MASS ESTIMATES IN INTERMEDIATE REDSHIFTS CLUSTERS OF GALAXIES

Gaël FOËX
Laboratoire d’Astrophysique de Toulouse Tarbes
Université Paul Sabatier

in collaboration with
SOUCAIL G., LIMOUSIN M., RICHARD J.
POINTECOUTEAU E., ARNAUD M. & PRATT G.W.
galaxy clusters = cosmological tool: mass function, matter power spectrum to be combined with other rulers such as SN, CMB, BAO, ...

requires large number of clusters with a mass estimate

use scaling relations (e.g. M-T, M-Lx, M-richness, ...)

find and calibrate the ‘best’ mass estimator (most secure, fastest)

take a representative sample of clusters, determine their masses with different and uncorrelated direct mass measurements

done for the local universe (e.g. with REXCESS sample)
do the same at higher redshifts (→ put constraints on their evolution)
**HOW TO FIND THE TOTAL MASS**

**X-rays**

- Measure of the surface brightness $S_x$ → $EM = f(n_e)$ → gas density
- Temperature profile (X-rays spectro.)
- HE & spherical symmetry

\[
M(r) = - \frac{kT r}{G \mu m_p} \left[ \frac{d \ln n}{d \ln r} + \frac{d \ln T}{d \ln r} \right]
\]

**Lensing**

- Measure of the shape of background galaxies → distortions = function of the gravitational potential
- → total (projected) mass

Compare and combine the 2 methods

Calibrate at high $z$ the scaling laws, $M-T, M-L_X, M-N_{200}, M-L_{200}, ...$
XMM-Newton Large Programme (P.I. M. Arnaud)

unbiased, flux limited sample

20 clusters

2.5 keV < kT < 12 keV

0.4 < z < 0.6

good sampling of Lx

total exposure time ~ 1.1 Msec

defined as the REXCESS = representative sample at z<0.15 → evolution with z

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Megacam @ CFHT
(Pi. G. Soucail)

11 brightest clusters
(Lx>3.10^{44} \text{ erg/s})

4 bands:
- g' (1.6ksec)
- r' (7.2ksec)
- i' (1.2ksec)
- z' (1.8ksec)

- homogeneous obs.
- good seeing (< 0.8'' for r’)
- low m_c (~ 26 for r’)

weak lensing on the r’ band

\rightarrow \text{photo-z’s}
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\rightarrow \text{photo-z's}
observer + deflector + background source

distorsions = f(positions, deflector mass)

need the ‘true’ shape, measure the ‘lensed’
shape, estimate the distances → mass

galaxy-cluster lensing:

source/image relation: $e = \frac{e^{(s)} + g}{1 + g^*e^{(s)}}$ with reduced shear $g = \frac{\gamma}{1 - \kappa}$ → shear

here:

low density regime ($\kappa \ll 1$, outskirts → no info. for the cluster center) : weak lensing

$g(z,M) \sim \gamma(z,M) = f(z_{\text{lens}}, z_{\text{source}}).f(M)$

$e^{(s)} = ?$ → stat. approach: $<e^{(s)}> = 0 \rightarrow <e> = g \rightarrow \text{mass}$
observer + deflector + background source

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GOING TO HIGH REDSHIFTS

catalogue of sources : compromise purity/density

★ signal = shape of background galaxies → remove foreground & cluster members

★ stat. approach = need large number of sources (> 10 gal./arcmin²)

clusters @ low z : mag (foreground) + color (cluster members) cuts
clusters @ high z : need more info. → photo-z’s (HyperZ code)

precise photo-z’s are challenging to obtain
BUT the integrated P(z) is a robust estimator to say if z<z_{cluster} or z>z_{cluster}

find the best δz and P_{sup} in

\[ P_{sup} = \int_{z_{cluster}+\delta z}^{z_{max}} p(z)dz \]

that give the highest purity and density

\[ P_{sup}=85\% \]
\[ \delta z=0.1 \]
geometry : $n(z) = \ ?$

we measure $\langle e \rangle = \langle g(z,M) \rangle \sim \langle \gamma(z,M) \rangle \propto \langle D_{ls}/D_{s} \rangle$

$\langle D_{ls}/D_{s} \rangle$ averaged over the redshifts distribution of the lensed galaxies

clusters @ low $z$ : $D_{ls}/D_{s} \sim C^{ste}$
\( \rightarrow \) take $D_{ls}/D_{s}$ for $\langle z \rangle \sim 1$

clusters @ high $z$ : $D_{ls}/D_{s} \neq C^{ste}!$
\( \rightarrow \) have to integrate $D_{ls}/D_{s}$ over $n(z)$

photo-z's not good enough to estimate $n(z)$ \( \rightarrow \) use a well calibrated catalogue (e.g. CFHTLS Deep fields), apply the same selection criteria to have similar $n(z)$ and determine $\langle D_{ls}/D_{s} \rangle$
**ERROR ESTIMATION**

**sources of uncertainties:**

- **shape measurements**
  - bias calibration in the shear measurement ➔ correction estimate with simus (STEP)

- **contamination**
  - photo-z’s simu. (i.e. \( n(m,z) + \text{mag theo.} + \text{noise} \)) ➔ contamination \( \sim 5\text{-}10\% \) with the best \( P_{\text{sup}} \)
  ➔ underestimate of the mass by a few \% only

depends on cluster redshifts and data quality
spatial resolution

shear profile $g(r)$ averaged in annulii

bin with $\theta = 75''$
$\sim 450$ kpc @ $z=0.5$

+ increasing err. towards the center
(WL approx., low $n_{\text{gal/bin}}$)

↓

no reliable info. on the concentration

Need other data (SL, X) to constrain the center and decrease error bars
For each cluster:

Fit analytical model
➔ Navarro-Frenk-White, \( f(\delta_c, r_s) = f(m_{200}, c) \) (derived from DM numerical simus.)

on the measured Xrays mass profile (from XMM data) ➔ \( m_{200} \) and \( c \)

on the measured shear profile ➔ \( m_{200}, c \) fixed (=4) from \( c(m_{200}) \)

(Duffy et al. 08)

fit using basic chi2 minimization

easy to combine the 2 data sets (sum of the chi2)
similar total masses: \( \langle (m_{200}, c=4)/(m_{200}, c<8) \rangle = 0.95 \pm 0.14 \)

smaller errors bars: \( \langle (err \ c=4)/(err \ c<8) \rangle = 0.85 \pm 0.1 \)
RESULTS II : lensing VS Xrays

differences X/WL :

- HE hypothesis
- T profile (only few points)
- spherical symmetry
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- LSS
- contaminated catalogue
- wrong estimation of the shear scaling
- poor detection (stars, seeing, low density, ...)

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differences $X/WL$ ? :

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RESULT II : lensing VS Xrays

~ same scatter at lower z (black points : Dahle06+Bardeau07, lower z)

D06+B07 : $<M_{wl}/M_x> = 1.25 \pm 0.45$ (25 clusters)

this work : $<M_{wl}/M_x> = 1.28 \pm 0.8$ (including ‘bad’ clusters)
RESULTS III : Xrays+lensing

\[ \langle M_{X+WL}/M_X \rangle = 0.97 +/- 0.27 \]
\[ \langle \text{err}_{X+WL}/\text{err}_X \rangle = 1.02 +/- 0.48 \]

\[ \langle M_{X+WL}/M_{WL} \rangle = 0.98 +/- 0.53 \]
\[ \langle \text{err}_{X+WL}/\text{err}_{WL} \rangle = 0.66 +/- 0.28 \]

essentially driven by X-rays m(r) (smaller errors bars than g(r))

better correlations, smaller errors for the lensing estimates
SUMMARY

weak lensing / X-rays / joint analysis of 11 clusters within 0.4 < z < 0.6

- contamination by foreground galaxies (= large fraction at these z)
- low density of background galaxies (= low detection, e.g. few sigma)
- need other data (X-rays, SL) to explore the clusters center

BUT

the quality of our WL masses @ high z is comparable with other works @ low z

the high quality XMM data give better constraints than WL

BUT

X-rays (XMM) data are more expensive!

WL alone can be used to calibrate scaling law + better to combine data sets