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XXL

The ultimate XMM extragalactic survey

die Kunst über in der Wissenschaft

The XXL survey: The 100 brightest galaxy clusters

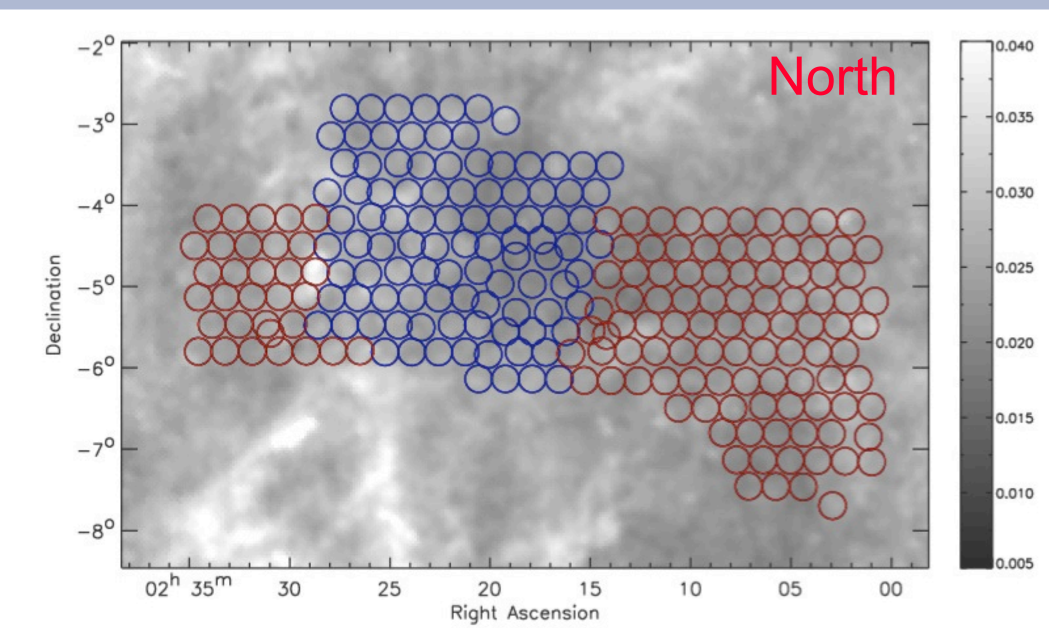
F. Pacaud
University of Bonn
on behalf of the XXL collaboration

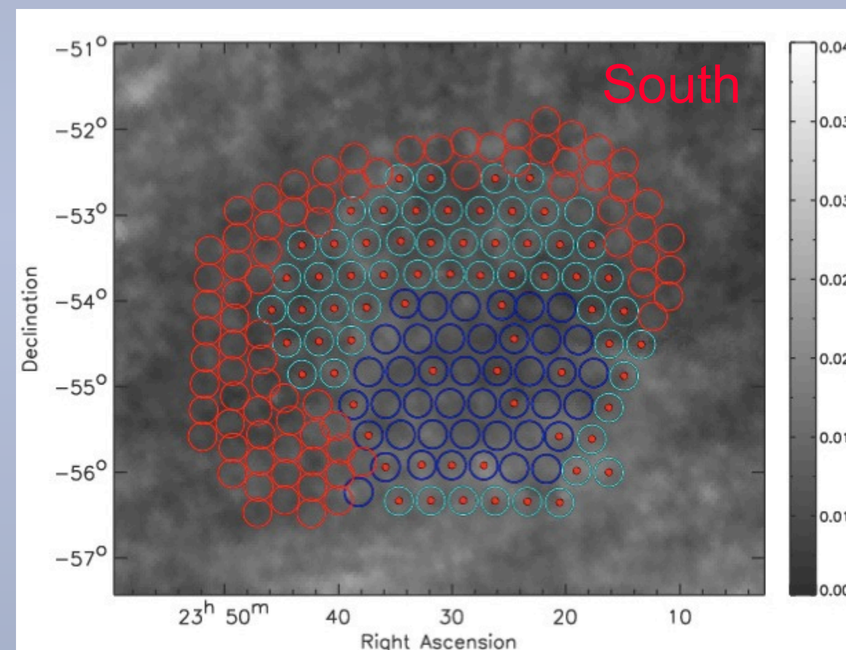
Main collaborators:
P. Giles, M. Lieu, C. Adami, N. Clerc, B. Maughan, M. Pierre, G. P. Smith

The XXL Survey

XMM survey based on a 2.9Ms VLP by M. Pierre (CEA/SAp)

- 2x25 deg^2 at high galactic latitude
- 10ks XMM exposure time (~6Ms in total)
- ~ 500 galaxy clusters and groups and 25000 AGNs





Rationale:
dark energy EoS with cluster counts and ξ (+ Planck CMB)
ξ improves constraints on w_0/w_a by a factor 2 (Pierre, Pacaud et al. 2011)

Paper I: Pierre, Pacaud, et al. (2016)

Associated multi-λ projects

- **Equatorial field (LSS) 25 deg^2**

– CFHTLS, HSC	optical
– VISTA/VIDEO	NIR survey 4.5 deg^2
– UKIDSS	NIR 9 deg^2
– WIRCAM	shallow K survey
– Spizter	MIR
– Herschel-*spire*	FIR 9 deg^2
– ACTpol deep	SZ survey
– CARMA, AMiBA	SZ follow-up

Southern field (BCS) 25 deg^2

BCS, DEcam	optical
VISTA/VHS	NIR
Spitzer/SSDF	MIR
Herschel-*spire*	FIR
ACT, SPTpol	SZ
ATCA	Radio (1.4GHz)

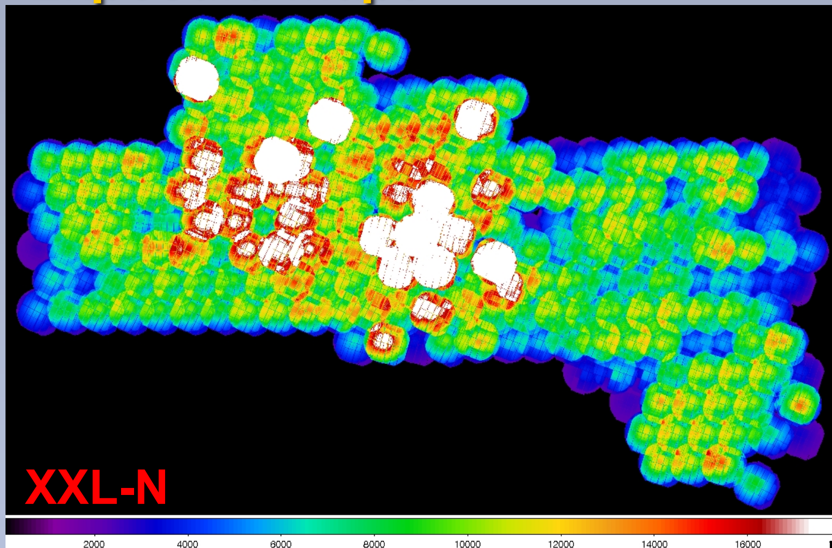
- **Optical spectroscopy**
  - ✧ ESO large program (VLT/FORS2 + NTT/EFOSC2) for cluster follow-up
  - ✧ Anglo-Australian Telescope/2DF survey of X-ray sources in the south
  - ✧ Access to spectra from the GAMA / VIPERS surveys
  - ✧ Smaller individual proposals:
    - William Herschel Telescope,
    - Large Binocular Telescope, …

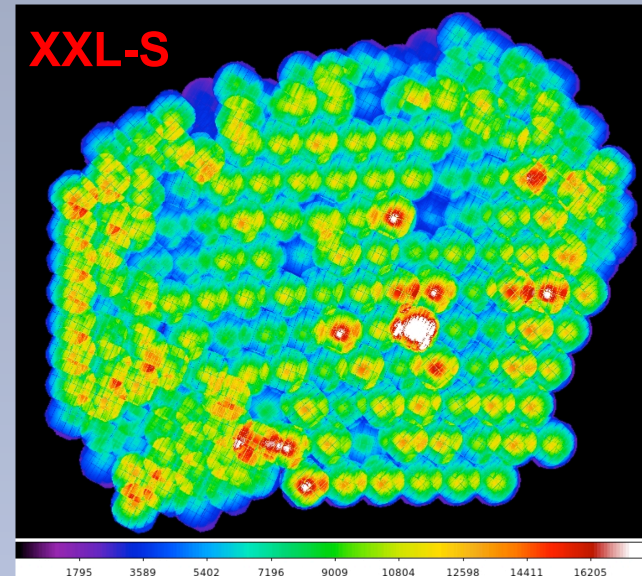
More information on the XXL associated datasets wiki : http://lenssearch.pbworks.com

Paper I: Pierre, Pacaud, et al. (2016)

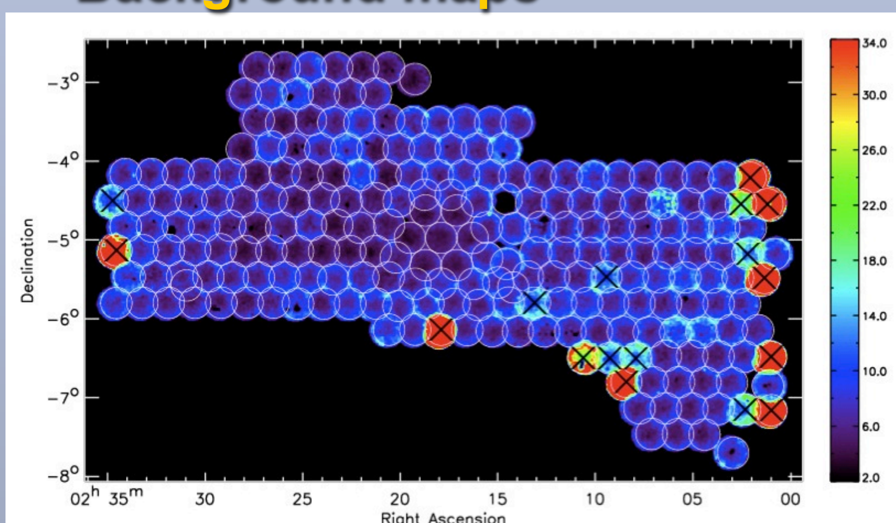
The XXL Survey: data quality

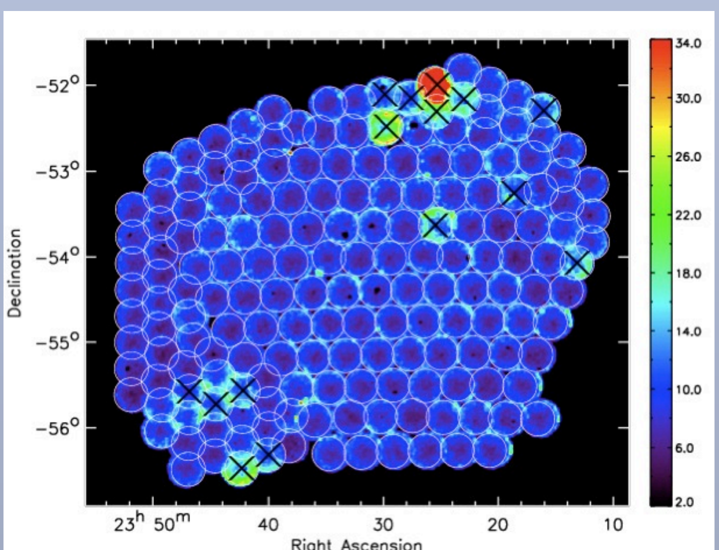
Exposure maps





Background maps

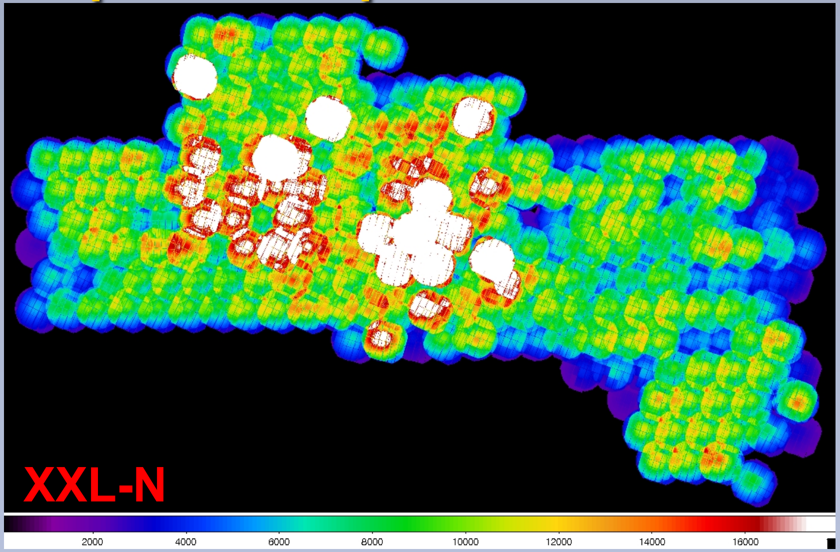


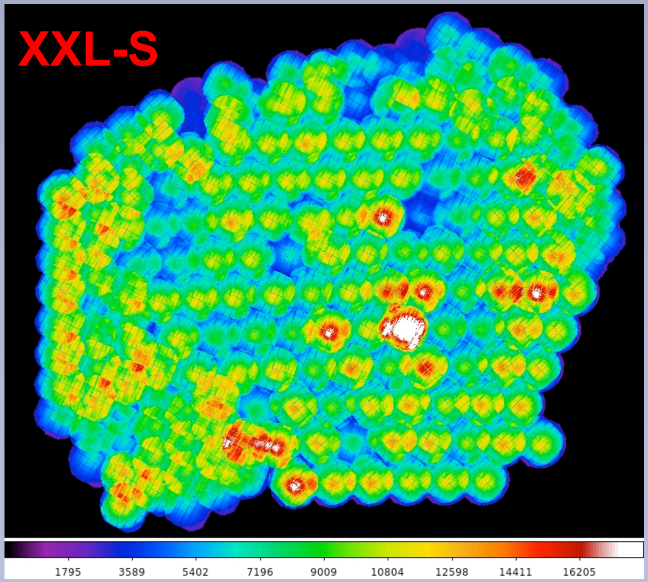


Paper I: Pierre, Pacaud, et al. (2016)

The XXL Survey: data quality

Exposure maps





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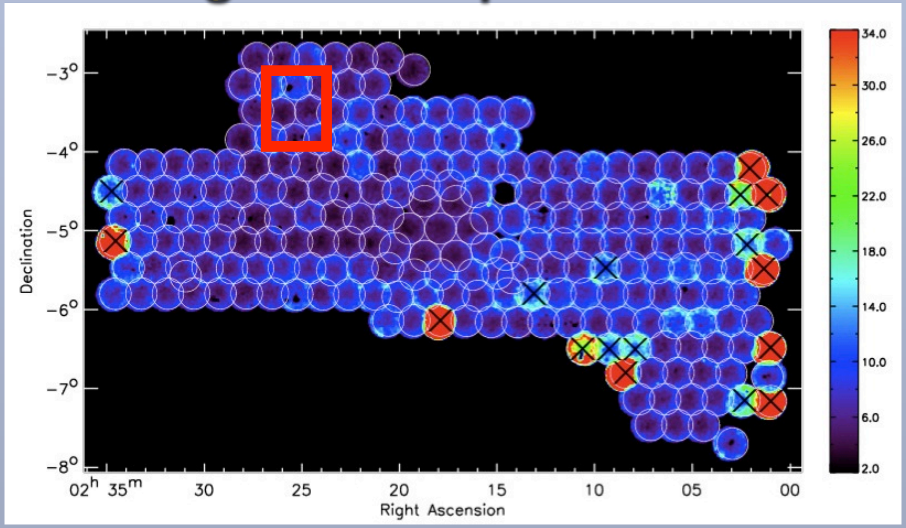
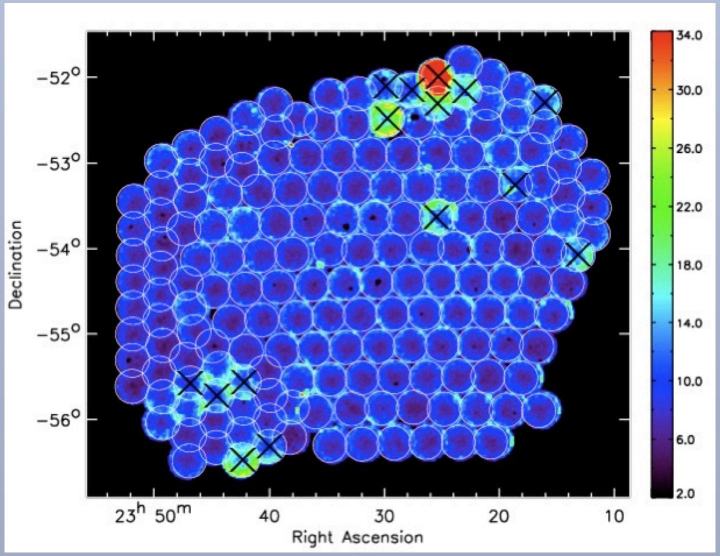
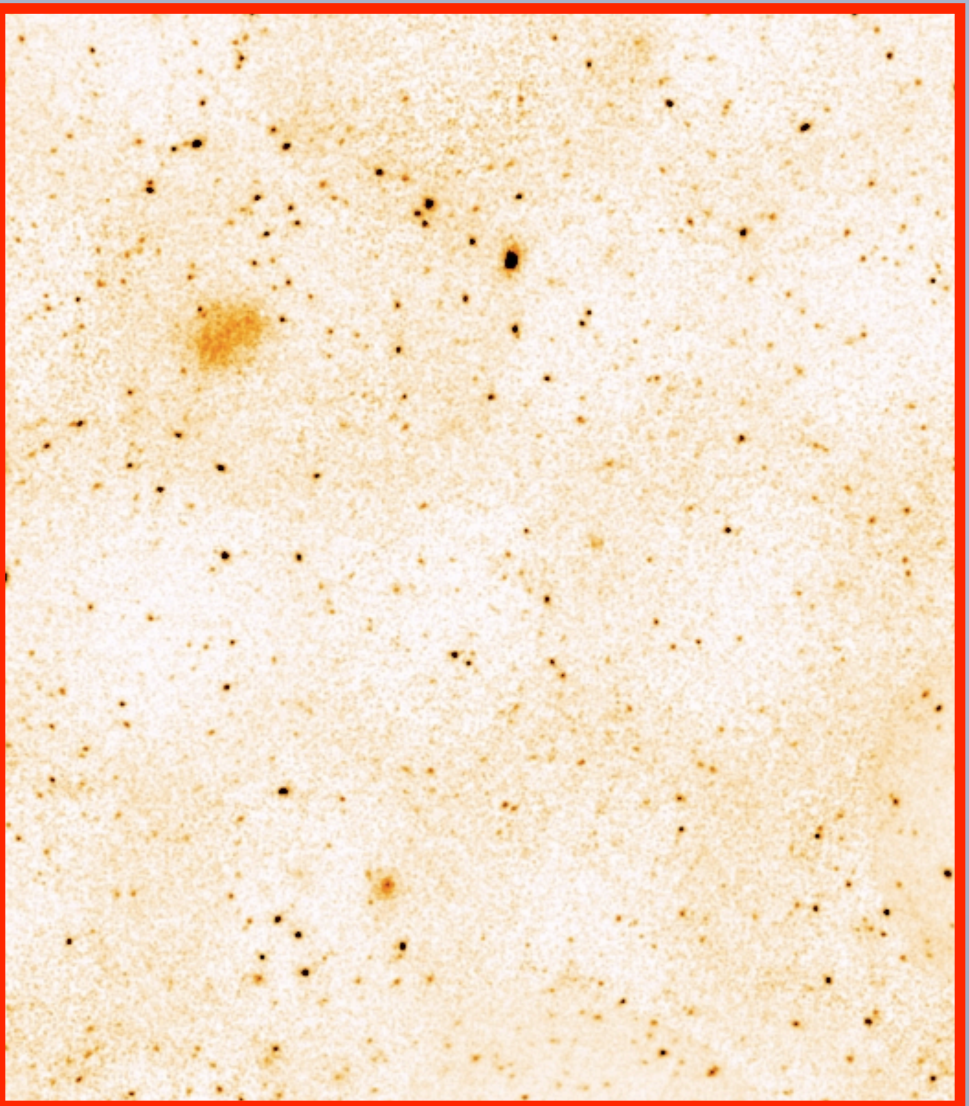


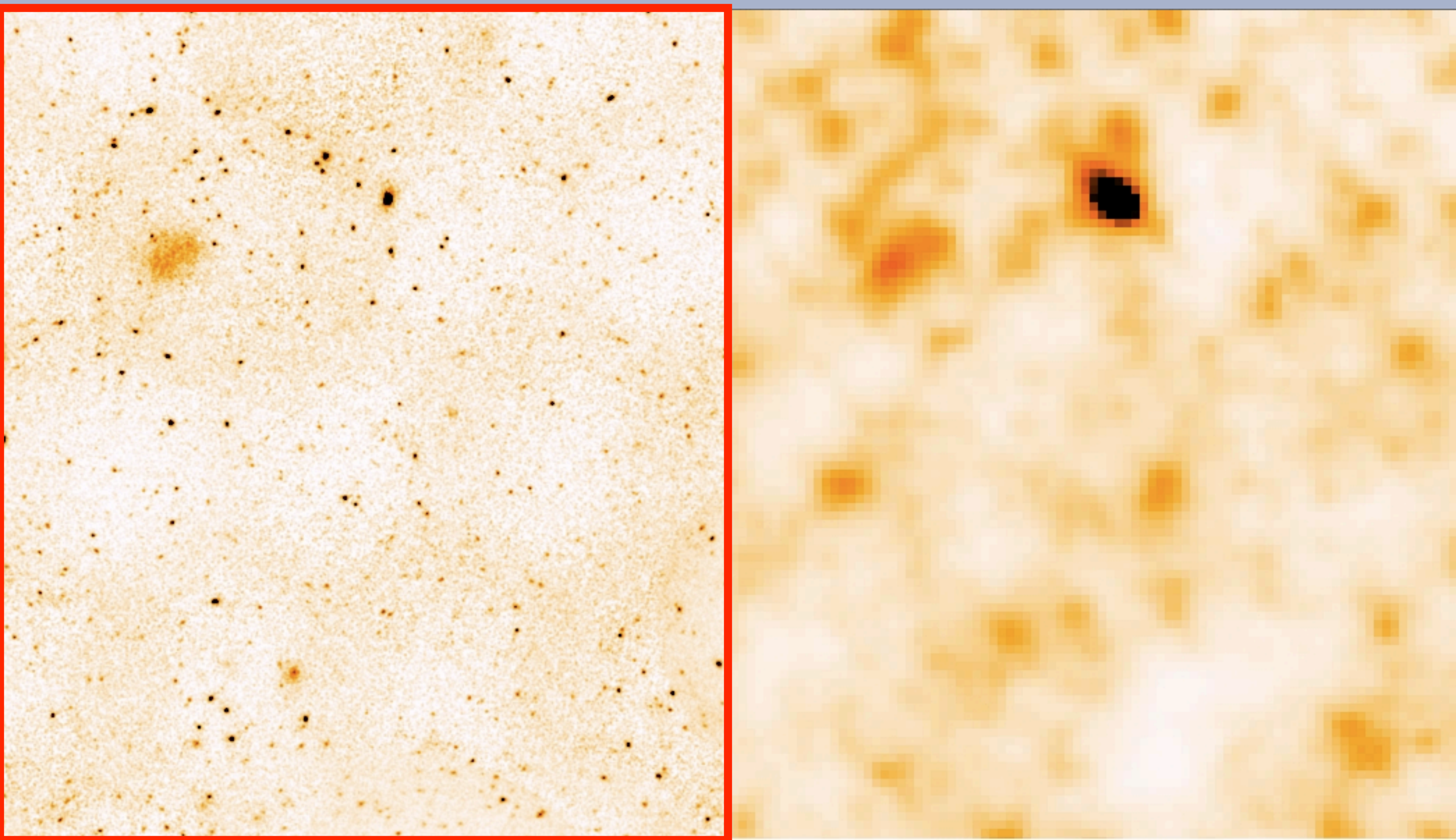


Paper I: Pierre, Pacaud, et al. (2016)

Zoom ~ 0.8 deg^2



Comparison with RASS



XXL 1st result release

15 accepted papers

(12 published today in an A&A special feature)

1 The XXL Survey
Pierre, Pacaud, et al.

2 The Bright Cluster Sample
Pacaud, Clerc, Giles, et al.

3 Luminosity –Temperature Relation
Giles, Maughan, Pacaud et al.

4 The Mass-Temperature Relation
Lieu, Smith, Giles et al.

5 Detection of the SZ effect at z=1.9
Mantz, Abdulla, Carlstrom, et al.

6 The 1000 Brightest Point Sources
Fotopoulou, Pacaud, Paltani, et al.

7 A Supercluster at z=0.43
Pompei, Adami, Eckert, et al.

8 Intracluster light in a z=0.53 Cluster
Adami, Pompei, Sadibekova, et al.

9 Radio Analysis of the Supercluster
Baran, Smolcic, Milakovic, et al.

10 Mass-K band luminosity relation
Ziparo, Smith, Mulroy, et al.

11 ATCA Continuum Observations
Smolcic, Delhaize, Huynh, et al.

12 Frequency of AGNs in Superclusters
Koulouridis, Poggianti, Altieri, et al.

13 The Baryon Content of Clusters
Eckert, Ettori, Coupon, et al.

14 AAOmega redshifts for XXL-S
Lidman, Ardila, Owers, et al.

15 BCG Growth in XXL Clusters
Lavoie, Willis, Démoclès, et al.

XXL 1st result release

The rest of the talk focuses on 4 papers

1 The XXL Survey
Pierre, Pacaud, et al.

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Pacaud, Clerc, Giles, et al.

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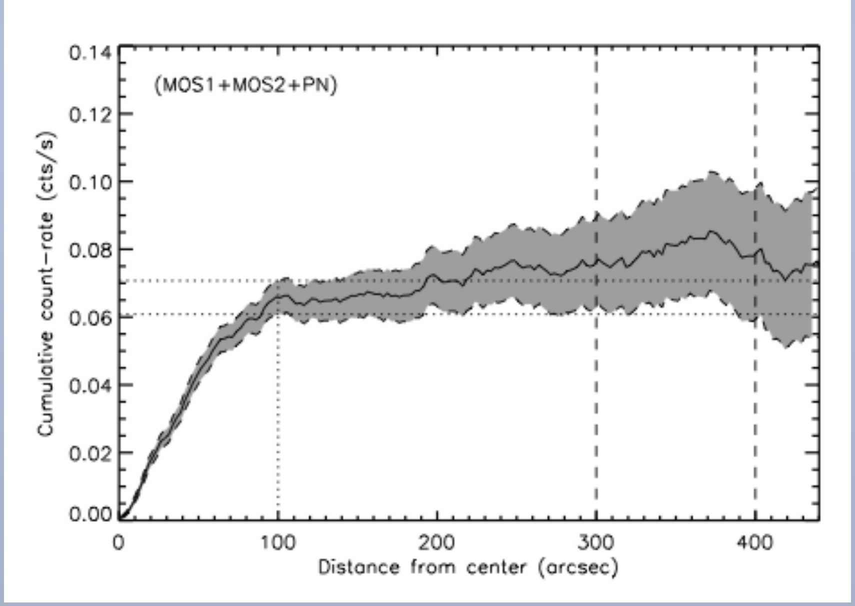
The Bright Cluster Sample: selection

⇒ 100 brightest galaxy clusters

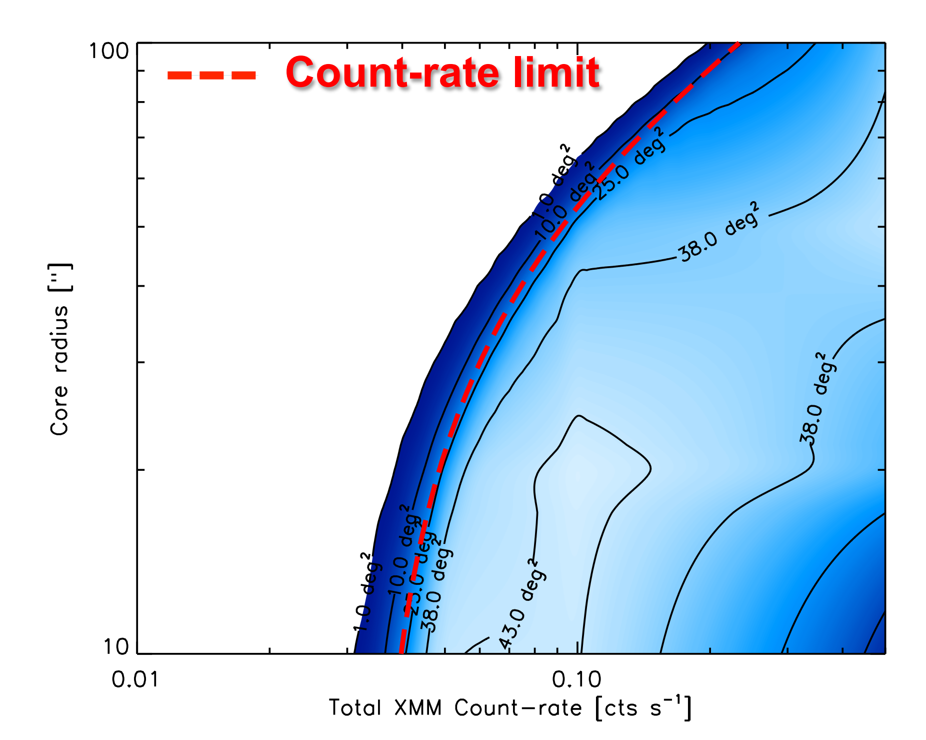
- Start from the pipeline extended source sample
- Perform growth curve analysis



⇒ Flux limit of 3.10^{14} erg/s/cm^2 in a 1' aperture

Paper II: Pacaud, Clerc, Giles et al. (2016)

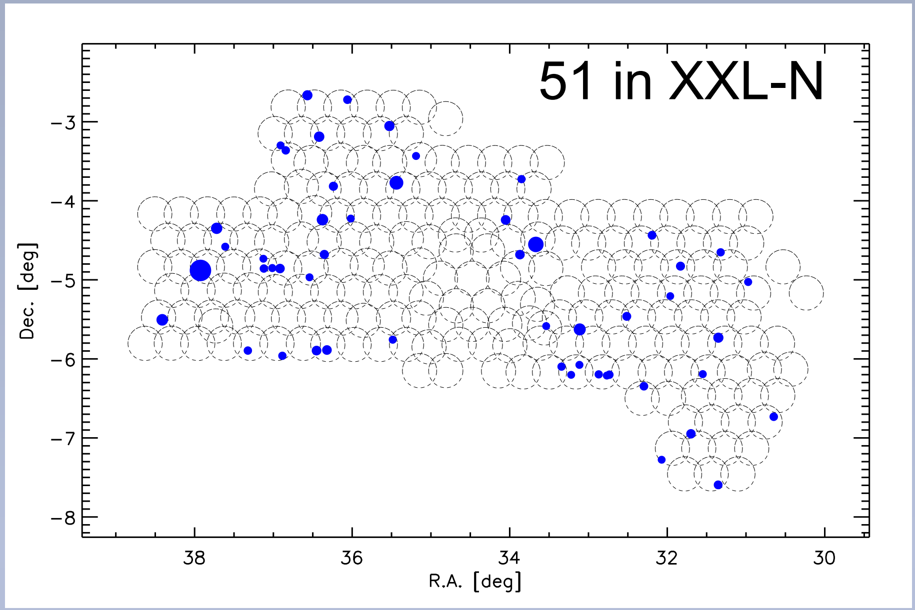
Selection function

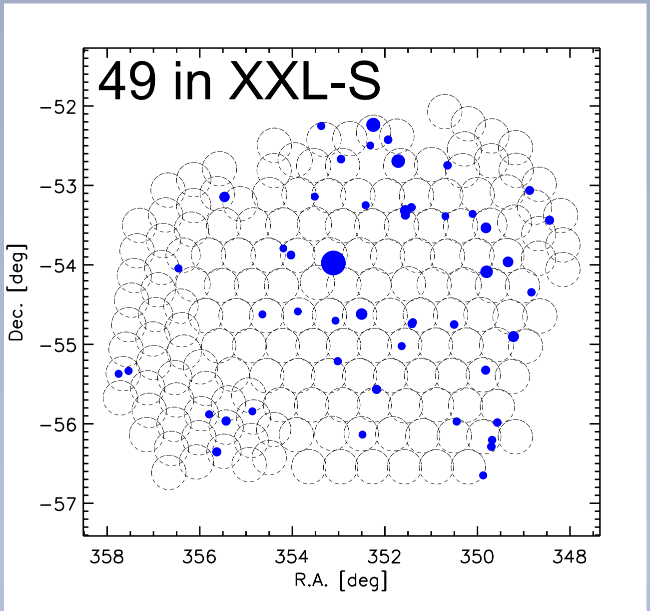


Includes:

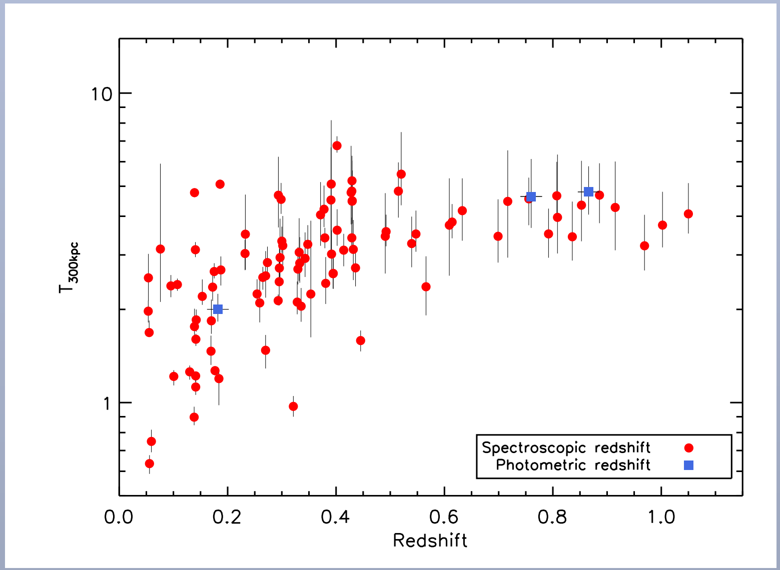
- Pipeline selection
- Aperture flux cut
- Flux uncertainty

The Bright Cluster Sample: XXL-100-GC





Paper II: Pacaud, Clerc, Giles et al. (2016)



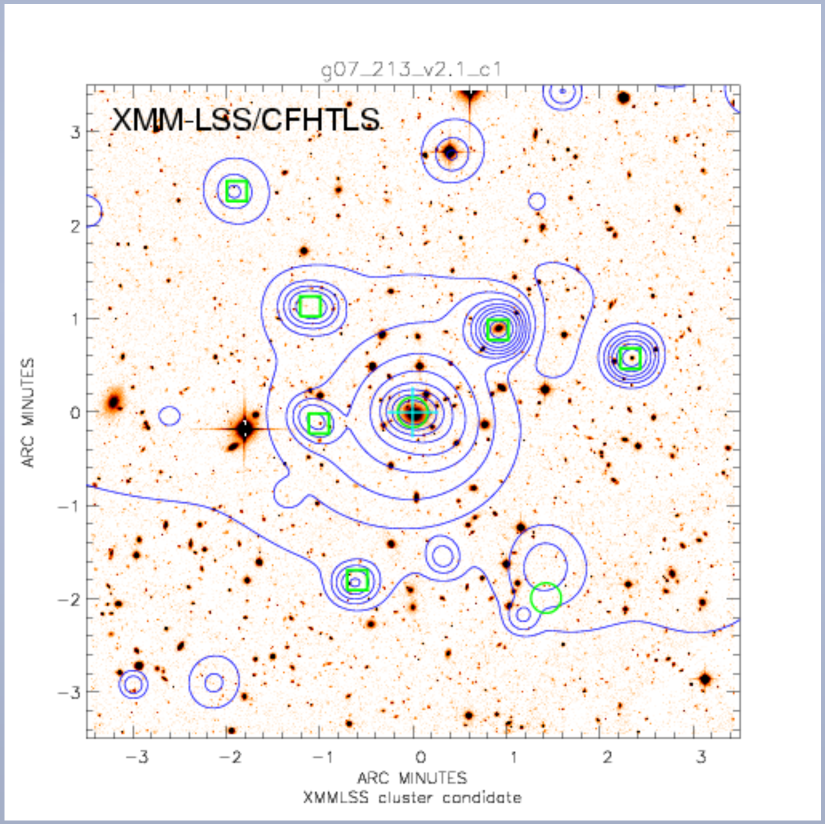
Available parameters :

- Spectroscopic z for 97/100
- T_{300kpc} for all from survey data
- L_{500} and M_{gas}

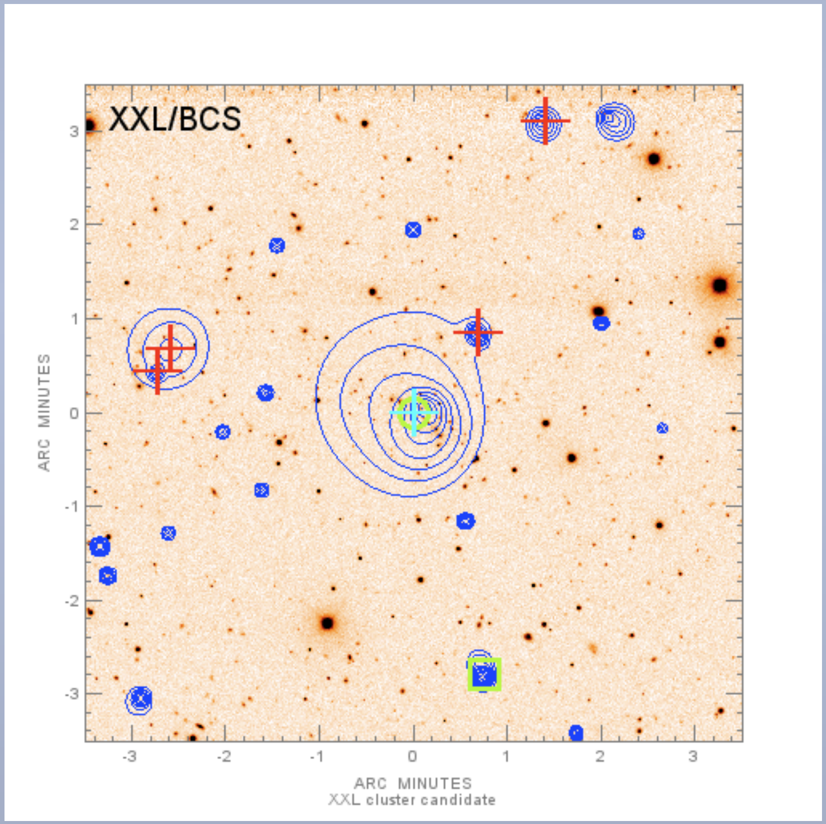
Paper III: Giles, Maughan, Pacaud et al. (2016)

Example of XXL-100-GC clusters

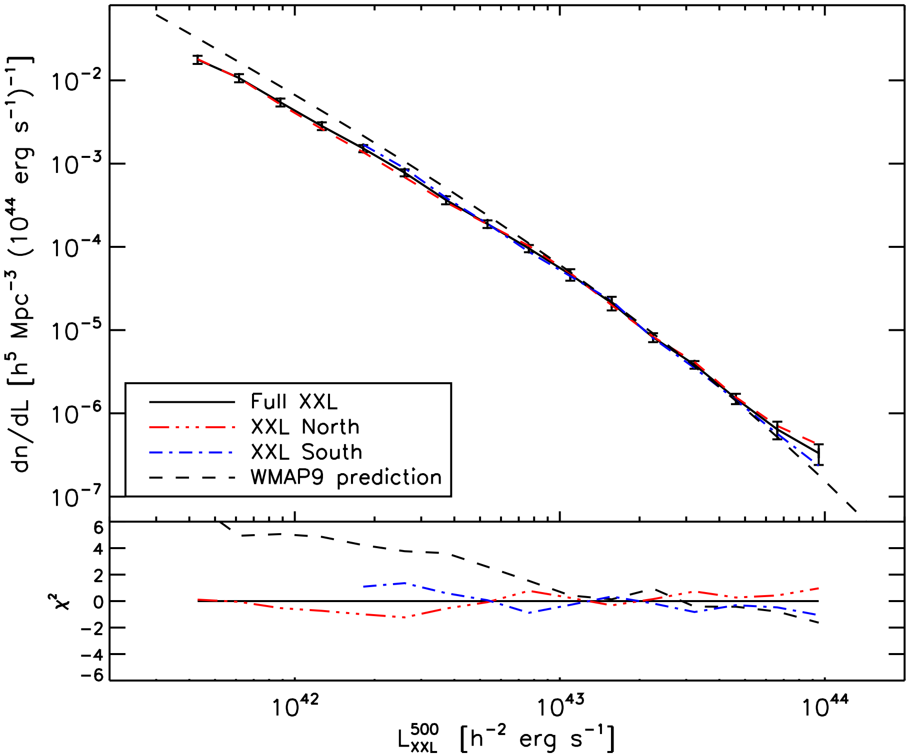
XLSSC 025 at z=0.27



XLSSC 509 at z=0.63

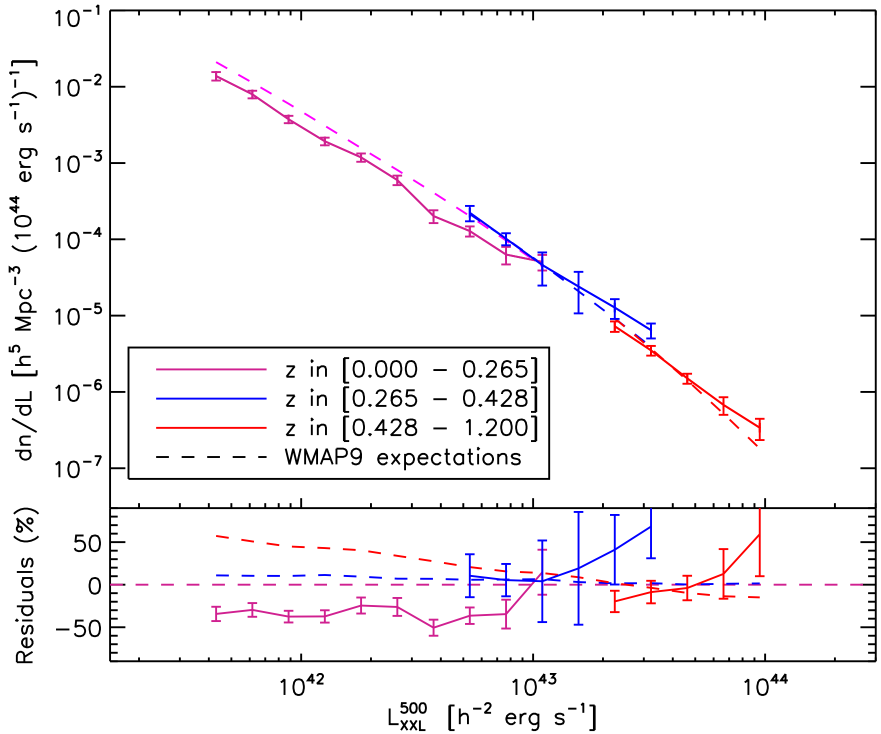


Luminosity function



Computed from numerical derivation of the cumulative function

Redshift evolution is weak !



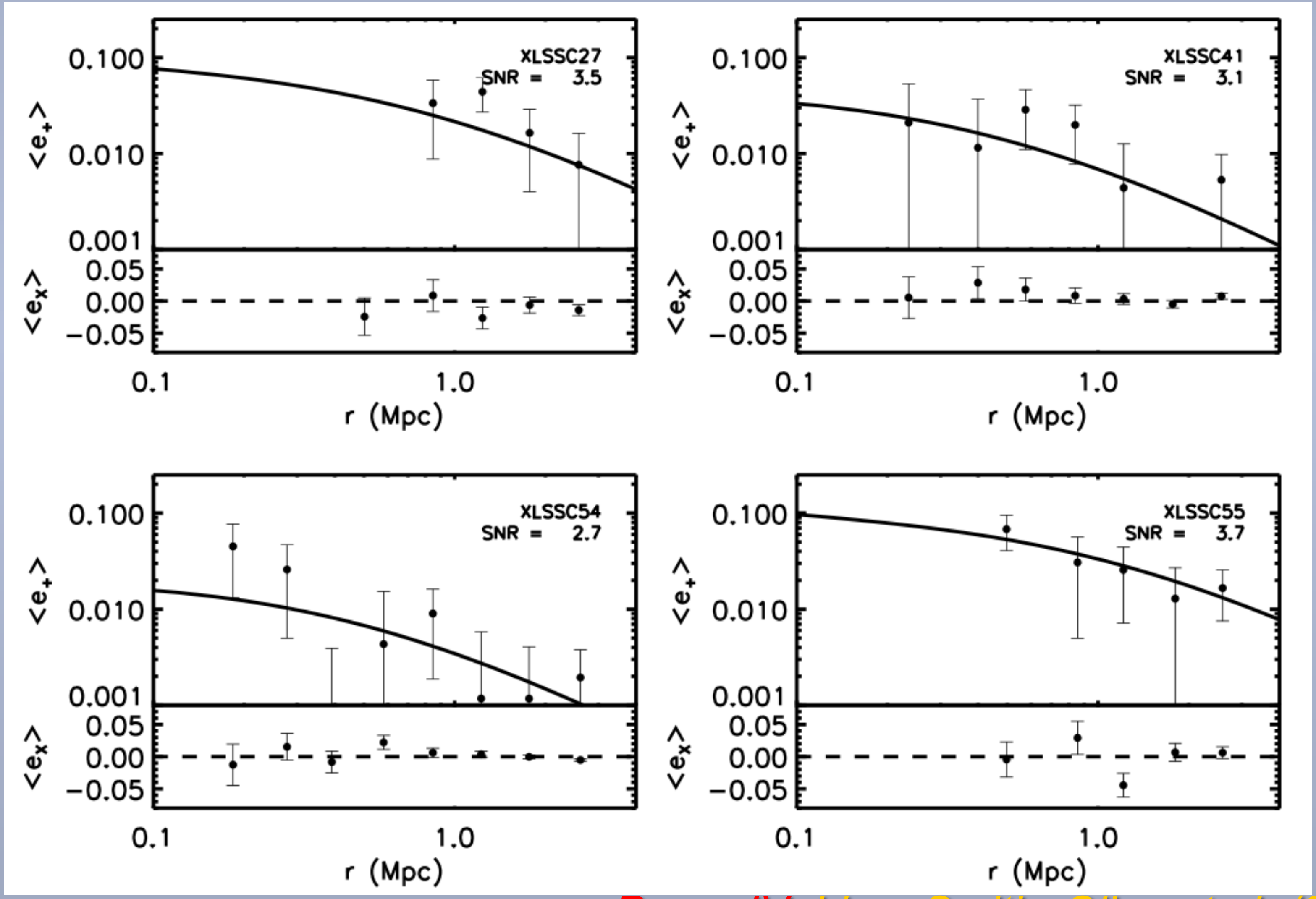
Depends on the assumed scaling relations through the estimate of the effective volume

Paper II: Pacaud, Clerc, Giles et al. (2016)

Weak lensing shear profiles

(and NFW profile fits)

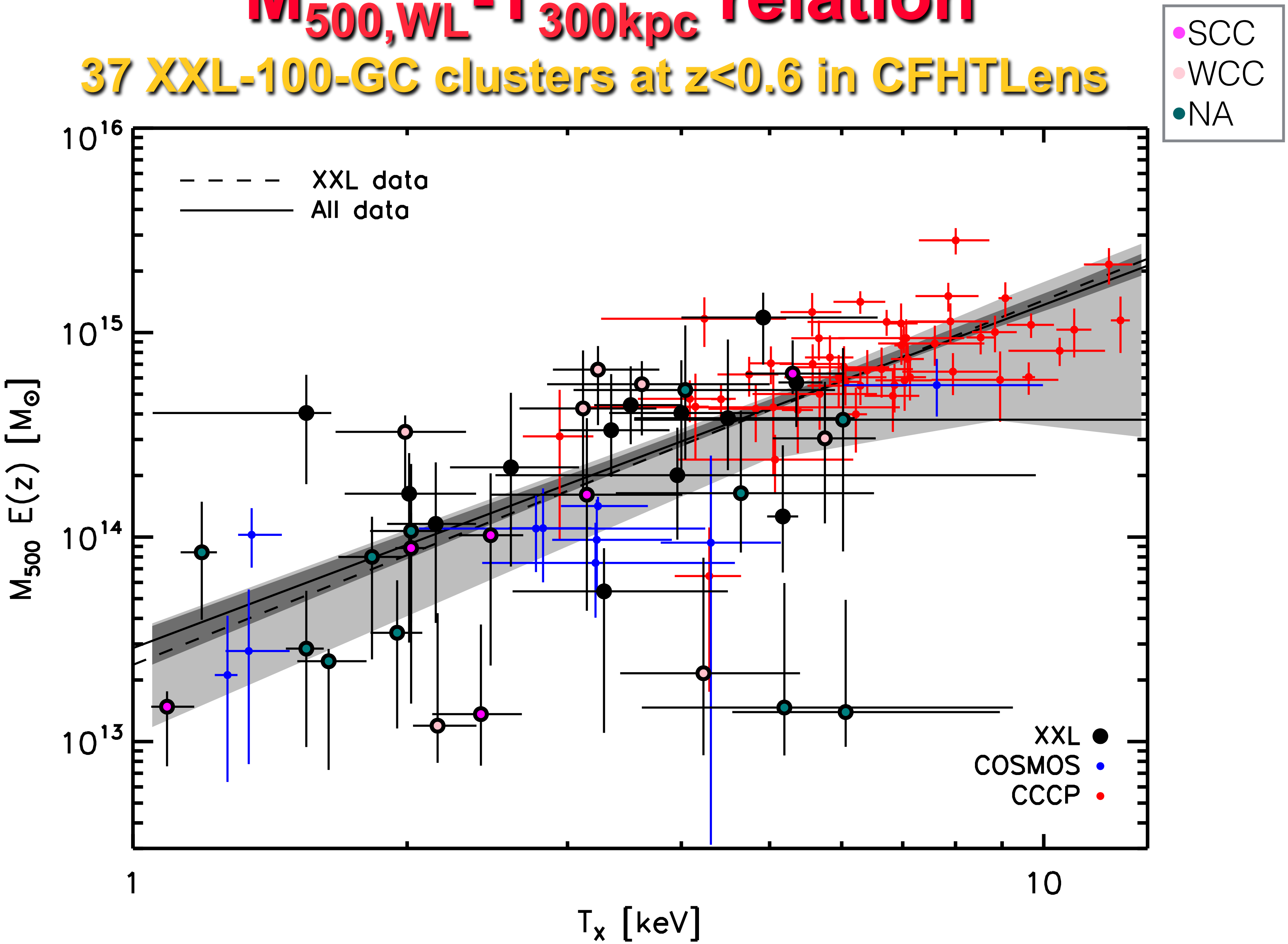
from CFHTLens data for 37 clusters at z<0.6



Paper IV: Lieu, Smith, Giles et al. (2016)

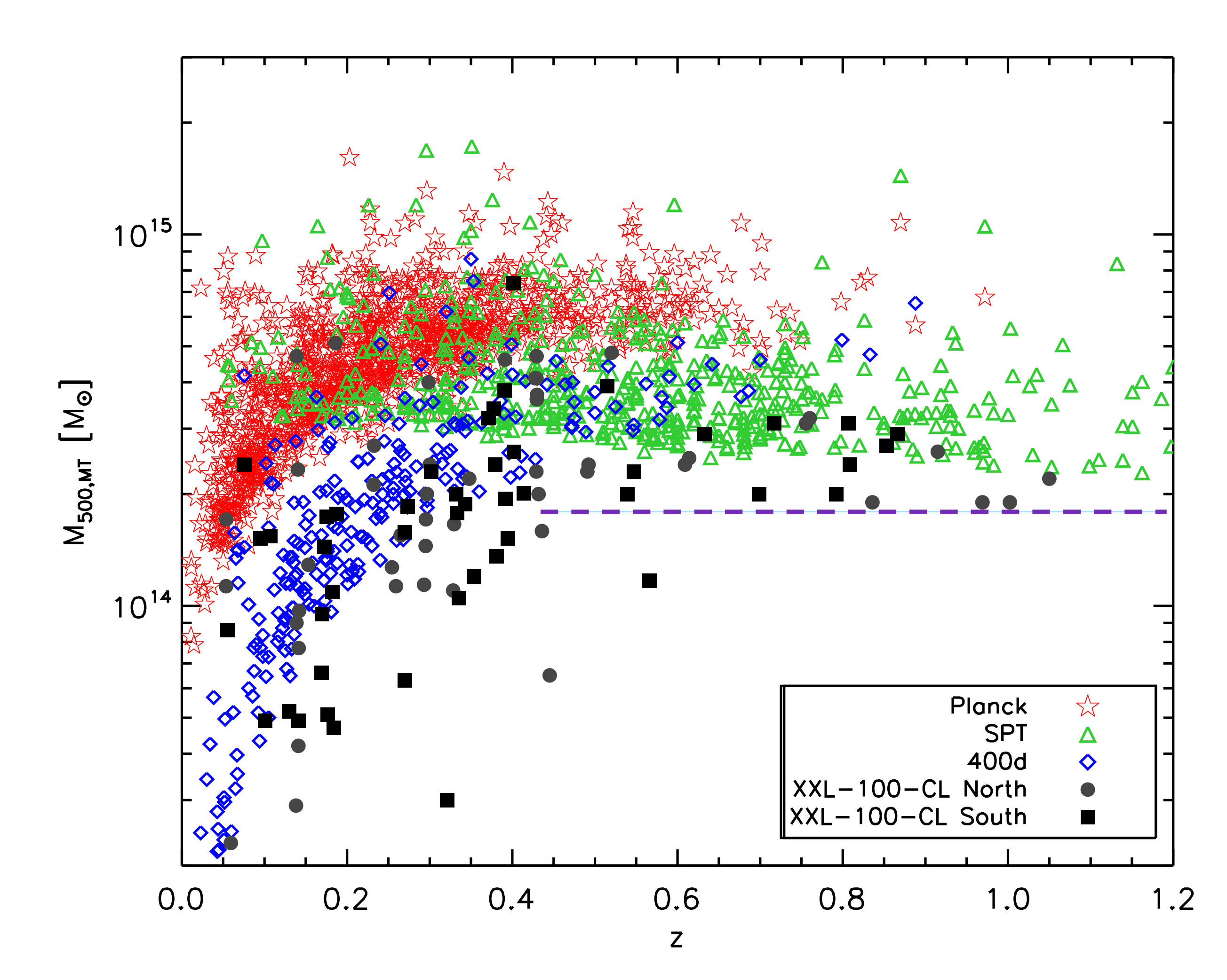
$M_{500,WL}$-T_{300kpc} relation

37 XXL-100-GC clusters at z<0.6 in CFHTLens



Paper IV: Lieu, Smith, Giles et al. (2016)

XXL-100-GC: Mass distribution



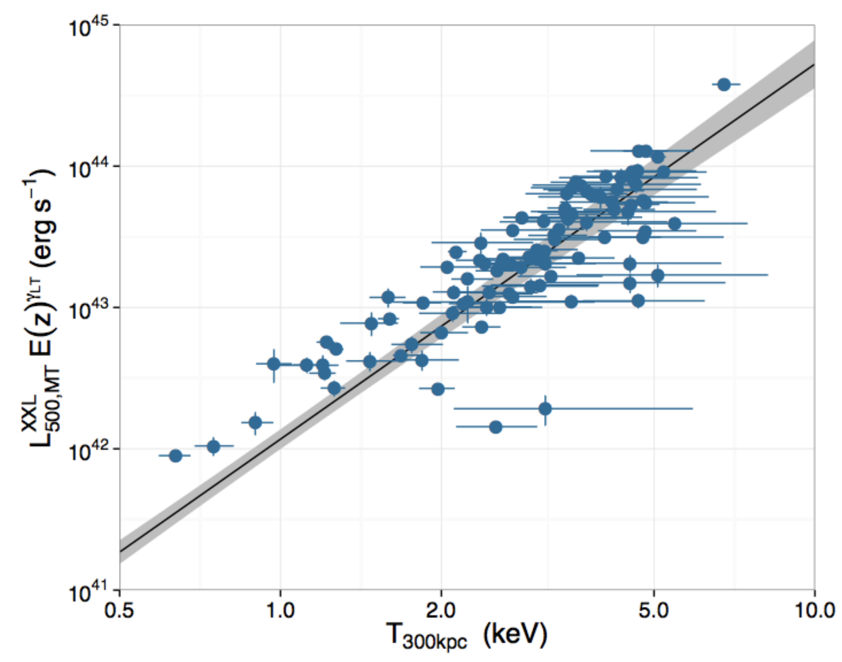
$M \geq 2x10^{14} M_\odot$
at $z \geq 0.4$

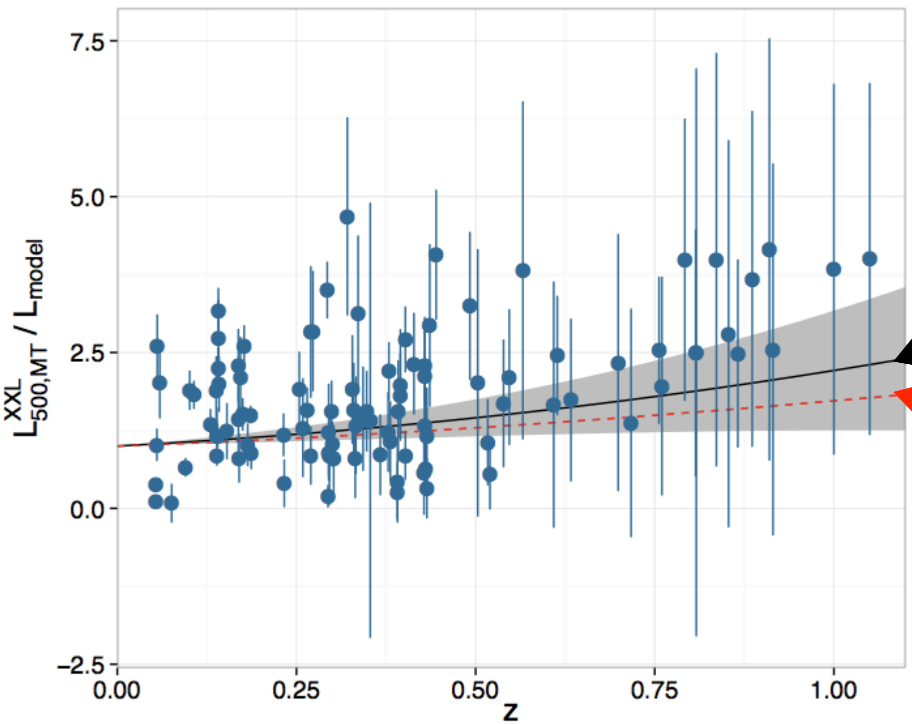
Paper II: Pacaud, Clerc, Giles et al. (2016)

L_{500}-T_{300kpc} relation

Self-consistent analysis:

- no local sample
- selection corrected
- Eddington bias corrected





$$L = A \,.\, T^{B} \,.\, E(z)^{\gamma}$$

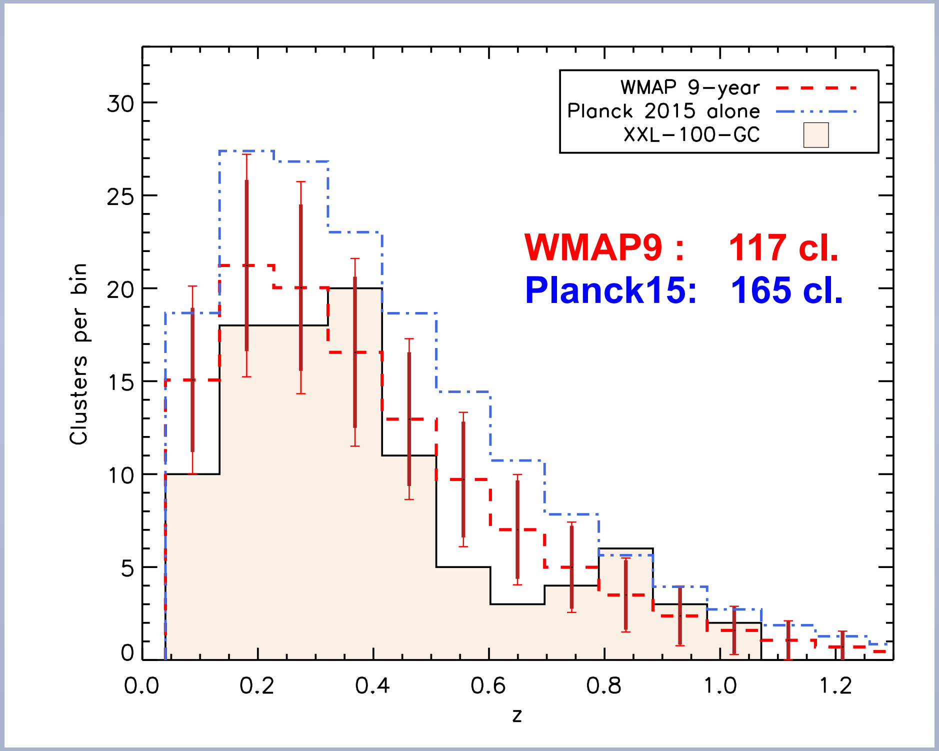
$\Rightarrow$ B=2.65 +/-0.15

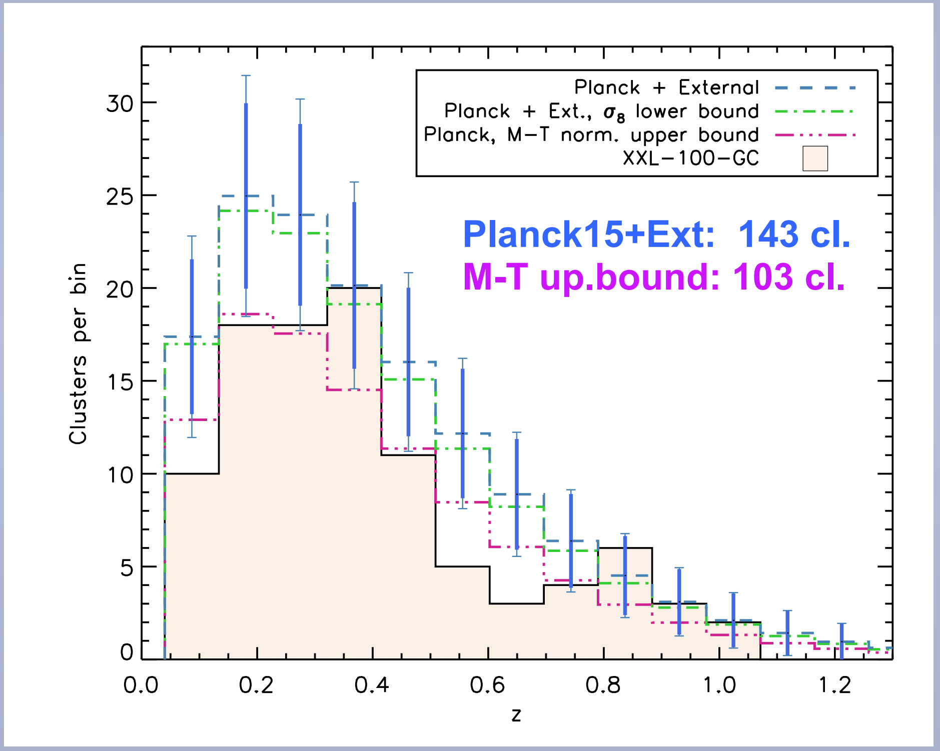
$\Rightarrow$ γ=1.46 +/- 0.8

Paper III: Giles, Maughan, Pacaud et al. (2016)

Cosmological modelling

<u>Assumption</u>: Tinker+08 mass function, XXL scaling laws, r_c=0.15 r_{500}

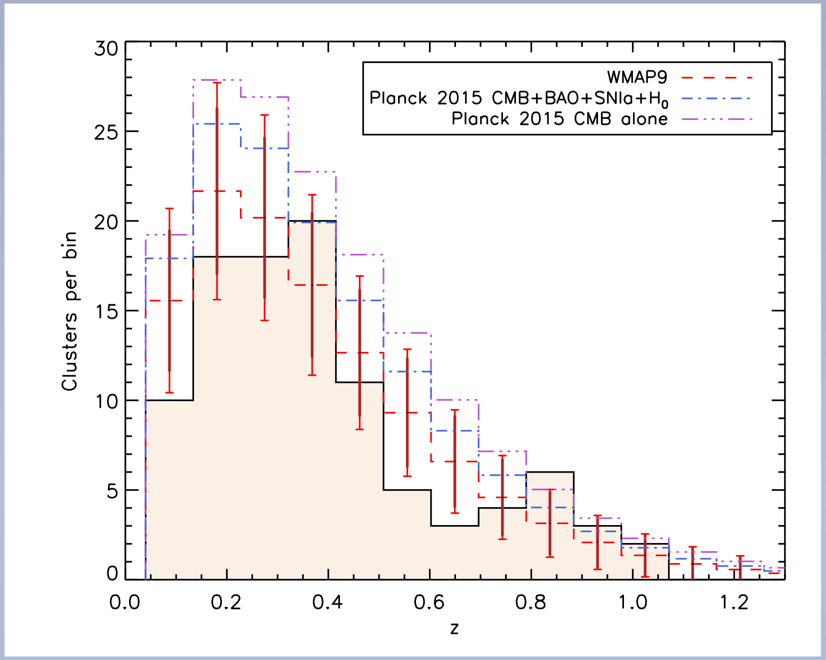




In addition, ~10% fluctuations from error on r_c/r_{500}

Paper II: Pacaud, Clerc, Giles et al. (2016)

Constraints on σ_8



- Tinker08 mass function
- XXL scaling laws
- β=2/3 and r_c=0.15 r_{500}

WMAP9 : 117 cl.

Planck15+: 143 cl.

Planck: 165 cl.

- **Extended Mantz likelihood fits to XXL-100**

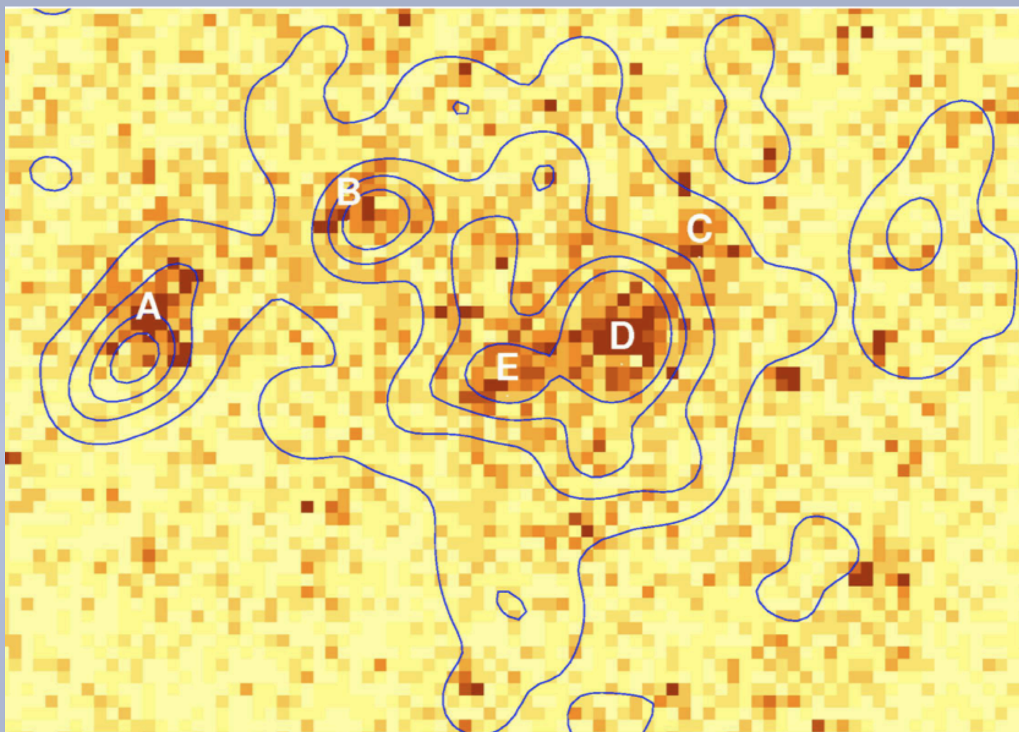
Fix all cosmological densities and H_0 to WMAP9

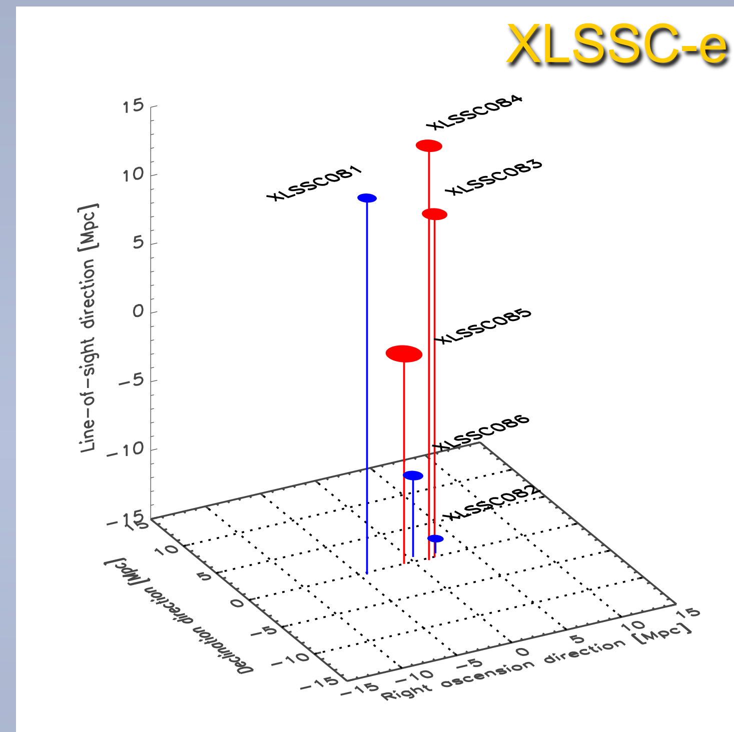
- **Using n(L_X,z)**:
  - All scaling relations fixed: σ_8=0.807 +/- 0.018
  - Only prior on L_X-T: σ_8=0.814 +/- 0.035
  - L_X-T fixed, but Ω_m free: $\Delta\sigma_8$ > 0.05

Paper II: Pacaud, Clerc, Giles et al. (2016)

Large Scale Structures

A prominent cluster of 6 groups at z=0.43 (3 in XXL-100-GC)



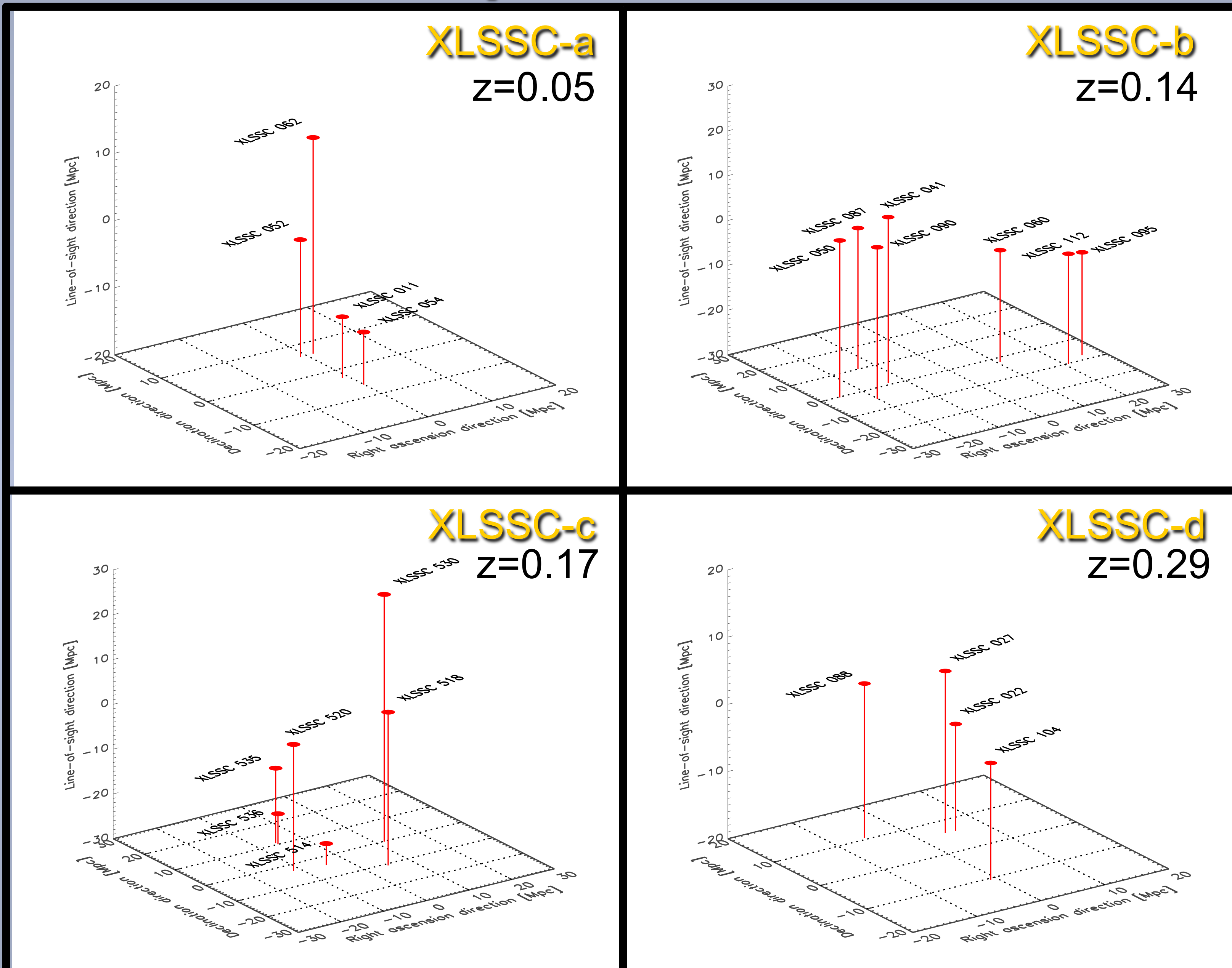


Paper VII: Pompei, Adami, Eckert, et al. (2016)
+ Paper IX: Baran, Smolcic Milakovic et al. (2016)

<u>Recipe to identify other similar structures (FoF like)</u>:

- Find pairs of clusters separated by less than 7 Mpc
- Add other clusters within 20 Mpc to any member

Superclusters

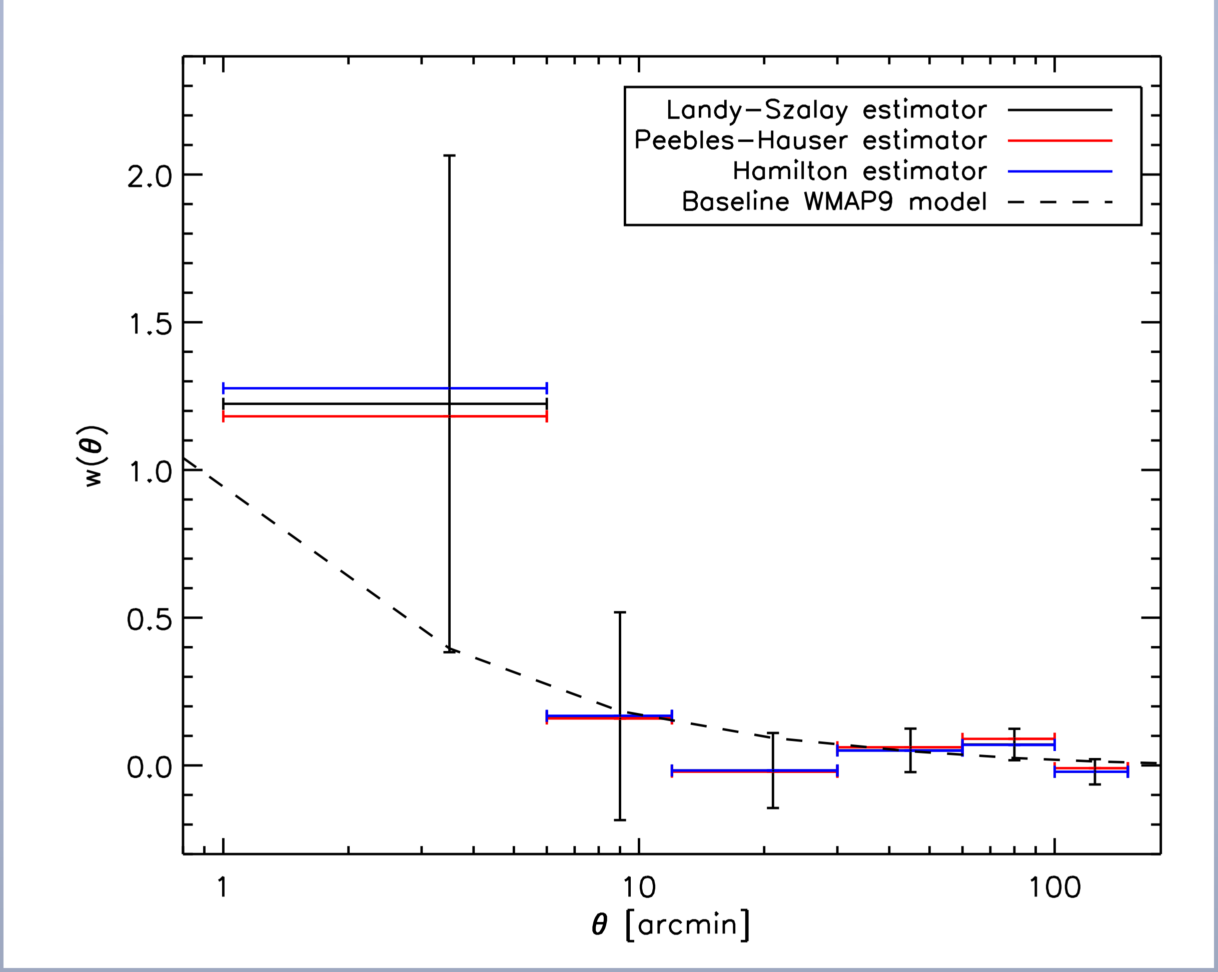


Paper II: Pacaud, Clerc, Giles et al. (2016)

Angular correlation function

Simulating random catalogues:

- For each cluster, select selection function map that matches its measured size/flux.
- Perform 100 realization => 10000 sources.



Conclusions

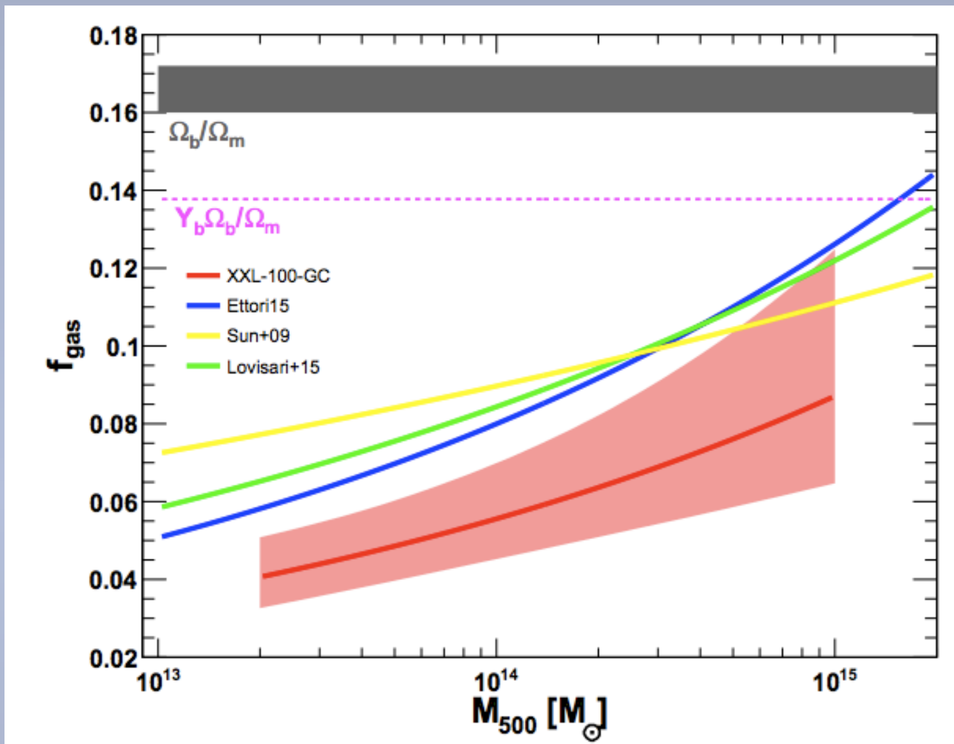
- XXL team assembling a unique multi-λ legacy data set
- First results of XXL (and X-ray maps) just issued:
  - ~ self-similar evolution of L500-T300kpc
  - Lower number density than predicted by Planck-CMB
  - Unveiling the 3d structures in the field
- Too many interesting details to describe here:

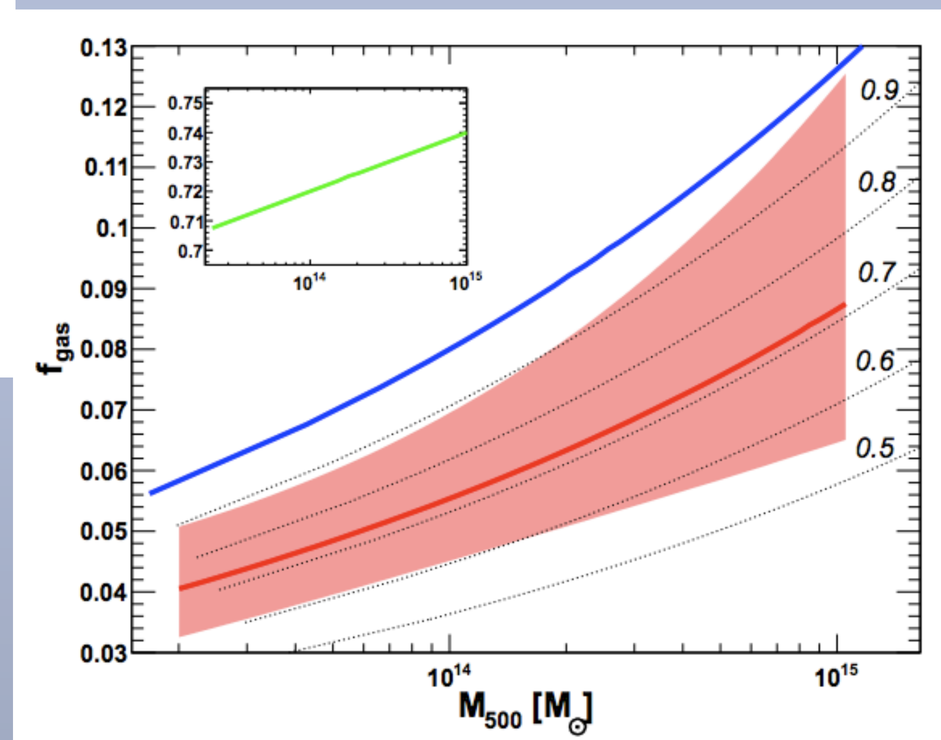
  Have a look at the papers in the A&A special feature !

- Next steps:
  - full sample (release planned in ~1 year)
  - two-point correlation function analysis (in 3D)
  - better mass-observables and selection modeling
  - more X-ray data to be expected

End

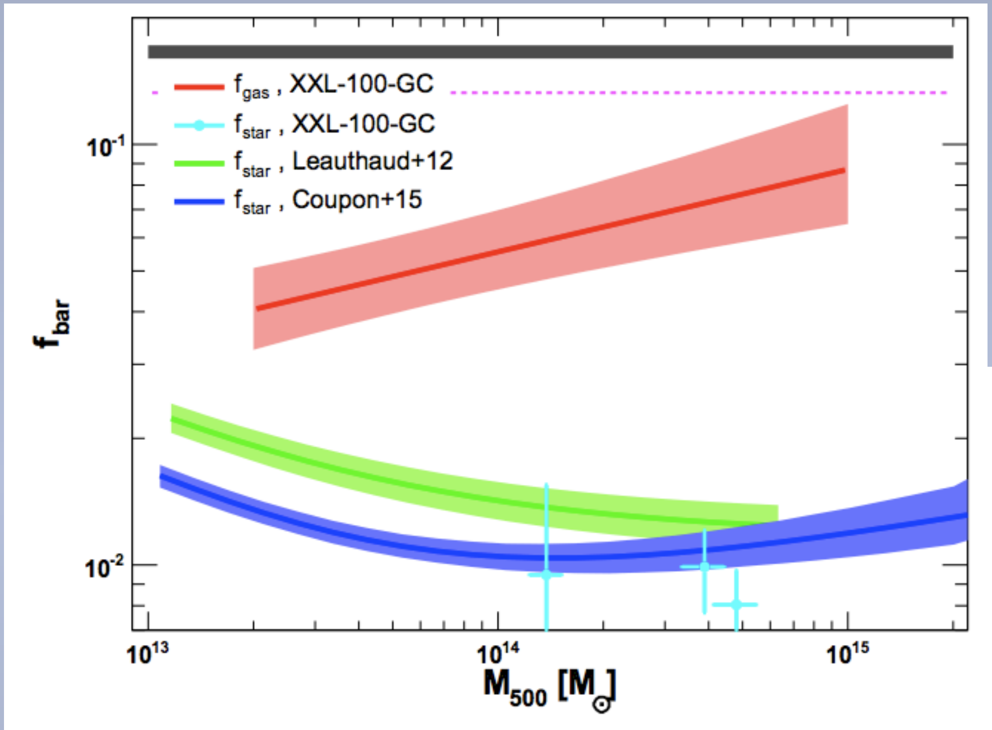
Gas mass content of XXL-100-GC

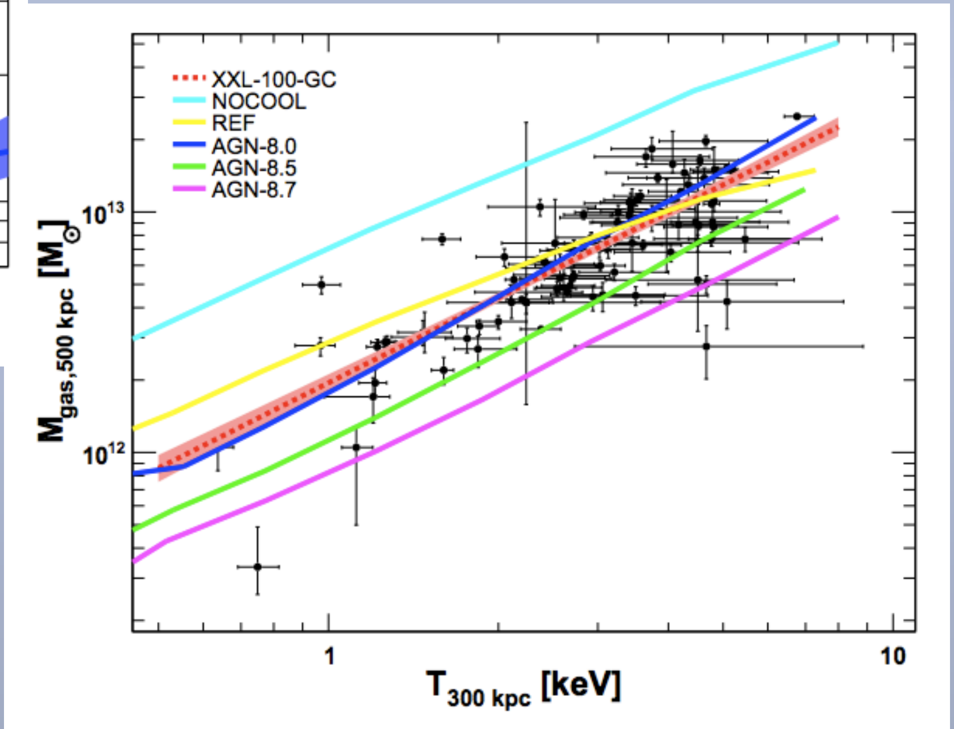




Paper XIII: Eckert, Ettori, Coupon et al. (2016)

Gas mass content of XXL-100-GC



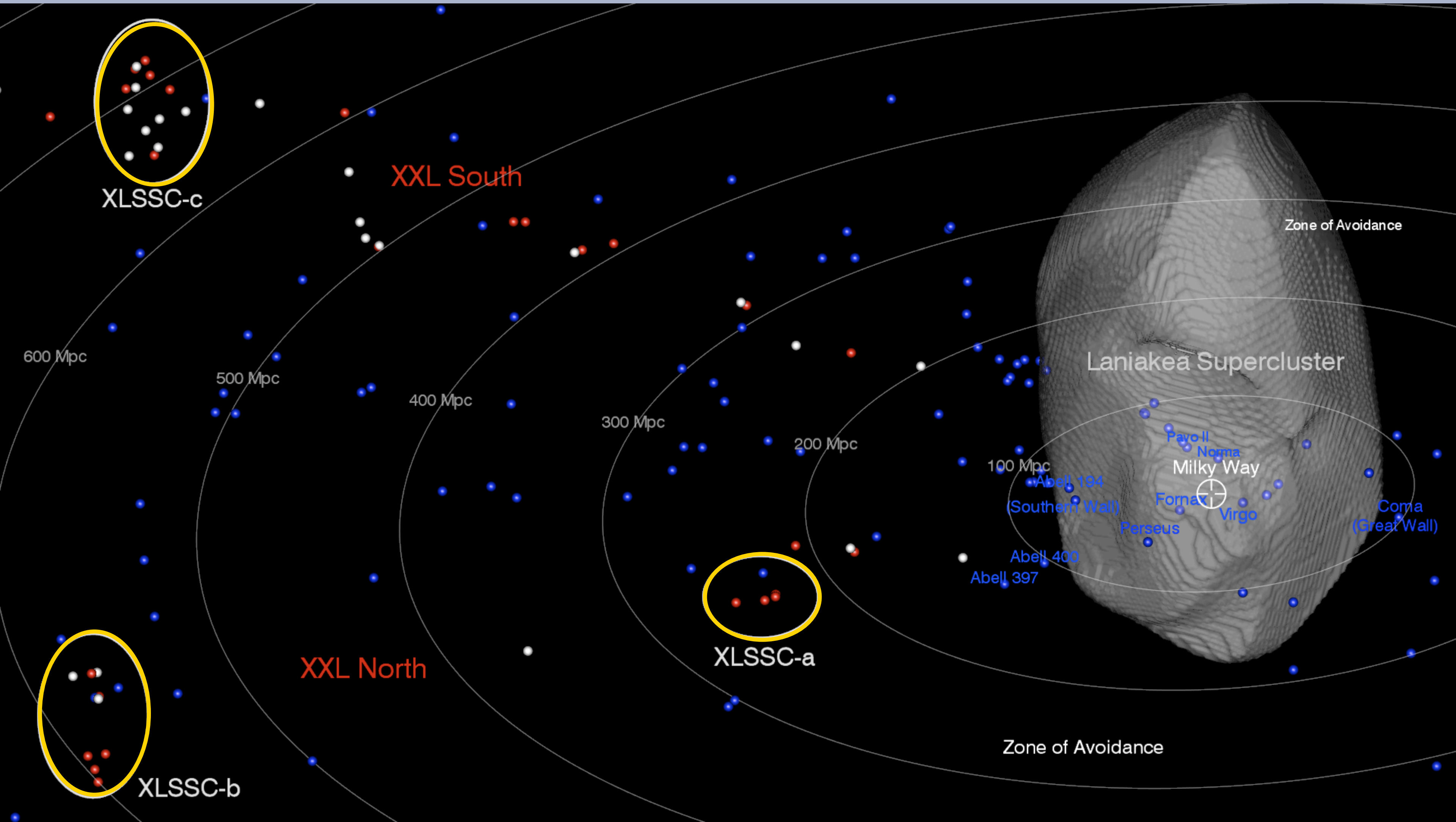


Paper XIII: Eckert, Ettori, Coupon et al. (2016)

LSS visualization

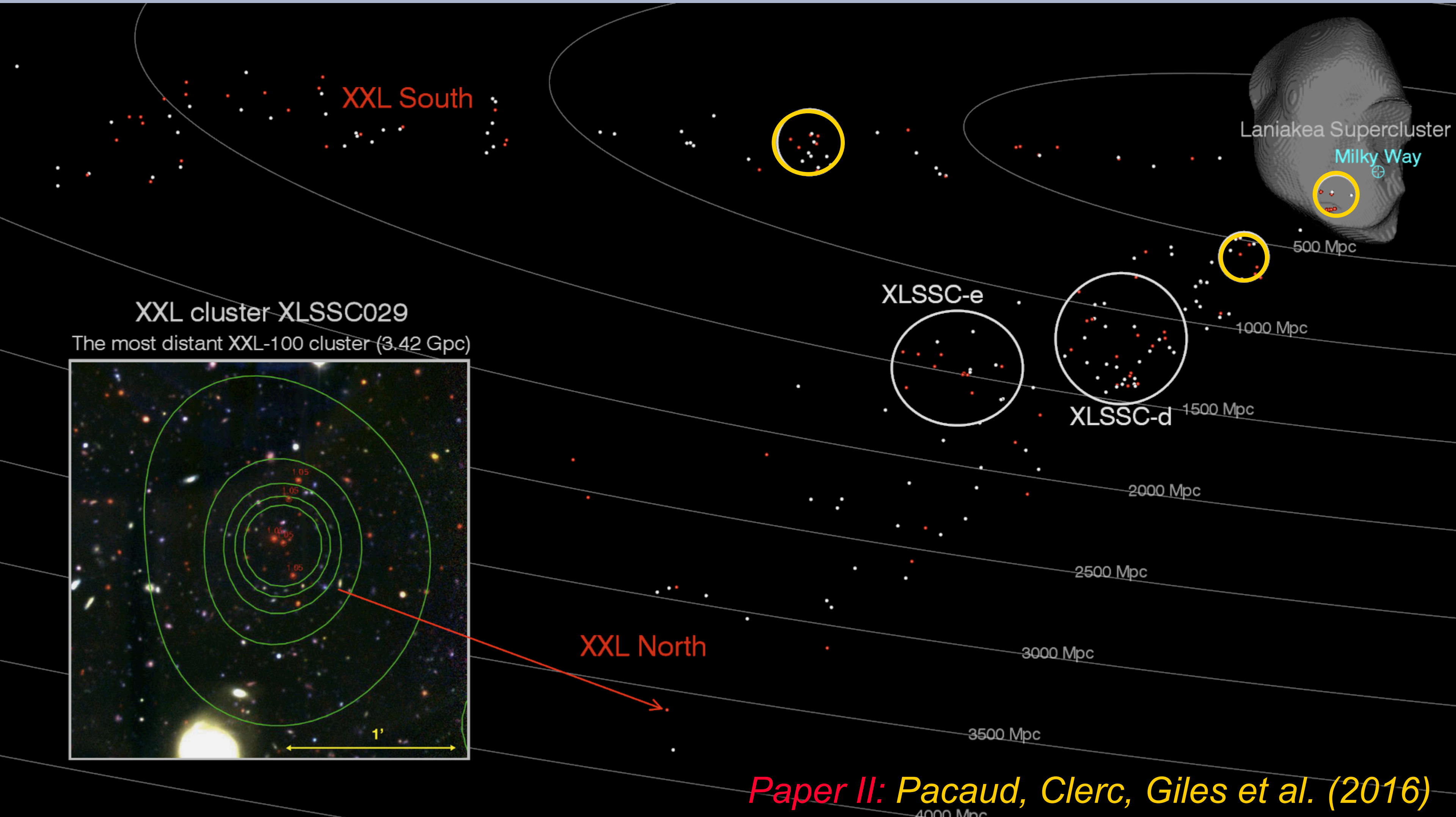
Credit: D. Pomarède

● XXL-100-GC clusters ○ Other XXL clusters ● ACO clusters



LSS visualization (II)

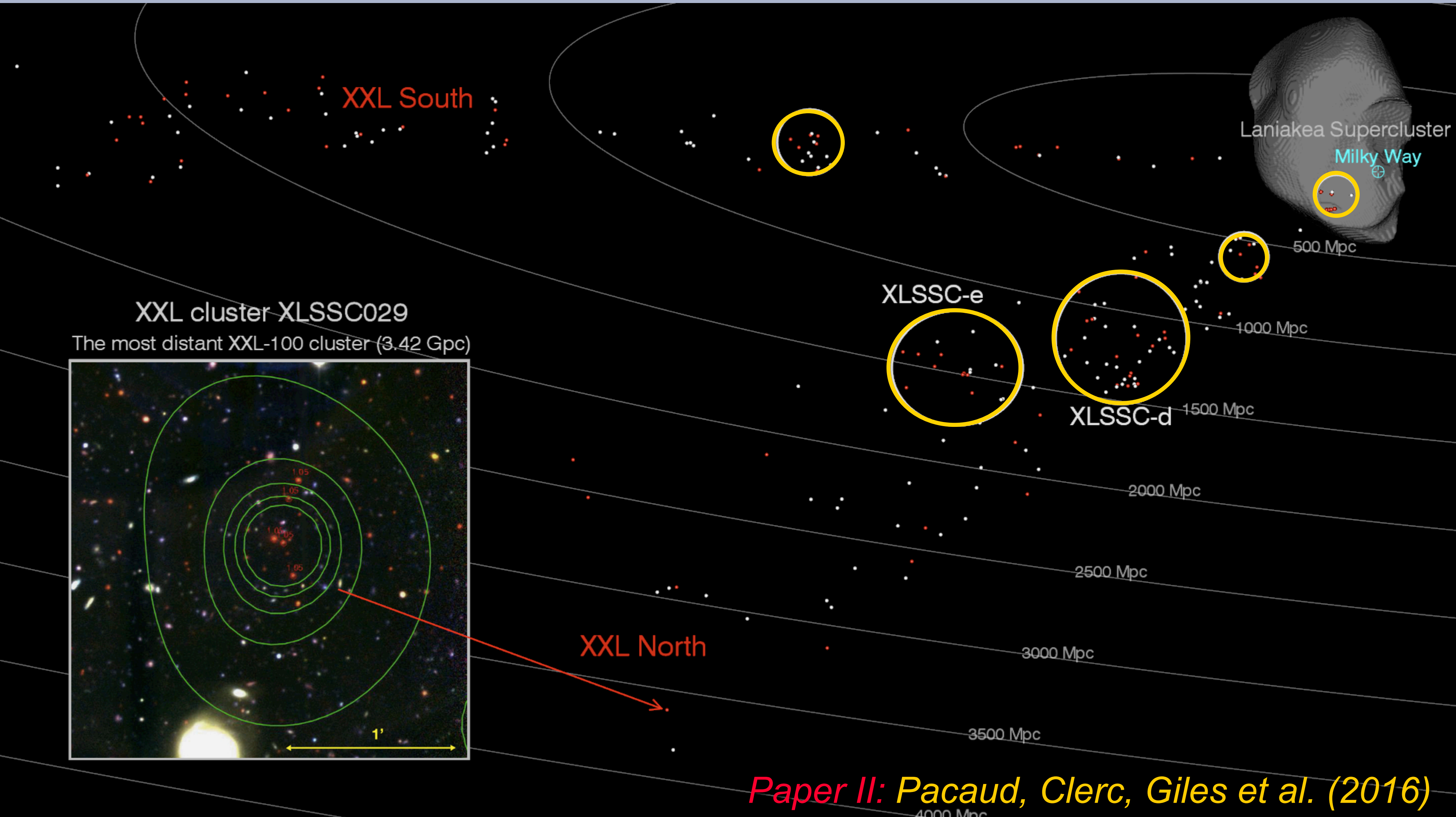
Credit: D. Pomarède



Paper II: Pacaud, Clerc, Giles et al. (2016)

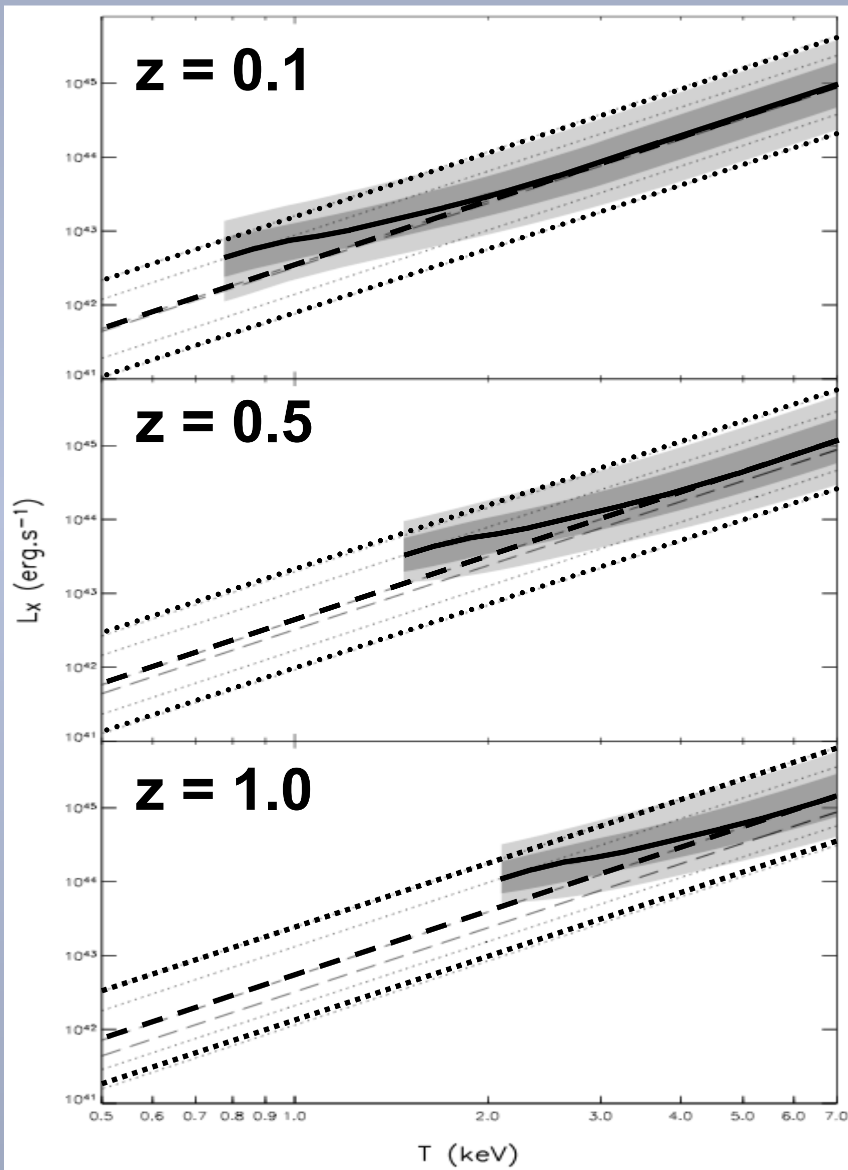
LSS visualization (II)

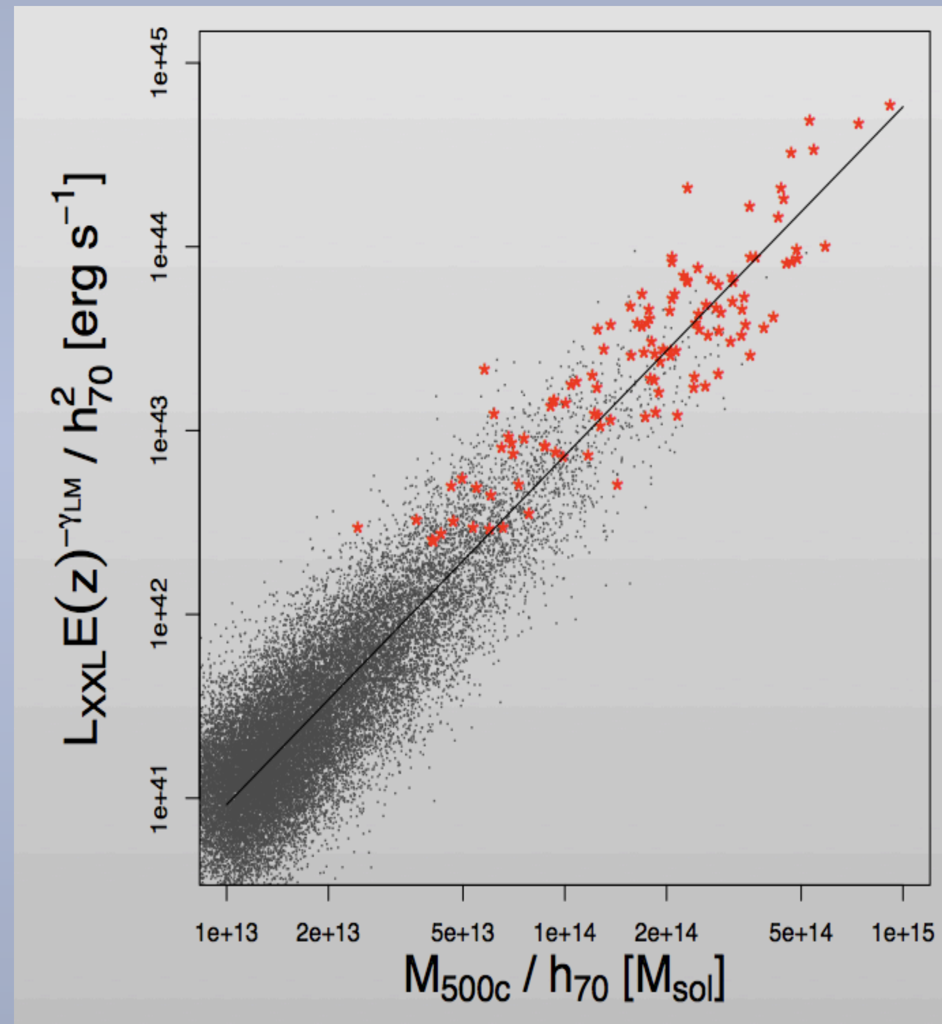
Credit: D. Pomarède



Paper II: Pacaud, Clerc, Giles et al. (2016)

Selection effects





Notations

We start from the mass function dn/dM/dz in units cluster per sky area
The link between M and observables O is provided by P(O|M) (e.g. a scaling relation with some scatter).

Let $\tilde{O}_i$ be the observed (noisy) value of O_i (i denotes i[th] cluster).
They are stochastically connected by the PDF $P_i(\tilde{O}|O)$.

The selection function, f_I, can depend on both O and Õ:

Real life number density: $$n(O,M,z) = \Omega_{tot} P(O \mid M) \frac{dn}{dM d\Omega dz}$$

Observable number density: $$\tilde{n}(\tilde{O},z) = \int dO \int_{M_{\min}}^{M_{\max}} f_I(O,\tilde{O}) P(\tilde{O} \mid O) n(O,M,z)\, dM$$

Average number of detected clusters : $$\langle N_{\det} \rangle = \int_{z_{\min}}^{z_{\max}} dz \int \tilde{n}(\tilde{O},z)\, d\tilde{O}$$

Paper II: Pacaud, Clerc, Giles et al. (2016)

Likelihood for scaling relations

- Well defined bayesian methods to fit scaling relations accounting for selection function using the number counts (e.g. Mantz 2010, 2015 and Jim's talk)
- Those however imposes the total number of sources to match the predictions which might be problematic given the unsolved Planck15/clusters issues
- Here, we aonly account for the distribution in the observable space (without the overall counts):

$$L(\pi) = \prod_{i=1}^{N_{\mathrm{det}}} P_{\mathrm{det}}(\tilde{O}_i, z_i \mid \pi)$$

- $P(\tilde{O}_i|z,\pi)$ can be estimated from the cosmological source distribution:

$$P_{\mathrm{det}}(\tilde{O}_i \mid z_i, \pi) = \frac{\tilde{n}\left(\tilde{O}_i, z \mid \pi\right)}{dn/dz\ (z \mid \pi)}$$

Paper II: Pacaud, Clerc, Giles et al. (2016) *Paper III: Giles, Maughan, Pacaud et al. (2016)*

Likelihood models

- Pacaud et al. (2007):

Apply selection effects on the scattered L-T distribution at a given z.

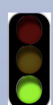
Use new modified P(L|T,z) as a PDF to build a likelihood model.

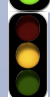
 **the effect of the mass function is not included**

- Mantz et al. (2010):

Start from a complete cluster population of N_{true} cluster

Considers all possible ways of selecting N_{obs} clusters based on the selection function and marginalize over N_{true}.

 **the effect of the mass function is included**

 **the cluster number density is included**

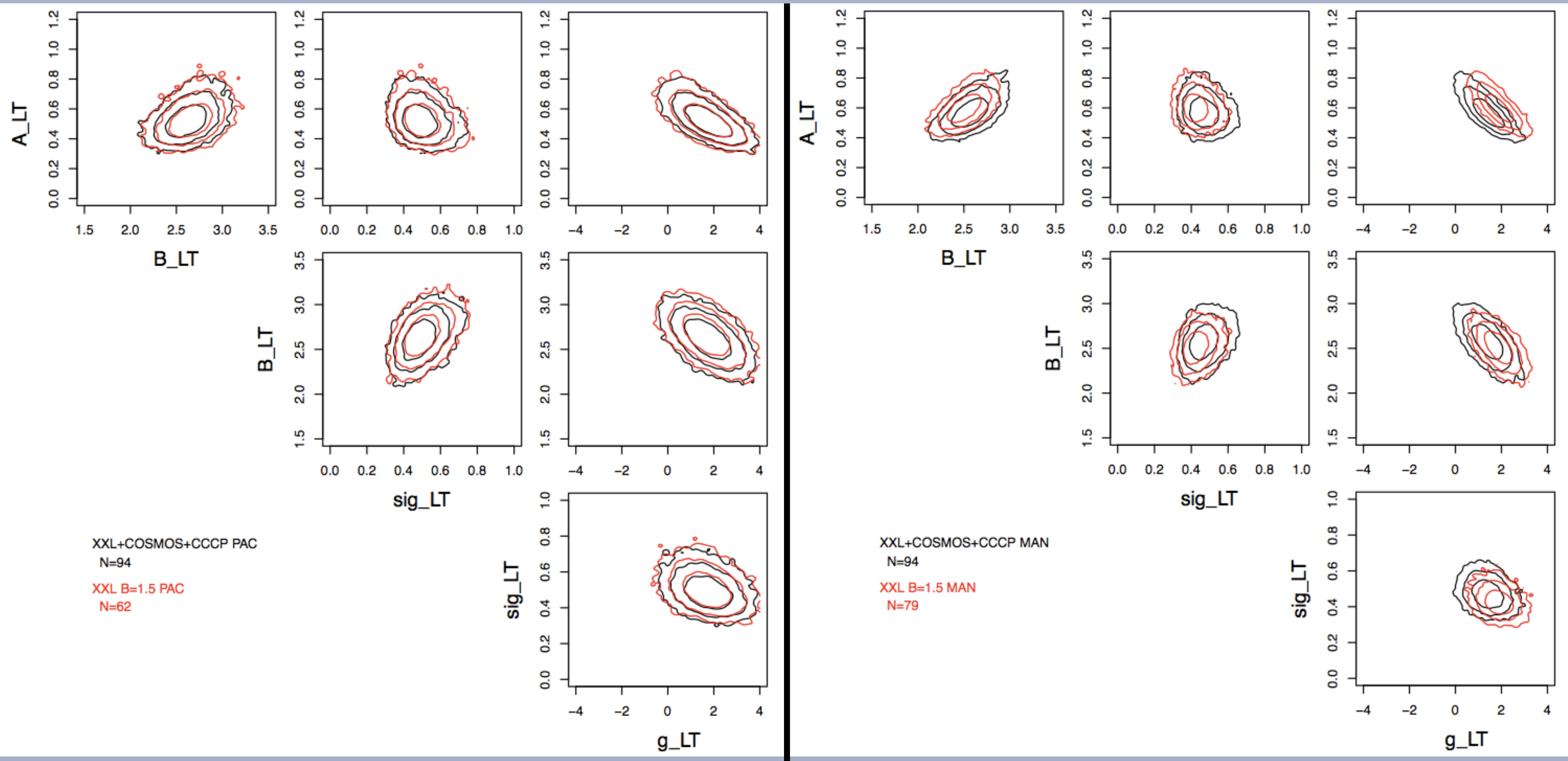
- Updated Pacaud et al. (2016):

Starting from input temperature function at a given z, then apply selection effects on the scattered L-T distribution at a given z.

Use P(L,T|z) as a PDF to build likelihood (normalized in 2D).

 **only the effect of the mass function is included**

Pacaud vs Mantz likelihood



Paper III: Giles, Maughan, Pacaud et al. (2016)

L_{500}-T_{300kpc} relation

- Start from WMAP9 cosmology and M-T from Lieu et al.
- Assume $x_c=r_c/r_{500}=0.15$ to apply selection function
- Parametrization:

$$E(z)^{\gamma_{LT}}\left(\frac{L}{L_0}\right)=A_{LT}\left(\frac{T}{T_0}\right)^{B_{LT}}$$

With $L_0 = 3 \times 10^{43}$ erg s^{-1}
$T_0 = 3$ keV

- Fit results

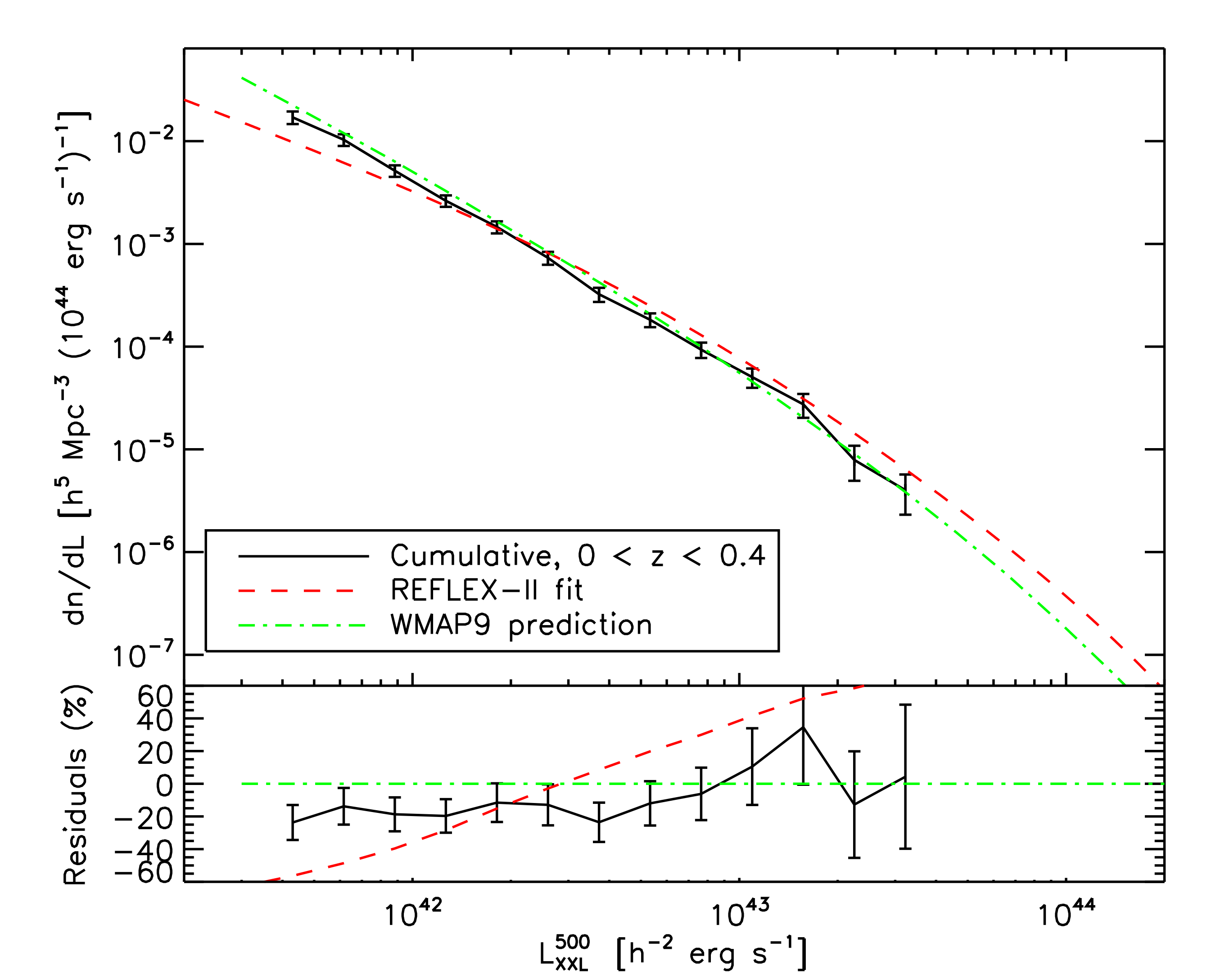
Likelihood Model	A_{LT}	B_{LT}	γ_{LT}	σ_{LT}
Mantz	0.71 +/-0.10	2.74 +/-0.15	1.17 +/-0.52	0.52 +/-0.06
Pacaud	0.72 +/-0.11	2.65 +/-0.15	1.46 +/-0.80	0.48 +/-0.07

$\Rightarrow$ Self-similar evolution or stronger

This apparently contradicts some recent results
(e.g. Reichert et al. 2011, Hilton et al. 2012, Clerc et al. 2014)

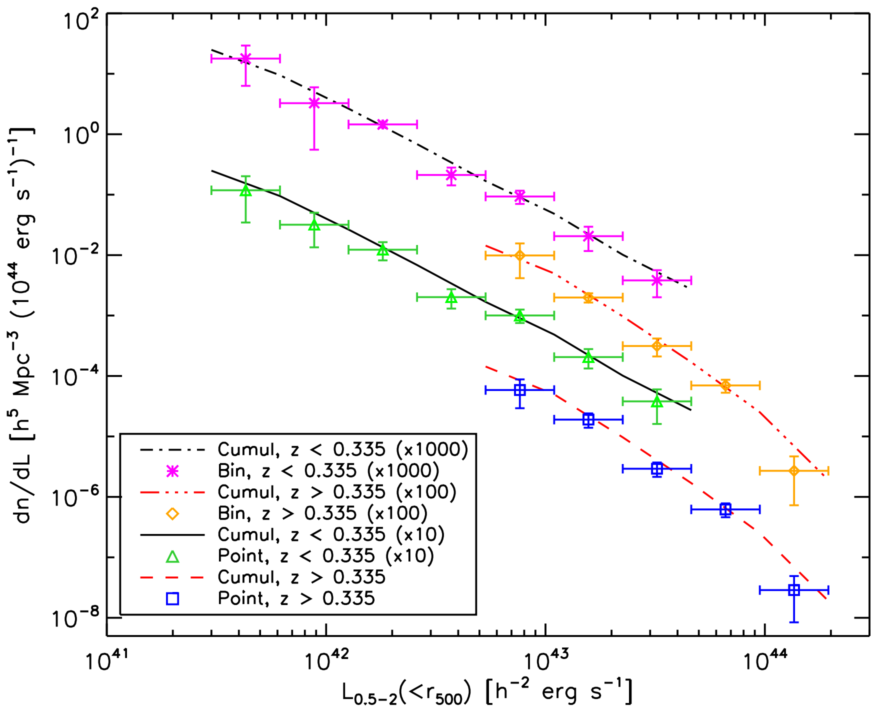
Paper III: Giles, Maughan, Pacaud et al. (2016)

Comparison with REFLEX-II



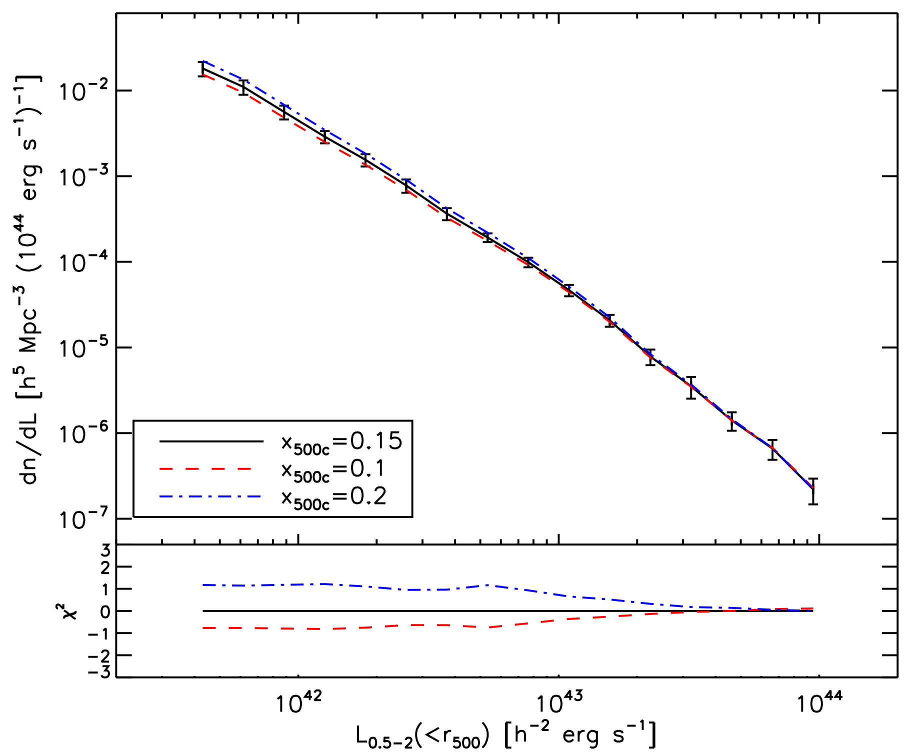
Paper II: Pacaud, Clerc, Giles et al. (2016)

Systematic errors on the luminosity function



Impact of estimator

Other assumptions for $x_c = R_c/R_{500}$



Paper II: Pacaud, Clerc, Giles et al. (2016)

More consistency checks

The L_X-T relation preferred by the observed luminosity function

Table 6. Indirect constraints on the $L_{500}^{\mathrm{XXL}} - T_{300\mathrm{kpc}}$ relation parameters obtained by fitting the (L, z) number density.

Free parameters	A_{LT}	B_{LT}	γ_{LT}
Reference	0.72	2.65	1.46
Norm. only	$0.655^{+0.063}_{-0.069}$	2.65	1.46
Norm.+evol	$0.63^{+0.10}_{-0.10}$	2.65	$1.61^{+0.42}_{-0.44}$
Norm.+pow+evol	$0.72^{+0.21}_{-0.15}$	$2.83^{+0.25}_{-0.22}$	$1.22^{+0.64}_{-0.74}$

Paper II: Pacaud, Clerc, Giles et al. (2016)

Likelihood formulation for number counts

- Unbinned likelihood:
  separate model normalization and PDF of the observables

$$L(\pi) = P(\tilde{O} \mid N_{\det}, \pi) P(N_{\det} \mid \pi)$$

- $P(\tilde{O}|N_{det},\pi)$ can be decomposed as a product of the probabilities for each cluster, namely :

$$P_{\det}(\tilde{O}_i, z) = \frac{\tilde{n}\left(\tilde{O}_i, z \mid \pi\right)}{\left\langle N_{\det} \right\rangle}$$

- In the simplest case, $P(N_{det})$ is a Poisson law of parameter $<N_{det}>$:

$$L(\pi) = \frac{e^{-\langle N_{det} \rangle} \left\langle N_{det} \right\rangle^{N_{\det}}}{N_{\det}!} \times \prod_{i=1}^{N_{det}} P_{\det}(\tilde{O}_i, z_i \mid \pi)$$

- This reduces to the same form as Mantz et al. 2010):

$$L(\pi) \propto e^{-\langle N_{det} \rangle} \times \prod_{i=1}^{N_{\det}} \tilde{n}(\tilde{O}_i, z_i \mid \pi)$$

Paper II: Pacaud, Clerc, Giles et al. (2016)

Cosmic variance

- To be fully rigorous:
  - Should account for the detailed covariance of cluster counts at different masses and position.
  - This could be significant if CV dominates over shot noise

- For XXL, CV is similar to shot noise. We can account for it to first order by replacing the Poisson term by a doubly stochastic Poisson process, i.e.:

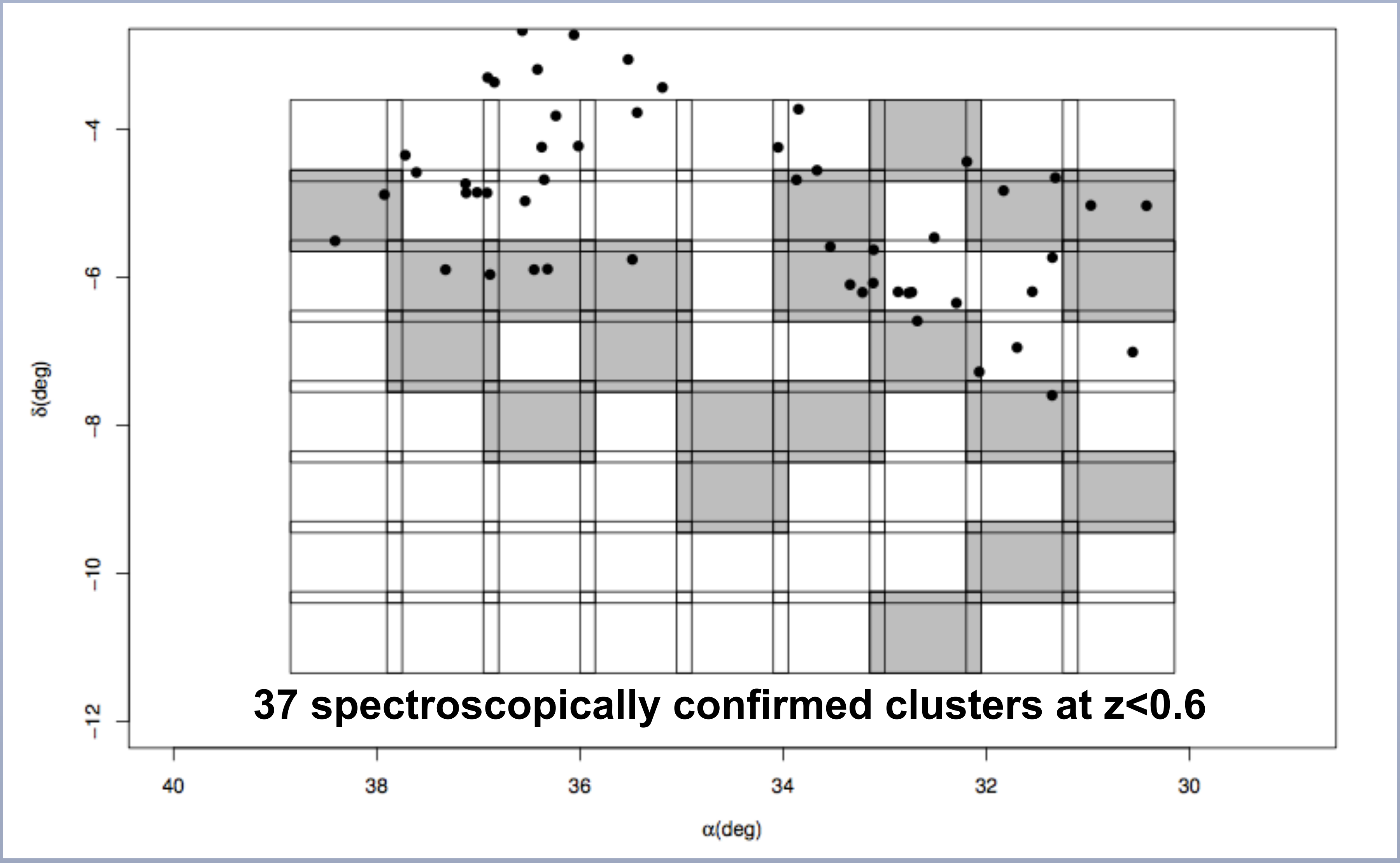
$$P(N_{\det} \mid \pi) = \int_{N_{field}} \frac{e^{-N_{field}} N_{field}^{N_{\det}}}{N_{\det}!} \times P(N_{field} \mid \langle N_{\det} \rangle) dN_{field}$$

for paper II $P(N_{field}|<N_{det>})$ is a suitably parametrized log-normal distribution

Paper II: Pacaud, Clerc, Giles et al. (2016)

Weak lensing analysis

Estimating weak lensing masses from NFW fits to CFHTLens shear data



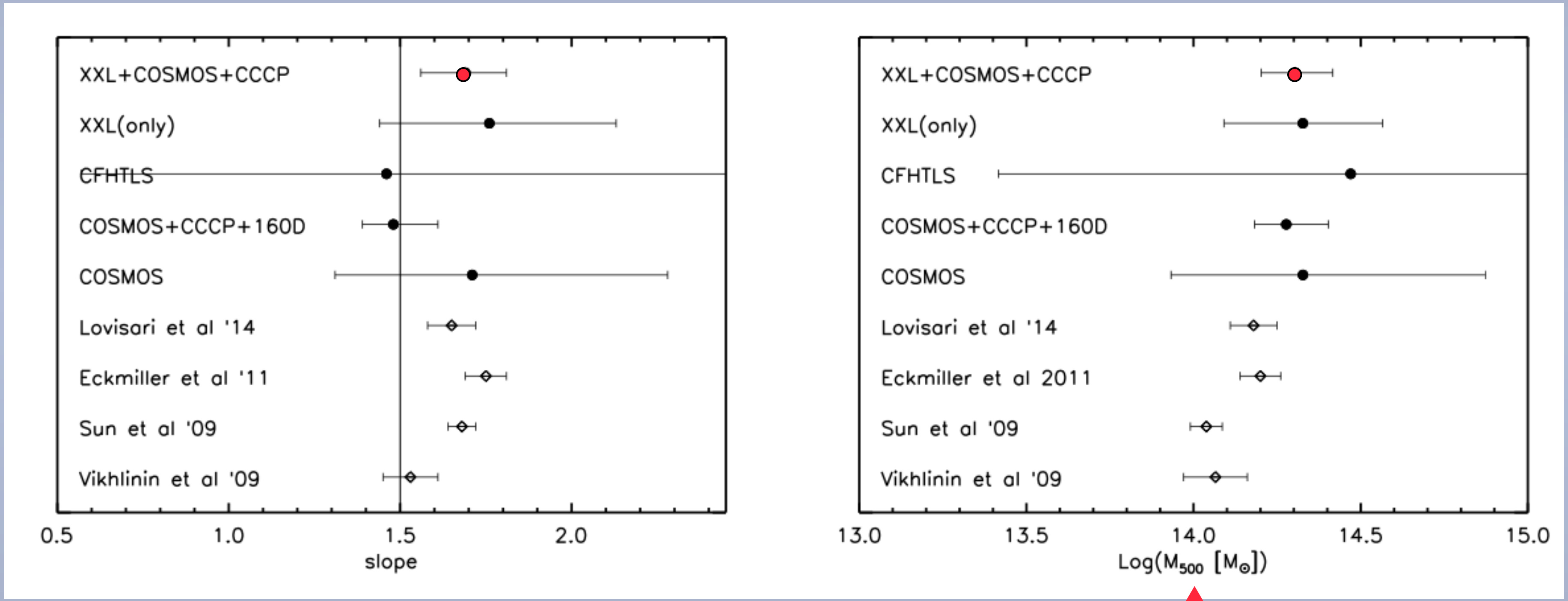
Paper IV: Lieu, Smith, Giles et al. (2016)

$$\mathrm{Log}_{10}(\mathrm{M}_{500}\mathrm{E(z)}) = \mathrm{Log}_{10}(\alpha) + \beta \mathrm{Log}_{10}(\mathrm{T_X})$$

sample	intercept (a)	slope (b)	intrinsic scatter ($\sigma_{\mathrm{int\,ln\,M|T}}$)	N
XXL	$13.55^{+0.16}_{-0.18}$	$1.76^{+0.37}_{-0.32}$	$0.56^{+0.19}_{-0.19}$	38
XXL+COSMOS+CCCP	$13.56^{+0.10}_{-0.08}$	$1.69^{+0.12}_{-0.13}$	$0.43^{+0.06}_{-0.06}$	95
XXL FS	$13.66^{+0.07}_{-0.07}$	1.50	$0.53^{+0.21}_{-0.12}$	38
XXL cool core	$13.44^{+0.21}_{-0.22}$	$1.88^{+0.46}_{-0.56}$	$0.67^{+0.24}_{-0.25}$	21
XXL non cool core	$14.20^{+0.44}_{-0.43}$	$0.81^{+0.70}_{-0.81}$	$0.51^{+0.26}_{-0.27}$	17
XXL undisturbed	$13.51^{+0.21}_{-0.16}$	$1.83^{+0.41}_{-0.33}$	$0.49^{+0.31}_{-0.23}$	19
XXL disturbed	$13.67^{+0.40}_{-0.49}$	$1.49^{+0.82}_{-0.89}$	$0.91^{+0.28}_{-0.32}$	19

Simple linear regressions in Log space
(Kelly et al. 2007)

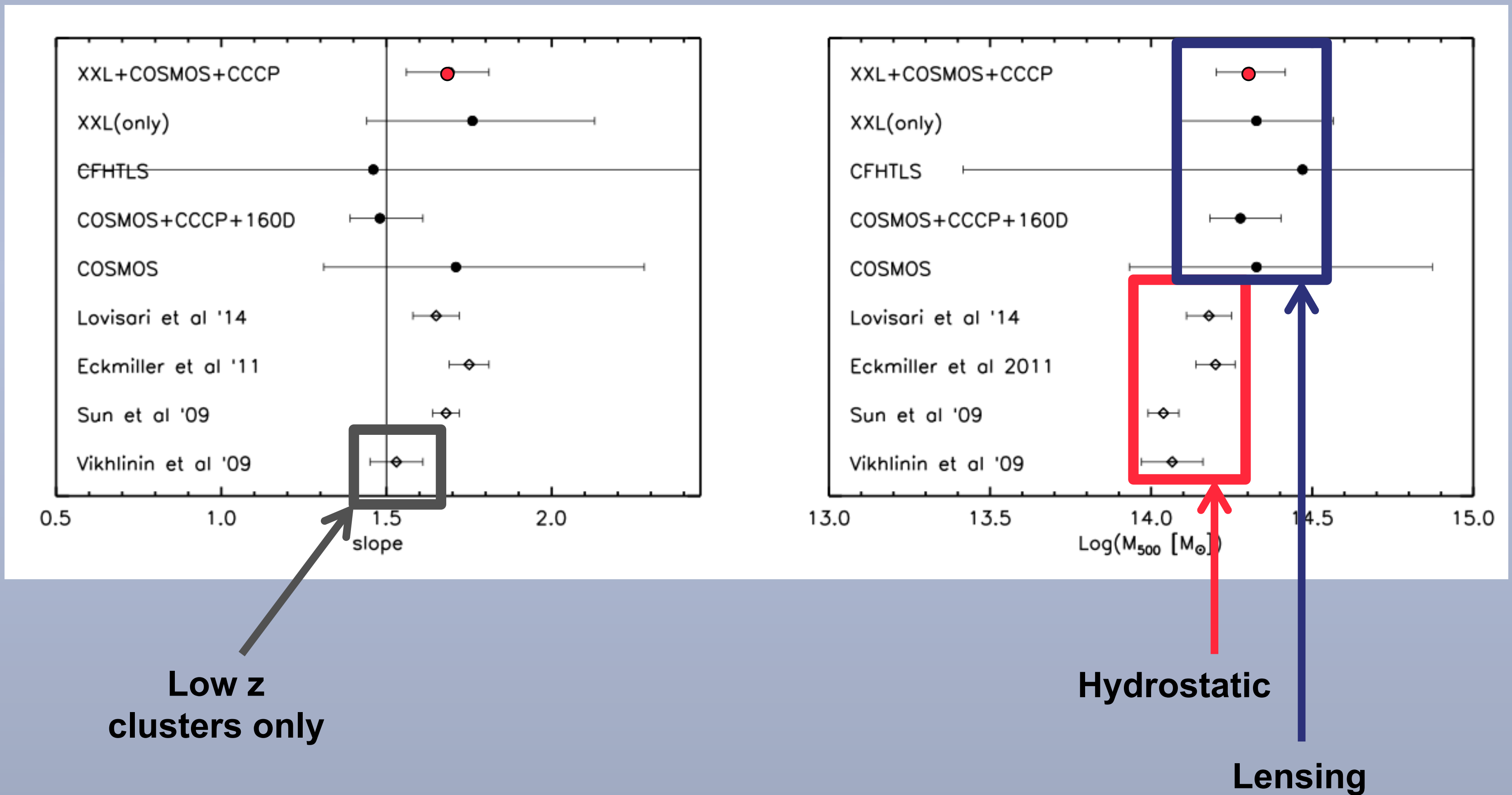
Comparison with previous works



Mass of a T=3 keV / z=0.3 cluster

Paper IV: Lieu, Smith, Giles et al. (2016)

Comparison with previous works



Paper IV: Lieu, Smith, Giles et al. (2016)