The cosmological analysis of X-Ray cluster surveys: AspiX

Lorenzo Faccioli
Nicolas Clerc
Marguerite Pierre
Andrea Valotti

Context

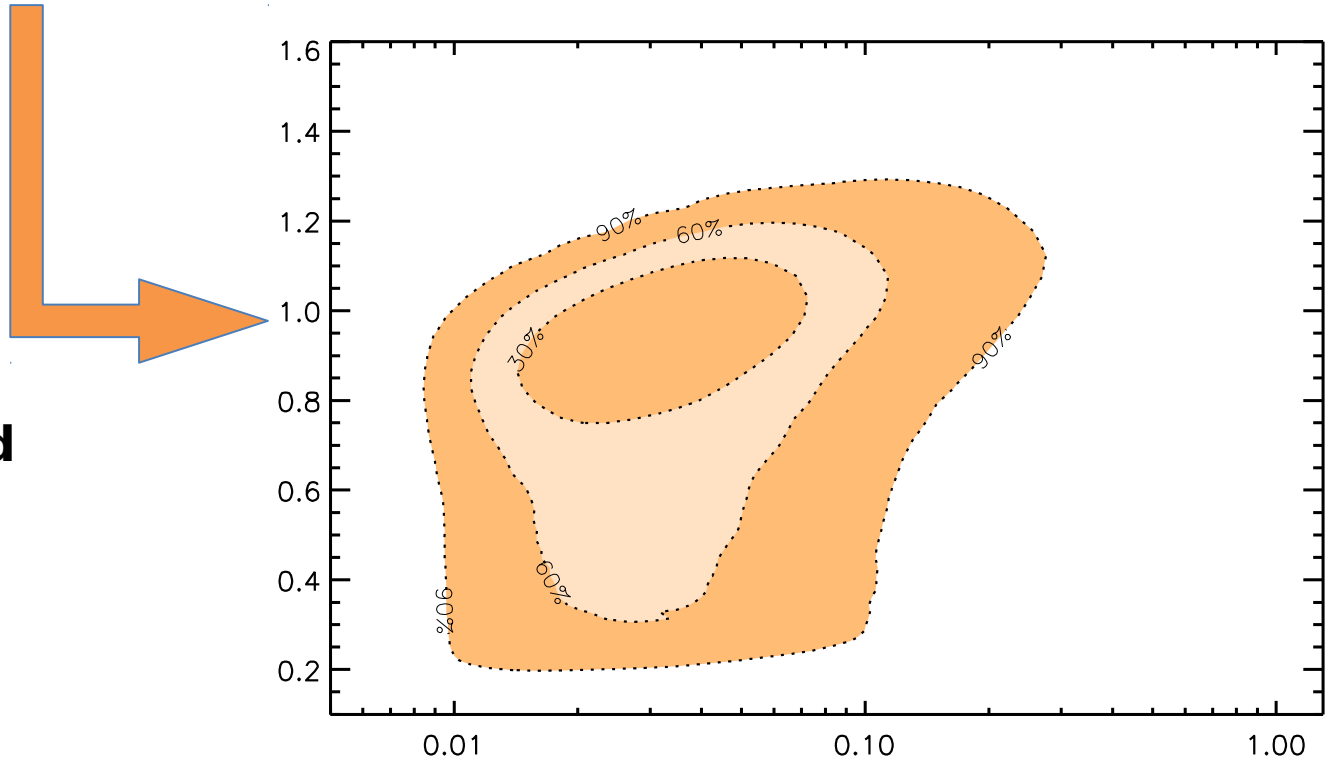
- We want to derive cosmological constraints from X-Ray selected samples of galaxy clusters without the need for redshifts (time consuming to get), thus enabling a fast analysis
- We introduce a new method of analyzing cluster sample
- We are applying it on the XMM archive

The principle

- Use only ***X-Ray signal variables***
- Top down: build synthetic ***XDDs*** (X-Ray Diagnostic Diagrams) from measured variables and compare with observed ones
- First implementation: ***CR-HR*** diagrams (Clerc et al 12a); applied on full XMM archive up to 2010 (Clerc et al 12b)
- Further developments: new variables, more accurate testing, application to larger datasets

The CR-HR distribution

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



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

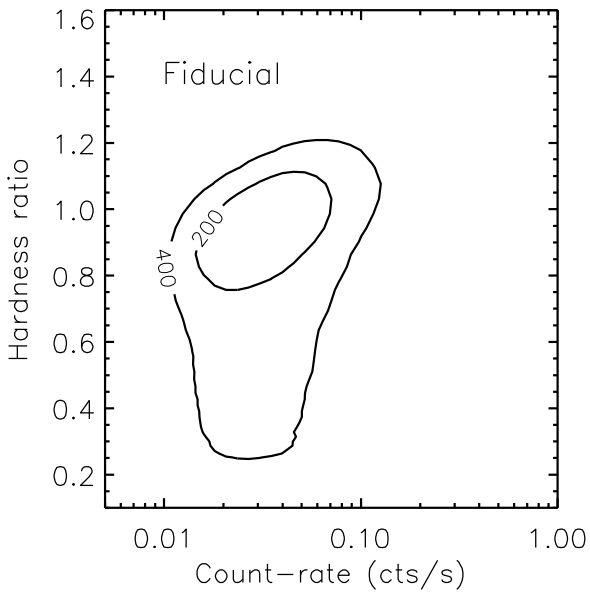
Diagram computed for :
WMAP5 cosmology
C1 selection
Local cluster scaling laws
Self-similar evolution

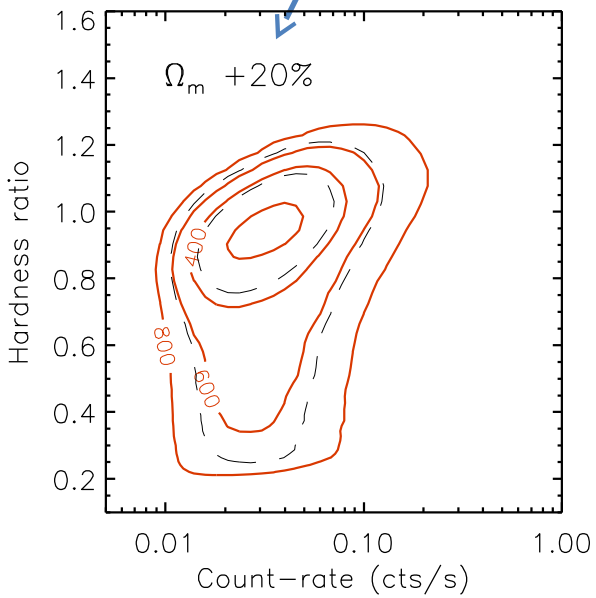
100deg2

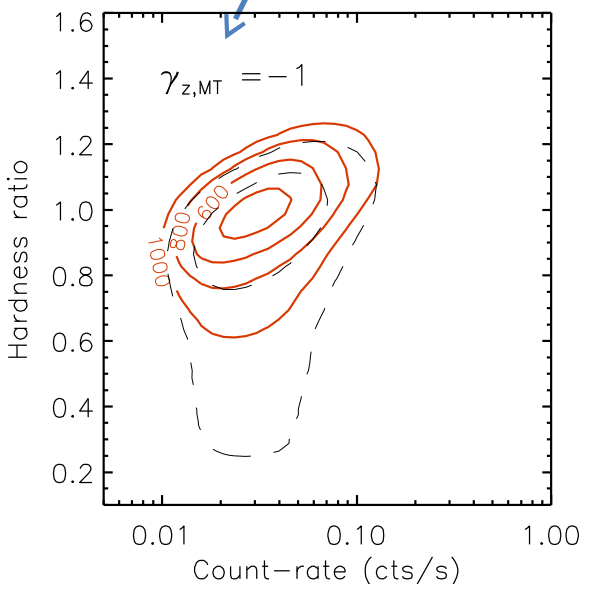
Clerc et al 12a

Non standard cosmology

Non self-similar evolution



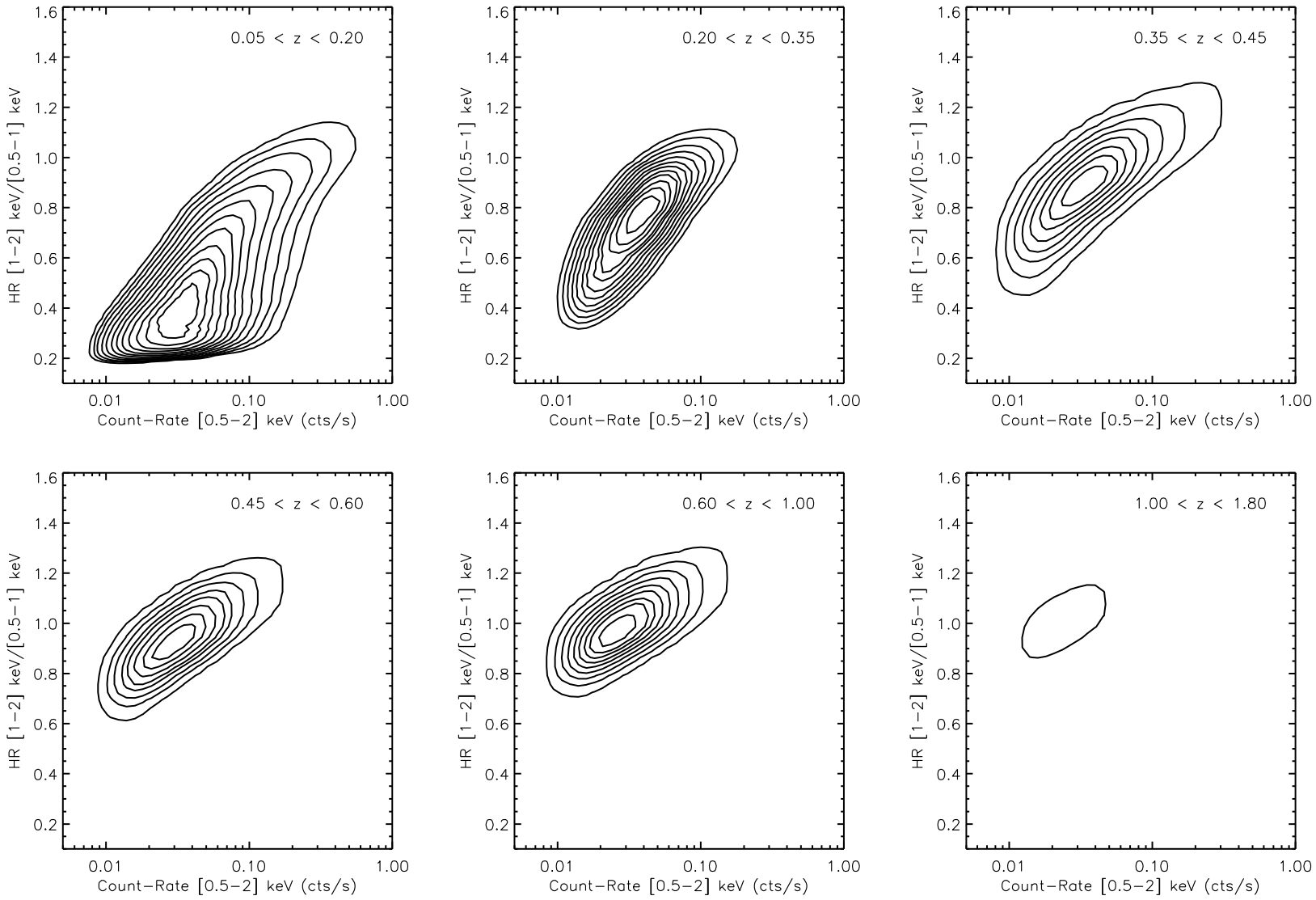




Clerc et al 12

Adding redshifts

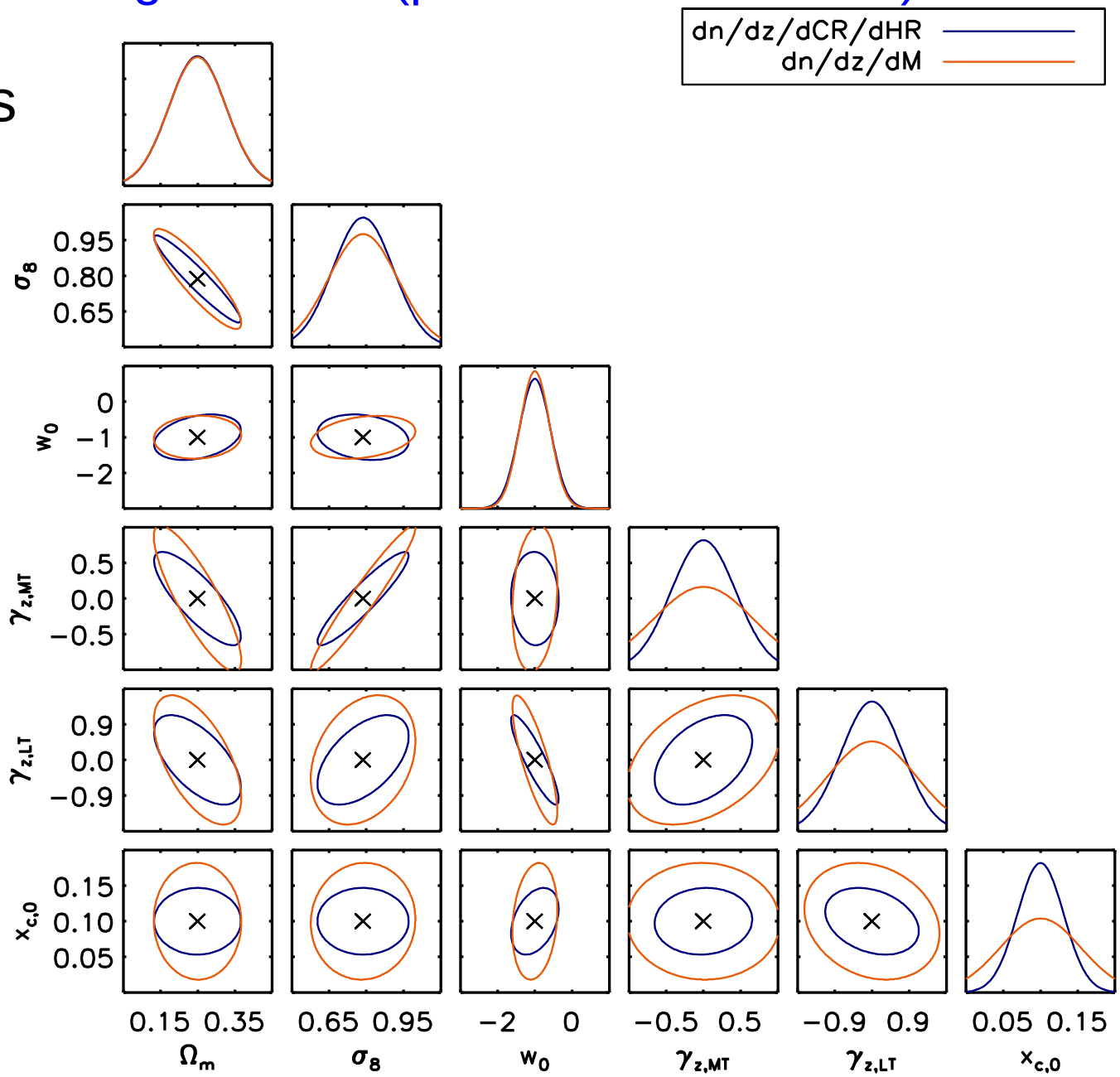
3rd dimension to the diagram



Clerc et al 12a

Adding redshifts (photo-z are sufficient)

CR-HR-z vs
N(M, z)



Clerc et al 12a

Analyzing the XMM archive

- Clerc et al 2012b: ***XCLASS*** catalogue
  - XMM archive up to May 2010
- ***C1 selection***, based on X-Ray measured variables: yields a ***high purity sample*** (Pacaud et al. 2006)
- ***850 C1 clusters*** in XCLASS catalogue
- ***347 high S/N C1 clusters*** for cosmological analysis
- Constraints on σ_8, Ω_m and ***Xc***
- ***Analysis being extended to XMM archive up to August 2015***

The latest development

Pierre, Valotti, Faccioli

ASpiX

Work in progress

New features

- Four observables: ***CR – HR – Rc – z***
- Toy model to
  - simulate cluster catalogues
  - test the impact of errors, scatters, area
- ***Cash statistics*** minimized via Nelder-Mead algorithm (Amoeba)
  - Test the impact of ***Rc***
  - Search for possible degeneracies
  - Evaluate the method wrt to ***dn/dM/dz***

Toy-model ingredients (1)

Relation	Slope	Normalisation	Scatter	Evolution
$M-T$	$\alpha_{MT}=1.49$	$A_{MT}=10^{0.46}$	20%	$\gamma_{MT}=0*$
$M-L$	$\alpha_{ML}=0.52$	$A_{ML}=10^{0.25}$	50%	$\gamma_{ML}=0*$
$M-R_c$	3	$X_c=0.24*$	50%	none

Table 1. Numerical values adopted for the cluster scaling relations
An evolutionary parameter γ of 0 implements the self-similar evolution hypothesis. The * indicates parameters that are possibly let free during the cosmological analysis

Pierre et al. 2016
to be submitted

Scaling laws from
Arnaud et al. 2005
Pratt et al. 2009

$$\frac{M_{200}}{10^{14}/h} = A_{MT} \times \left(\frac{T}{4}\right)^{\alpha_{MT}} \times E(z)^{-1}(1+z)^{\gamma_{MT}}$$

$$\frac{M_{200}}{10^{14}/h} = A_{ML} \times \left(\frac{L}{10^{44}}\right)^{\alpha_{ML}} \times E(z)^{-1.5}(1+z)^{\gamma_{ML}}$$

$$M_{500} = \frac{4}{3}\pi R_{500}^3 \quad X_c = \frac{R_c}{R_{500}}$$

Toy-model ingredients (2)

- Assumed errors on *CR, HR, Rc*
  Either 0 or log-normal 20%

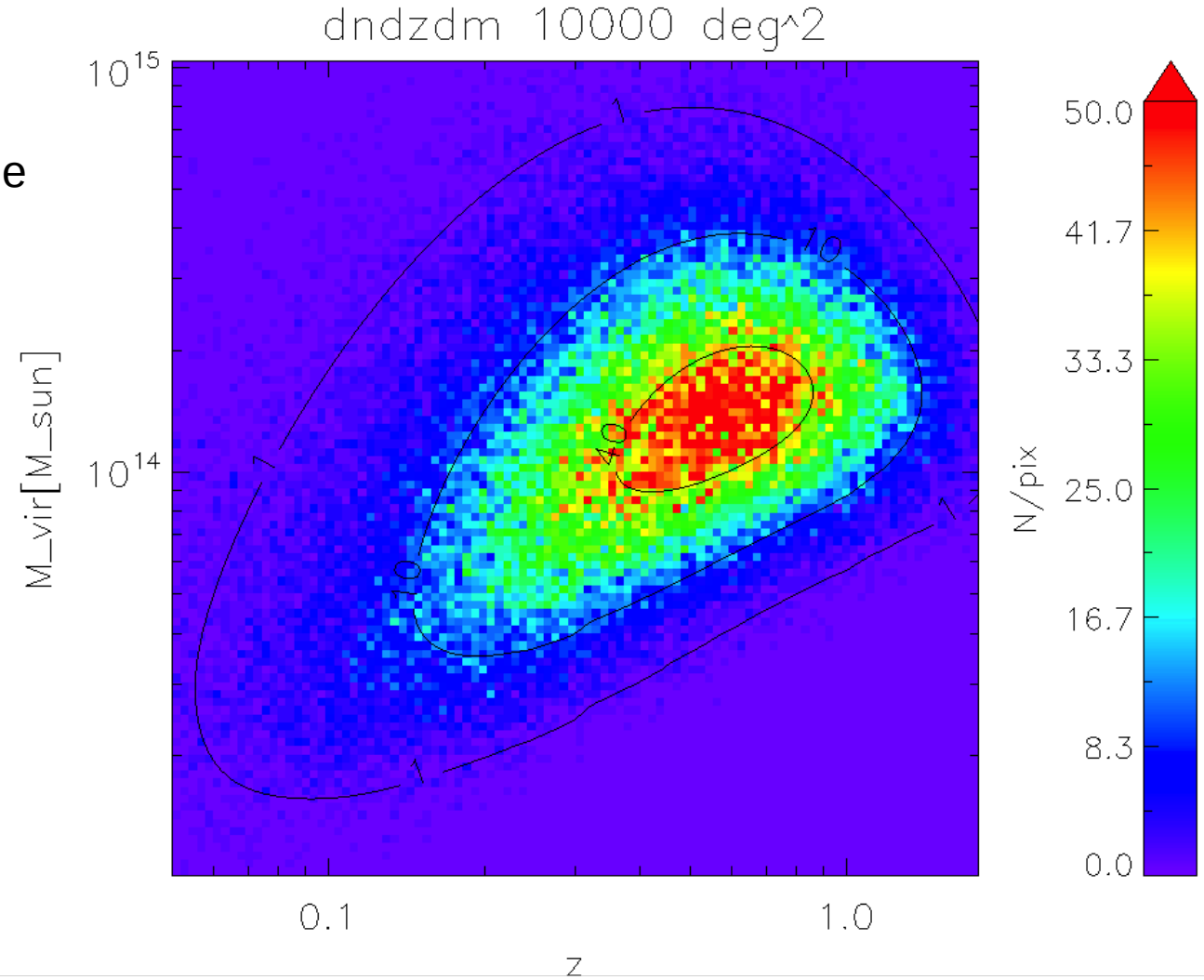
Pierre et al. 2016
to be submitted

- Assumed error on *z*
  0

The C1 cluster population 10,000 deg2 M-z plane

C1 selection:
low contamination sample
Bona fide clusters

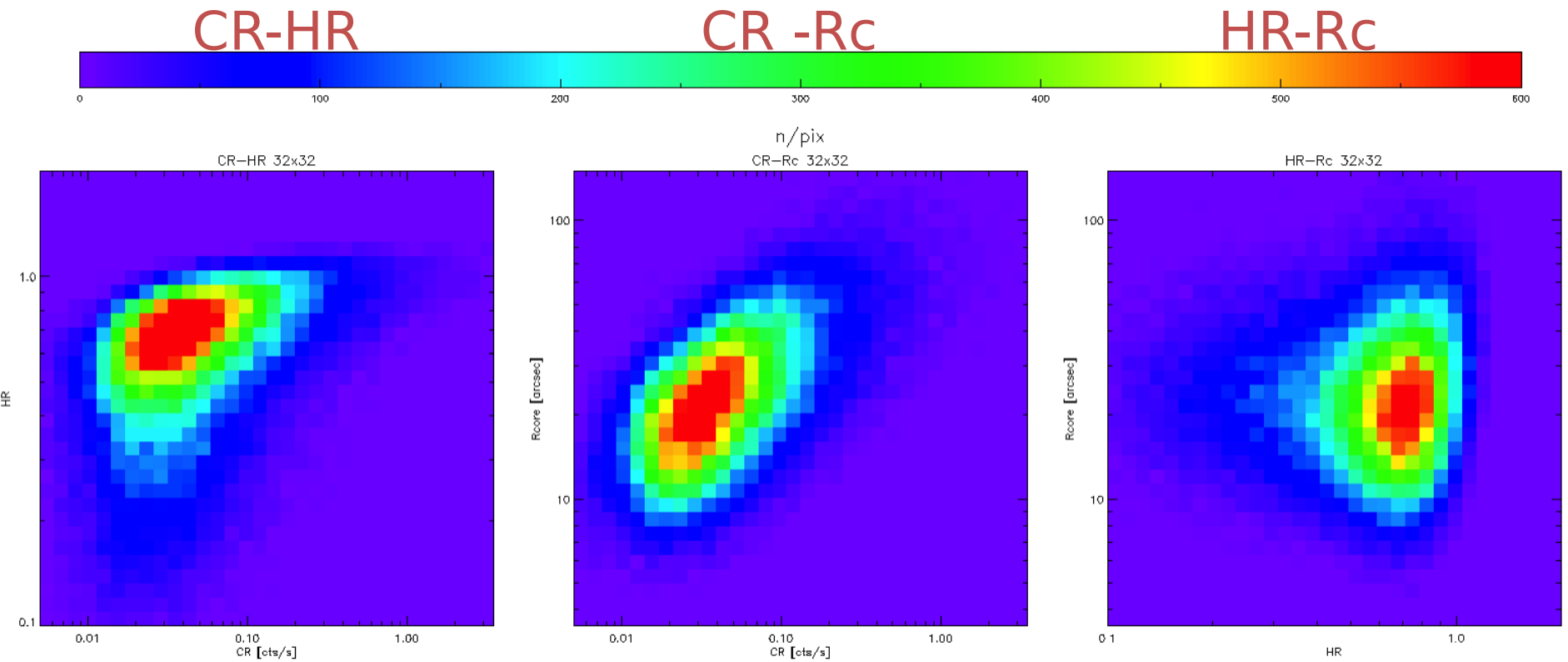
Pierre et al. 2016
to be submitted



Principle

Project the 2-D ***dn/dM/dz*** population into the 4-D ***CR-HR-Rc-z*** observed parameter space

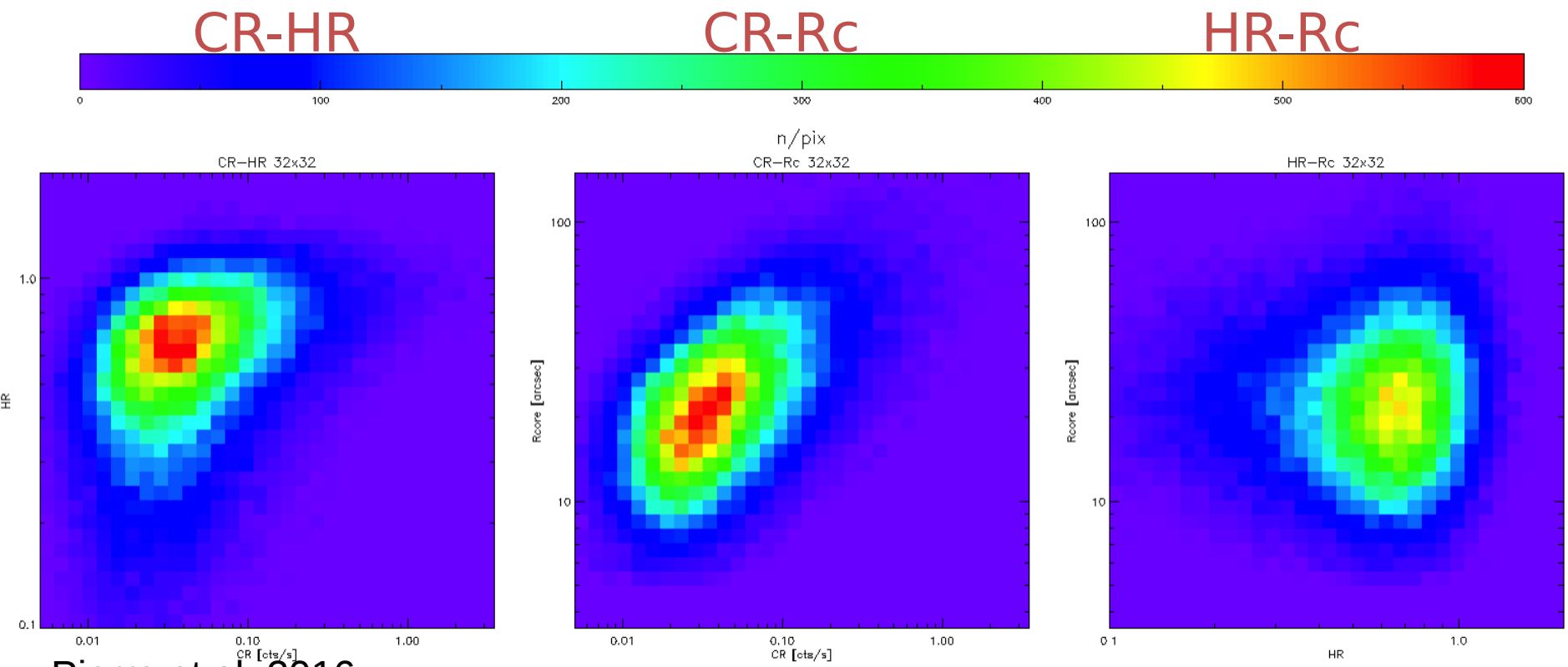
The C1 cluster population
10,000 deg2 - observable space



Pierre et al. 2016
to be submitted

Integrated over z

The C1 cluster population 10,000 deg2 - observable space adding error measurements

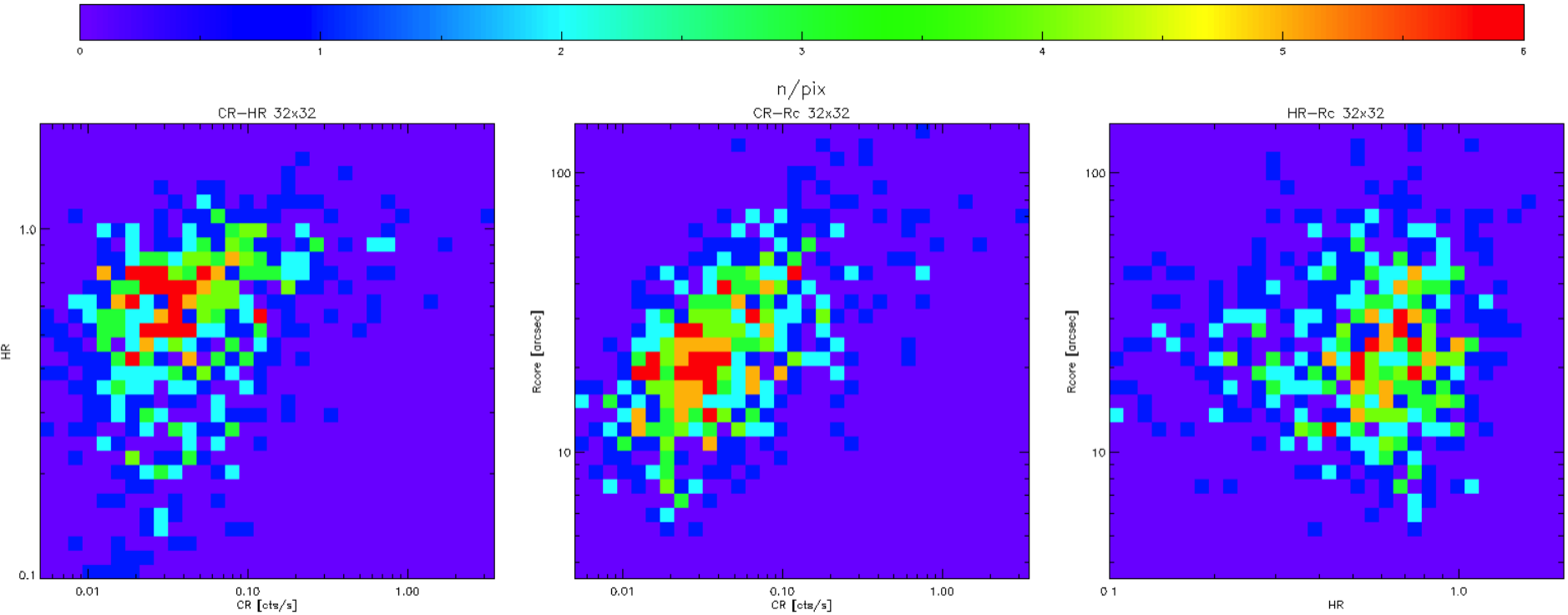


Pierre et al. 2016
to be submitted

Integrated over z

The C1 cluster population 100 deg2 - observable space adding error measurements

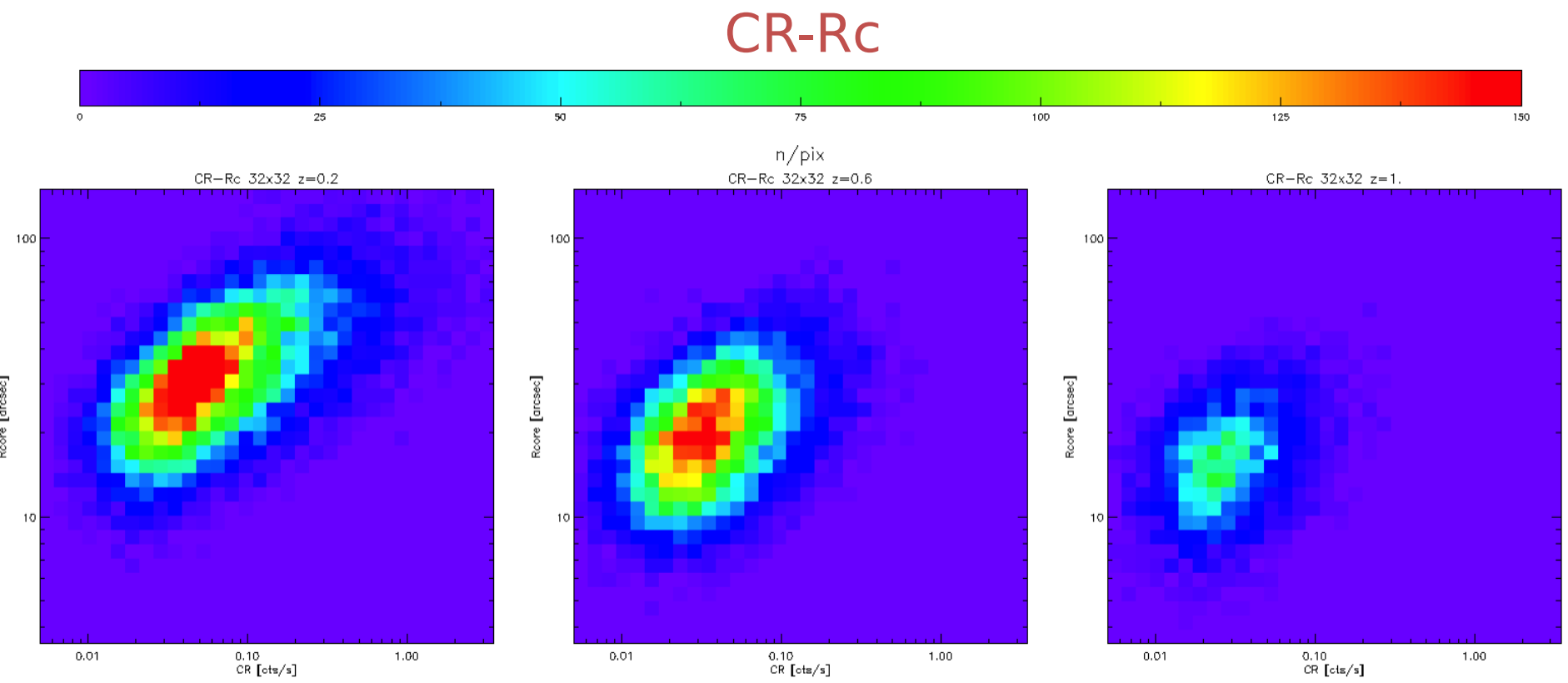
CR-HR CR-Rc HR-Rc



Pierre et al. 2016
to be submitted

Integrated over z

The C1 cluster population 10,000 deg2-observable space



redshift slices

0.2 0.6 1

Pierre et al. 2016
to be submitted

Principle of ASpiX

- Compute the likelihood (minimizing the ***Cash statistic***) of an ***observed XDD***, by comparison with a model
- Explore likelihood space with Amoeba
- Are there strong local minima? (degeneracy in the XDD 4-D space)
- Launch 100 independent Amoeba runs with different starting points

Set of explored parameters

	fiducial	main
• Ω_m	0.23	x
• σ_8	0.83	x
• X_c	0.24	x
• γ_{ML}	0.00	
• γ_{MT}	0.00	
• w_o	-1.00	x
• w_a	0.00	

Pierre et al. 2016
to be submitted

dn/dM/dz 100 deg2, 50% error on mass as a reference case

Average over 10 deg2 catalogues

Parameter	Mean	Std
Ω_m	0.24	0.02
σ_8	0.81	0.01
X_c	0.25	0.02
w_0	-1.00	0.10

Caveat

The ~500 clusters are supposed to have their mass measured at 50%, even those with 50 photons

Pierre et al. 2016
to be submitted

The reality

CR-HR-Rc-z

100 deg2

20% error on ***CR, HR, Rc***

Average over 10x100 deg2 catalogues

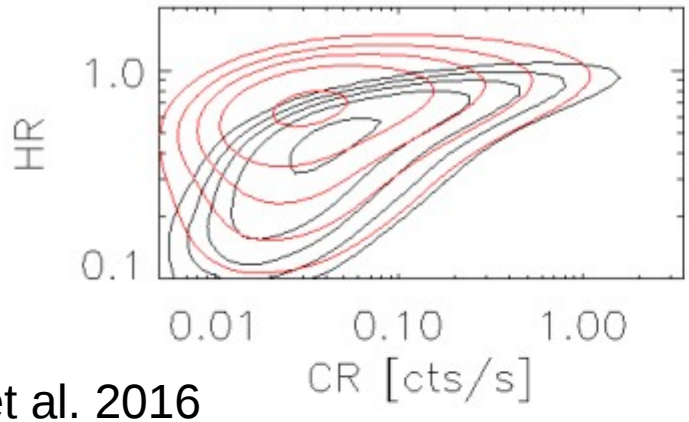
Parameter	Mean	Std
Ω_m	0.23	0.01
σ_8	0.82	0.01
X_c	0.24	0.01
w_0	-0.92	0.08

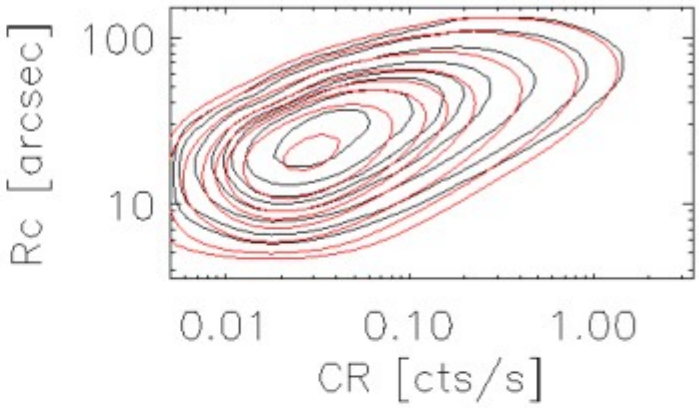
Better performance than dn/dm/dz

Pierre et al. 2016
to be submitted

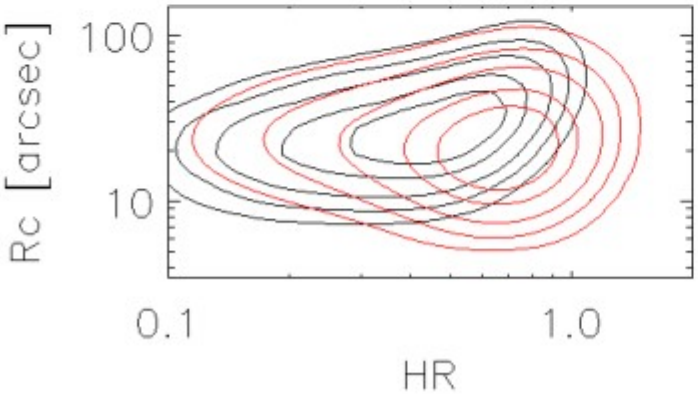
Lifting degeneracies

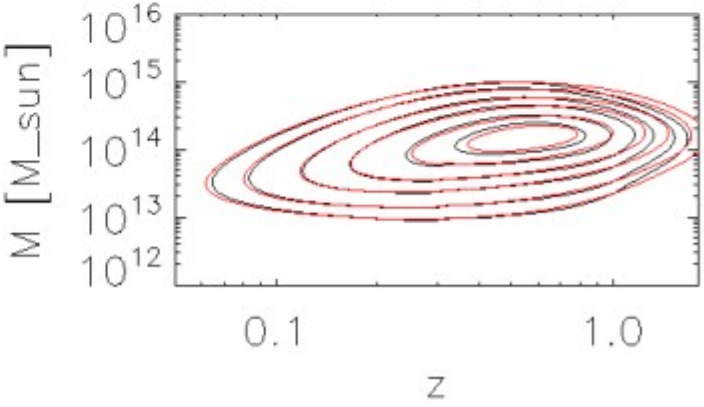
Fiducial vs. recovered model for one of the 100 deg2 catalogs
Red: fiducial, black: Xc 0.27 γMT 1.41 vML -0.54 w0 -0.66 wa -8,38
`





Pierre et al. 2016
to be submitted





Degeneracy in N(m,z) space resolved in CR-HR-Rc space

Summary of the current assumptions

- Scaling relations known
- Evolution self-similar
- Scatter values in the scaling relations:
  - known
  - independent
- Selection perfectly monitored
- ***In the future we will explore the method under more realistic assumptions***

Future plans: test on more realistic simulations

- Test on the ***Aardvark N body (Farahi et al 16) simulations*** painted with a β=2/3 model (Valotti et al. in preparation)

- Test on ***Cosmo OWLS hydrodynamical simulations (LeBrun et al 14)*** (Faccioli et al. in preparation)
  - cluster irregular shapes
  - physical modelling of the AGN

Future plans: apply AspiX to real data

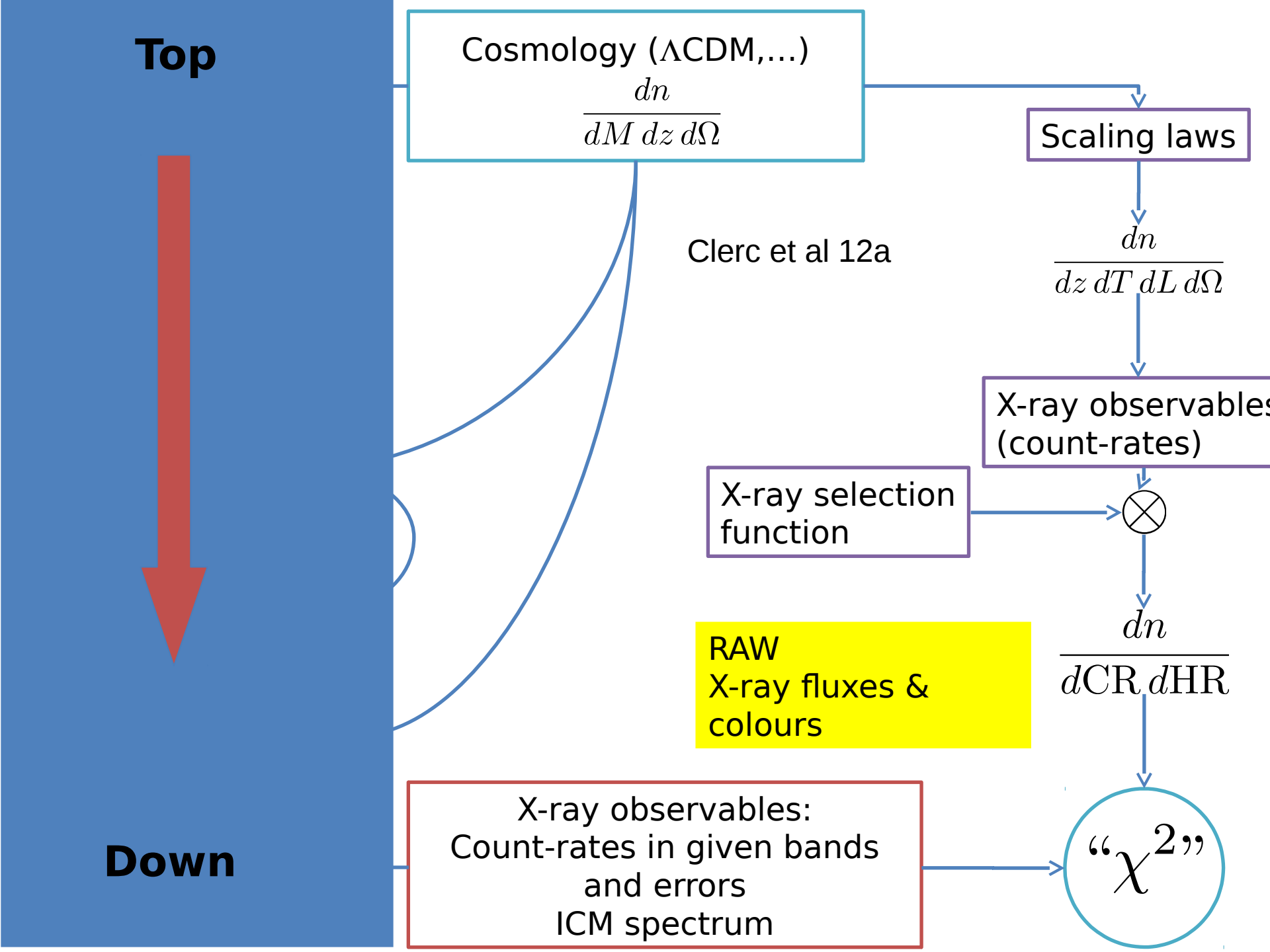
- ***CR-HR*** method with ***photo-z*** applied to XCLASS sample (Ridl et al., in preparation; see also J. Ridl talk, this afternoon)

- Apply ASpiX to the ***expanded XCLASS sample*** (includes all XMM pointings from 2000 to August 2015); pointings already reprocessed and being analyzed

- Apply ASpix on the ***full XXL sample***

Supplementrary slides

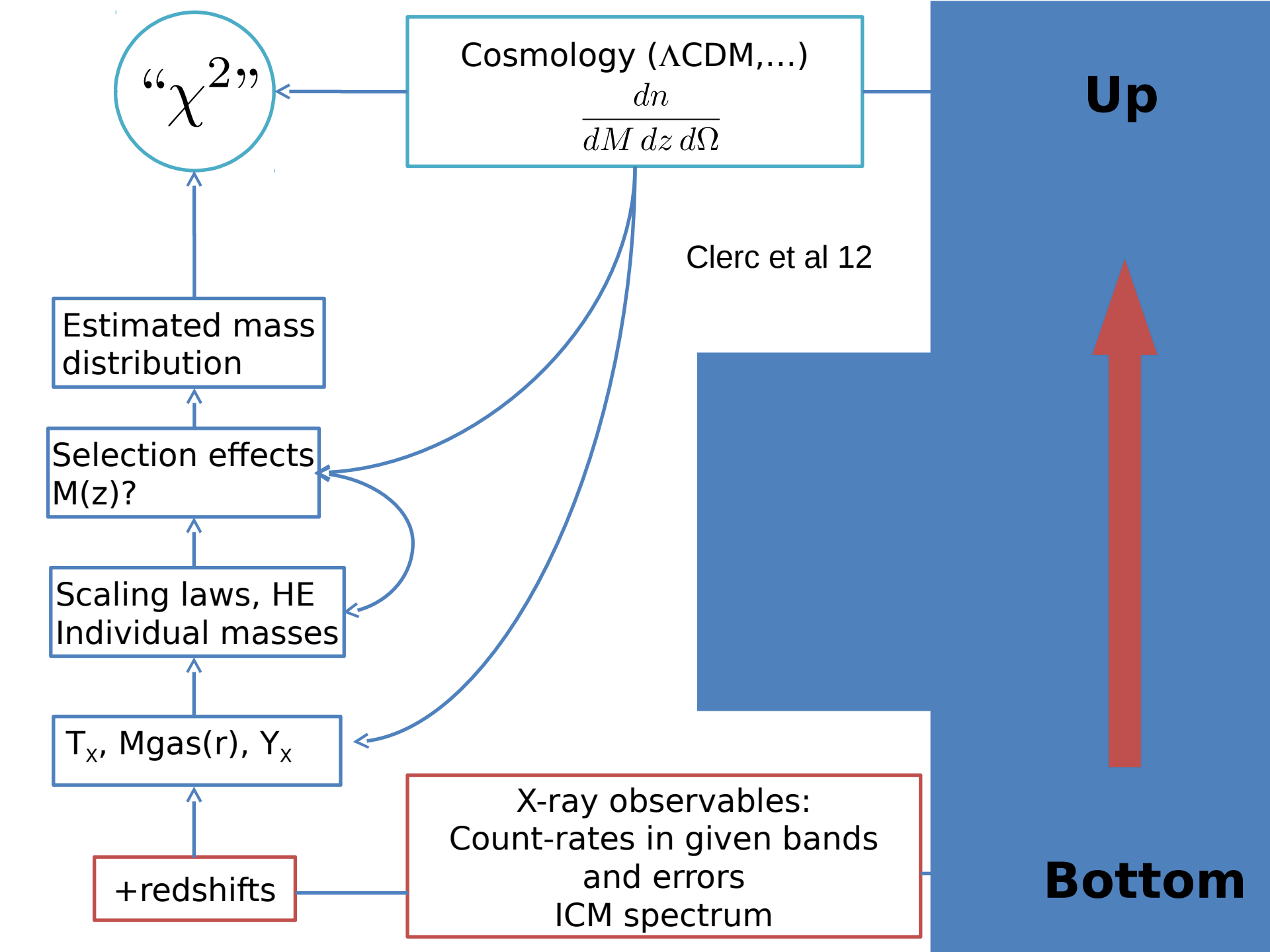
Doing cluster cosmology without masses


Top
Down
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Scaling laws
Clerc et al 12a
$\frac{dn}{dz\,dT\,dL\,d\Omega}$
X-ray observables
(count-rates)
X-ray selection
function
RAW
X-ray fluxes &
colours
$\frac{dn}{d\mathrm{CR}\,d\mathrm{HR}}$
X-ray observables:
Count-rates in given bands
and errors
ICM spectrum
"χ^2"

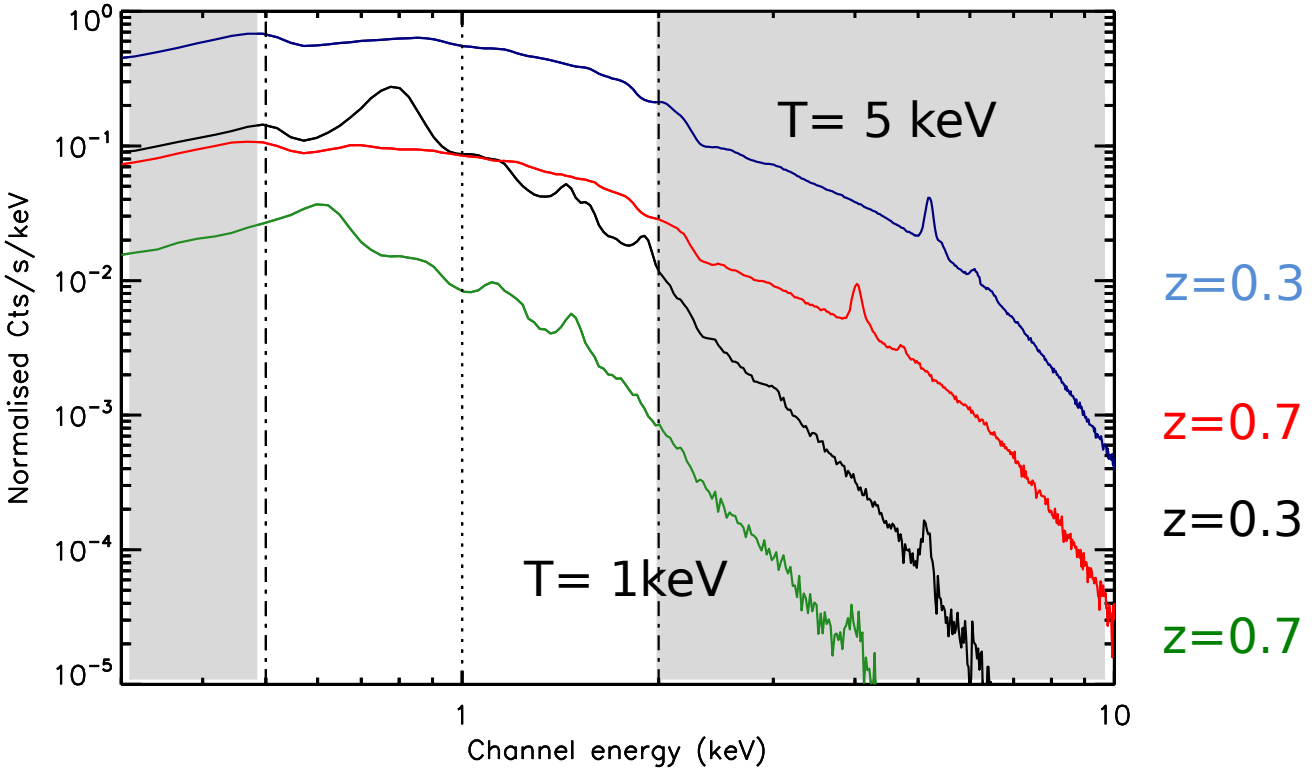
New developments on the HR-CR method: ASpiX

Lorenzo Faccioli
Nicolas Clerc
Marguerite Pierre
Andrea Valotti

Reminder – *Clerc et al 2012*


"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Clerc et al 12
Estimated mass distribution
Selection effects M(z)?
Scaling laws, HE Individual masses
T_X, Mgas(r), Y_X
+redshifts
X-ray observables:
Count-rates in given bands and errors
ICM spectrum
Up
Bottom

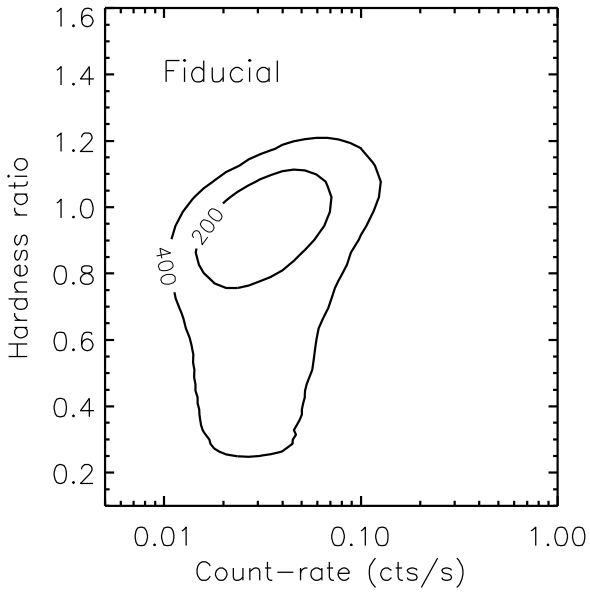
- CR in [0.5-2] keV ~ Magnitude
- HR = [1-2]/[0.5-1] ~ Colour

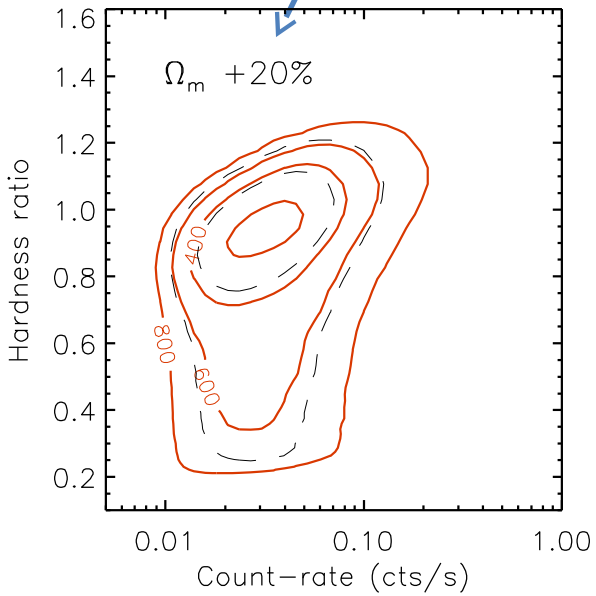


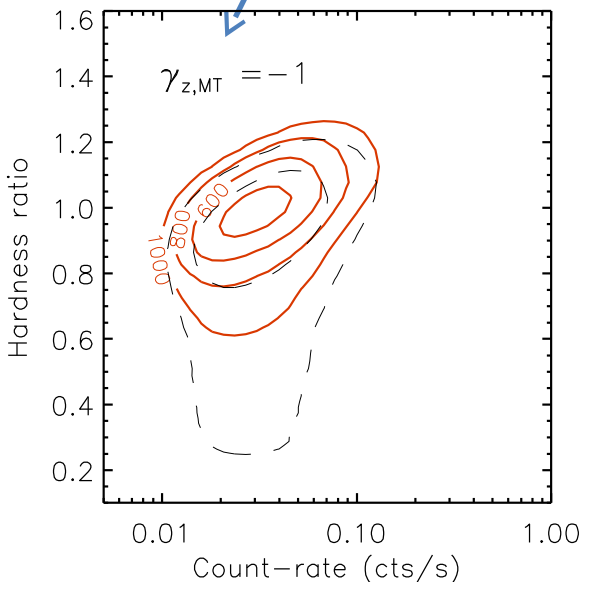
Clerc et al 12

Non standard cosmology

Non self-similar evolution

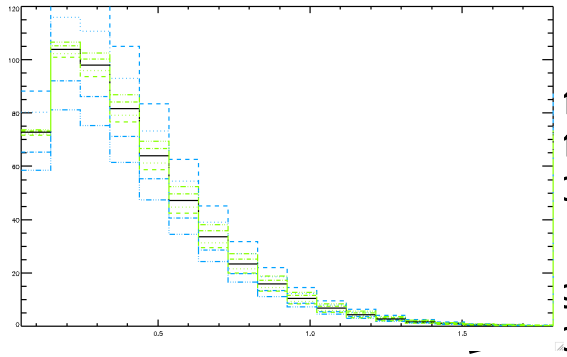


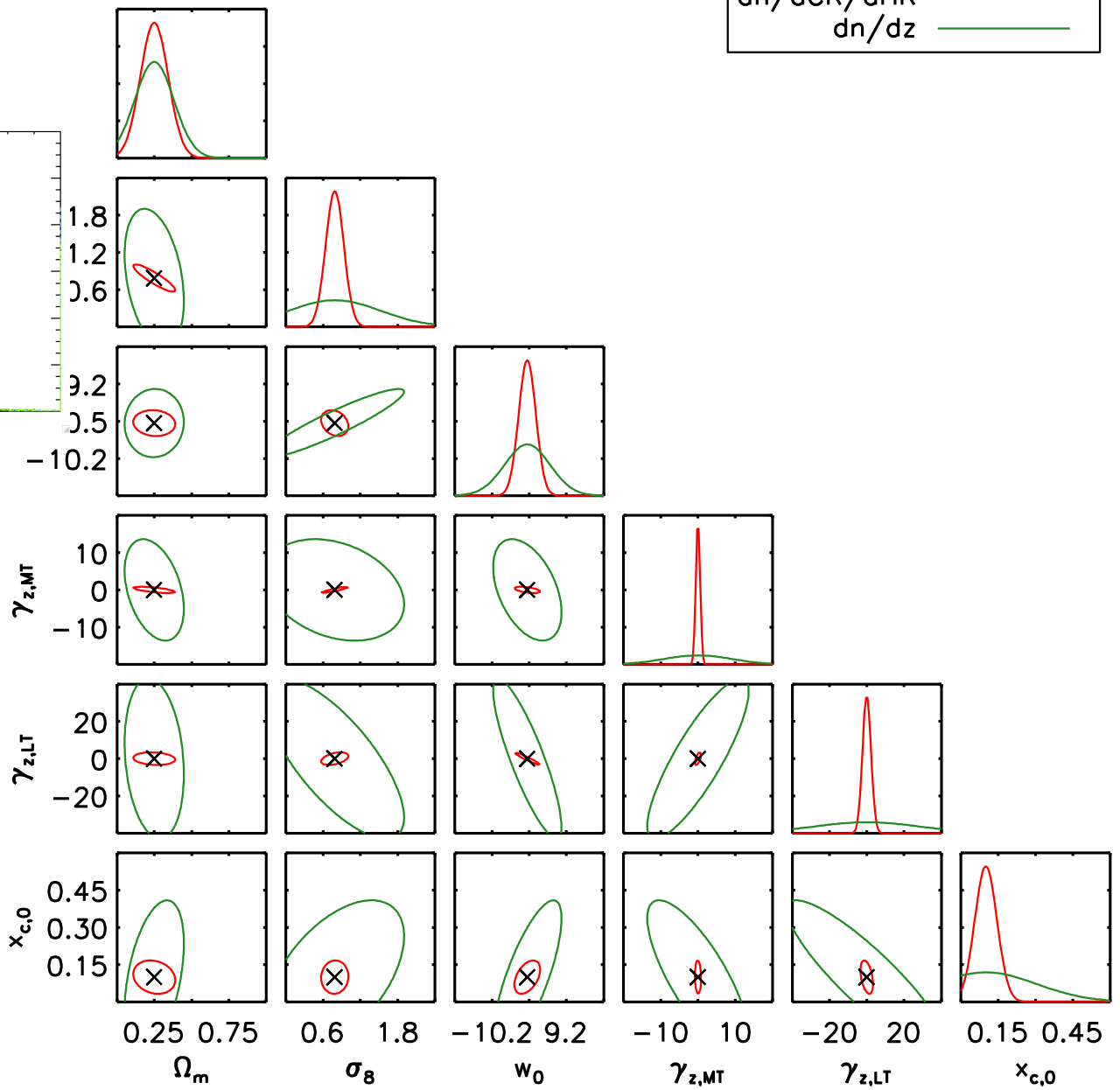




Clerc et al 12

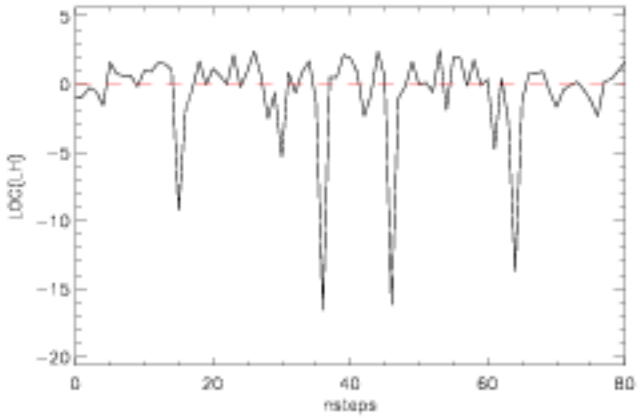
1) CR/HR vs dn/dz

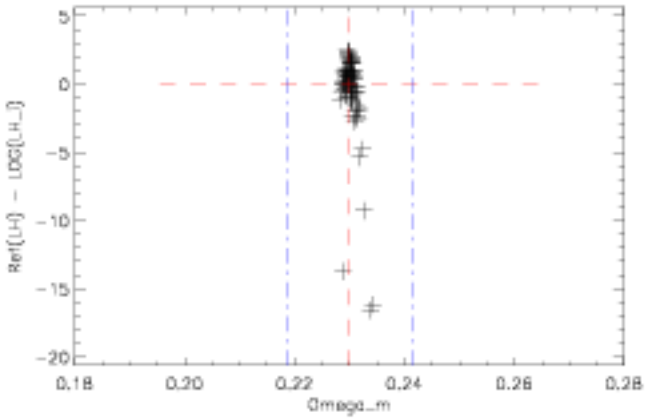


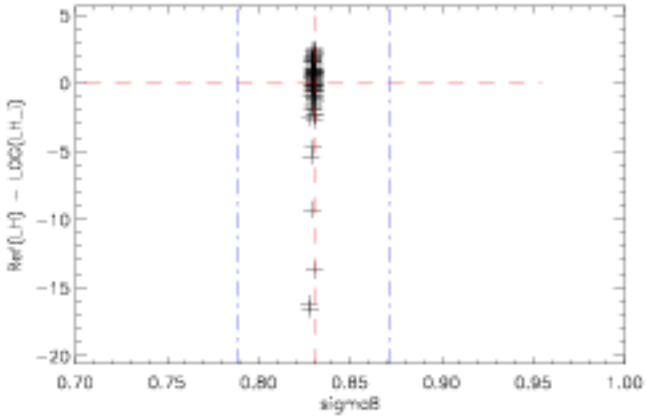


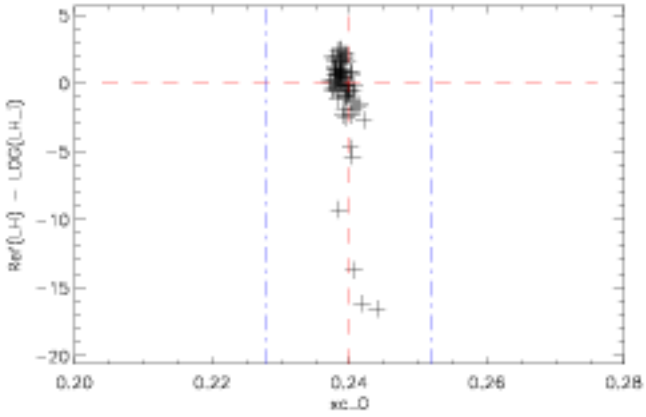
Does not need redshifts!

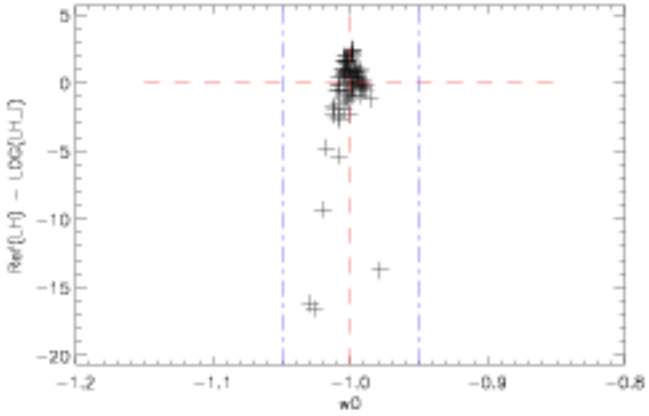
Clerc et al 12


LDG(L-H)
nsteps

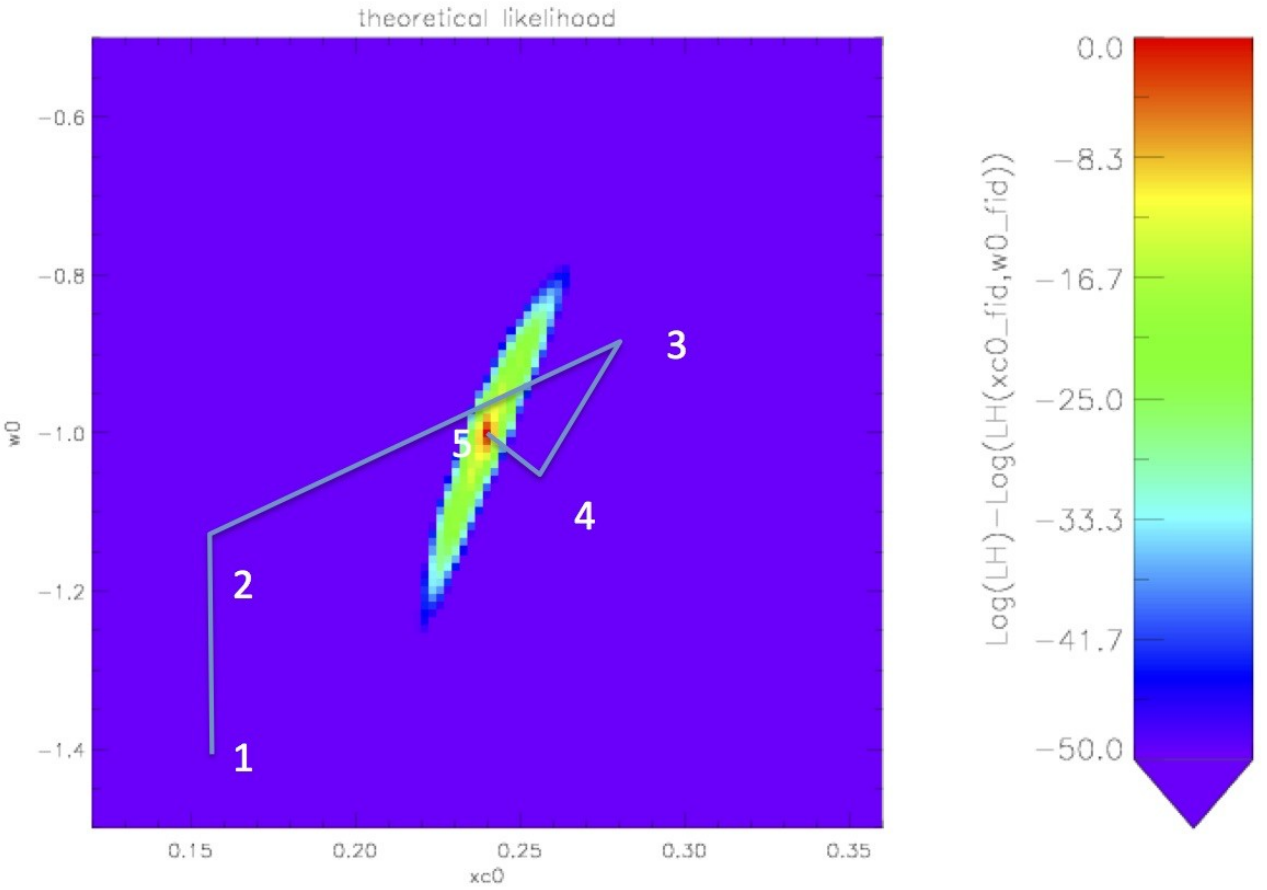

Ref(L-H) - LDG(L-H_)
Omega_m


Ref(L-H) - LDG(L-H_)
sigma8

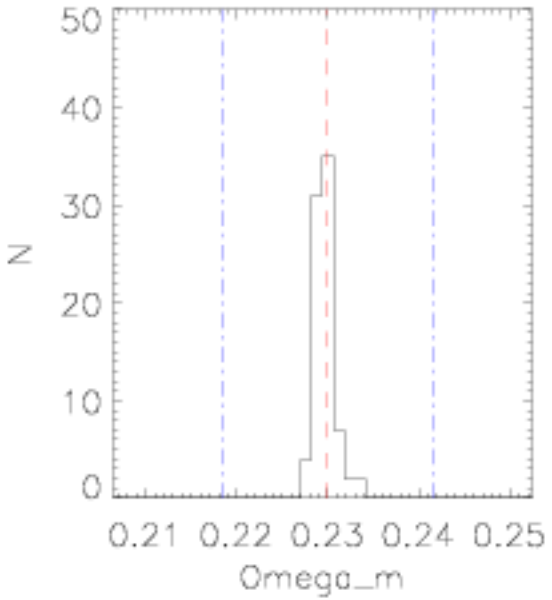

Ref(L-H) - LDG(L-H_)
xc_0

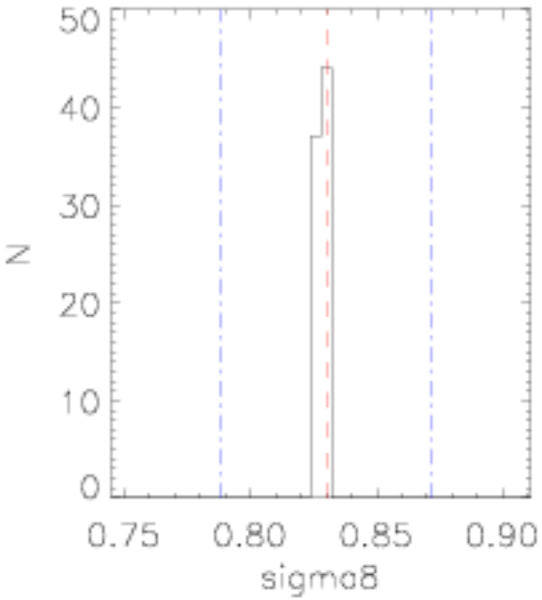

Ref(L-H) - LDG(L-H_)
w0

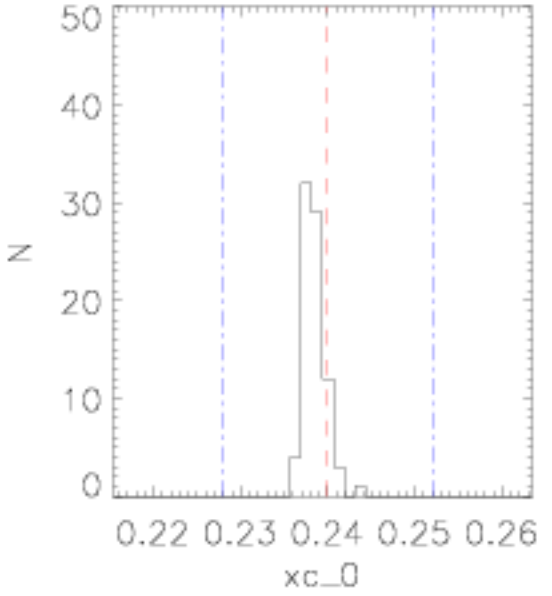
Example: Xc-W_0 likelihood plane from the CR-HR-Rc space

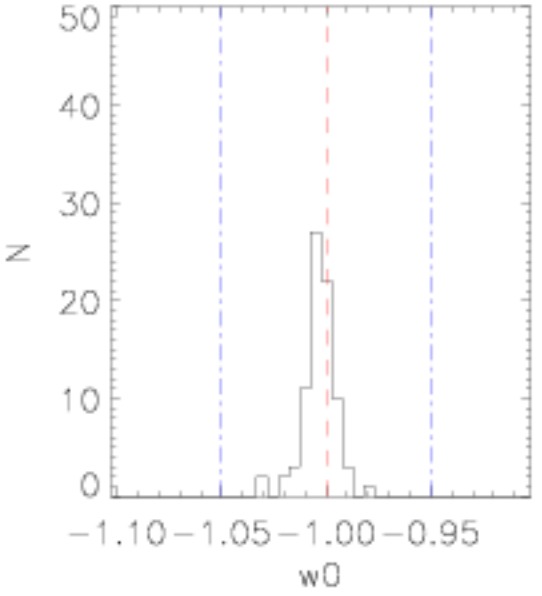


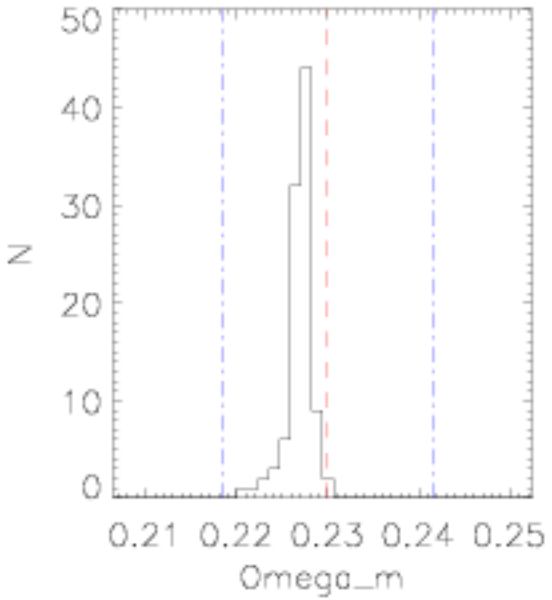
Take ***dn/dM/dz***, 10,000 deg2, no error on mass as a reference case

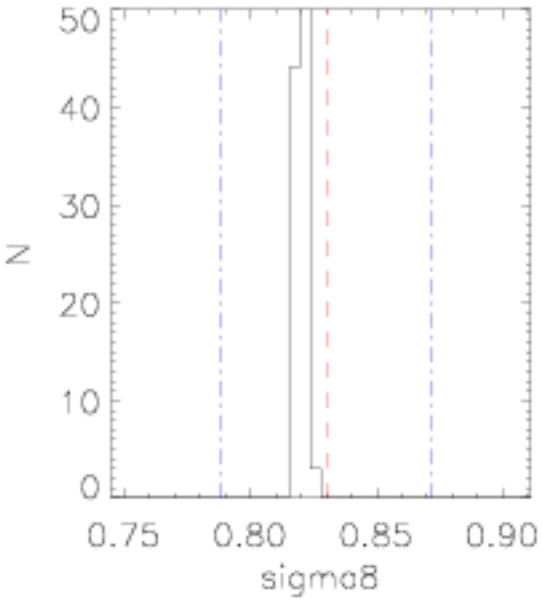

N
0
10
20
30
40
50
0.21 0.22 0.23 0.24 0.25
Omega_m

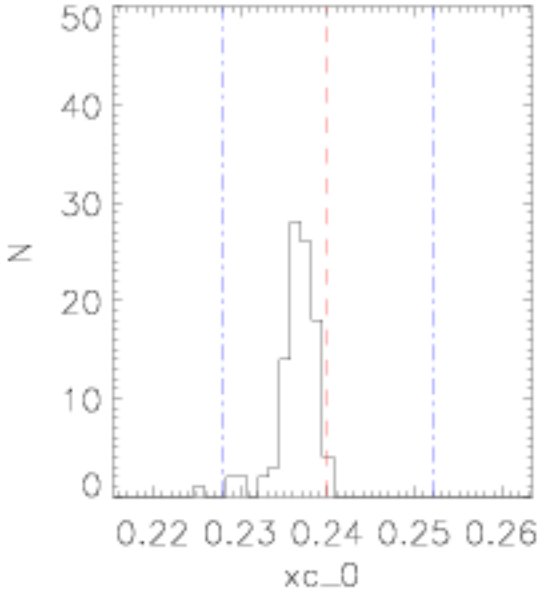

N
0
10
20
30
40
50
0.75 0.80 0.85 0.90
sigma8

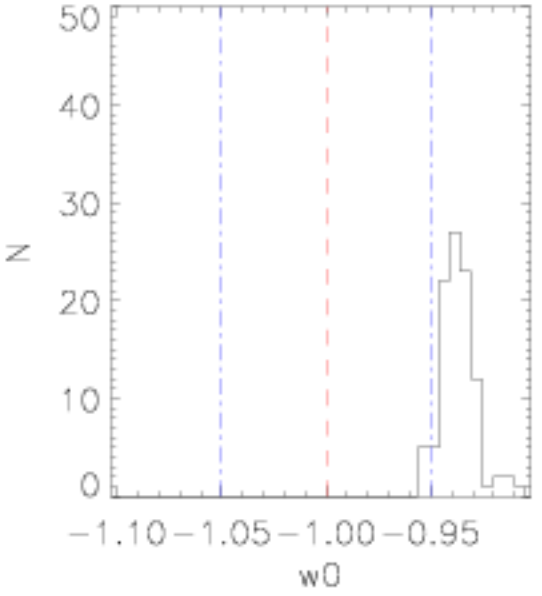

N
0
10
20
30
40
50
0.22 0.23 0.24 0.25 0.26
xc_0


N
0
10
20
30
40
50
−1.10 −1.05 −1.00 −0.95
w0


N
0
10
20
30
40
50
0.21 0.22 0.23 0.24 0.25
Omega_m

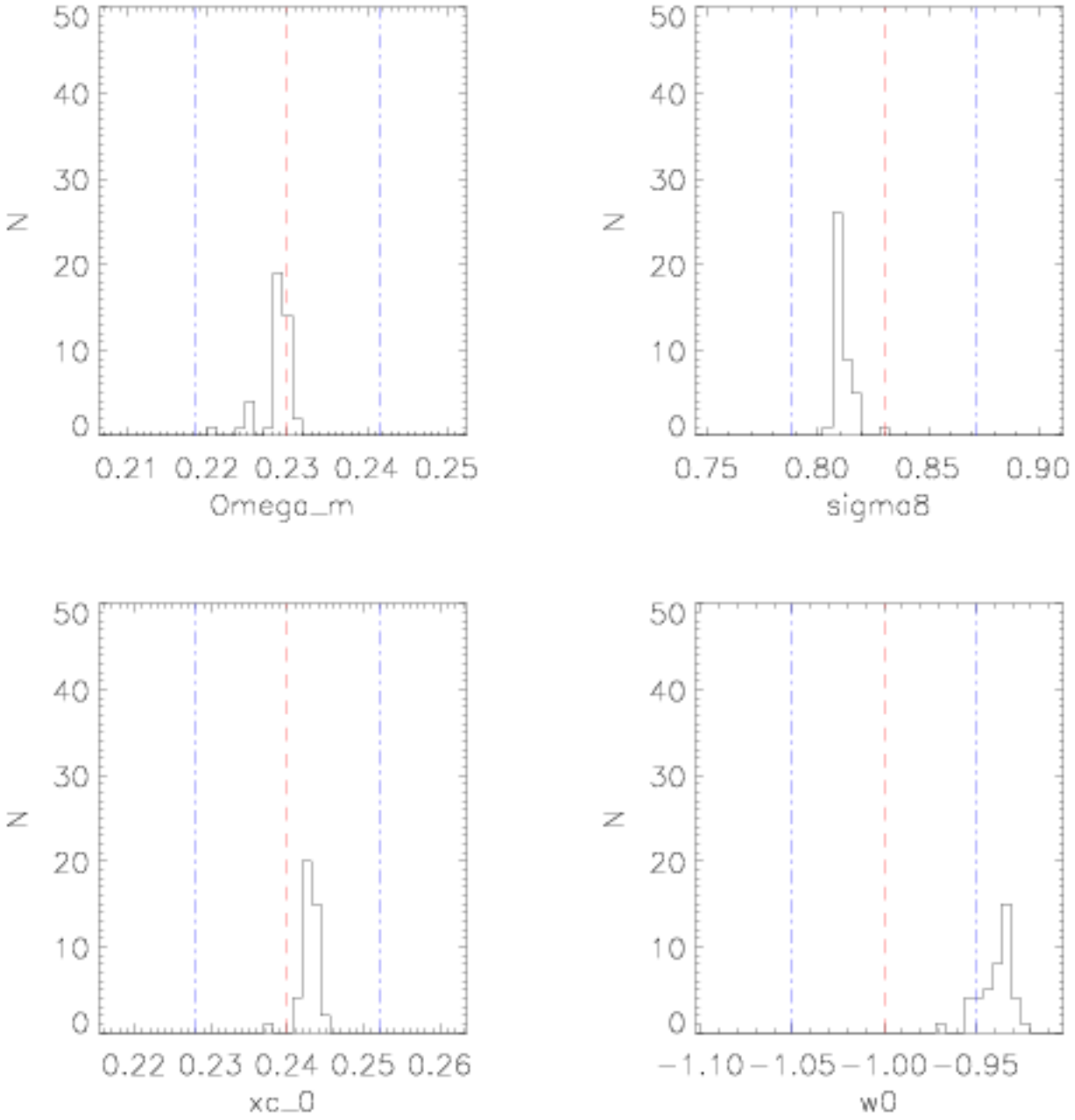

N
0
10
20
30
40
50
0.75 0.80 0.85 0.90
sigma8


N
0
10
20
30
40
50
0.22 0.23 0.24 0.25 0.26
xc_0


N
0
10
20
30
40
50
−1.10 −1.05 −1.00 −0.95
w0

JLS_v1.1	dndzm				
	20 best LH		10 best LH		best LH
Omega_m	0.2296	+/- 0.0003	0.2295	+/- 0.0002	0.2298
Sigma8	0.8305	+/- 0.0004	0.8305	+/- 0.0003	0.8308
Xc_0	0.2386	+/- 0.0006	0.2386	+/- 0.0005	0.2385
W0	-0.9963	+/- 0.0023	-0.9962	+/- 0.0018	-0.9990

One catalogue



One 100 deg2 catalogue

JLS_v1.1	dndzdm + error				
	20 best LH		10 best LH		best LH
Omega_m	0.2278	+/- 0.0008	0.2274	+/- 0.0007	0.2276
Sigma8	0.8221	+/- 0.0007	0.8222	+/- 0.0007	0.8219
Xc_0	0.2373	+/- 0.0010	0.2271	+/- 0.0009	0.2377
W0	-0.9386	+/- 0.0036	-0.9364	+/- 0.0026	-0.9330

Average over 10x100 deg2 catalogues

Mean error

JLS_v1.1	dndzdm	
	mean (2-10 best LH)	
Omega_m	0.2399	+/- 0.0178
Sigma8	0.8102	+/- 0.0099
Xc_0	0.2479	+/- 0.0234
W0	-0.9989	+/- 0.1089

One 100 deg2 catalogue

JLS_v1.1	dndzdm + error				
	20 best LH		10 best LH		best LH
Omega_m	0.2278	+/- 0.0008	0.2274	+/- 0.0007	0.2276
Sigma8	0.8221	+/- 0.0007	0.8222	+/- 0.0007	0.8219
Xc_0	0.2373	+/- 0.0010	0.2271	+/- 0.0009	0.2377
W0	-0.9386	+/- 0.0036	-0.9364	+/- 0.0026	-0.9330

Average over 10x100 deg2 catalogues

Mean error

JLS_v1.1	dndcrdhrdrcore	
	mean (1-10 best LH)	
Omega_m	0.2295	+/- 0.0091
Sigma8	0.8150	+/- 0.0113
Xc_0	0.2440	+/- 0.0043
W0	-0.9161	+/- 0.0736

Preliminary conclusions

- Current accuracy predicted for 100 deg2:
  - Ω_m ~ 5%
  - σ_8 ~ 2%
  - X_c < 1%
  - w_o ~ 8%

NB: There is some Amoeba imprint in these estimates

➔ Slightly better than dn/dM/dz with 50% mass error !

Sample variance not taken into account