Calibrating the galaxy cluster mass scale for cosmology

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Outline

• Calibrating the Planck SZ mass proxy using the velocity dispersion - mass relation

S. Amodeo, S. Mei, A. Stanford, J.G. Bartlett, J.-B. Melin, C. Lawrence, R. R. Chary & Planck collaborators

• The relation between mass and concentration in X-ray galaxy clusters at high redshift

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Cosmological constraints from cluster counts

\[
d\frac{N}{d\Omega} = \int d\Omega \int dM_{500} \chi(z, M_{500}, l, b) \frac{dN}{dz dM_{500} d\Omega}
\]

Survey selection function
Scaling relation observable - Mass

Mass function
• Planck XXIV 2015: cosmology from 439 SZ detected clusters

• SZ Y - Mass relation
  based on XMM hydrostatic masses (Planck XX 2013)

\[ E^{-\beta}(z) \left[ \frac{D_A^2(z) \bar{Y}_{500}}{10^{-4} \text{Mpc}^2} \right] = Y_* \left[ \frac{h}{0.7} \right]^{-2+\alpha} \left[ \frac{(1 - b) M_{500}}{6 \times 10^{14} \text{M}_\odot} \right]^\alpha \]

• **Mass bias parameter**: accounts for any difference between
  the Planck SZ mass proxy and the true mass

\[ M_{500, \text{SZ}} = (1 - b) M_{500} \]
Planck 2015, XXIV

Tension between cluster and primary CMB constraints

Mass bias priors from
• gravitational shear: WtG, von der Linden et al. 2014a
  CCCP, Hoekstra et al. 2015
• CMB halo lensing: Melin & Bartlett 2014
Planck 2015, XXIV

Tension between cluster and primary CMB constraints

Agreement with

\[ 1 - b = 0.58 \pm 0.04 \]

*Are clusters more massive than predicted from SZ-M?* … or …

*Do we need extensions to the standard ΛCDM?*
• Mass bias: main uncertainty in cluster counts cosmology

• Use independent techniques to estimate Mass

**Galaxy dynamics**

- assume virialization
- independent of ICM properties
- $\sigma - M$ well calibrated with cosmological N-body and hydrodynamical simulations (e.g. Evrard et al. 2008, Munari et al. 2013)

$$\sigma_{1D} = A_s \left[ \frac{E(z) M_{200}}{10^{15} M_\odot} \right]^{1/3}$$
Gemini follow-up of a sample of Planck SZ clusters (P.I. J.G. Bartlett)

- 14 clusters $0.25 < z < 0.45$, $10 < N_{\text{gal}} < 40$
- significant range in mass (Planck 2015, XXVII)

$$2 \times 10^{14} M_{\odot} \lesssim M_{500, SZ} \lesssim 10^{15} M_{\odot}$$

- Gemini - GMOS optical spectroscopy
- Velocity dispersions and dynamical masses
- SZ Planck $M_{200, SZ}$ from $c_{200} - M_{200}$ by Dutton & Macciò 2014
\[ \sigma_{1D} = A \times \left( \frac{E(z)M_{200,\text{SZ}}}{10^{15}M_\odot} \right)^{1/3} \]

\[ A = 1185 \pm 65 \text{ km/s} \]

\[ \sigma_{tot} = 0.07 \pm 0.01 \text{ dex} \]
\[ M_{500, SZ} = (1 - b) M_{500} \]

- assume \( l \cdot b \) independent of overdensity

- assume \( M_{200, \sigma_{1D}} = M_{200} \)

- compare to Munari et al. 2013:
  hydrodynamical simulations of galaxies + SF + gas cooling driven by SN + AGN feedback
  \[ A_s = 1177 \pm 4.2 \text{ km/s} \]

\[ (1 - b) = \left( \frac{A_s}{A} \right)^3 = 0.98 \pm 0.16 \]
Conclusions 1

1. We obtain an interesting constraint on \((1-b)\) with only 14 clusters

\[
(1 - b) = 0.98 \pm 0.16
\]

2. The result maintains the tension between Planck cluster counts and primary CMB at >2\(\sigma\)

3. More clusters and at lower mass would notably improve the constraints
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Galaxy clusters described by the universal NFW profile
2 parameters: \( (r_s, c) \) or \( (M, c) \)

Navarro, Frenk & White (1997)

\[
\rho(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}
\]

\[
c_\Delta \equiv \frac{r_\Delta}{r_s}
\]

Navarro, Frenk & White (1997)
Distribution of matter & Mass Assembly History

- Galaxy clusters described by the \textit{universal} NFW profile
  2 parameters: \((r_s, c)\) or \((M, c)\)

- \(c(M)\) linked to the halo’s assembly history and time of formation

- CDM predicts anti-correlation

- what is observed at high \(z\)? \((z \approx 1)\)

Credit: Diemer & Kravtsov
The relation between mass and concentration in X-ray galaxy clusters at high redshift


- 47 galaxy clusters by the Chandra X-ray Observatory
- $0.4 < z < 1.2$
- regular X-ray morphology
- very luminous at each $z$
Total mass profile from X-ray analysis

1. spherical symmetry

2. hydrostatic equilibrium

\[
M_{\text{tot}}(< r) = -\frac{k T_{\text{gas}}(r)}{\mu m_p G} \left( \frac{d \ln n_{\text{gas}}}{d \ln r} + \frac{d \ln T_{\text{gas}}}{d \ln r} \right)
\]

3. NFW mass model: 2 free parameters \((r_s, c)\)

4. constraints on \((r_s, c)\) by minimising:

\[
\chi_T^2 = \sum_i \frac{(T_{\text{data},i} - T_{\text{model},i})^2}{\epsilon_T^2,i}
\]

Ettori et al. 2010
The concentration - mass relation

First constraints @ \( z > 0.7 \) from X-ray data

No evidence of plateau/upturn

Amodeo et al. 2016
At a fixed mass range, systems with lower concentration are found at higher redshifts.

Amodeo et al. 2016
Fitting the observed $c(M,z)$

$$\log c_{200} = A + B \log \left( \frac{M_{200}}{10^{14} M_\odot} \right) + C \log(1 + z) \pm \sigma_{\log c_{200}}$$

LIRA (Sereno 2016)
Bayesian linear regression

<table>
<thead>
<tr>
<th></th>
<th>$A$</th>
<th>$B$</th>
<th>$C$</th>
<th>$\sigma_{\log_{10} c_{200}}$</th>
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<tbody>
<tr>
<td></td>
<td>$1.15 \pm 0.29$</td>
<td>$-0.50 \pm 0.20$</td>
<td>$0.12 \pm 0.61$</td>
<td>$0.06 \pm 0.04$</td>
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Green: constraints from Weak-lensing by Sereno & Covone 2013
Conclusions II

1. We characterise the high-mass end of the distribution of galaxy clusters at $0.4 < z < 0.7$

2. We obtain the first constraints on the c-M at $z > 0.7$ from X-ray data

3. We confirm the expected trend of lower concentrations for higher mass systems and, at a fixed mass range, lower concentrations for higher redshift systems

4. A homogeneous sample, extended to lower redshifts, would improve the constraints on the c-M-z relation