Properties of SZ-selected vs X-ray selected galaxy clusters: evidence for selection biases.

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“The majority of newly discovered Planck clusters show evidence for significant morphological disturbances”

(Planck Collaboration 2011, Planck Early results IX)

To confirm, complete samples are needed

Do we expect SZ-selected systems to be more dynamically disturbed than X-rays?

* Is the Planck selection biased towards disturbed objects?

Test with simulations:
Injection of SZ maps of disturbed/relaxed clusters in simulated sky.

No significant differences in the selection function.

*(Planck 2015 Results, XXVII)*
Selection biases in X-rays?

At a given mass, relaxed cool core clusters are overall more luminous than NCC (30% scatter in L-M scaling relations)

Excess of CC due to **Malmquist bias** (in flux limited X-ray surveys) and **Eddington bias** (in X-ray surveys with a luminosity cut)
Selection biases in X-rays?

Even if CC had the same total luminosity than NCC, they would still be more easily detected in a survey.

SHAPE MATTERS!
Cool core bias

Simulations of CC bias from Eckert et al 2011

The effect is stronger close to the detection limit of the survey

It affects X-rays surveys ($L_x \approx n_e^2$, Pesce et al 1990, Eckert et al 2011) and is predicted to be small in SZ-surveys ($I_{SZ} \approx n_e$, Lin et al 2015, Pipino & Pierpaoli 2010), especially with Planck
Testing selection biases

Comparing the properties of samples derived with different techniques allows to test for selection biases with real data.

Compare samples with similar M and z distribution

<table>
<thead>
<tr>
<th>Merger state</th>
<th>CC state</th>
</tr>
</thead>
<tbody>
<tr>
<td>With dynamical or morphological indicators</td>
<td>With indicators of “coolcoreness”</td>
</tr>
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</table>
The dynamical state of Planck clusters

Offset between X-ray peak and BCG* position as a dynamical indicator

(Hudson et al 2010, Sanderson et al 2009, Mann & Ebeling 12)

*BCG= Brightest Cluster Galaxy

The dynamical state of Planck clusters

Measured on almost complete sample (128/132) of Planck high S/N clusters with public X-ray (Chandra or XMM) observations and BCG identification (literature + archival analysis)

Literature information on the BCG – Xray peak offset available for many samples, often with heterogeneous selection. We compared only with purely X-ray selected samples.

**ME-MACS** (*Mann & Ebeling 2012*): 108, most massive high-z (>0.15) objects in RASS data

**HIFLUGCS** (*Zhang+ 2011*): 62, Brightest X-ray clusters, local, low mass objects

**REXCESS** (*Haarsma+2010*): 30, intermediate mass and z
SZ vs X-ray samples

Relaxed $D_{X-BCG}=0.02R_{500}$ Disturbed

Sanderson+ 09

Frequency

$D_{X-BCG}$ (R$_{500}$)

SZ vs X-ray samples

Kolmogorov-Smirnov test
KS Statistic = 0.228
Null hypothesis probability = 0.4%

Relaxed fraction
Planck: 52±4%
ME-MACS: 73±4%

Fewer relaxed objects in Planck than in ME-MACS
The CC state of Planck clusters

$D_{\text{X-BCG}}$ is not a direct indicator of the presence of a prominent density peak

*Redo the analysis with the concentration parameter (Santos et al 2008)*

\[
c = \frac{I(R < 40 \text{ kpc})}{I(R < 400 \text{ kpc})}
\]

---

**Abell 2204: CC**

- $C=0.30$

**Abell 2069: NCC**

- $C=0.02$

*MR et al (2017), MNRAS 468, 1917*
The CC state of Planck clusters

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c = \frac{I(R < 40 \text{ kpc})}{I(R < 400 \text{ kpc})}
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**Sample:**

* Almost complete sample (169/189) based on the PSZ1 cosmo catalogue (high S/N objects)

* Comparison with 104 ME-MACS clusters (overlap in mass and z), same analysis

The CC state of Planck clusters

![Graph showing the CC state of Planck clusters]

The CC state of Planck clusters

CC fraction

Planck: 29 ± 4%
ME-MACS: 59 ± 5%

KS test: KS statistic $D = 0.35$, Null hyp. Prob. $p_0 = 1.7 \times 10^{-5}$
Even more significant difference between Planck and ME-MACS
Simulating the CC bias

Simulations updated from Eckert et al (2011) to reproduce CC-bias in a ME-MACS-like survey starting from a Planck-like sample

IDEA:
Assume that the population of clusters in the Universe follows the Planck c distribution.

Simulate the X-ray and SZ selection
Simulating the CC bias


Input CC frac: 29%
Output CC frac: 48%
Observed CC frac: 59%

Secondary CC peak in simulated distribution

The CC-bias plays a large role
Consistent results (I)

Andrade-Santos et al (2017)

Planck (ESZ): early catalogue, 164 obj. \(z<0.35\)

**VS**

X-ray: extended from Voevodkin & Vikhlinin (2004), 129 obj with \(f_x>7.5 \times 10^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\) in RASS, mostly \(z<0.2\)

**CC fraction:**

Planck (36 ±5)% vs X-ray (60±7)%

“Our X-ray flux limited sample, compared to approximately mass-limited SZ selected sample is over-represented with CC”
Lovisari et al (2017)
Planck (ESZ): early catalogue, 155 obj. z<0.55
VS
X-ray: REXCESS, z<0.2

KS test:
D=0.33 (w) and D=0.36 (c) -> p<0.01%

“In this paper, we confirmed that Planck-selected clusters tend to be morphologically more disturbed than their X-ray counterparts by using the centroid shift, which is more related to the dynamical state of the clusters than to their core properties”
Not so consistent results?

**Nurgaliev et al (2017):** Measure of the dynamical state with X-ray morphology indicators

**SPT (SZ-selected):** 91 clusters 0.25<z<1.2

**400sd (X ray-selected):** 36 clusters 0.35<z<0.9

“We find no evidence for a statistically significant difference in the X-ray morphologies of clusters selected via X-ray or SZ”
Not so consistent results?

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Measure of the dynamical state with X-ray morphology indicators

**SPT (SZ-selected):**
91 clusters $0.25 < z < 1.2$

**400sd (X ray-selected):**
36 clusters $0.35 < z < 0.9$

Planck ($0.3 < z < 0.6$) (25 +/- 8)%

SPT ($0.3 < z < 0.6$) (29 +/- 7)%
Nurgaliev et al (2017):  
Measure of the dynamical state with X-ray morphology indicators

**SPT (SZ-selected):**
91 clusters $0.25 < z < 1.2$

Planck(0.3-0.6) (25 +/- 8)%
SPT(0.3-0.6) (29 +/- 7)%

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36 clusters $0.35 < z < 0.9$

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Table in MR et al (2017), MNRAS 468, 1917
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**Nurgaliev et al (2017):**
Measure of the dynamical state with X-ray morphology indicators

**SPT (SZ-selected):**
- 91 clusters $0.25<z<1.2$
- Planck(0.3-0.6) $(25 \pm 8\%)$
- SPT(0.3-0.6) $(29 \pm 7\%)$

**Vikhlinin et al (2009):**
The only X-ray selected sample apparently unaffected by the CC-bias.

**NOT FLUX-LIMITED**
**But LUMINOSITY-LIMITED**

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Luminosity limited sample can be less affected by CC-bias (Vikhlinin et al 2009)

Chon & Bohringer (2017): comparison of a parent luminosity-limited sample with flux-limited subsamples

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<th>flux limit</th>
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<tr>
<td></td>
<td>VLS</td>
<td>FLS1</td>
</tr>
<tr>
<td>Non-CC</td>
<td>57</td>
<td>27</td>
</tr>
<tr>
<td>Cool core</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>93</strong></td>
<td><strong>51</strong></td>
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CC fraction 38% 47% 48%
Difference in the disturbed and CC fraction in Planck and most X-ray selected samples

CC bias plays a large role in this difference

Not all X-ray selections are the same

Present and future prospects

Many information on cluster properties have been based so far on X-ray selected samples. Now, we can have large SZ-selected samples.

Some results produced by the Chandra SPT Visionary Program (McDonald+ 14,15,17, Sanders+18, Chiu+ 17, ...)

$0.3 < z < 1.9$, most $2 < M < 5 \times 10^{14} M_{\odot}$
Present and future prospects

Planck may provide the complementary low-z and high-M
Some follow-up programs already providing results

Complete ESZ Chandra/XMM follow up
PSZ1-cosmo almost complete
Results on morphology published
Other results probably soon
Relatively short observations
Present and future prospects

An XMM-Newton Heritage Program:
Witnessing the culmination of structure formation in the Universe
PIs: M. Arnaud & S. Ettori

Steering group:

3 Ms awarded in XMM-Newton AO17 to be planned in 3 years
Complete sample of 118 objects
Exposures tailored for getting thermodynamic and mass profiles up to $R_{500}$
Present and future prospects

An XMM-Newton Heritage Program:
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**S/N >6.5**

**Tier 1:** the “recent” clusters population
0.05<0<0.2 (2<M<9 $10^{14}$ $M_{\odot}$)

**Tier 2:** the massive clusters population
M>7.25 $10^{14}$ $M_{\odot}$, z<0.6
Present and future prospects

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Results at next Snowcluster!

Thank you