High redshift clusters and their evolution

M. Arnaud (CEA-Sap Saclay France)
• Primordial fluctuations (DM) that growth under the influence of gravity
  ⇒ the cosmic ‘web’: Voids, Filaments, Blobs: The clusters of galaxies

• Hierarchical clustering:
  clusters: forming/growing since $z \sim 2$ till now by merger/accretion along LS filaments

• The cluster population is an evolving population
  ⇒ test of structure formation scenario \textit{(Dark Matter and Gas)}
  ⇒ constrain the cosmological parameters
Clusters do exist up to high $z$

Stanford et al, 06

XMMXCS J2215.9-1738 @ $z=1.45$

The most distant (confirmed) cluster

$T \sim 7$ keV
High $z (> 0.5)$ clusters:

more substructures dynamically younger

as expected in hierarchical scenario

See also Hashimoto et al, 07; Maughan et al, 08
Evolution of (cooling) core

0.7<z<1.4

Santos et al, 08
See also Vikhlinin et al, 06

No strong CC

Likely related to higher merger rate & lower $t_H$ vs $t_{cool}$
The evolution of scaling properties

as compared to the self-similar model
The dark matter

$\Lambda$CDM simulations of structure formation:
Universal $\rho/\rho_c(z)$ cuspy profiles

Universal profile shape as expected from simulations

XMM/Chandra: precise mass profiles from $kT(r) - n(r)$ and HE (relaxed clusters)
The dark matter profile evolution

Smaller evolution?

or an artefact of steeper c-M?

Still large uncertainties (e.g. from T(r) mapped up to 0.3R_{200} only)

Evolution study just starting …
Gas scaling properties

- Standard self similar model
  ICM evolving in the gravitational potential of the DM
  - universal gas profiles as for the DM
  - scaling laws from
    1) \( \frac{GM}{R^3} = \langle \rho \rangle = \delta \rho_c(z) = \delta h^2(z); \delta \sim 500-200 \)
    2) The virial theorem: \( kT \propto GM/R \)
       e.g. \( M \propto h^3(z) T^{3/2} \); \( L_x \propto h(z) T^2 \)

- Observation local clusters: ‘modified’ self-similarity
  effect of non gravitat. processes:
  cooling and/or AGN/SN heating

- Interest of evolution study:
  understand physics of structure formation
  empirical X-M laws when using clusters for cosmology
The challenge of evolution studies (1)

An illustration: the *most studied* $L_X$-T

- expected: $L(T,z) = L(T,0) \ [h(z) (1+z)^{0.6-0.9} ]$
- observed: no consensus
  - larger: $(1+z)^{1.8\pm0.3}$ [Kotov & Vikhlinin, 05]
  - smaller: $h(z) (1+z)^{-1.04\pm0.3}$ [Ettori et al 04]
- larger or smaller depending on $z$?

![Diagram](image)

$\frac{L_{\text{obs}}}{L(T,0)}$

Fit without selection effects

Self-similar

No evolution

Fit with selection effects

and must take into account Malmquist bias:

$\Rightarrow$ evolution as expected?
The challenge of evolution studies (2)

• Expected ‘standard’ evolution is not large: \( h(z) \geq 30\% \) @ \( z=0.5 \) for \( \Lambda CDM \)
  \[ \Rightarrow \text{High precision required to measure deviations from standard model} \]

• Decreasing systematics is the main issue

• Recent progresses from:
  - archival Chandra/XMM studies
    \[ \Rightarrow \text{(now) large samples covering } 0.2 < z < 1 \]
    \[ \Rightarrow \text{quantities derived from same instrument and with same method/definition} \]
    \[ 10\% \text{ syst on } T_X \text{ due to cross-calibration} \equiv 30\% \text{ syst on } L_X \equiv \text{standard evolution} \]
  
  - better estimate of ‘virial’ radius \( R_{500} \)
    - need to compare quantities @ various \( z \) within given fraction of \( R_{500} \)
    - use (now better understood/calibrated) mass-proxy relations rather than HE eq.
    specially for unrelaxed clusters and too poor stat. data

• More (on going) progresses from dedicated LP on ‘unbiaised’ cluster samples
  including at \( z \sim 0 \)
The (fundamental) mass-proxy relations

not only for $R_v$ but also to compare observ. with theory ($N(M,z); \gasprop$ versus $M$)

Precise converging calibration of the local M-T and M-$Y_X$ relations
(normalisations differ from pure grav. models)
The mass-proxy relations: evolution

Mass at high $z$ from HE and spatially resolved $kT$ profiles

$$M_{500} = h(z)^{1.02 \pm 0.20} T^{3/2}$$
XLSSJ022403.9  $z=1.05$

(likely) up to $z \sim 1$
The gas properties - $Y_X$ relations

Archival Chandra data $0.1<z<1.3$

$L_X[(0.15-1)R_{500}]$ with $R_{500}$ from $M-Y_X$

Scatter 3 lower for $L_X$ with core excluded $\Rightarrow$ $L_X$ also a ‘good’ mass proxy

Standard evolution
The gas properties - $T_X$ relations

$O'Hara, Mohr & Sanderson, 08$

$X(T,z)/E(z)X(T,0)$

$R_{500-2500}$ from $h(z)R-T$ calibrated at $z=0$; assume slope indpt $z$

Less evolution than in standard model

consistent with $f_{\text{gas}} \equiv (1+z)^{-0.39\pm0.13}$

more consistent with SSM when core excluded (CC evolution)
Evolution from representative cluster samples

**REXCESS XMM-LP**

31 clusters  
0.05 < z < 0.2

Böhringer et al, 2007

**distant cluster XMM-LP (PI: MA)**

20 clusters, 0.4 < z < 0.6

ACDM (Ω=0.3, Λ=0.7)

Pratt et al, 07; Croston et al, 08

Selected in log(Lx) bin

⇒ ‘unbiased’
⇒ good coverage of 2-10 keV range ⇒ slope evolution
Evolution from representative cluster samples (cont)

Böhringer et al, 2007

REXCESS

0.4 < z < 0.6 sample

Arnaud, Jetha, Pointecouteau, Pratt, Bohringer et.al
Evolution from representative cluster samples (cont)

REXCESS: adapted from Croston et al, 08
Distant sample: Pointecouteau et al in prep

(Slight) departure from Standard evolution

\[ R_{500} \text{ from } h(z)^{2/5} M_{500} - Y_X \]
More on baryon physics

First evidence of significant decrease of Fe abundance with $z$

Might be due to progressive sinking of low entropy gas enriched at high $z$  (Cora et al, 06)

Balestra et al, 07; see also Maughan et al, 08
Cosmology with clusters and cluster surveys
**Cosmology from gas mass fraction**

**Principle:**

\[ f_{\text{gas}} \left(1 + \frac{f_{\text{gal}}}{f_{\text{gas}}}\right) = \frac{\Omega_b}{\Omega_m} \]

Normalisation \( \Rightarrow \Omega_m \)
Distance indicator (as SNI) \( \Rightarrow \Omega_m \Omega_\Lambda w \)

*Allen et al, 08*
Evolution of the mass function

Chandra follow-up of flux limited RASS and 400SD (sub)samples

M and $L_x - M$ (selection function) from precise mass-proxy relations with correction of Malquist bias

Evolution as expected in concordance cosmology

Vikhlinin et al, 08
New (XMM) cluster surveys (1)

COSMOS

XMM-LP:
72 cluster/groups up to z=1.25

Probe evolution of the faint end of XLF

No significant evolution up to z=1.3

Consistent COSMOS and XMMLSS (Pacaud et al, 07) results
New (XMM) cluster surveys (2)

XCS: serendipitous survey from XMM archive

- Area 500 deg$^2$
- Clusters (> 500 cts $\Rightarrow$ $kT$): 250-700 (124 with $z$ so far))
- Measure $\Omega_m$ and $\sigma_8$ to $\sim$5% accuracy
- Evolution of scaling relations: first results see Llyod-Davies talk
Prospects with SZ (Planck) surveys
combined with XMM follow-up
Gain from SZ surveying

\[ \Delta i_v \propto y \propto \int_{\text{los}} n_e T \, dl \]

no \((1+z)^4\) dimming

\[ Y = \int d\Omega \frac{M_{\text{gaz}} T}{D_A^2(z)} \]

gas thermal energy

\[ Y = y_d \]

Closely related to the mass

Motl et al, 05

Bonamente et al, 08

\[ Y_x (\text{keV} M_\odot) \]

\[ t \]

\[ t \]

\[ t \]

\[ t \]
Planck SZ survey

![Planck SZ Mass Limit](image)

Planck: all-sky VOLUME

\[ Y > 6 \times 10^{-4} \text{arcmin}^2 \]

SPT: 4000 deg² DEPTH

\[ Y > 10^{-4} \text{arcmin}^2 \]

Planck \(|b|>15\) deg Fiducial Model

![Planck SZ Differential Redshift Distribution](image)

Courtesy of A. Chamballu & J. Barlett; See also Bartlett et al, AN, 08

Close to mass selected survey
Efficient at high \(z\)
Planck SZ survey (cont)

~50-fold increase in sample size of massive clusters

Pt-source approx

N \sim 200
z > 0.6
kT > 6 \text{ keV}

N \sim 10
@ z > 1

Matched filters

Courtesy of A. Chamballu, J. Barlett & J. B. Melin
X-ray bright clusters: \( S_{X}[0.5-2] \) keV > 10\(^{-13}\) cgs kT with 10% errors and kT profiles with 25-70 ks XMM per cluster

⇒ Cosmology from \( f_{\text{gas}} \) and \( N(Y_{\text{SZ}}, z) \) with well calibrated \( M - Y_{\text{SZ}} \)

⇒ Full test of DM collapse models
CONCLUSION

Significant progress in the determination of the evolution of cluster properties (decrease of systematical errors).

Mass - (new) proxy relations evolve as in standard model
   => good new for cosmology using clusters
   => Still need to improve constrains on DM properties

Slight but significant deviations observed in gas scaling (Mg-T, Lx-T) relations.
   => new constrains on non grav effects models
   => Need to study the entropy evolution

Evolution of N(M,z) now established and extension of N(Lx,z) to low mass
   => more expected from XCS survey

Major step forward expected by combining XMM with forthcoming Planck data