Studying scaling relation and their scatter with 10000+1 galaxy clusters

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• In next few years large cluster surveys will be underway (e.g. eRosita, SPT, DES)
• We need to understand the connection between the observable cluster properties, the intrinsic properties and the underlying mass distribution.

1 complicated cluster
• eRosita would not have a spatial resolution as good as Chandra -> more difficult to classify objects by their morphology.
• We need to study the impact of scaling relation scatter by objects which are dynamical unstable

INTRODUCTION

10000 clusters
• Investigate the systematics that could affect the analysis of real data
• Provide a concrete theoretical framework for the statistical studies
• This entails the multivariate halo function $P(L_X, T_X, Y_{SZ}, T_{MW}, c|M)$ and its evolution
1 special simulated cluster

- Physics: radiative cooling, uniform time-dependent UV background, star formation from multi-phase interstellar medium, galactic winds powered by SN
- Mass resolution: DM particle = $1.74 \times 10^8 M_{\text{sun}}/h$ GAS particle = $2.6 \times 10^7 M_{\text{sun}}/h$
- Physical resolution: softening 2.5 kpc/h
- Total mass at $R_{200}$: $M_{200} = 2 \times 10^{15} M_{\text{sun}}/h$
- Active dynamic history and strong merging (Mach number 2.5)

**GOAL**: Test scaling relations in a very unstable dynamical situation
Scaling relation by Kravtsov et al 06

\[ M_{\text{tot}} = 10^{14.41} \left( \frac{T_X}{3 \text{ keV}} \right)^{1.521} \]
\[ 10^{14.35} \left( \frac{M_{\text{gas}}}{2 \times 10^{13}} \right)^{0.921} \]
\[ 10^{14.27} \left( \frac{Y_X}{4 \times 10^{13}} \right)^{0.581} \]

\[ Y_X = \frac{M_{\text{gas}}}{T_X} \]

our cluster location \( \approx \) their biggest one

all clusters

\[ [710^{13} 210^{15}] M_{\text{sun}}/h \]

all \( z (=0, 0.6) \)

All quantities at \( R_{500} \)

excluding 0.15 \( R_{500} \)
1 special simulated cluster

DM

GAS

galaxies

Courtesy of Klaus Dolag
1 special simulated cluster

DM

GAS

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Evolution intrinsic properties

Merger begins

2 centers coincide

DM bullet-like+
cold blob
Exiting $R_{500}$

2nd cold blob
Scaling relation

• **SIMULATION**
  • All the quantities $(T_{\text{sl}}, M_{\text{gas}}, Y_X = T_{\text{sl}} M_{\text{gas}})$ computed inside $R_{500}$ (excluding 0.15 $R_{500}$) with $R_{500}$ determined from the simulation itself

• **OBSERVATION**
  • Cluster processed through XMAS2 to obtained X-ray images
  • Mask blobs
  • All the quantities from X-ray measurements computed in $R_{500}$ (excluding the core) estimated from X-ray.
The overall behavior of the M-T is changed substantially. Points are closer to the relation by Kravtsov et al. and within 10% of scatter.
The is a larger spread in the gas mass computed with the X-ray technique, at the same time more points approach to the best-fit by Kravtsov.
The observed $Y_x$ parameter is in agreement with Kravtsov relation. The "observed scatter" is substantially reduced.
Conclusions

• We test the robustness of the scaling relation and we find that they are satisfied also in the case of a strong merger
• The X-ray Temperature is good proxy for mass when an accurate masking is done
• The $Y_X$ parameter is very robust again merger due to the opposite effect that $M_{\text{gas}}$ and $T_X$ are experiencing
• NEXT STEP: upcoming surveys will have less spatial and spectral resolution, a detailed masking would not be possible.
10000 galaxy clusters

- Millenium Gas Simulations (Pearce et al. 07).
- $\Omega_L = 0.75$, $\Omega_M = 0.25$, $\Omega = 0.045$, $h = 0.73$, $n = 1$, $\sigma_8 = 0.9$
- Volume = comoving cube 500 Mpc/h
- N particles = $5 \times 10^8$ DM + $5 \times 10^8$ GAS
- Mass resolution = $1.422 \times 10^{10}$ M$_{\text{sun}}$/h (DM), $3.12 \times 10^9$ M$_{\text{sun}}$/h
- Gravitational Softening 25 kpc/h

Clusters with $M_{200} > 5 \times 10^{13}$ M$_{\text{sun}}$/h
- 3791 at $z=0$
- 3734 at $z=0.21$
- 2653 at $z=0.51$
Comparing intrinsic simulation temperature measurements with the

$\sigma^2_{EW} = 0.04$

$\sigma^2_{sl} = 0.015$

$\sigma^2_{MW} = 0.03$

- $T_{MW}$ is almost 10% lower than $TX$, with high scatter.

- $T_{sl}$ describes more properly the X-ray temperature, since it is on average closer and shows a very small scatter.

Global temperature in $[0.15-1] \times R_{500}$
Scaling relation: M-T

- Region: [0.15-1] $R_{500}$
- All clusters with $T > 3.5$ keV.
- Power law consistent with Arnaud et al 05, Sanderson et al. 03, Finoguenov et al. 01.
- Steeper than simulations with cooling.
- Standard deviation bigger at high redshift
  - $\sigma^2_{z=0} = 0.10$
  - $\sigma^2_{z=1} = 0.13$
Scaling relation: M-L

- The scatter of our M-L relation is low both at high and low redshift
  - $\sigma^2_{z=0} = 0.08$
  - $\sigma^2_{z=1} = 0.09$
- Excluding core reduces a lot the scatter (Maughan 07)
Scaling relation: L-T

- L-T relation of clusters with $T > 3.5$ keV is steeper than observed.
- $\sigma^2_{z=0} = 0.13$
  $\sigma^2_{z=1} = 0.15$
- Fixing $\alpha = 3.3$ the difference in normalization is consistent to an negative evolution.
Conclusions & Future plans

• The X-ray temperature overestimate the true temperature of the clusters ($T_{MW}$)
• M-T: scatter is bigger to high redshift, relation are steeper than in cooling simulations
• M-L: excluding the core reduces the scatter
• L-T relation presents the highest scatter in the relation studied. The relation at redshift 0.5 is consistent with slightly negative evolution
• FUTURE: big covariance matrix considering both