Cosmology with XMM clusters

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Clusters of galaxies as cosmic laboratories -
Stockholm -13 Sept. 2011

Slide 0 : advertising the XXL survey

- 2x25 sq.deg. paved with 10ks XMM observations : 3Ms allocated 12/2010 + 3Ms already existing (XMM-LSS & BCS)
- PI : Marguerite PIERRE (CEA/Saclay)

Table 7. Cosmological constraints. Survey configuration A2 - 50 deg^2 1/4 depth (10 ks XMM exposures) 1-σ errors on w_0 / w_a

XXL

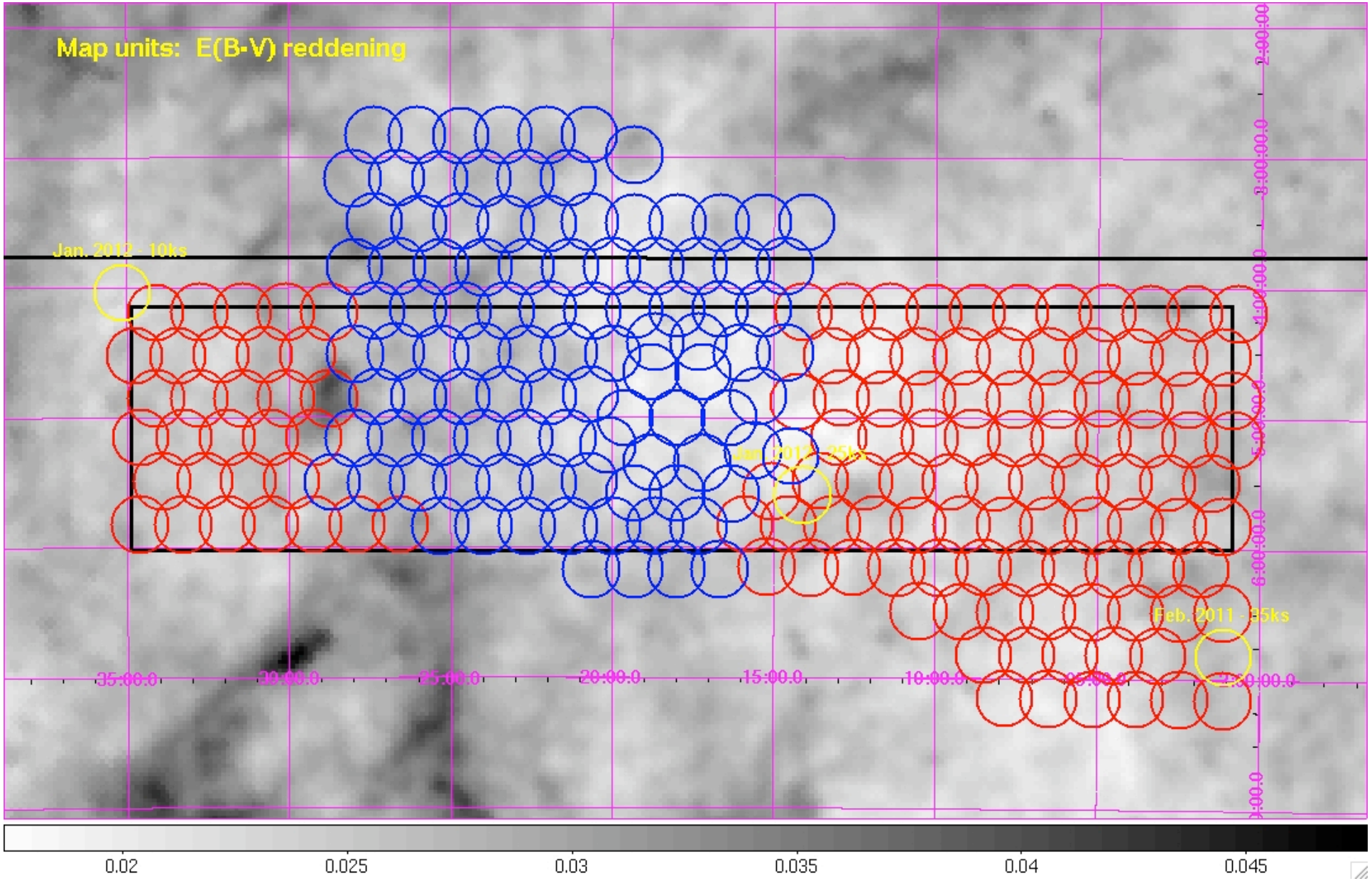
Selection	Redshift range	dn/dz + Planck	dn/dz + ξ + Planck
C1 (pessimistic)	$0 < z < 1$	2.77 / 5.98	**0.97 / 3.08**
C2 (optimistic)	$0 < z < 2$	1.14 / 2.44	**0.55 / 1.70**

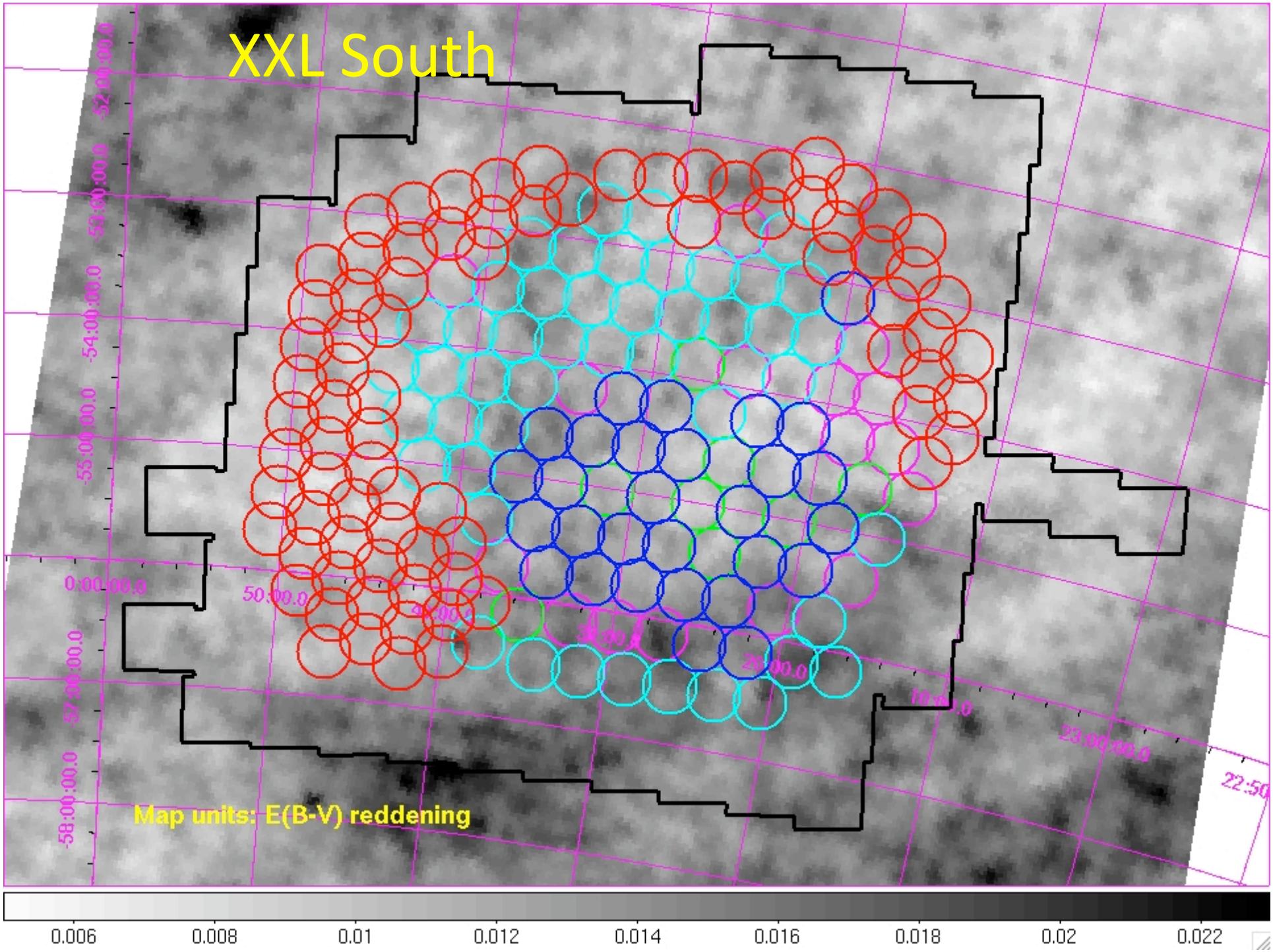
Table 8. Cosmological constraints from clusters following the DETF survey designs 1-σ errors on w_0 / w_a

Ref.
Dark Energy Task Force
clusters

Stage	Pessimistic	Optimistic
III	0.70 / 2.11	0.26 / 0.77
IV	0.73 / 2.18	0.24 / 0.73

XXL North


Map units: E(B-V) reddening
Jan. 2012 - 10ks
Jan. 2012 - 35ks
Feb. 2011 - 35ks
35:00.0
30:00.0
25:00.0
20:00.0
15:00.0
10:00.0
05:00.0
2:50:00.0
2:00:00
3:00:00.0
4:00:00.0
5:00:00.0
6:00:00.0
0.02
0.025
0.03
0.035
0.04
0.045


XXL South
Map units: E(B-V) reddening
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0.022

Advertising the XXL survey

« The ultimate XMM extragalactic survey »

- Legacy aspects :
  - X-ray catalogues (500 clusters, 10,000 sources)
  - Multi-λ catalogues : from X-ray to FIR
  - Spectroscopy
- 80+ members in the consortium
- Lots of scientific applications !
- Collaborators still welcome
  http://irfu.cea.fr/xxl

Outline

1. CR-HR diagrams : a new method for interpreting cluster number counts
2. Application of the CR-HR method to the XMM archival data : the X-CLASS catalogue

submitted to MNRAS

1. CR-HR ANALYSIS

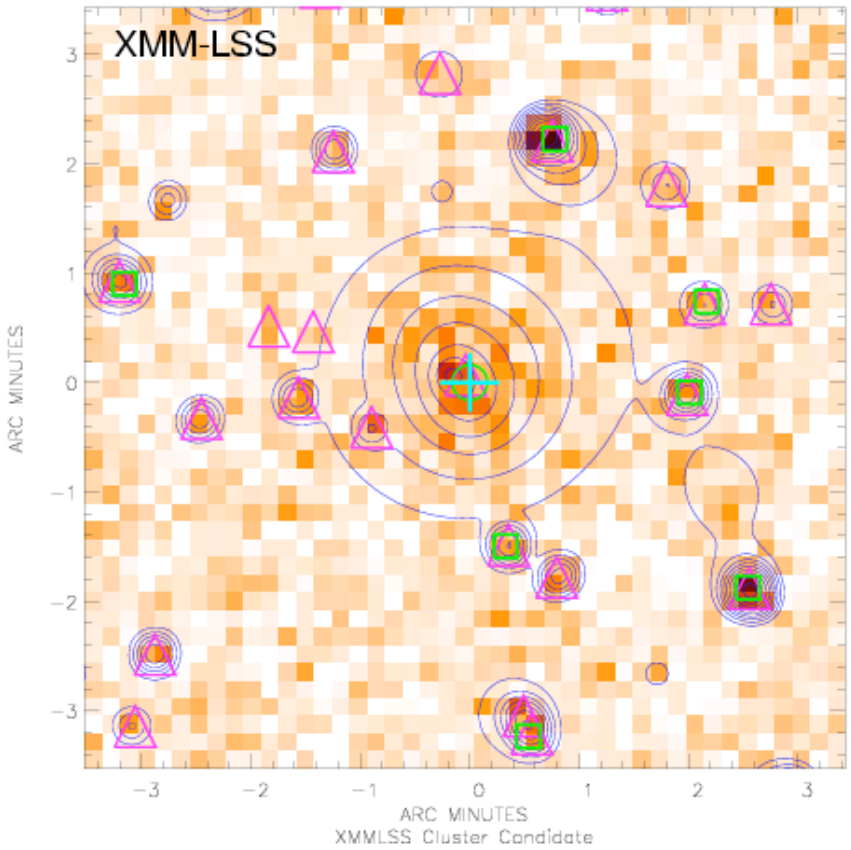
Background

- Shallow X-ray cluster survey
- Large area
- Detected clusters : ~few hundred photons
  - Temperature estimates T_X $(\Delta T/T \sim 10 - 50\%)$
  - No temperature profiles $T_X(r)$

- Case study :
  100 deg^2 , 10 ks XMM
  sensitivity (clusters) : $\sim 10^{-14} \mathrm{ergs/s/cm}^2$

- Possible additional redshift follow-up

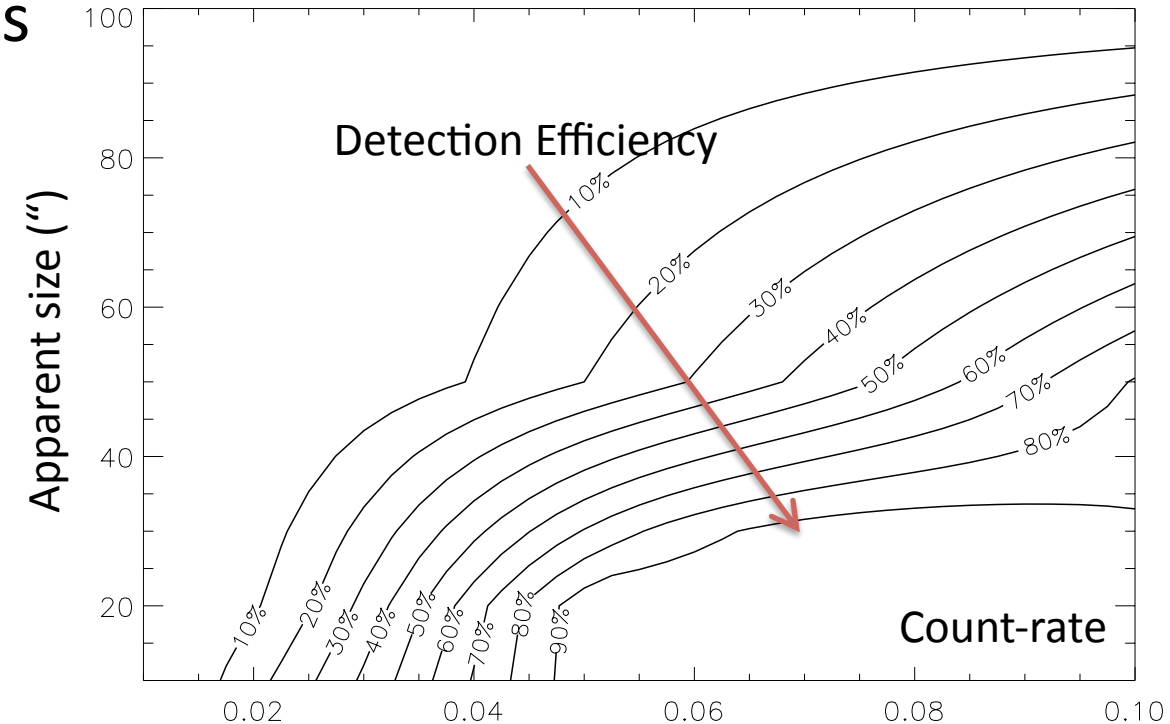
Background

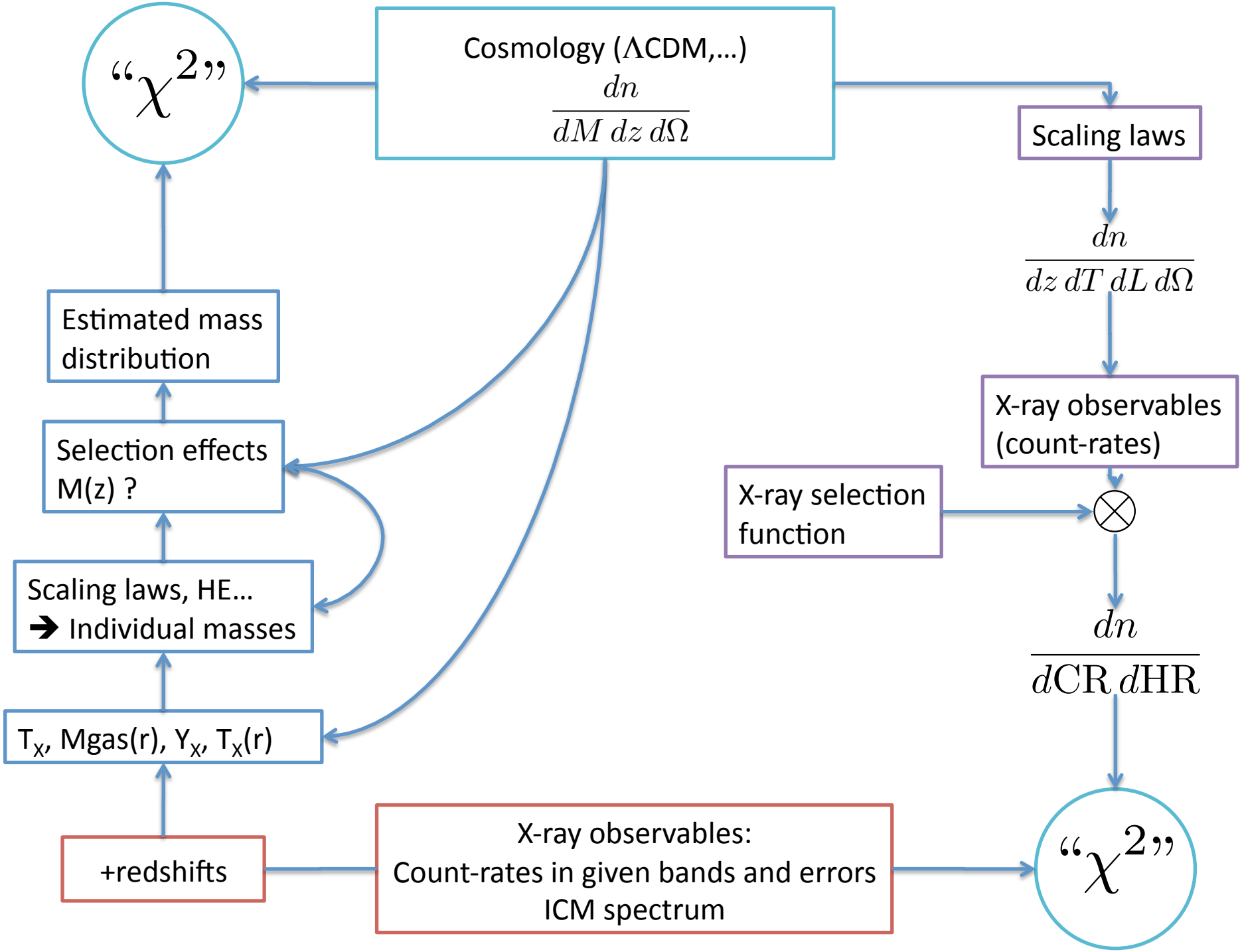


Example : XLSSC 051 (Pacaud et al. 2007)
300 counts in 0.5-2 keV

Goal

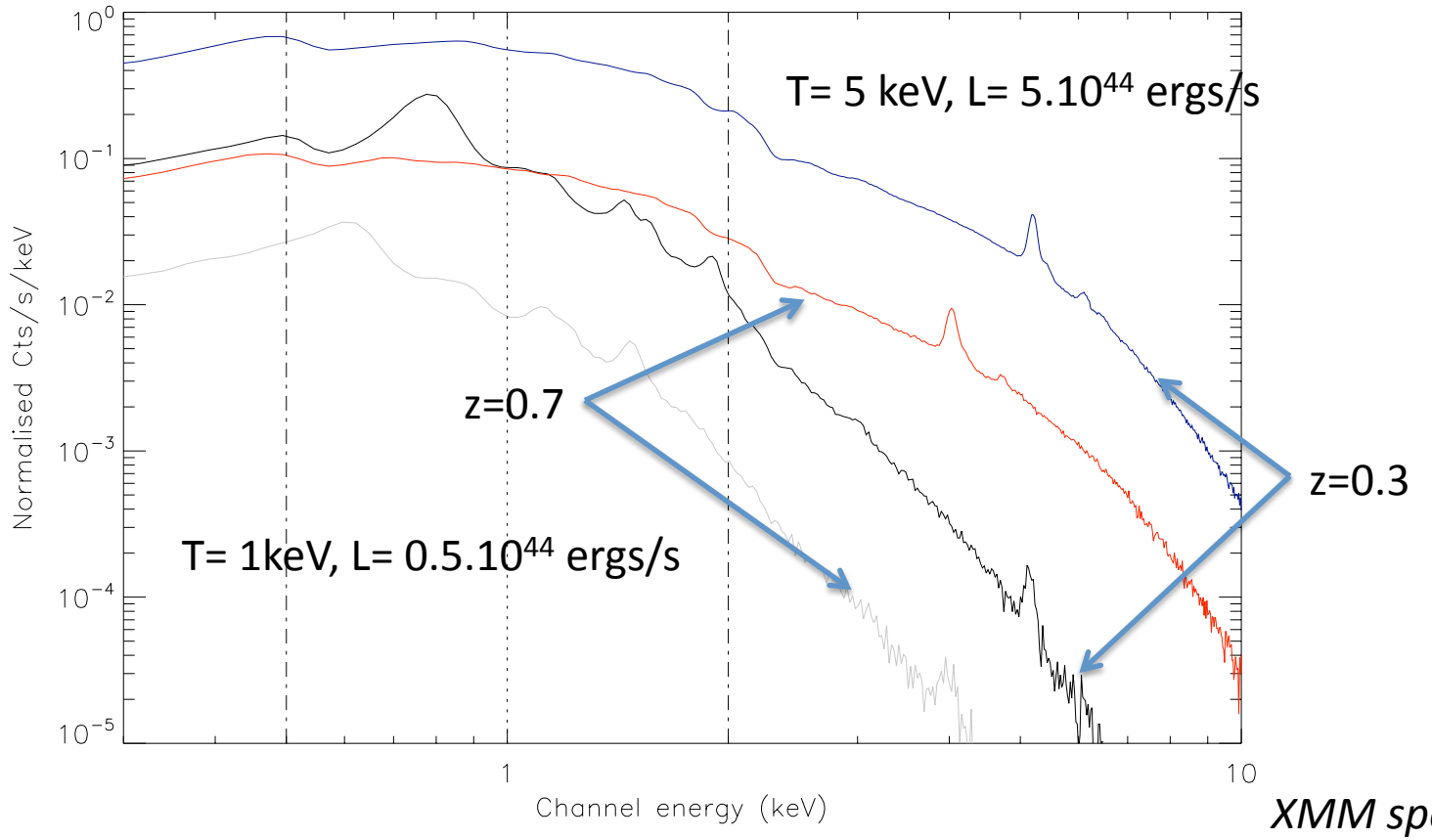
- Modeling the cluster population
  - Cosmology
  - Cluster emissivity (scaling laws+instrument)
  - Selection effects




"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Scaling laws
$\frac{dn}{dz\,dT\,dL\,d\Omega}$
X-ray observables (count-rates)
X-ray selection function
$\frac{dn}{d\mathrm{CR}\,d\mathrm{HR}}$
"χ^2"
Estimated mass distribution
Selection effects M(z) ?
Scaling laws, HE...
➔ Individual masses
T_X, Mgas(r), Y_X, T_X(r)
+redshifts
X-ray observables:
Count-rates in given bands and errors
ICM spectrum

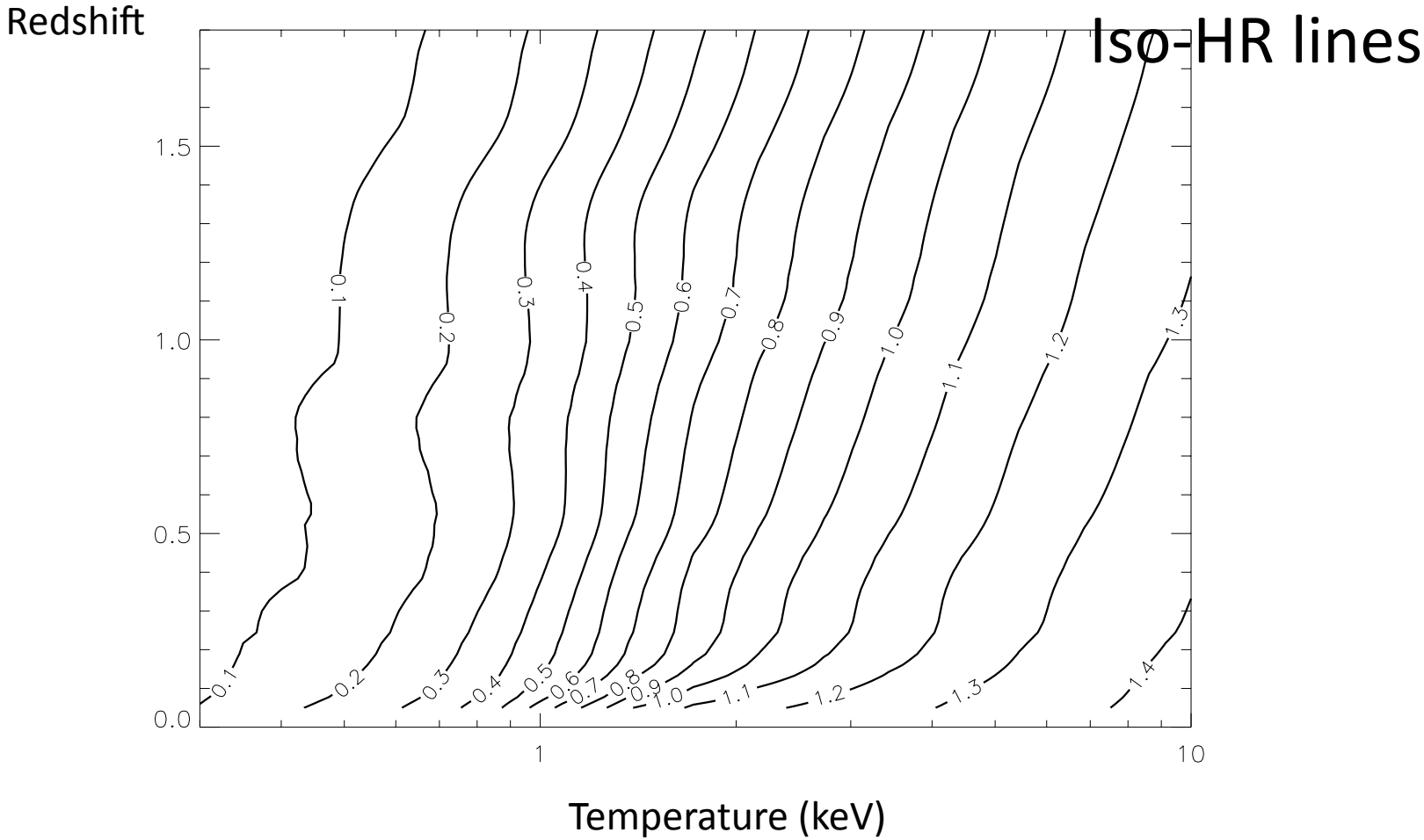
Principle

- Count-rates measurements in several bands
- CR in [0.5-2] keV (~flux) and HR = [1-2]/[0.5-1] (~spectrum)



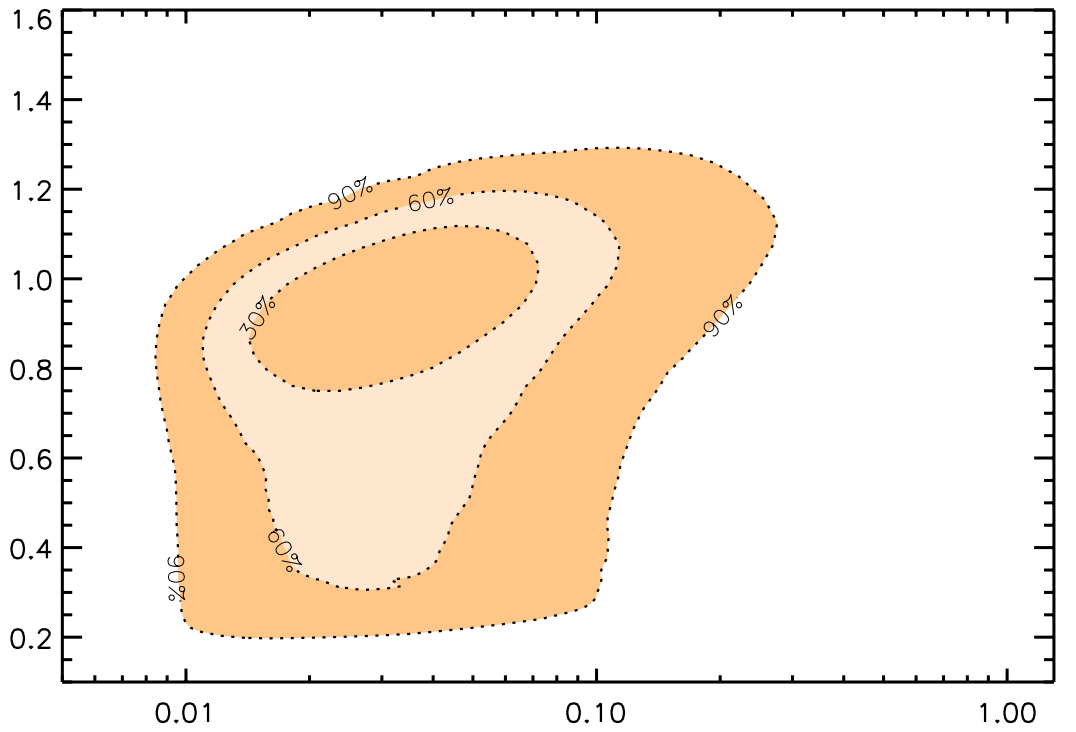
XMM spectra, $T_{exp}= \infty$

Principle


Redshift
Iso-HR lines
1.5
1.0
0.5
0.0
1
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Temperature (keV)

CR-HR distribution

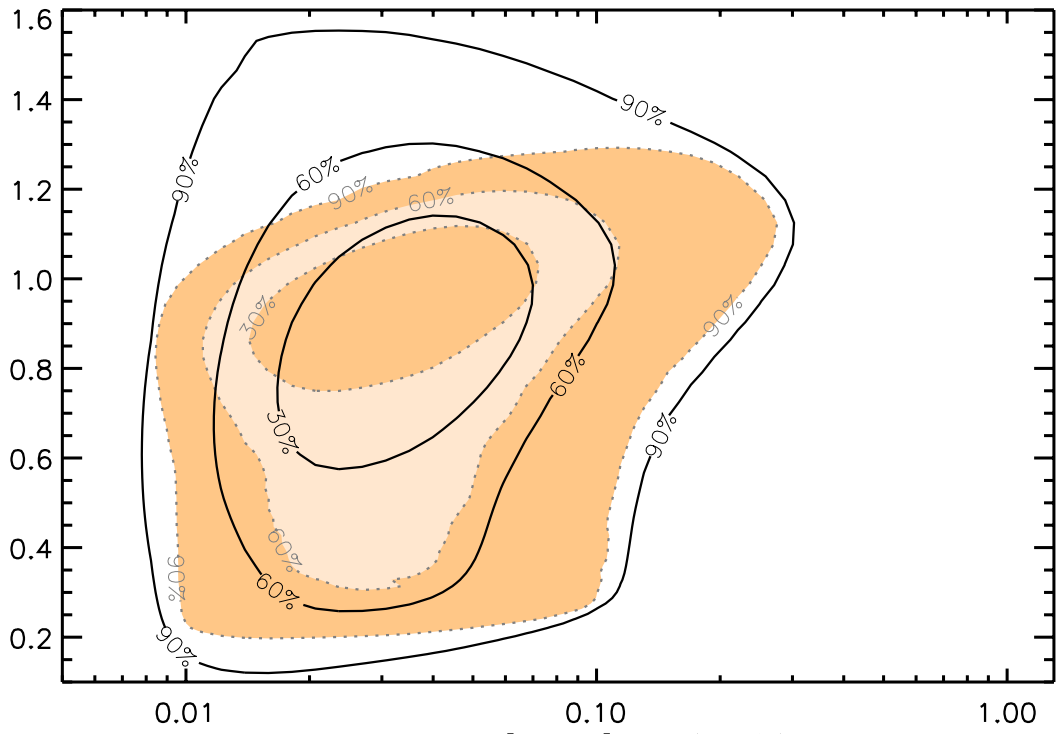
[1-2] keV / [0.5-1] keV hardness ratio (HR)



[0.5-2] keV Count-rate (CR, cts/s)

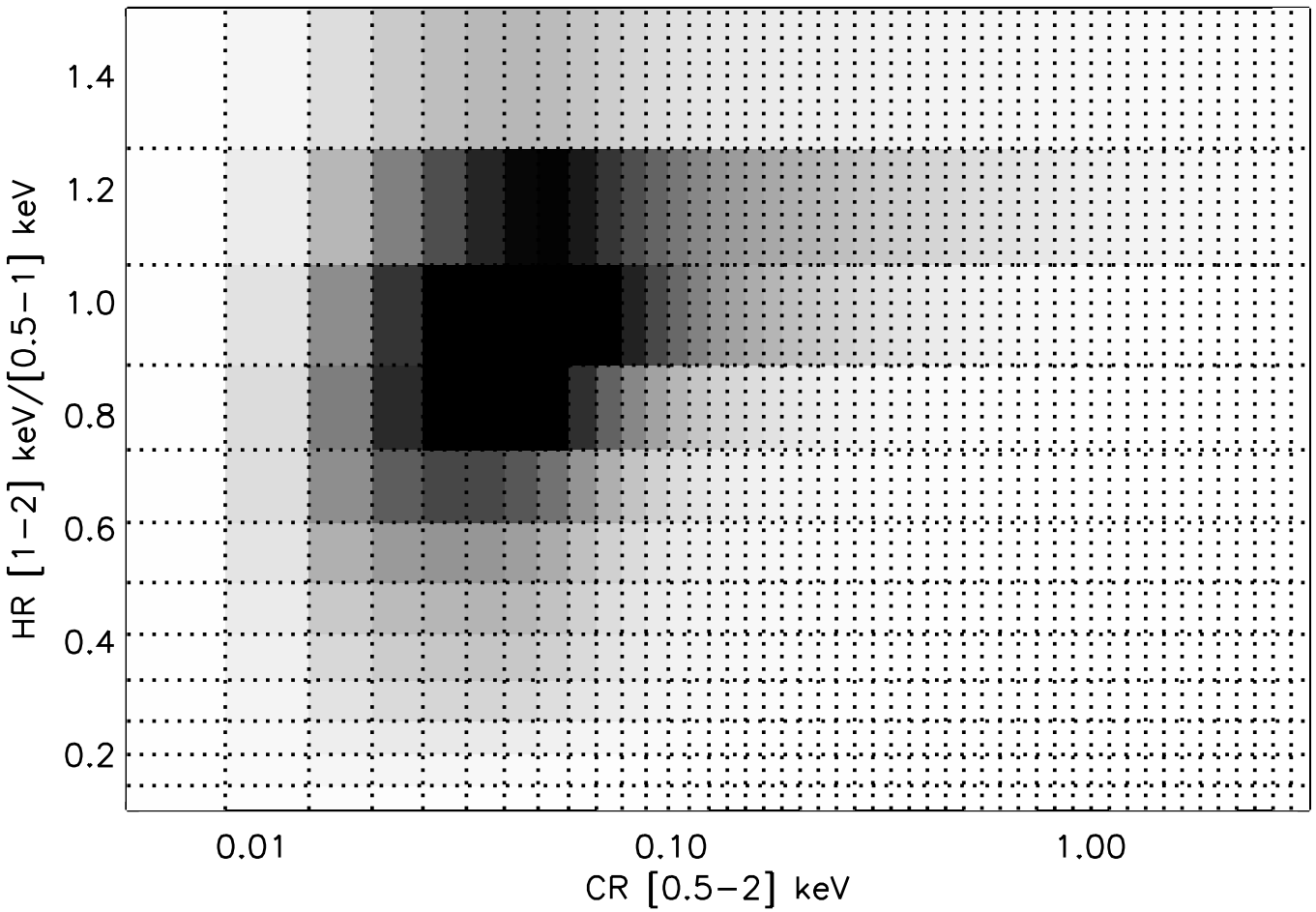
+ measurement errors

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



[0.5-2] keV Count-rate (CR)

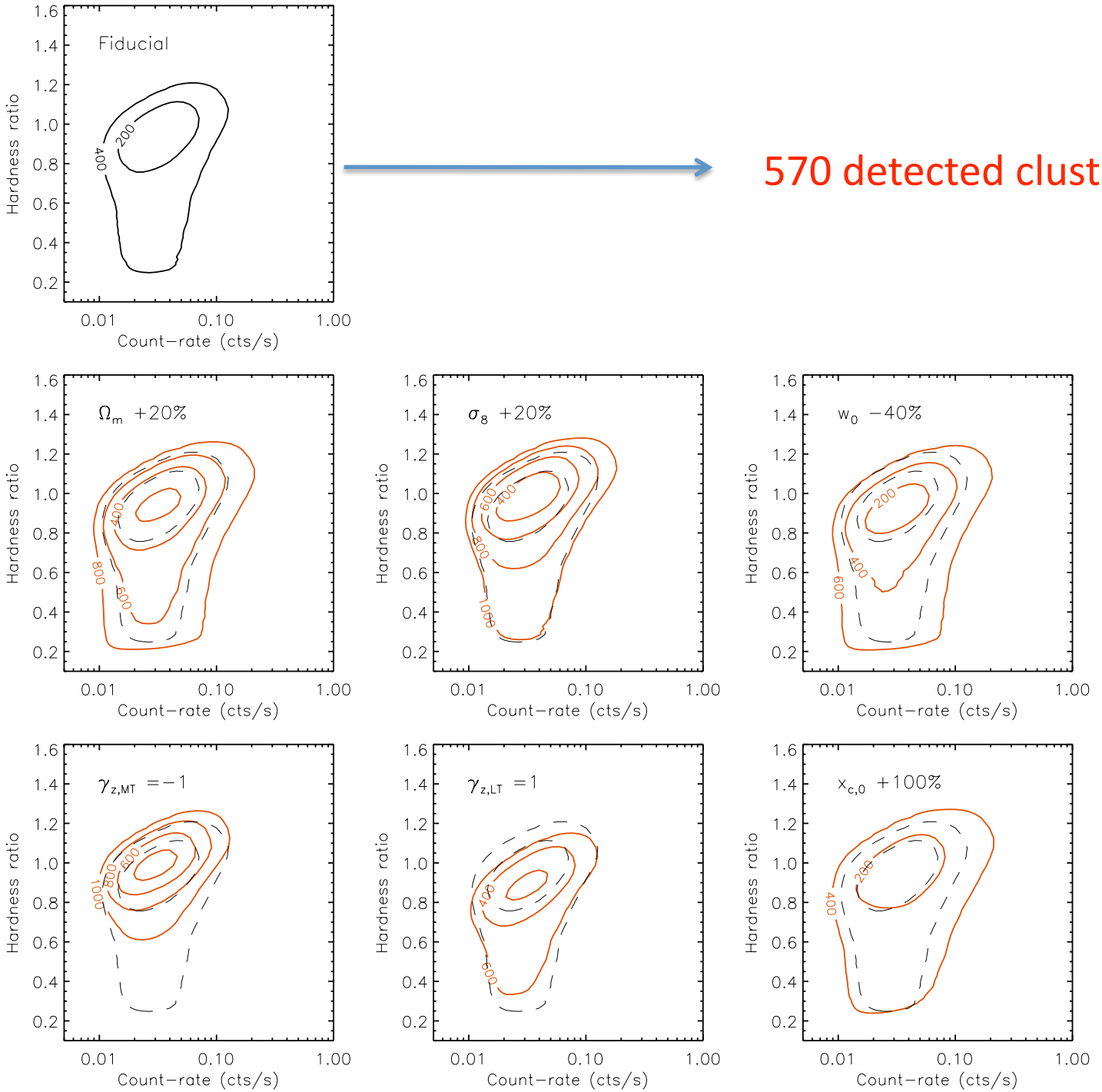
+ measurement errors



Working hypotheses

- Known local scaling laws
  - M_{200c}-T (Arnaud & Pointecouteau 2005) + scatter
  - L_X – T (Pratt et al. 2009) + scatter
  - Evolution of the normalisations :$(1+z)^{\gamma_{MT}}$, $(1+z)^{\gamma_{LT}}$

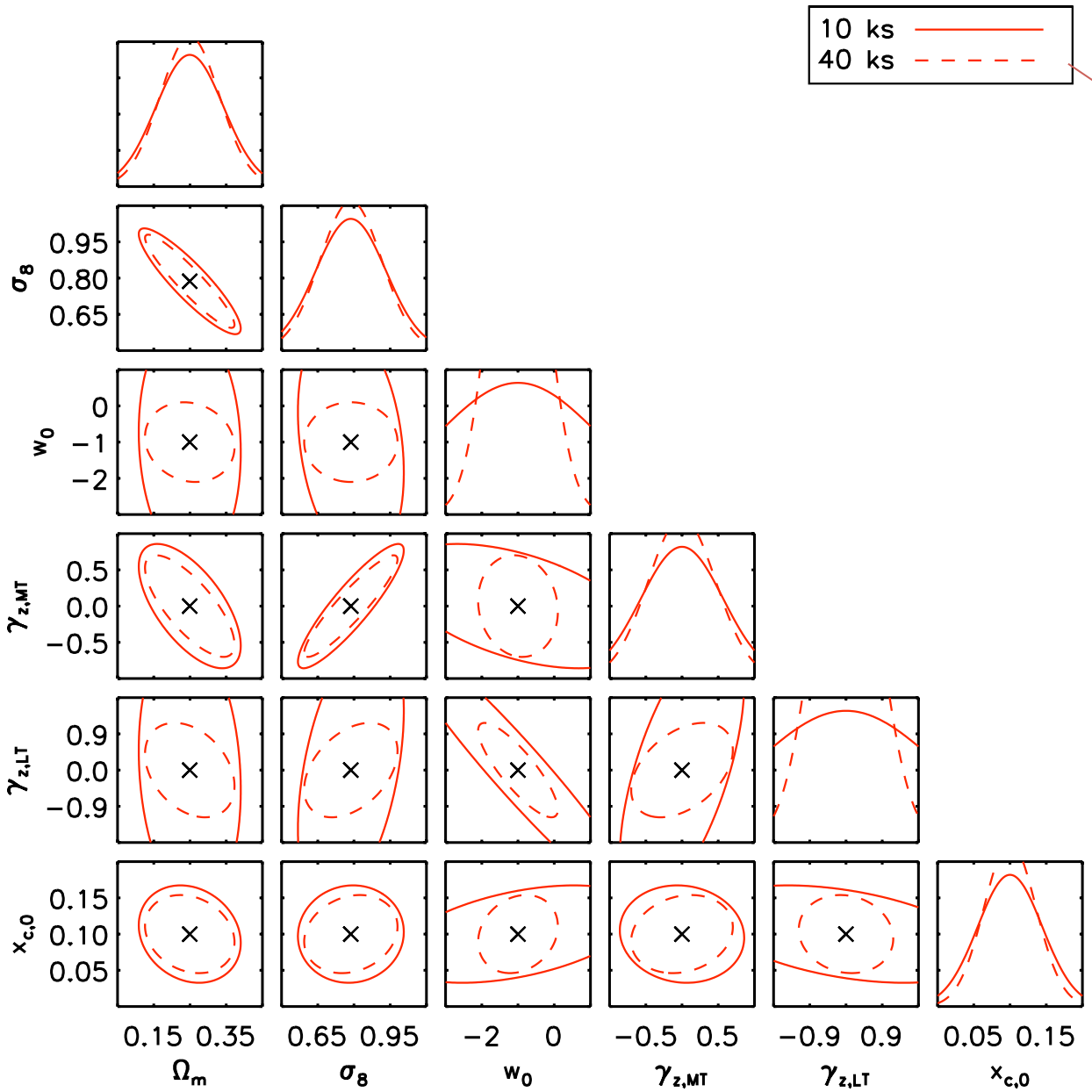
- Cosmo : WMAP priors except Ω_m , σ_8
- Profile : β-model with core-radius $\propto R_{500c}$



570 detected clusters over 100 deg^2

➔ Fisher analysis

Without redshifts



X-ray follow-up of each detected cluster

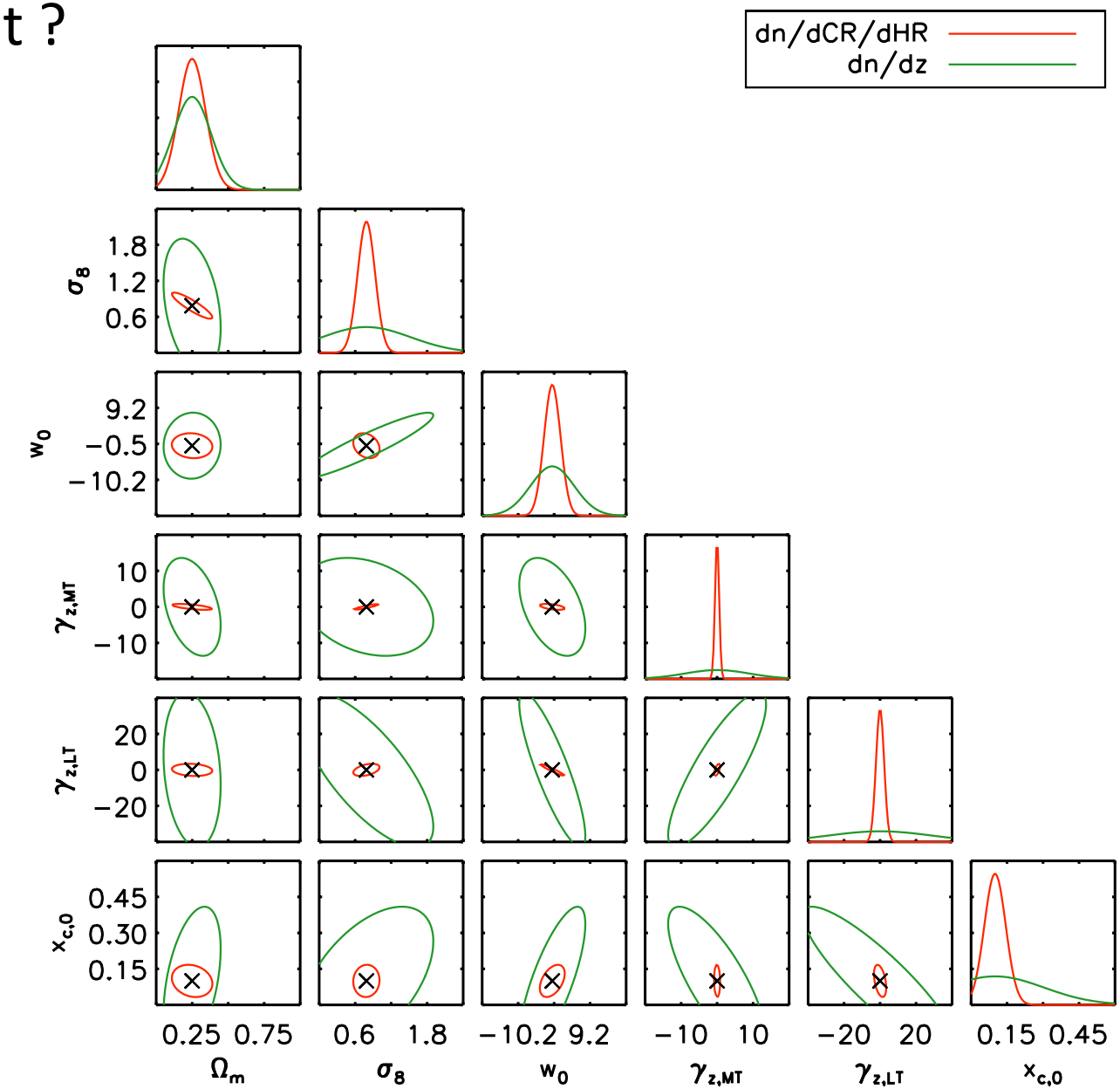
$$\frac{\Delta\Omega_m}{\Omega_m} \sim 30\%$$

$$\frac{\Delta\sigma_8}{\sigma_8} \sim 15\%$$

Adding redshifts

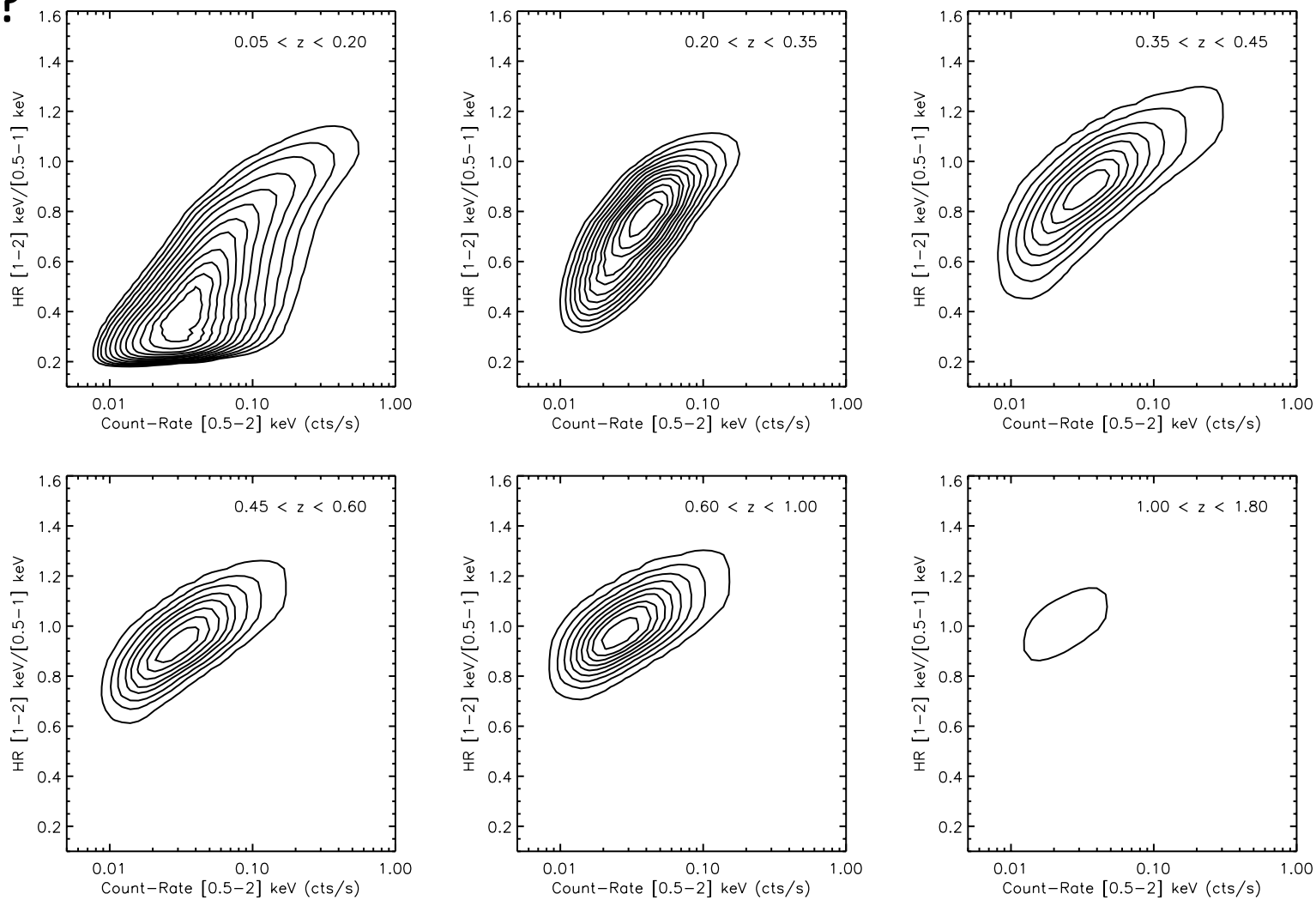
1) Is dn/dz sufficient ?

No, degeneracies



Adding redshifts

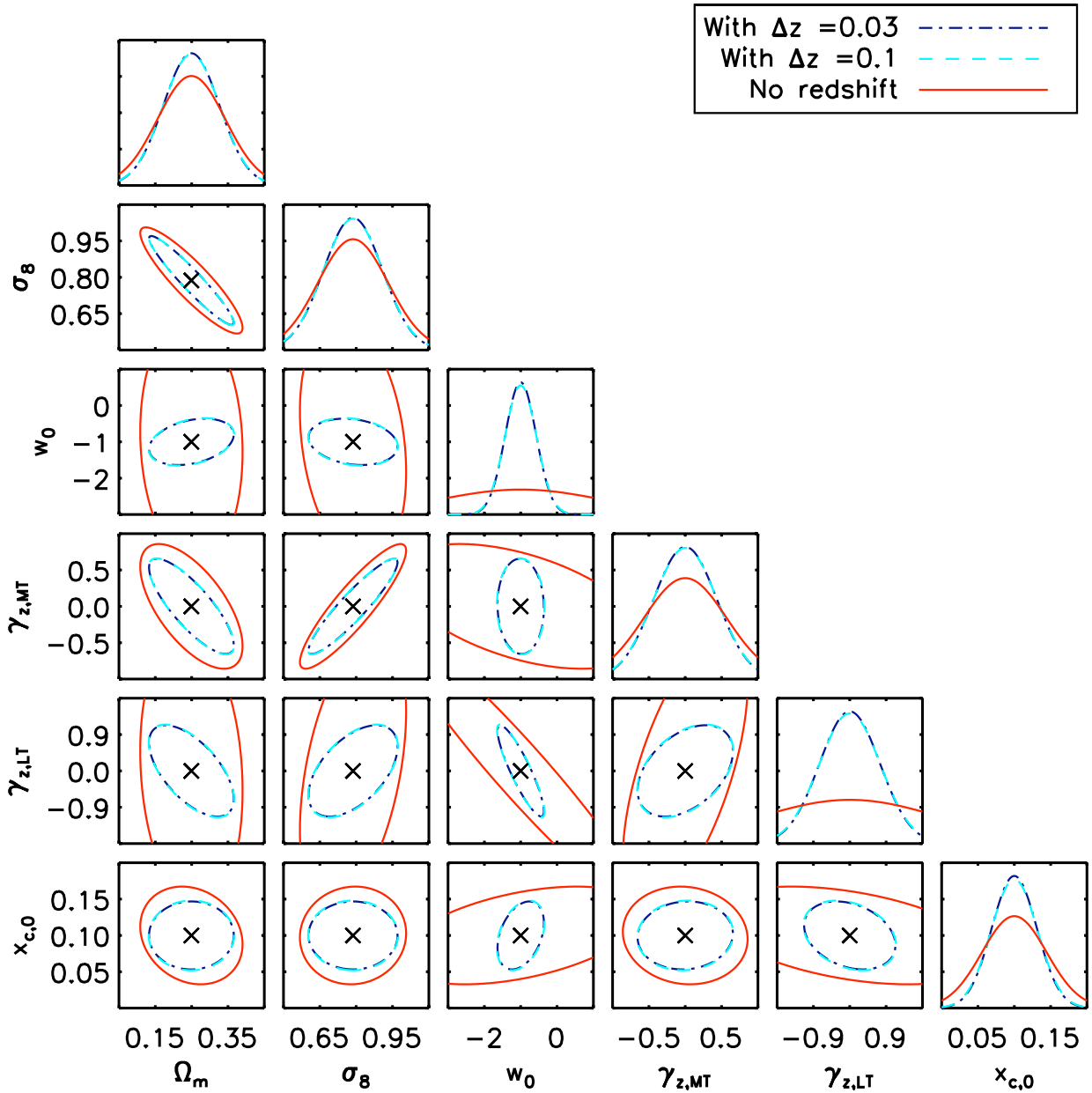
2) 3rd dimension to the diagram?



Adding redshifts

2) 3rd dimension to the diagram?

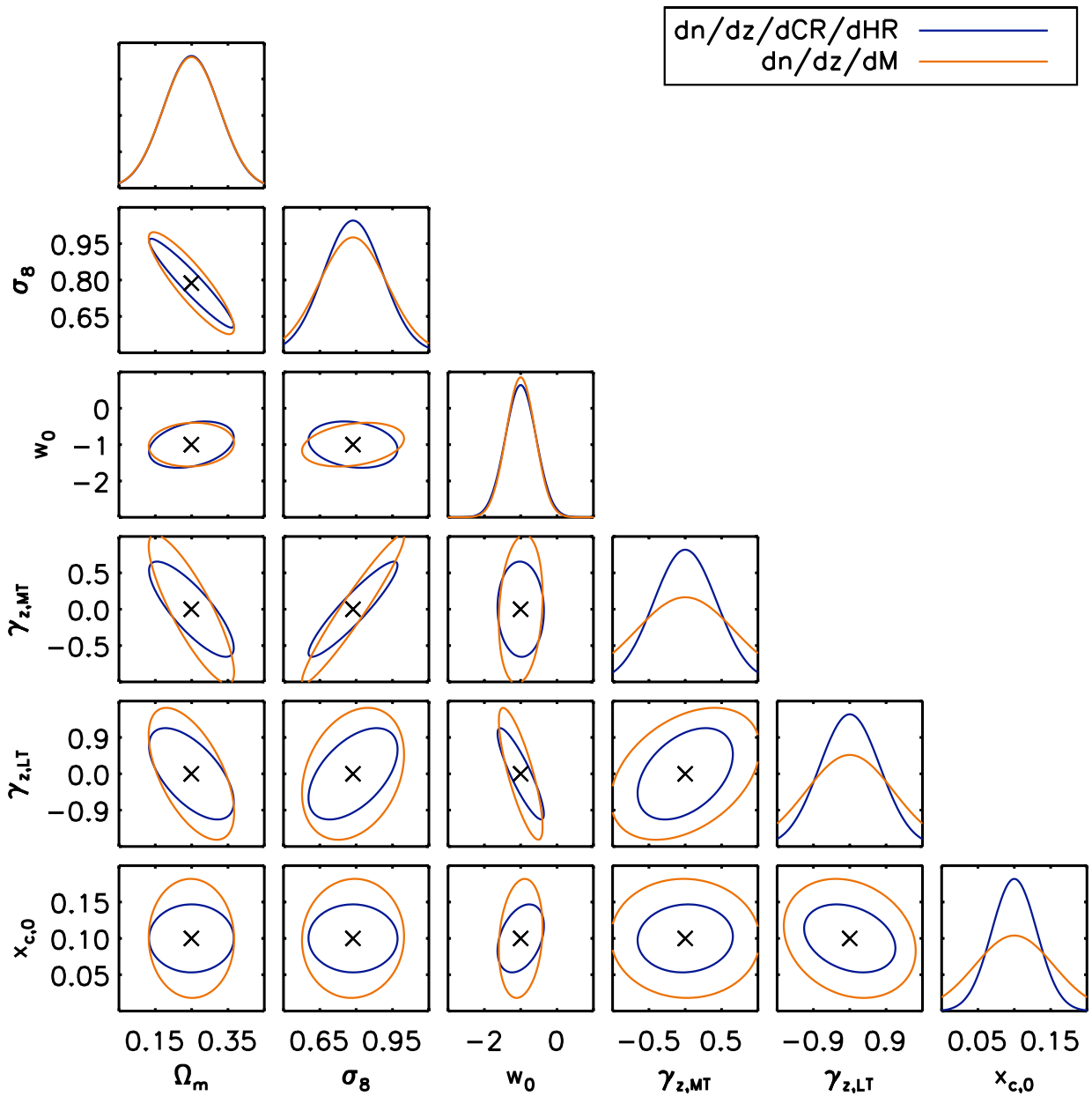
« z-CR-HR » diagram



Adding redshifts

3) Calculating masses ?

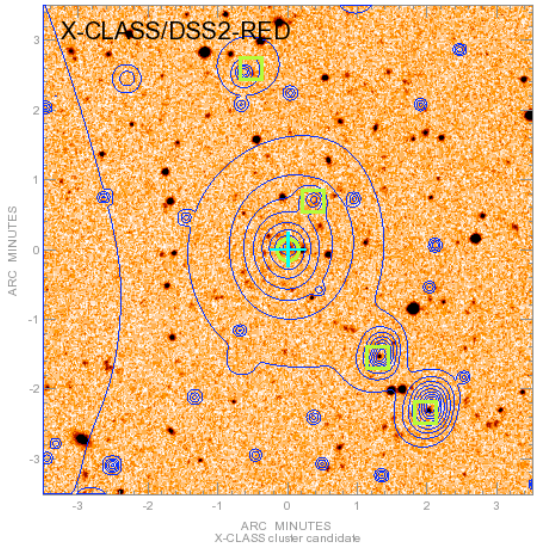
- $T_X \rightarrow M$
- dn/dz/dM
- measurement errors (z and M)

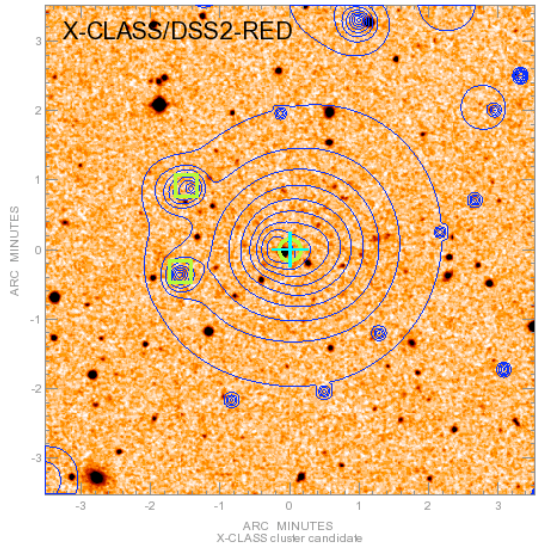


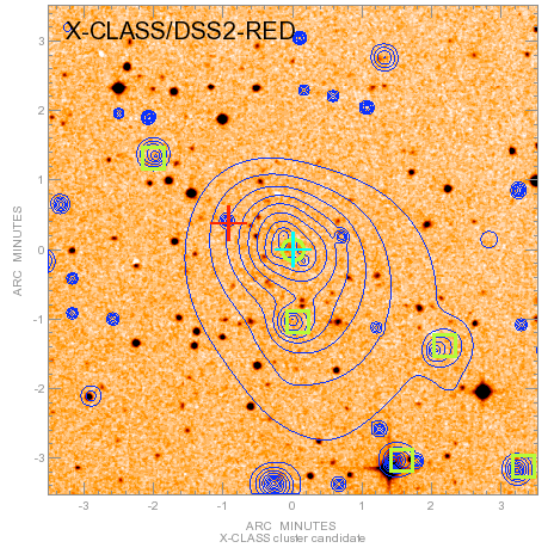
Summary (1)

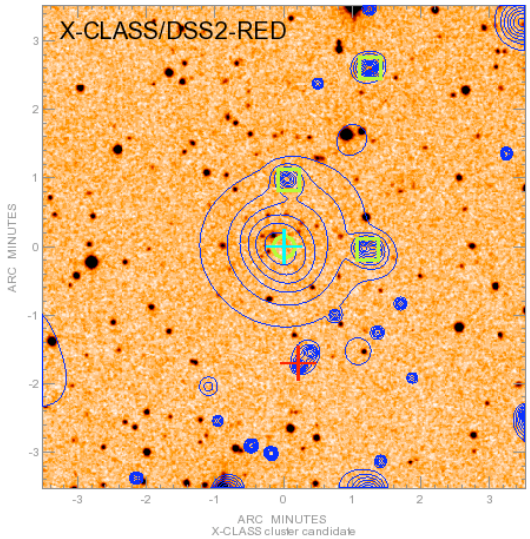
- A new method based on purely X-ray observables and z, if available : (z)-CR-HR
- CR-HR method efficient for current shallow X-ray surveys, needs local scaling laws
- z-CR-HR well suited to the analysis of large cluster samples with photo-z
- Straightforward method, easily set up (compared to dn/dz/dM) for equivalent results

2. APPLICATION TO THE XMM ARCHIVE









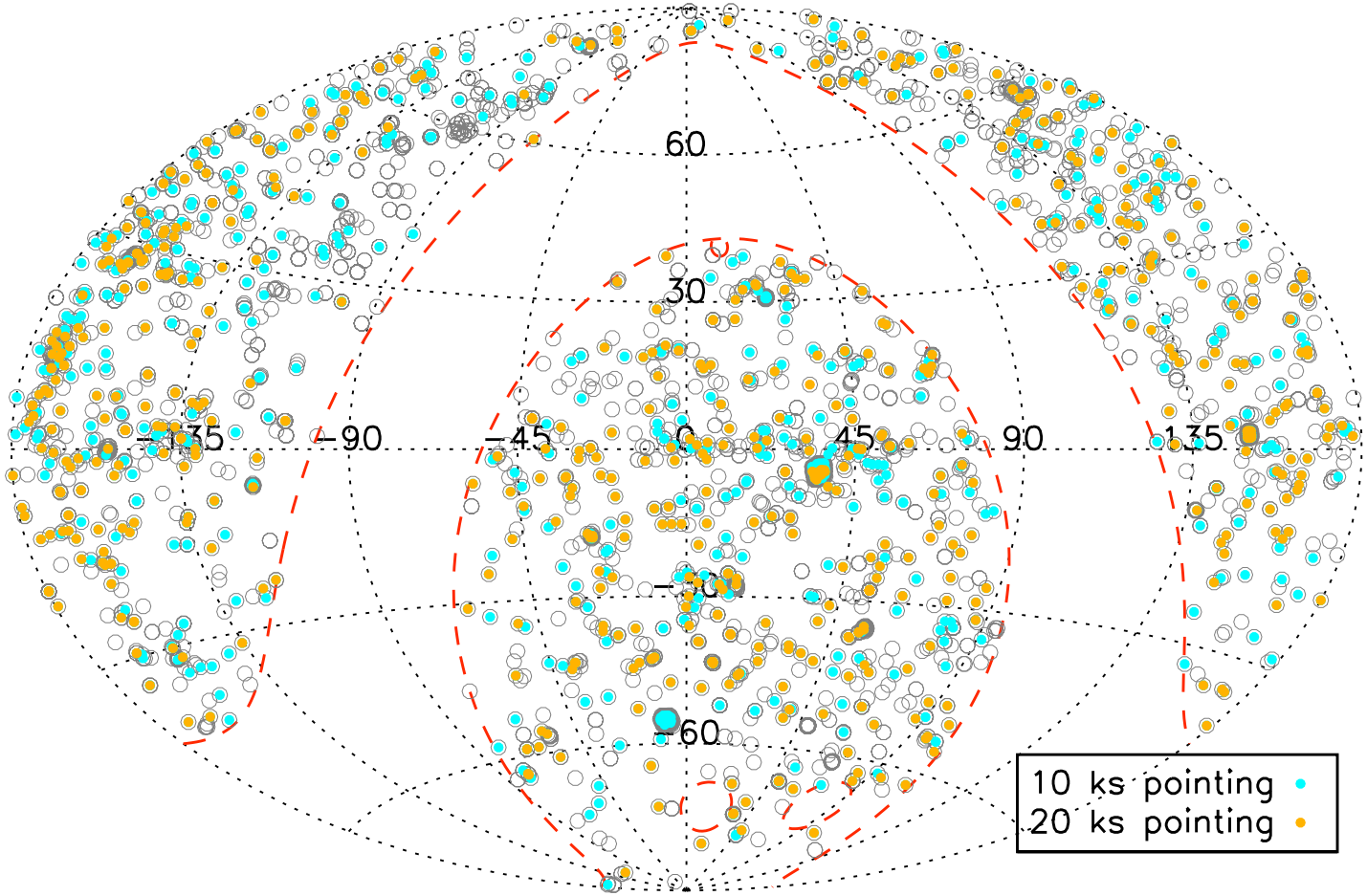
XMM
CLuster
Archive
Super
Survey

= ‘X-CLASS’

X-CLASS

- Extending the well-assessed XMM-LSS methodology (Pierre et al. 07) to 2774 observations selected in the XMM archive
  - High galactic latitude
  - Texp = 10 or 20ks
  - Imaging mode

X-CLASS



X-CLASS

- C1 selection (Pacaud et al. 06, 07) :
  - EXT likelihood/ Apparent extension criteria
  - Pure X-ray cluster sample

- POSS-II sufficient to remove nearby galaxies, planets, some saturated point sources

- 845 candidates in total

X-CLASS ‘science’ sample

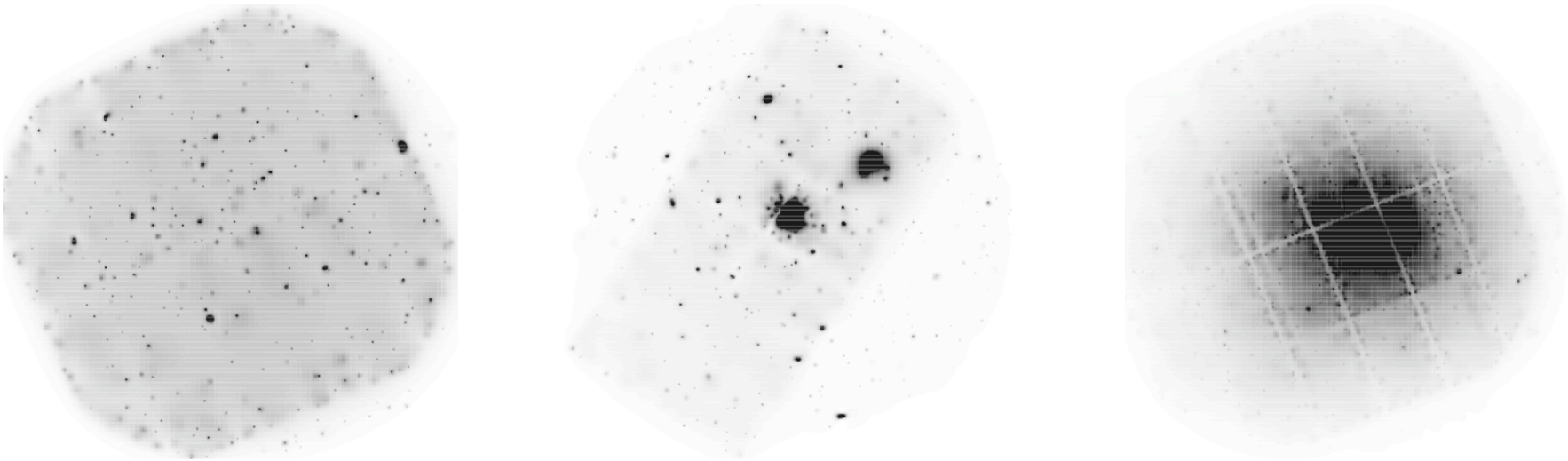
- More restrictive selection (C1+)
- < 10 arcmin offaxis on XMM detectors
- Count-rate selection : 0.009<CR<0.5 cts/s (eliminates very faint sources, and bright clusters for which the cluster selection function is much more complicated)

➔ 347 high signal-to-noise sources

➔ Count-rates measured by hand in several energy bands

X-CLASS ‘science’ sample

- Subsample of interesting pointings:
  - Remove highly flared, partial window detector mode, and pointings with very extended source in the foreground



- 90 sq.deg. area

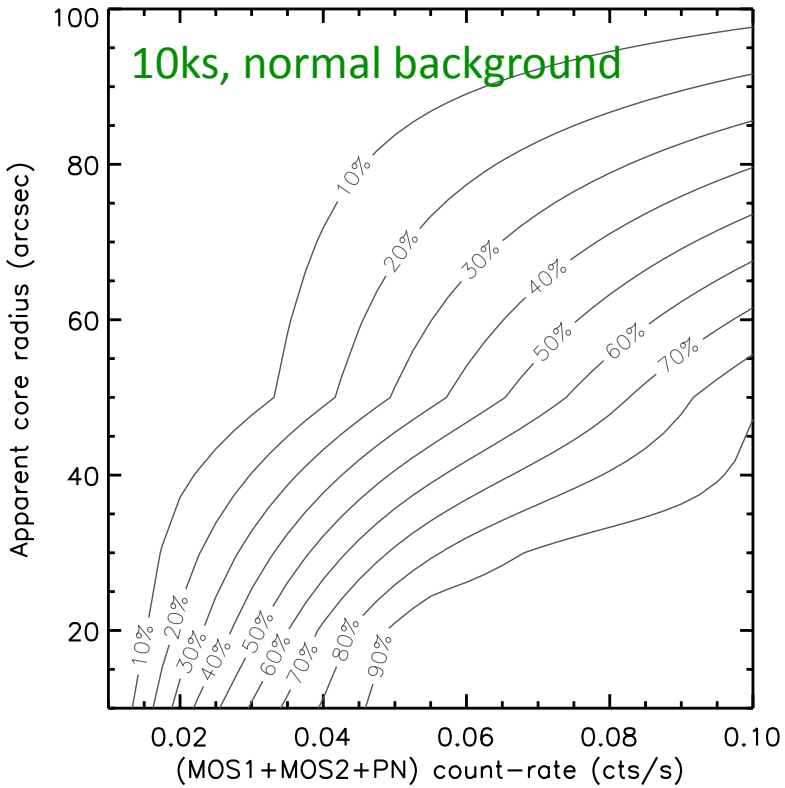
Dedicated interactive database

id	xclass	name	R.A. *pipeline measured*	DEC *pipeline measured*	NED	quality	class	obs	main	nb links	redshift	status	total rate	profile
20	0020	0001930301_84_v3.3_c1_10ks	193.438 193.438	10.195 10.195	-	1	z > 0.3	0001930301_10ks					0.052	data
23	0023	0010420201_53_v3.3_c1_10ks	194.292 194.292	-17.412 -17.406	21	1	0 < z <~ 0.3	0010420201_10ks			0.047	confirmed	12.622	data
33	0033	0030140101_1_v3.3_c1_10ks	193.679 193.674	-29.223 -29.223	7	1	0 < z <~ 0.3	0030140101_10ks			0.053	confirmed	4.290	data
34	0034	0030140101_3_v3.3_c1_10ks	193.595 193.593	-29.016 -29.013	25	1	0 < z <~ 0.3	0030140101_10ks			0.053	confirmed	3.667	data
35	0035	0032141201_44_v3.3_c1_10ks	196.274 196.274	-10.280 -10.279	-	1	z > 0.3	0032141201_10ks			0.330	photometric	0.047	data
38	0038	0037981801_11_v3.3_c1_10ks	36.567 36.568	-2.666 -2.666	1	1	0 < z <~ 0.3	0037981801_10ks					0.165	data
39	0039	0037981801_112_v3.3_c1_10ks	36.499 36.499	-2.827 -2.828	1	1	0 < z <~ 0.3	0037981801_10ks			0.280	confirmed	0.031	data
40	0040	0037982601_56_v3.3_c1_10ks	35.188 35.189	-3.434 -3.434	1	1	z > 0.3	0037982601_10ks			0.330	confirmed	0.050	data

➔ Images, NED correlations, redshifts (if available), count-rates…

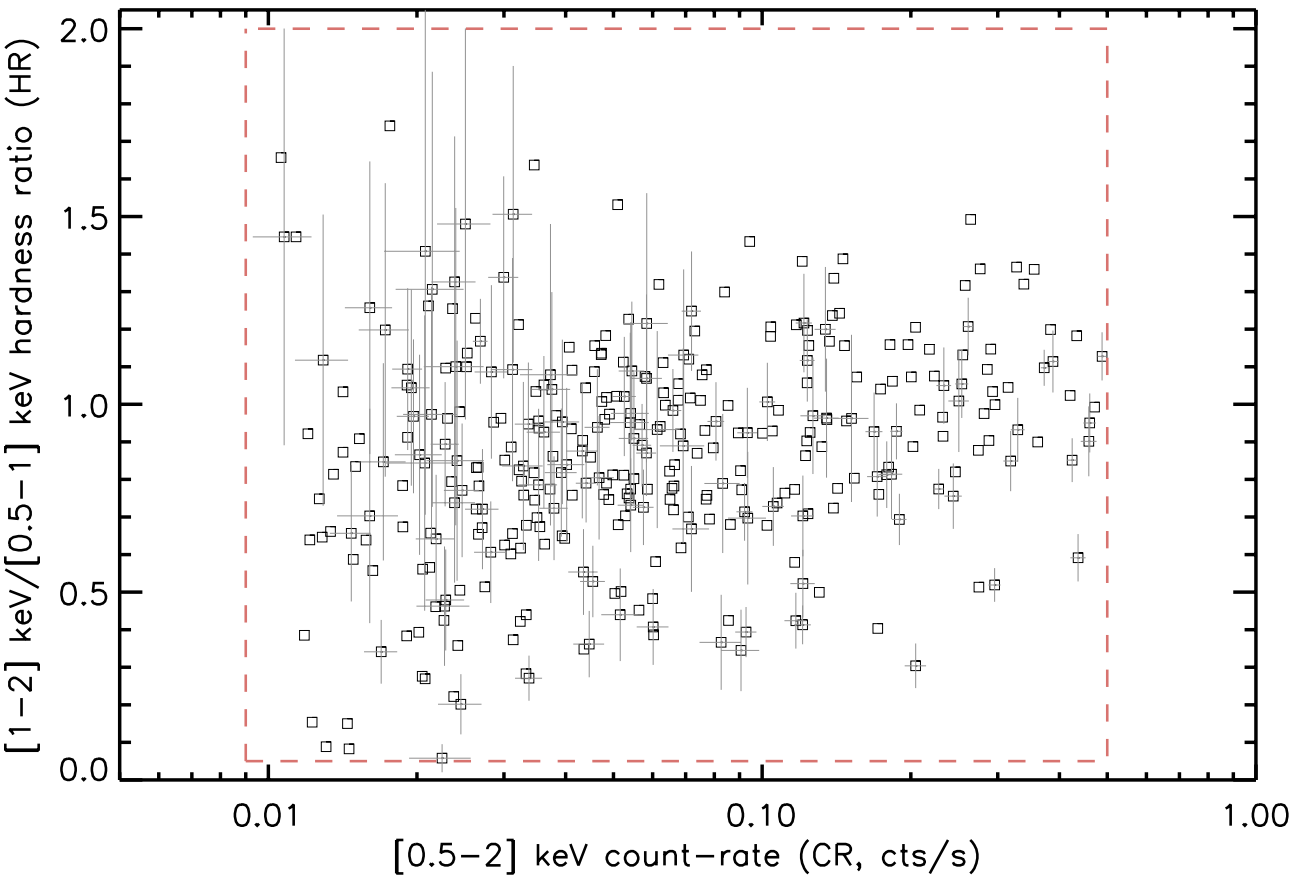
http://xmm-lss.in2p3.fr:8080/l4sdb/

X-CLASS selection function



- > 18000 fake XMM observations with varying Texp, background
- Fake clusters with varying sizes, fluxes
- Detection efficiency = f(*size,count-rate*) for each pointing

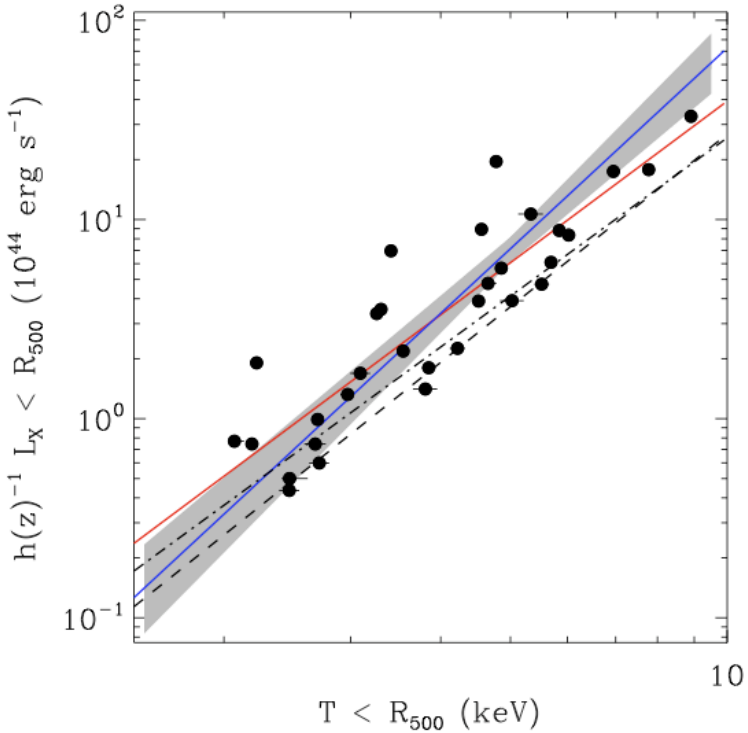
CR-HR analysis



Fitting procedure

- Flat ΛCDM
- Fixed local M-T
- Fixed local L-T
  - Pratt 09 'ALL'
  - Pratt 09 'Non Cool Core'

- MCMC chains



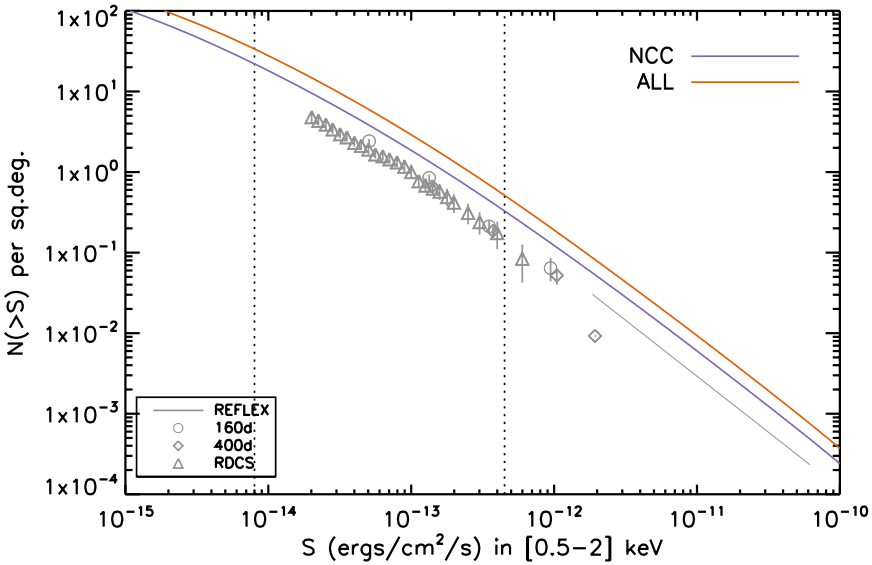
Pratt et al '09

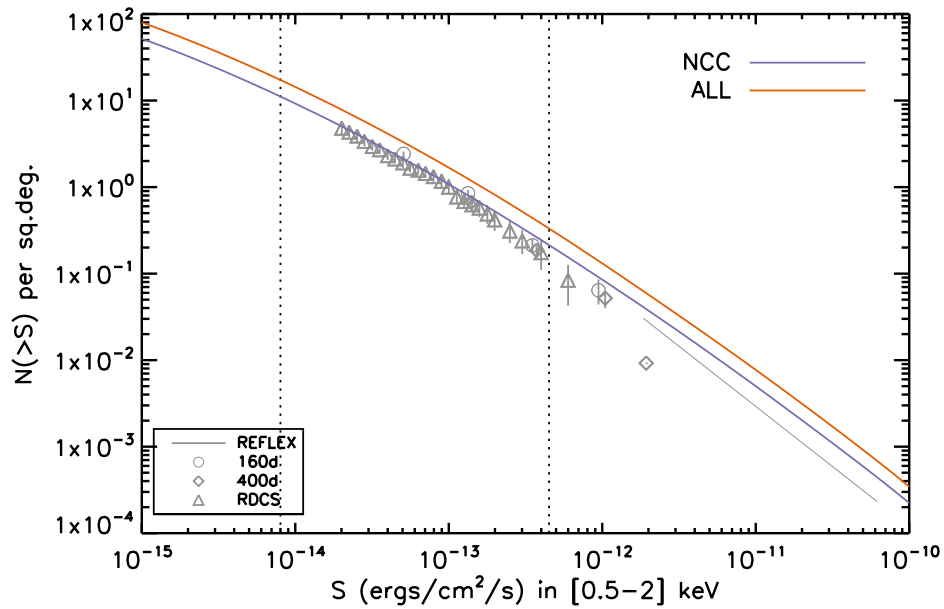
Fixed cosmology

- WMAP-5
- Preference for the 'NCC' relation with a high scatter
- Points toward a negative evolutions of the T-M and the L-T (rel. to self-similar)
- Results consistent with published logN-logS

Local L–T:	NCC		ALL	
$\sigma_{lnL\|T}$:	0.3	0.7	0.3	0.7
$\gamma_{z,\mathrm{MT}}$	0.60 ± 0.15	0.32 ± 0.13	0.17 ± 0.18	$-0.13^{+0.16}_{-0.12}$
$\gamma_{z,\mathrm{LT}}$	-1.23 ± 0.41	$-1.30^{+0.54}_{-0.37}$	$-2.25^{+0.61}_{-0.48}$	$-2.06^{+0.56}_{-0.43}$
$x_{c,0}$	0.17 ± 0.02	0.26 ± 0.03	0.27 ± 0.02	0.39 ± 0.04
$C - C_{\mathrm{NCC},0.7}$	7.9	(0)	9.1	8.4

Fixed cosmology





Self-similar evolution

$$\sigma_{\ln L|T} = 0.7$$

Best-fit evolution

$$\sigma_{\ln L|T} = 0.7$$

Cosmo+evolution of scaling laws

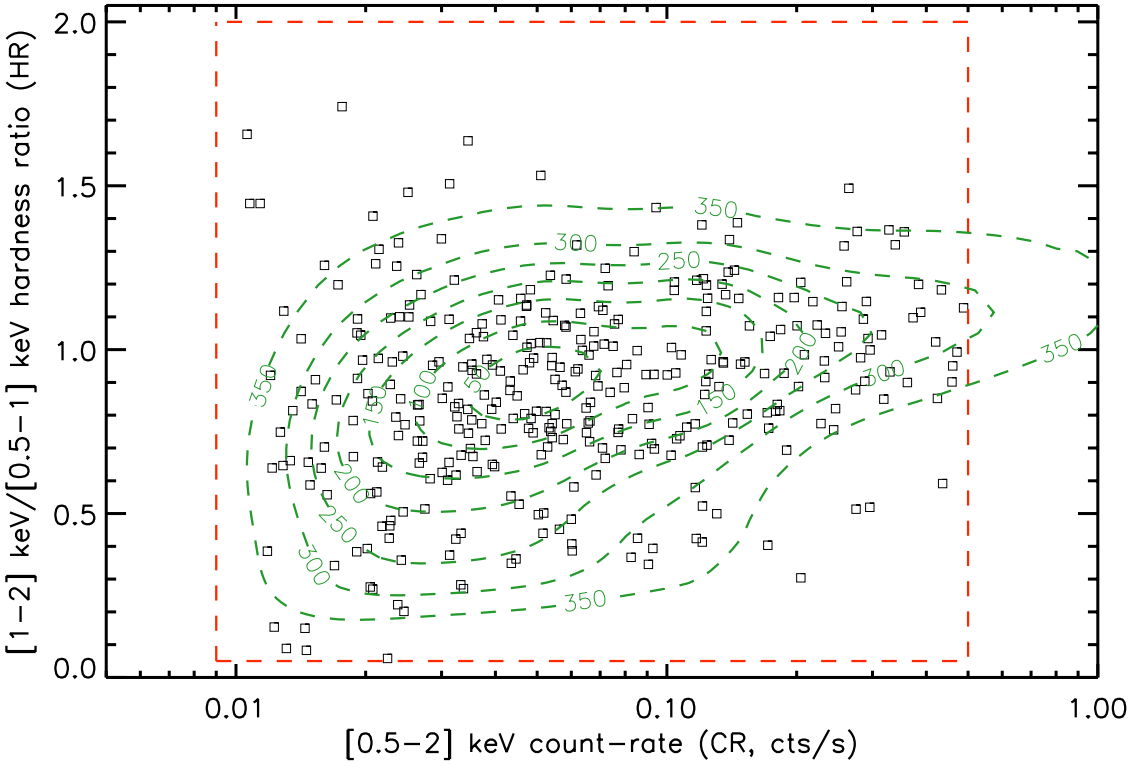
Ω_m , σ_8

$$\frac{M_{200c}}{10^{14}h^{-1}\mathrm{M}_\odot} = 10^{C_{\mathrm{MT}}}\left(\frac{T}{4\mathrm{keV}}\right)^{\alpha_{\mathrm{MT}}} E(z)^{-1}(1+z)^{\gamma_{\mathrm{z,MT}}}$$

$$\frac{L_X}{10^{44}\mathrm{ergs/s/cm}^2} = 10^{C_{\mathrm{LT}}}\left(\frac{T}{4\mathrm{keV}}\right)^{\alpha_{\mathrm{LT}}} E(z)(1+z)^{\gamma_{\mathrm{z,LT}}}$$

$x_{c,0} \equiv r_c/R_{500c}$

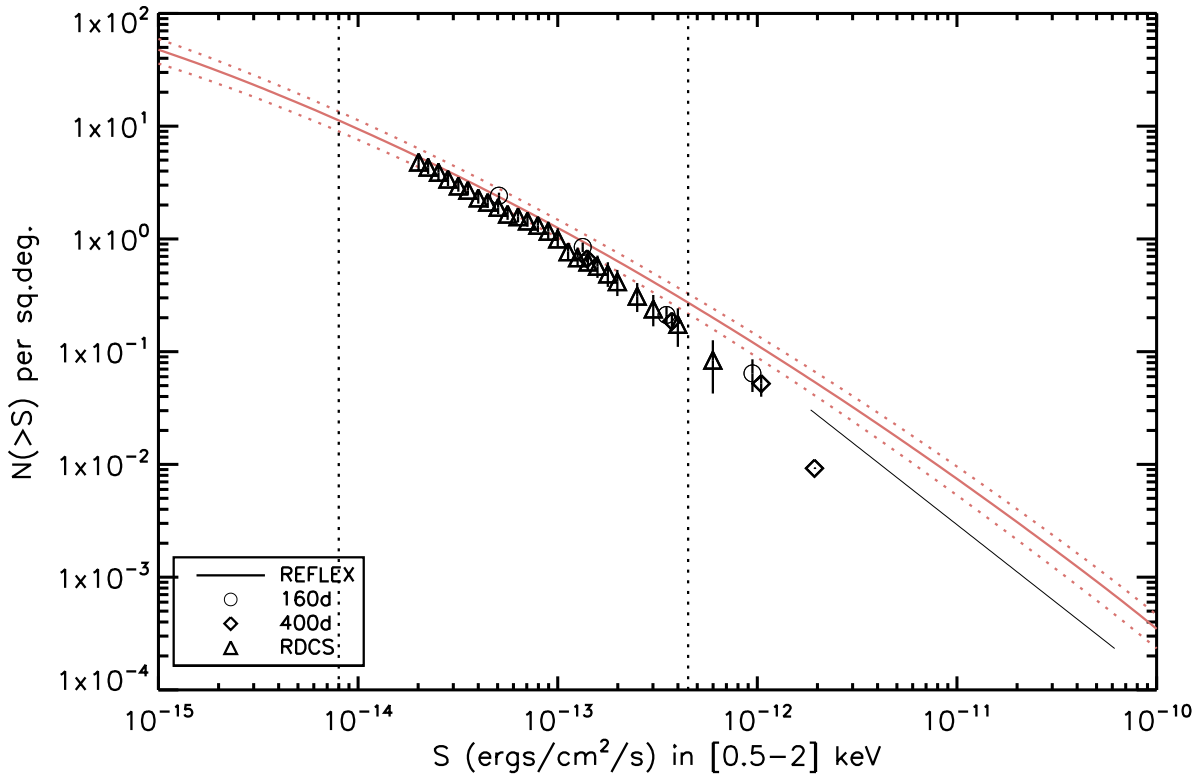
Cosmo + evolution of scaling laws



$$\Omega_{\rm m} = 0.24^{+0.04}_{-0.09},$$
$$\sigma_8 = 0.88^{+0.10}_{-0.13},$$
$$\gamma_{\rm z,MT} = 0.83^{+0.45}_{-0.56},$$
$$\gamma_{\rm z,LT} = -1.3^{+1.3}_{-0.7},$$
$$x_{c,0} = 0.24 \pm 0.04.$$

Still assuming L-T Pratt 09, 'NCC'

Cosmo + evolution of scaling laws



Predicted logN-logS with best model (red)

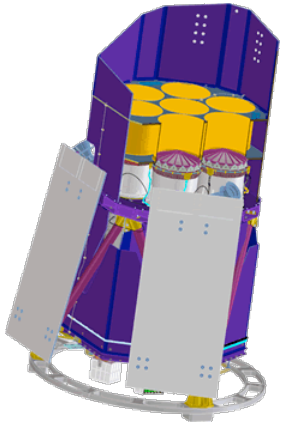
Use of local scaling laws

- Main hurdle in our study

- Differences between different scaling laws lead to different results :
  - 'ALL' : $\Omega_m \sim 0.15$, $\sigma_8 \sim 0.96$

- Selection biases affecting samples for calibration of scaling laws
- Importance of scatter, degenerate with sc. laws

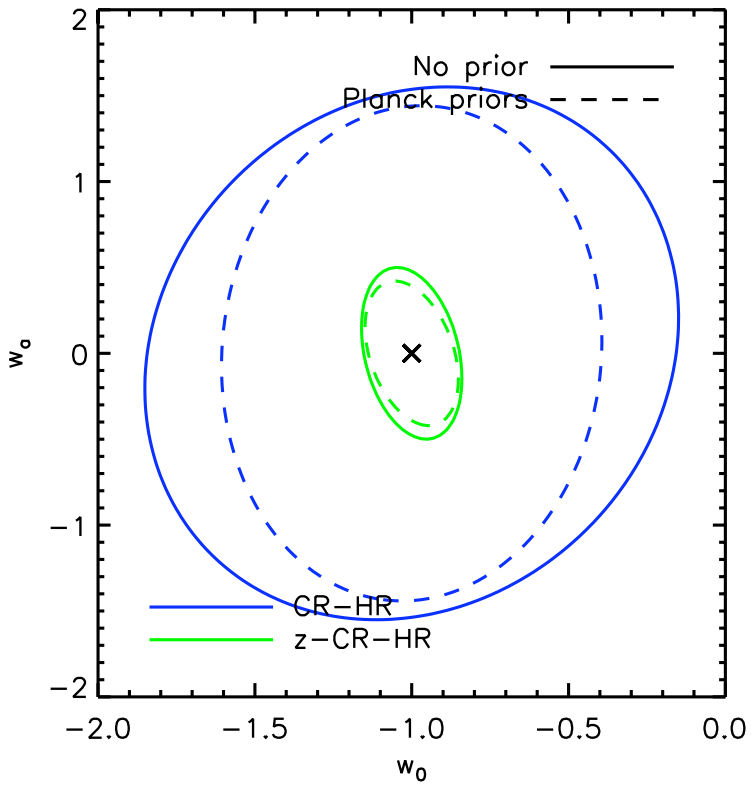
Future : eRosita

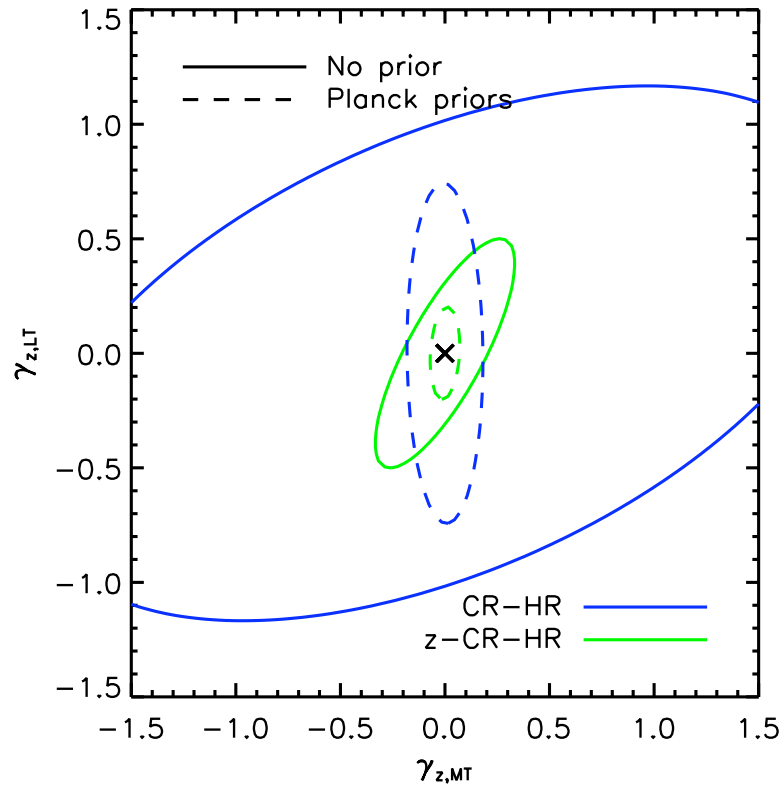


- All-sky survey: 20,000 deg2 extragal.
- Lim. Flux ~ 3 10^{-14} ergs/s/cm2 (clusters)
- Eff. Area ~ XMM EPIC MOS+PN

- Hypotheses: 2.5 clusters/deg2
- z-phot Δz=0.03
- Planck priors : Ω_m , σ_8 , Ω_b , n_s , h

Future : eRosita + (z)-CR-HR





	CR-HR		z-CR-HR	
	No prior	Planck priors	No prior	Planck priors
w_0	0.6	0.4	0.1	0.1
w_a	1.0	0.9	0.3	0.3
$\gamma_{z,\mathrm{MT}}$	1.3	0.1	0.2	0.05
$\gamma_{z,\mathrm{LT}}$	0.8	0.5	0.3	0.1

Local scaling laws completely free (even scatter)

Summary (2)

- X-CLASS : a catalogue of X-ray selected clusters in the XMM-archive
- Analysis based on CR-HR distribution
- Local scaling laws + scatter critical
- Optimally, need to fit cosmo, scaling laws, evolution and selection function at the same time → possible with eRosita all-sky survey