XXL

The ultimate XMM extragalactic survey

die Kunst über in der Wissenschaft

Tracing the universe with the XMM-XXL survey

2018 cosmological results

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Service d'Astrophysique du CEA

Colloque Energie Sombre, 24 octobre 2018 IAP

Outline

1. XMM serendipitous cluster surveys

2. Principle of the selection function

3. Results from DR2 - October 2018

4. Forward cosmological modelling

XMM-XXL

The largest XMM programme to date:

- 6.9 Ms of XMM time covering 2 x 25 deg^2 fields
- ~ 100 collaborators
- 1st series of 14 papers published in 2016
- 2nd series of 20 papers published in october 2018

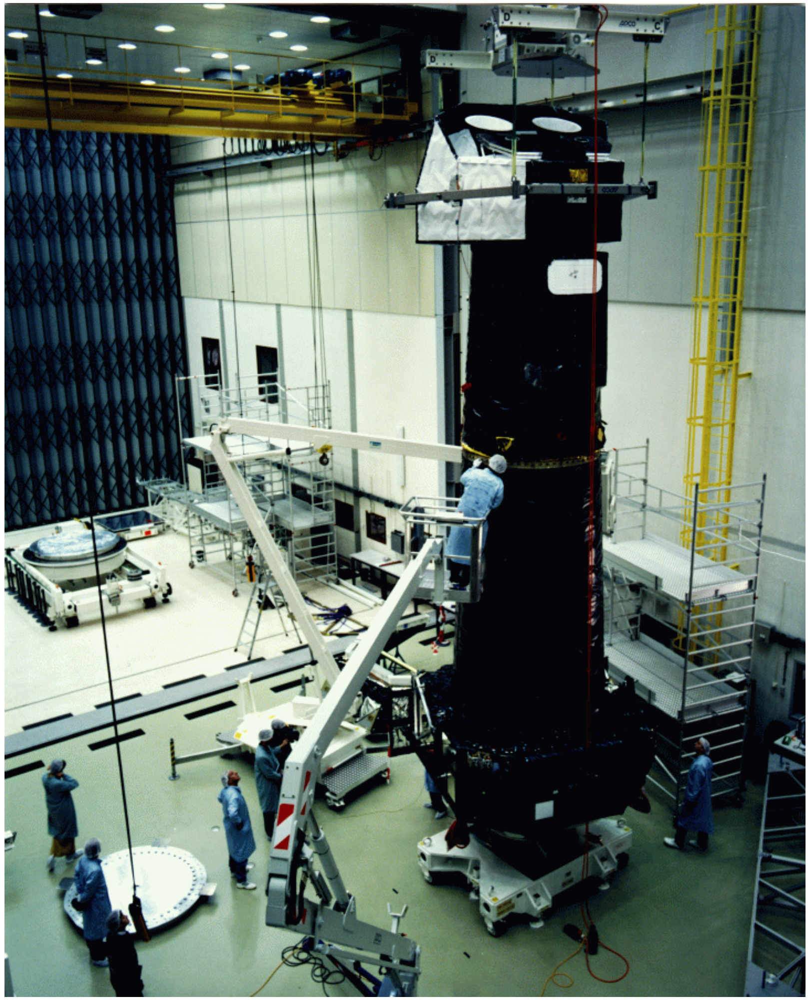
Primary goal : cosmology with the 0<z<1 clusters

Reminder:
cosmology with galaxy clusters

- Based on cluster number counts
  - dn/dz
  - dn/dz/dM
- Also on the correlation function
  - If *w* is free, then combining dn/dz + ξ improves the constraints by a factor of ~ 2 *(Pierre et al 2011)*
- Caveat: we must know how clusters evolve !
  - Encrypted in the scaling relations = mass-observable relations

1. Finding and characterizing serendipitous XMM clusters

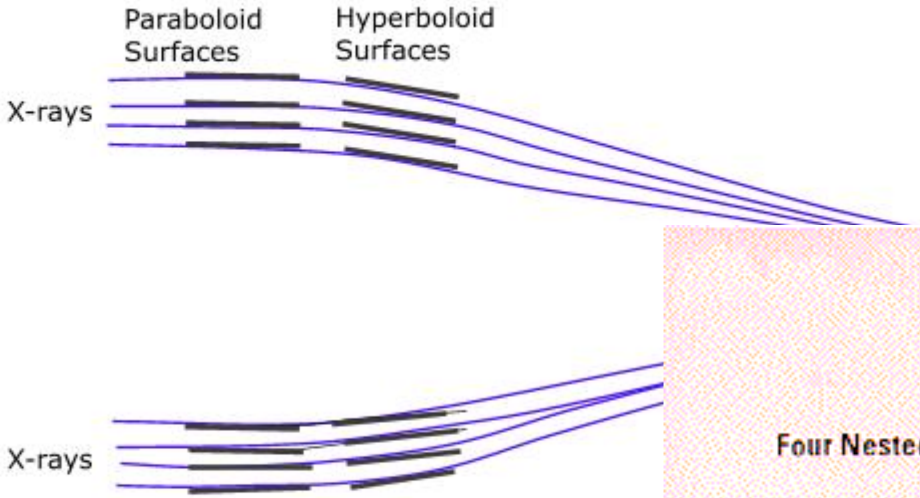
XMM



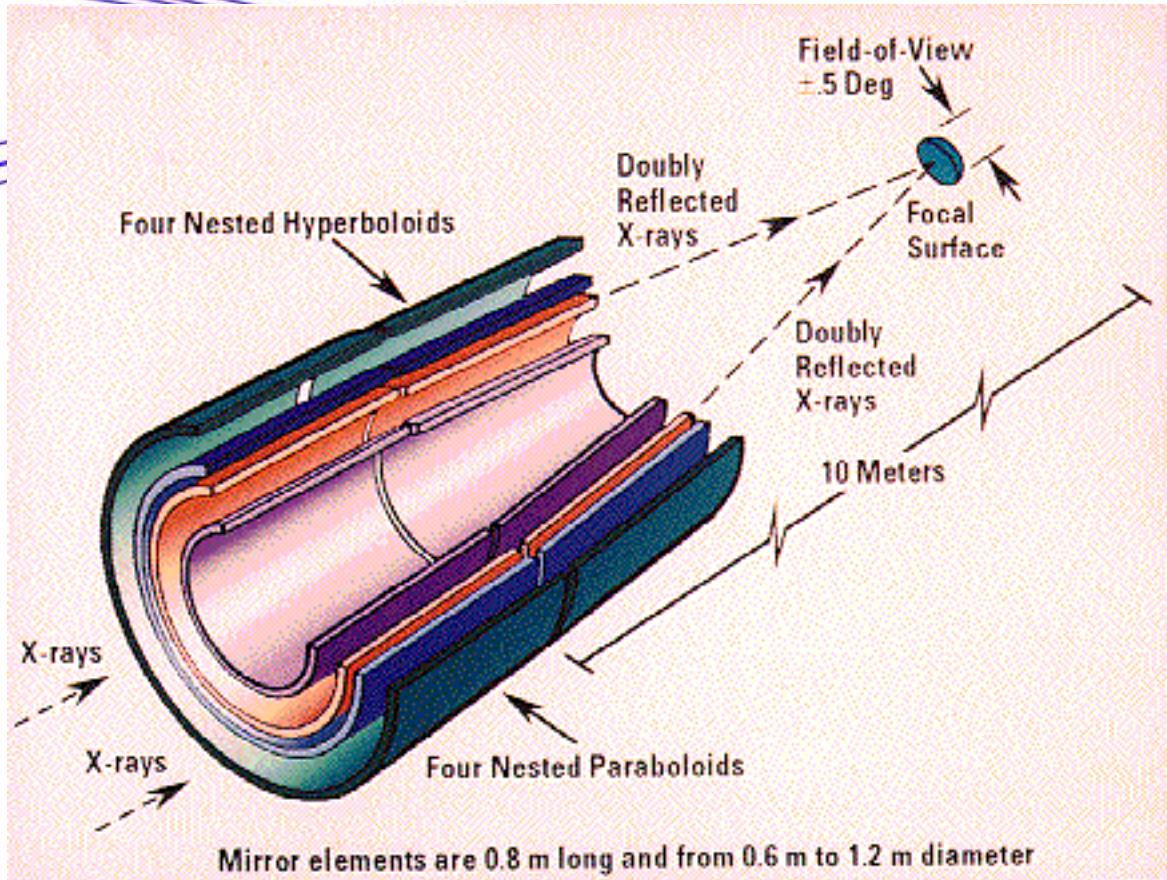
The largest ESA telescope
0.1-10 keV (~100-1 Å)

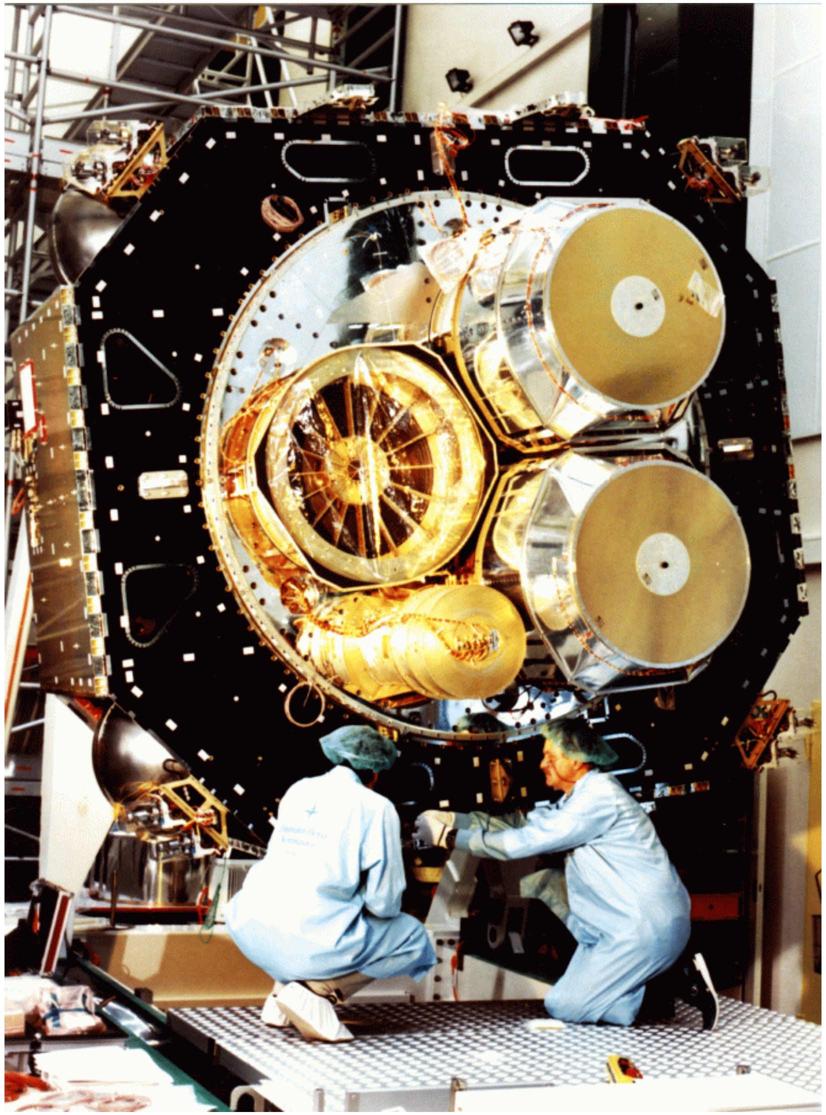
Launched: 1999

collect and focus X-ray light



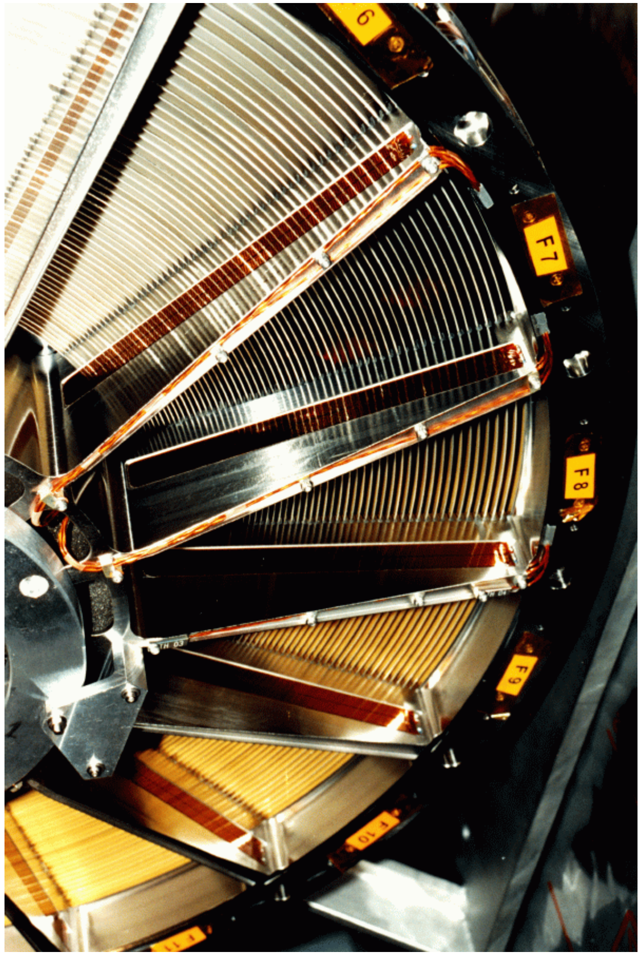
Grazing incidence:
Wolter telescope



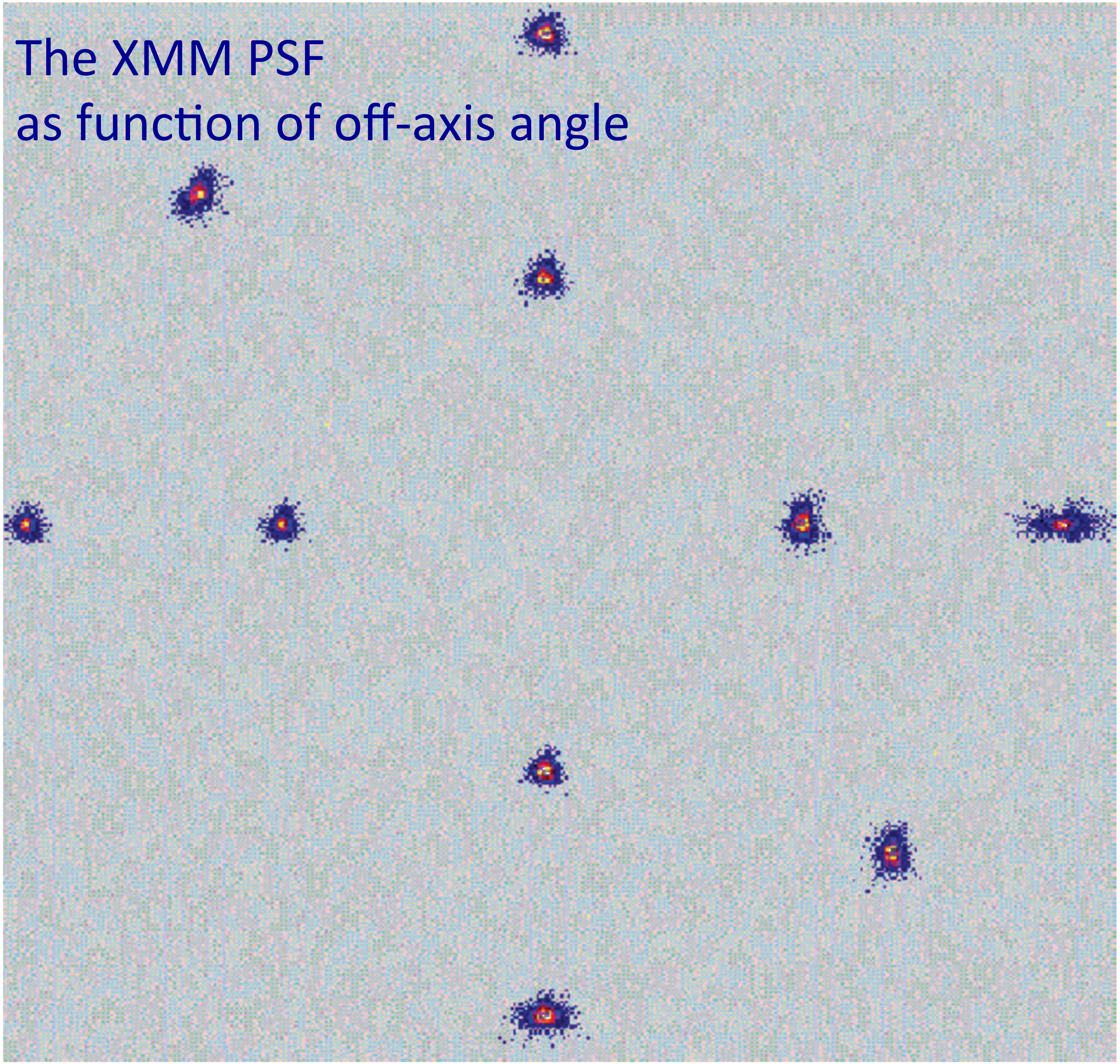


3 X-ray telescopes

58 nested mirror shells



The XMM PSF
as function of off-axis angle

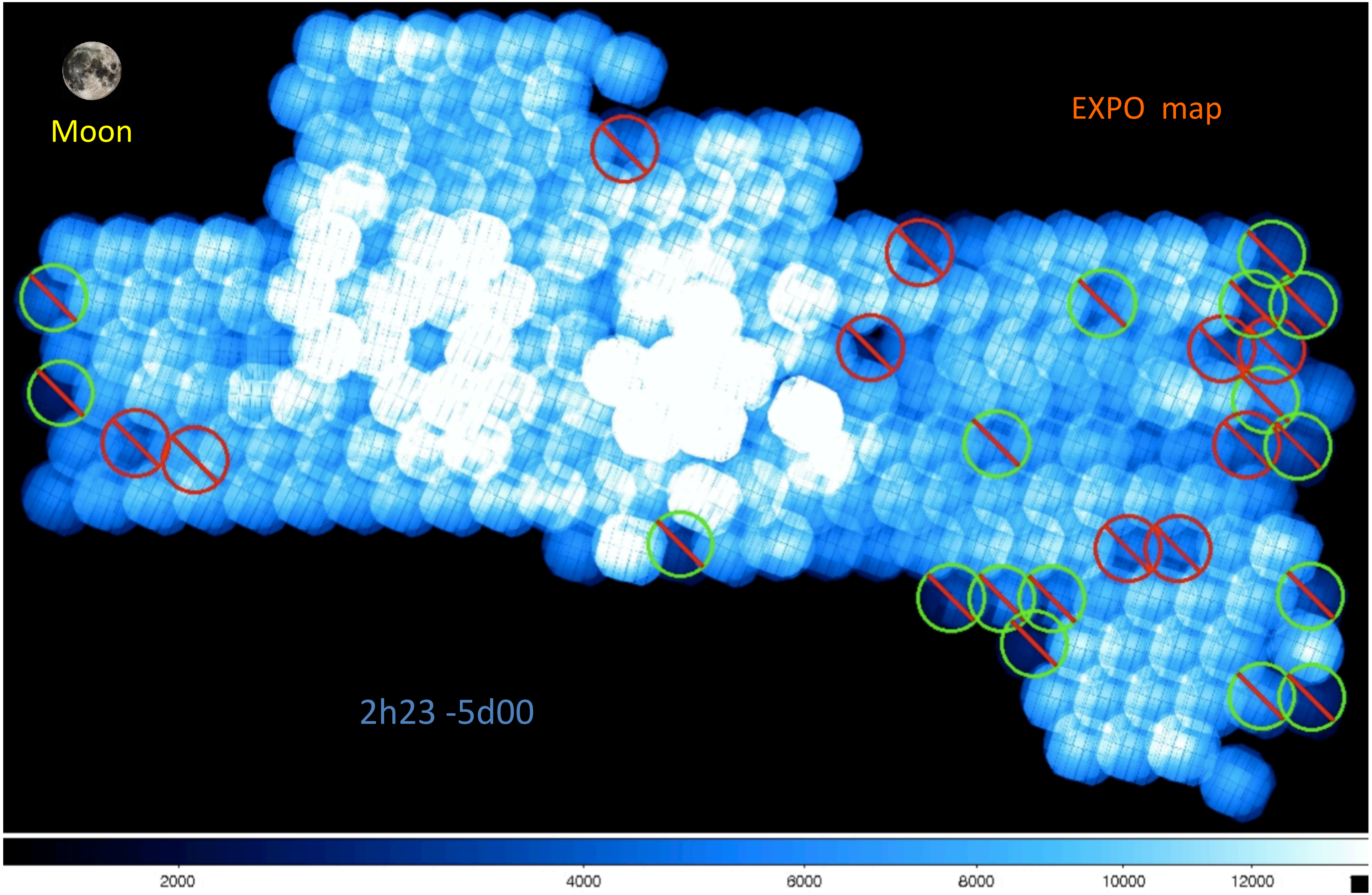


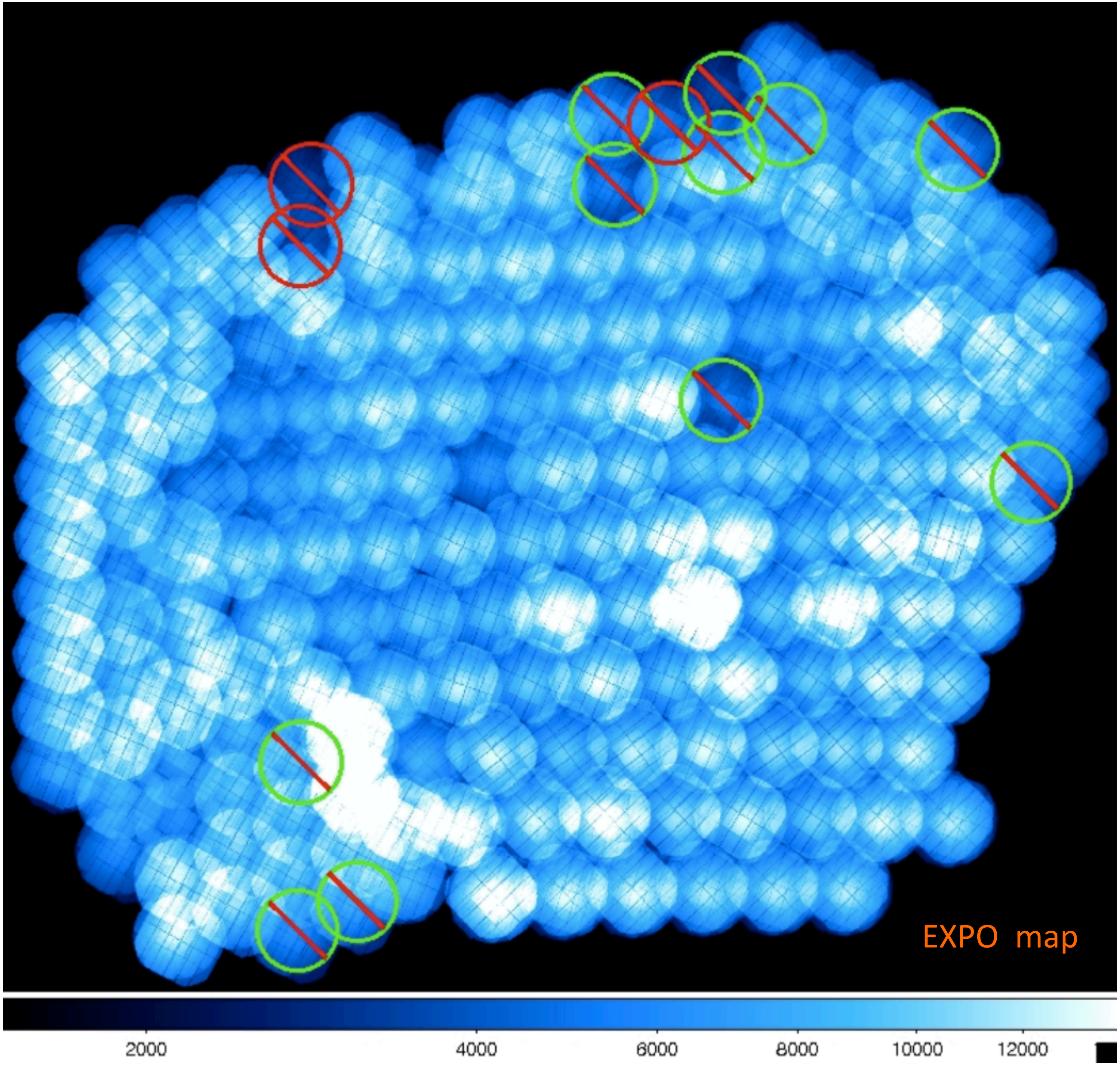
Field of view:
30 arcmin diam.

Photon counting mode.
we register:

- Arrival time
- Position
- Energy

XXL-N 25 deg^2

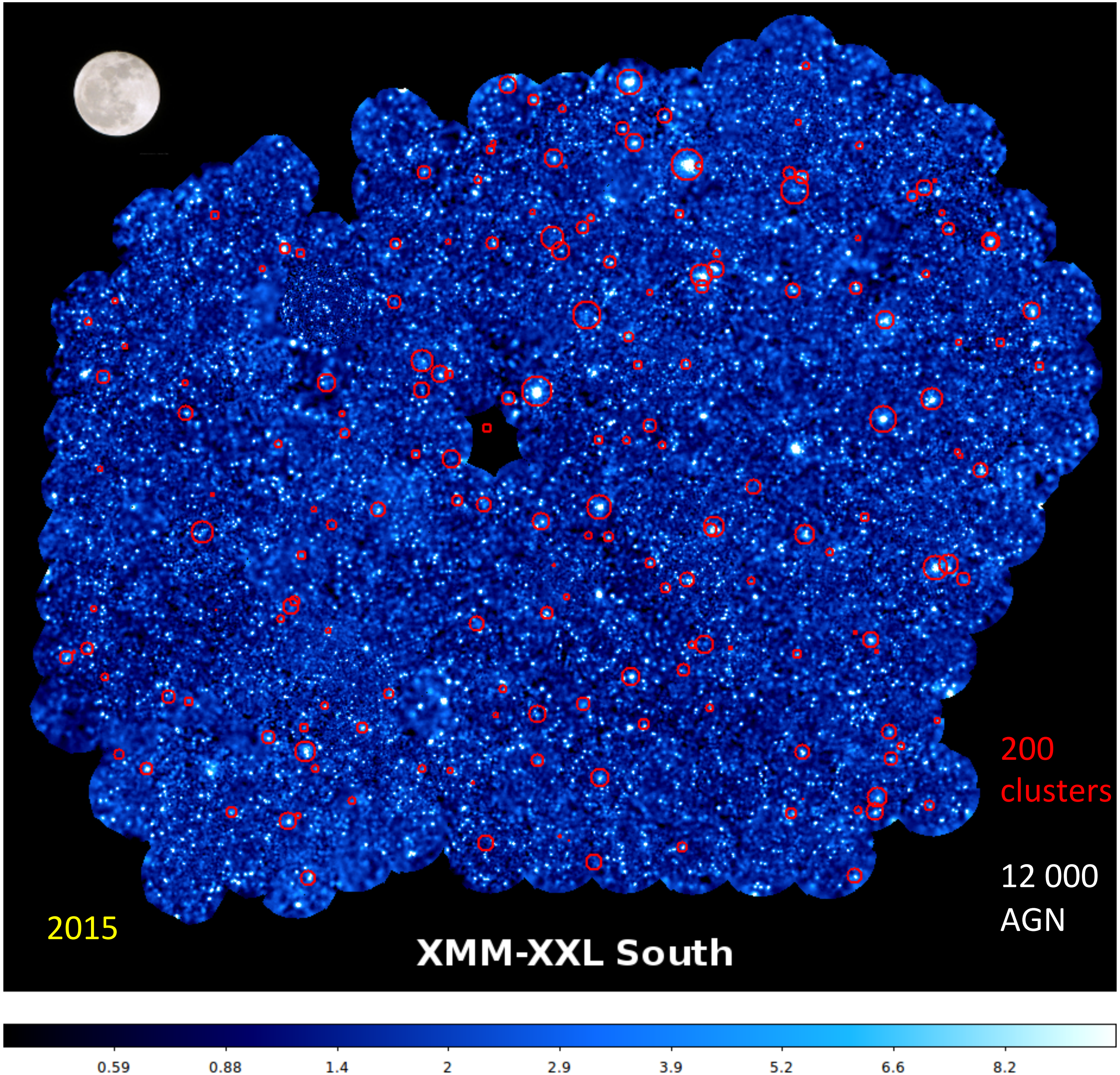


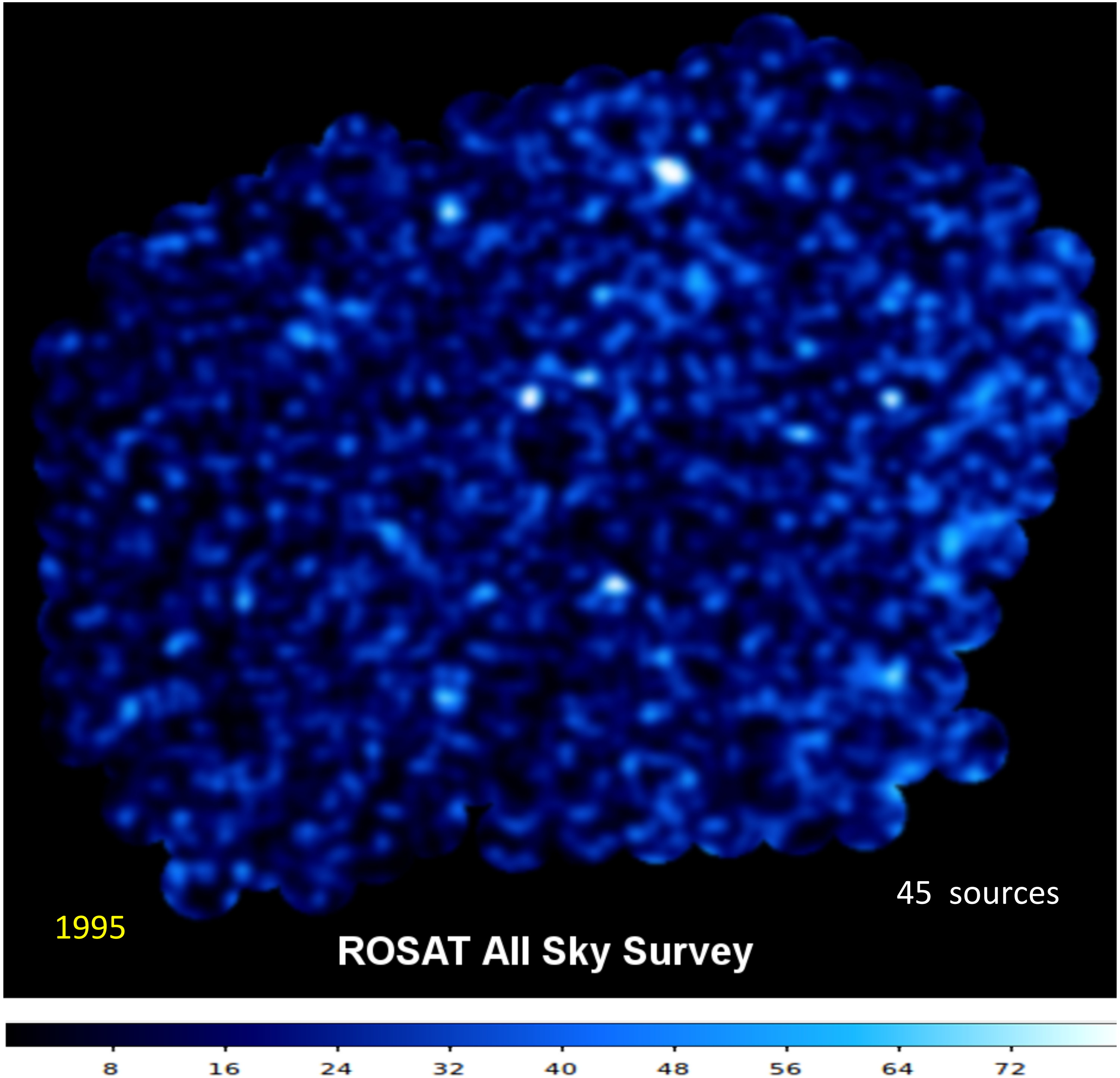


XXL-S
25 deg^2

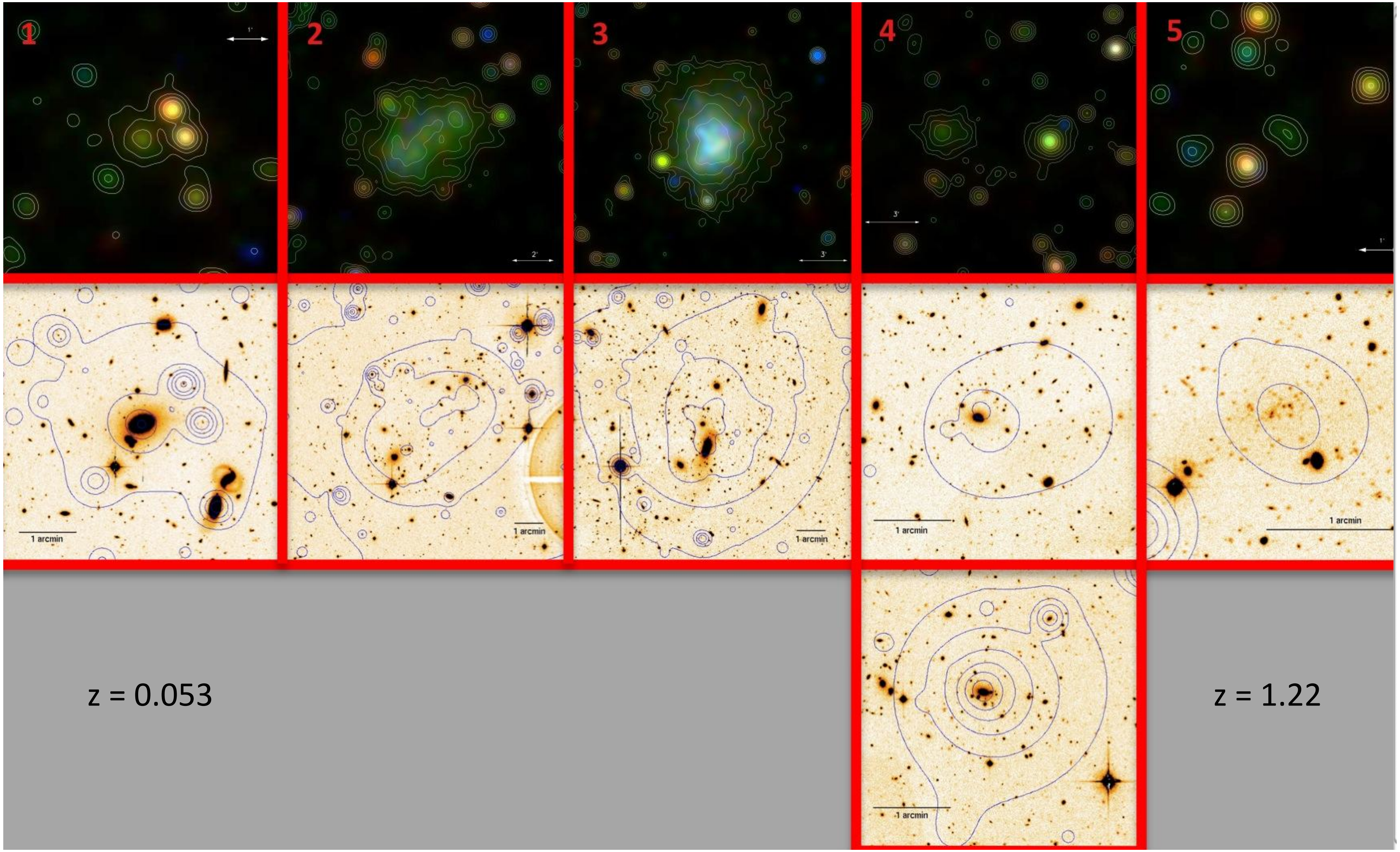
23h30 -55d00

within the SPT
100 deg2
Deep Field


2015
XMM-XXL South
200 clusters
12 000 AGN
0.59
0.88
1.4
2
2.9
3.9
5.2
6.6
8.2


45 sources
1995
ROSAT All Sky Survey
8
16
24
32
40
48
56
64
72

XXL clusters of galaxies and their optical counterpart (CFHTLS)



Why are X-ray especially good?

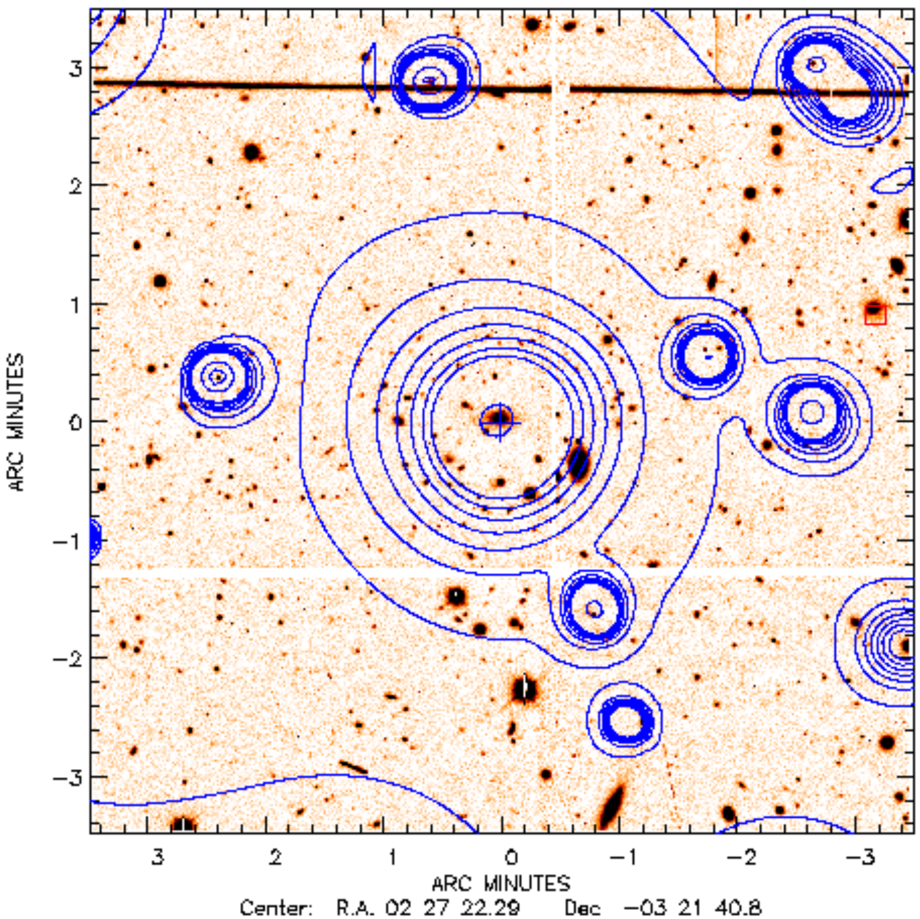
- The presence of X-ray emitting gas witnesses collapsed structures

- The X-ray properties can be modelled rather easily :
  - Ab initio analytical modelling
  - Hydrodynamical simulations
  - (ad hoc) analytical scaling relations

➔ link to cosmology

1. Principle of the selection function

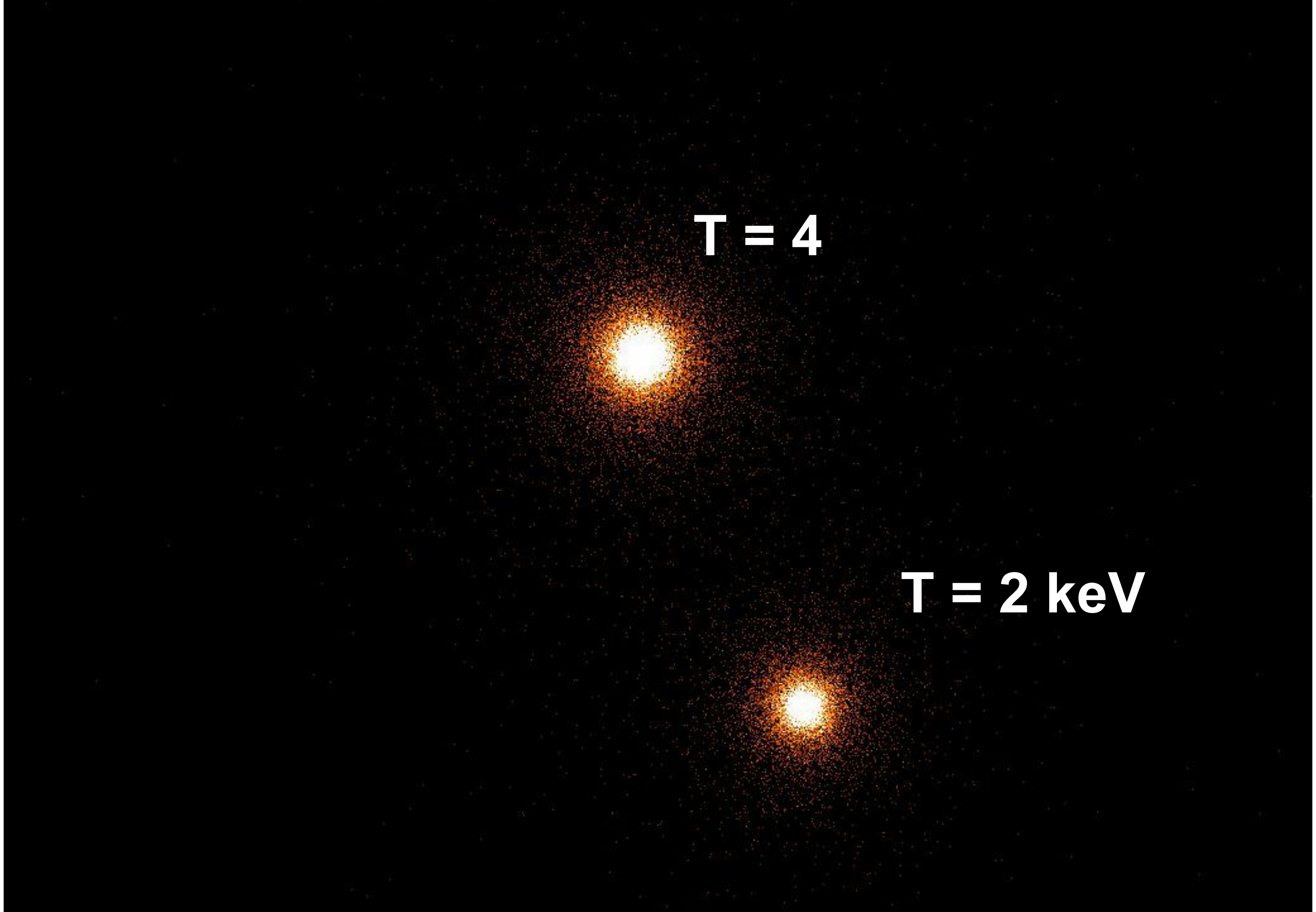
A cluster field



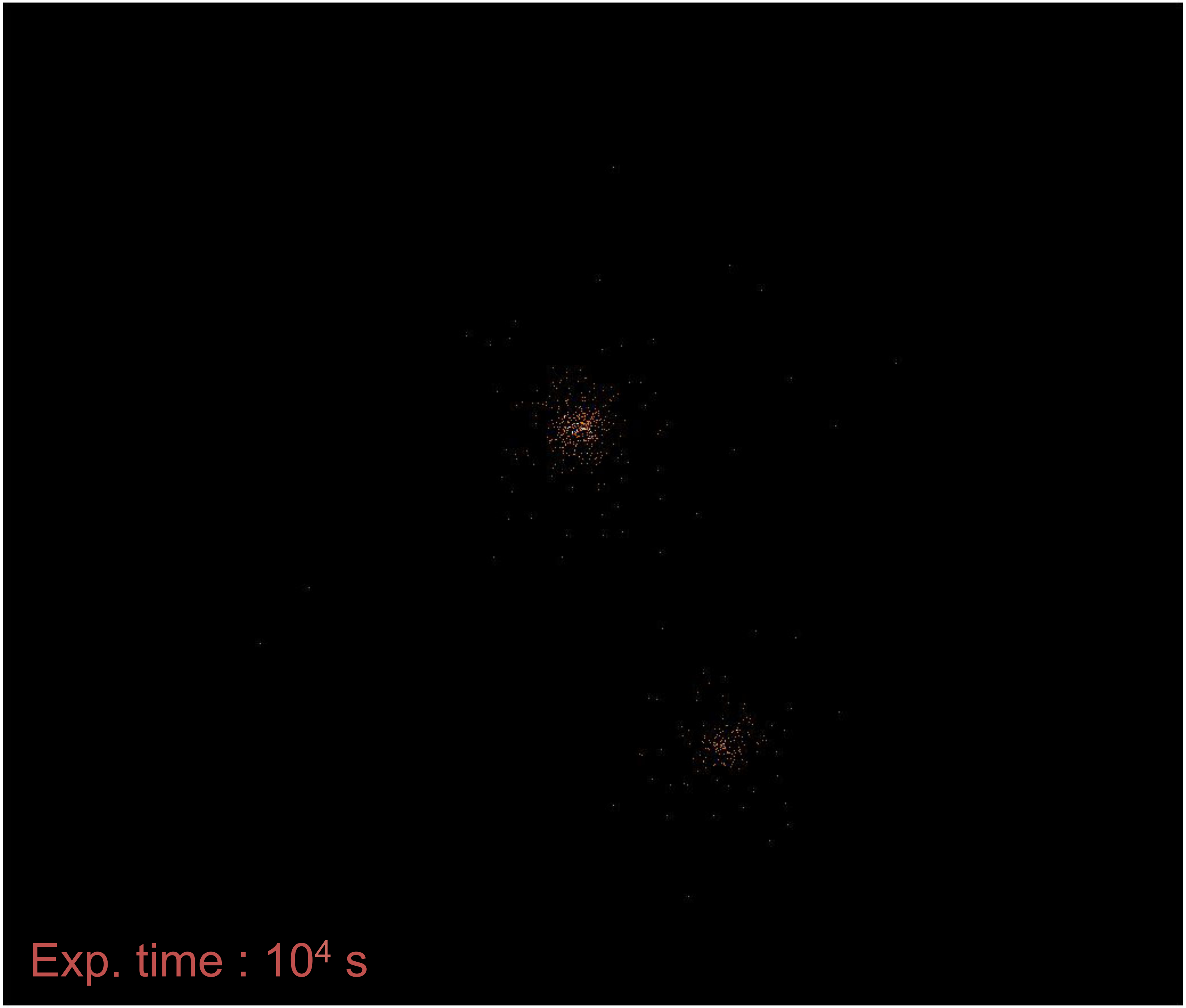
Background image: CFHT, I band

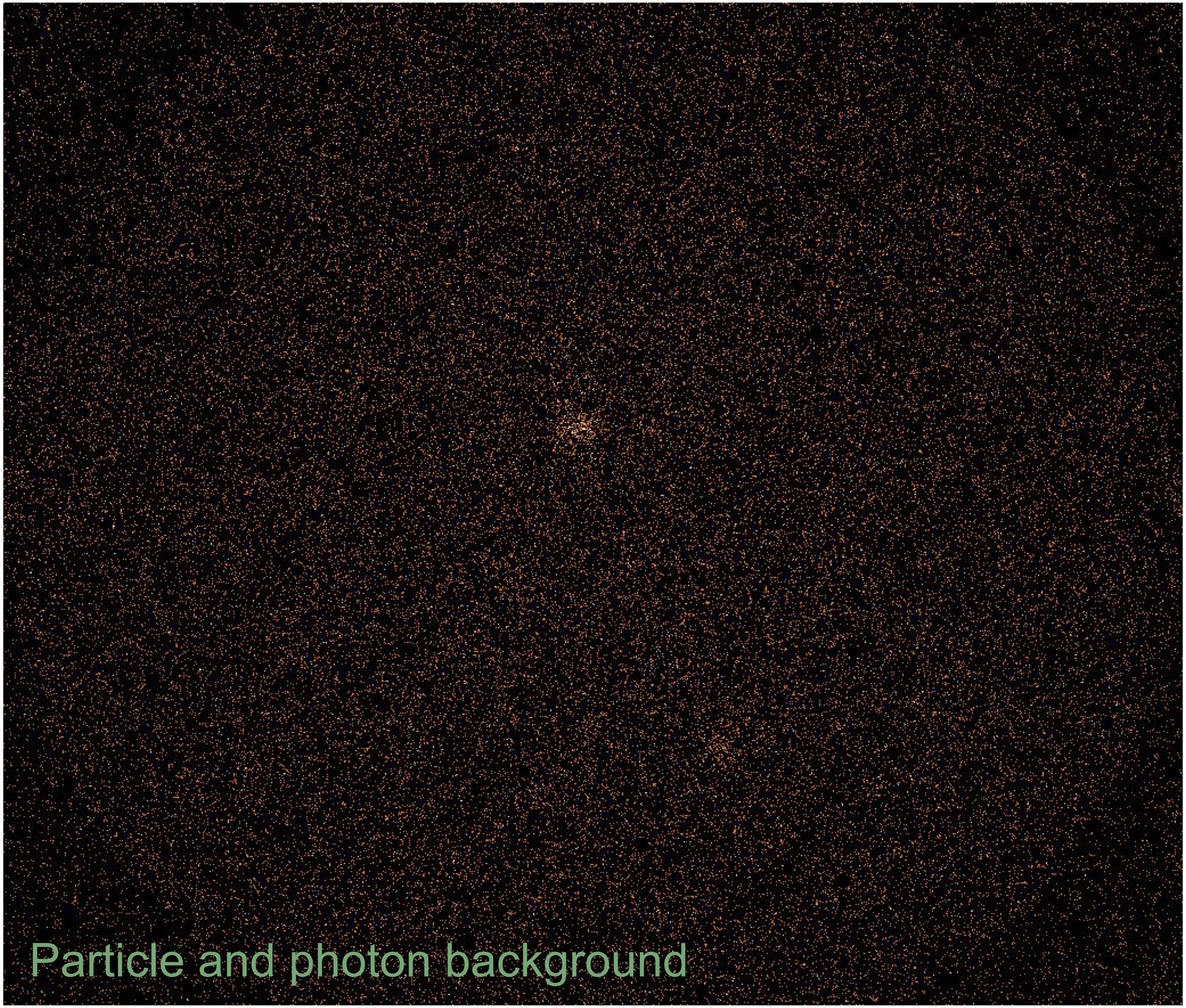
Blue contours: X-ray

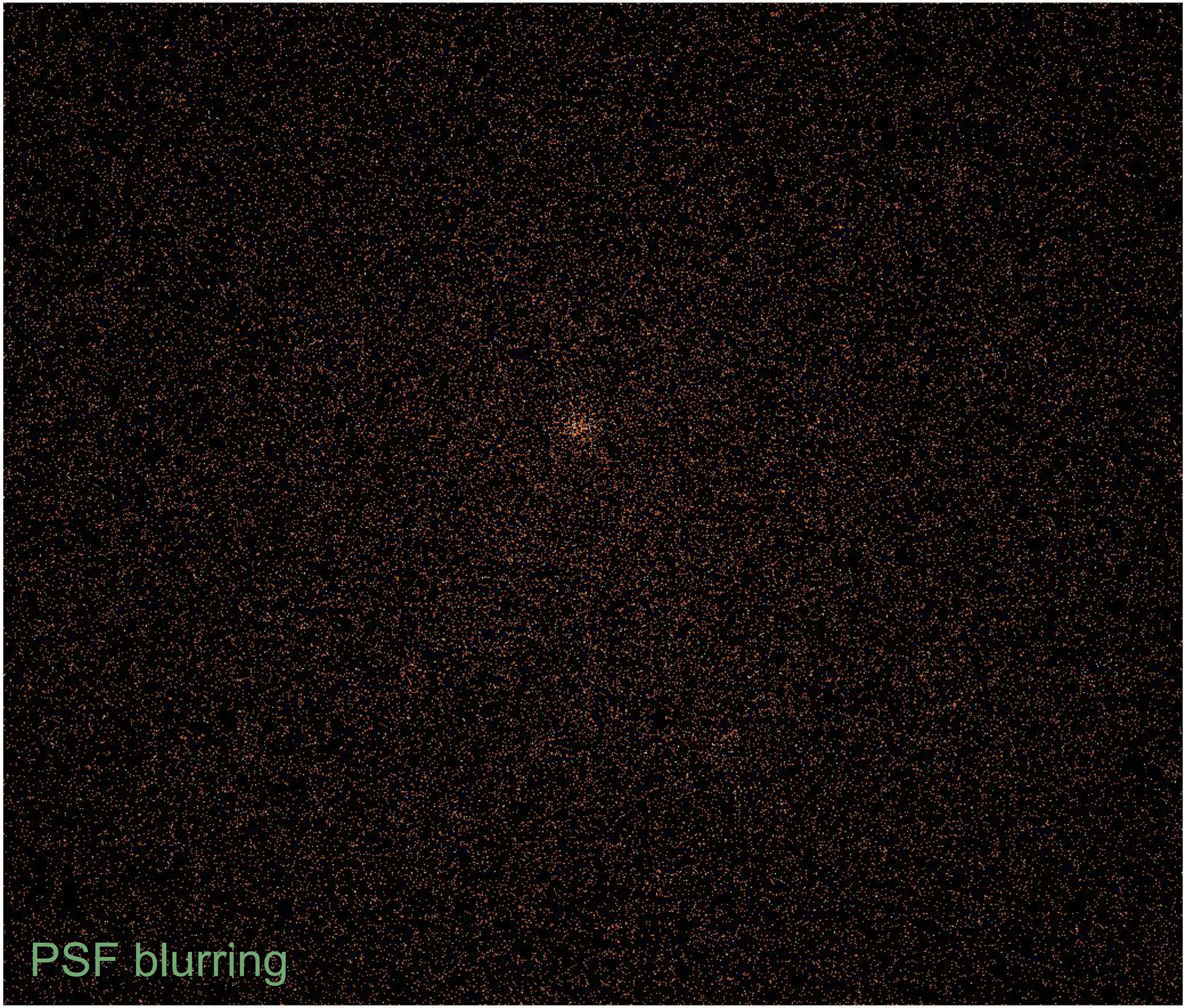
Simulation example: two clusters at z=0.5

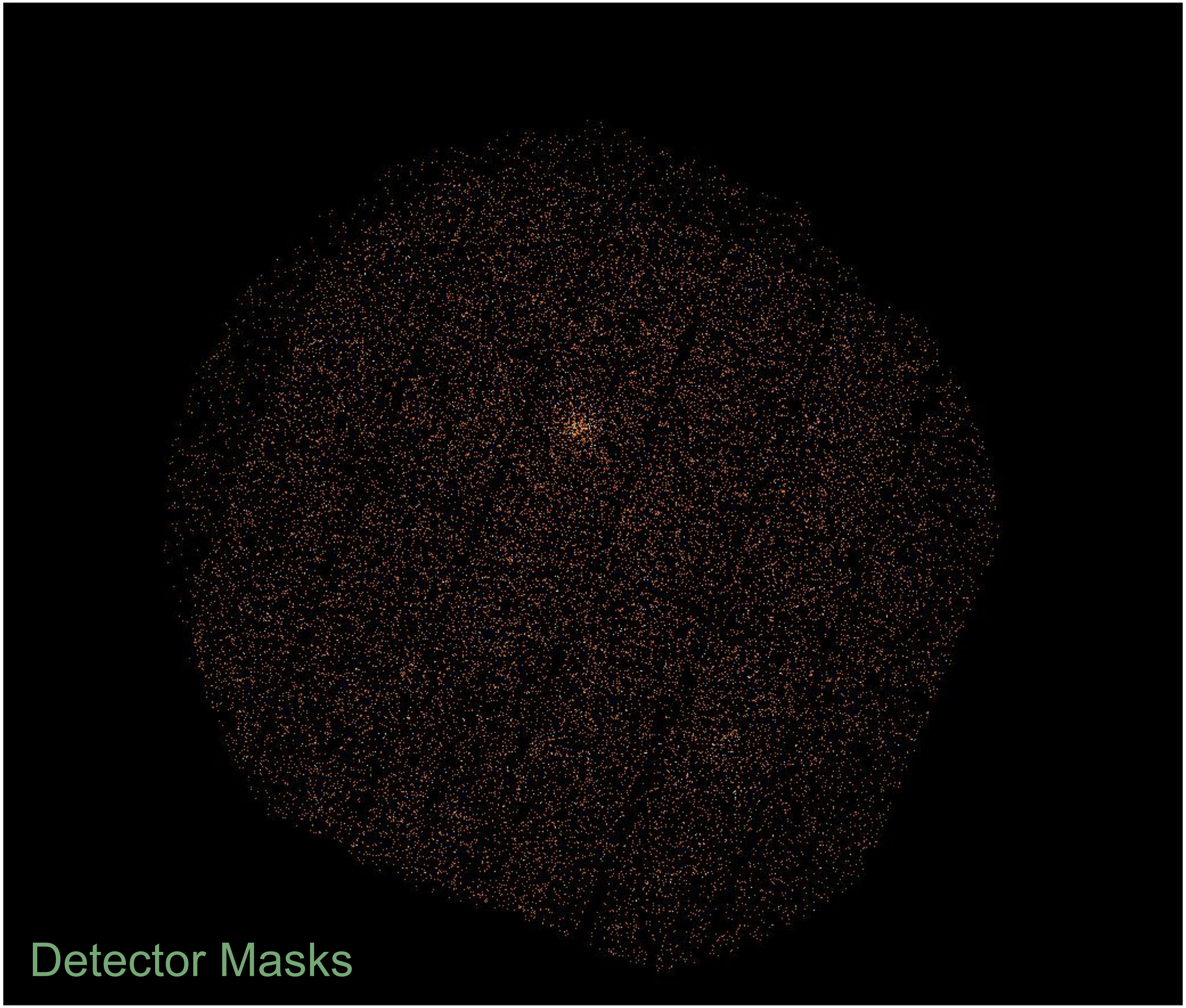


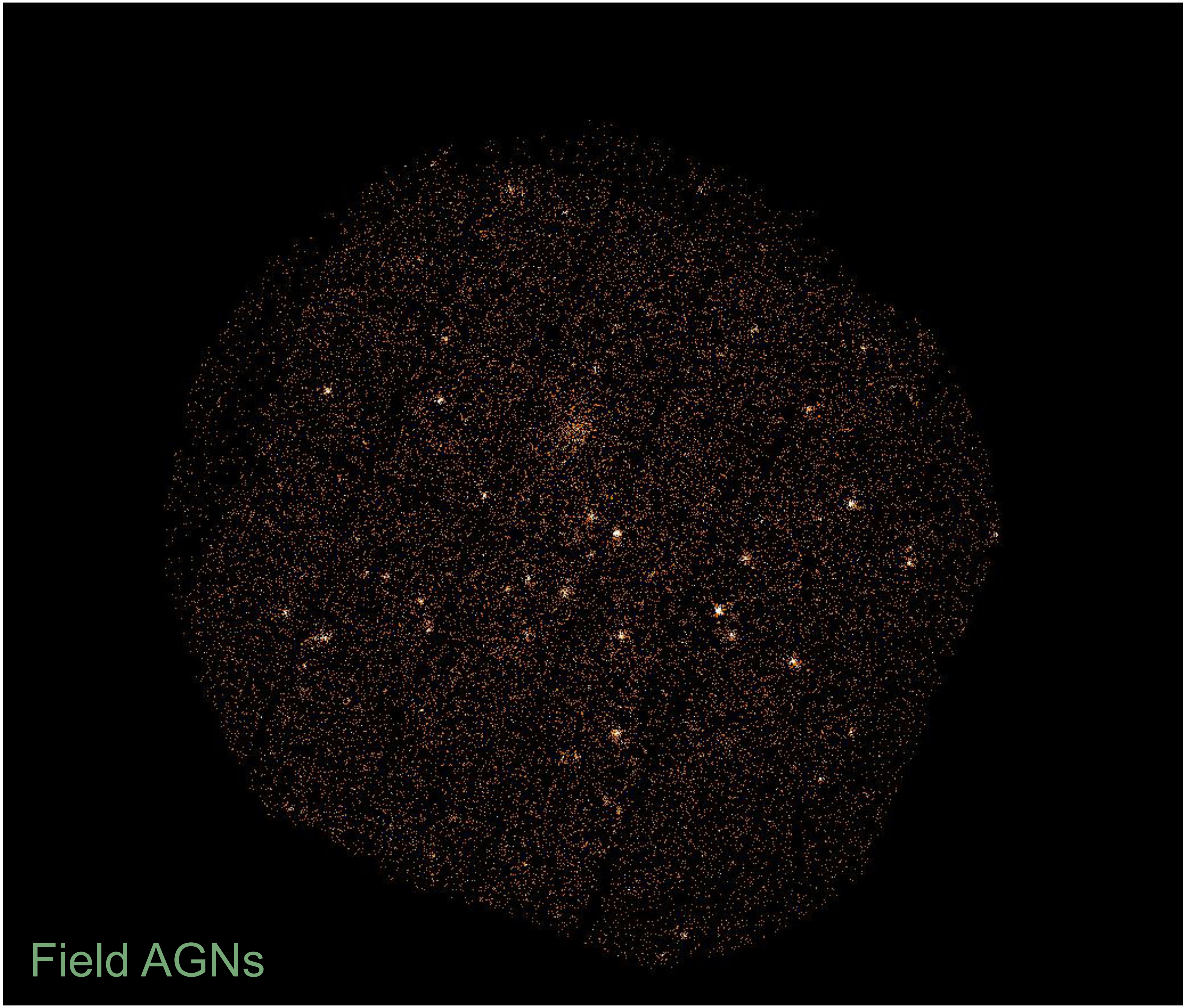
Exp. time : 10^6 s


Exp. time : 10^4 s

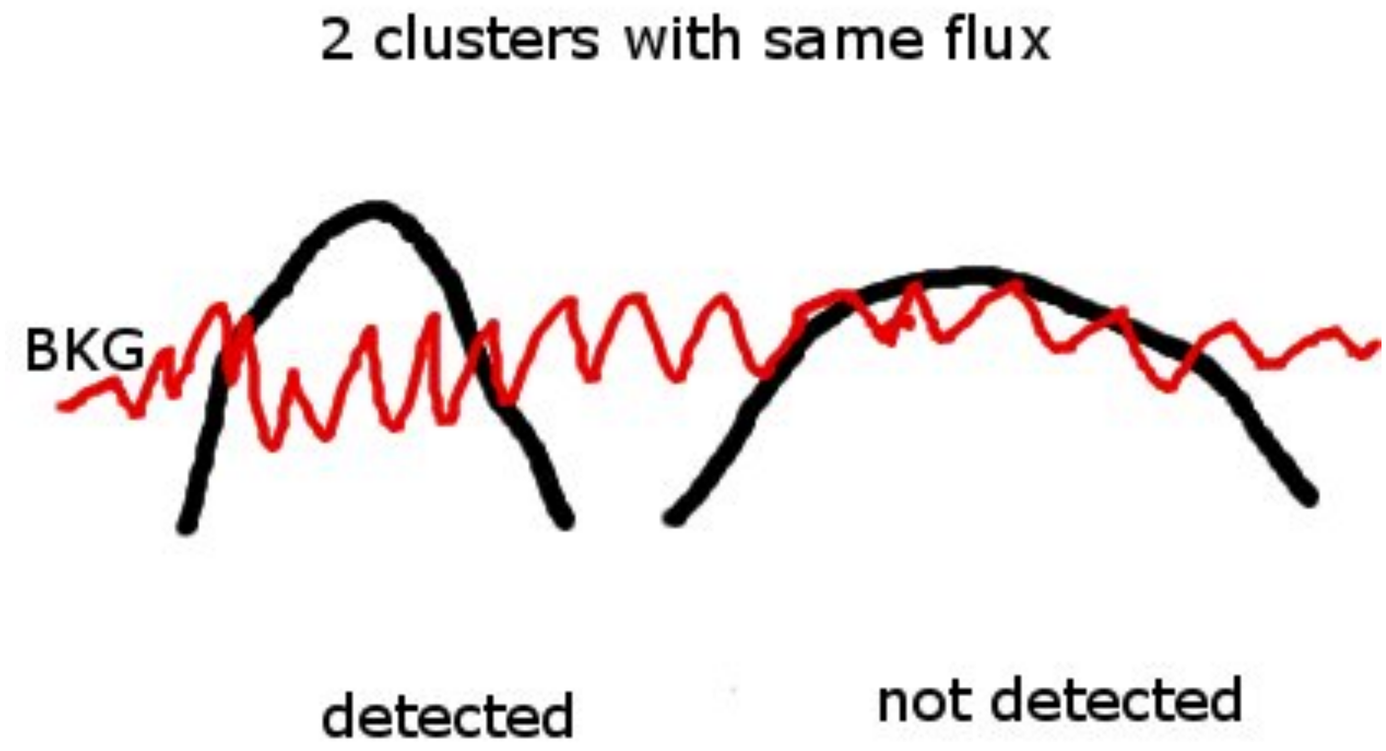

Particle and photon background


PSF blurring


Detector Masks


Field AGNs

Not a flux limit !



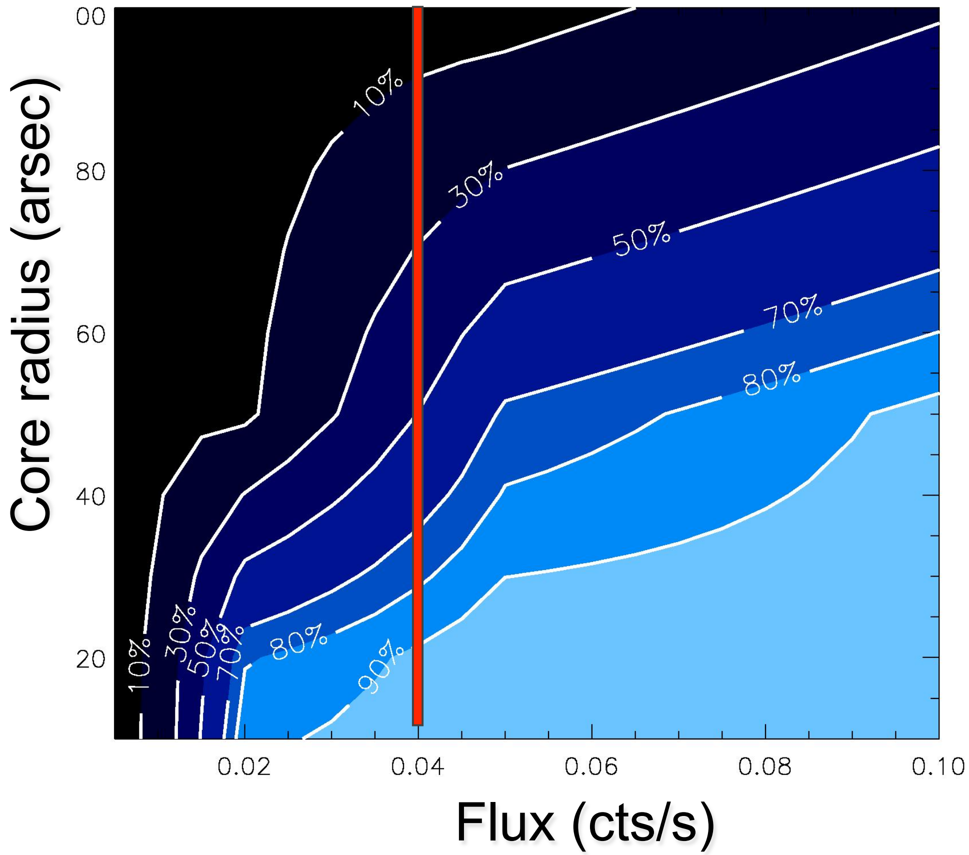
~ surface brightness limited

Detection rates

from analytical simulations

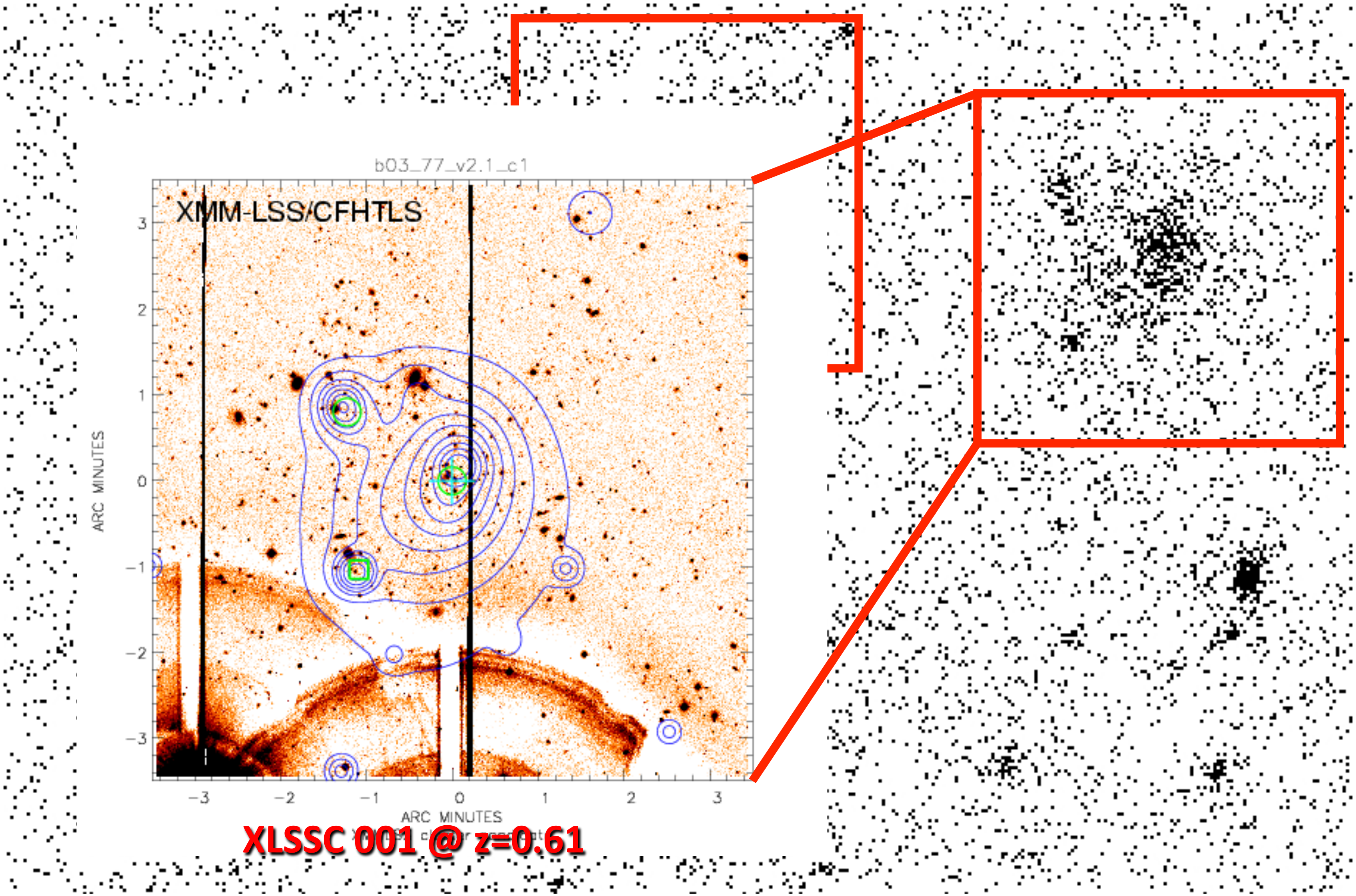
Class 1 sample : < 5% contamination

Not a flux limit !

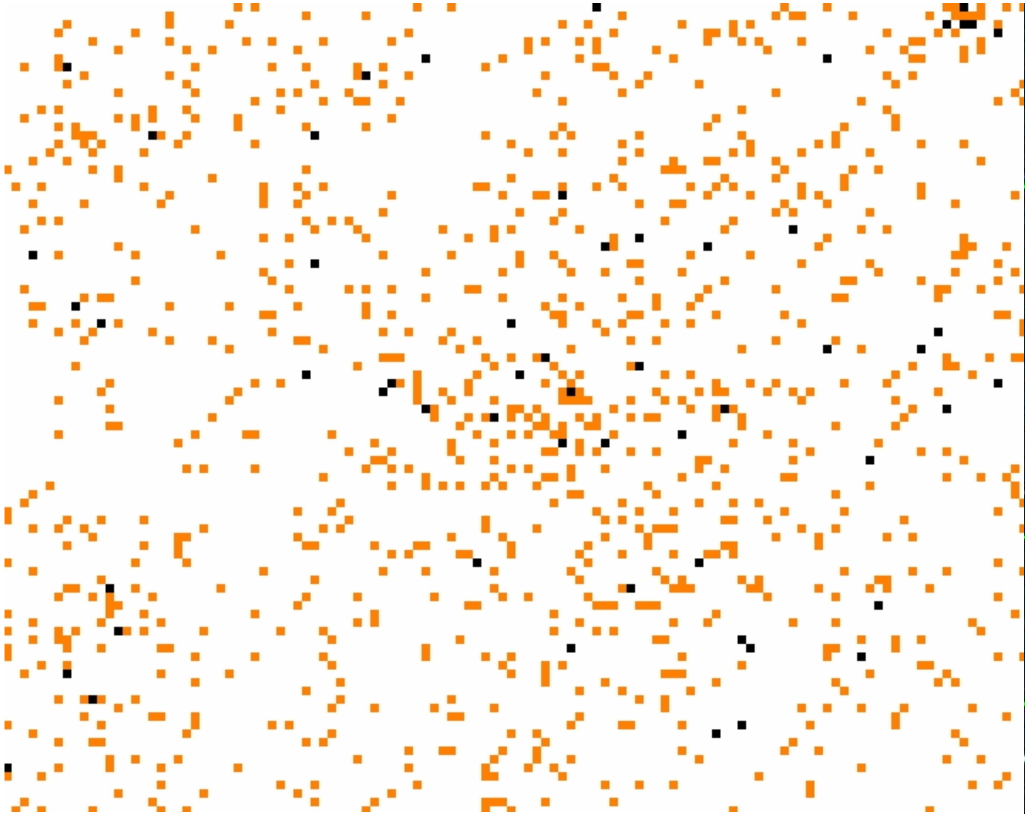


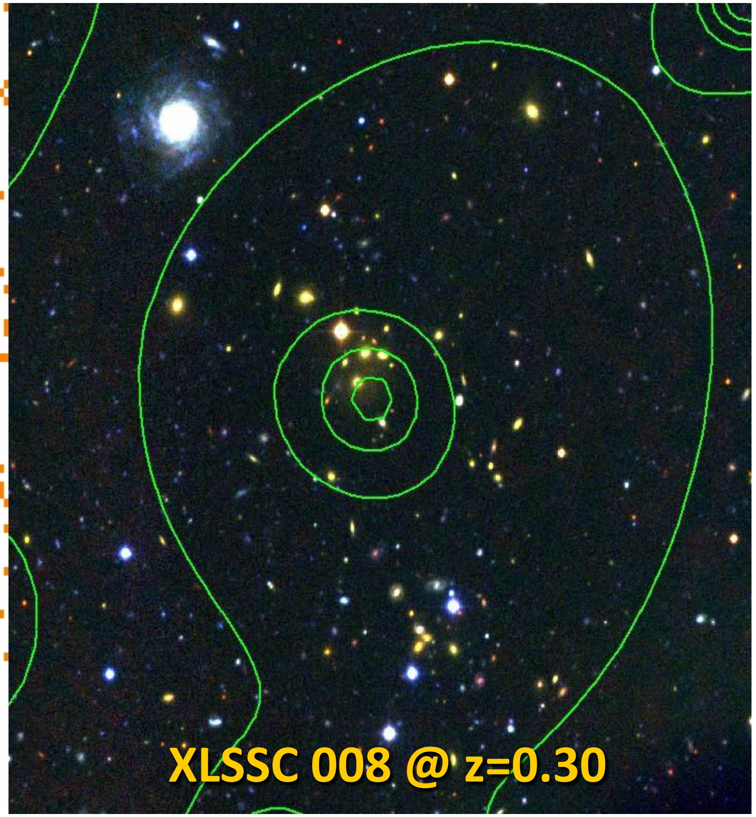
Pacaud et al 2006

An XMM image (10ks) of an 'empty field'



An XMM image (10ks) of an ‘empty field’





Working with these data: difficult !

: misleading (Poisson statistics)

: ambitious

… but feasible

3. The 2018 DR2 results

The XXL fields

- Two 25 deg^2 areas
  - CFHTLS W1 : 2h23min -4deg30'
  - BCS/SPT : 23h30min -55deg00'

- With extensive multi-λ coverage from UV to radio

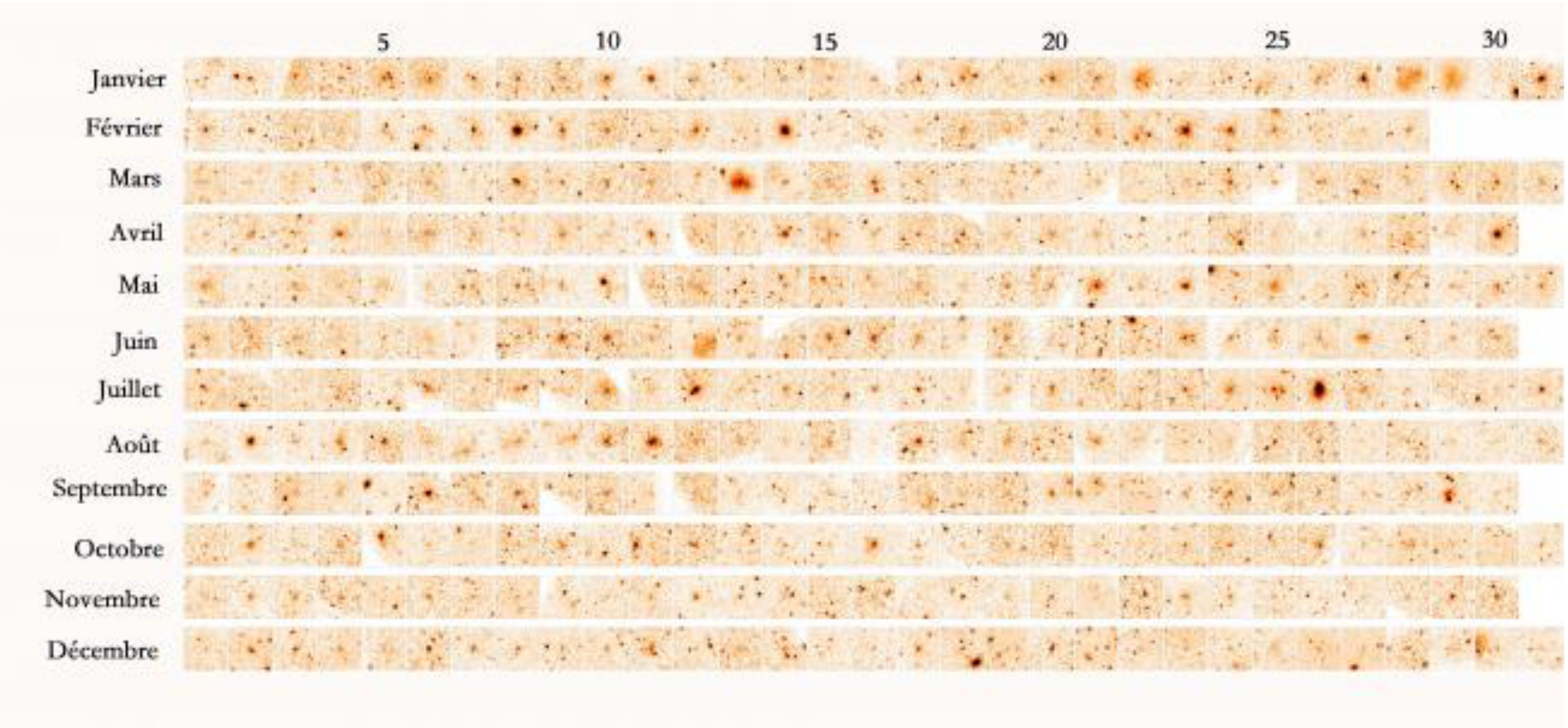
XXL DR 2

- 20 articles in an A&A special issue
- 4 main catalogues
  - 365 clusters
  - 26 000 AGN
  - GMRT (610 MHz) survey in XXL-N
  - ATCA (2.1 GHz) survey in XXL-S
- 3 cosmology papers
- The other papers :
  - Galaxy and AGN properties in clusters

- I'll concentrate on the cluster results

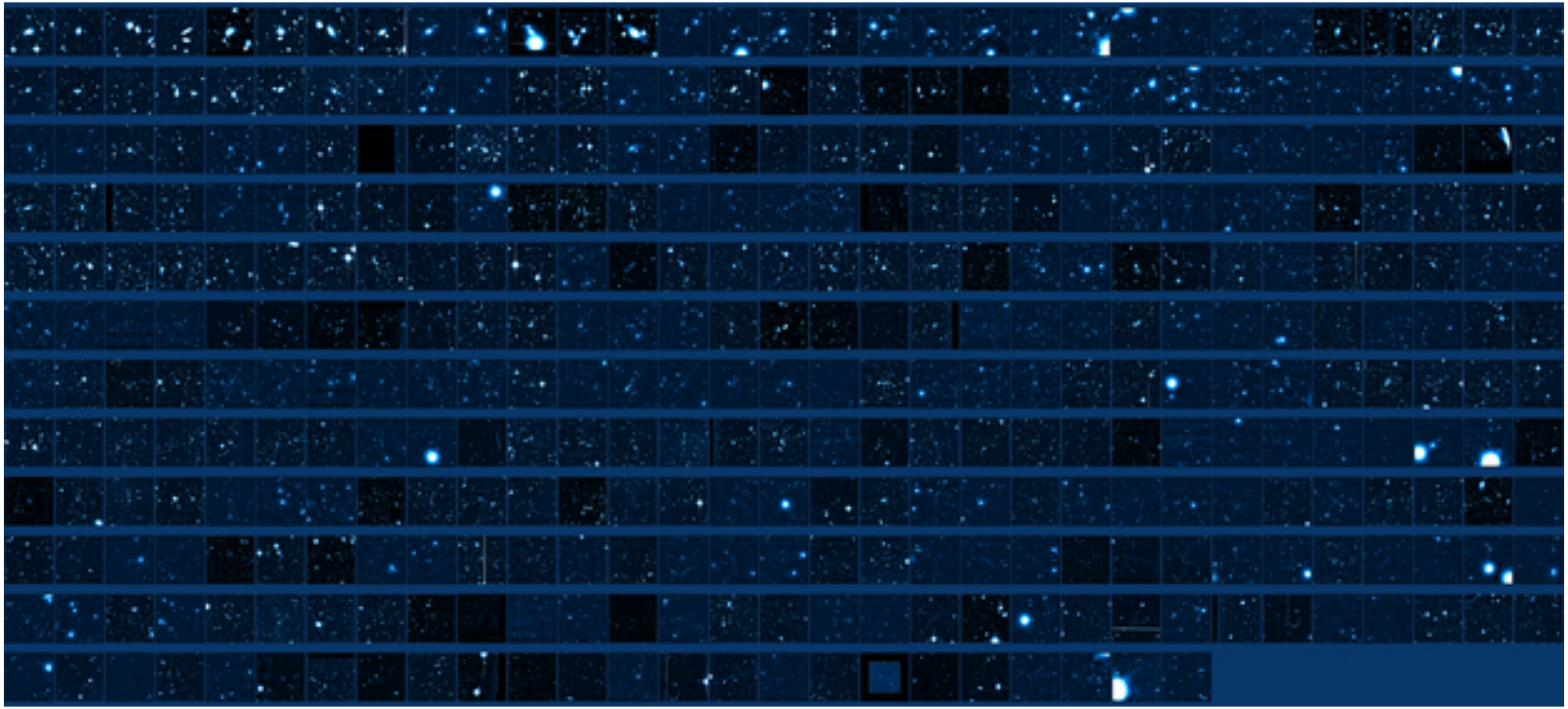
The XXL calender

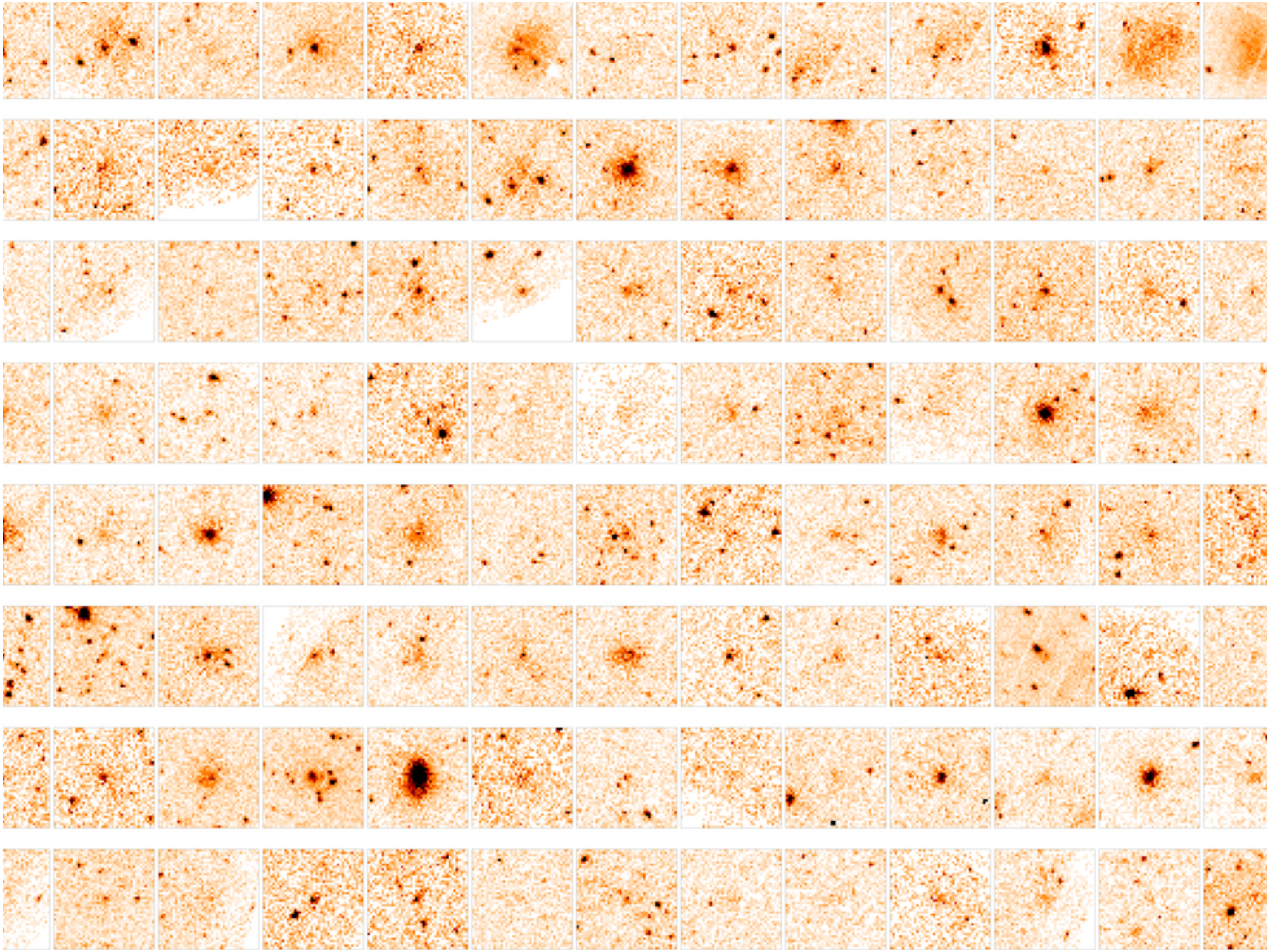
XMM images (7'x7')
0.03 < z <1.9



The XXL calender

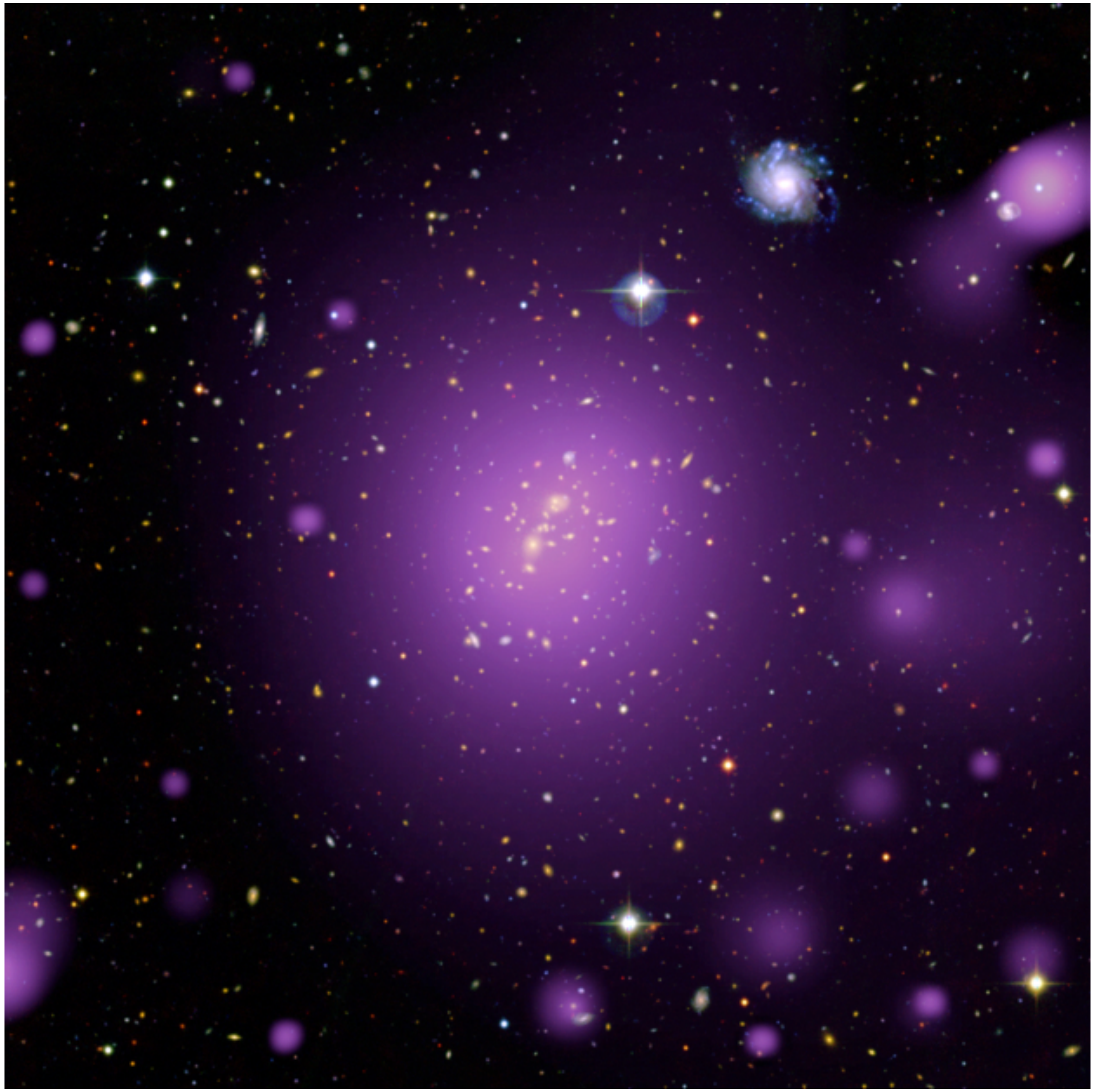
CFHTLS images (7’x7’)
0.03 < z <1.9





XLSSC006 z=0.43

ESA picture of the week 8-14 October 2018



The cluster catalogue release

365 objects

(paper XX : Adami et al 2018)

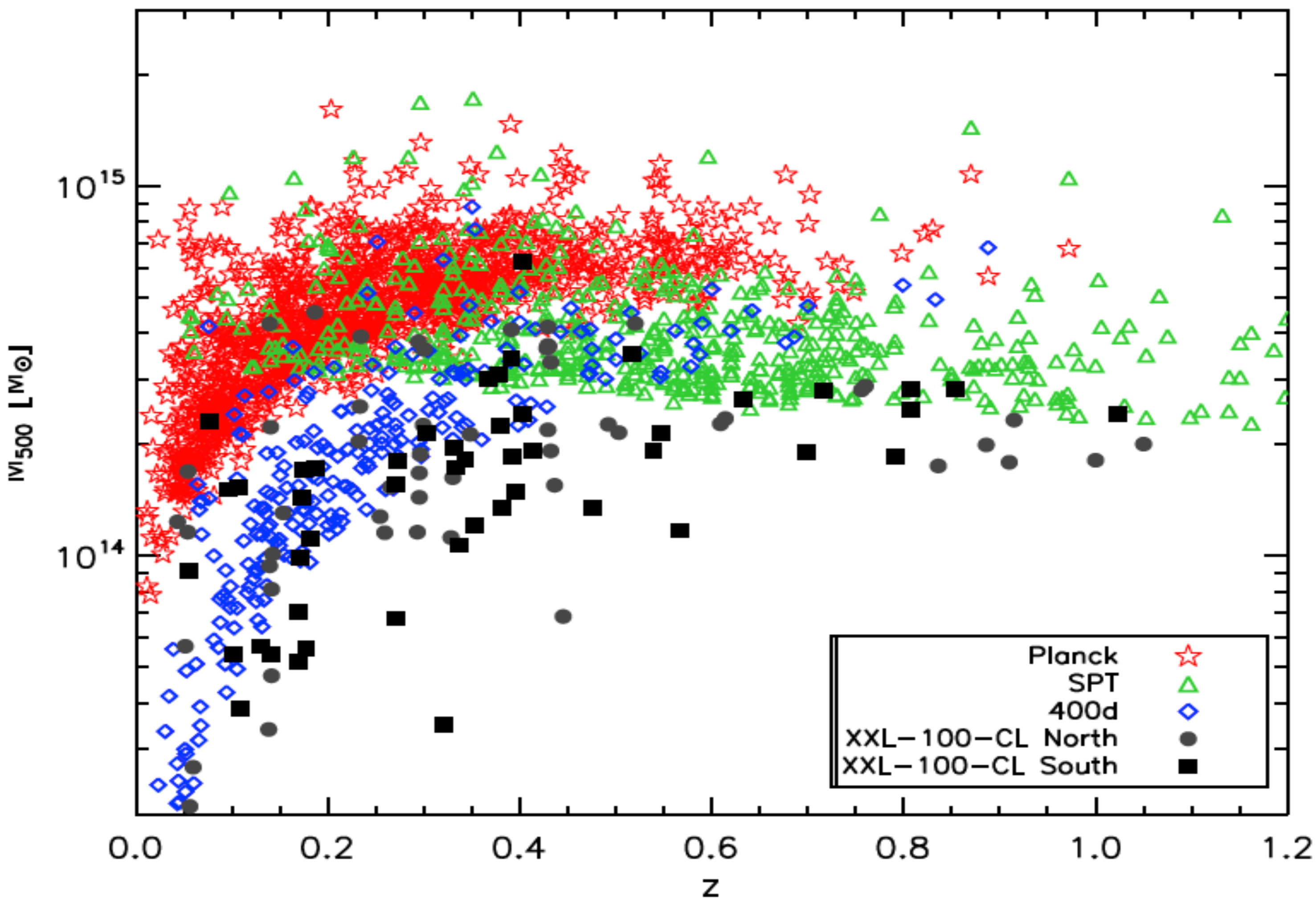
- Positions   (cluster and cD)
- Spectroscopic redshifts
- X-ray fluxes and temperature
- Masses
  - Lensing measurements
  - From our own scaling relations
- 35 superclusters

➔ **Visit our cluster DB:**

http://xmm-lss.in2p3.fr:8080/xxldb/index.html

Cluster mass range

XXL paper II : 100 brightest clusters   Pacaud et al 2106



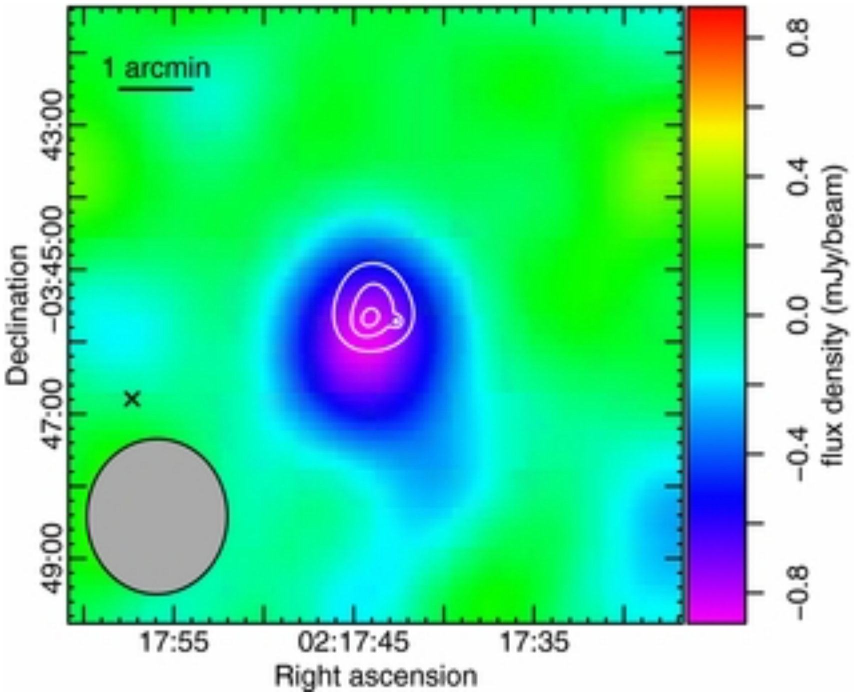
XLSSC-122

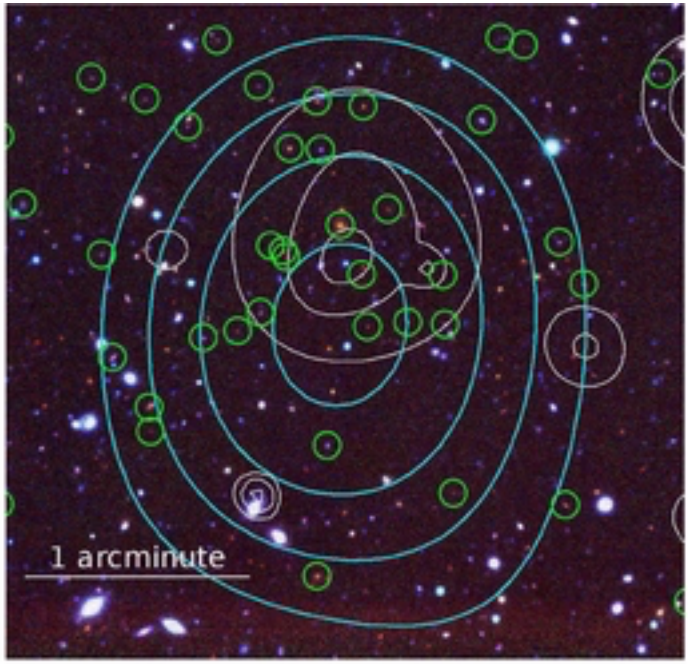
Mantz at al 2014

XXL paper V

z-phot~1.9

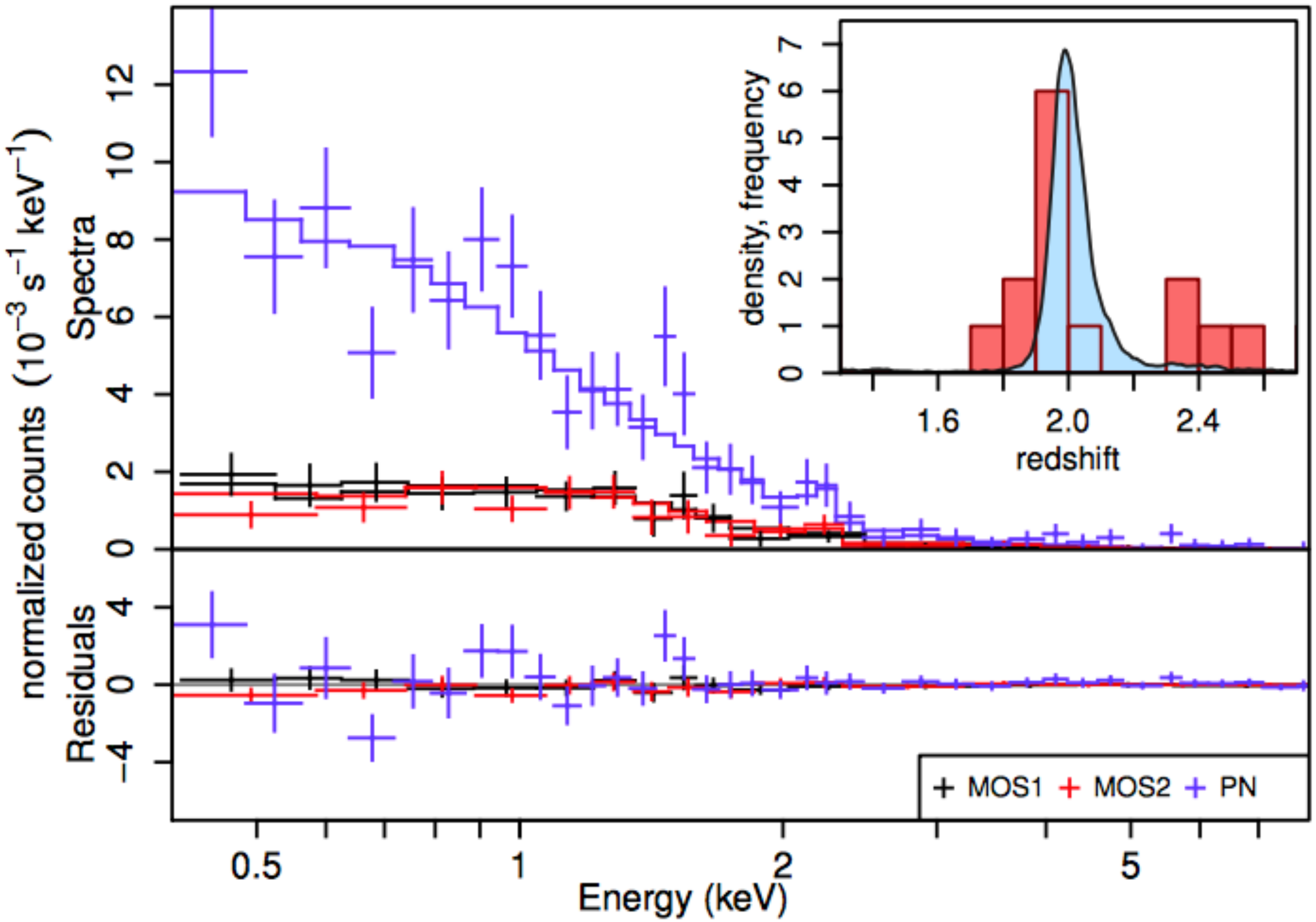
CARMA XMM CFHT





Redshift confirmation by deep XMM obs.

Mantz et al   2018, XXL paper XVII



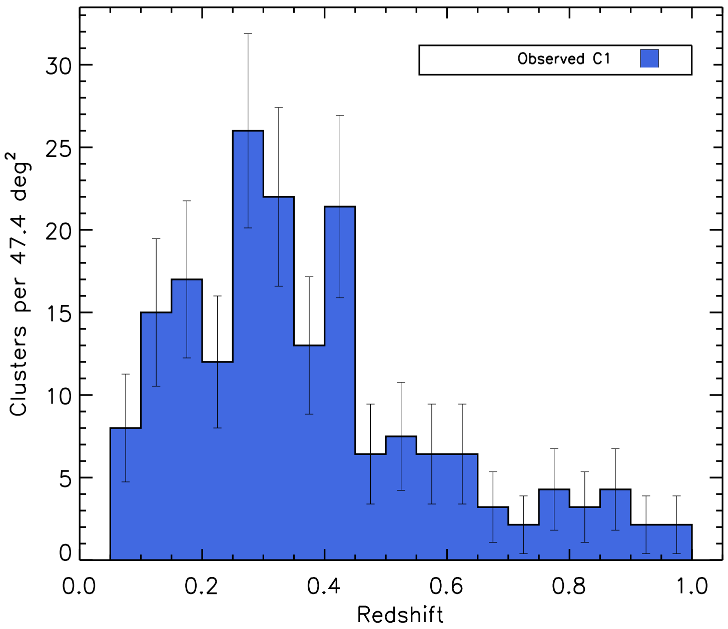
z = 2.0

kT =
5.0 ± 0.7 keV

The SZ-X offset remains

Cluster sample and observables

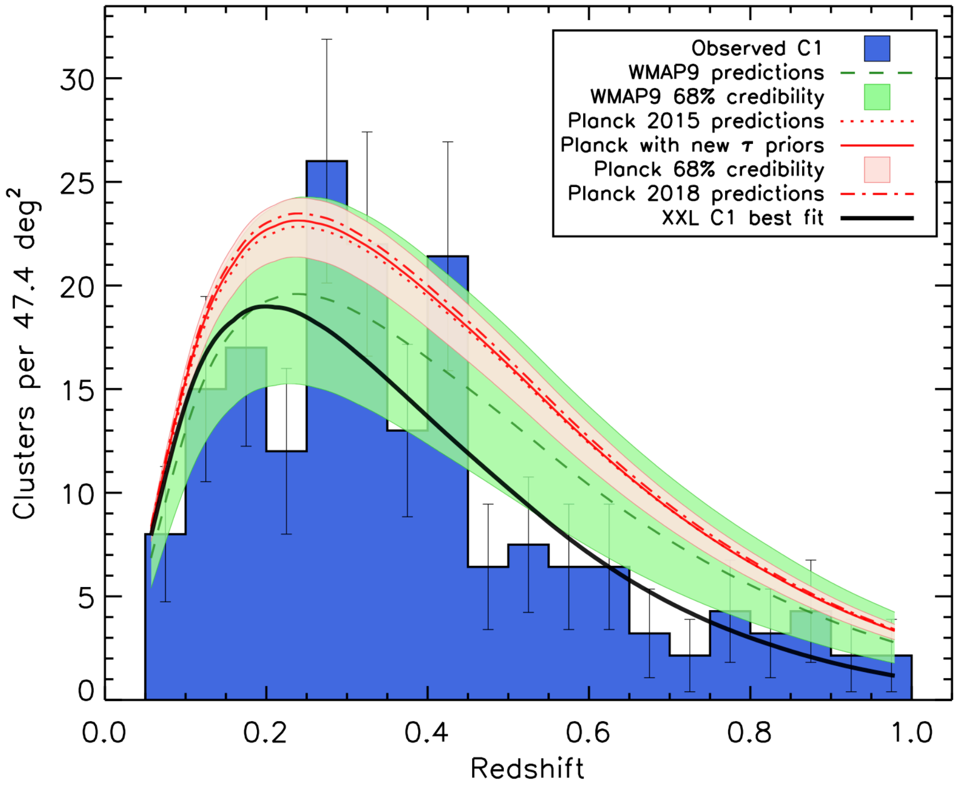
- Based on the XXL C1 sample of the XXL 2nd release (Adami et al. 2018)
- Cosmological constraints from the cluster density in redshift space (dn/dz), restricting to the redshift range [0.05-1.0] :
  - 178 clusters with measured redshifts
  - 5 clusters without a measured redshift – modeled as a 6.6% incompleteness for z>0.4



$M_{500} \sim 5\ 10^{13} – 3\ 10^{14}$

XXL paper XXV , Pacaud et al 2108

Comparison with CMB predictions



Using our best-fit scaling relations

CMB overestimates the cluster density

WMAP9 model : **+37%**

Planck15 model : **+ 61%**

Results very much comparable to the Planck SZ clusters !

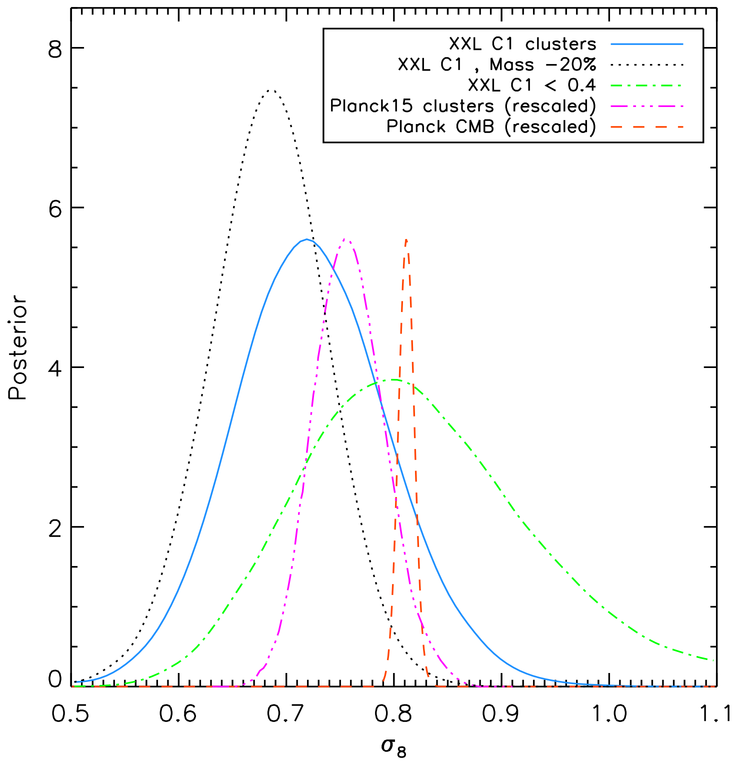
How significant is this discrepancy ?

Which cosmology do the XXL C1 clusters favour ?

XXL paper XXV , Pacaud et al 2108

Flat ΛCDM analysis

- We ran MCMC chains based the likelihood of the predicted redshift density.
- Priors on Ω_b and n_s included to stabilize the convergence.
- Additional weak prior on h = 0.7 +/- 0.1
- Cosmic variance accounted for as gaussian fluctuations on the total counts



A low value of $\boldsymbol{\sigma_8}$**=0.72±0.07** is prefered

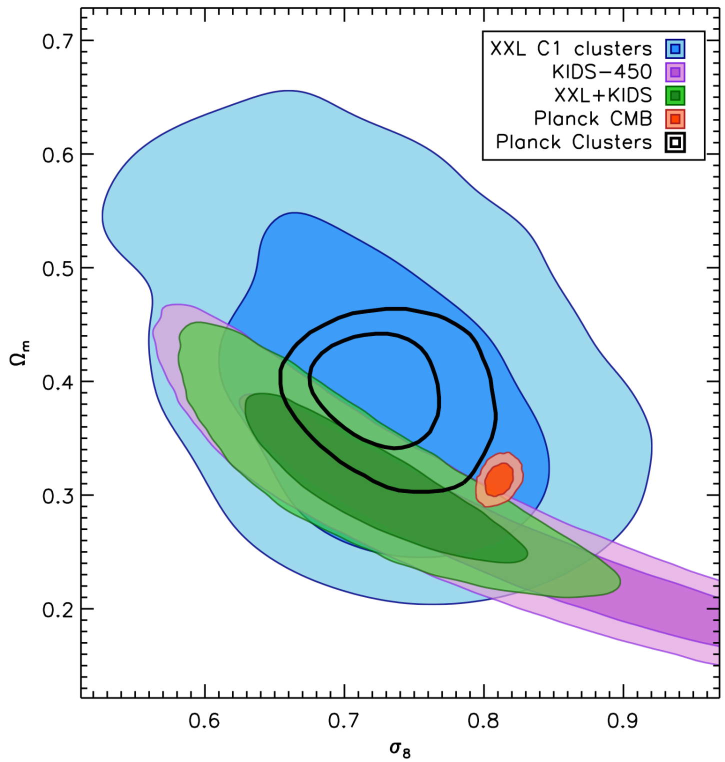
σ_8 driven low by the density at z>0.4

Results **comparable with Planck15** clusters but for a **different M_{500} and z regime**

XXL paper XXV , Pacaud et al 2108

XXL/CMB comparison in Flat ΛCDM

- Errors are still larger than the Planck SZ cluster analysis (using only redshift distribution, conservative assumptions on scaling laws and half as many clusters)
- Tension with Planck CMB remains unsignificant at this stage ($<0.1\sigma$)



XXL-C1 + KiDS-450 yield tighter constraints :

Ω_m=0.31±0.05, σ_8=0.72 ±0.06

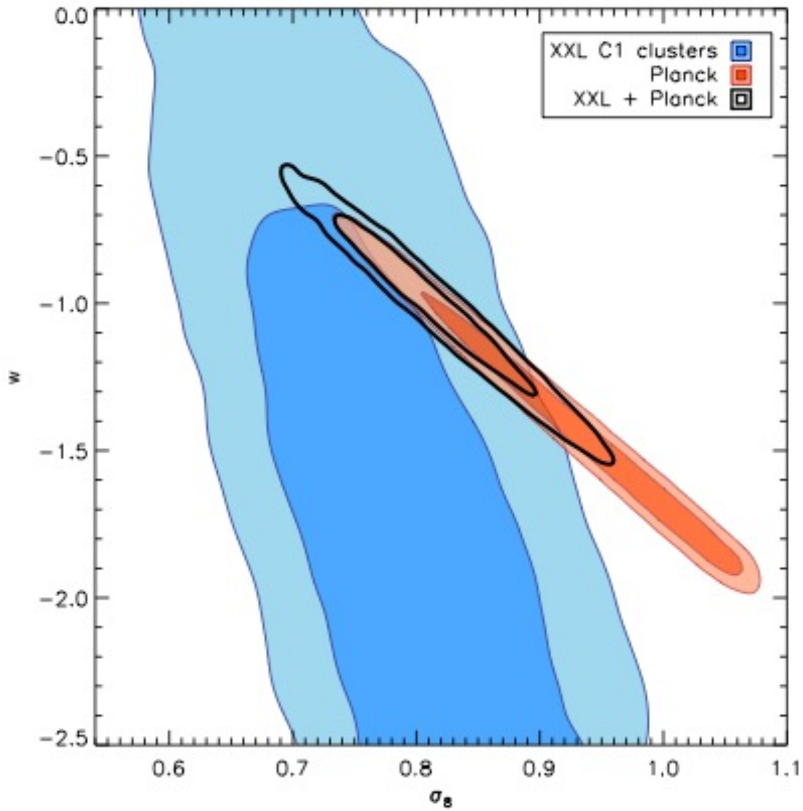
But tensions are similar that for KiDS alone (see Hildebrandt 2017)

Despite the low cluster density, everything seems compatible with Planck CMB results

XXL paper XXV , Pacaud et al 2108

wCDM constraints

- For dark energy models (w=Cst), Planck CMB constraints are weaker
- Even with the early analysis, XXL can already improve constraints on w
  - Planck 2015 : $w = -1.44 \pm 0.3$
  - **Planck + XXL :** $\boldsymbol{w = -1.02 \pm 0.2}$



- Still no significant tension ($\sim 0.5\sigma$), despite best fit offsets
- The combination of clusters and CMB disfavours phantom DE models

XXL paper XXV , Pacaud et al 2108

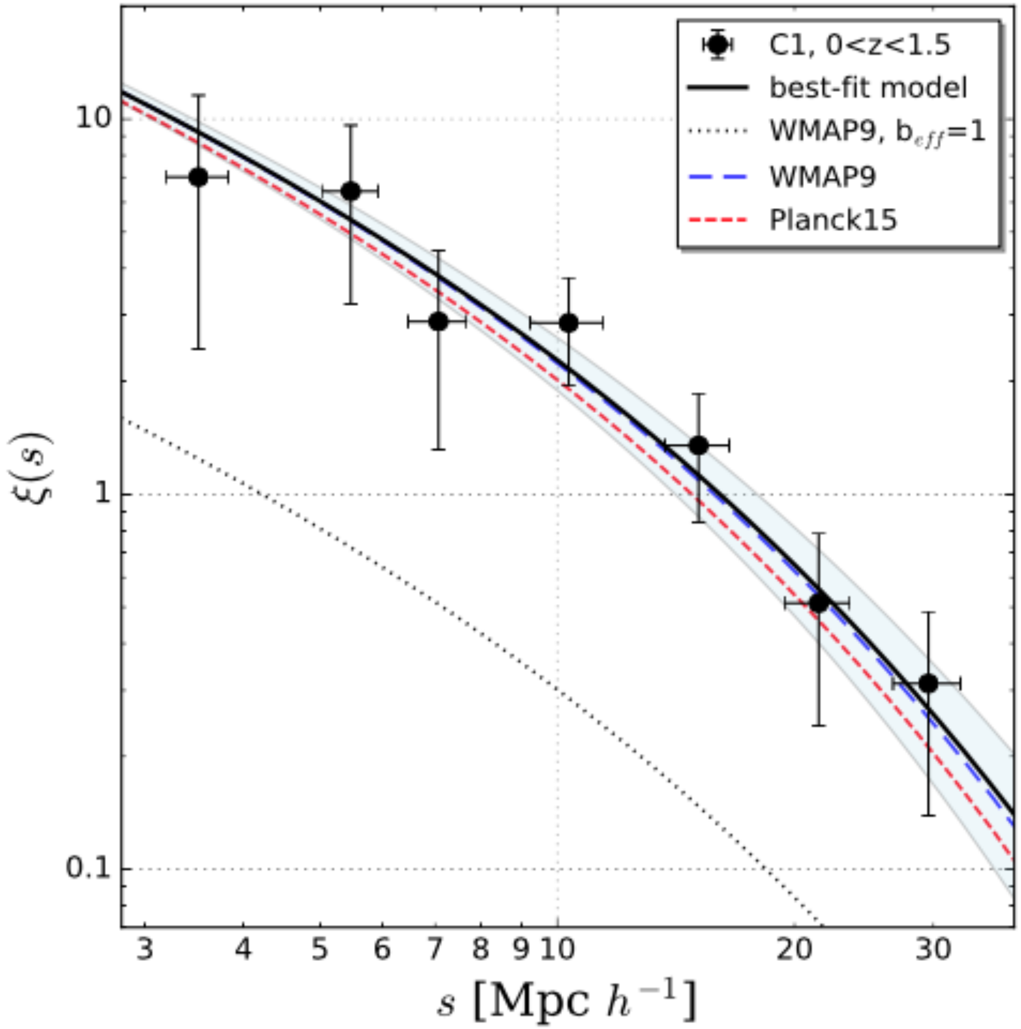


Fig. 3. Redshift-space 2PCF of the C1 XXL clusters at $z < 1.5$ (black dots) compared to the best-fit model, i.e. the median of the MCMC posterior distribution (black solid line). The shaded area shows the 68% uncertainty on the posterior median. The derived best-fit model correlation length is $s_0 = 16 \pm 2\, h^{-1}$ Mpc .

The 3D cluster-cluster ξ

XXL paper XVI , Marulli et al 2018

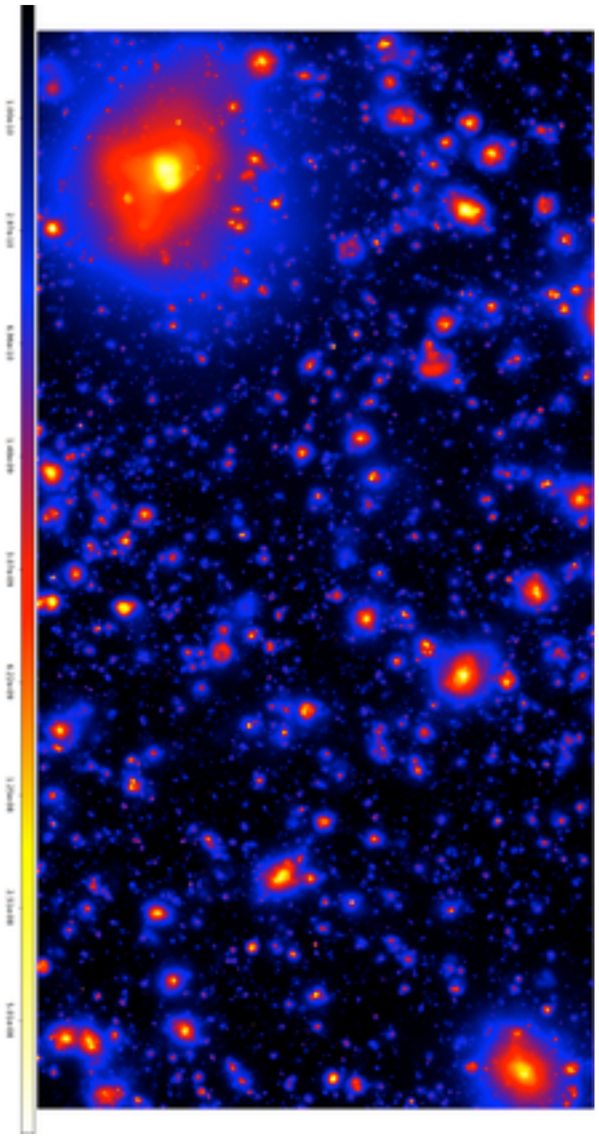
NOW:
Inventory of the systemactic errors

- Accuracy of the mass calibration
- Average cluster shape (β = 2/3)   (sel. funct.)
- Effect of 'peaked' clusters (sel. funct.)
- Scatter in the scaling relations
- Uncertainties in the theoretical mass function

➔ Will be adressed in the final analysis with the complete cluster sample (~400 objects) along with numerical simulations

Cosmos-OWLS simulation

Le Brun, McCarthy et al 2014



1x2 deg^2 FIELD

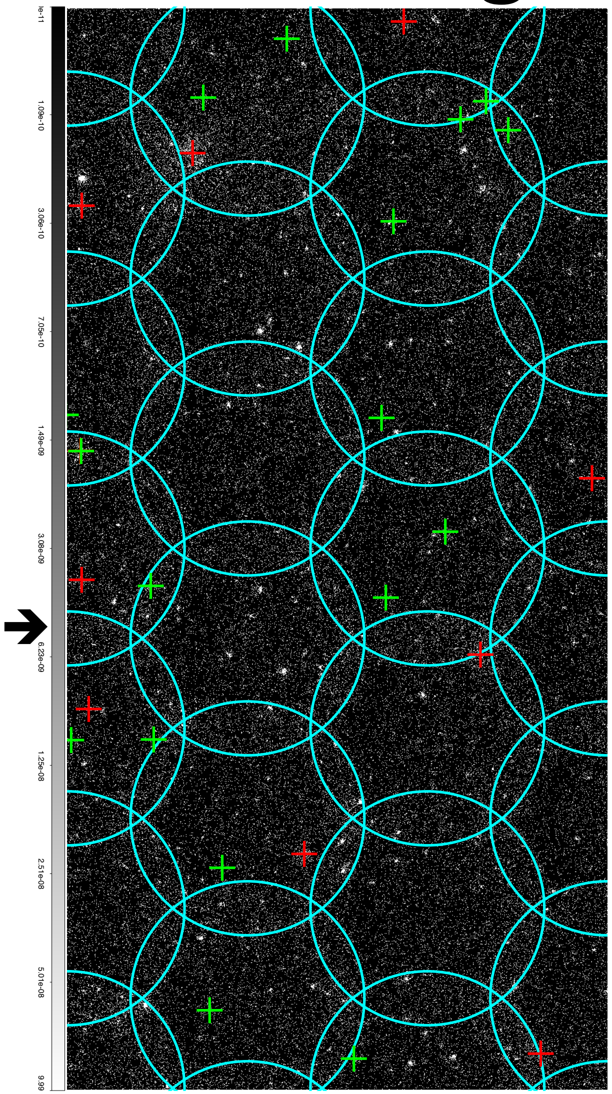
← Input = hot gas

Output = XMM photon image →

All instrumental effects and background components are taken into account

AGN are added

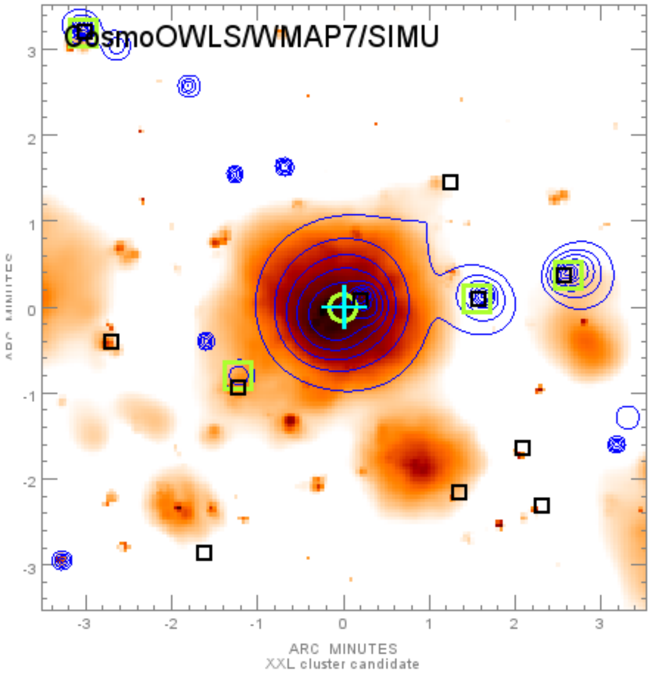
XMM image



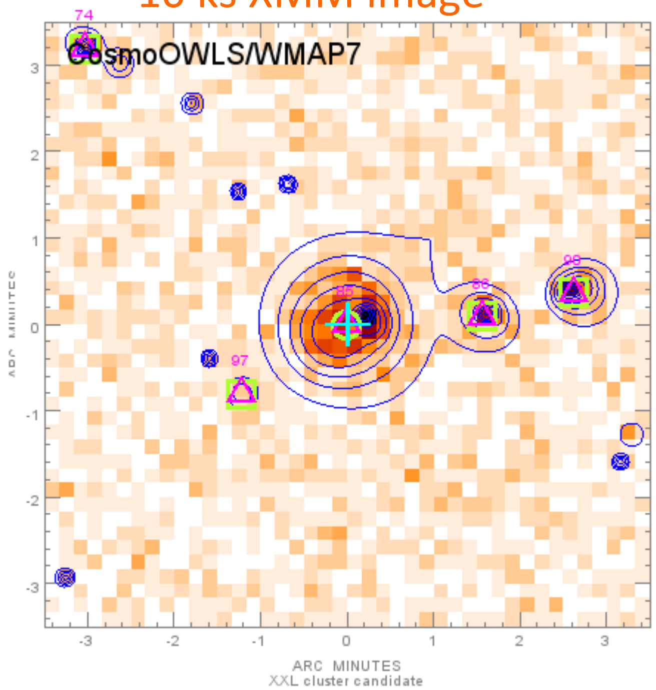
X-ray pipeline output

Cosmo-OWLS simulations, *Le Brun et al 2014*
AGN X-ray contribution, *Koulouridis et al, XXL paper XIX*

X-ray emissivity



10 ks XMM image

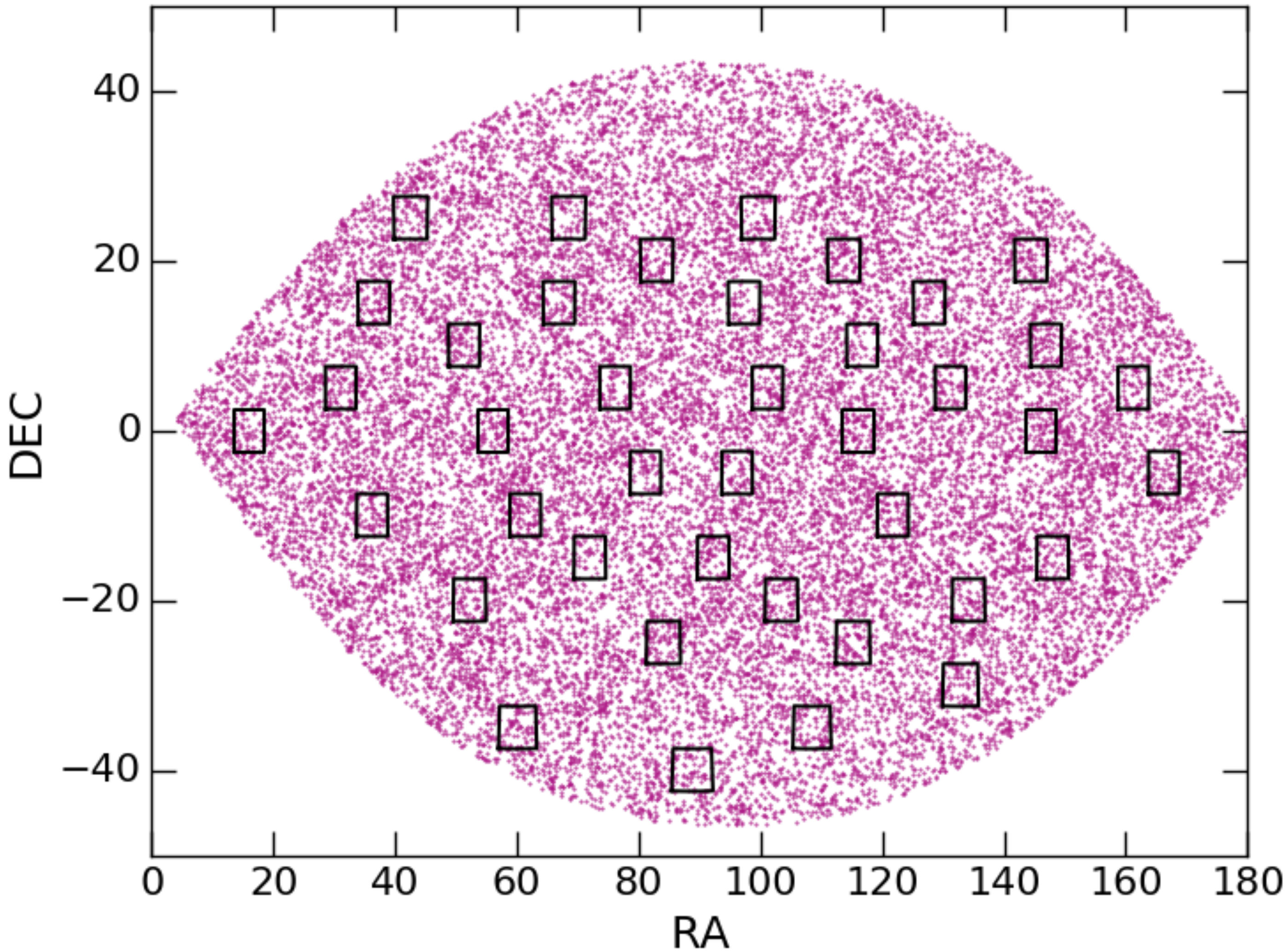


7'x7' image centered on a z = 0.95 cluster ; M_{500} = 3.5 10^{14}M
– the black squares are the in-situ simulated AGN

The 700 deg^2 simulations

DM: Aardwark

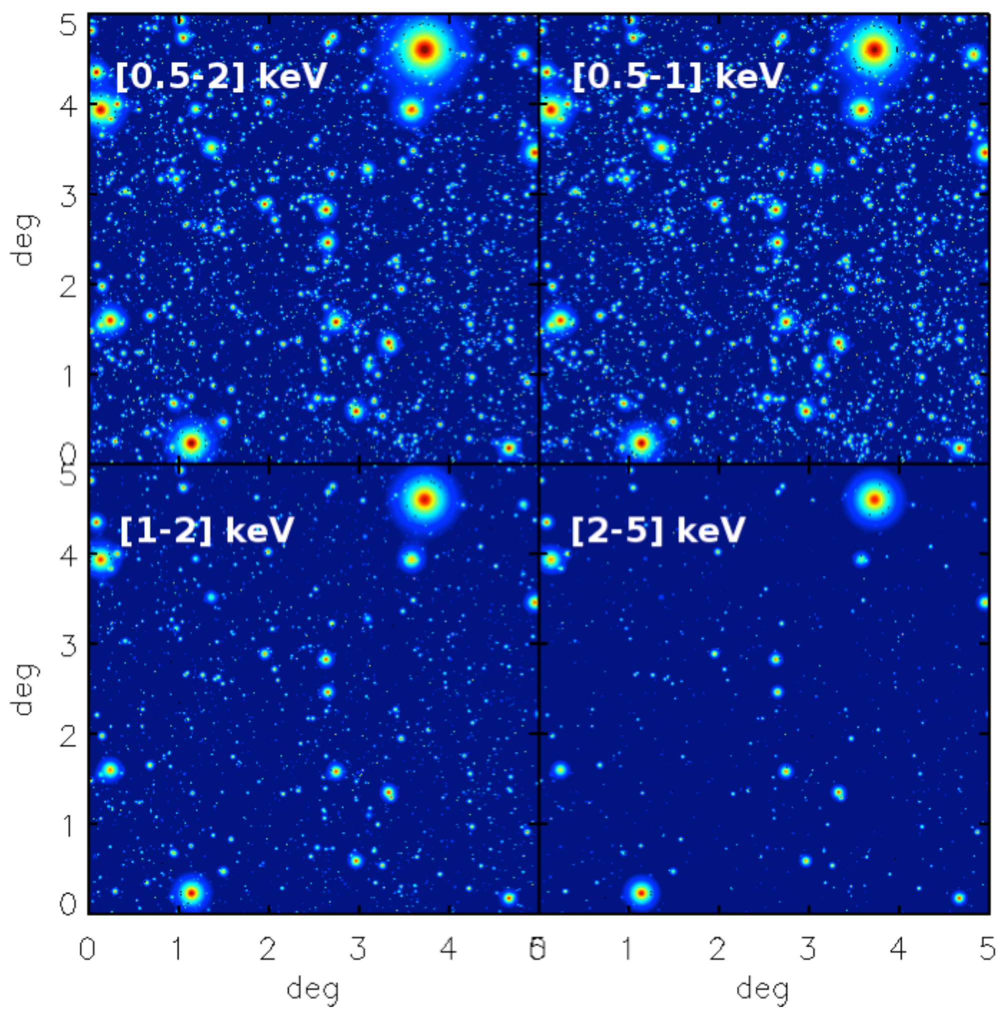
39 x 25deg^2 fields



5x5 deg^2 emissivity maps: one XXL field

Gas painting ad libitum ; here: β=2/3 profiles

Valotti et al 2018



3. X-ray cluster forward cosmology modelling

Cluster cosmology

- **Old route:**

Flux, Temp => Mass => dn/dM/z => compare with theory

Masses - and scaling relations - must be computed for each tested cosmology

- **Quick way:**

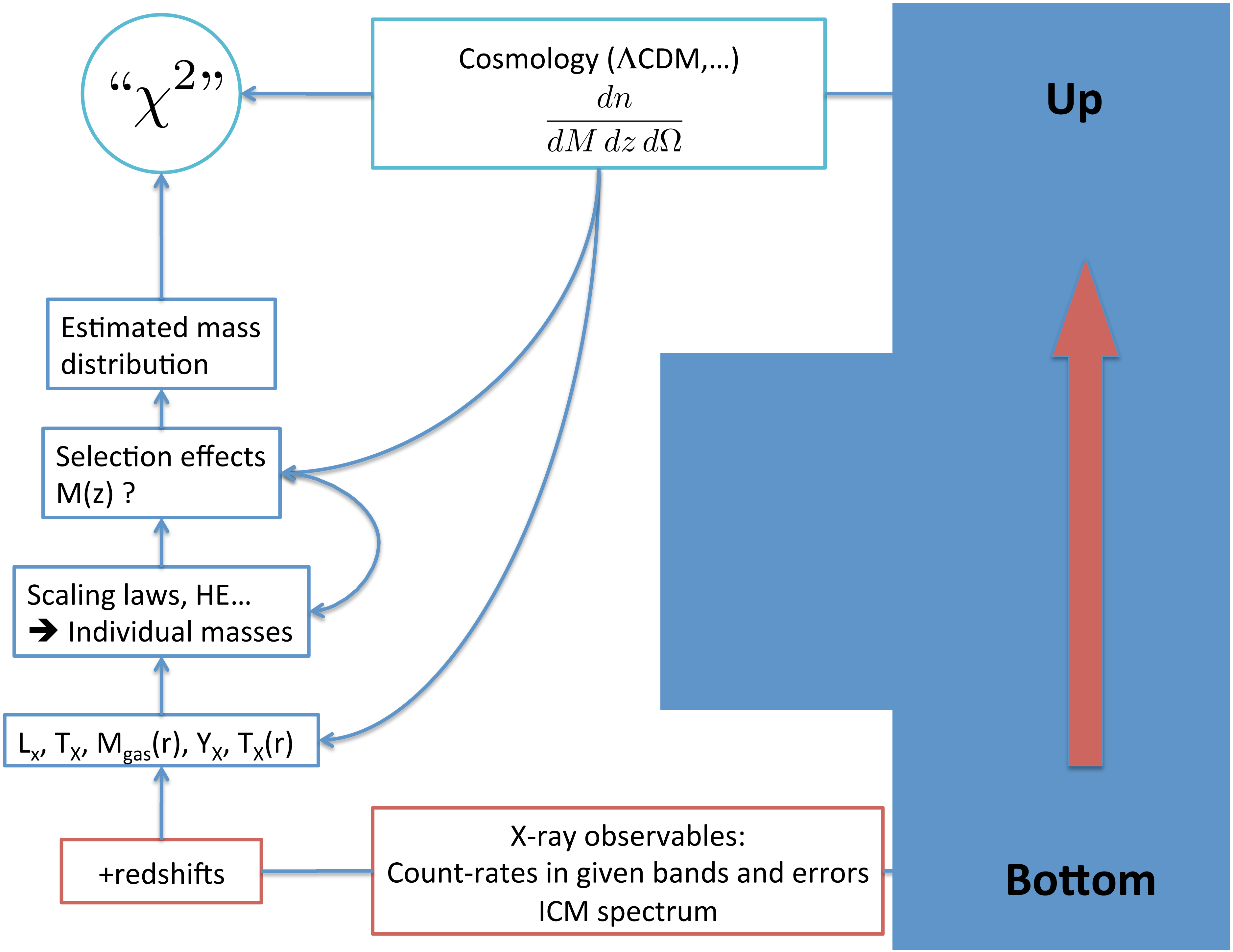
Work in directly in the observed parameter space

➔Predicted   X-ray colour-magnitude diagrams

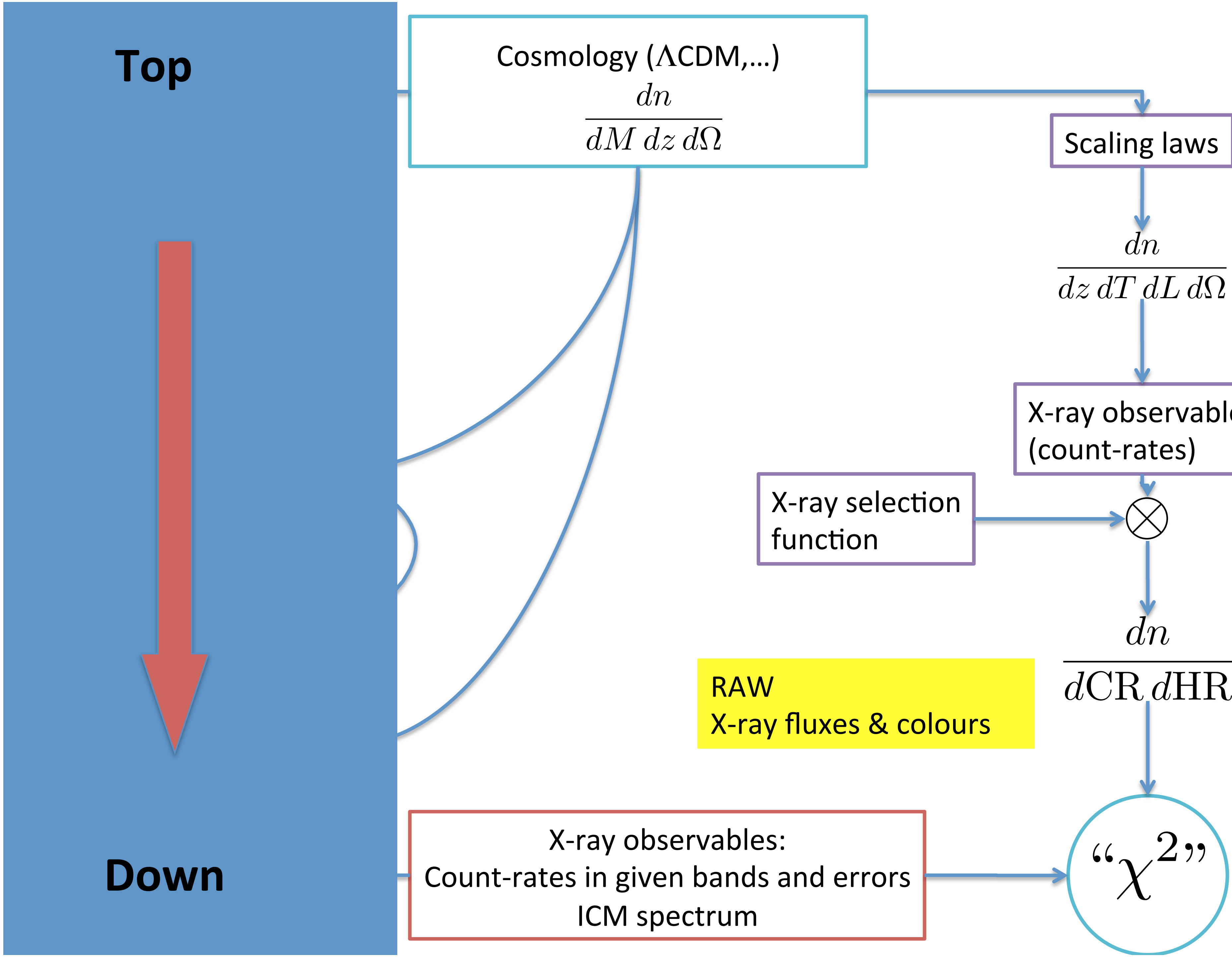
Clerc et al 2012, Pierre et al 2017, Valotti et al 2017

Fit simultaneously:

cosmology - cluster physics & evolution - selection effects

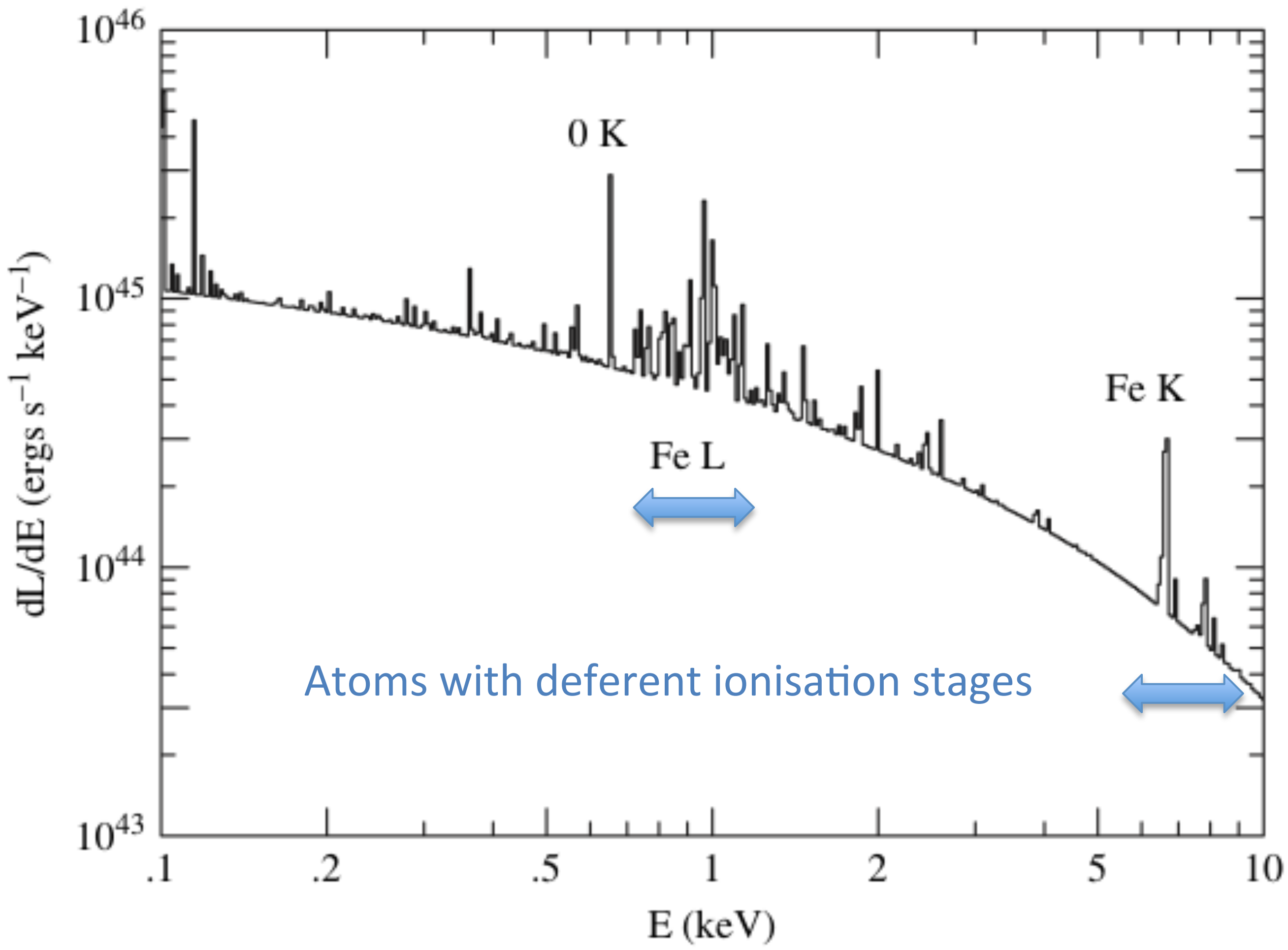


"χ^2"
Cosmology (ΛCDM,...)
$\frac{dn}{dM\,dz\,d\Omega}$
Up
Estimated mass distribution
Selection effects M(z) ?
Scaling laws, HE...
➔ Individual masses
L_X, T_X, $M_{gas}(r)$, Y_X, $T_X(r)$
+redshifts
X-ray observables:
Count-rates in given bands and errors
ICM spectrum
Bottom



Top
Down
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
$\frac{dn}{d\mathrm{CR}\,d\mathrm{HR}}$
RAW
X-ray fluxes & colours
X-ray observables:
Count-rates in given bands and errors
ICM spectrum
"χ^2"

X-ray emission complex



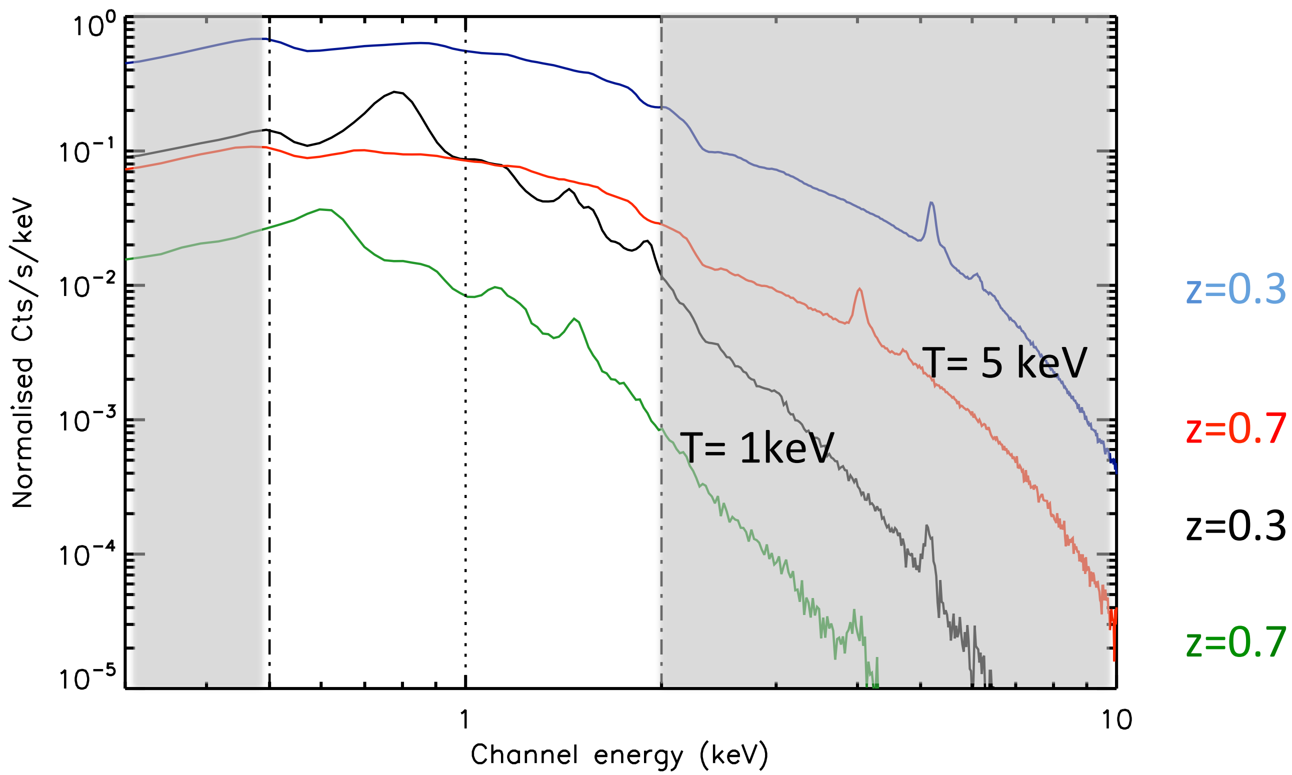
Cluster spectrum = bremsstrahlung continuum + emission lines

Example :
Iron
Atomic number: 26

Stable isotopes
54
56 92%
57
58

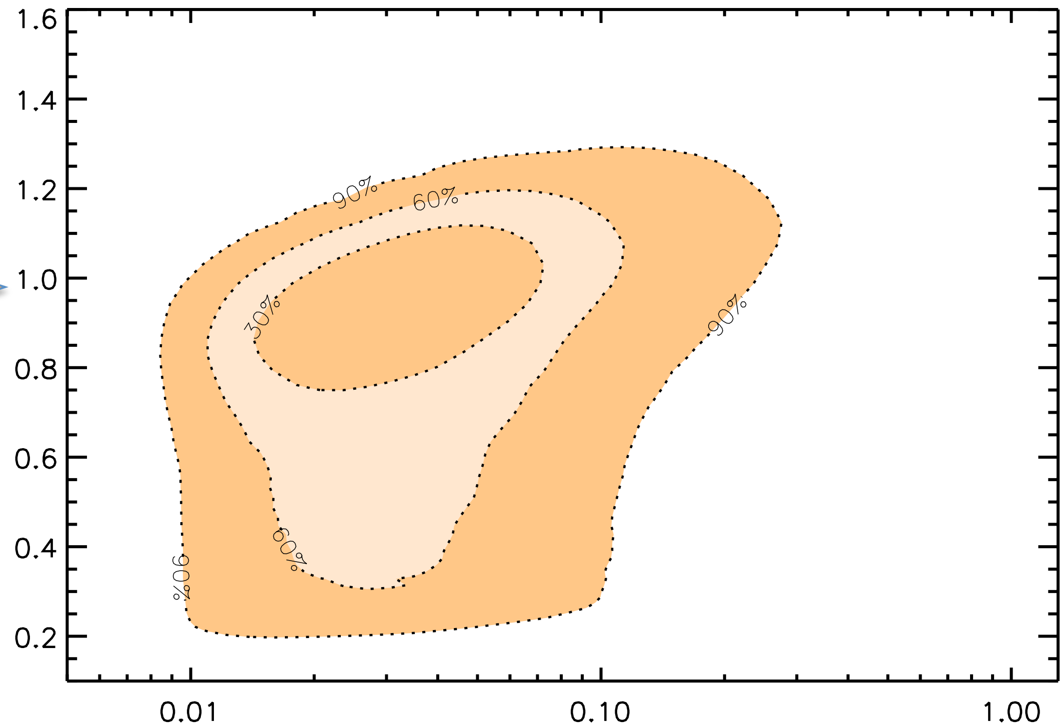
Raw XMM cluster spectra

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



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 :

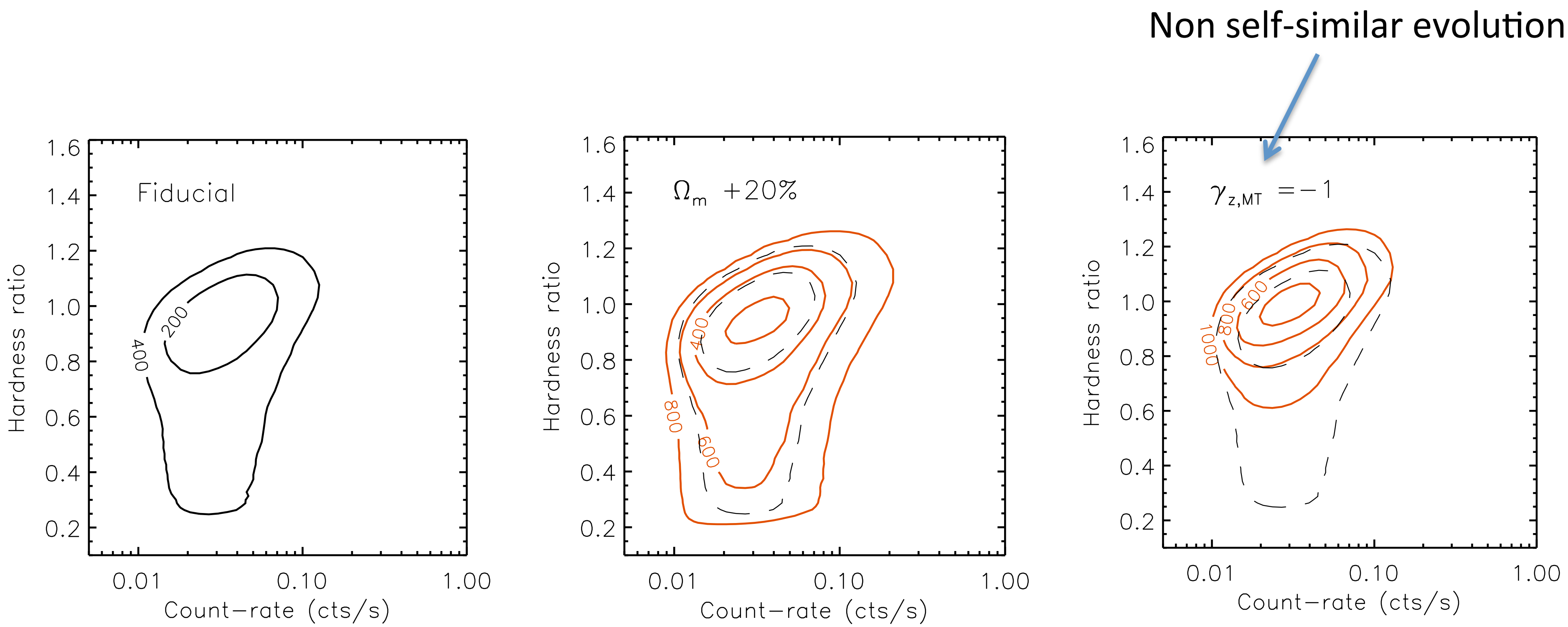
WMAP5 cosmology

C1 selection

Local cluster scaling laws

Self-similar evolution

100 deg^2


Non self-similar evolution
Fiducial
Ω_m +20%
$\gamma_{z,MT}$ = −1
Hardness ratio
Count−rate (cts/s)
200
400
600
800
1000

The selected
X-ray observable cluster parameters

1. XMM count-rate in [0.5-2] keV
2. XMM 'hardness ratio' : CR[1-2] / CR[0.5-1]
3. Apparent size : core radius of the β-profile
4. Redshift

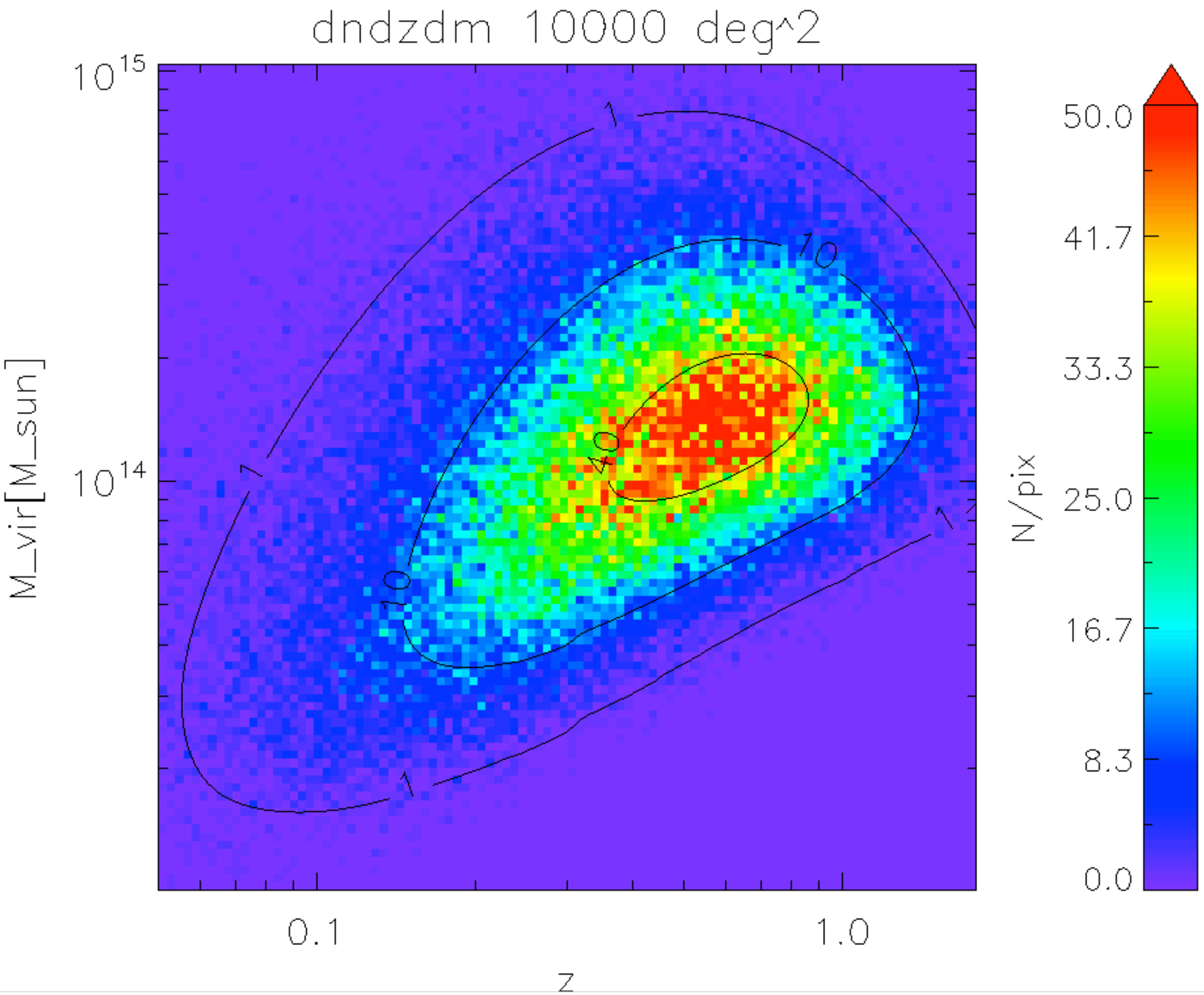
- Useful: the selection is expressed in terms of 1+3

$\Rightarrow$ We project the predicted [M-z] space into the 4D [CR-HR-Rc-z] space for any cosmology + scaling relations

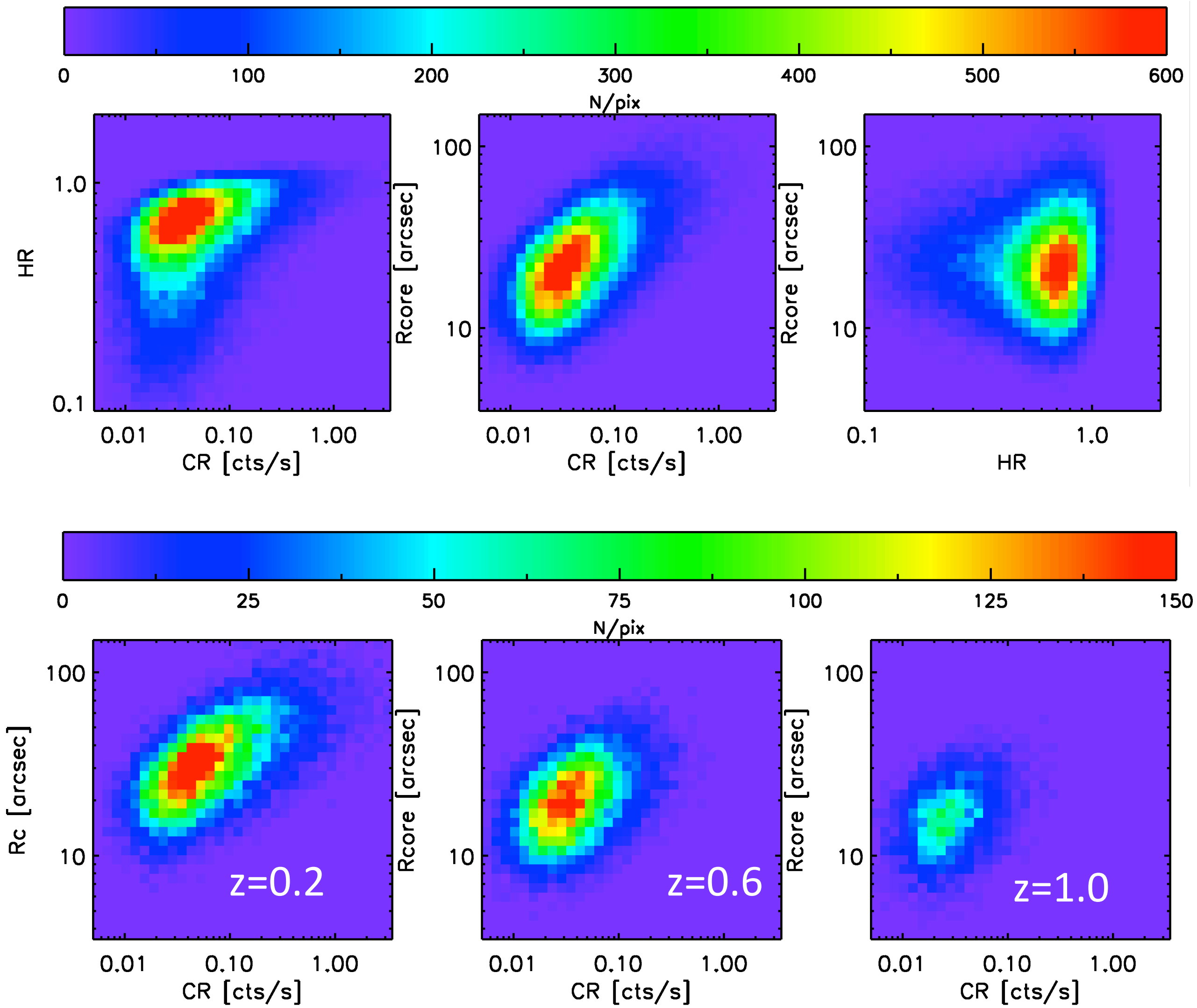
$\Rightarrow$ Fit to the observed 4D diagram

The M-z plane (10,000 deg²)

for the selected C1 clusters



Projection into the 4D observational space



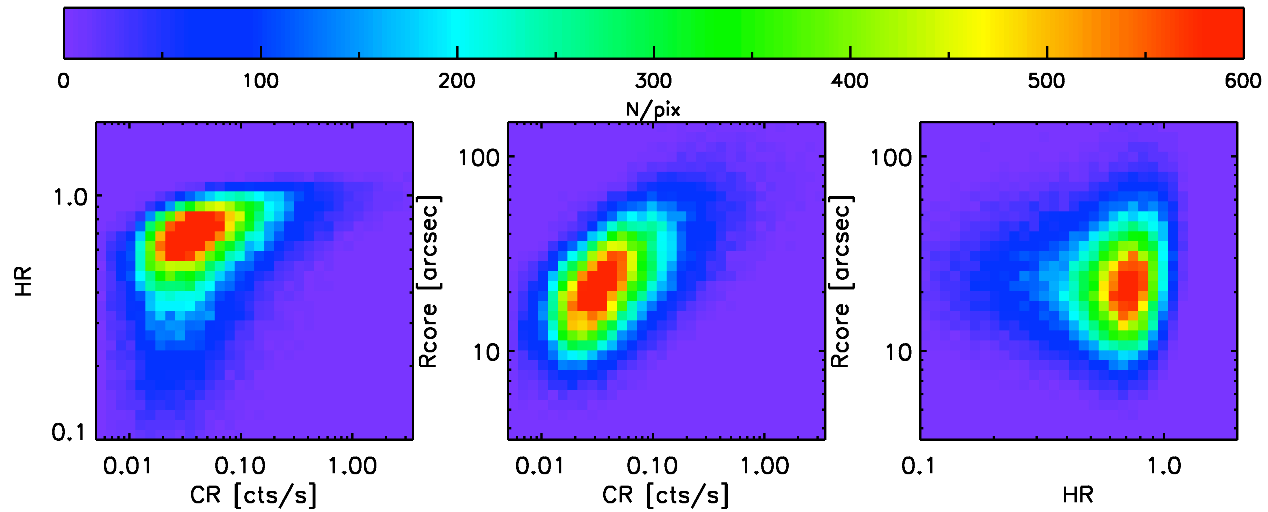
CR, HR, Rc

integrated over z

Rc-CR
intergated over HR

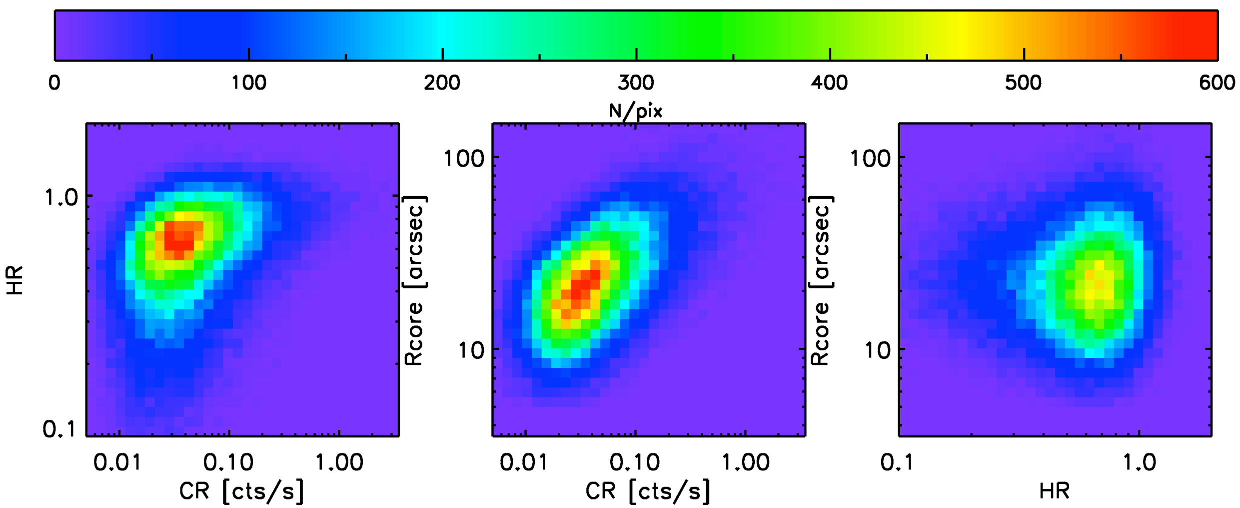
3 z-slices

Easy: introducing error measurements



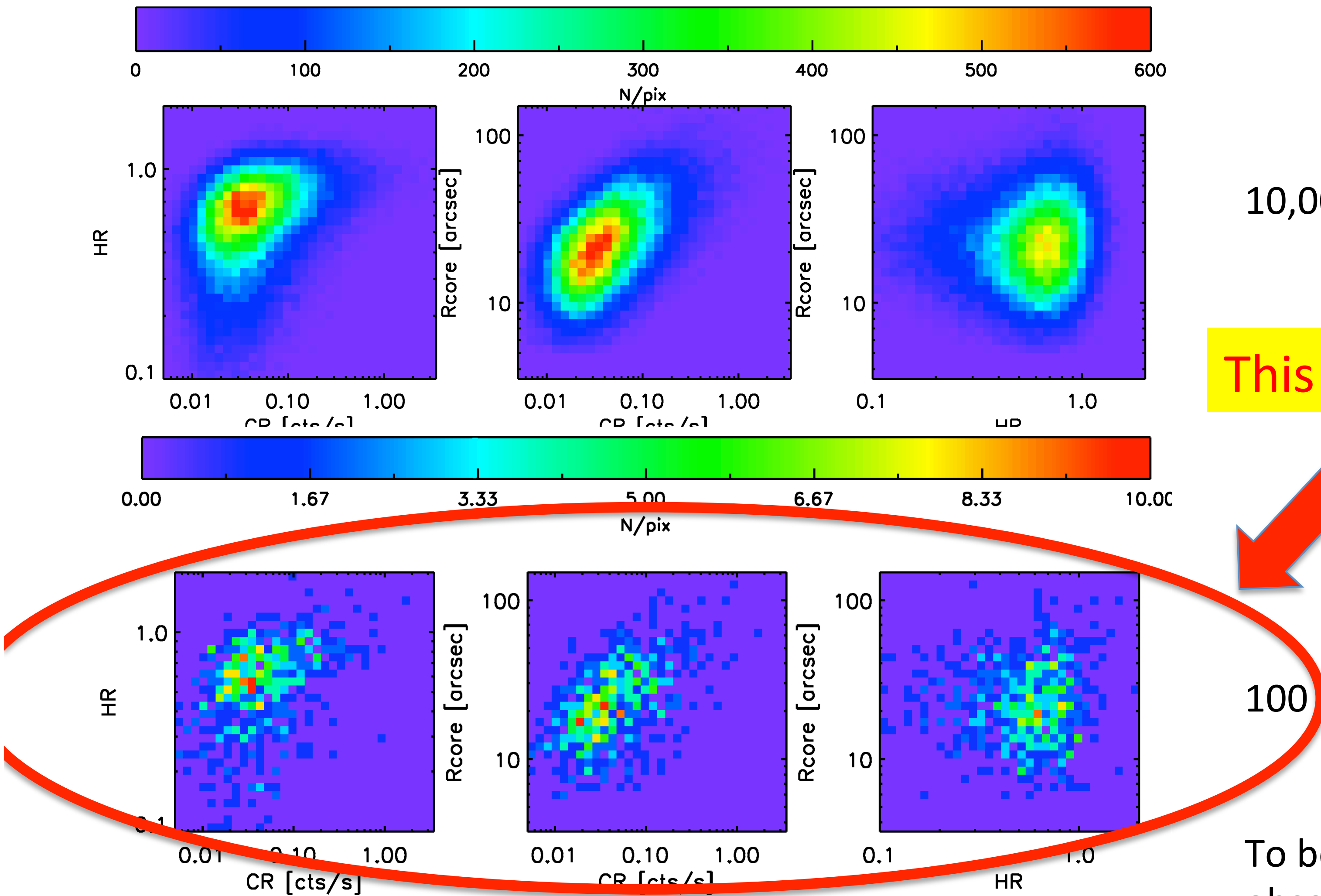
CR, HR, Rc

integrated over z



+ 20% err
on all parameters

Reducing the area



10,000 deg^2

This is what we fit

100 deg^2

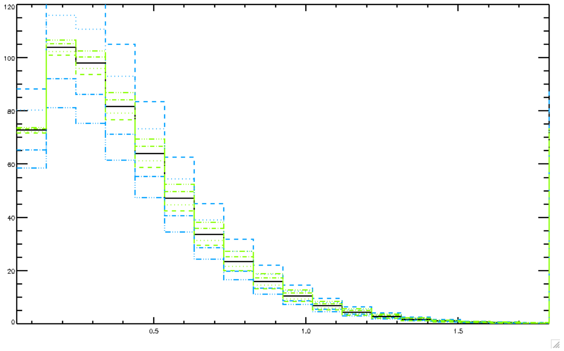
To be fitted to the observed 4D diagram

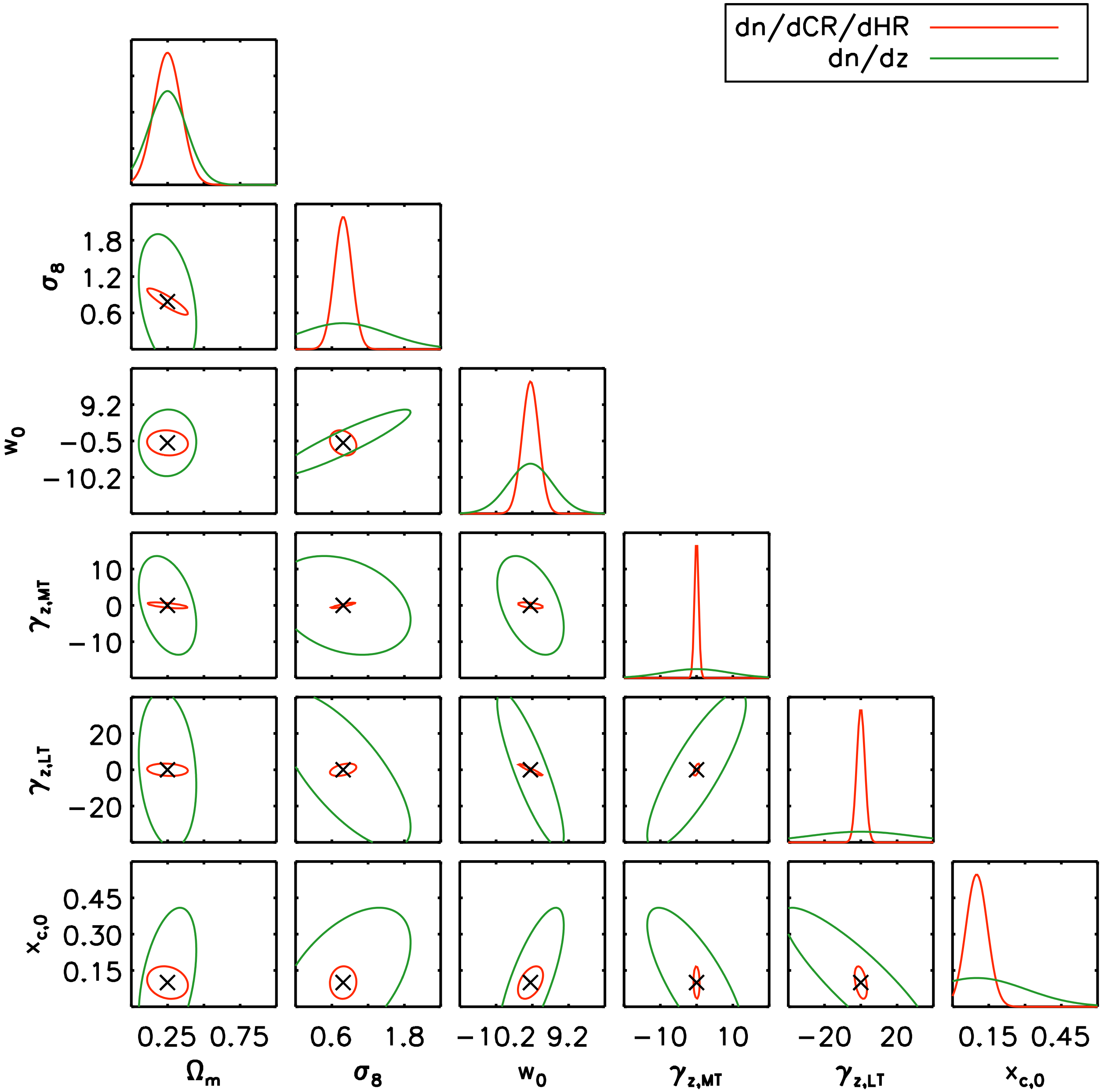
Comparison with the standard approaches

Fisher analysis

Clerc et al 2012

1) CR-HR vs dn/dz

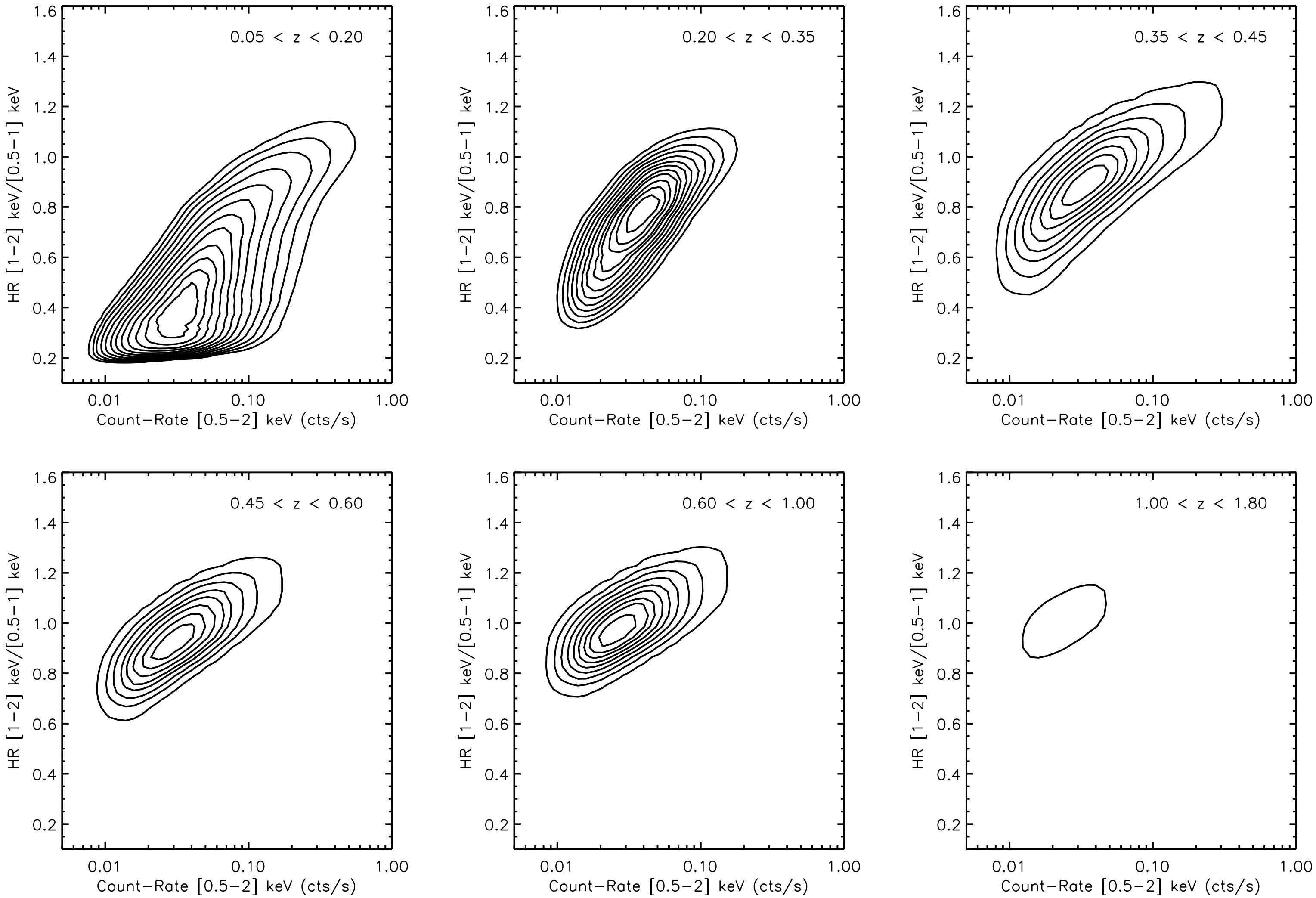




Does not need redshifts!

Adding redshifts

➔ 4th dimension to the diagram

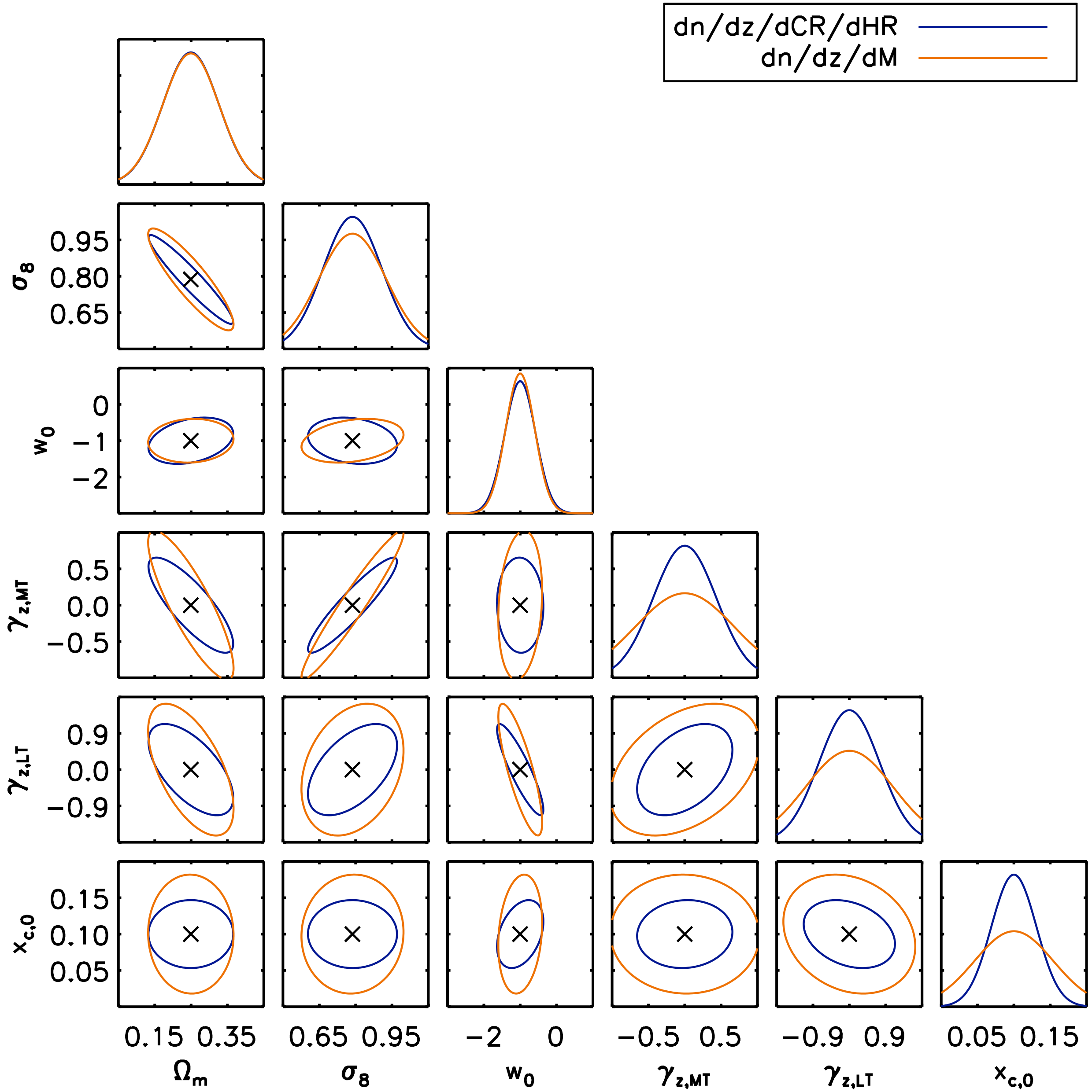


Adding redshifts
(photo-z are sufficient)

2) CR-HR-dz

vs

N(M, z)



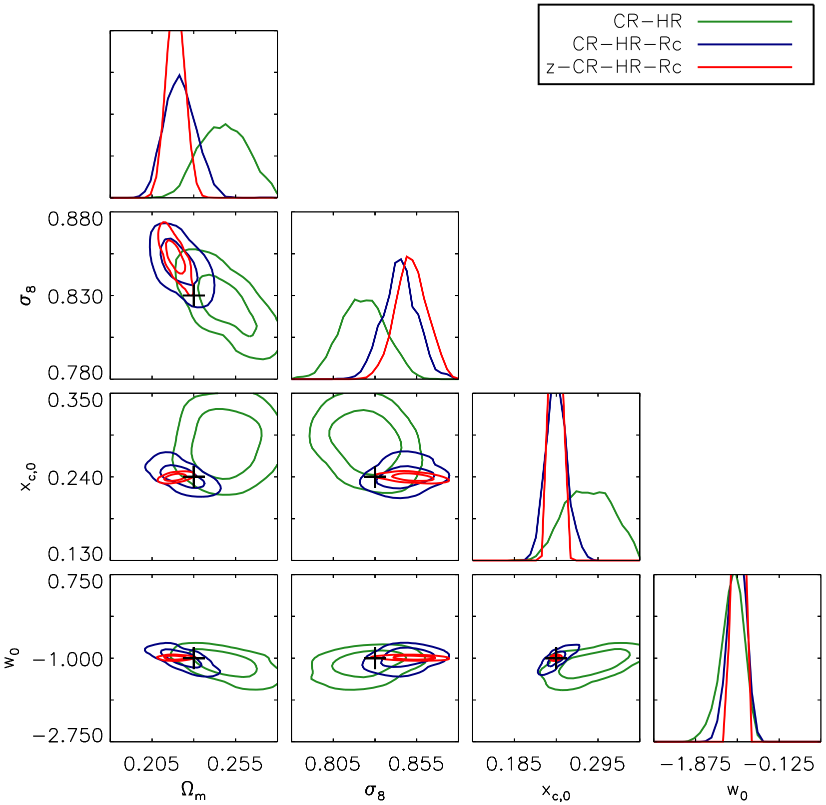
Processing of 700 deg^2
~ 900 fake XMM observations
(Aardvark simulations)

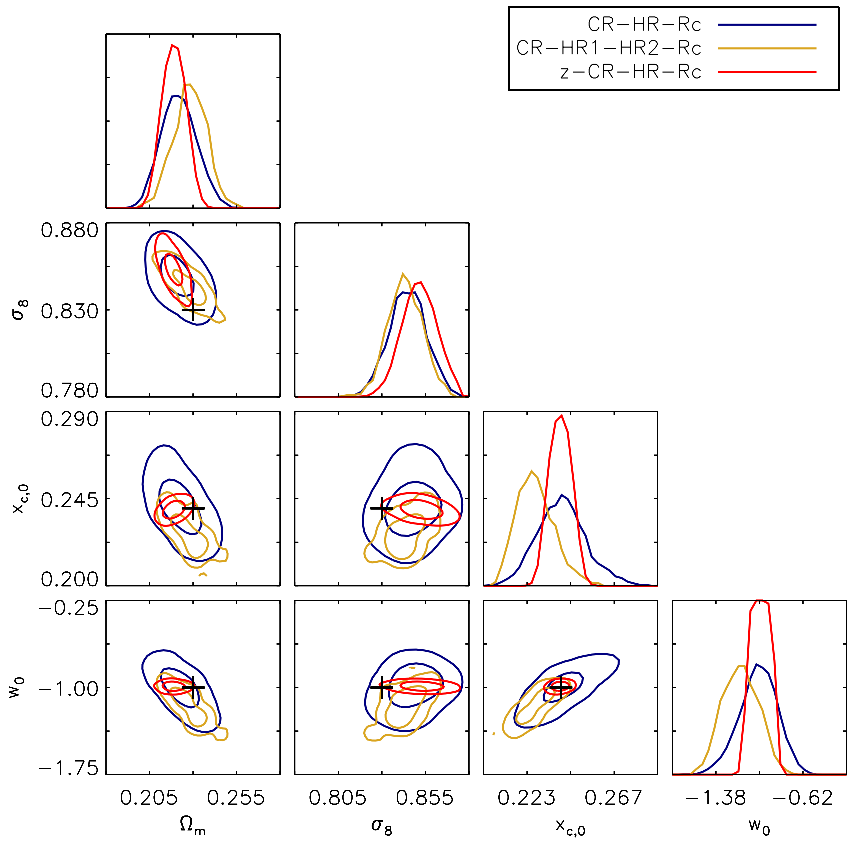
Valotti et al 2018

- Selection of the C1 clusters
- Construction of te CR-HR-Rc-z diagrams

- Analyses   with +/- free parameters
  - MCMC
  - Amoeba
  - Check Fisher analysis

A few results





A few results (a)

ID	Observable combination	Fitted parameters	$<p>$ MCMC	*best-10* Amoeba	Toy catalogues[x10] Amoeba	Fisher analysis
A1	CR-HR$_1$	Ω_m	$0.249^{+0.014}_{-0.019}$	0.245	0.234±0.019	0.23 ± 0.013
		σ_8	0.823±0.014	0.825	0.830±0.018	0.83 ± 0.012
		$x_{c,0}$	$0.285^{+0.033}_{-0.034}$	0.290	0.232±0.024	0.24 ± 0.031
		w_0	$-1.117^{+0.212}_{-0.218}$	-1.037	-1.204±0.296	-1.00 ± 0.246
A2	CR-HR$_1$-r$_c$	Ω_m	0.222±0.010	0.220	0.226±0.013	0.23 ±0.012
		σ_8	$0.846^{+0.011}_{-0.010}$	0.846	0.832±0.015	0.83 ± 0.011
		$x_{c,0}$	$0.240^{+0.011}_{-0.013}$	0.247	0.248±0.014	0.24 ± 0.017
		w_0	$-1.009^{+0.153}_{-0.144}$	-0.969	-0.980±0.198	-1.00 ± 0.21
A3	z−CR-HR$_1$-r$_c$	Ω_m	0.219 ±0.005	0.218	0.229±0.004	0.23 ± 0.005
		σ_8	0.852±0.009	0.854	0.832±0.009	0.83 ± 0.009
		$x_{c,0}$	0.240±0.003	0.239	0.240±0.003	0.24 ± 0.003
		w_0	$-0.990^{+0.029}_{-0.027}$	-0.990	-1.041 ±0.033	-1.00 ± 0.032
A4	CR-HR$_1$-HR$_2$-r$_c$	Ω_m	$0.228^{+0.008}_{-0.009}$	0.227	0.226± 0.013	0.23 ± 0.008
		σ_8	$0.844^{+0.008}_{-0.009}$	0.843	0.833 ± 0.012	0.83 ± 0.010
		$x_{c,0}$	$0.226^{+0.008}_{-0.009}$	0.229	0.247 ± 0.012	0.24 ± 0.009
		w_0	$-1.166^{+0.148}_{-0.146}$	-1.121	-0.975 ± 0.195	-1.00 ± 0.113

Table 6. Summary table for the cosmological analysis of the Aardvark C1 CLEAN catalogue over 711 deg^2. The first column gives the run ID. The second column lists the signal variables used in the fit and the third one, the subset of free parameters. The fourth and fifth columns show the results from the MCMC analysis at the 68% confidence level and from the Amoeba best-10 fit, respectively. The sixth column shows the results obtained by running Amoeba over 10 toy catalogues of 700 deg^2, for which the mass function is taken to be Tinker's. The last column shows the Fisher analysis forecast for 1σ errors .

A few results (b)

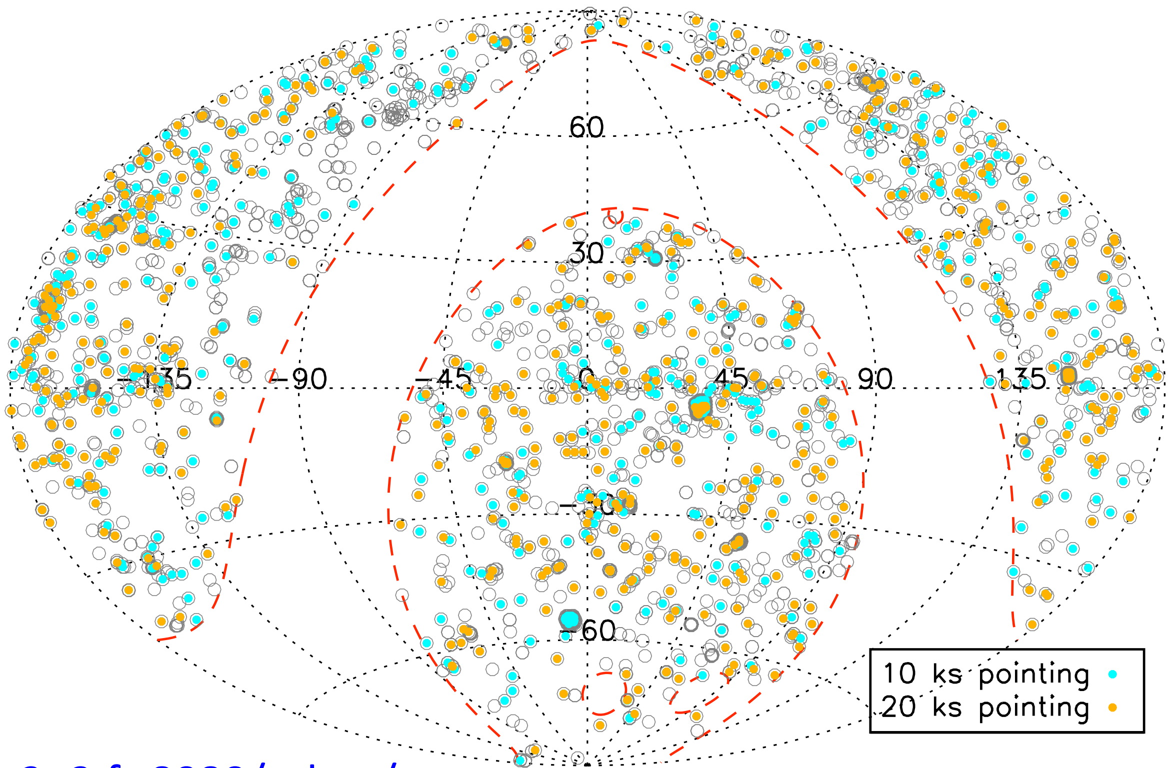
Parameter	MCMC fit	Amoeba *best-10*	Fisher analysis
Ω_m	0.228 ±0.020	0.207	0.23 ±0.025
σ_8	0.876 ±0.073	0.814	0.83 ±0.156
w_0	-0.981 ±0.053	-0.940	-1.00 ±0.065
x_c	0.249 ±0.016	0.258	0.24 ±0.034
σ_{x_c}	0.500 ±0.019	0.504	0.50 ±0.023
α_{MT}	1.538 ±0.096	1.453	1.49 ±0.169
γ_{MT}	0.268 ±0.136	0.162	0.00 ±0.244
C^{MT}	0.502 ±0.140	0.490	0.46 ±0.297
σ_{MT}	0.258 ±0.133	0.112	0.10 ±0.206

Table 7. Fit results (z–CR-HR-r_c) over the 711 deg^2 Aardvark C1 CLEAN catalogue when cosmological and cluster physics parameters are let free.

4. Summary and conclusion

X-CLASS

- Extending the XXL methodology to ~ 4200 observations selected in the XMM archive (as of August 2015)
  ➔ ~ 2500 serendipitous clusters



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

Summary

- XXL DR2 : 20 articles; 365 clusters and 26 000 AGN
  - 6 papers led or co-led by French institutes

- First self-consistent comological analysis of XMM serendipitous clusters

- Already improves the Planck constraints on *w*
- *For the final analysis, we expect a factor of 3 improvement*
  - *400 clusters; inclusion of the mass information and of* ξ

- Stay tuned for the final release and analysis in 2021 !

FIN