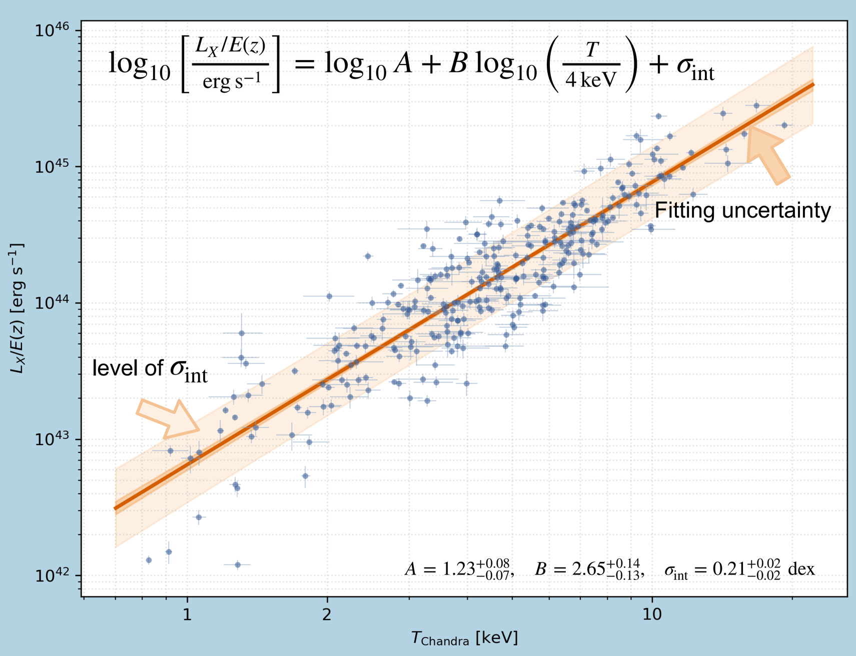
Motivation

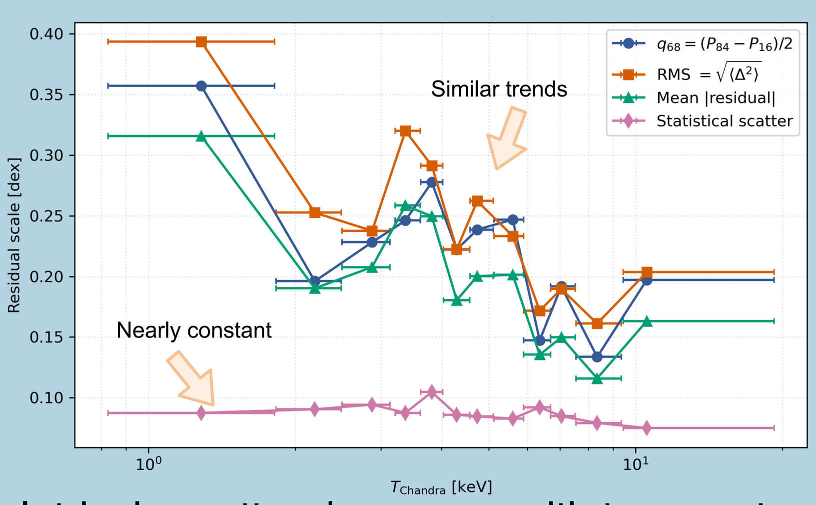
The intrinsic scatter of the X-ray luminosity–temperature $L_X - T$ relation reflects the thermodynamical diversity of the ICM(intracluster medium) and the impact of non-gravitational processes such as radiative cooling and AGN feedback. Its temperature dependence is therefore especially relevant for understanding the transition from galaxy groups to massive clusters.

Previous analyses of eeHIFLUGCS indicate that the intrinsic scatter may vary with temperature. However, because X-ray cluster samples are flux-limited, the observed relation and its scatter can be distorted by selection effects, particularly in the low-temperature regime where only the more luminous systems are preferentially detected.

A reliable measurement of the temperature dependence of the intrinsic scatter therefore requires disentangling genuine astrophysical variation from observational selection.

Observed scatter trend in eeHIFLUGCS





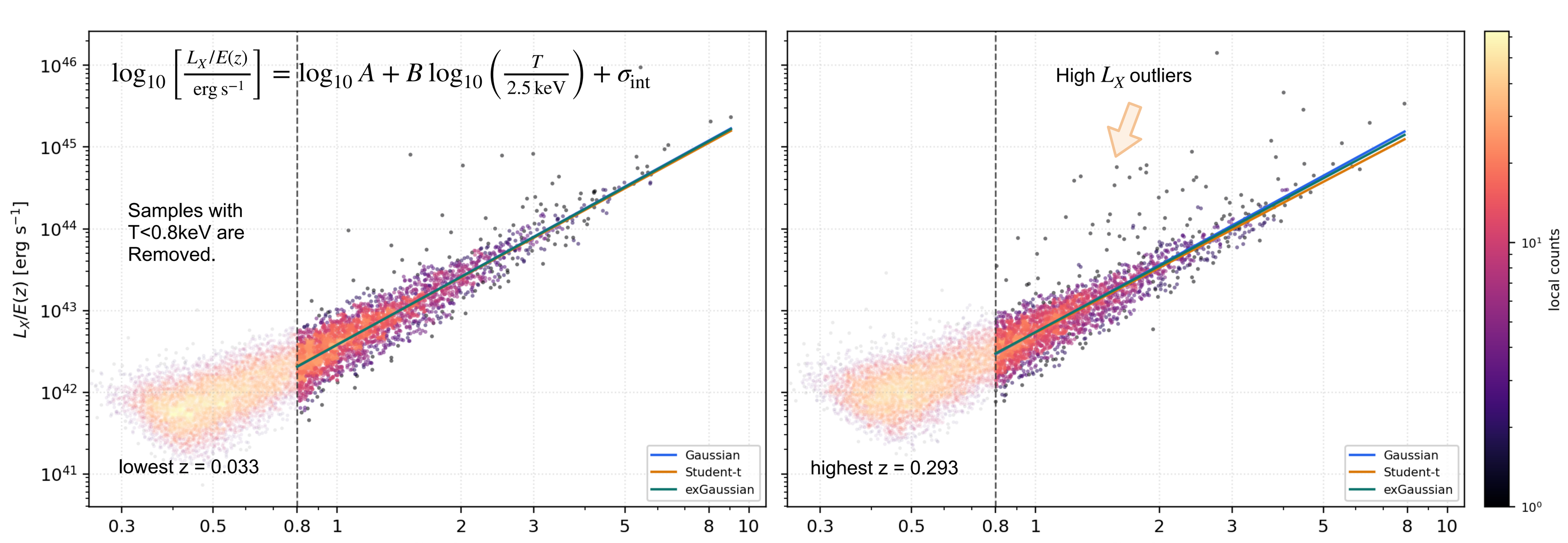
Intrinsic scatter decreases with temperature systematically across different estimators.

Objective

- Characterize the Magneticum parent population, including the mean $L_X - T$ relation and the temperature dependence and its scatter distribution.
- Compare candidate scaling-relation models to determine which features are sufficiently robust and practical for the subsequent analysis.
- Model the observational selection and construct mock detection catalogues to quantify how selection alters the observed relation and residual distribution.
- Test whether the known parent population can be recovered from the mock catalogues using a selection-aware likelihood.
- Apply the validated framework, together with the full detection selection model, to eeHIFLUGCS.

Magneticum parent population

We use 8 low-z snapshots from Magneticum **Box2/hr**, spanning $z \simeq 0.03 - 0.30$, comparable to the redshift range of eeHIFLUGCS. The snapshots are sufficiently separated in cosmic time that correlations between repeated structures are neglected in the present analysis. Because the simulated population becomes very densely sampled at low temperatures, those objects would otherwise dominate the fitting weight. We therefore restrict the analysis to a temperature range closer to that of eeHIFLUGCS, adopting a lower cut of $T = 0.8\,\mathrm{keV}$. After this cut, each snapshot still contains more than 2000 systems.



The $L_X - T$residual distribution is clearly asymmetric, with a pronounced excess of high-luminosity outliers that produces heavy positive tails, particularly at higher redshift. As a consequence, a Gaussian residual model tends to infer bit steeper slopes and higher normalizationtion than a Student's-t model at higher redshift, as the mean relation compensates for extreme outliers. An ex-Gaussian model captures the asymmetry but not the heavy tail, leading to a similar slope and normalization compensation.

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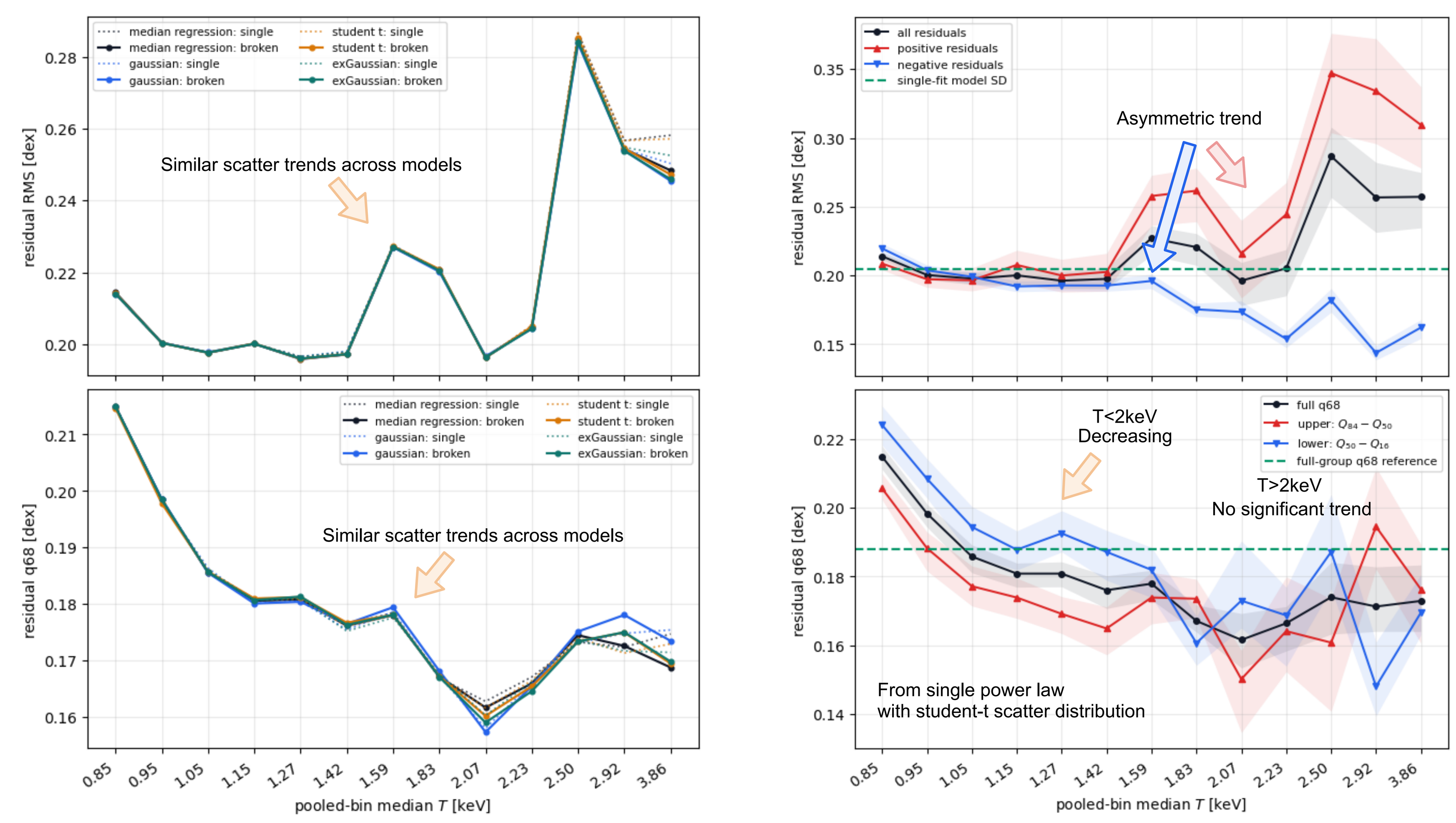
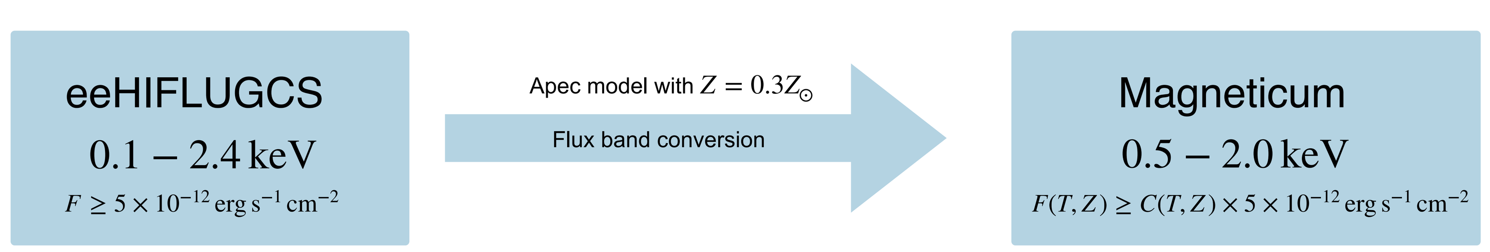
The normalization shows clear redshift evolution, whereas the high-temperature slope of the broken power-law relation is consistent with no significant evolution, as expected if the high-T regime is predominantly governed by gravitational physics.

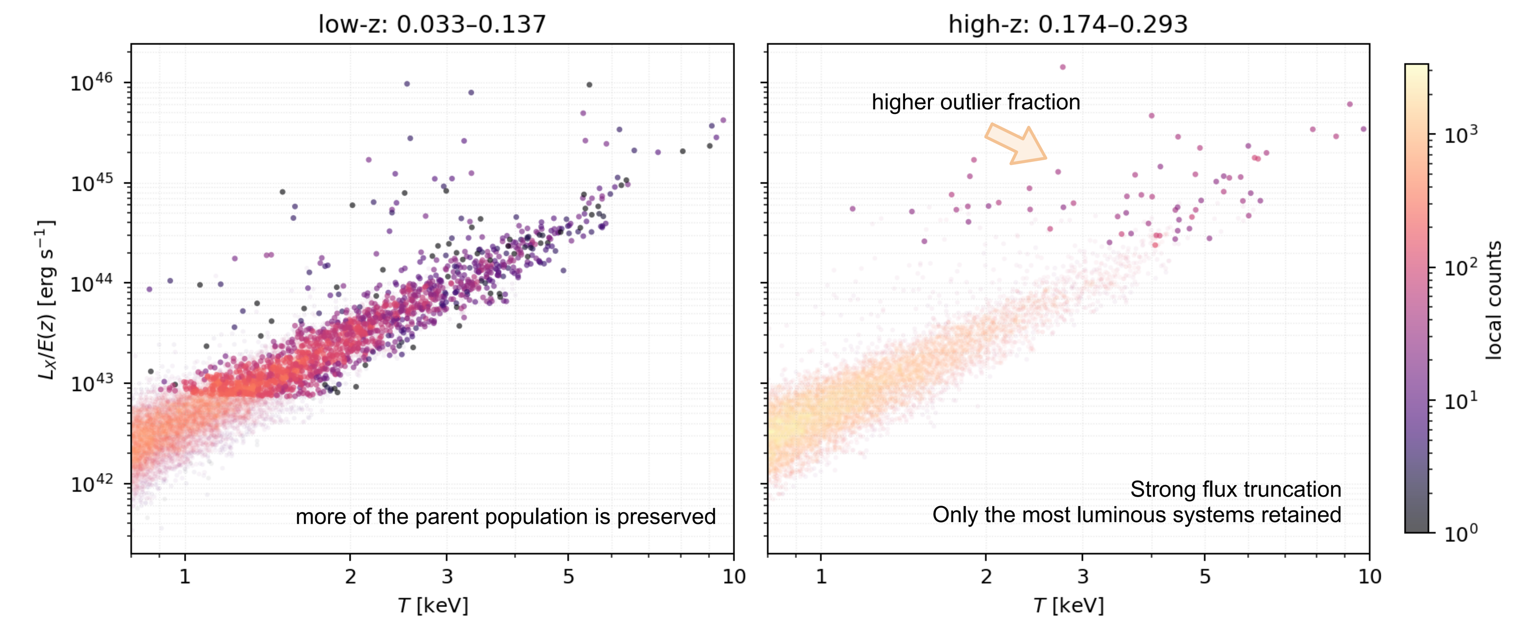
The scatter trend is robust against the choice of mean-relation model. Across both single and broken power laws, the residuals remain asymmetric, q_{68} decreases clearly below $2\,\mathrm{keV}$ but shows little trend at higher T while the RMS is enhanced by high-L_X outliers. The negative-residual RMS decreases similarly to q_{68}, supporting the interpretation that the RMS excess is driven by the positive tail.



Flux limit selection



The eeHIFLUGCS flux limit is first converted from $0.1 - 2.4$ keV to the Magneticum $0.5 - 2.0$ keV band using an APEC model with $Z = 0.3Z_{\odot}$.Using the Magneticum cosmology, the corresponding luminosity threshold is then calculated as $L_{X,\mathrm{lim}}(T,z) = 4\pi D_L^2(z)\,F_{\mathrm{lim}}(T,z)$. Clusters over $L_{X,\mathrm{lim}}(T,z)$ are retained to construct the flux-selected Magneticum sample.



Each snapshot samples the same simulation volume, but different redshift shells correspond to different observable volumes. We therefore apply shell-volume weighting. Mock catalogues are generated by shell-volume-weighted resampling, with $N = 296$ objects per catalogue to match the eeHIFLUGCS sample size.

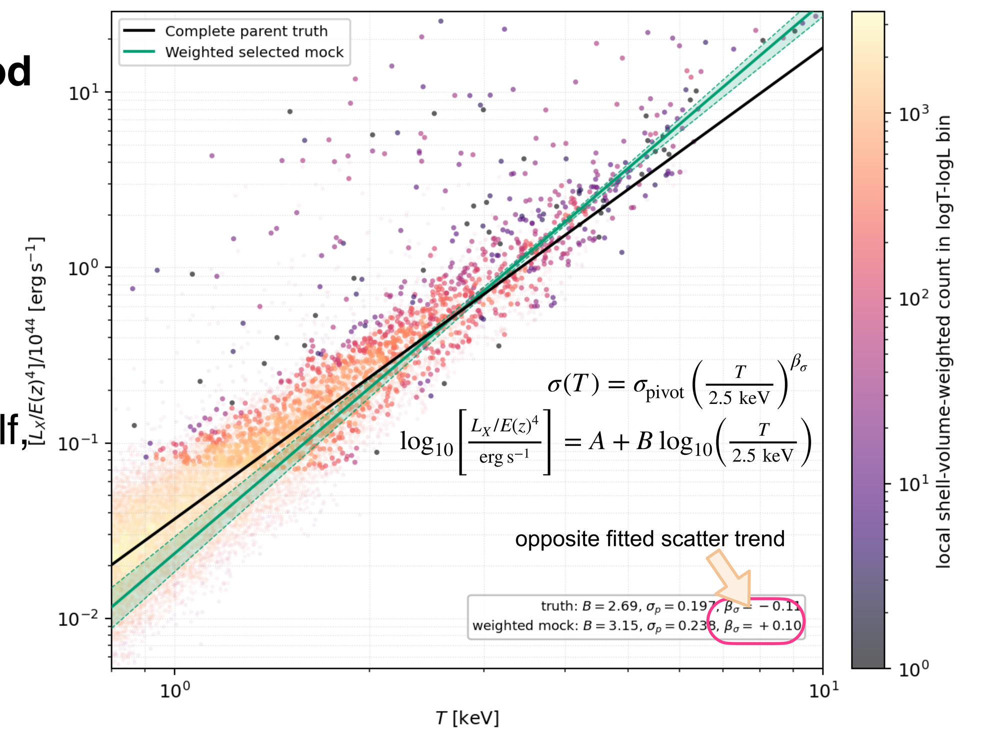
Accounting for selection in the likelihood

$$p(y_i \mid T_i, z_i, S_i = 1, \theta) = \frac{p(y_i \mid T_i, z_i, \theta)\, S(F_i)}{\alpha_i(\theta)}$$

with $\alpha_i(\theta) = \int p(y \mid T_i, z_i, \theta) S[F(y, T_i, z_i)]\, dy$

Selection is modelled in the likelihood itself, rather than corrected through inverse-completeness weights.

The Student's-t residual model is used as the baseline.



Reference

- **eeHIFLUGCS** (Lovisari & Reiprich, 2019; Migkas et al. 2020; Pacaud et al., in prep.)
- **Magneticum Box2/hr** (Hirschmann et al. 2014)
- **APEC model** (Smith et al. 2001)