The cosmological analysis of X-Ray cluster surveys: AspiX

Lorenzo Faccioli
Nicolas Clerc
Marguerite Pierre
Andrea Valotti
Context

• We want to derive cosmological constraints from X-Ray selected samples of galaxy clusters without the need for redshifts (time consuming to get), thus enabling a fast analysis

• We introduce a new method of analyzing cluster sample

• We are applying it on the XMM archive
The principle

- Use only **X-Ray signal variables**
- Top down: build synthetic **XDDs** (X-Ray Diagnostic Diagnostic Diagrams) from measured variables and compare with observed ones
- First implementation: **CR-HR** diagrams (Clerc et al 12a); applied on full XMM archive up to 2010 (Clerc et al 12b)
- Further developments: new variables, more accurate testing, application to larger datasets
The CR-HR distribution

[1-2] keV / [0.5-1] keV hardness ratio (HR)

Diagram computed for:
WMAP5 cosmology
C1 selection
Local cluster scaling laws
Self-similar evolution

100deg2

Clerc et al 12a
Non standard cosmology  Non self-similar evolution

Clerc et al 12
Adding redshifts

3rd dimension to the diagram

Clerc et al 12a
Adding redshifts (photo-z are sufficient)

**CR-HR-z VS**

**N(M, z)**

Clerc et al 12a
Analyzing the XMM archive

- Clerc et al 2012b: **XCLASS** catalogue
  - XMM archive up to May 2010
- **C1 selection**, based on X-Ray measured variables: yields a *high purity sample* (Pacaud et al. 2006)
- **850 C1 clusters** in XCLASS catalogue
- **347 high S/N C1 clusters** for cosmological analysis
- Constraints on $\sigma_8$, $\Omega_m$, and $X_c$
- **Analysis being extended to XMM archive up to August 2015**
The latest development

*Pierre, Valotti, Faccioli*

ASpiX

Work in progress
New features

- Four observables: \textbf{CR} - \textbf{HR} - \textbf{Rc} - \textbf{z}
- Toy model to
  - simulate cluster catalogues
  - test the impact of errors, scatters, area
- \textbf{Cash statistics} minimized via Nelder-Mead algorithm (Amoeba)
  - Test the impact of \textbf{Rc}
  - Search for possible degeneracies
  - Evaluate the method wrt to \textbf{dn/dM/dz}
Toy-model ingredients (1)

<table>
<thead>
<tr>
<th>Relation</th>
<th>Slope</th>
<th>Normalisation</th>
<th>Scatter</th>
<th>Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M - T$</td>
<td>$\alpha_{MT} = 1.49$</td>
<td>$A_{MT} = 10^{0.46}$</td>
<td>20%</td>
<td>$\gamma_{MT} = 0^*$</td>
</tr>
<tr>
<td>$M - L$</td>
<td>$\alpha_{ML} = 0.52$</td>
<td>$A_{ML} = 10^{0.25}$</td>
<td>50%</td>
<td>$\gamma_{ML} = 0^*$</td>
</tr>
<tr>
<td>$M - R_c$</td>
<td>3</td>
<td>$X_c = 0.24^*$</td>
<td>50%</td>
<td>none</td>
</tr>
</tbody>
</table>

Table 1. Numerical values adopted for the cluster scaling relations

An evolutionary parameter $\gamma$ of 0 implements the self-similar evolution hypothesis. The * indicates parameters that are possibly let free during the cosmological analysis.

Scaling laws from Arnaud et al. 2005
Pratt et al. 2009

$$
\frac{M_{200}}{10^{14}/h} = A_{MT} \times \left(\frac{T}{4}\right)^{\alpha_{MT}} \times E(z)^{-1}(1 + z)^{\gamma_{MT}}
$$

$$
\frac{M_{200}}{10^{14}/h} = A_{ML} \times \left(\frac{L}{10^{44}}\right)^{\alpha_{ML}} \times E(z)^{-1.5}(1 + z)^{\gamma_{ML}}
$$

$$
M_{500} = \frac{4}{3} \pi R_{500}^3 \quad X_c = \frac{R_c}{R_{500}}
$$

Pierre et al. 2016 to be submitted
Toy-model ingredients \( (2) \)

- Assumed errors on \( CR, HR, Rc \)
  Either 0 or log-normal 20%

- Assumed error on \( z \)
  0

Pierre et al. 2016 to be submitted
The C1 cluster population
10,000 deg2 M-z plane

C1 selection:
low contamination sample
Bona fide clusters

Pierre et al. 2016
to be submitted
Principle

Project the 2-D $dn/dM/dz$ population into the 4-D $CR-HR-Rc-z$ observed parameter space
The C1 cluster population
10,000 deg^2 - observable space

Pierre et al. 2016
to be submitted

*Integrated over z*
The C1 cluster population
10,000 deg² - observable space
adding error measurements

Pierre et al. 2016
to be submitted

Integrated over z
The C1 cluster population
100 deg2 - observable space
adding error measurements

CR-HR                    CR-Rc                    HR-Rc

Pierre et al. 2016
to be submitted

Integrated over z
The C1 cluster population
10,000 deg2-observable space

CR-Rc

redshift slices

Pierre et al. 2016 to be submitted
Principle of ASpiX

• Compute the likelihood (minimizing the \textit{Cash statistic}) of an observed \textit{XDD}, by comparison with a model
• Explore likelihood space with Amoeba
• Are there strong local minima? (degeneracy in the \textit{XDD} 4-D space)
• Launch 100 independent Amoeba runs with different starting points
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fiducial</th>
<th>Main</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_m$</td>
<td>0.23</td>
<td>X</td>
</tr>
<tr>
<td>$\sigma_8$</td>
<td>0.83</td>
<td>X</td>
</tr>
<tr>
<td>$X_c$</td>
<td>0.24</td>
<td>X</td>
</tr>
<tr>
<td>$\gamma_{ML}$</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>$\gamma_{MT}$</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>$w_o$</td>
<td>-1.00</td>
<td>X</td>
</tr>
<tr>
<td>$w_a$</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Pierre et al. 2016 to be submitted
**dn/dM/dz** 100 deg2, 50% error on mass as a reference case
Average over 10 deg2 catalogues

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_m$</td>
<td>0.24</td>
<td>0.02</td>
</tr>
<tr>
<td>$\sigma_8$</td>
<td>0.81</td>
<td>0.01</td>
</tr>
<tr>
<td>$\chi_c$</td>
<td>0.25</td>
<td>0.02</td>
</tr>
<tr>
<td>$w_0$</td>
<td>-1.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Caveat**

The ~500 clusters are supposed to have their mass measured at 50%, even those with 50 photons

Pierre et al. 2016

to be submitted
The reality

CR-HR-Rc-z

100 deg2

20% error on CR, HR, Rc
Average over 10x100 deg2 catalogues

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_m$</td>
<td>0.23</td>
<td>0.01</td>
</tr>
<tr>
<td>$\sigma_8$</td>
<td>0.82</td>
<td>0.01</td>
</tr>
<tr>
<td>$\chi_c$</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>$w_0$</td>
<td>-0.92</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Better performance than dn/dm/dz

Pierre et al. 2016
to be submitted
Lifting degeneracies

Degeneracy in $N(m,z)$ space resolved in $CR$-$HR$-$Rc$ space

Red: fiducial, black: $Xc$ 0.27 $\gamma MT$ 1.41 $vML$ -0.54 $w0$ -0.66 $wa$ -8.38

Pierre et al. 2016

to be submitted

Degeneracy in $N(m,z)$ space resolved in $CR$-$HR$-$Rc$ space
Summary of the current assumptions

• Scaling relations known
• Evolution self-similar
• Scatter values in the scaling relations:
  – known
  – independent
• Selection perfectly monitored
• In the future we will explore the method under more realistic assumptions
Future plans: test on more realistic simulations

- Test on the *Aardvark N body (Farahi et al 16) simulations* painted with a $\beta=2/3$ model (Valotti et al. in preparation)

- Test on *Cosmo OWLS hydrodynamical simulations (LeBrun et al 14)* (Faccioli et al. in preparation)
  - cluster irregular shapes
  - physical modelling of the AGN
Future plans: apply AspiX to real data

• **CR-HR** method with *photo-z* applied to XCLASS sample (Ridl et al., in preparation; see also J. Ridl talk, this afternoon)

• Apply ASpiX to the *expanded XCLASS sample* (includes all XMM pointings from 2000 to August 2015); pointings already reprocessed and being analyzed

• Apply ASpix on the *full XXL sample*
Supplementary slides
Doing cluster cosmology without masses
Cosmology ($\Lambda$CDM,...)

\[ \frac{dn}{dM \, dz \, d\Omega} \]

Scaling laws

\[ \frac{dn}{dz \, dT \, dL \, d\Omega} \]

X-ray observables (count-rates)

X-ray selection function

RAW X-ray fluxes & colours

X-ray observables: Count-rates in given bands and errors ICM spectrum

Clerc et al 12a

\[ \frac{dn}{dCR \, dHR} \]

\[ \chi^2 \]
New developments on the HR-CR method: ASpiX

Lorenzo Faccioli
Nicolas Clerc
Marguerite Pierre
Andrea Valotti
Reminder – Clerc et al 2012
Cosmology (\(\Lambda CDM, \ldots\) )

\[
\frac{dn}{dM \ dz \ d\Omega}
\]

X-ray observables:
- Count-rates in given bands and errors
- ICM spectrum
- +redshifts

Estimated mass distribution

Selection effects
- \(M(z)\)?

Scaling laws, HE
- Individual masses

\(T_X, M_{\text{gas}}(r), Y_X\)

X-ray observables:
- Count-rates in given bands and errors
- ICM spectrum

Clerc et al 12
• CR in [0.5-2] keV
• HR = [1-2]/[0.5-1] ~ Magnitude
• HR = [1-2]/[0.5-1] ~ Colour

Clerc et al 12
Non standard cosmology  Non self-similar evolution

Clerc et al 12
1) CR/HR vs \( \frac{dn}{dz} \)

Does not need redshifts!

Clerc et al. 12
Example: $Xc-W_0$ likelihood plane from the CR-HR-Rc space
Take $\frac{dn}{dM/dz}$, 10,000 deg2, no error on mass as a reference case
<table>
<thead>
<tr>
<th>JLS v1.1</th>
<th>dndzm</th>
<th>20 best LH</th>
<th>10 best LH</th>
<th>best LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega_m</td>
<td>0.2296</td>
<td>+/- 0.0003</td>
<td>0.2295</td>
<td>+/- 0.0002</td>
</tr>
<tr>
<td>Slgma8</td>
<td>0.8305</td>
<td>+/- 0.0004</td>
<td>0.8305</td>
<td>+/- 0.0003</td>
</tr>
<tr>
<td>Xc_0</td>
<td>0.2386</td>
<td>+/- 0.0006</td>
<td>0.2386</td>
<td>+/- 0.0005</td>
</tr>
<tr>
<td>W0</td>
<td>-0.9963</td>
<td>+/- 0.0023</td>
<td>-0.9962</td>
<td>+/- 0.0018</td>
</tr>
</tbody>
</table>
One catalogue

- $\Omega_m$: Distribution of values ranging from 0.21 to 0.25.
- $\sigma_8$: Distribution of values ranging from 0.75 to 0.90.
- $x_c_0$: Distribution of values ranging from 0.22 to 0.26.
- $w_0$: Distribution of values ranging from -1.10 to -0.95.
### One 100 deg2 catalogue

<table>
<thead>
<tr>
<th>JLS_v1.1</th>
<th>dndzdm + error</th>
<th>20 best LH</th>
<th>10 best LH</th>
<th>best LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega_m</td>
<td>0.2278 ± 0.0008</td>
<td>0.2274 ± 0.0007</td>
<td>0.2276</td>
<td></td>
</tr>
<tr>
<td>Sigma8</td>
<td>0.8221 ± 0.0007</td>
<td>0.8222 ± 0.0007</td>
<td>0.8219</td>
<td></td>
</tr>
<tr>
<td>Xc_0</td>
<td>0.2373 ± 0.0010</td>
<td>0.2271 ± 0.0009</td>
<td>0.2377</td>
<td></td>
</tr>
<tr>
<td>W0</td>
<td>-0.9386 ± 0.0036</td>
<td>-0.9364 ± 0.0026</td>
<td>-0.9330</td>
<td></td>
</tr>
</tbody>
</table>

### Average over 10x100 deg2 catalogues

<table>
<thead>
<tr>
<th>JLS_v1.1</th>
<th>dndzdm</th>
<th>mean (2–10 best LH)</th>
<th>mean error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega_m</td>
<td>0.2399 ± 0.0178</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sigma8</td>
<td>0.8102 ± 0.0099</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xc_0</td>
<td>0.2479 ± 0.0234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W0</td>
<td>-0.9989 ± 0.1089</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
One 100 deg2 catalogue

<table>
<thead>
<tr>
<th>JLS_v1.1</th>
<th>JLS_v1.1 dndzdm + error</th>
<th>20 best LH</th>
<th>10 best LH</th>
<th>best LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega_m</td>
<td>0.2278</td>
<td>+/- 0.0008</td>
<td>0.2274</td>
<td>+/- 0.0007</td>
</tr>
<tr>
<td>Sigma8</td>
<td>0.8221</td>
<td>+/- 0.0007</td>
<td>0.8222</td>
<td>+/- 0.0007</td>
</tr>
<tr>
<td>Xc_0</td>
<td>0.2373</td>
<td>+/- 0.0010</td>
<td>0.2271</td>
<td>+/- 0.0009</td>
</tr>
<tr>
<td>W0</td>
<td>-0.9386</td>
<td>+/- 0.0036</td>
<td>-0.9364</td>
<td>+/- 0.0026</td>
</tr>
</tbody>
</table>

Average over 10x100 deg2 catalogues

<table>
<thead>
<tr>
<th>JLS_v1.1</th>
<th>dndcrdhrdrcore</th>
<th>mean (1–10 best LH)</th>
<th>+/- 0.0091</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega_m</td>
<td>0.2295</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sigma8</td>
<td>0.8150</td>
<td></td>
<td>+/- 0.0113</td>
</tr>
<tr>
<td>Xc_0</td>
<td>0.2440</td>
<td></td>
<td>+/- 0.0043</td>
</tr>
<tr>
<td>W0</td>
<td>-0.9161</td>
<td></td>
<td>+/- 0.0736</td>
</tr>
</tbody>
</table>
Preliminary conclusions

• Current accuracy predicted for 100 deg\(^2\):
  – \(\Omega_m\) \(\sim 5\%\)
  – \(\sigma_8\) \(\sim 2\%\)
  – \(X_c\) \(< 1\%\)
  – \(w_0\) \(\sim 8\%\)

NB: There is some Amoeba imprint in these estimates

\(\Rightarrow\) Slightly better than \(dn/dM/dz\) with 50% mass error!

Sample variance not taken into account