Kinematic, lensing & X-ray mass estimates of a poor cluster

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+ P. Popesso, J.P. Dietrich, Y.-Y. Zhang, G. Erfanianfar, M. Romaniello, B. Sartoris
Introduction

**Matching discrepancies**

X-ray and optical cluster samples 
*(Donahue+02, Gilbank+04, Basilakos+04, Sadibekova+14)*

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*Bower+97*: optically selected distant clusters have low $L_X$ for their velocity dispersion, probably overestimated because of projection effects (filaments along the los) or because of a large population of infalling galaxies.
Introduction

Popesso, AB+07: “Abell X-ray Underluminous (AXU) clusters”:
spectroscopically confirmed Abell clusters with unsecure X-ray detection.

AXU stacked distribution of rest-frame cluster galaxy velocities is long-tailed in the outer regions, suggestive of an infalling population.

AXU clusters appear to have lower galaxy number density near the center than X-ray-normal Abell clusters, and higher bluer galaxy fraction.
Introduction

Dietrich, AB, Popesso+09: “Weak lensing observations of potentially X-ray underluminous galaxy clusters”: A315 @z=0.174 & A1456 @z=0.135, observed with WFI@ESO/MPG-2.2m to obtain their masses via Weak Lensing

Weak Lensing Mass maps:

**clear detection for A315**  **no detection for A1456**
Introduction

*Dietrich, AB, Popesso+09*: “Weak lensing observations of potentially X-ray underluminous galaxy clusters”: A315 @z=0.174 & A1456 @z=0.135, observed with WFI@ESO/MPG-2.2m to obtain their masses via Weak Lensing

Masses from lensing confirms A315 is X-ray underluminous for its mass (AXU) while A1456 is not

Bimodal velocity distribution of A1456: unrelaxed dynamical state or projection effects → mass overestimate from velocity dispersion
A315: new data

VIMOS@VLT spectroscopic observations: 479 reliable redshifts, $\delta v \sim 110$ km/s
+ SDSS-III DR10: 499 redshifts, 32 in common → total: 946 redshifts in $1^\circ \ 12' \times 45'$ field

Number-density map of photometric members used to define cluster center as density peak (yellow +)
(yellow diamond: weak lensing peak from Dietrich, AB+09)

Grey shading: member number density contours corrected for incompleteness
Dots: all spectroscopic members

$r_{200}(\sigma_v) = 1.24$ Mpc
A315: members

Cluster members identified in projected phase-space diagram using the Shifting Gapper method (Fadda+96) – confirmed by the Clean method (Mamon, AB, Boué 13)

222 cluster members identified (filled dots)

$\sigma_v = 603 \pm 30 \text{ km/s}$

Assuming NFW $M(r)$, mass concentration from c-M relation of Macciò+08, velocity anisotropy profile from Mamon+Łokas 05,

$\sigma_v \rightarrow r_{200}^\sigma = 1.24 \pm 0.06 \text{ Mpc}$

Note: $G M_{200} = 100 H(z)^2 r_{200}^3$
A315: substructures

Use the DSb algorithm (AB+96, +02; after Dressler+Shectman 88) to identify substructures: 17 cluster members assigned to subclusters (green dots) → 205 cluster members left.

10 subcluster galaxies are in the same group, with $\sigma_v = 282 \pm 70$ km/s.
A315: substructures

Use KMM algorithm (McLachlan & Basford 88; Ashman+94) on remaining 205 members: chek for bimodality in velocity distribution. 2-Gaussian fit significantly better than 1-Gaussian fit for $R \leq r_{200}^\sigma$ velocity distribution. 1-Gaussian fit is adequate for $R > r_{200}^\sigma$ velocity distribution.

The centers of the inner KMM-main cluster and KMM-subcluster are 0.7 Mpc apart.
Caustic method \((\text{Diaferio} \& \text{Geller} \ 97; \text{Diaferio} \ 99)\): discontinuity in projected-phase space is related to escape velocity of galaxies from the cluster potential. Method is robust vs. presence of subcluster → we do not remove DSb and KMM subclusters from the analysis.

However this method does not provide strong constraints on the cluster mass:

\[
r_{200c} = 0.9 \ [-0.3, +0.6] \text{ Mpc}
\]

At face value, \(r_{200c} < r_{200\sigma}\)
A315: mass profile

**MAMPOSSSt method** (*Mamon, AB, Boué 13*): Maximum Likelihood analysis of the projected phase-space distribution of cluster members, finding best-fit for models of $M(r)$ and the velocity anisotropy profile based on the Jeans equation for dynamical equilibrium.

Use $R \leq r_{200}^\odot$ members, excluding DSb substructures; weigh the MAMPOSSSt likelihood by the member probabilities of belonging to the KMM-main cluster.

Red (blue) dots: cluster members with higher (resp. lower) probability of belonging to KMM-main

Use MAMPOSSSt in ‘Split’ mode, fitting the spatial distribution of cluster members separately from their velocity distribution:

- (projected) NFW with $r_{2,\nu}=1.0$ [-0.3,+0.7] Mpc
- $r_{200}^\odot=1.24$ Mpc
A315: mass profile

MAMPOSS method (Mamon, AB, Boué 13):

3 models for the mass profile $M(r)$ - mass density profile $\rho(r)$:

A) Burkert 95, ‘Bur’, $(d \log \rho / d \log r)_0 = 0$, $(d \log \rho / d \log r)_\infty = -3$
B) Hernquist 90, ‘Her’, $(d \log \rho / d \log r)_0 = -1$, $(d \log \rho / d \log r)_\infty = -4$
C) Navarro+ 96,97, ‘NFW’, $(d \log \rho / d \log r)_0 = -1$, $(d \log \rho / d \log r)_\infty = -3$

4 models for the velocity anisotropy profile $\beta(r) \equiv 1 - (\sigma_t/\sigma_r)^2$:

a) constant, b) Mamon+Łokas 05, c) Osipkov 79 + Merritt 85, d) modified-Tiret+07

3 Free parameters:

\[ \{ M_{200}, r_2, c = r_{200}/r_2 \} \]

(1) $r_{200}$, the mass profile normalization
(2) $r_2$, the scale-radius of the mass profile
(3) a velocity-anisotropy parameter
**A315: mass profile**

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<th>Mean of all models</th>
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<td>$r_{200}$ [Mpc]</td>
<td>$0.85^{+0.16}_{-0.18}$</td>
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- NFW is best-fit $M(r)$ model
- Tiret is best-fit $\beta(r)$ model
- Uncertainties in best-fit model
  - *(filled blue dot)*
  - $\gg$ variance among different models
  - *(other symbols)*
  - $\rightarrow$ statistical error dominates
- Low concentration, $c \equiv r_{200}/r_{-2} < 1$
- Isotropic (or tangential) orbits
A315: mass profile

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- MAMPOSSSt $r_{200} < r_{200}^\sigma$
- MAMPOSSSt $r_{200} \approx r_{200}^C$
- Marginally inconsistent with the results from the kinematic analysis of Dietrich, AB, Popesso+09 (dashed line, shaded regions indicating random and random+systematic uncertainties)
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...and with the results from the weak lensing analysis of same authors (red diamond with error bars)
### A315: mass profile

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- **M(r) concentration**
  - $\ll$ theoretical expectation for given $M,z$ (from Correa+15)

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Andrea Biviano, Trieste
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*Dietrich, AB, Popesso+09* derived $r_{200}^{\text{WL}}$ from the weak lensing map, using NFW model fitting with fixed $c=7$ (theoretically motivated)

- Using $c=1$ we find:
  \[ r_{200}^{\text{MAMPOSSt}} \approx r_{200}^{\text{WL}} \quad (\text{gold diamond}) \]
The new $r_{200}$ determinations (MAMPOSSt, lensing c=1) are in good agreement with $r_{200}^X$ from $L_X$ using the Rykoff+08 scaling relation (yellow line and shading)

→ A315 no longer X-ray underluminous
Conclusions

➔ A315 is a low-mass cluster ($8 \times 10^{13} M_\odot$); this explains its low $L_X$

➔ Previous mass estimates were biased high because of:
  a) complex kinematics structure (unaccounted substructures)
  b) wrong assumption on $M(r)$ concentration (lensing)
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➔ Can all Abell X-ray Underluminous clusters be explained by a wrong mass estimate caused by line-of-sight, infalling structures \((Bower+97)\)?
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➔ Can all Abell X-ray Underluminous clusters be explained by a wrong mass estimate caused by line-of-sight, infalling structures (Bower+97)?

...the game is not quite over yet...
Conclusions

➔ Both A315 and A1456 appear to be in a (minor?) merging process (also: tangential orbits)

➔ The low-concentration measured for A315 is uncommon (both observationally, e.g. Groener+16, and theoretically, e.g. Correa+15); it could originate from the merging process; could this also lower $L_X$?

➔ **Planck collaboration 2016:** “Planck 2015 results. XXVII. The second Planck catalogue of Sunyaev-Zeldovich sources”: some clusters have SZ $Y_{500}$ compatible with their redMaPPer richness $\lambda$, but too high for their $L_X$. Are both $\lambda$ and $Y_{500}$ biased high, or are their X-ray underluminous for their mass?

*See also talk by Ewan O’Sullivan: some X-ray groups might remain undetected (mergers, non-CC, AGN-disrupted...)*
Conclusions

Need follow-up observations of more candidate X-ray underluminous clusters for the issue to be settled down.

Nice score if it was a soccer game, but looks like it’s a basketball game!