GALAXY CLUSTER SEARCHES IN THE CFHTLS AND APPLICATIONS

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1) COSMOLOGICAL USE OF GALAXY CLUSTERS

Considering groups and clusters of galaxies as cosmological probes, two questions are still being asked:

- When did these structures form?
- Could they constrain cosmological models when they are consistently counted with redshift and mass?

Obviously, both questions point out the need for complete samples of clusters and groups.

2) HOW TO IDENTIFY THEM? PROS AND CONS

Physically, groups and clusters are deep gravitational potential wells containing dark matter (DM hereafter), hot gas, and galaxies. Each of these components could then be used to detect their parent host.

a) DM:
Usually sampled via (weak and strong) lensing studies\textsuperscript{1,2,3,4} since DM traces the mass directly. However, lensing detection is efficient up to $z$ that are not too high.

b) HOT GAS:
Detected in X-rays\textsuperscript{5}, it should probe gravitational wells without projection effects, but diffuse emissions are contaminated by line-of-sight stars or active galaxies.

The Sunyaev-Zeldovich technique works at any redshift, but in practice is limited for distant objects due to the lack of spatial resolution.

c) GALAXIES:
Spectroscopic redshift surveys probe directly the distance and dynamics but spatial sampling is partial and not homogeneous and high-redshift clusters are not probed well due to slits/fibers overlap problems.

Photometric catalogues provide homogeneous spatial coverage, but the contrast of structures decreases rapidly with distance with respect to the total background. Optimization is possible by using matching filter techniques\textsuperscript{6,7,8} and/or selecting galaxies on a (multiple) colour-basis\textsuperscript{11,12}. 
3) THE CFHTLS\textsuperscript{13}: AN OPTIMAL DATABASE FOR GALAXY CLUSTERS HUNT

1) The data: T004 Release (5 filters)

The Deep (80\% complete up to i\_AB = 26.0) and Wide (80\% complete up to i\_AB = 24.0) surveys explore respectively 4 and 171 deg\textsuperscript{2}.

The Wide fields are expected to contain 1000 to 5000 clusters up to z \sim 1, complemented by 50 to 200 up to z \sim 1.5 within the Deep.

This work used the parts of D2 + D3 + D4 and W1 + W3 + W4 where 5 colours (u*, g', r', i', z' T004) were available.

Photometric redshifts\textsuperscript{14} were computed using the Le Phare software\textsuperscript{15}.

For the Wide fields, at the limiting magnitude i' = 23 used, the redshift statistical error is \sim 0.043.

Deep fields have nearly constant redshift statistical errors of the order of 0.026 for i’ between 20.5 and 24.

Galaxies are selected in the range 0 \leq z \leq 1.5 for the Deep fields and 0 \leq z \leq 1.2 for the Wide fields.

2) The method: slicing space with photometric redshifts

Most of the detection methods usually used, make assumptions about cluster properties. Ideally a method that minimizes potential biases will be best suited for studies of galaxy clusters and cosmological tests.

Here we search for contrasts in numerical density maps of galaxies computed using Adaptive Kernel (AK)\textsuperscript{16,17}.

To eliminate fore and background contaminations as much as possible, they are built within redshift (distance) slices.

For each studied field galaxy catalogs are built in running slices of 0.1 in redshift displaced by 0.05.
Two clusters are detected at $S/N \geq 6$. Density maps of the D2 field for the $z = 0.65-0.75$ redshift bin. 

Multicolour image of a structure in D4 at $z \sim 0.4$. 

**4) EXAMPLES**
### 5) COMPARISON TO OTHER STUDIES

<table>
<thead>
<tr>
<th>Authors</th>
<th>Detection Method</th>
<th>Covered Area (deg²)</th>
<th>Number of Detections</th>
<th>Maximal Redshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work Deep (5 colours)</td>
<td>AK within photometric redshift slices accounting for masking</td>
<td>2.5</td>
<td>171</td>
<td>1.5</td>
</tr>
<tr>
<td>This work Wide 5 colours</td>
<td>AK within photometric redshift slices</td>
<td>28</td>
<td>1029</td>
<td>1.2</td>
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<tr>
<td>Olsen et al 2007</td>
<td>Matched filter</td>
<td>4</td>
<td>162</td>
<td>1.15</td>
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<td>Mazure et al 2007 D1</td>
<td>AK within photometric redshift slices accounting for masking</td>
<td>0.8</td>
<td>44</td>
<td>1.5</td>
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<tr>
<td>Cabanac et al 2007</td>
<td>Strong lensing</td>
<td>28</td>
<td>40</td>
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<tr>
<td>Limousin et al 2007</td>
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<td>0.85</td>
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<tr>
<td>Gavazzi &amp; Soucail 2007</td>
<td>Weak lensing</td>
<td>4</td>
<td>14</td>
<td>0.55</td>
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<tr>
<td>Bergé et al 2008</td>
<td>Weak lensing</td>
<td>4</td>
<td>7</td>
<td>0.5</td>
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<tr>
<td>Thanjavur et al 2009</td>
<td>K2 Method</td>
<td>161</td>
<td>~6000</td>
<td>0.8</td>
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<tr>
<td>Milkeraitis et al 2010</td>
<td>3D Matched Filter</td>
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<td>~700</td>
<td>1.0</td>
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<tr>
<td>Koester et al 2007</td>
<td>Max BCG</td>
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<td>~14000</td>
<td>0.3</td>
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</table>
6) ASSESSING THE METHOD: THE «MODIFIED MILLENIUM SIMULATIONS»

In order to assess our detection levels we applied the same method to a modified version of the Millenium numerical simulation\textsuperscript{18}

- Galaxy catalogues were produced using SAM prescriptions\textsuperscript{19} at the same magnitude cuts than the analyzed ones
- Magnitudes errors were injected in order to reproduce the observed ones
- Noise was added to the true redshifts in order to mimic the observed photometric redshift distribution

Detection rates are calibrated

For the Wide, false detection rates are basically null for S/N \( \geq 4 \) and remain small for S/N \( \leq 3 \) and \( z \leq 0.8 \).

For the Deep survey, false detection rates are small whatever the S/N for \( z \leq 1 \).

As a compromise between detection rate and false detection rate, only S/N \( \geq 2 \) are used.

S/N = 2 and 3 allows to include numerous real structures as well as to keep fake detections to a level < 10%.

Relation between S/N and minimal mass threshold
7) APPLICATIONS (I)

One application was the assessment of extended XMM_LSS sources as physical structures via an optical identification

1) We compare firstly our detections to the 15 XMM-LSS C1 sources contained within the W1 with $z > 0.1$

XMM-LSS C1 sources are by definition well extended and contamination-free X-ray sources

Ten of our detections are well identified with C1 emissions. The remaining ones are all affected by masked areas in optical data preventing from the obtention of a reliable signal.

An illustration of the masking problems caused by the presence of bright stars, haloes of bright galaxies and CCD defects. Green points correspond to these regions while red and blue squares correspond to XMM-LSS sources in D1

2) But except this question of masking, the detection of the C1 class is relatively easy as they appear as rather rich structures

More difficult and stringent is the detection of C2 sources which by definition could be 50% contaminated in X-rays and are also less rich structures than the C1 in optical

Among the 7 C2 present in the considered area, 4 are unambiguously identified up to $z = 1$. Among the missing, 2 have a small flux with large error bars and the 3rd one could be contaminated along the l.o.s both in X-ray and optical

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8) APPLICATIONS (II)

The CFHLS and extensions are optimal to find new clusters in the redshift range [0.3 - 0.9] which is also optimal for Weak Lensing Tomography with clusters (WLTC) by using HST images of a well defined cluster sample. A large multicolor survey is under process to complement the necessary data.

WLTC is a «weak lensing tomographic» approach in the direction of already known clusters of galaxies in order to increase the lensing signal.

The tomography technique uses signals from background galaxies located in different spatial slices defined using photometric redshifts.

The ratio of the shear for pairs of galaxies is then independent of the lens mass. Measured over a large number of background galaxies, this gives access to cosmological parameters.

9) CONCLUSIONS

The CFHLS is a unique multicolor and wide field database allowing in particular the obtention of precise photometric redshifts.

Use of a model-free analysis (an Adaptive Kernel method applied within spatial slices) calibrated on realistic numerical simulations, leads to detect about 1200 structures (minimal mass ~ \(10^{13} \, M_\odot\)).

The reliability of the method is assessed by the comparison to C1 and C2 XMM-LSS sources.

A cosmological application to WLTC is in progress.
### REFERENCES

10. Gladders & Yee 2005 APJS, 157, 1
11. Thanjavur et al 2009, APJ, 706, 571
20. Adami et al, submitted