Application of wide field X-ray cluster surveys to cosmology

illustrated by XMM-LSS, XXL, X-CLASS

M. Pierre   CEA Saclay

The two basic cluster quantities used in cosmology

- Cluster number counts
  - dn/dnz
  - dn/dM/dz

➔ Calculating cluster masses is the BIG problem !

- The cluster-cluster correlation function ξ

- Cosmology (DE) has two effects
  - Geometrical (as for SN)
  - Gravitational (structure formation)

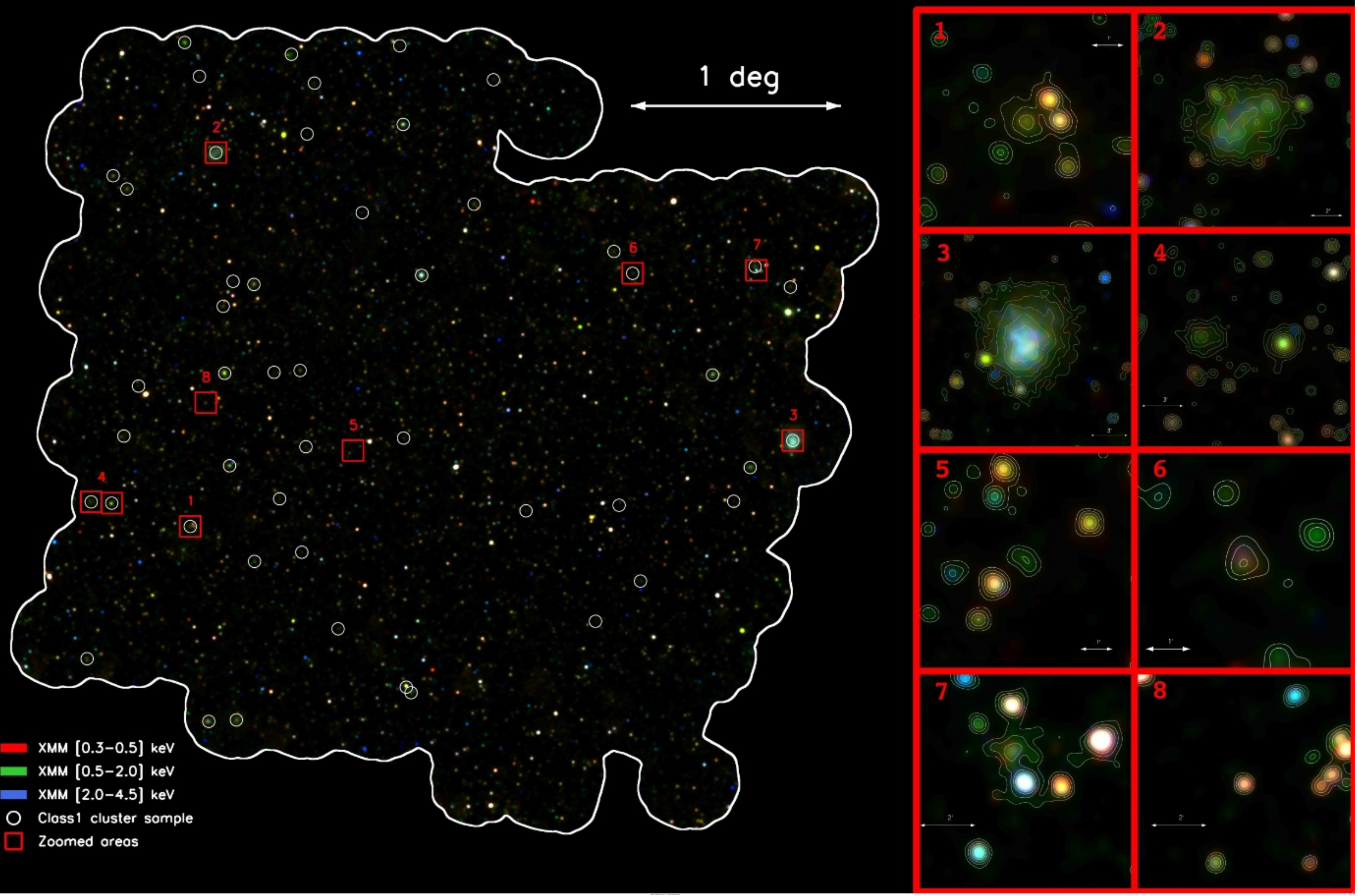
Outline

1. The XMM-LSS pilot survey
2. DE with XXL, the largest XMM programme
3. X-class : a new method for interpreting cluster number counts
4. Future

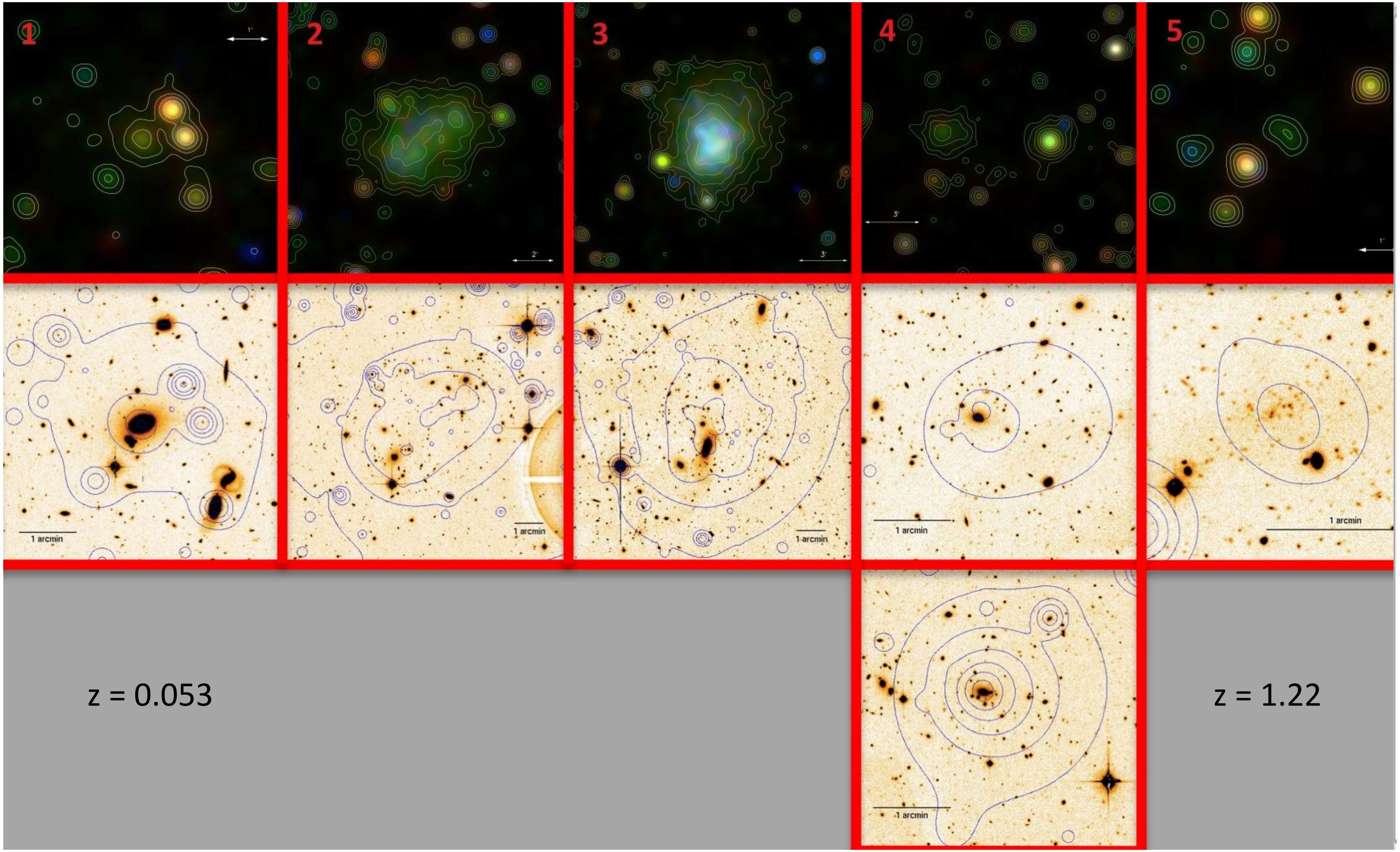
The XMM-LSS field

- 11 deg2 paved with 10-20 ks and including the SDS : 99 observations separated by 20’
- Optical coverage by the CFHTLS
- IRAC + MIPS survey from SWIRE
- Plus many others (VLA, GMRT, Integral, …)
- A European consortium of ~ 30 scientists

The XMM-LSS survey



XMM-LSS clusters of galaxies and their optical counterpart (CFHTLS)



Main results from
the XMM-LSS 'pilot-survey'

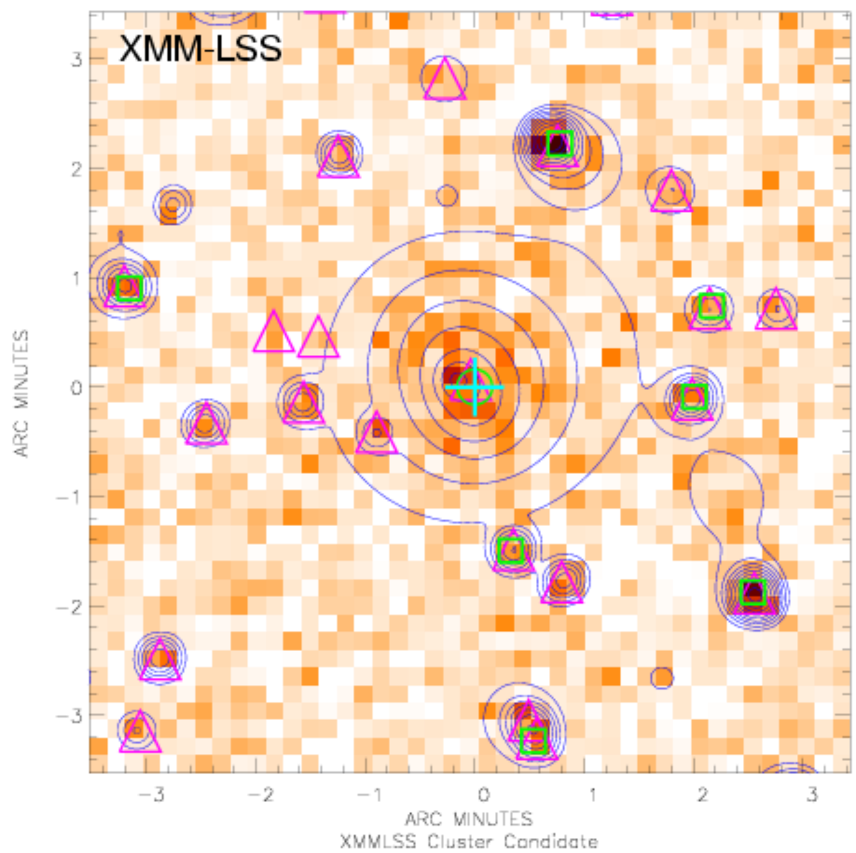
has unveiled a number of practical/theoretical issues

1) An unambiguous selection function

- For cosmological purposes, it is very necessary to have **a purely X-ray selected cluster sample**
  ➔ *ab initio* modeling

- This implies a 2D selection function

Pacaud et al 2006, 2007



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

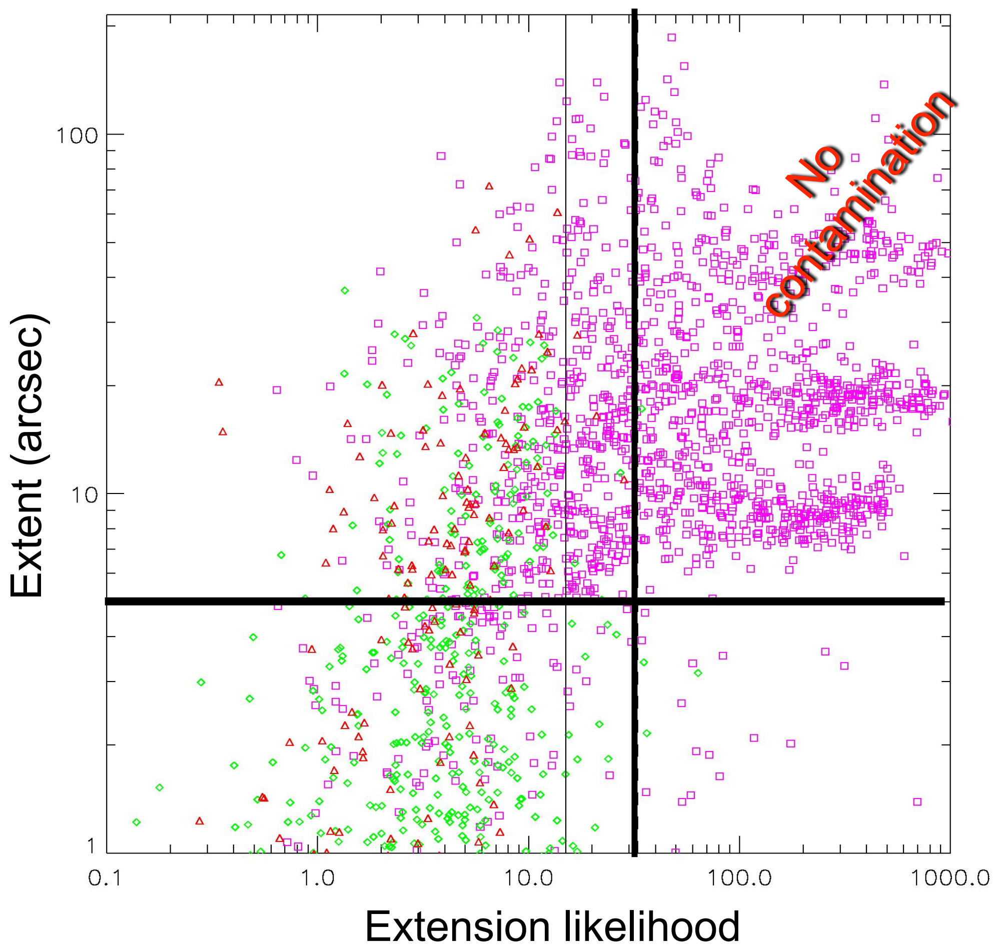
Not a flux limit !

~ **surface brightness limited**

The cluster selection process

3 classes of extended sources

Green = AGNs Magenta = clusters Red = Spurious



Class 1 (C1):

~ 6/deg^2

no contamination

Class 2 (C2):

~ 5 more / deg^2

+ 5 false det.

50% contamination

Class 3 (C3):

other clusters

15-20/deg^2

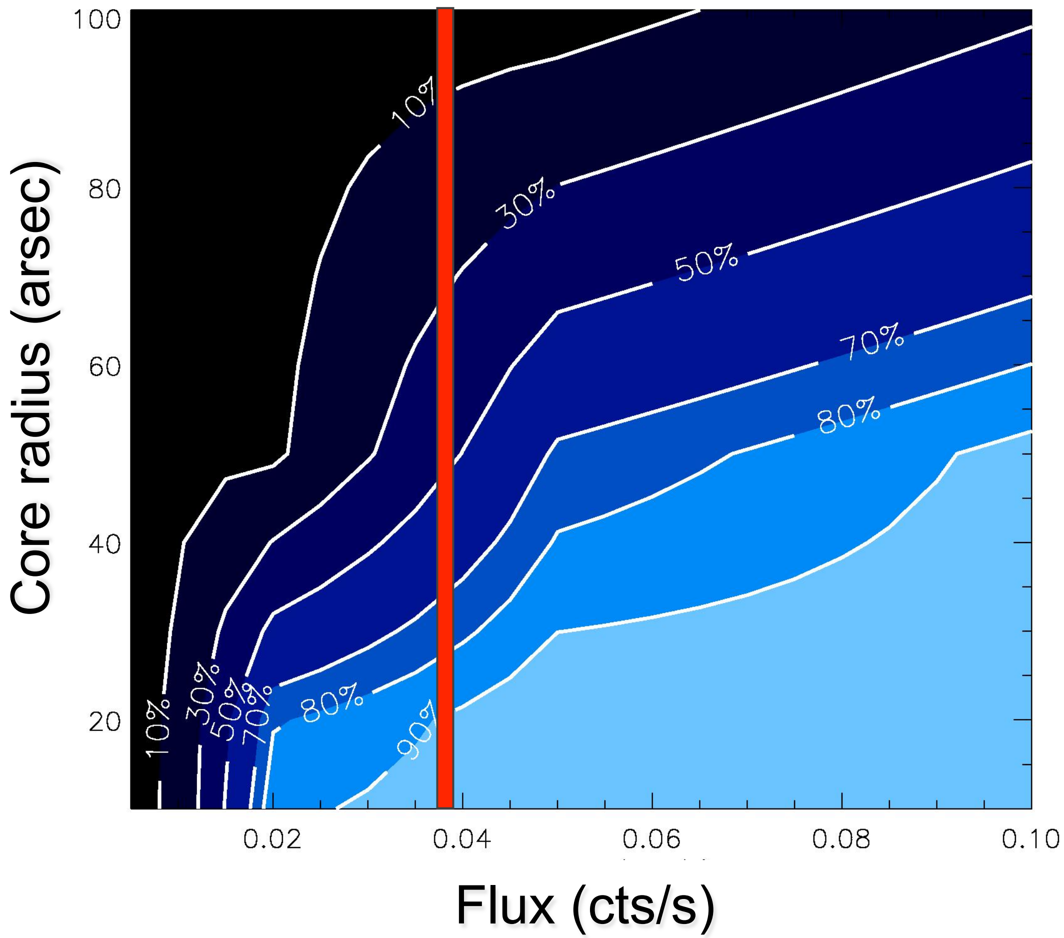
Pacaud et al 2006

Detection rates

Class 1 sample

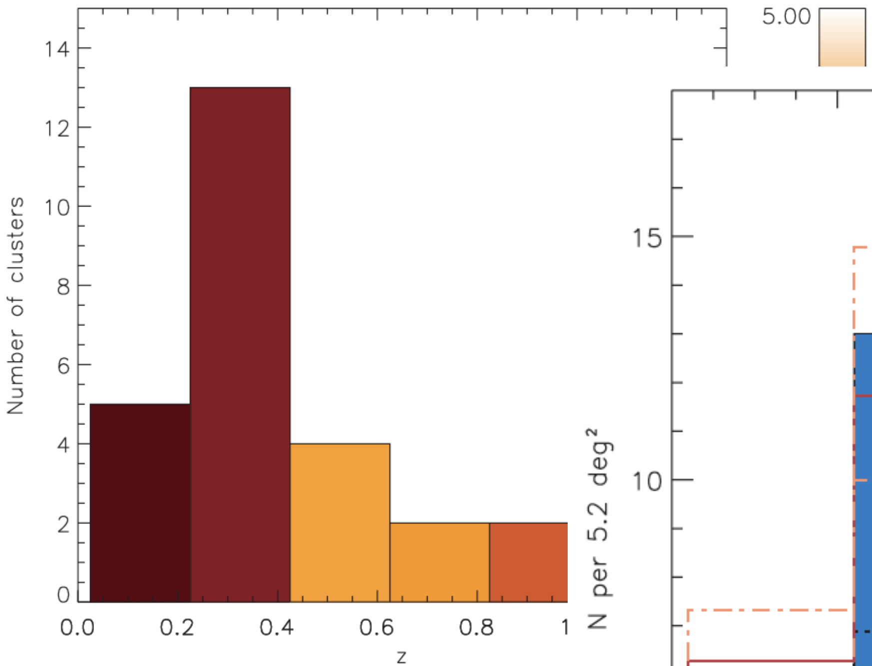
Not a flux limit !

~ surface brightness limited

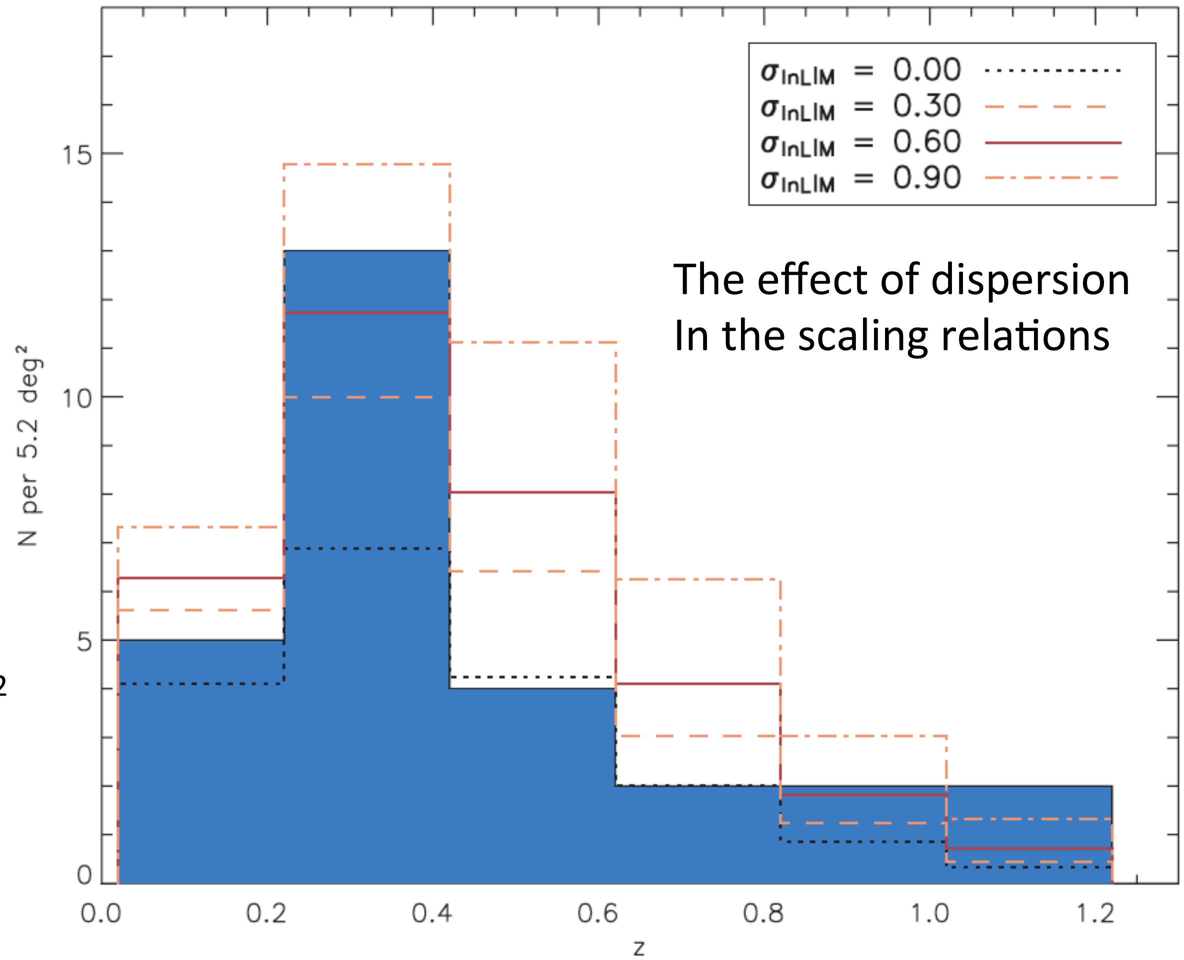


Pacaud et al 2006

Results from the first 5 deg2

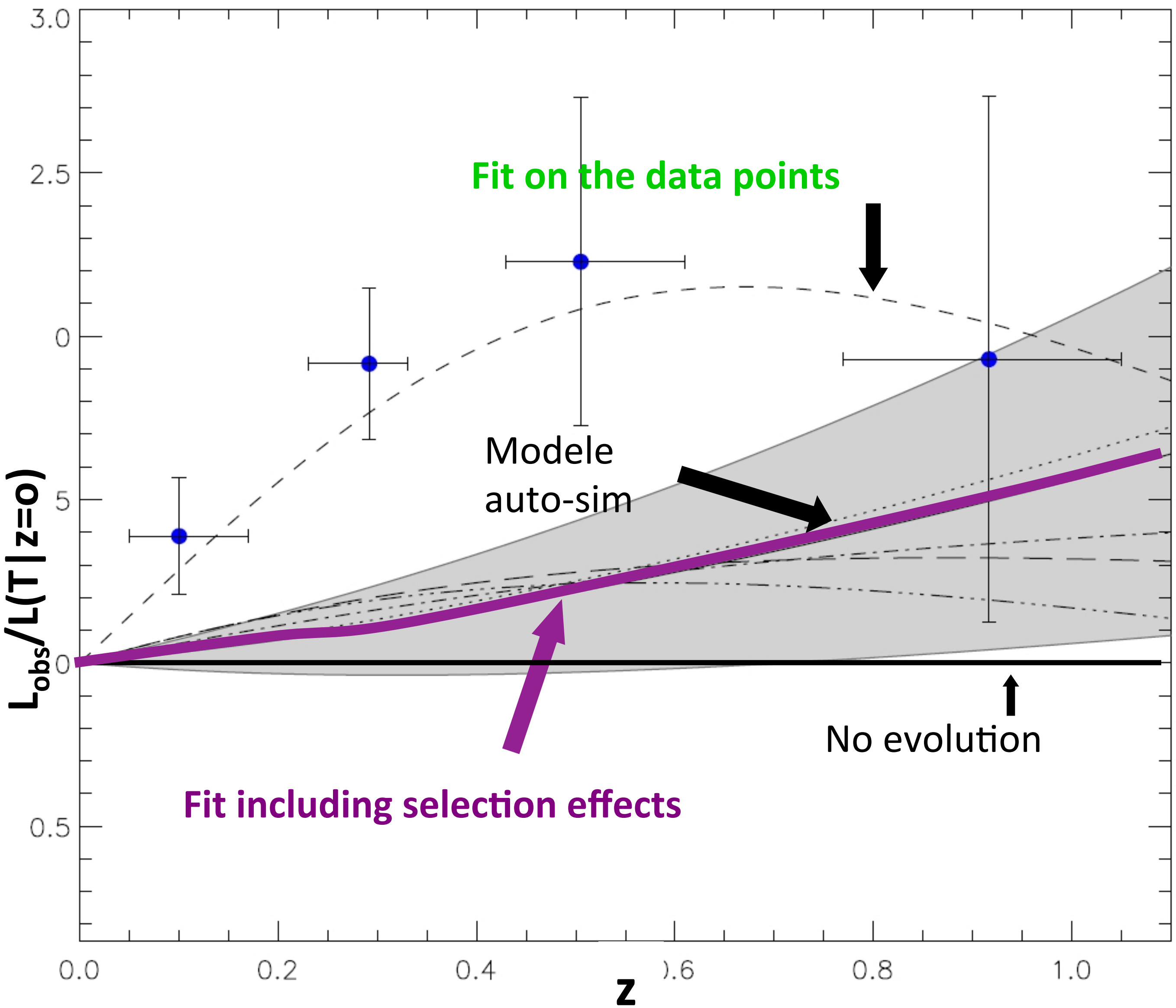


Lower fluxes ~ 10^{-14} erg/s/cm^2
In [0.5-2] keV



The effect of dispersion
In the scaling relations

First attempt to self-consistenlty model selection effects in the scaling relations



Pacaud et al 2007

2) For cluster scaling laws, selection effects appear to be critical

- Clusters selected for the determination of the scaling relations are biased toward the brightest objects with respect to the mean (as are the current parent samples)
- This explains the discrepant results, not only in evolution but also for the local laws (still recently– see *e.g. Reichert et al 2011 for a review*).
- The role of dispersion (still uncharacterised at z~0) :
  - Needed to correct for the selections effects
  - degenerate with σ_8, and to some extent with the slope and normalisation of the S.L.

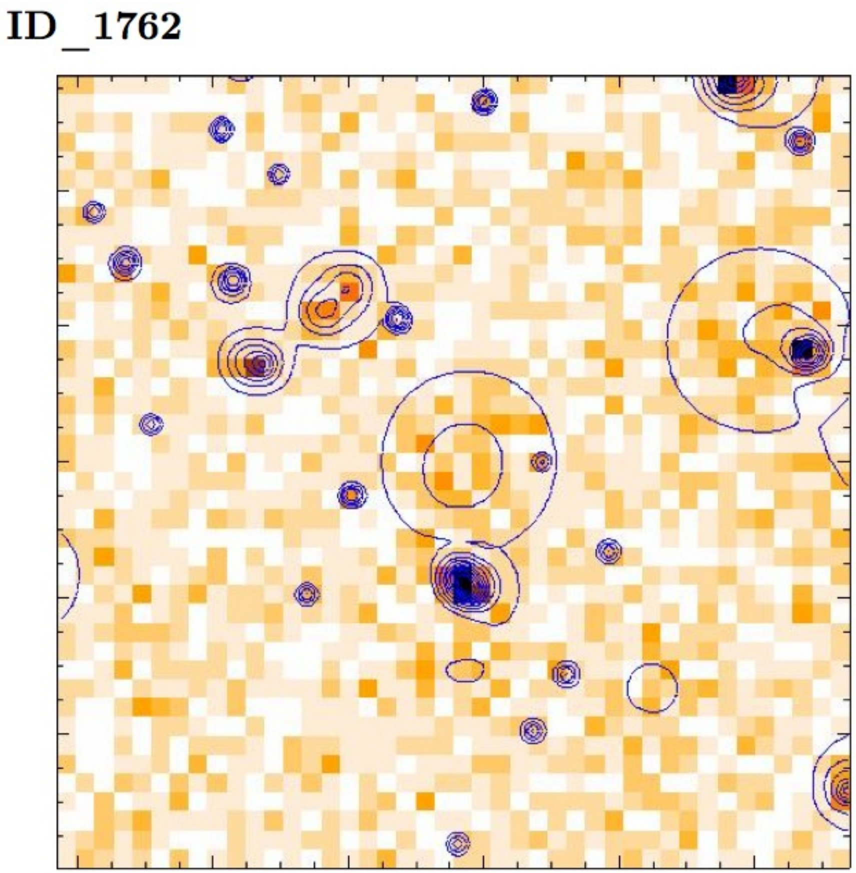
- **Sole escape route: fit scaling relations, cosmology and selection effects at the same time** (*e.g CH-HR method*).
  - ➔ Homogeneous cluster surveys greatly help

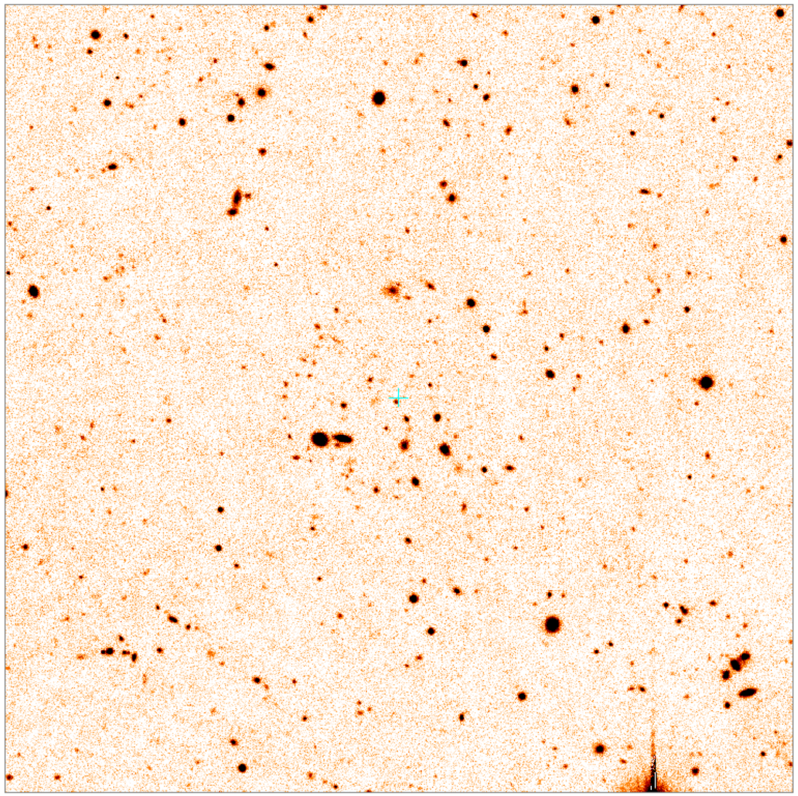
3) Distant clusters

- 10 ks XMM are enough to detect a Coma cluster at z = 2.
- 1-2   C1 clusters per deg^2 beyond z>1

- Clusters at z>1.2 are readily identifiable
  - extented sources without counterpat in the I band
  - always have a counterpart in IRAC!
  - we have some 8 candidates, observed with HAWKI and undergoing spectroscopic confirmation

A distant candidate at z ~ 1.5





I 3.6 μm 4.5 μm

Ancillary data

- Having uniform coverage in u,g,r,i,z + 3.5, 4.6 μm has proven extremely poverful
  - Cluster ID
  - Photo-z

- Optical spectroscopy (clusters <1) is the bottle neck

- IR spectroscopy (clusters >1.5) is a nightmare

The XXL survey
or
Dark Energy Now!

More than 100 Co-Is officially registered
Website http://irfu.cea.fr/xxl

The XXL survey
an XMM Very Large Programme

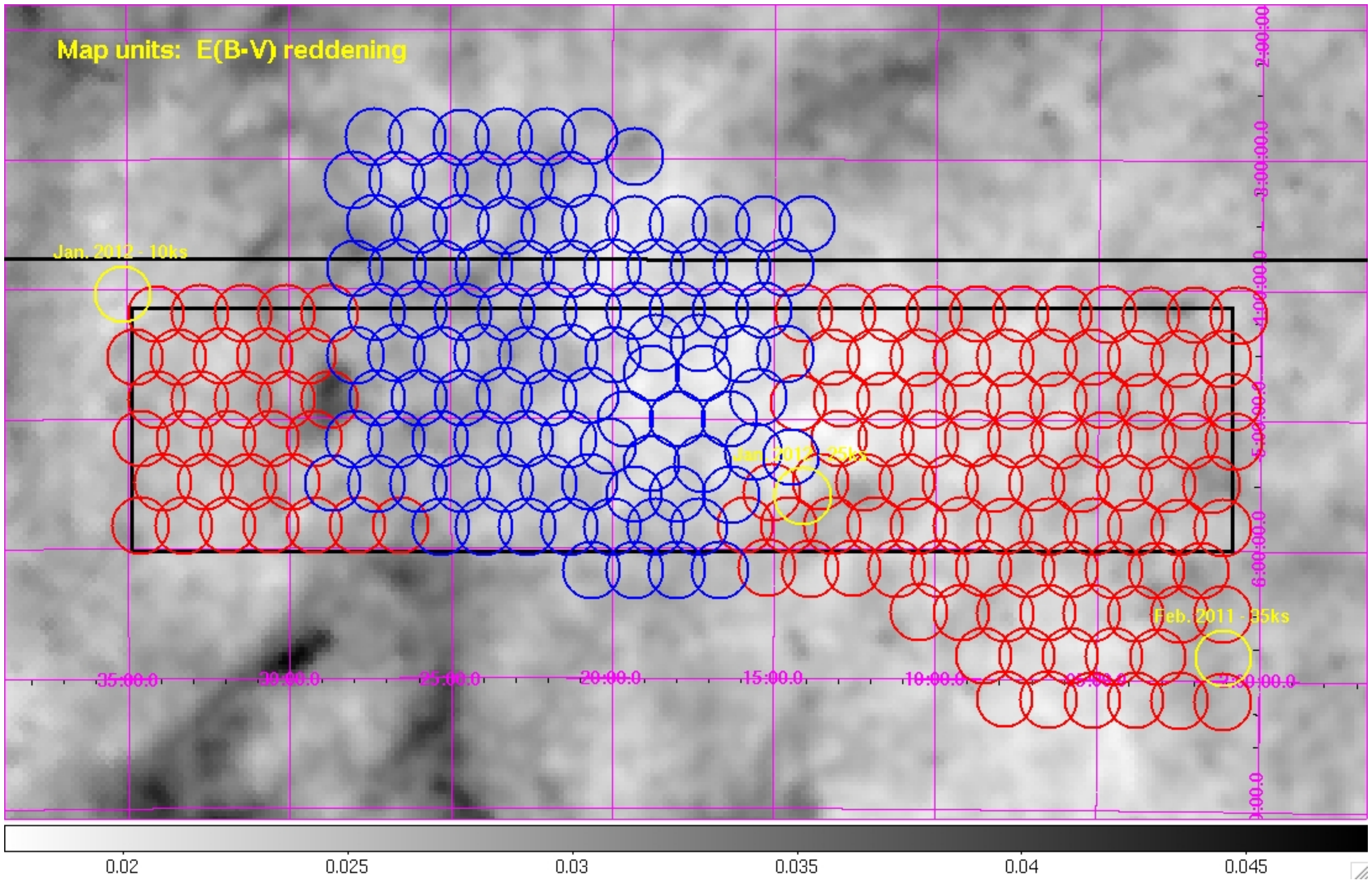
- Builds on the XMM-LSS experience
- 2 areas of 25 deg^2 each, paved with 10 ks XMM observations
  - 3Ms allocated in December 2010
  - Some 3Ms of already existing data

- Main science goal: the equation of state of the dark energy from clusters of galaxies

- Hot topics for AGNs and clusters and XRB

25 deg^2 in CFHTLS-W1 2h23 -5d00

(extension of the XMM-LSS field)

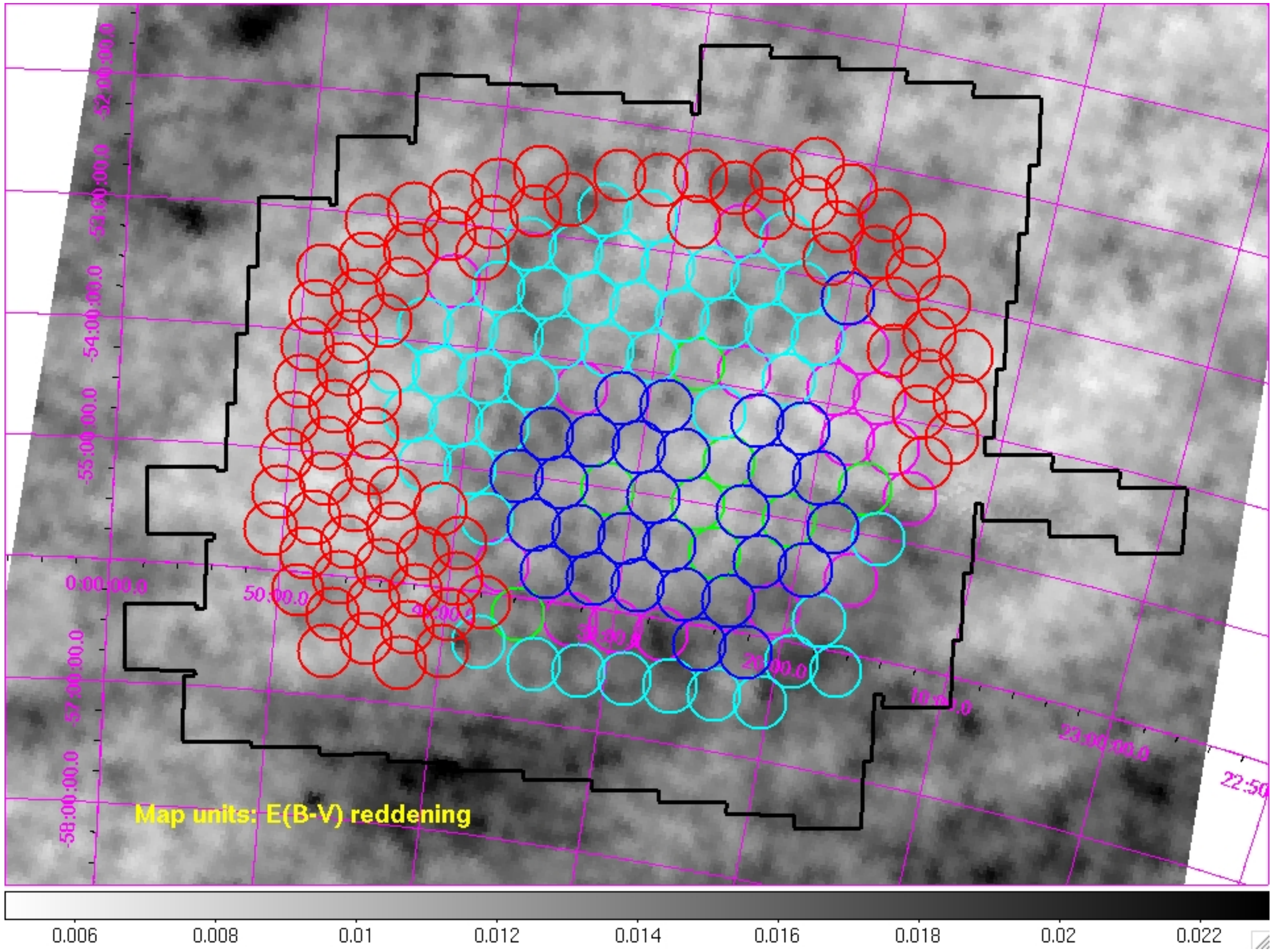


In red: the new observations (126)

$\Delta\alpha = \Delta\delta = 20'$ everywhere

25 deg^2 in BCS 23h30 -55d00

(extension of the XMM-BCS field)



In red: the new observations (80)

$\Delta\alpha = \Delta\delta = 20'$ ($\Delta\alpha = \Delta\delta = 23'$ in the initial central survey)

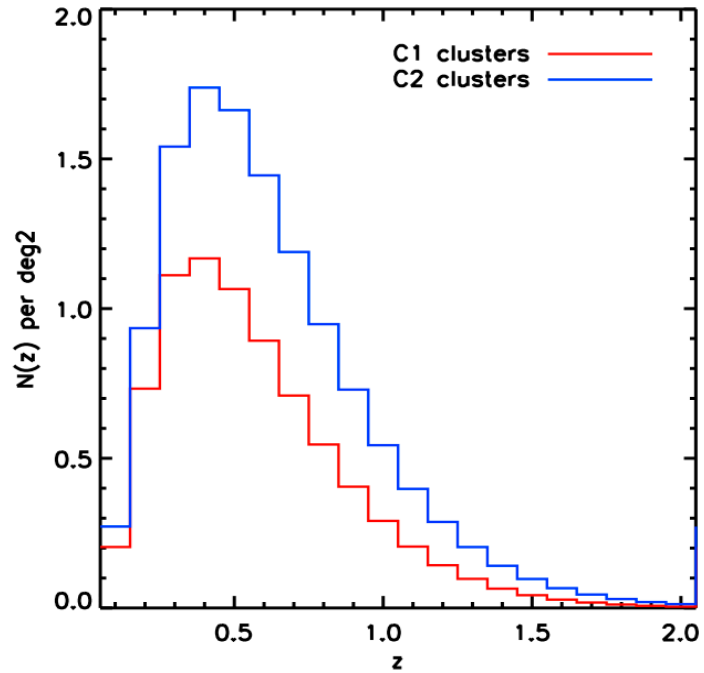
The cosmological quantities

- dn/dz

  for a given selection function

C1: 6 clusters /deg^2 ~ 1/deg^2 at z>1

C2: 12 clusters /deg^2



- ξ : 3D correlation function

➔ ξ increases the contraints by a factor of ~ 2

Predictions for XXL
= 50 deg^2

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

Pierre et al 2011

Cluster 'hot topics'

Specific to XXL

- The DE equation of state
- The group population at z~0.5
- Mass measurements (X,optical, lensing, IR, S-Z)
- Census of the 1<z<2 clusters
  - volume : 0.6 Gpc^3
  - compared to the SDSS within 0<z<0.3 : 1.4 Gpc^3

AGN ‘hot topics’

Specific to XXL

More than 200 X-ray AGNs/deg2

- Large Scale Structure
- Distant / Exotic AGNs
- The statistics of lensed QSOs

Associated surveys

- **Equatorial field (LSS) 25 deg^2**
  - CFHTLS, HSC optical
  - ACTpol, AMiBA SZ
  - UKIDSS NIR 9 deg2
  - Spizter/SWIRE MIR 9 deg2
  - Herschel/HERMES FIR 9 deg2
  - VISTA/VIDEO deep survey 4.5 deg2
  - WIRCAM shallow K survey
  - eRosita X
  - GAMA spectroscopy and multi-λ $z<0.5$
  - VIPERS spectroscopy (VIMOS@VLT) 14 deg2
  - Euclid optical, NIR
- **Southern field (BCS) 25 deg^2**
  - BCS, DES optical
  - Spitzer/SSDS MIR
  - ACT, SPT SZ
  - VISTA/VHS NIR
  - Herschel-*spire* FIR
  - eRosita X
  - Euclid optical, NIR

  - … and many others in preparation (Chandra, eVLA, Herschel, ASKAP, ATCA , WIRCAM_deep, LOFAR….)

Black: existing or on-going or planned survey (if the area covrered is not indicated, this means that the full region 25 deg^2 is covered)

Pink: in preparation

Legacy

- Individual source catalogues
- Multi-λ catalogues
- Photo-z
- Special efforts on:
  - Requirements for band merging
  - Photometric uniformity

2) XMM surveys using the XMM archive.

Cumulative area to date: ~ 100 deg^2

The XCS survey

started in 2000 by Romer et al

Traditionnal approach of dn/dz => redshifts are needed!

A catalogue of 503 clusters published in 2011
464 with redshift
462 with temperature

No cosmological analysis published to date

The HR-CR method
and
the X-CLASS survey

started in 2009

N. Clerc, M. Pierre, F. Pacaud, T. Sadibekova,
arXiv:1109.4440, MNRAS in press
N. Clerc, T. Sadibekova, M. Pierre, F. Pacaud, J.-P. Le Fevre, C. Adami, B. Altieri, I. Valtchanov
arXiv:1109.4441 MNRAS in press

Rationale

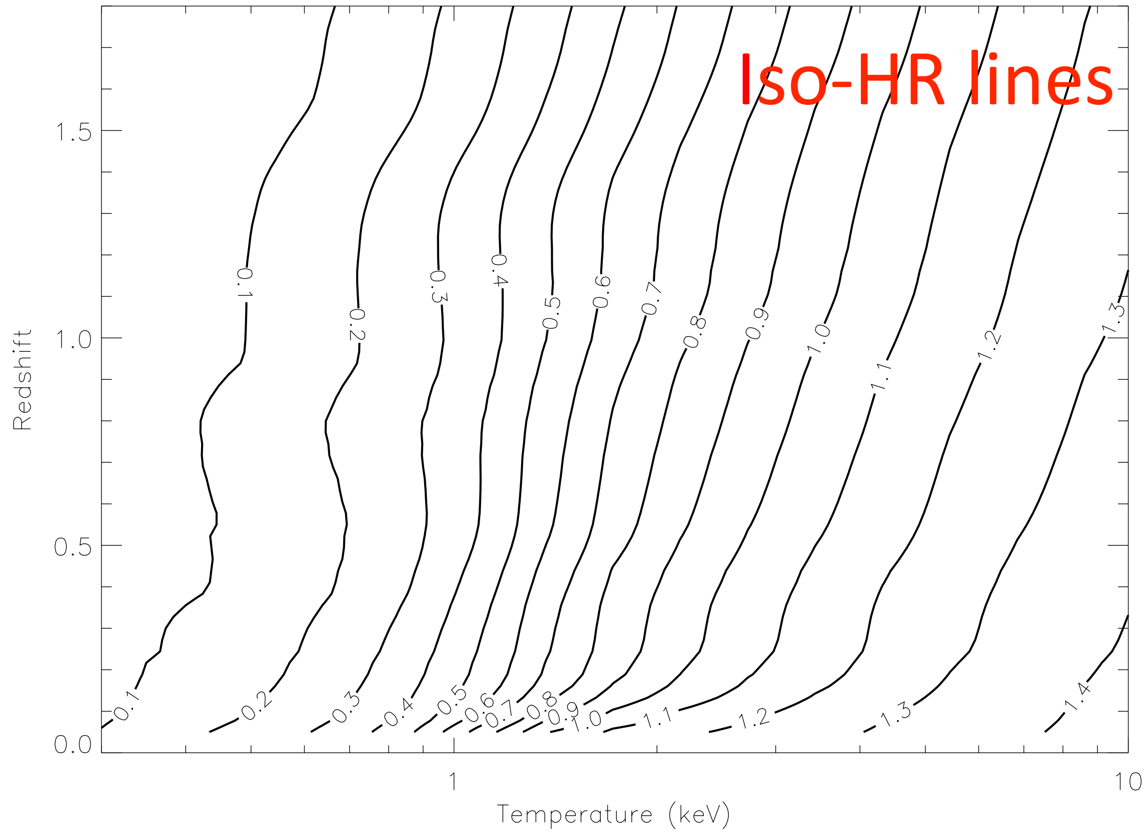
- We have a quasi-automatic pipeline that allows a ~ blind selection of X-ray clusters: C1
- We have a data management facility that provides :
  - a quick ingestion of the cluster X-ray/optical data
  - a screening procedure

➔ **Process the XMM archive to inventory all C1 clusters**

- Use the DSS to remove nearby galaxies, saturated point-sources, etc…
- Study the LogN-LogS (logN-LogCR) in several bands to constraint the cluster scaling laws for a given cosmology.
- … actually, more info is available…
- **Construct X-ray colour-magnitude diagrams based on instrumental count-rates.**

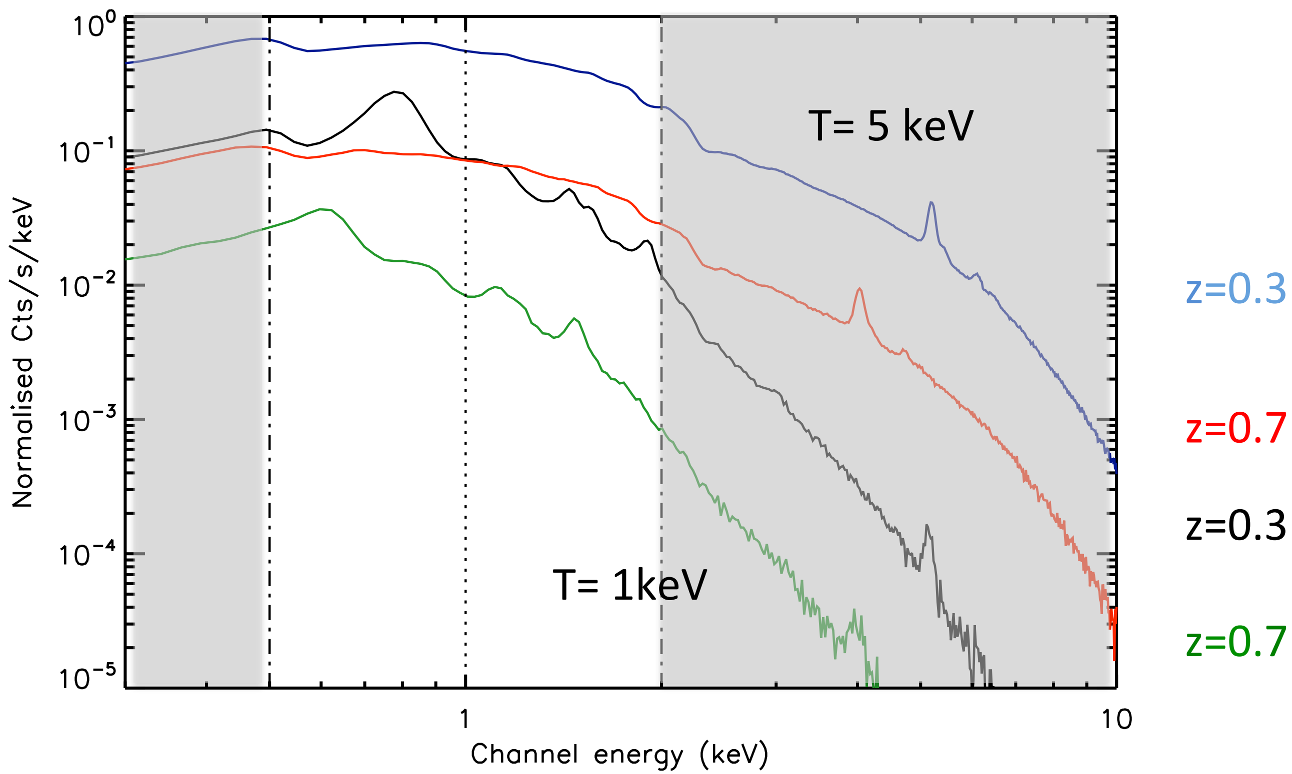
$HR = f(T, z)$

Redshift



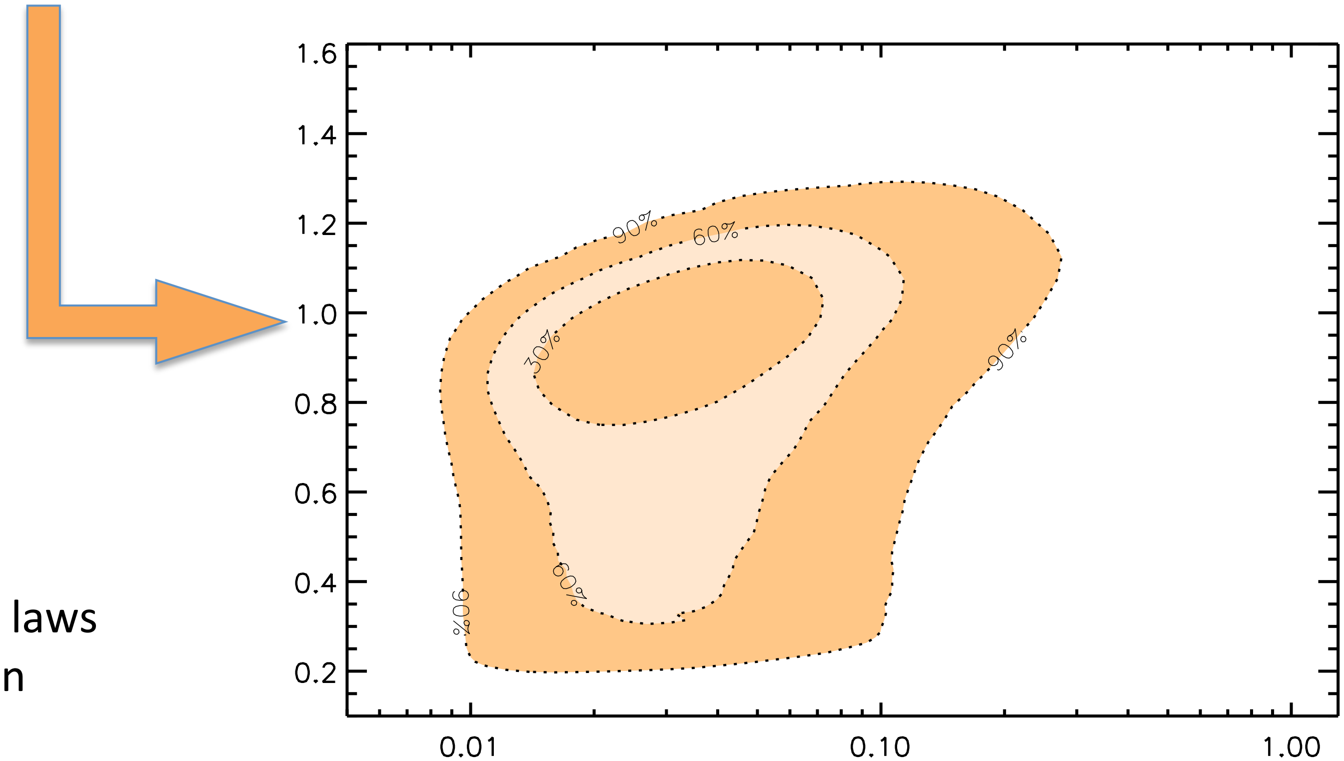
Temperature (keV)

- CR in [0.5-2] keV (~flux)
- HR = [1-2]/[0.5-1] (~spectrum)



The CR-HR distribution

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

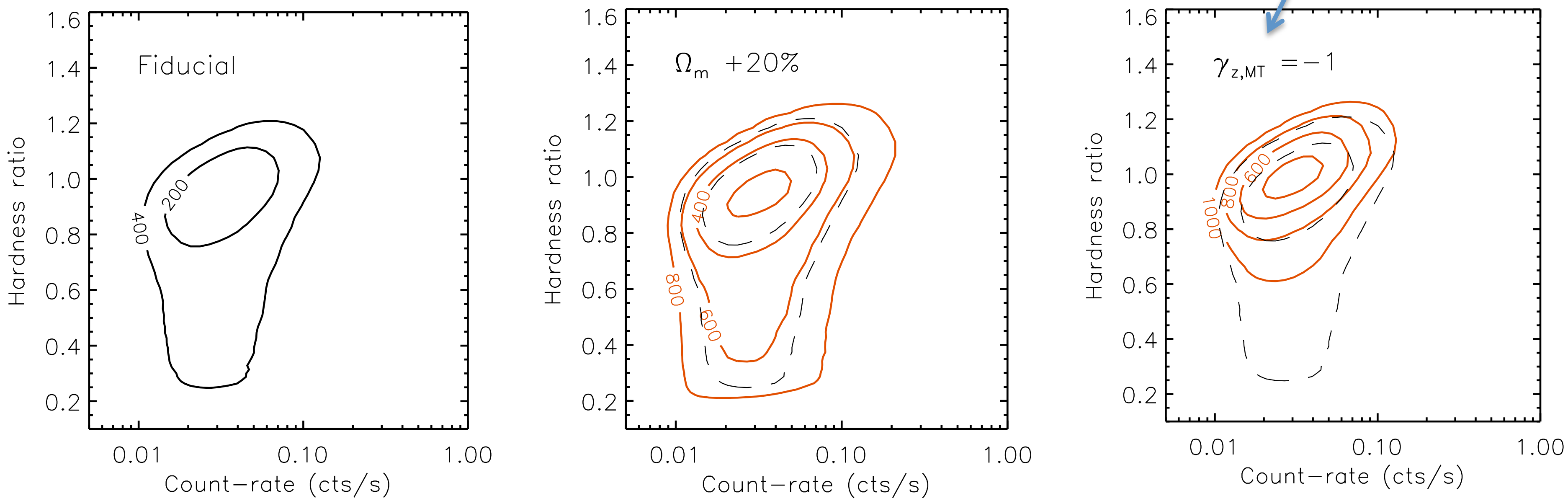


[0.5-2] keV Count-rate (CR, cts/s)

Diagram computed for :

WMAP5 cosmology
C1 selection
Local cluster scaling laws
Self-similar evolution

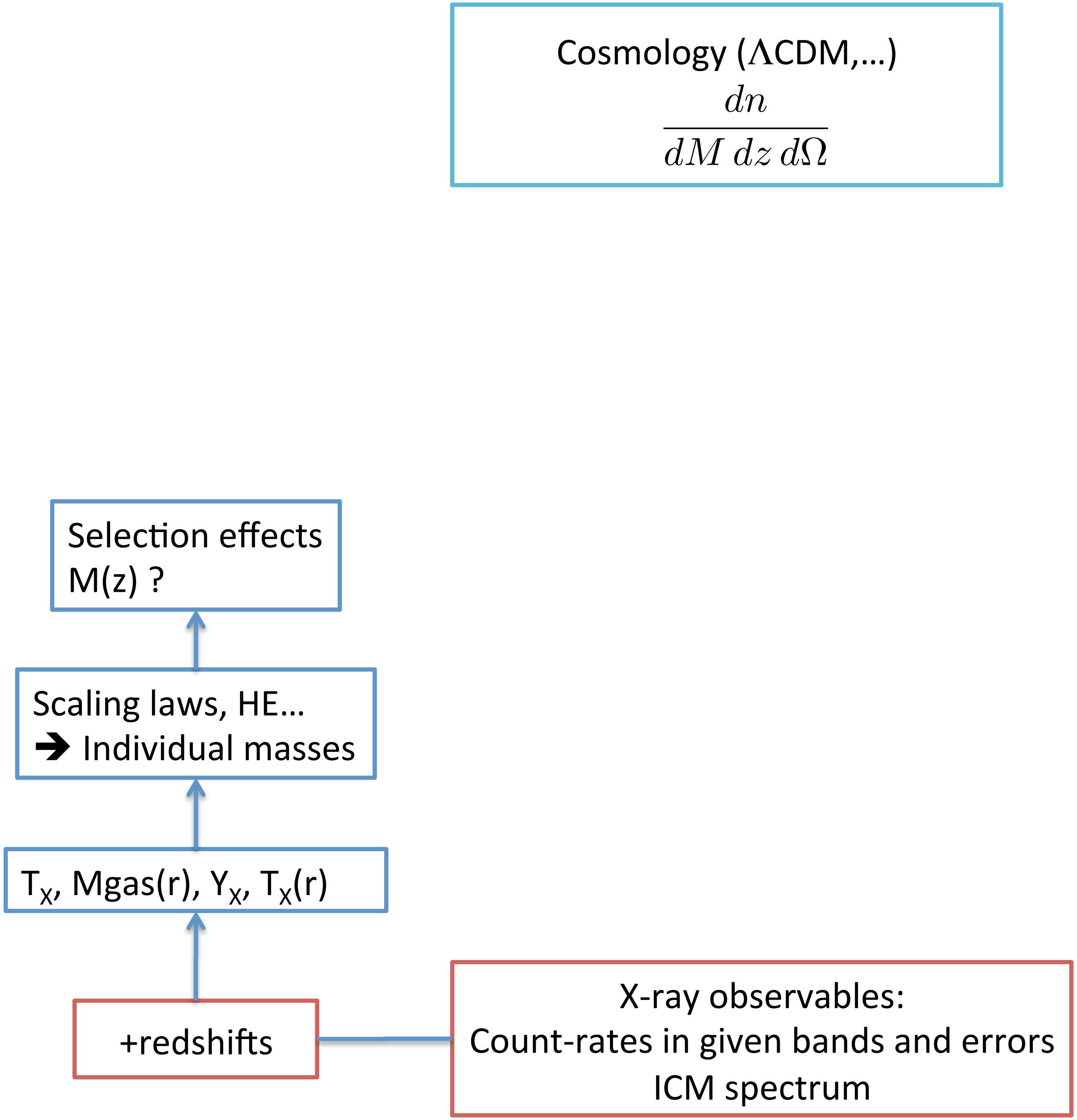
Non self-similar evolution



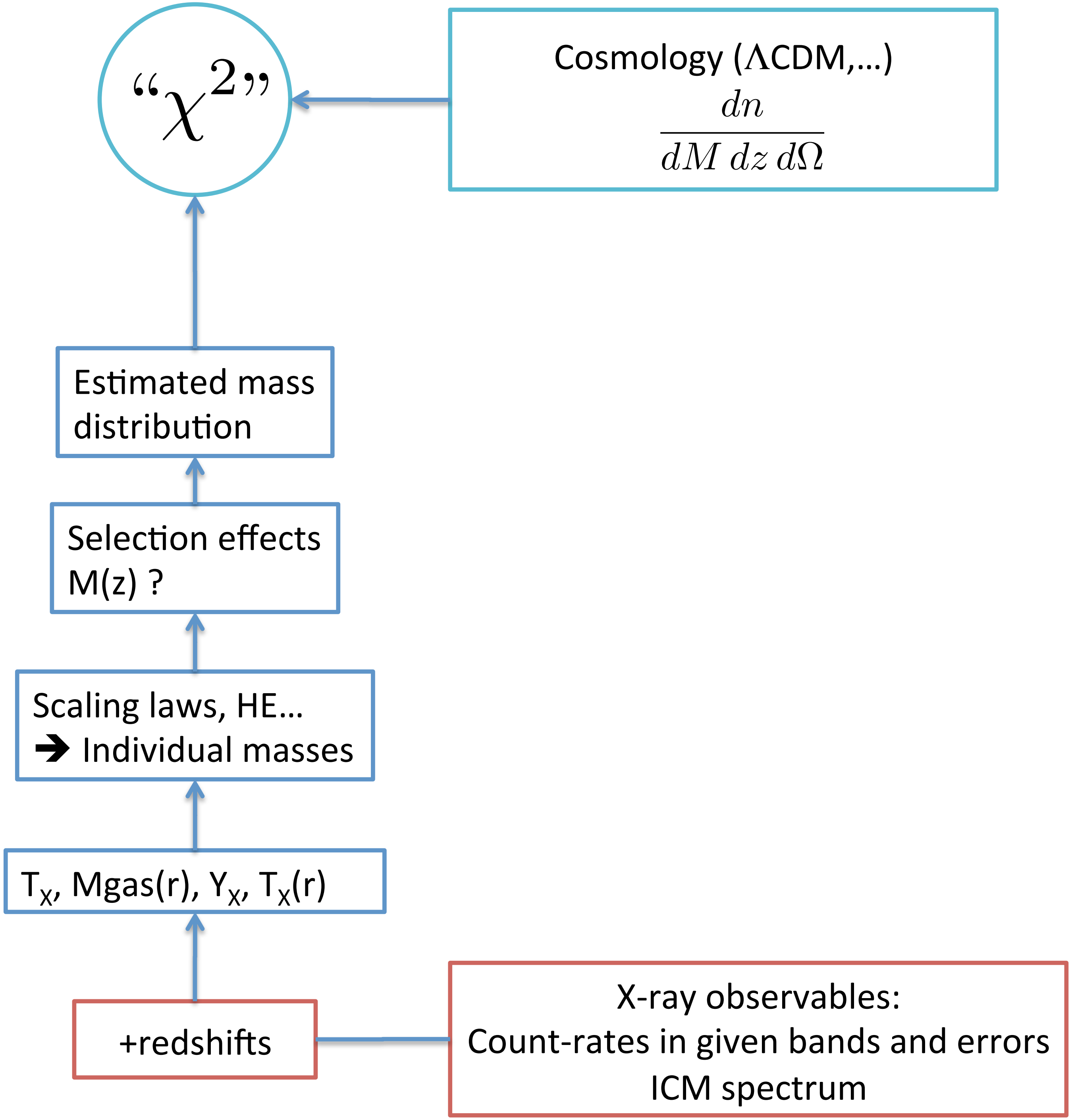
Cosmology (ΛCDM,…)

$$\frac{dn}{dM\,dz\,d\Omega}$$

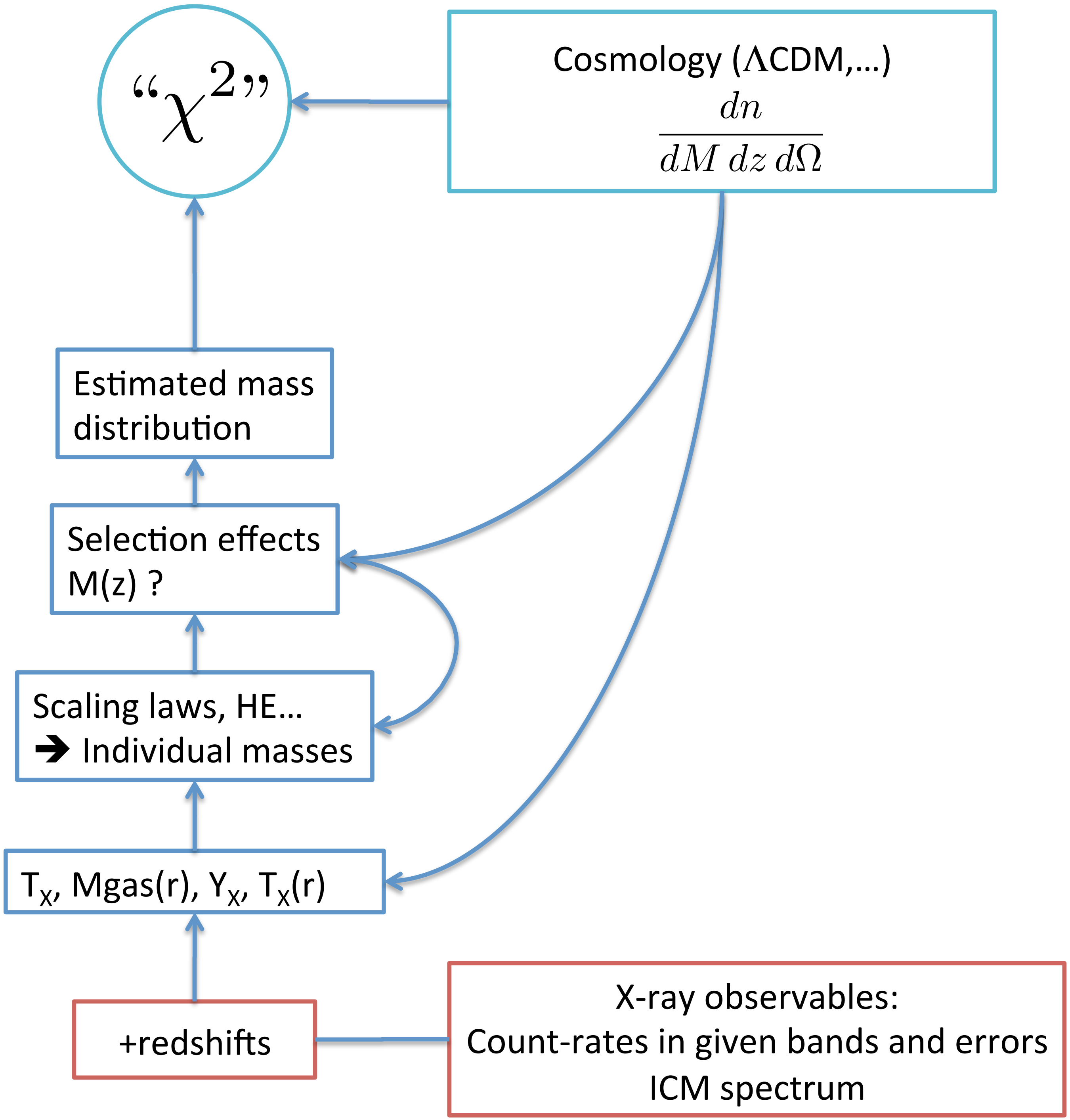
X-ray observables:
Count-rates in given bands and errors
ICM spectrum

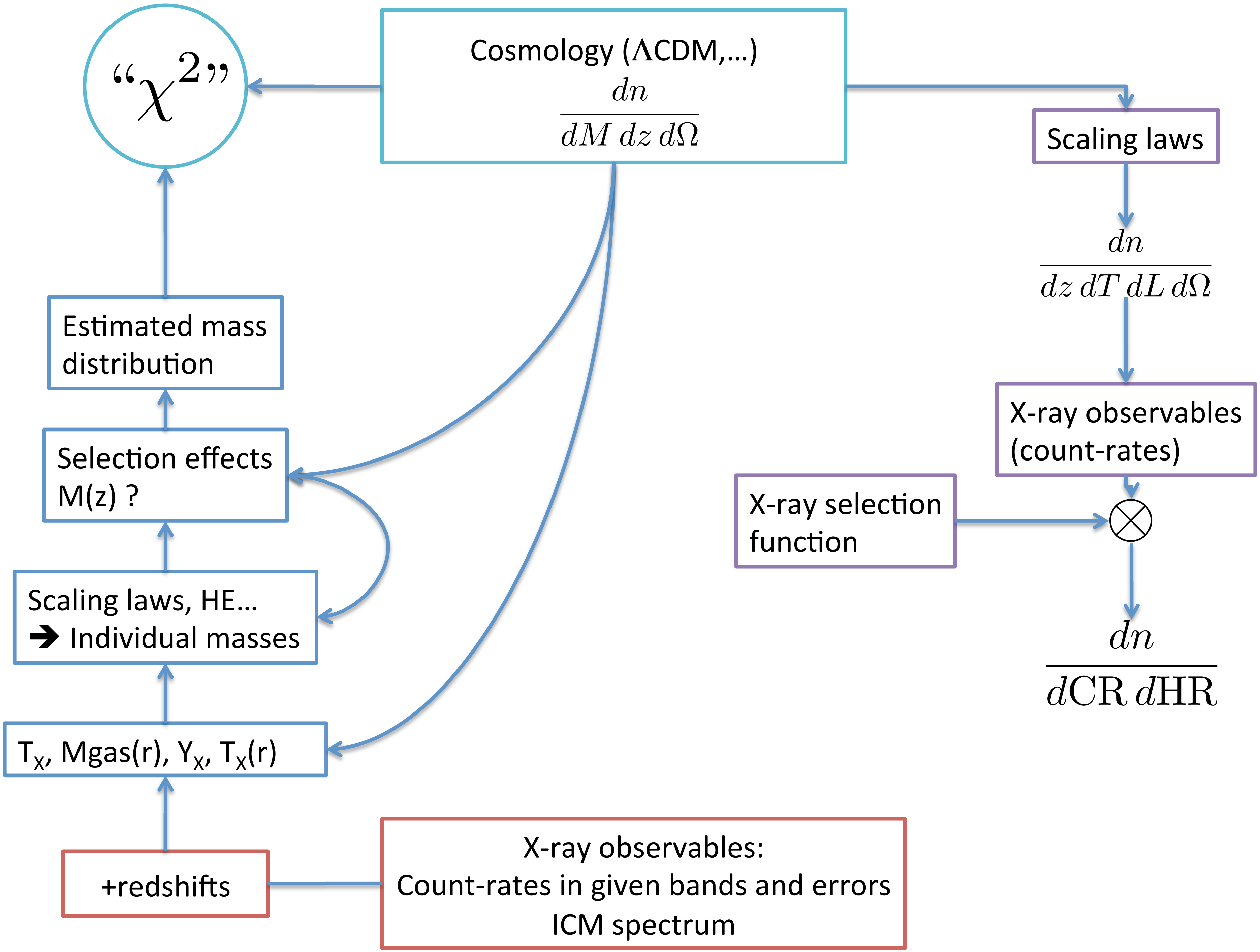


Cosmology (ΛCDM,…)
$$\frac{dn}{dM\,dz\,d\Omega}$$
Selection effects
M(z) ?
Scaling laws, HE…
➔ Individual masses
T_X, Mgas(r), Y_X, T_X(r)
+redshifts
X-ray observables:
Count-rates in given bands and errors
ICM spectrum

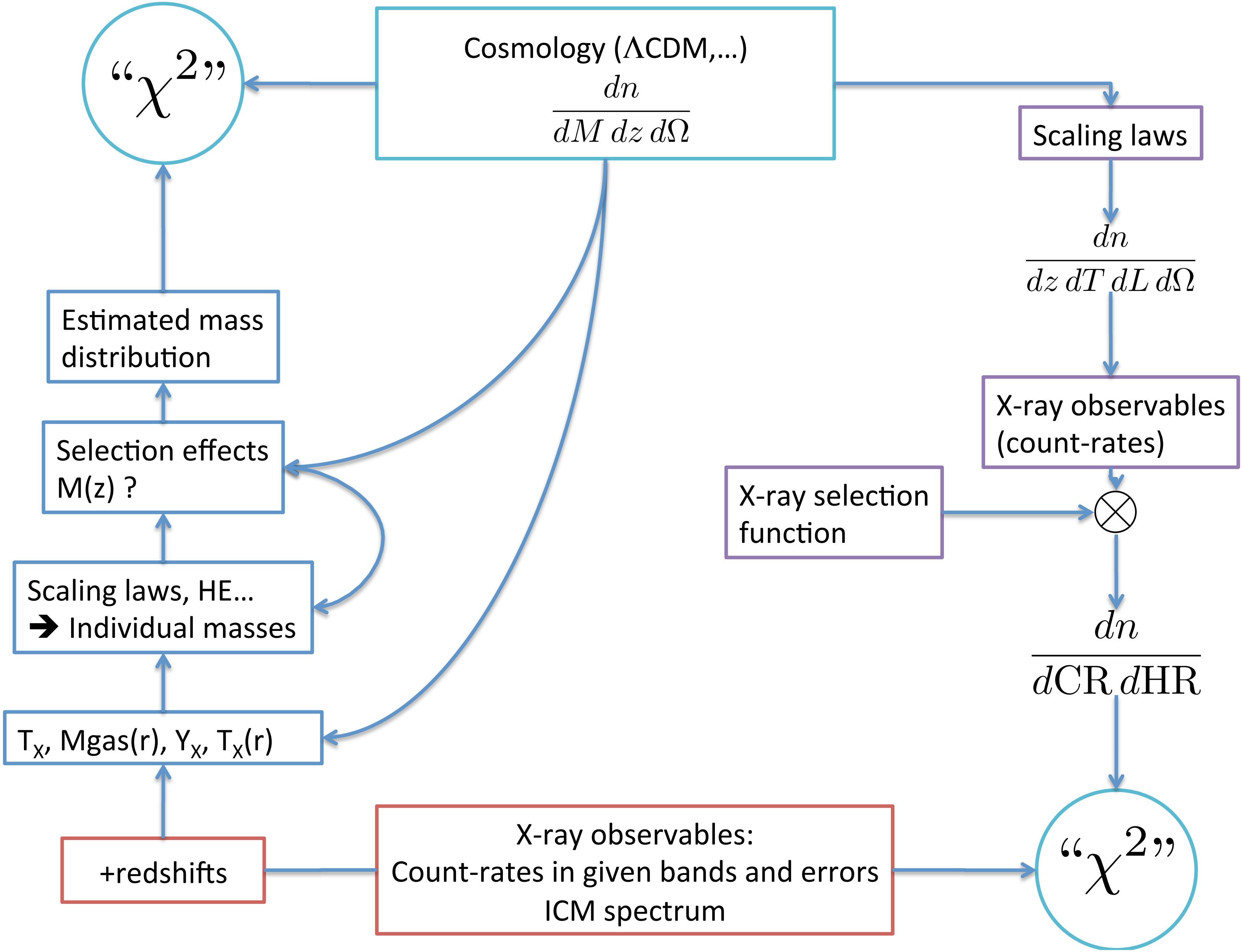


"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Estimated mass distribution
Selection effects M(z) ?
Scaling laws, HE...
➔ Individual masses
T_X, Mgas(r), Y_X, T_X(r)
+redshifts
X-ray observables:
Count-rates in given bands and errors
ICM spectrum


"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\, dz\, d\Omega}$
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



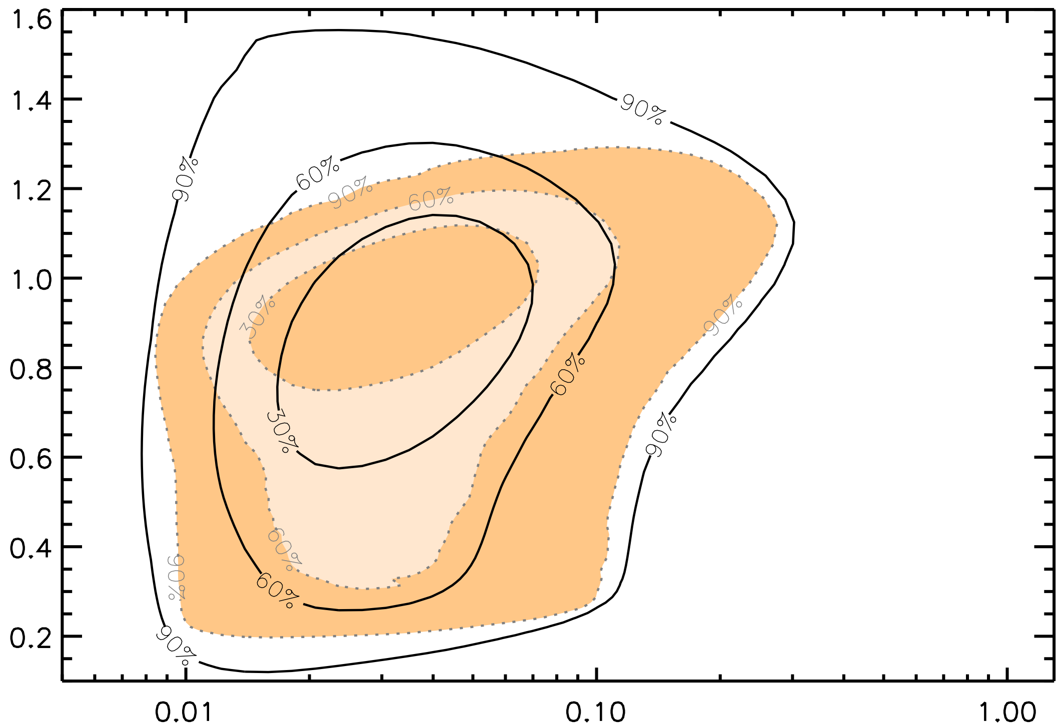
"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Scaling laws
$\frac{dn}{dz\,dT\,dL\,d\Omega}$
X-ray observables (count-rates)
X-ray selection function
$\frac{dn}{d\mathrm{CR}\,d\mathrm{HR}}$
Estimated mass distribution
Selection effects M(z) ?
Scaling laws, HE...
➔ Individual masses
T_X, Mgas(r),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



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

+ measurement errors

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



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

10 ks XMM exposures

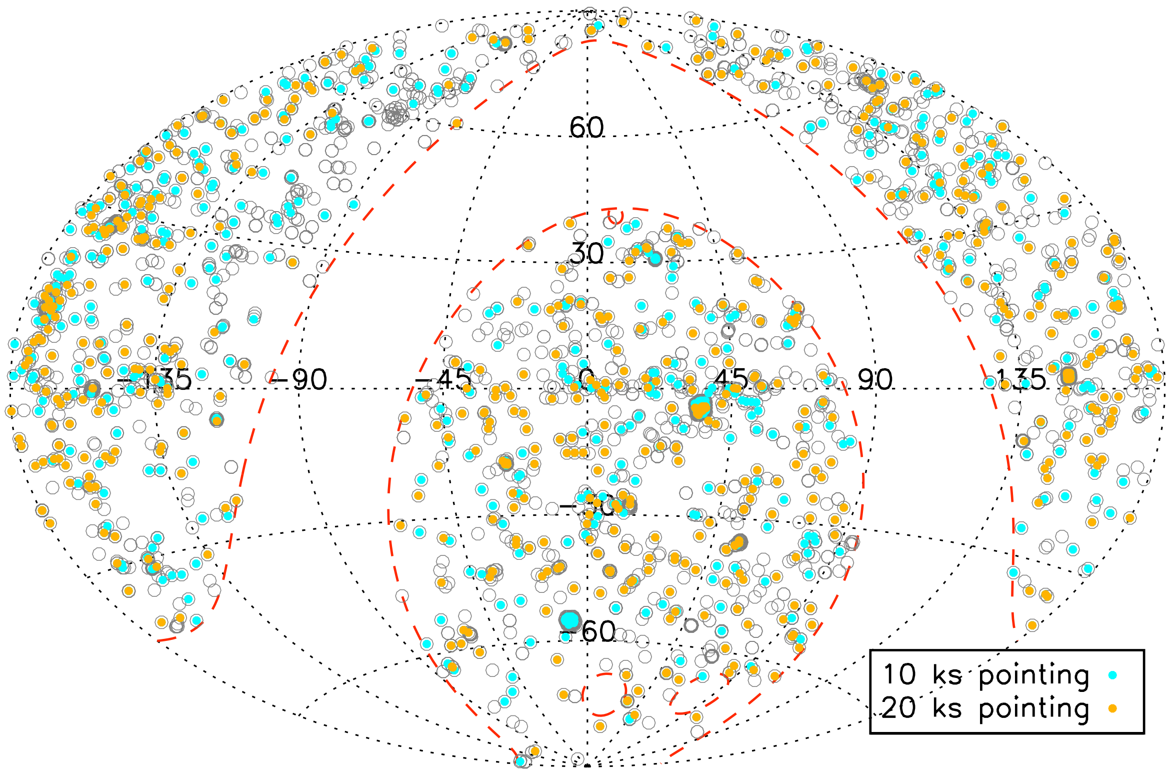
Fisher analysis

with a realistic implementation of the impact of the CR measurement errors

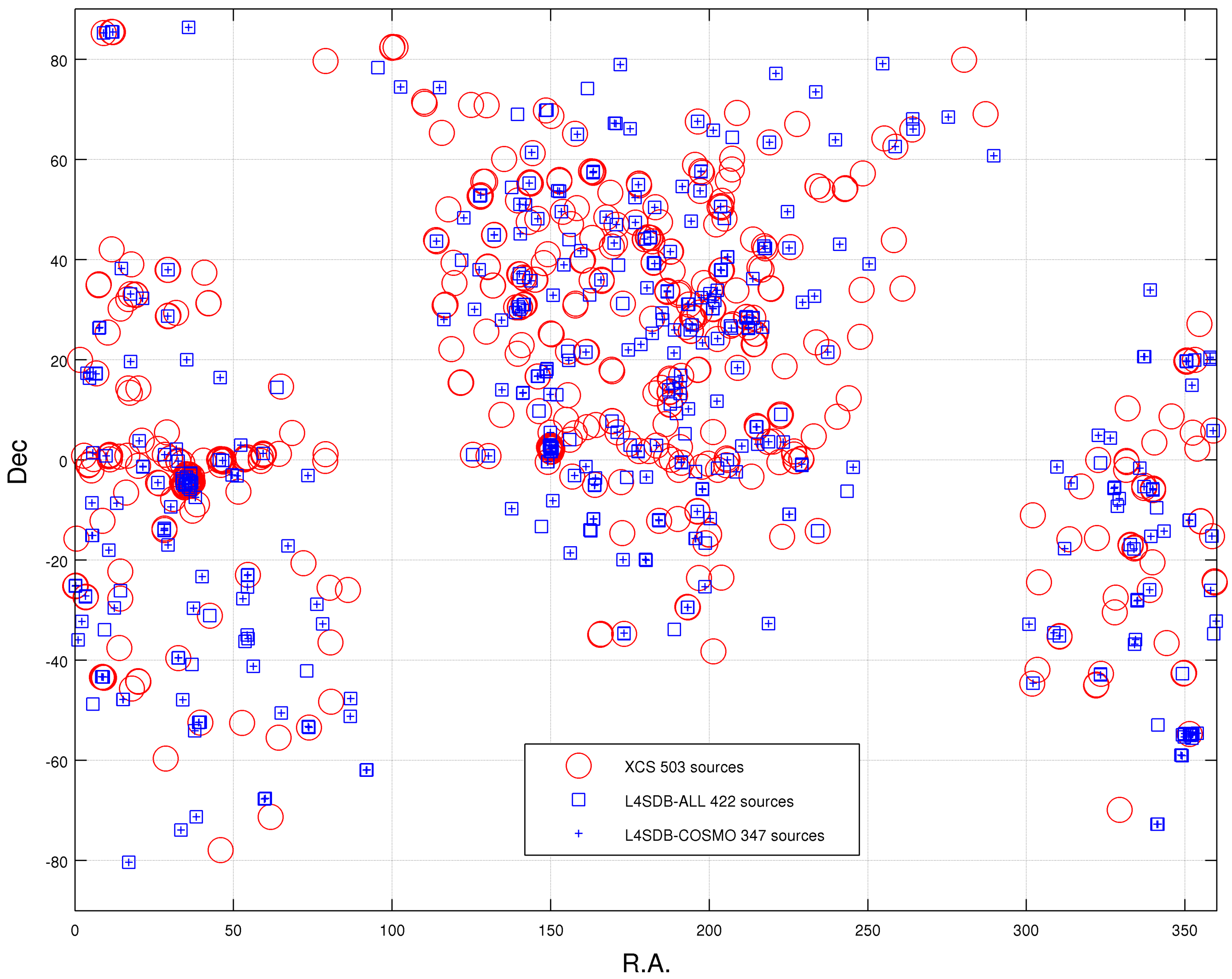
- HR-CR (no z) is much more efficient than dn/dz (requiring z)
- z-HR-CR is comparable to dn/dM/dz for cosmology
- z-HR-CR is more efficient than dn/dM/dz for cluster evolutionary physics.
- For the z-HR-CR method, photo-z are sufficient

X-CLASS

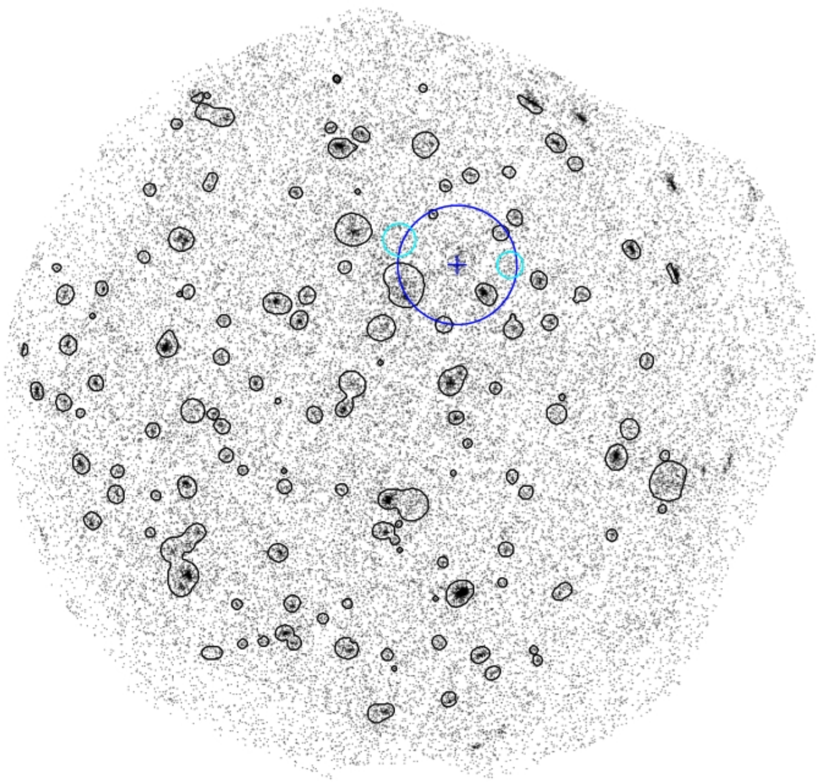
- Extending the XMM-LSS methodology to 2774 observations selected in the XMM archive (public as of May 2010)

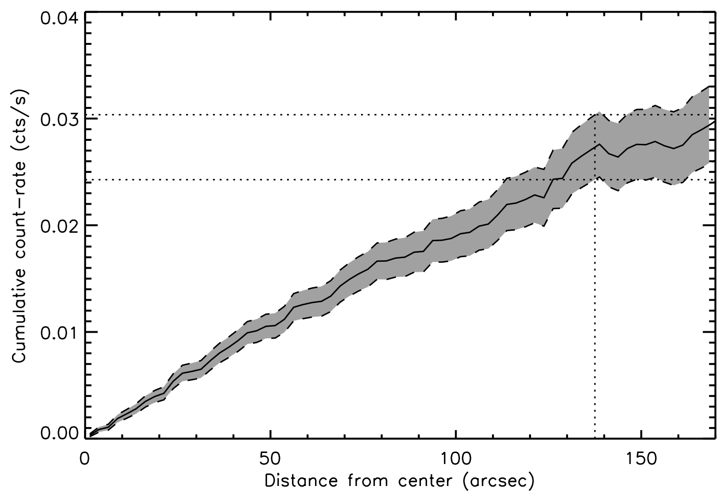


Comparison between XCS and X-CLASS



Count-rate measurements





~ 'GCA' technique (Böhringer 2000)

Semi-automatic (= semi-manual !) procedure :

- Masking of contaminants
- Background adjustment
- Aperture photometry
- Same scheme for all other bands

Final sample

- 845 C1 candidates in total
- 220 « new » (not in NED, not in XCS-DR1)
- Dedicated 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	[illegible]						data

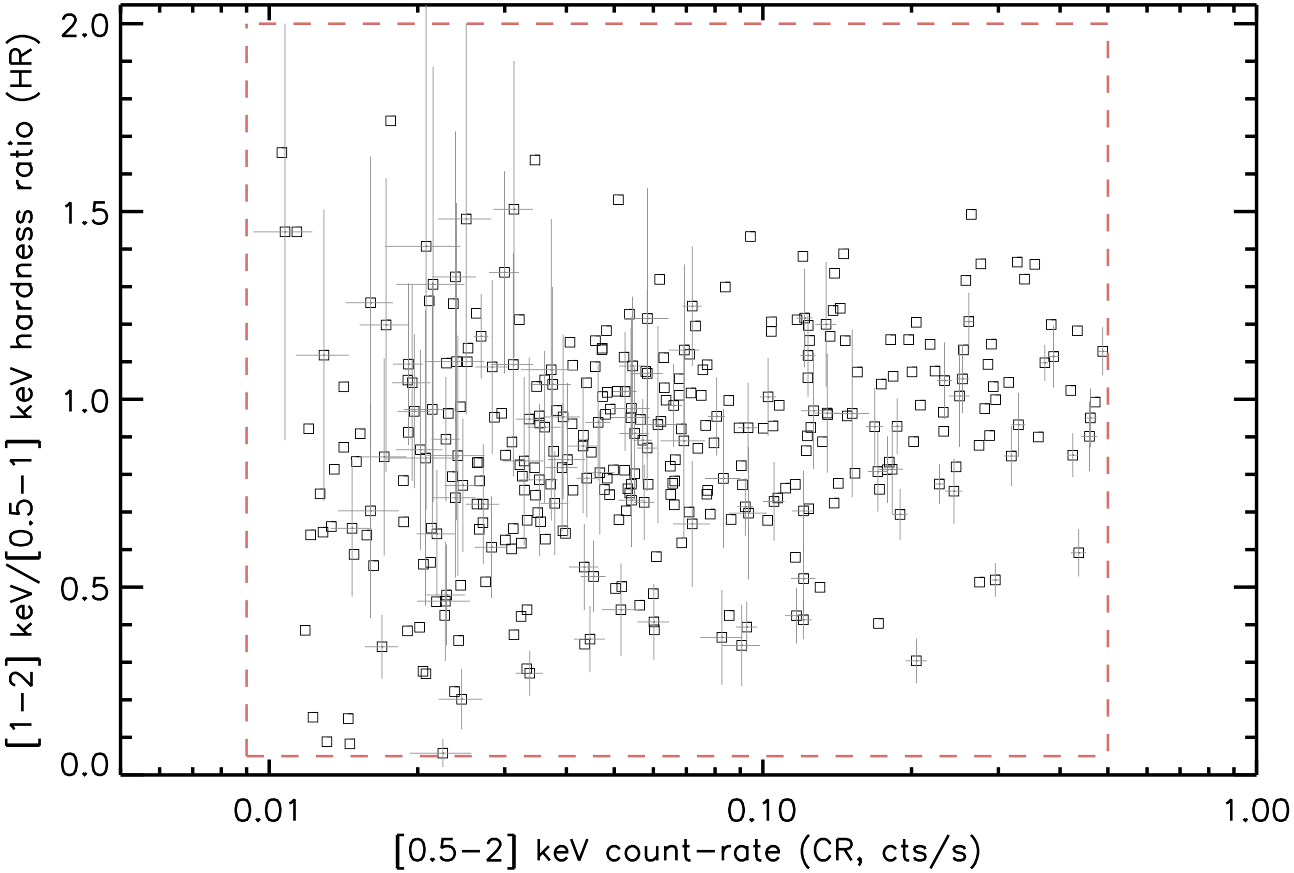
http://xmm-lss.in2p3.fr:8080/l4sdb/

The X-CLASS ‘science’ sample

- More stringent selection (C1+)
- Restricted to off-axis < 10’
- Count-rate selection : 0.009<CR<0.5 cts/s
  - Eliminates very faint sources
  - Eliminates bright clusters for which the cluster selection function is much more complicated

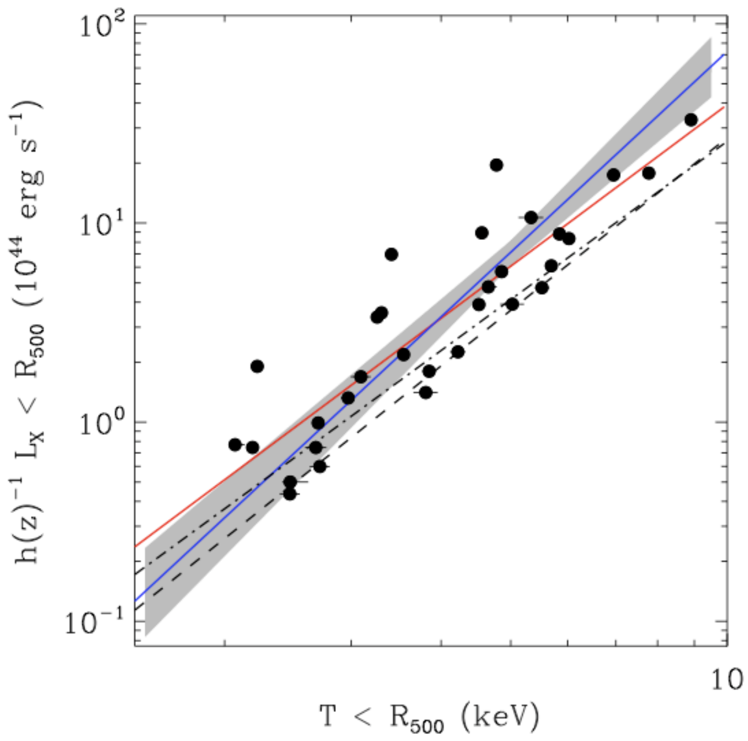
➔ 347 high signal-to-noise sources

CR-HR analysis



Fitting procedure

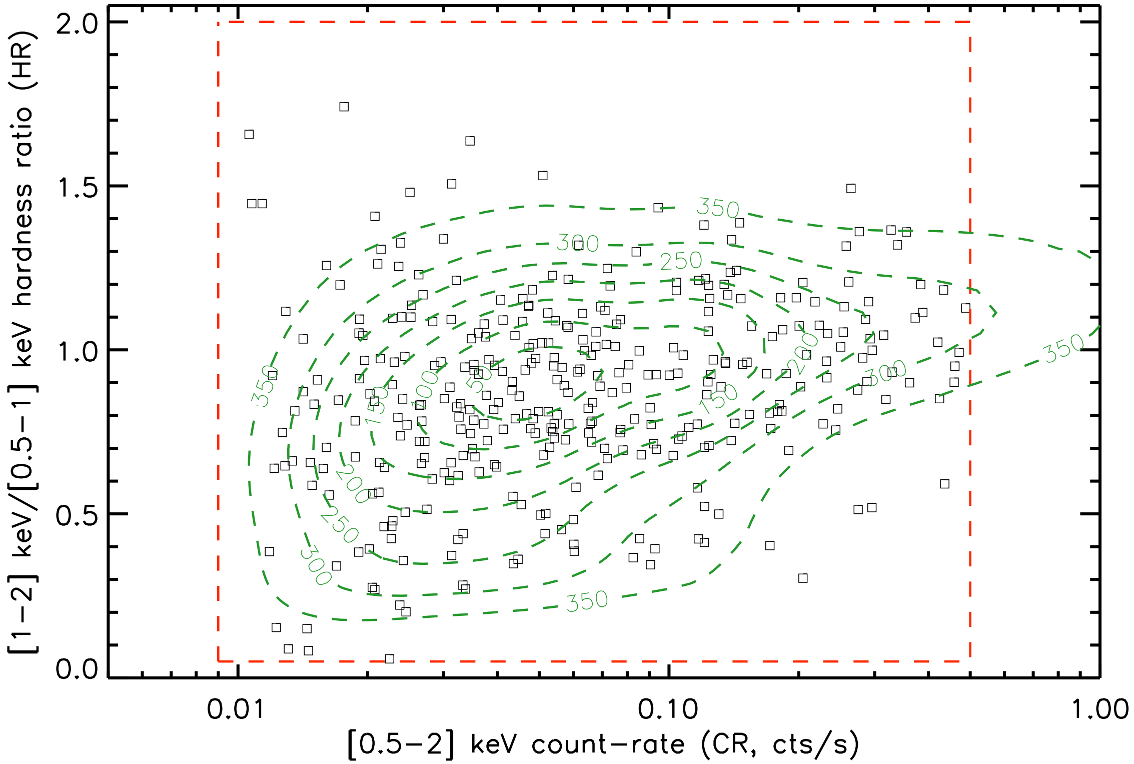
- Flat ΛCDM
- Fixed local M-T
- Fixed local L-T
  - Pratt 09 'ALL'
  - Pratt 09 'Non Cool Core'
- MCMC chains



SIMULTANEOUS FIT of
Cosmology – Scaling Relations – Selection function

Pratt et al '09

Cosmo + evolution of scaling laws

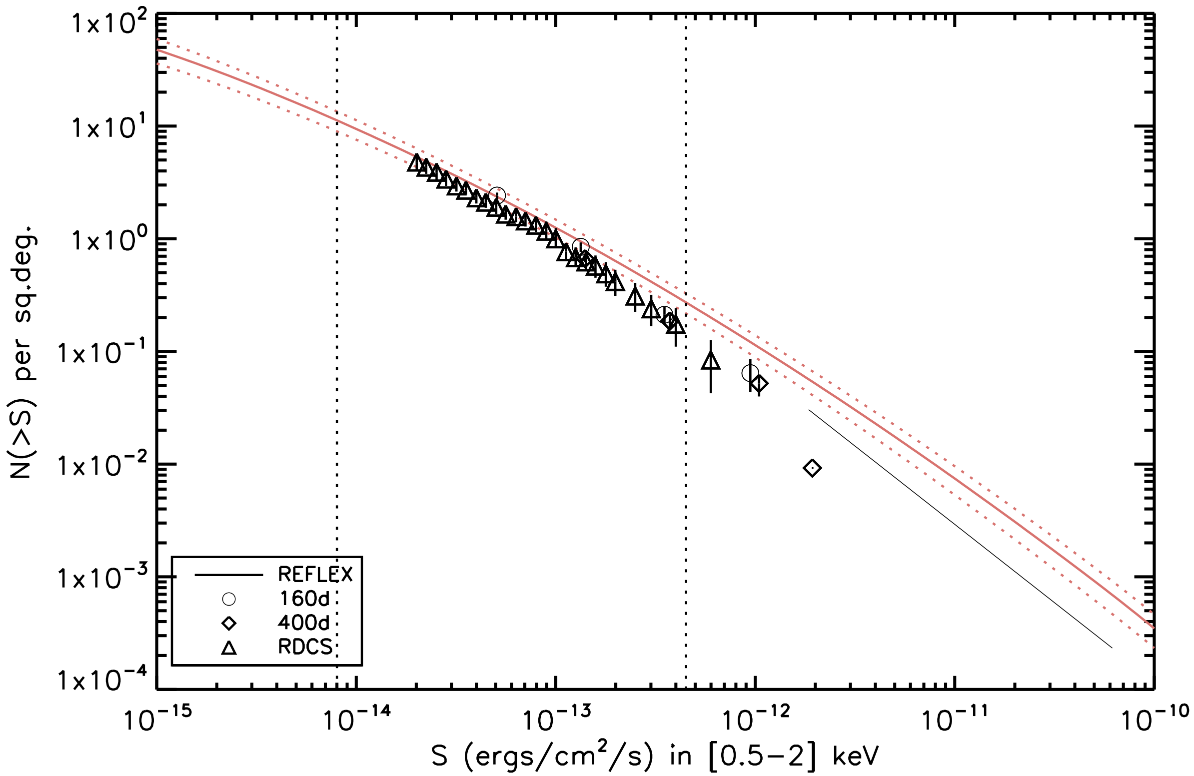


$$\Omega_m = 0.24^{+0.04}_{-0.09},$$
$$\sigma_8 = 0.88^{+0.10}_{-0.13},$$
$$\gamma_{z,MT} = 0.83^{+0.45}_{-0.56},$$
$$\gamma_{z,LT} = -1.3^{+1.3}_{-0.7},$$
$$x_{c,0} = 0.24 \pm 0.04.$$

assuming L-T Pratt 09, 'NCC'

Without any redshift information !

Cosmo + evolution of scaling laws



Predicted logN-logS with best model (red)

Use of local scaling laws

- Main hurdle in the study

- Differences between different scaling laws lead to different results :
  - 'ALL' :

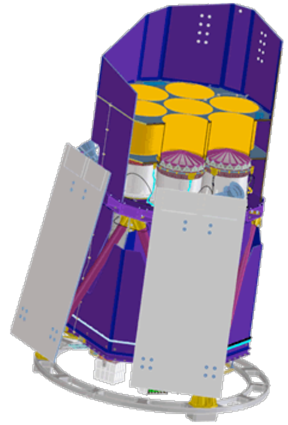
$$\Omega_m \sim 0.15\,,\ \sigma_8 \sim 0.96$$

- Selection effects affecting samples for calibration of scaling laws ?

- Importance of scatter, degenerate with S.L.

Forcasts for eRosita

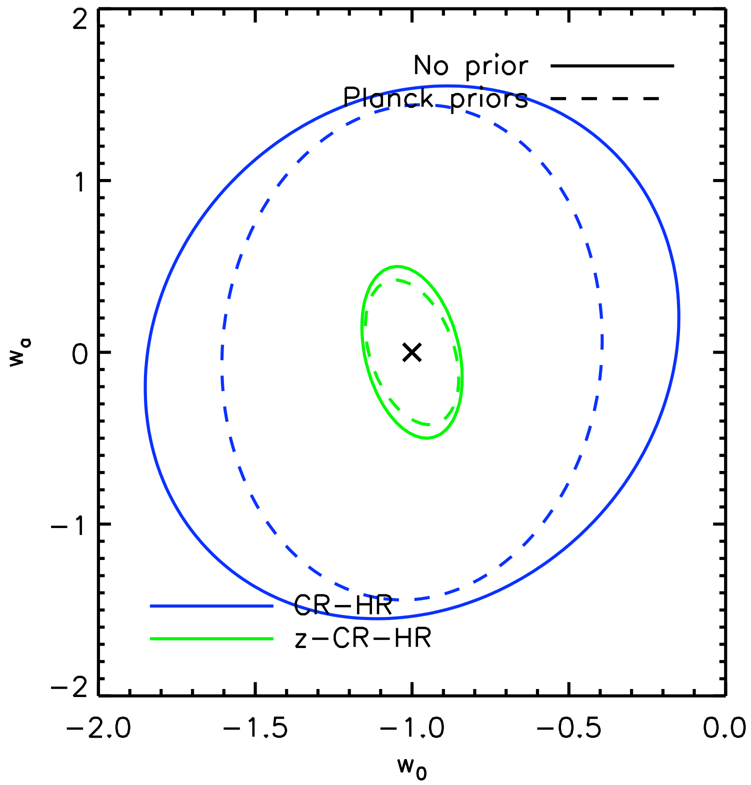
Future : eRosita

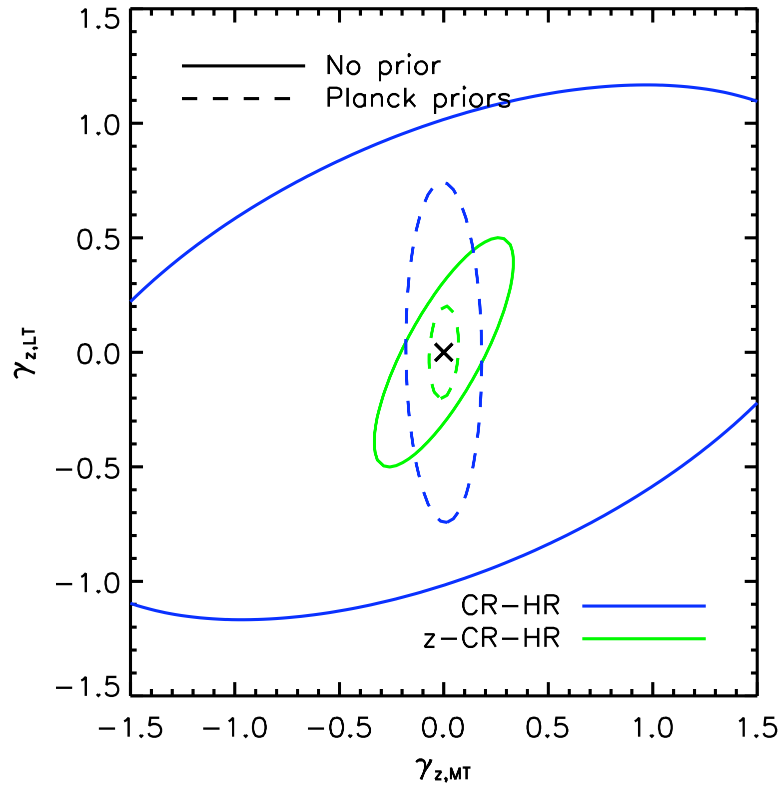


- All-sky survey: 20,000 deg2 extragal.
- Eff. Area ~ XMM EPIC MOS+PN
- 2.5 ks mean exposure

- Sensitivity: 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)

CONCLUSION

Summary

- An appropriate knowledge of the scaling laws - including dispersion - is critical for doing cosmology with X-ray clusters… **will this ever be achievable by dedicated programmes (limited in *z-mass* range – single slope) ?**

- The CR-HR method allows a direct and simultaneous fit of
  - cosmology
  - scaling laws + dispersion
  - selection effects

  And allows by-passing the mass determination steps

- In reality, S.L. act like catalysts in the CR-HR procedure (for given mass and redshift ranges)

- For the (next?) future, one can imagine drawing a wide range of CR-HR diagrams from simulations where both cosmology and physics are varied

  And thus, completely by-pass the mass and S.L. determinations:

  Cluster physics will be constrained by the best fitting simulation run.

FIN