Le survey XMM-LSS

et ses applications cosmologiques

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Plan de l'exposé

- Les amas de galaxies et la cosmologie
- **XMM**
- Le survey XMM-LSS
- Comment détecter les amas?
- Résultats
  - L'echantillon
  - Modéliation
  - Lois d'échelle et évolution

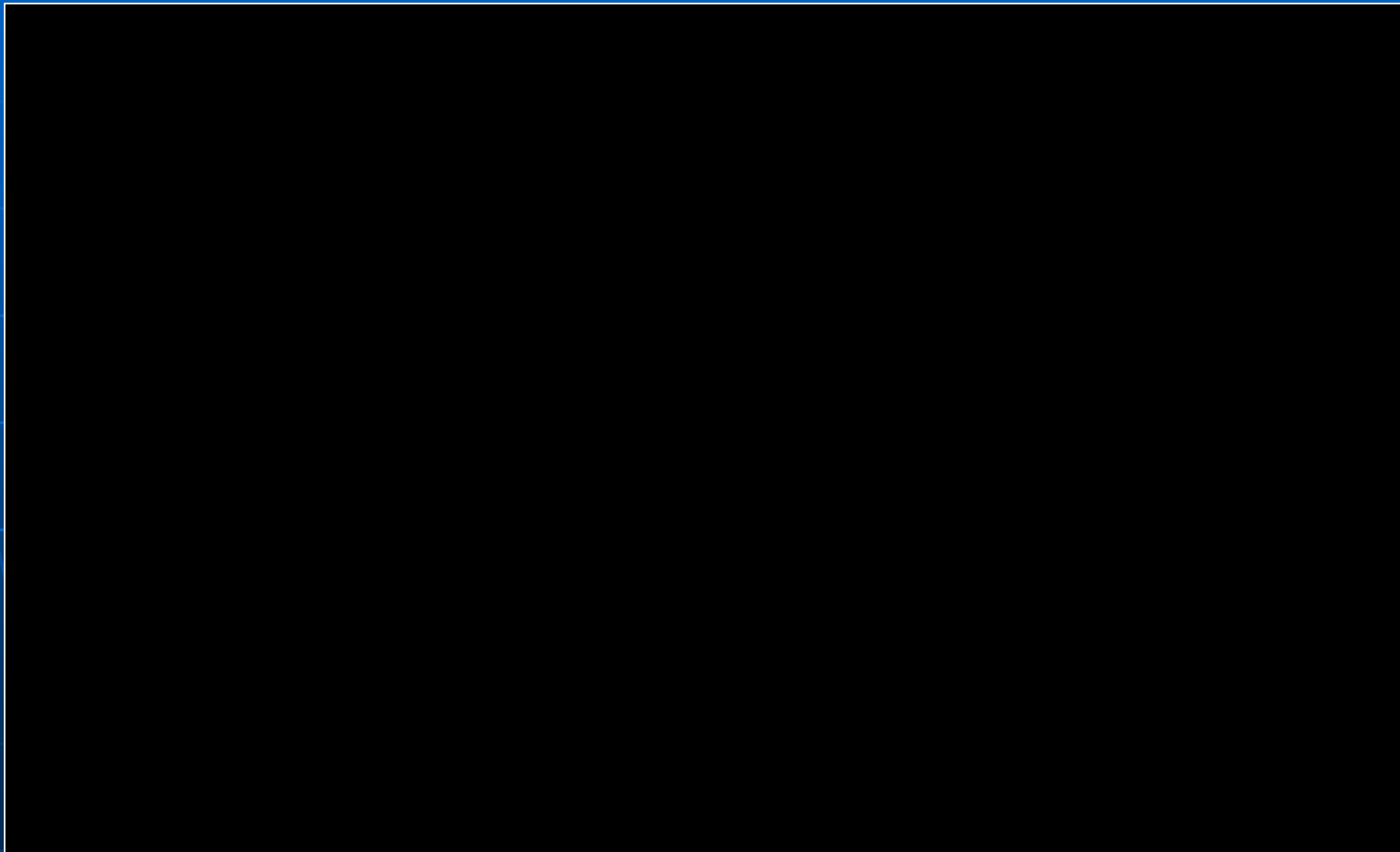
La cosmologie

- Branche de l'astrophysique qui étudie l'univers en tant que "tout"

  (densité, fini-infini, structure, topologie, nature et quantité de matière noire, etc…)

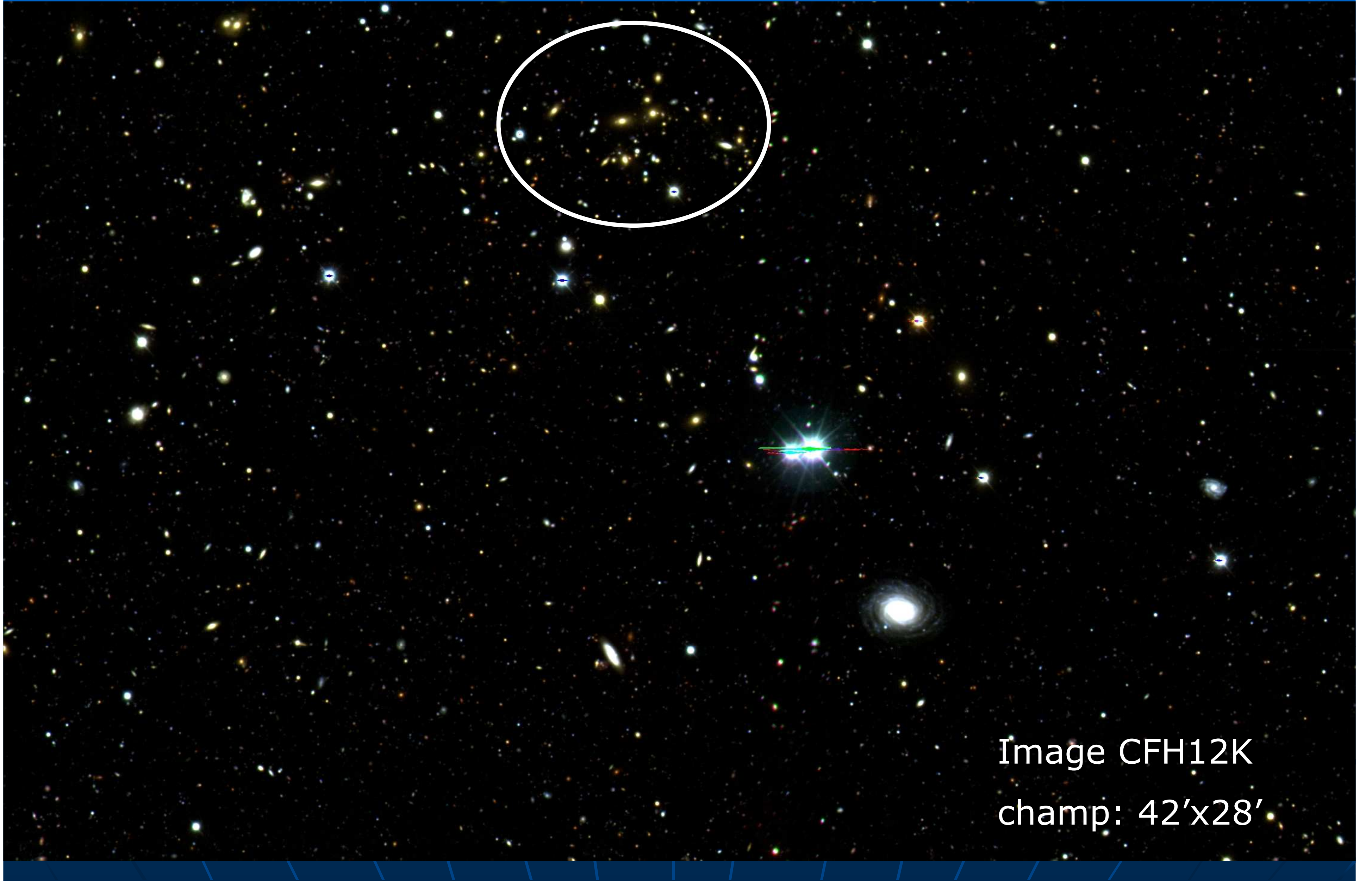
- Science des "champs vides"

Un champ vide:

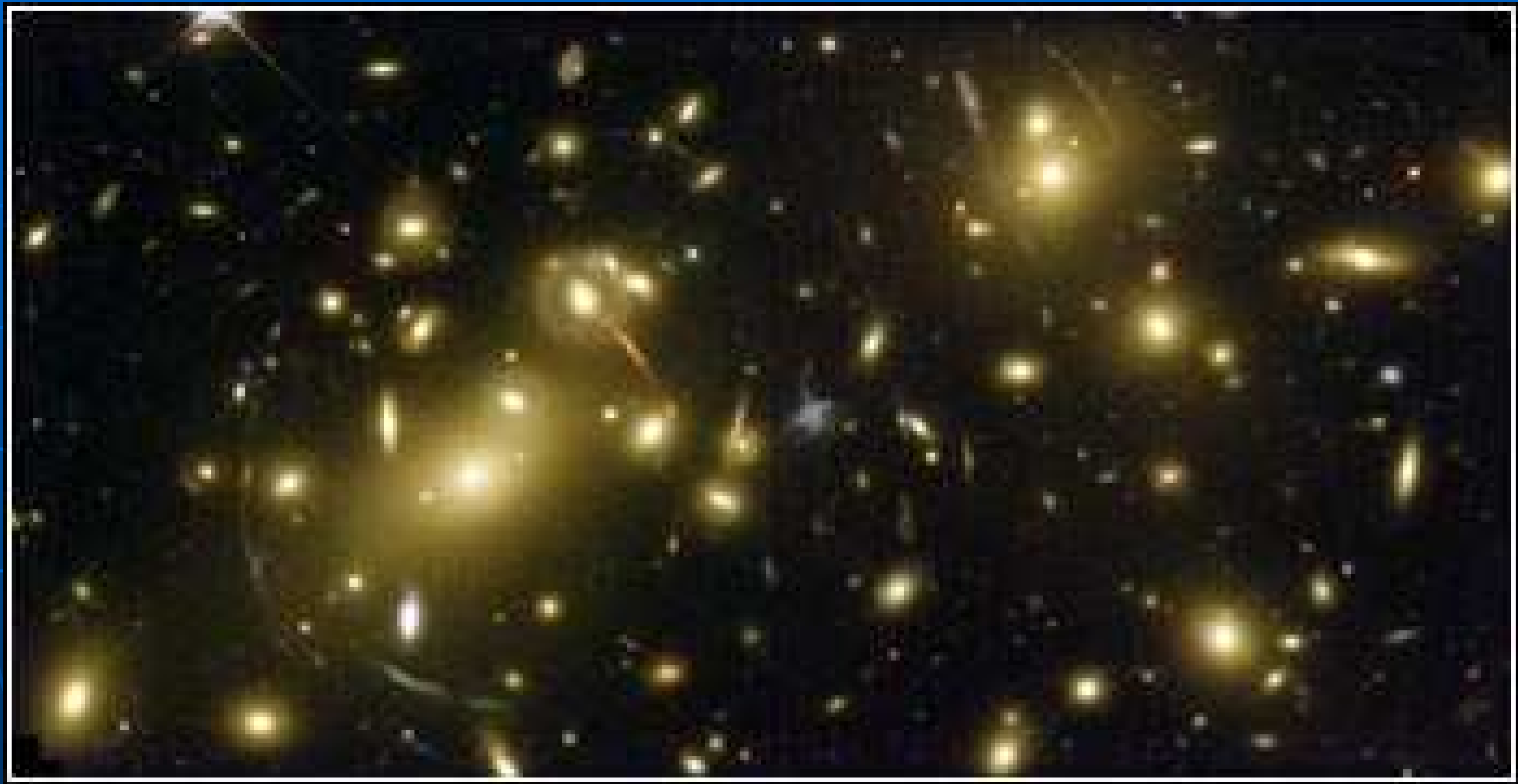


Longues poses avec un grand télescope …… =>

Le ciel dans la bande optique



Clusters of galaxies

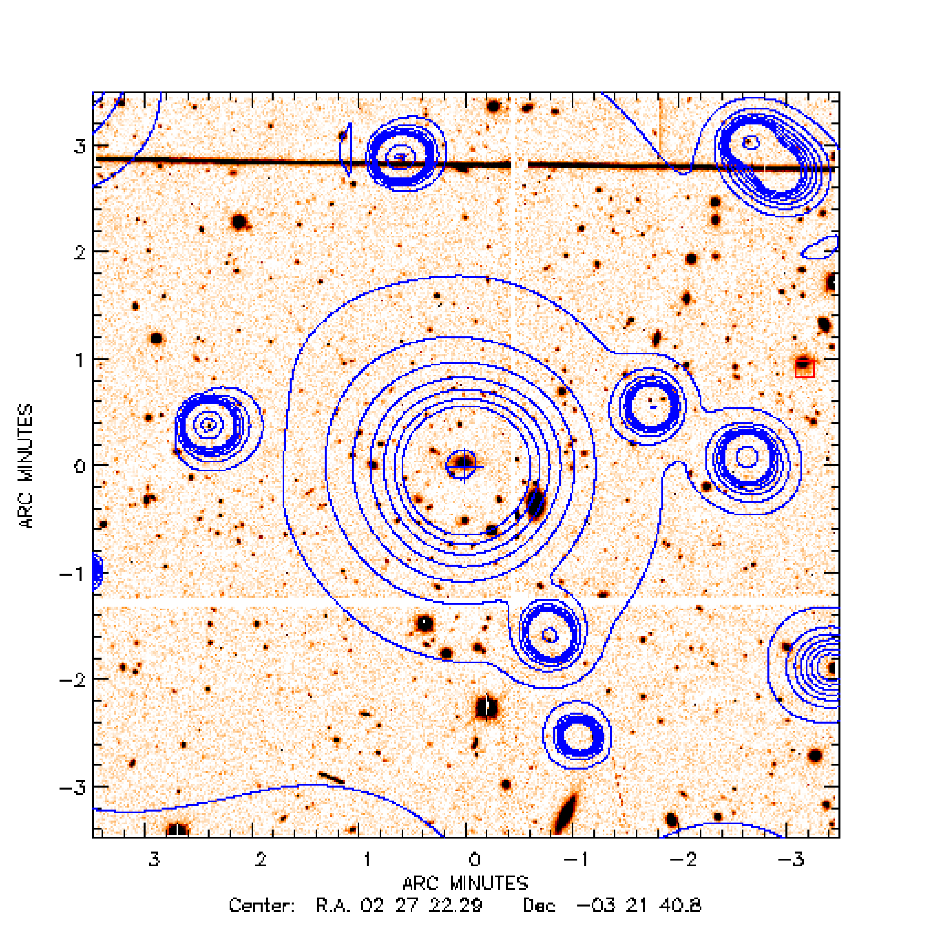


Center of Abell 2218 viewed by HST

$z = 0.176$

Dark matter: Zwicky 1933

X-ray emission from clusters



- MASS fractions:
- Dark matter : 80%
- Hot gas : 15%
- Galaxies : 5%

- Theory's pov

A cluster of galaxies = an object with a MASS of ~10^{14} Mo

Orders of Magnitude

Dark matter:

Total Mass	=	10^{13}-10^{16} $M_{\odot}$
Virial radius	=	1 Mpc/h

Diffuse gas:

Density	=	1 ion/liter
Temperature	=	6.10^{6}-2.10^{8} K
		0.5-15 keV
Distribution	=	β-model
Core radius	=	200 kpc/h
L_X (bremsstrahlung)	=	10^{42}-10^{46} erg/s

~ 5 times emptier than the emptiest artificial vacuum
yet hotter than the center of the sun

Petits paradoxes : résumé

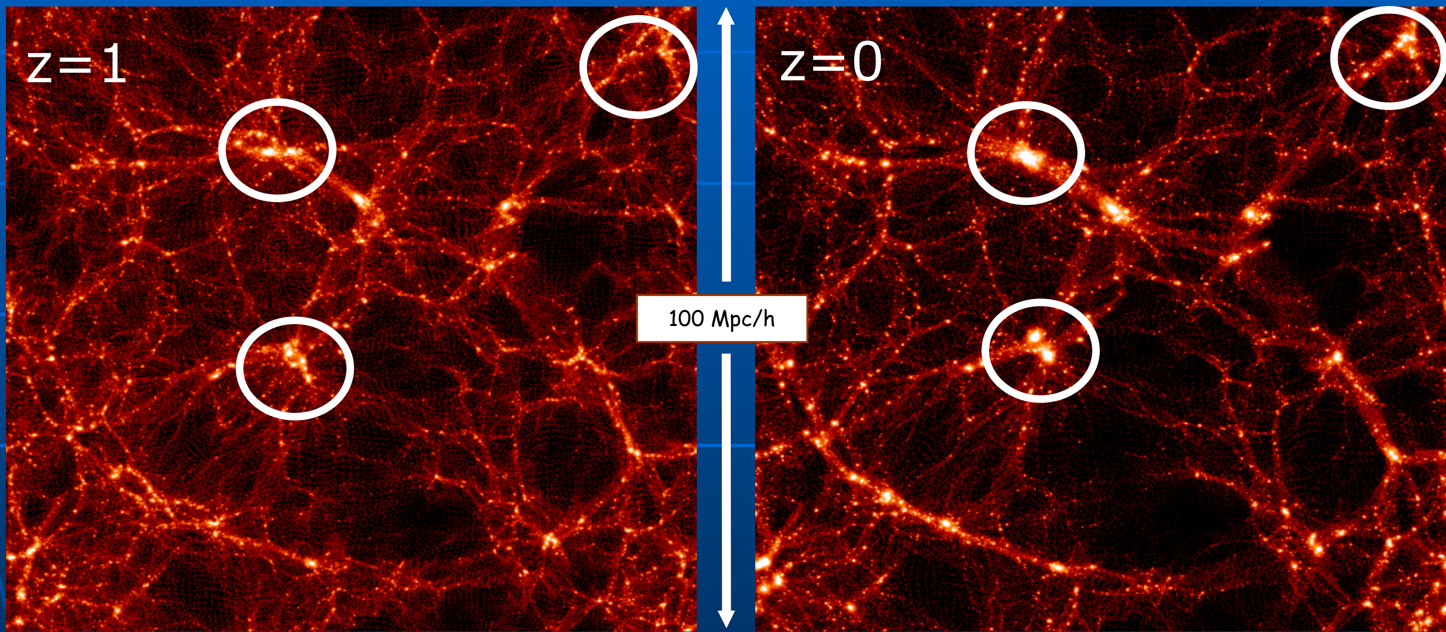
- Dans les amas de galaxies la masse des galaxies est negligeable

- Avec un atome par litre, le milieu intra-amas est 5 fois plus vide que le vide le plus parfait obtenu sur terre…mais la masse de l'IGM d'un amas est ~10^{14} Mo

- Nous collectons ~ 1 photon de l'IGM par minute pour nos amas avec XMM
  i.e. ~ 100-400 photons en 2h30
  i.e. moins de photons que de galaxies par amas!

Cosmology with clusters $0 < z < 2$

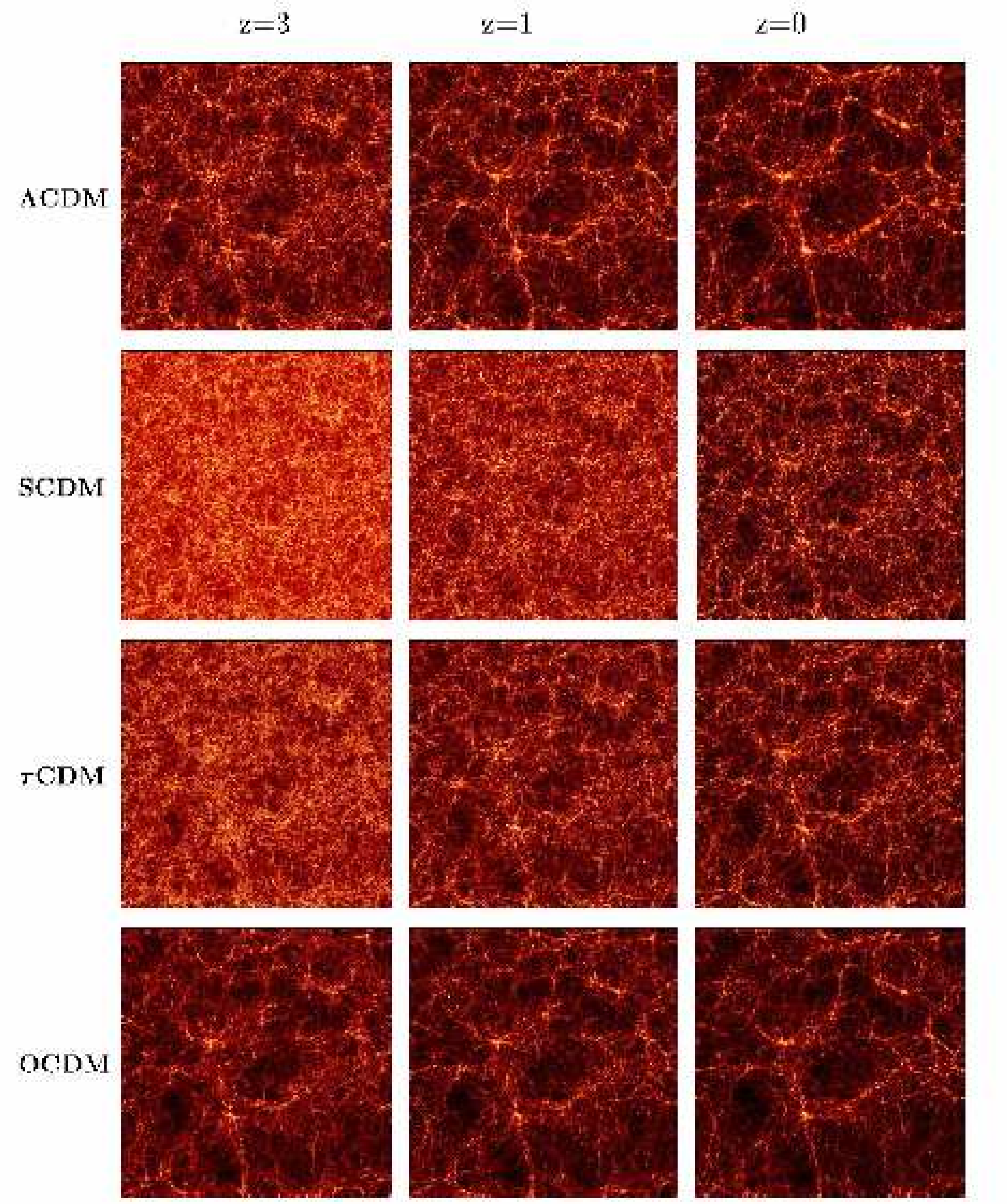
Clusters are the most massive entities of the universe
⇒Trace the nodes of the cosmic structure = potential wells
(much better than galaxies !)



Constraints on cosmology from clusters are complementary to those provided from the CMB and the SN:

They do not rely on the same physical phenomena

Images from the Virgo simulations (Jenkins et al 1998)



The history of cluster fomation depends strongly on the cosmological model

Credits: Joerg Colberg

How does it work ?

- Assuming gaussian initial fluctuations, growth of structures can be computed analytically in the linear regime.

- Non-linearities can be included using simplified models

$\Rightarrow$ Mass and spatial distribution of clusters

Very well tested over numerical simulations but …

We don't directly observe mass

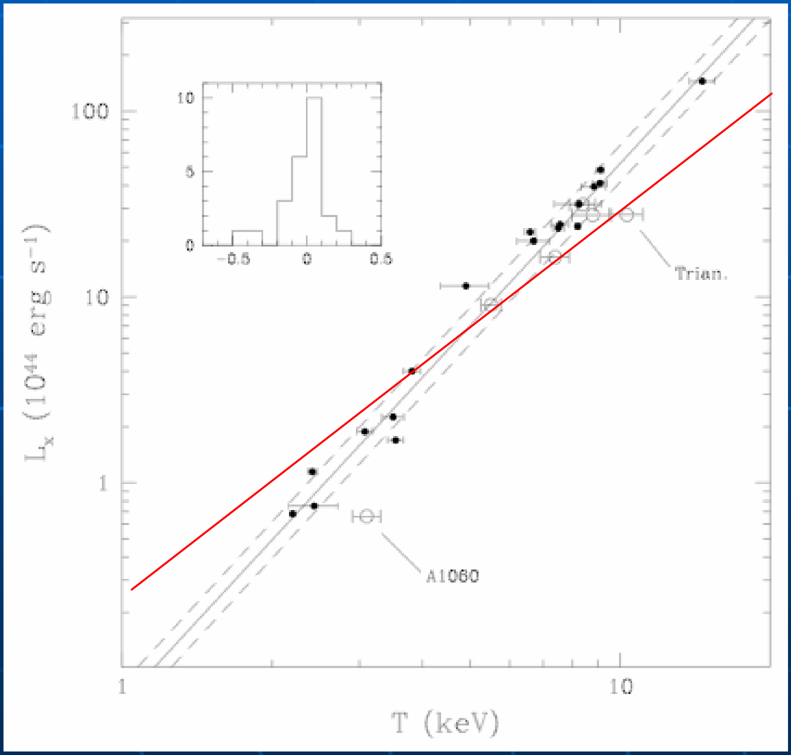
what is M/L ?

Scaling relations

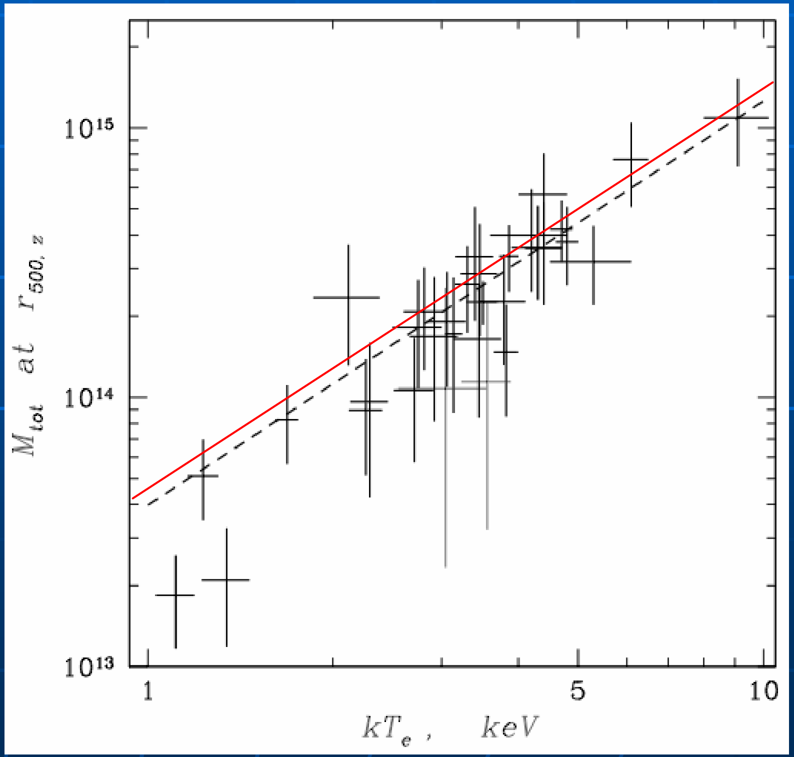
If gravitation only is acting:

clusters are scaled versions of each other (self-similarity)

L



M



T

Arnaud & Evrard (1999)

T

Finoguenov et al (2001)

Before XMM/Chandra

ROSAT All Sky Survey (1990-1997):

⇒ Several flux limited samples:

Wide and shallow :

e.g. REFLEX (450 clusters up to z~0.3)

Narrow and deep:

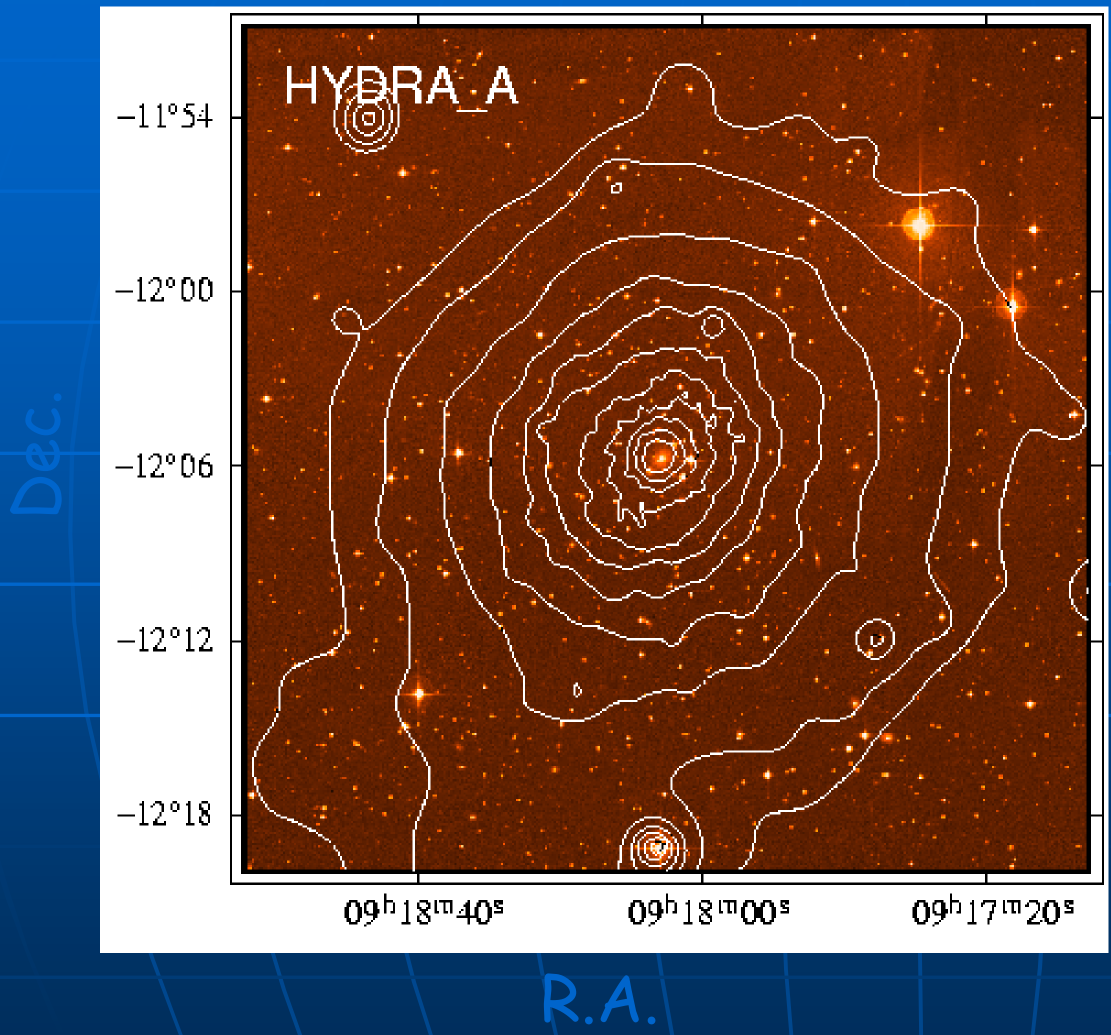
e.g. RDCS (150 clusters to z~0.8)

⇒ almost no groups above z~0.2

GINGA (1988-1991) / ASCA (1993-2000) / BeppoSAX (1996-2002):

⇒ First estimates of scaling relations,
but many pending questions

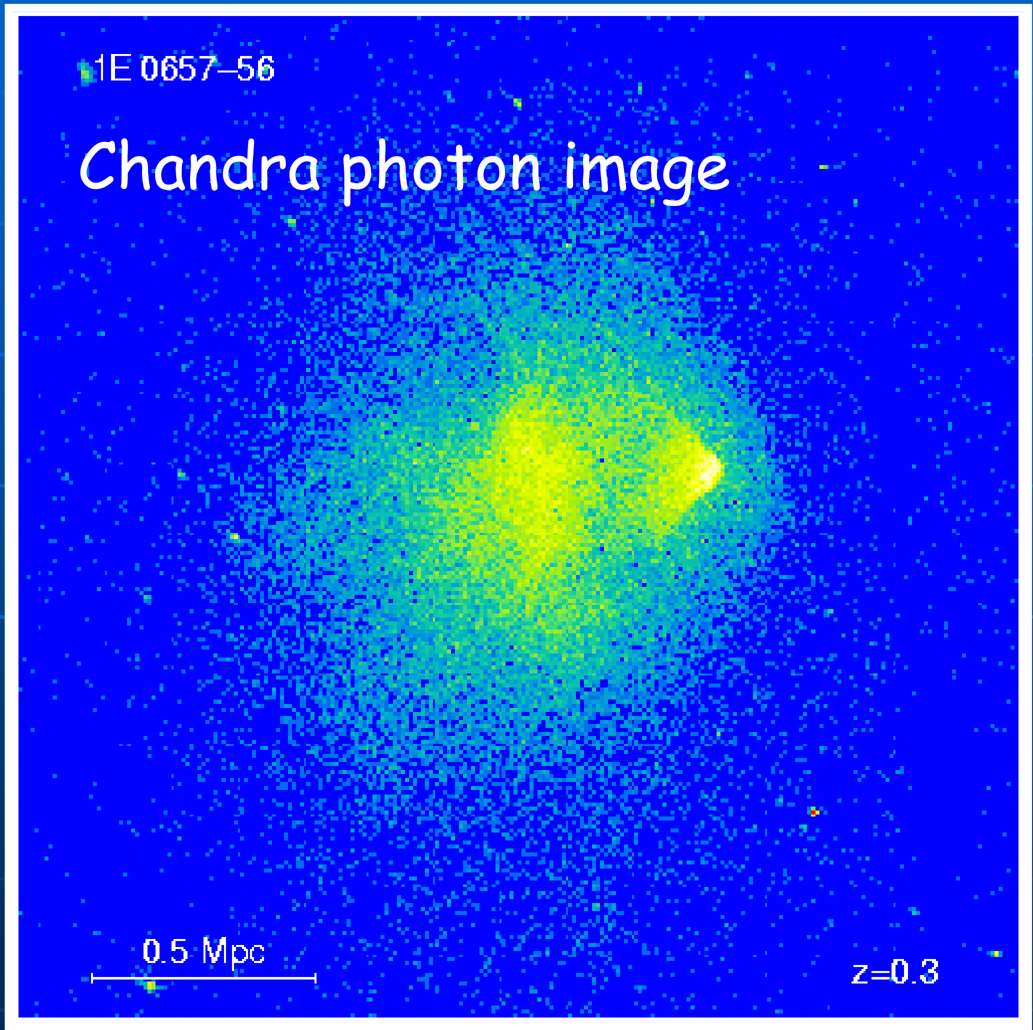
Before XMM/Chandra



- Mostly relaxed systems
- Spherically symetric
- Smooth distribution
- Cooling flows in massive ones

Image: Thomas Reiprich from DSS + ROSAT PSPC

XMM/Chandra era



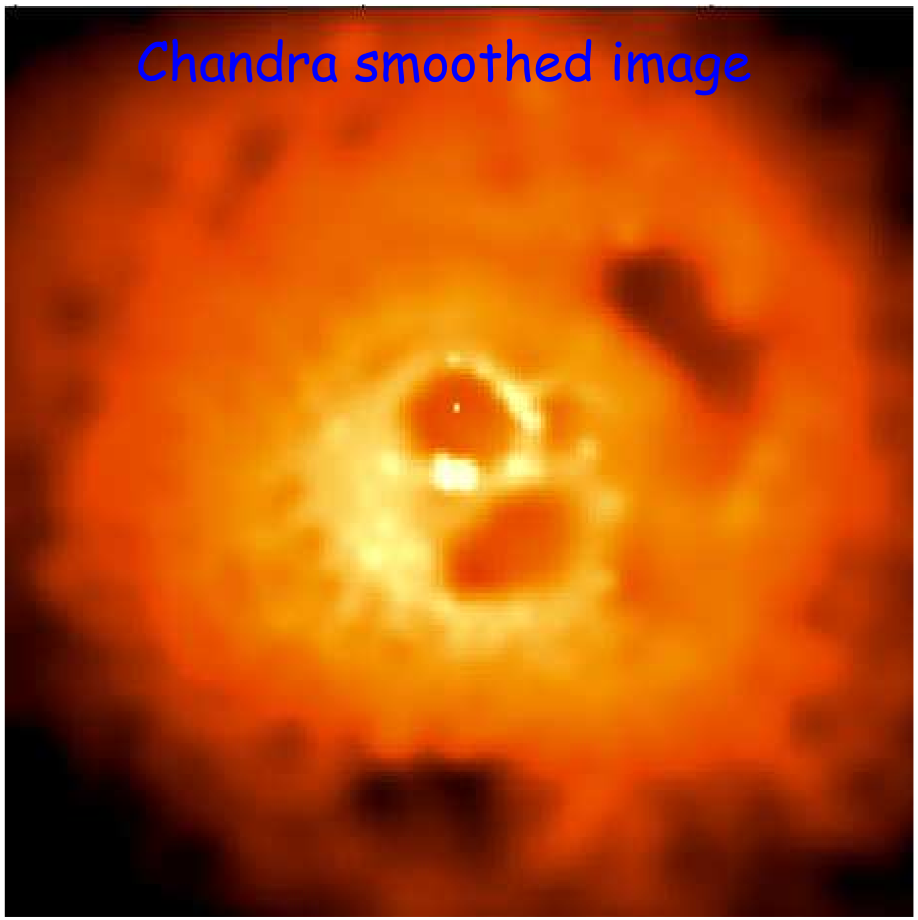
1E0657-56

Markevitch et al. 2002

XMM/Chandra era (2)

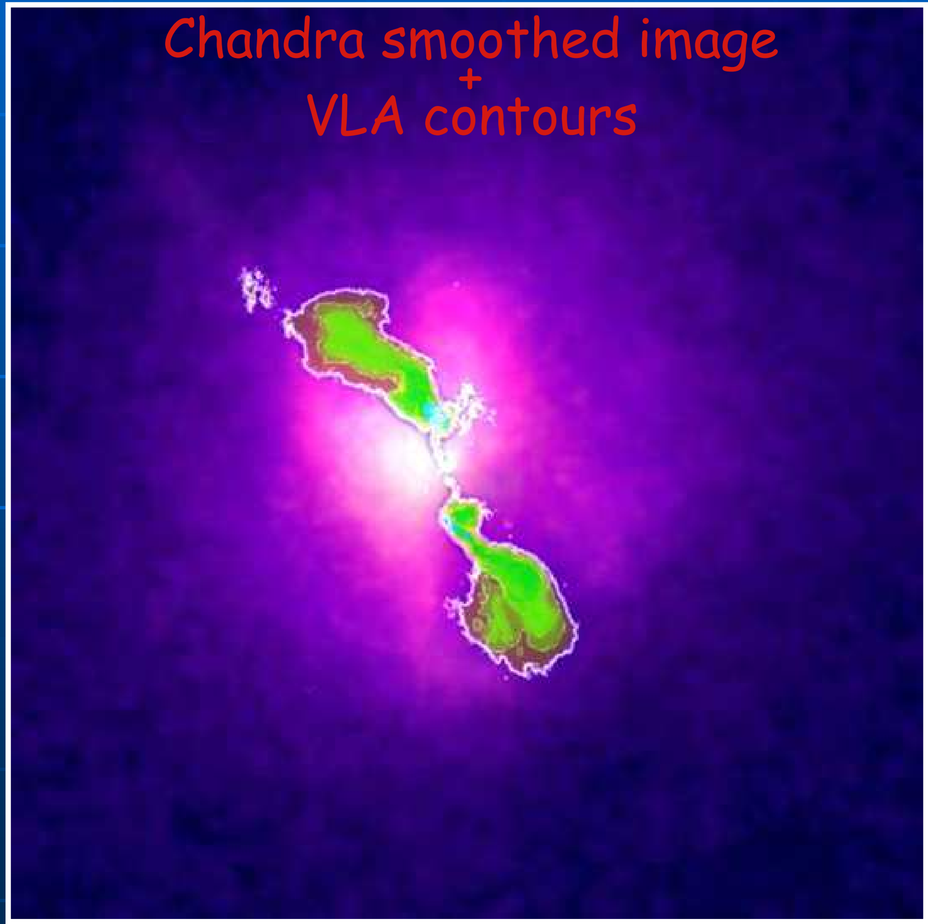
Perseus

Fabian et al. 2002



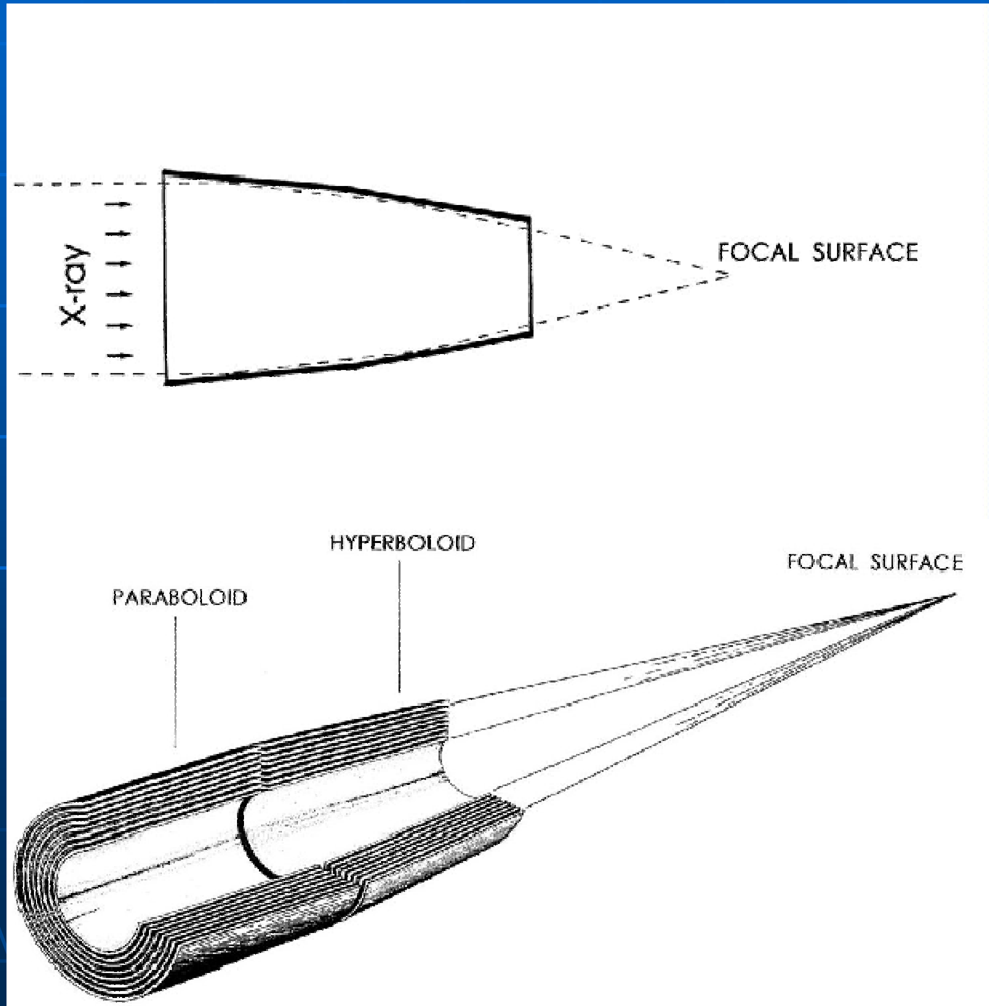
Hydra A

McNamara et al. 2000



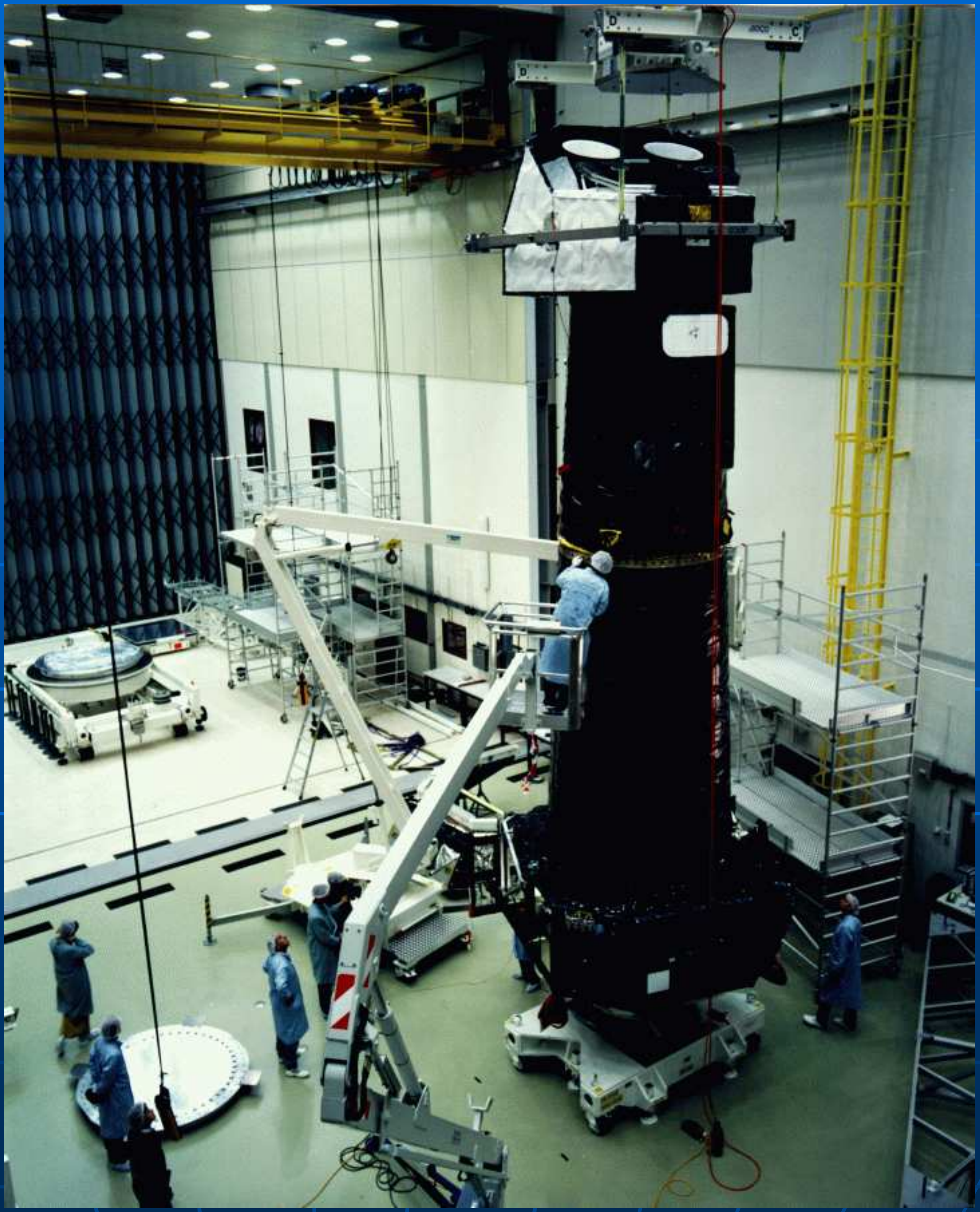
2. XMM

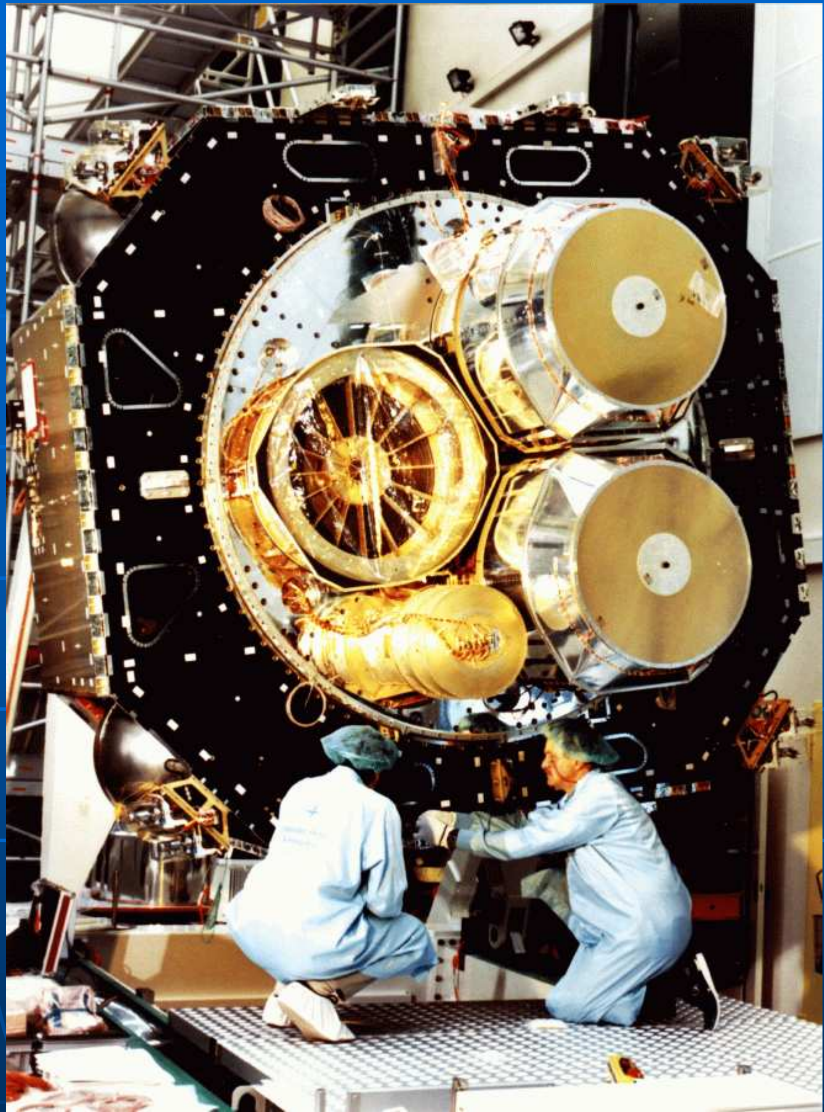
Collecting and focussing X-ray photons: grazing incidence => Wolter telescope



Focal length:

7.5 m



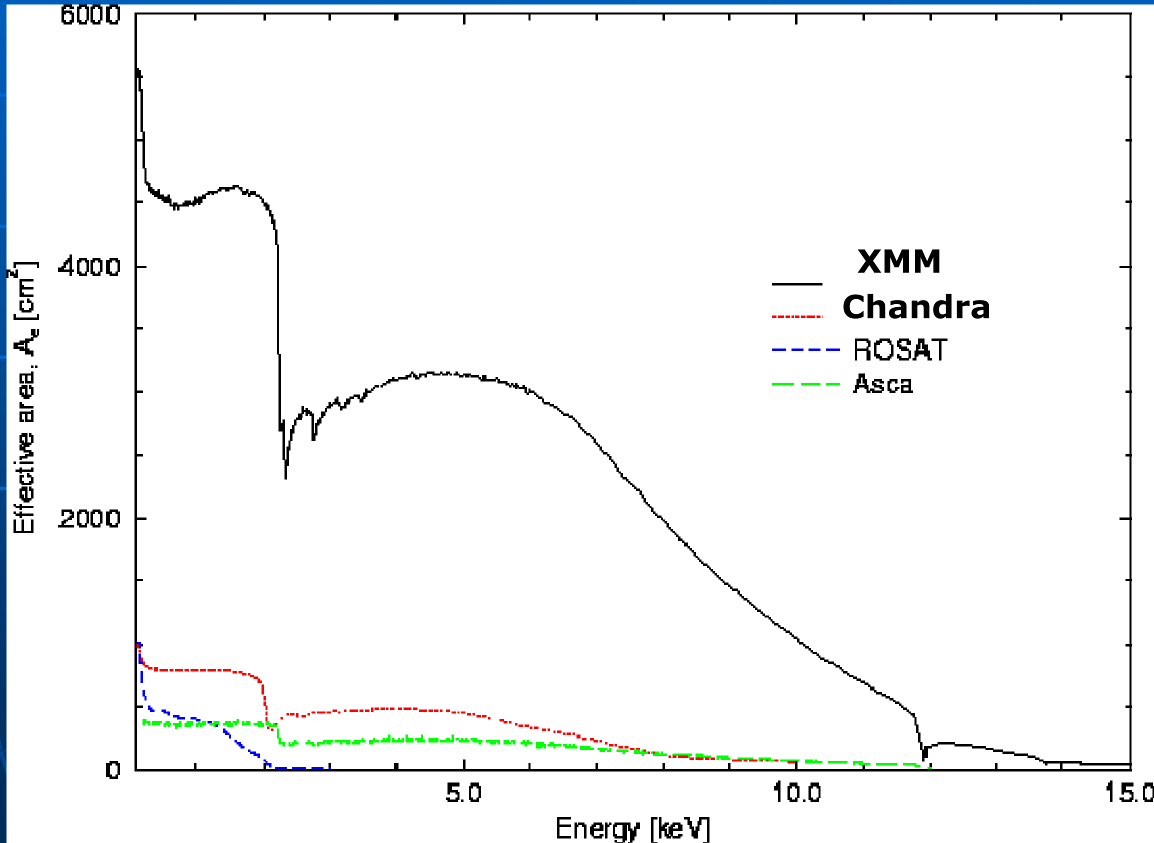


58 nested mirror shells

3 X-ray telescopes

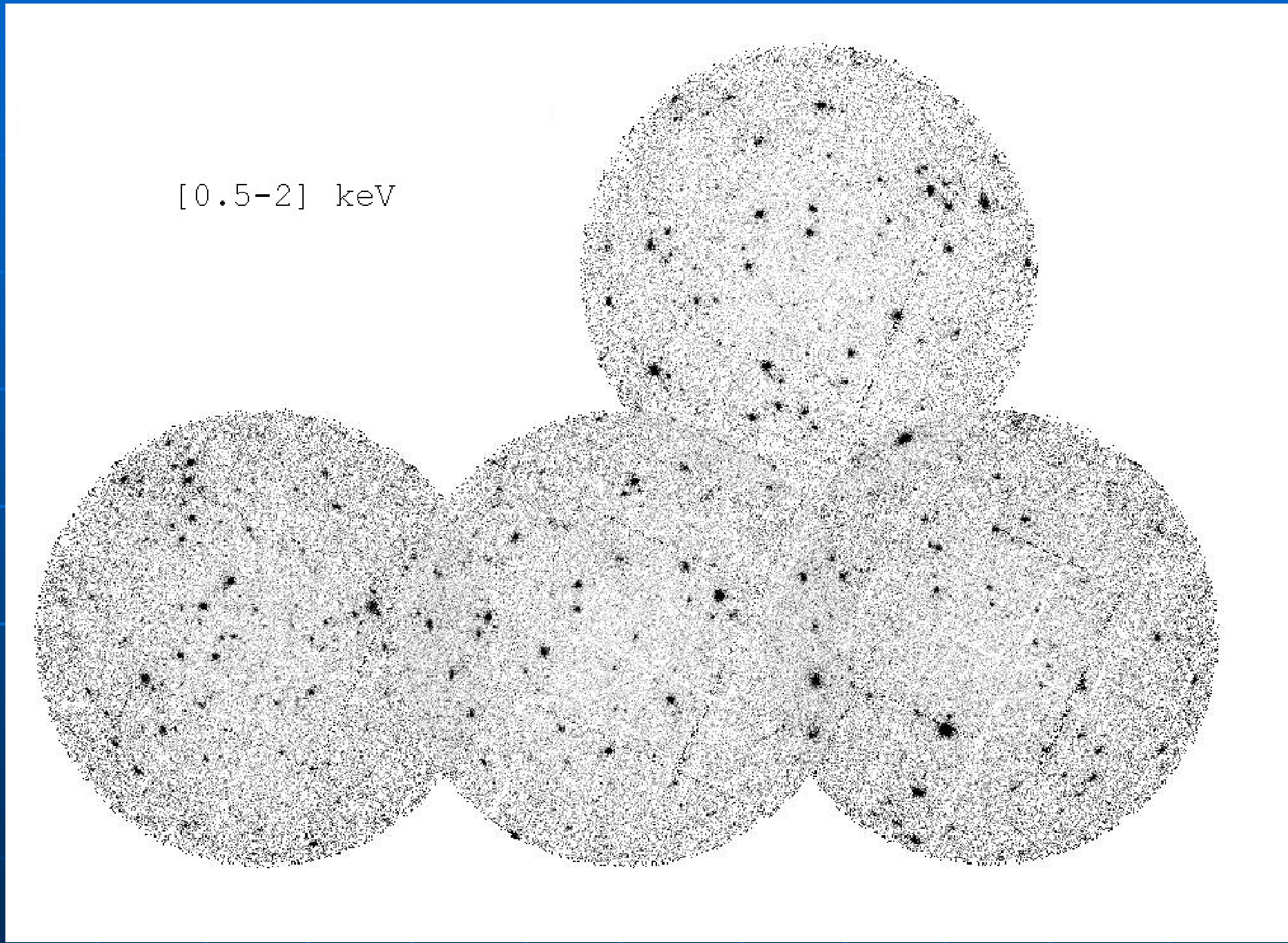
Launched: Dec 1999

XMM sensitivity



125 A **1.25A**

XMM field of view = 30 arcmin



Extragalactic fields …

The XMM eye

FoV = 30 arcmin **on-axis PSF ~ 6'' FWHM**

=> Clusters detected as extended sources out to z ~ 1-2

=> A high galactic latitude field observed by XMM is clean

Only two types of objects:

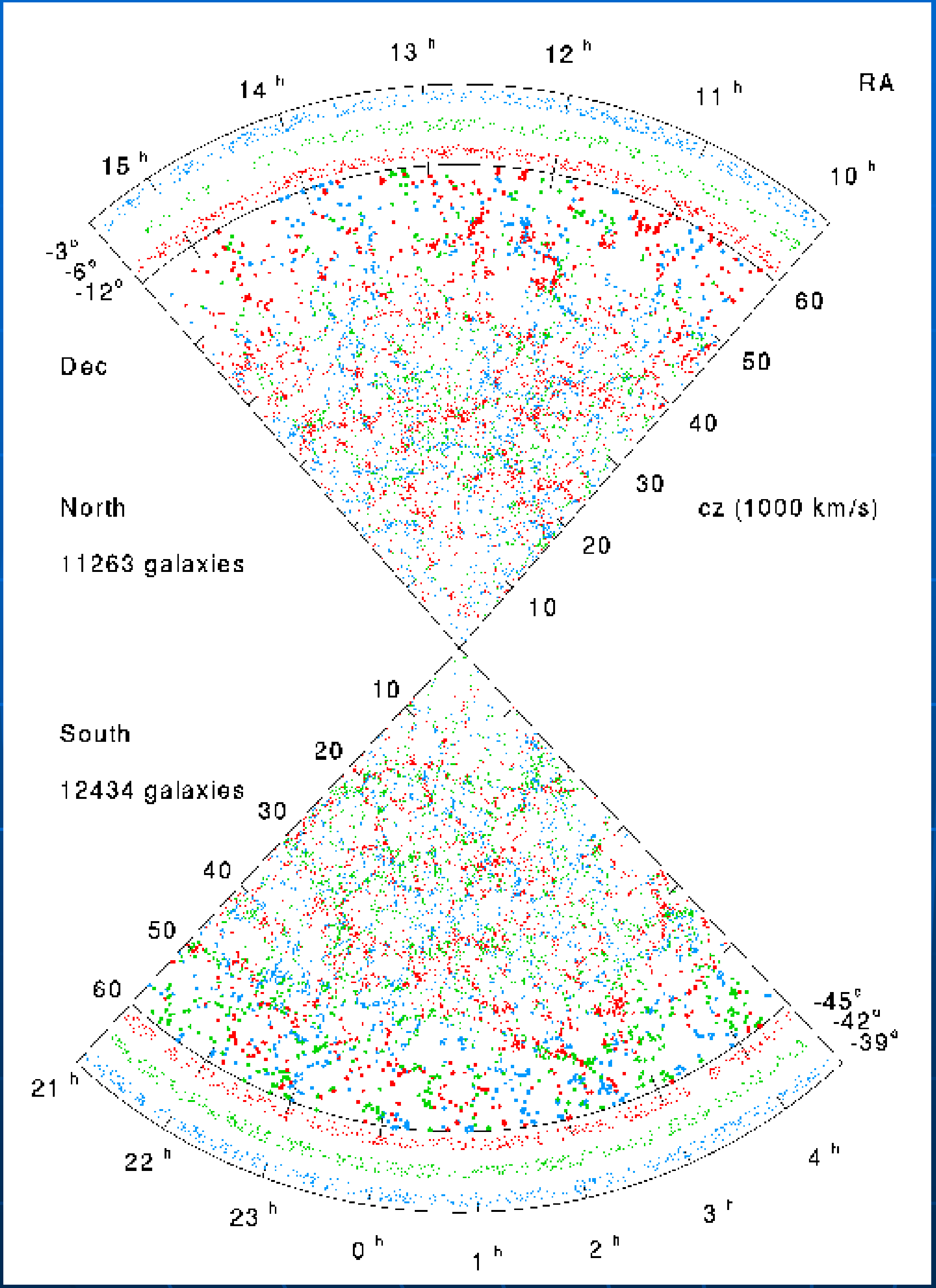
- QSOs: pointlike

- Clusters: extended

Thanks to its

- unrivalled sensitivity
- large field of view
- good PSF

XMM opens a new area for cluster LSS



From galaxy maps (optical)

to

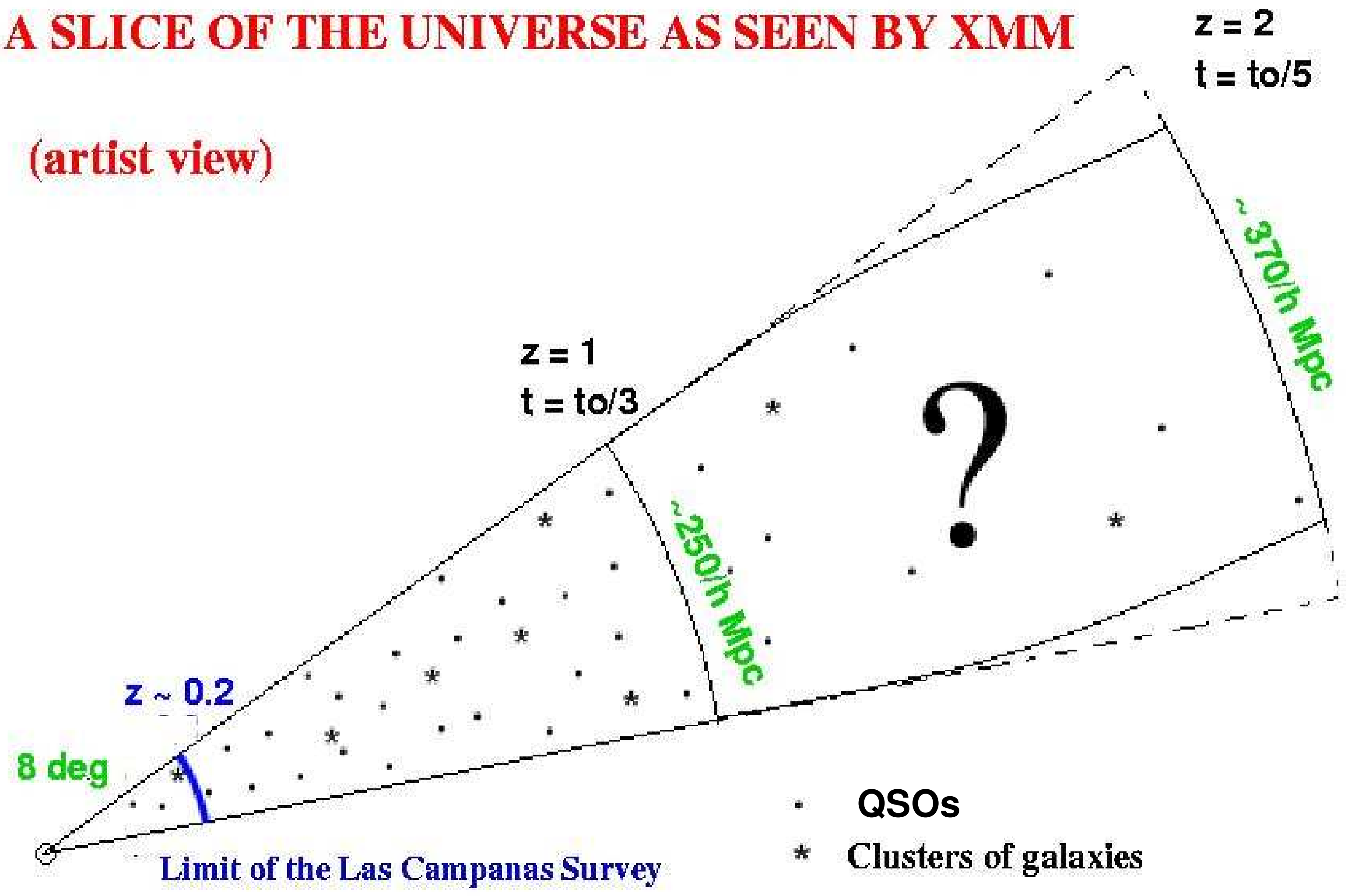
X-ray clusters

=

the deep potential wells of the universe

A SLICE OF THE UNIVERSE AS SEEN BY XMM

(artist view)



3. The XMM-LSS survey

Primary science goals

GOAL

Map the evolution of LSS of the universe out to z = 1-2

with the galaxy cluster and QSO populations

For the first time !

The new generation of X-ray cluster LSS surveys

- **So far** : the REFLEX sample from the ROSAT All Sky Survey . $S = 3\ 10^{-12}$ erg/s/cm^2 *(Böhringer et al)*

  $z < 0.2$

  => the cluster correlation function with ~ 450 clusters

- **Our goal** : determine the cluster correlation function :

  in two redshift bins $0 < z < 0.5$ $0.5 < z < 1$

  each bin containing 450 clusters.

A European/Chilean Consortium

PI : Saclay, France

- Birmingham
- Bristol
- Dublin
- ESO/ Santiago
- Leiden
- Liège
- Marseille (LAM)
- Milano (AOB)
- Milano (IFCTR)
- Munich (MPA)
- Paris (IAP)
- Santiago (Uni. Cato.)

Concept

XMM observations

Optical imaging with the **CFHT Legacy Survey**

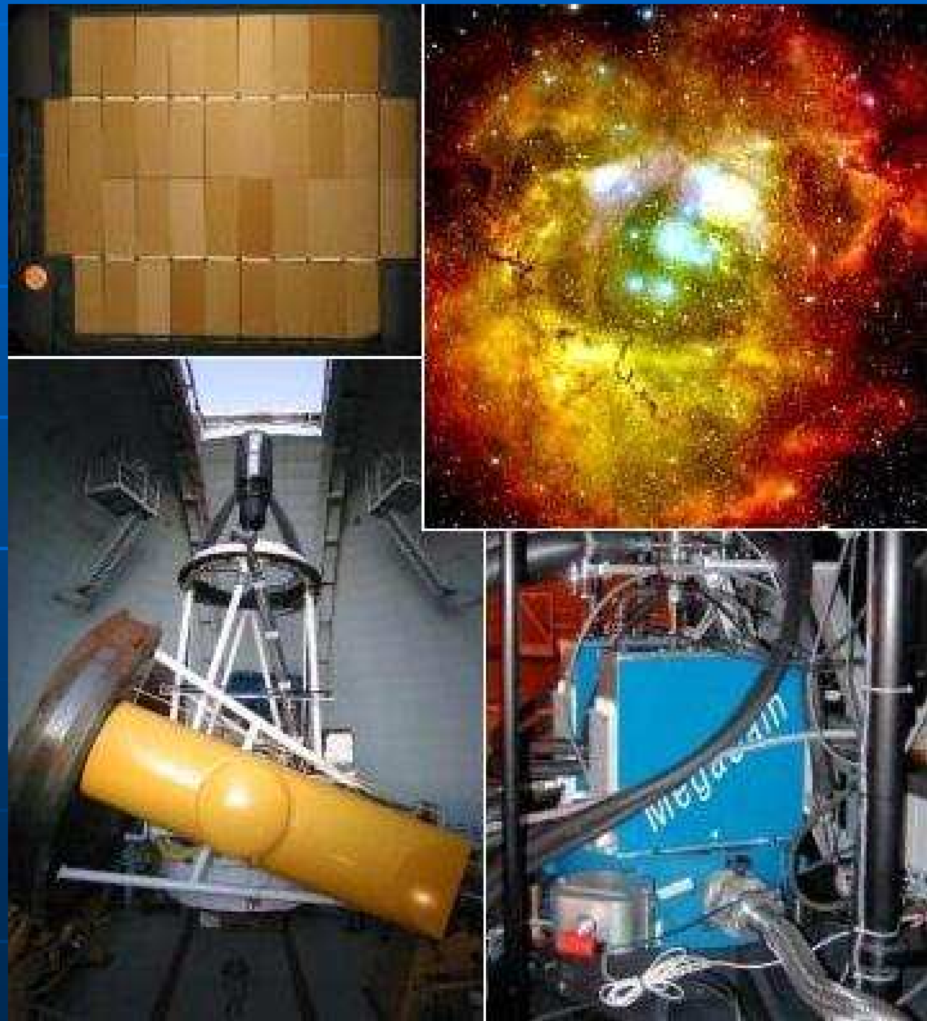
- Optical ID
- Spectroscopic survey with **FORS, VIMOS…**
- **Cluster and QSO ξ**

- **Weak lensing mass determination**

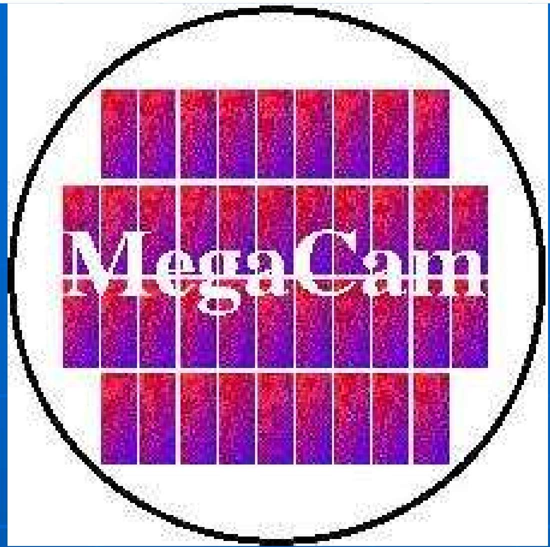
COSMOLOGY

MegaCam at CFHT

Building the mosaic at CEA



The CFHT-LS



1deg FOV Camera for CFHT

Several patches at various depths.

The one centered on XMM-LSS will cover 8 x 9 deg^2 in :

u* = 25.5 g' = 26.5 r'=25.7 i' = 25.5 z'=24.0

Data reduction by

Terapix at IAP/Paris

Numbers of objects

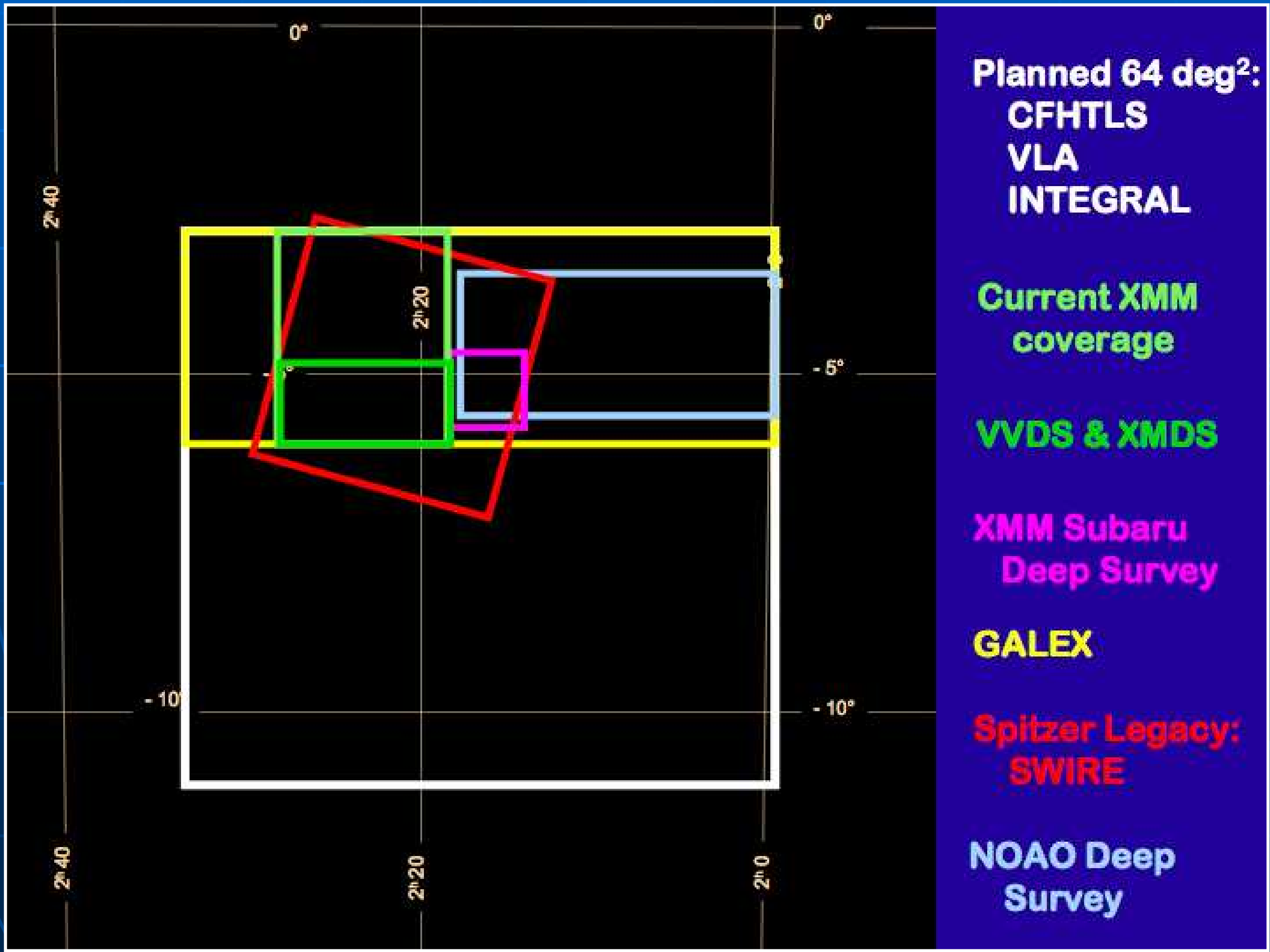
At the survey sensitivity: ~ 3E-15 erg/s/cm2 in [0.5-2] keV

- 300 QSO/AGN (40% z < 1)
- 15 clusters z<~1
- Galaxies + stars

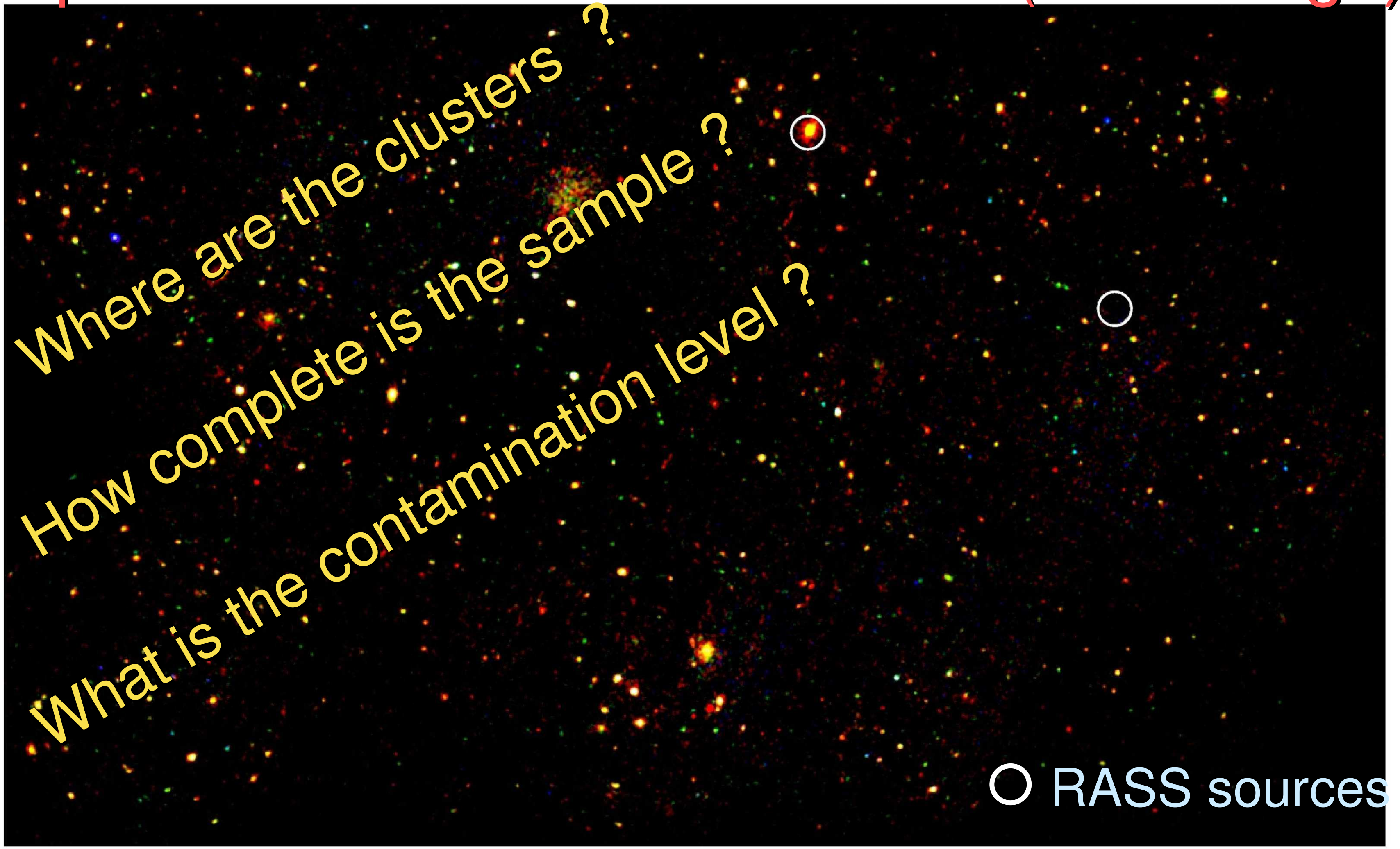
Current multi-λ coverage

X-ray data status: - Received - received - received - ($5deg^2$)

- AO5 Large Program - accepted - (10 deg2)



A piece of the XMM-LSS mosaic (2 x 1 deg^2)



10 ks exp. red [0.3-1] keV green [1-2.5] keV blue [2.5-10]keV

The problem of cluster detection

…

critical for cosmological interpretation !

What’s the problem ?

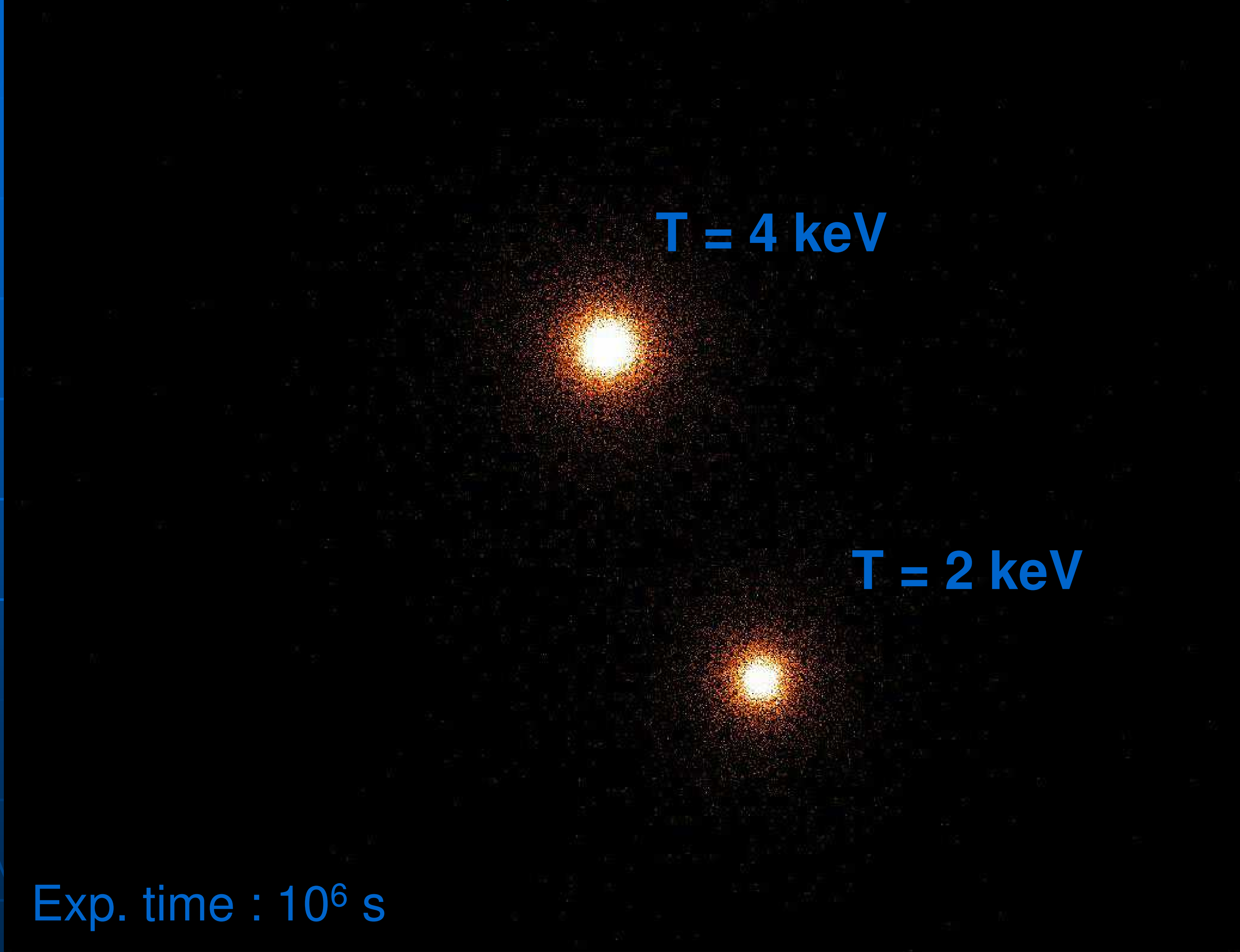
For z in [0.1-1], 20” < Rc < 100”.

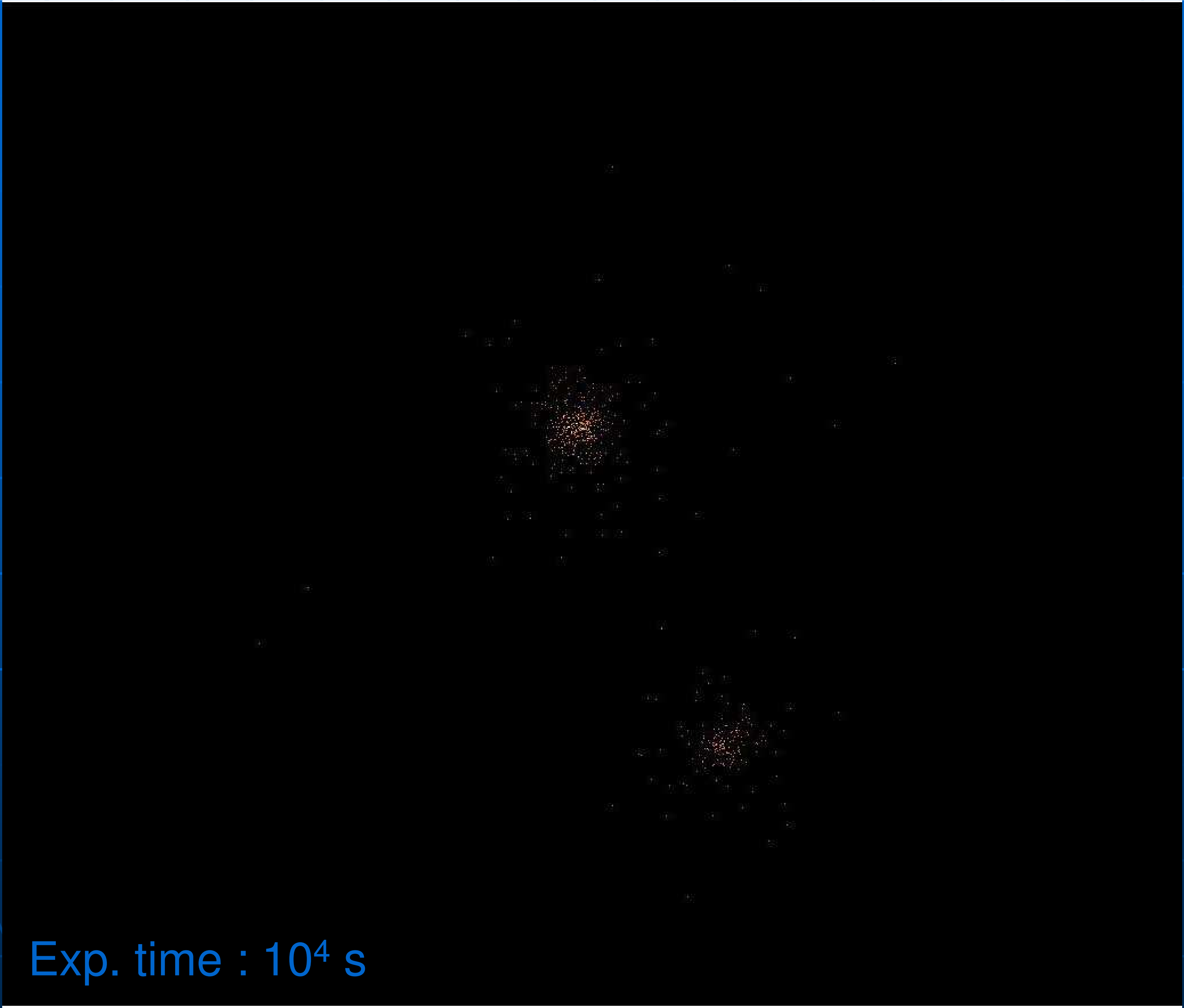
⇒ Detecting extended sources (PSF ~ 6”)

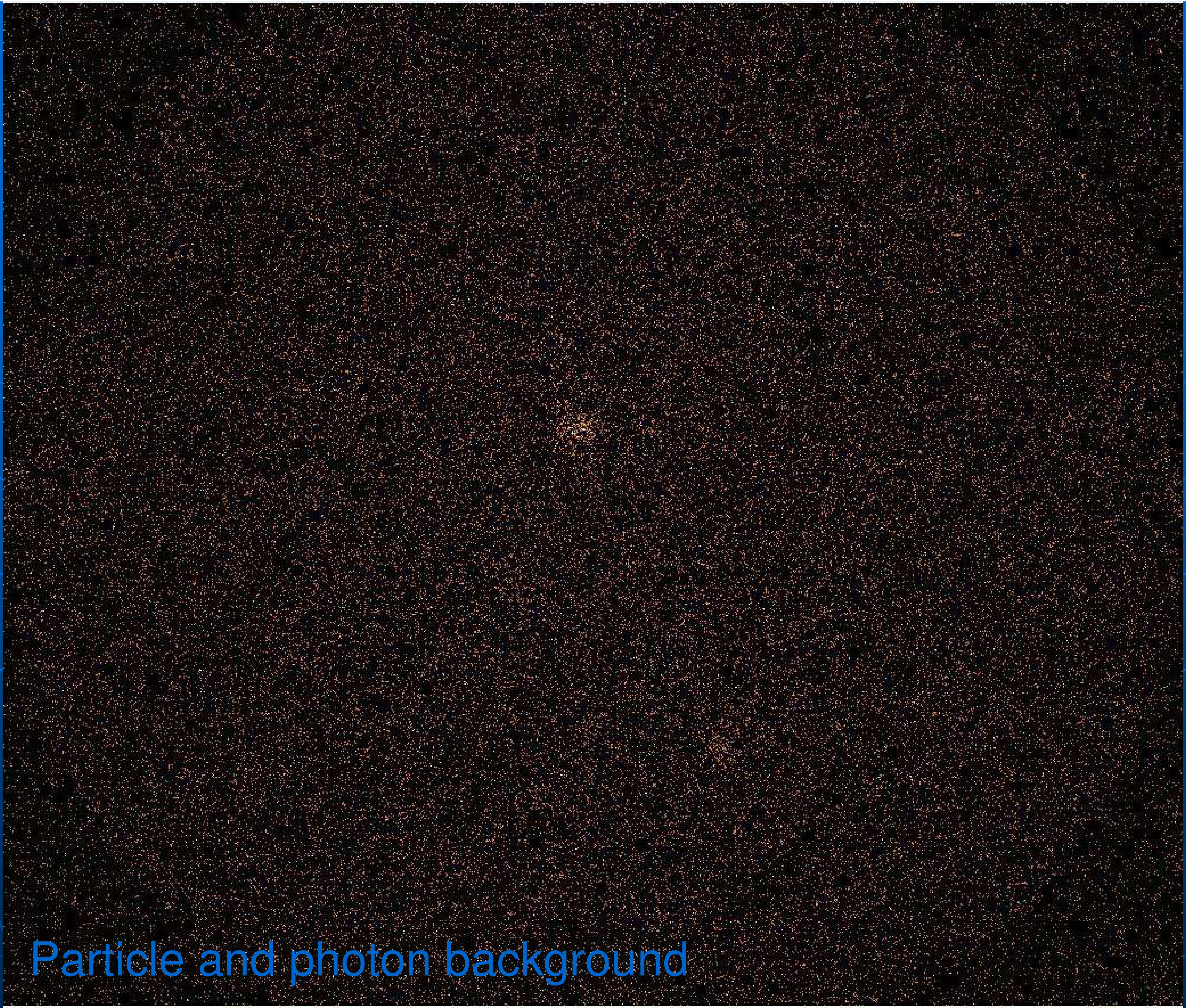
For a typical source, we receive 1 photon / min.

⇒ Detection is a very specific task as we are in the Poisson regime.

Simulation example: two clusters at z=0.5



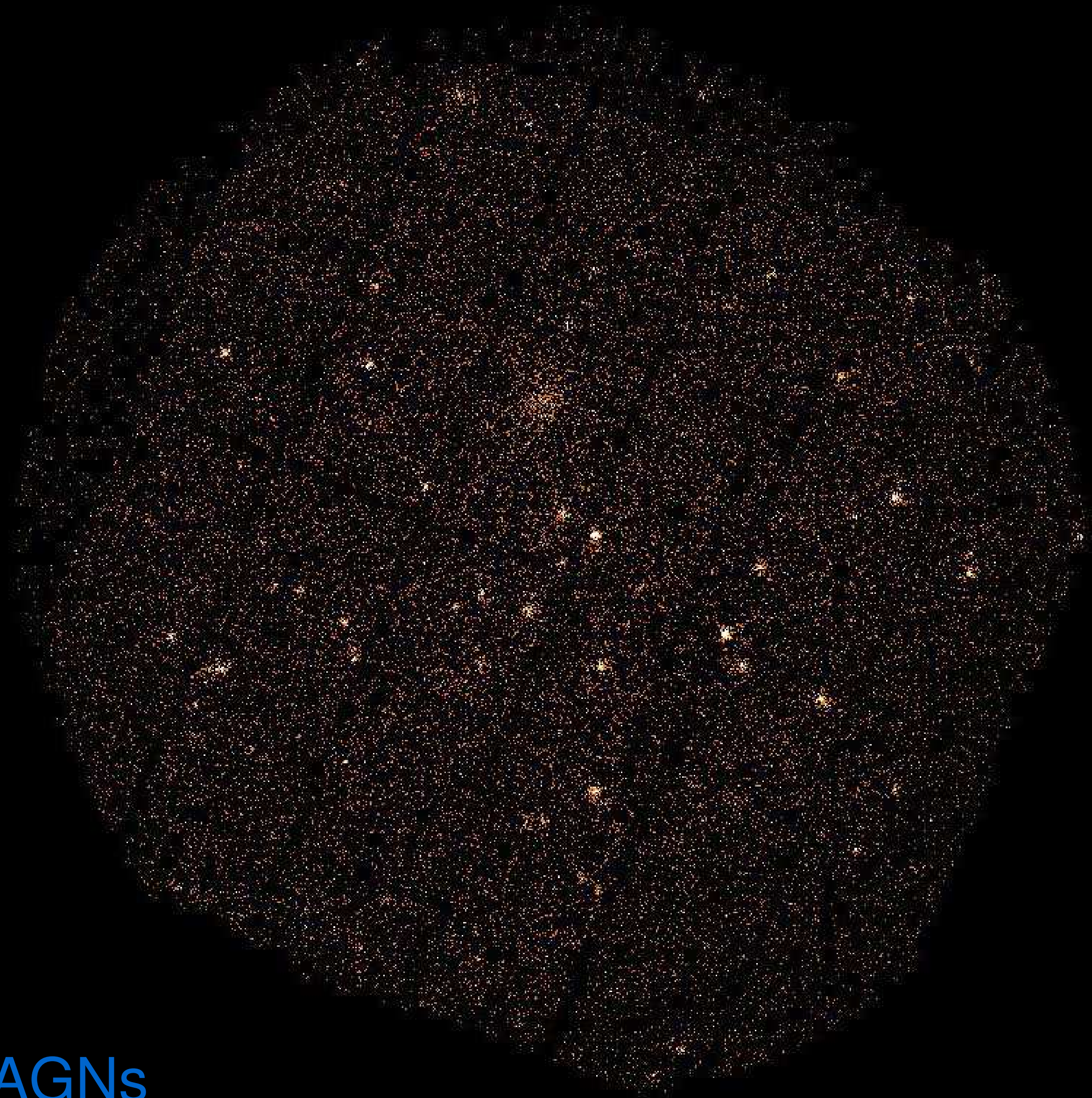

Exp. time : 10⁴ s



Particle and photon background


PSF blurring

Detector Masks



Field AGNs

The XMM LSS pipeline

-1- Image filtering in wavelet space

- source detection at a low level

-2- Maximum likelihood analysis

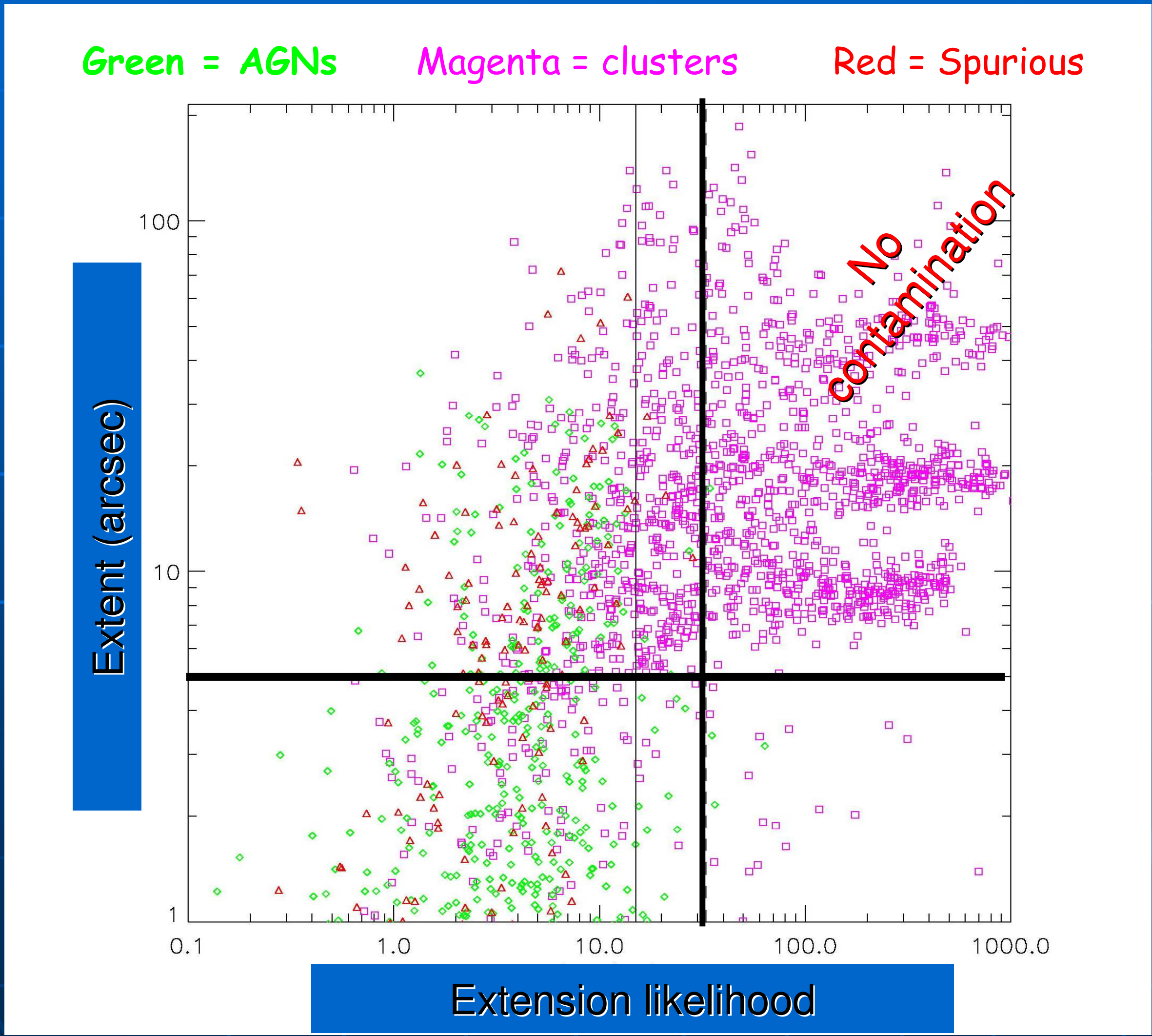
- **Test 2 source models**: **point** & **β-profile**
- Final catalogue:
  - Count-Rate and Extent
  - Detection Likelihood
  - Extent Likelihood
  - ... etc

Designed and tested using extensive in-situ simulations

Pacaud et al 2006

The cluster selection process

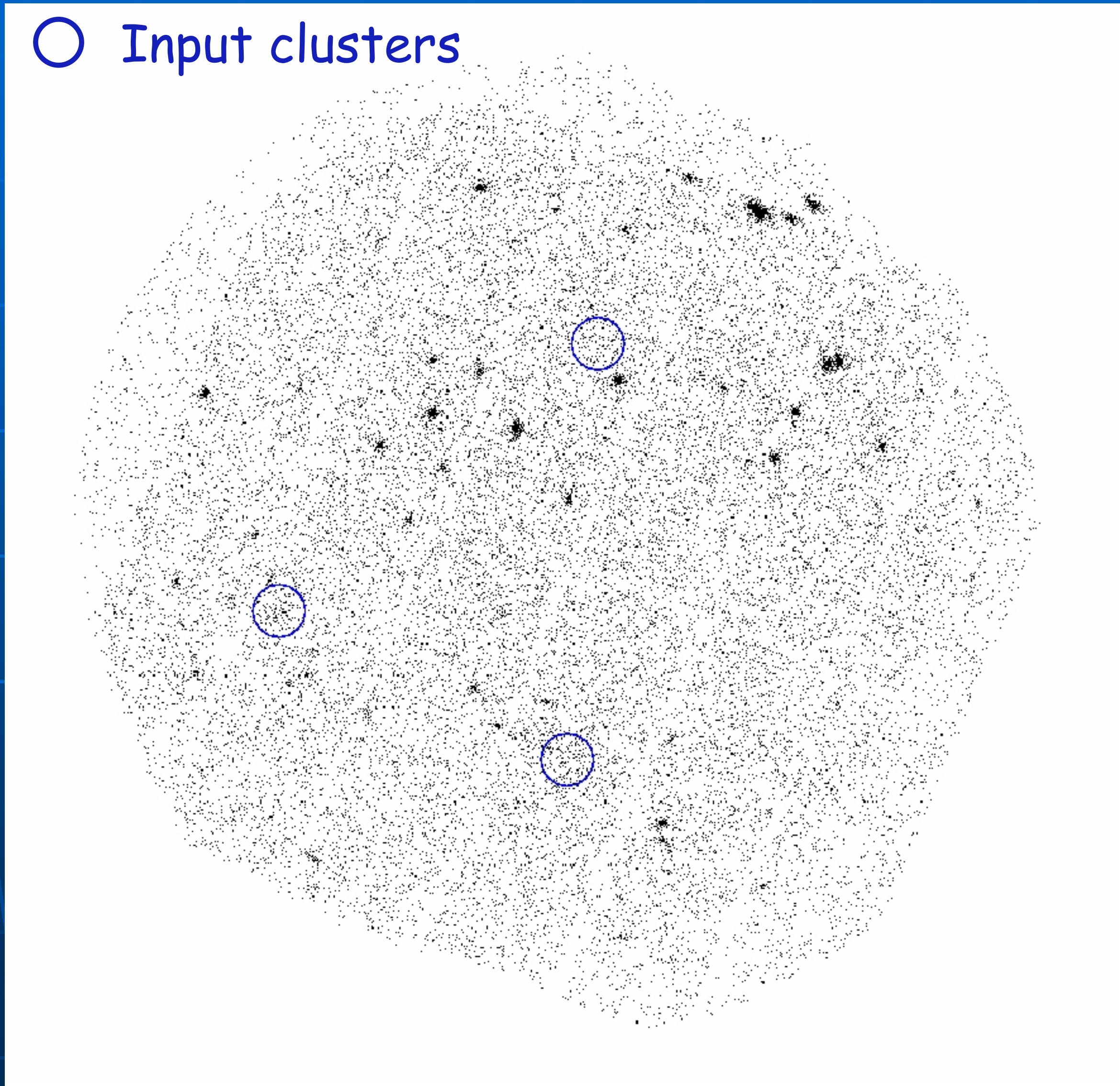
3 classes of extended sources



- Class 1 (C1):
  ~ 7/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

Illustration: with limiting cases!



3 clusters

core radius = 50”

nb of photons

200 , 300, 500

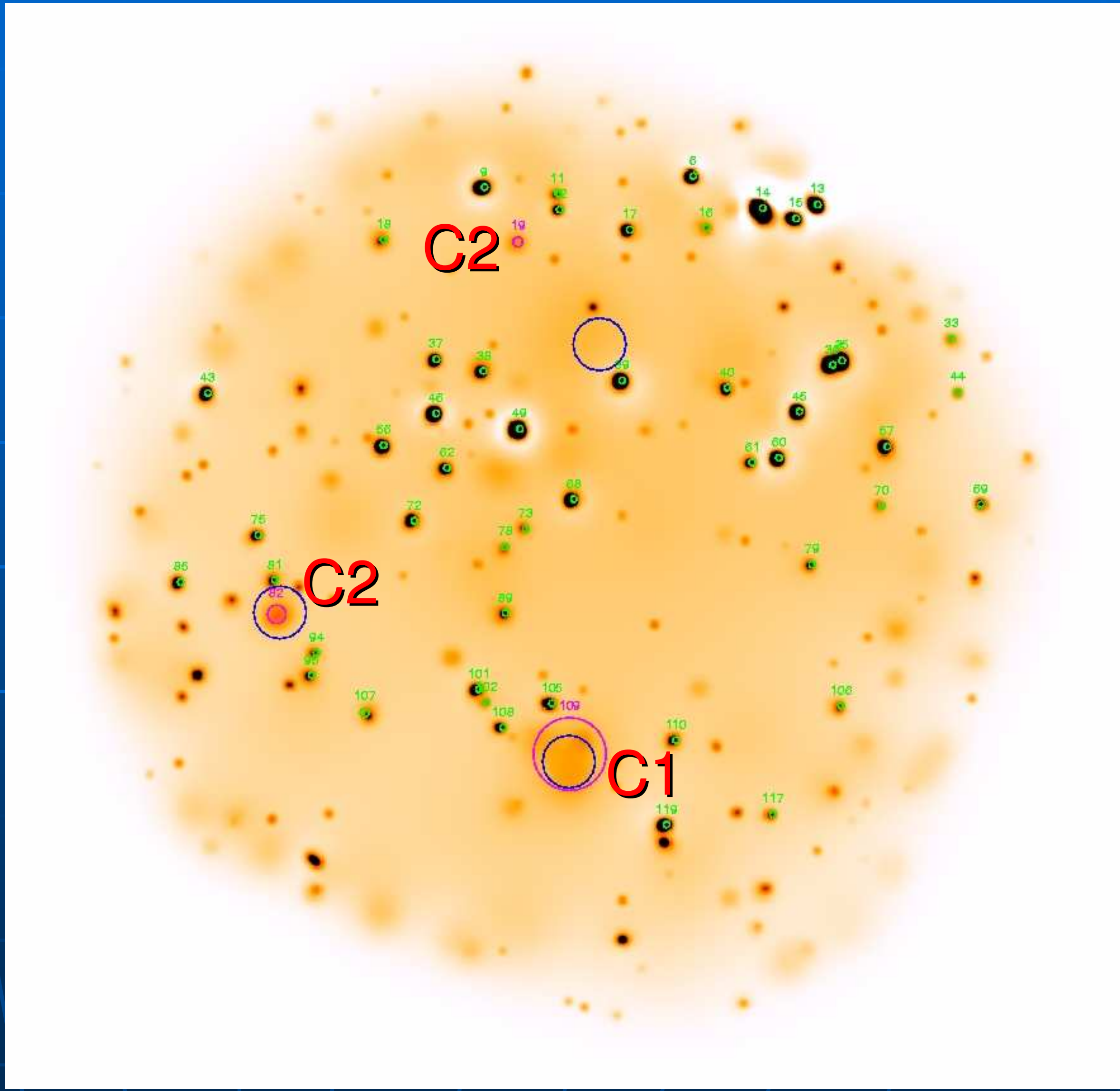
x vignetting

Result of the likelihood fit

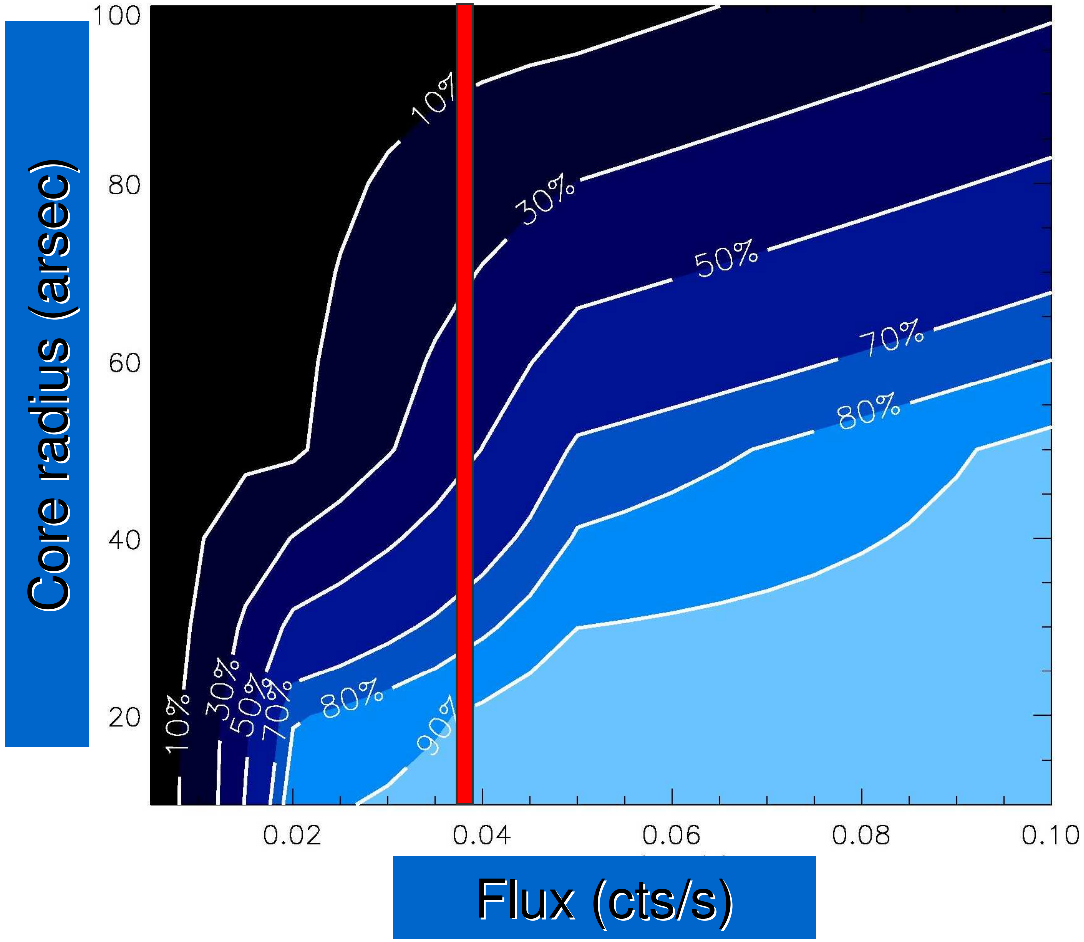
Input clusters

Detected AGNs

Detected clusters



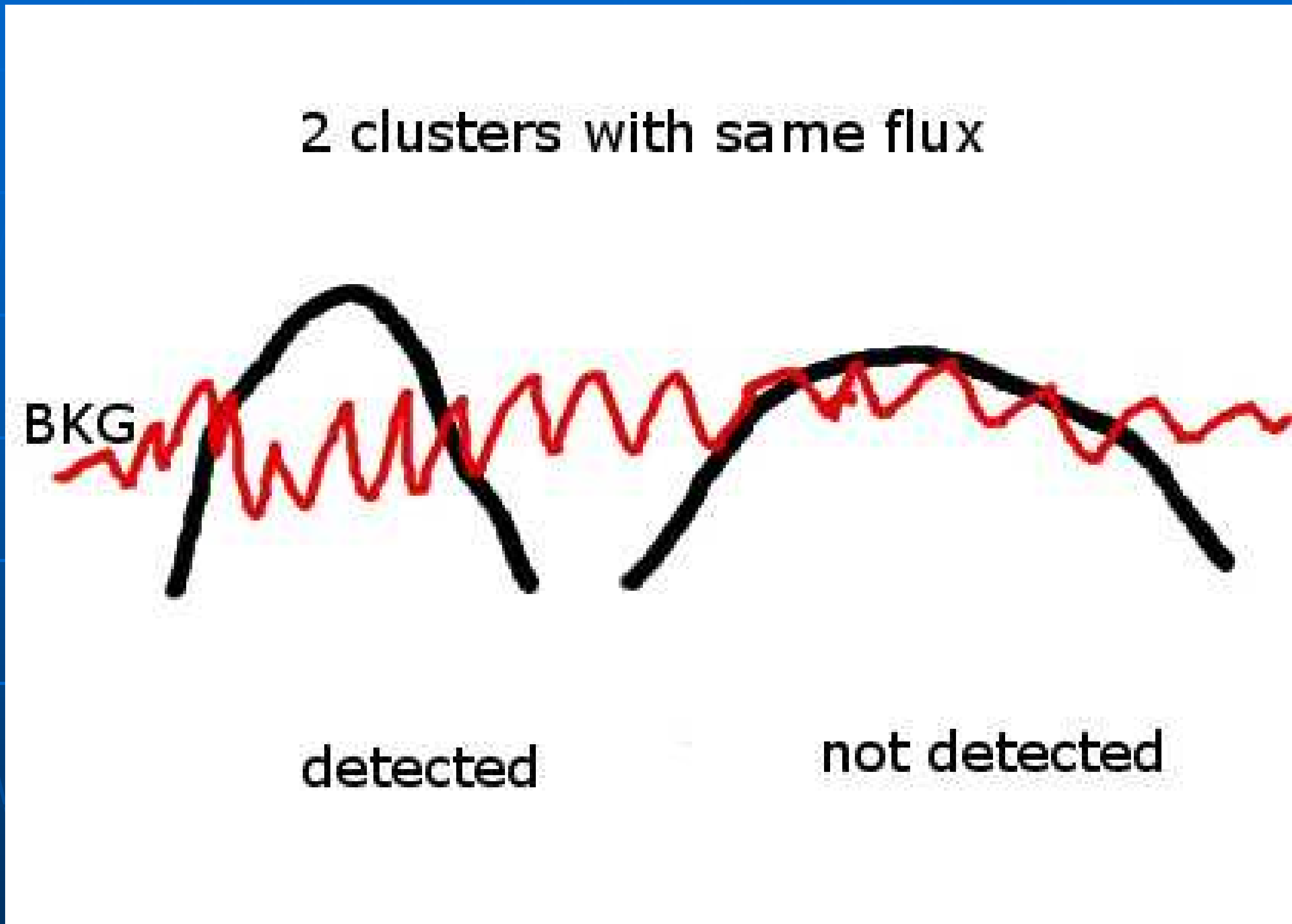
Detection rates



Not a flux limit !

Pacaud et al 2006

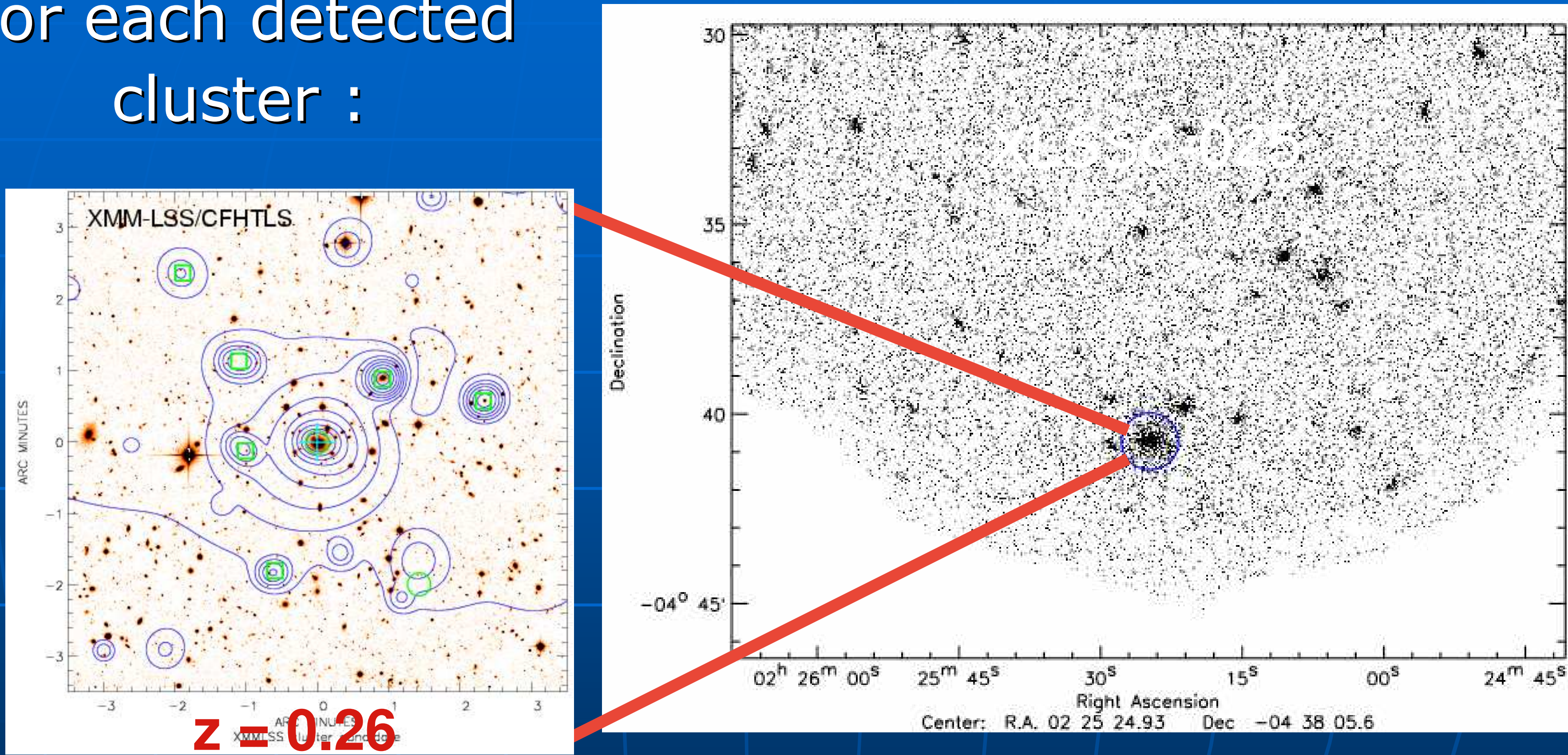
Not a flux limit



~ surface brightness limited

Assessing cluster properties

For each detected cluster :

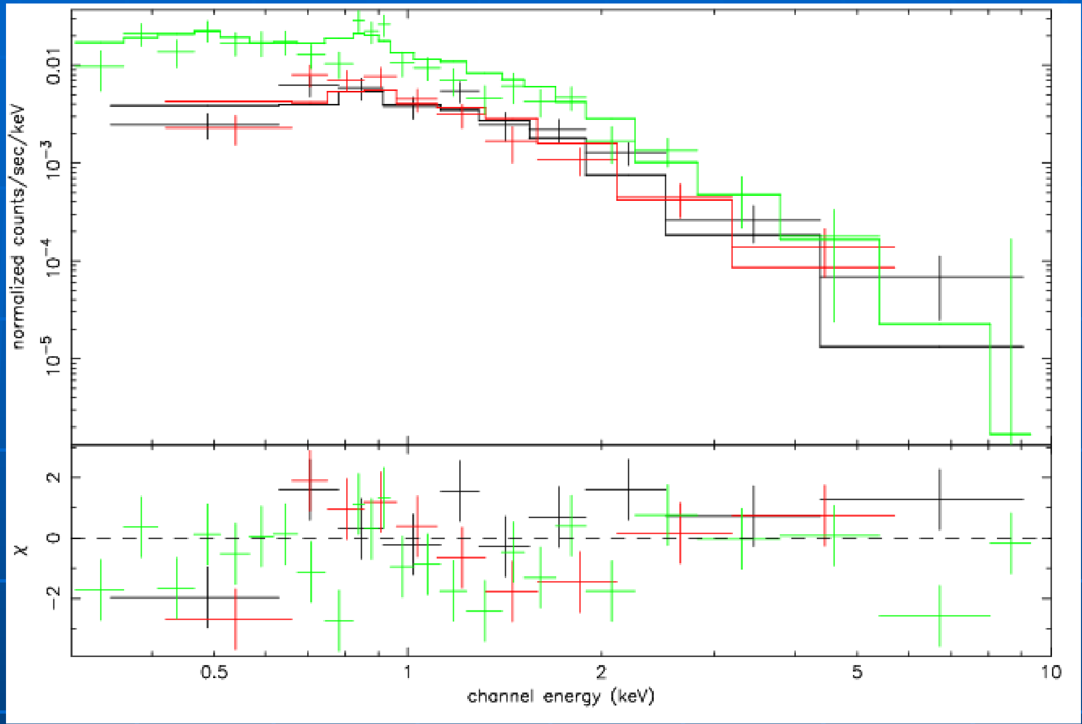


The source is confirmed with optical spectroscopy

Spectral analysis

When possible we measure a temperature by fitting a thermal plasma model to the source emission

~ possible for C1 sample



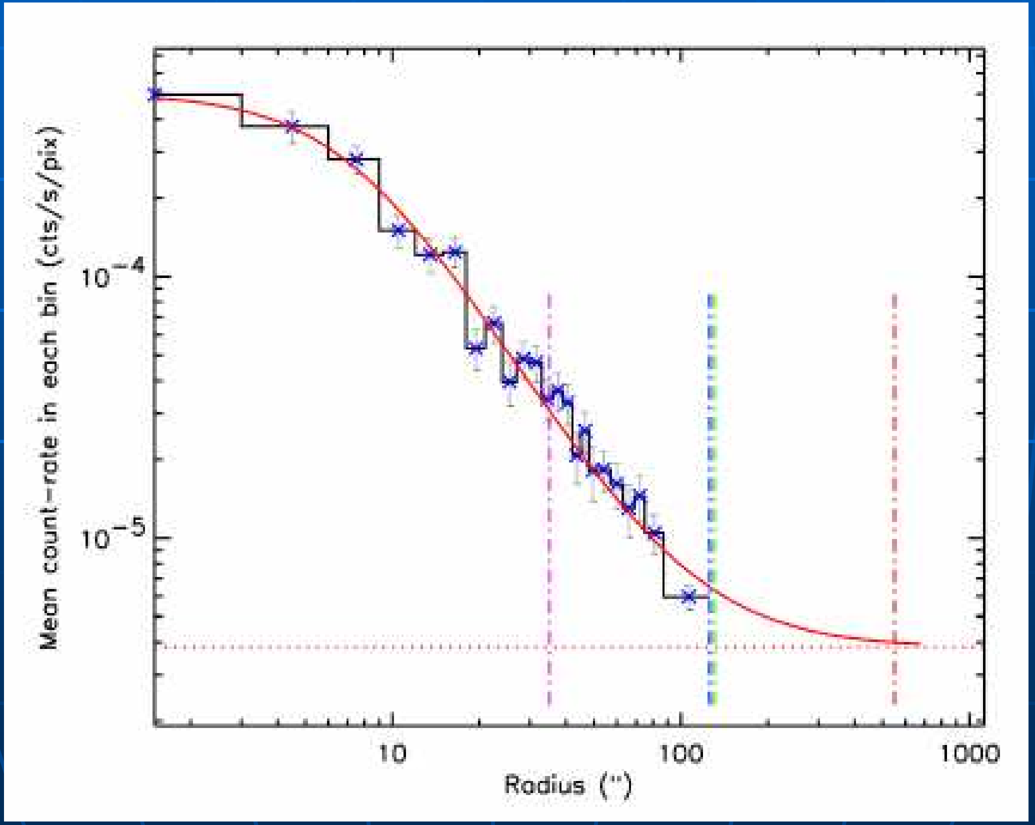
Willis, Pacaud, Valtchanov et al. (2005)

For XLSSC-025 using fixed abundance (0.3 solar):
T = 2.02 keV ([1.73-2.51] at 1σ)

Luminosity estimate

We measure F_X by fitting a surface brightness profile

~ possible for C1-C2 sources



Pierre, Pacaud, Duc et al. (2006)

The cluster sample

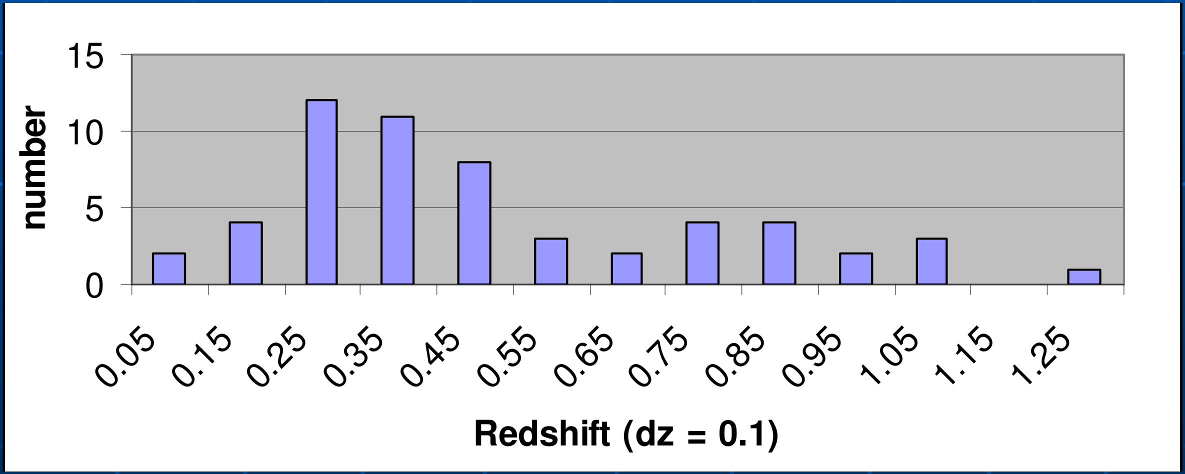
VLT at Paranal

ESO PR Photo 43a/99 (8 December 1999)

The cluster Catalogue

- Results over the first 5deg^2 (~4.1 usable): 29 C1, 41 C2 candidates

- Result of 3 seasons of spectroscopic follow-up: (2002,2003,2004@NTT,VLT,Magellan)
  => ~ 60 confirmed clusters (26, 8)



- Some 20 more candidates (3, 4) being processed

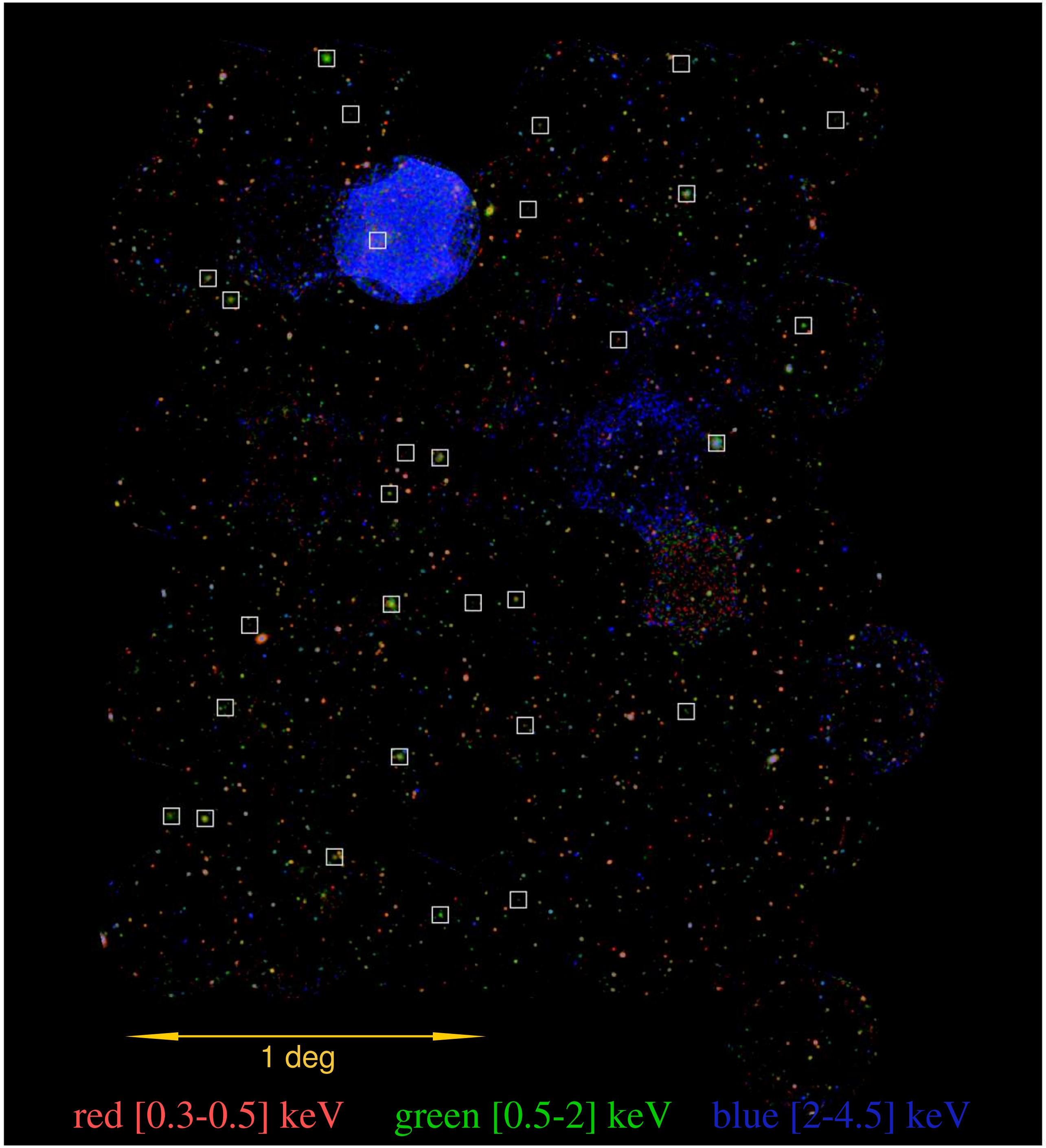
L'échantillon C1

Pacaud et al, in prep.

L3SDB

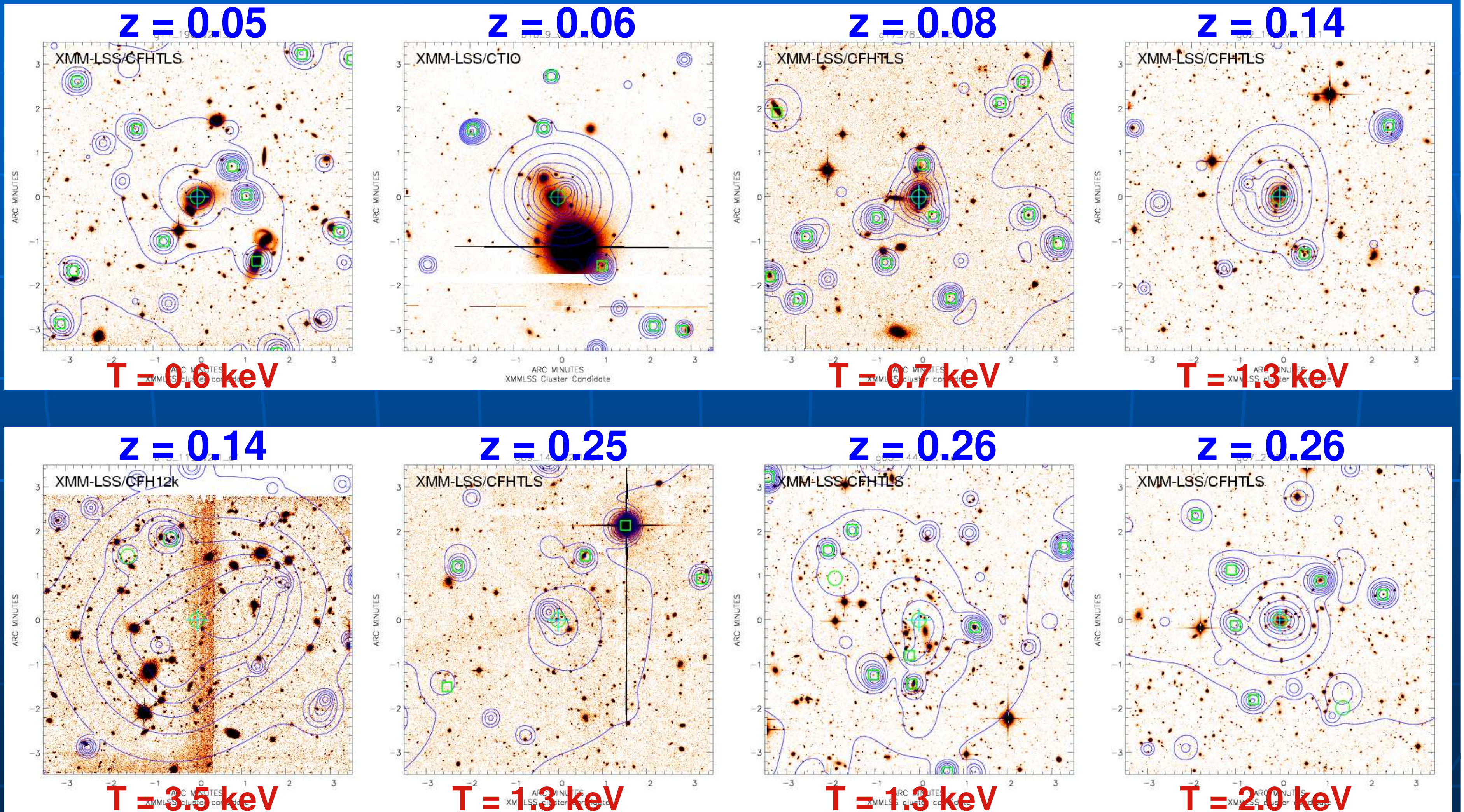
Base d'amas publique

J.P. Le Fevre



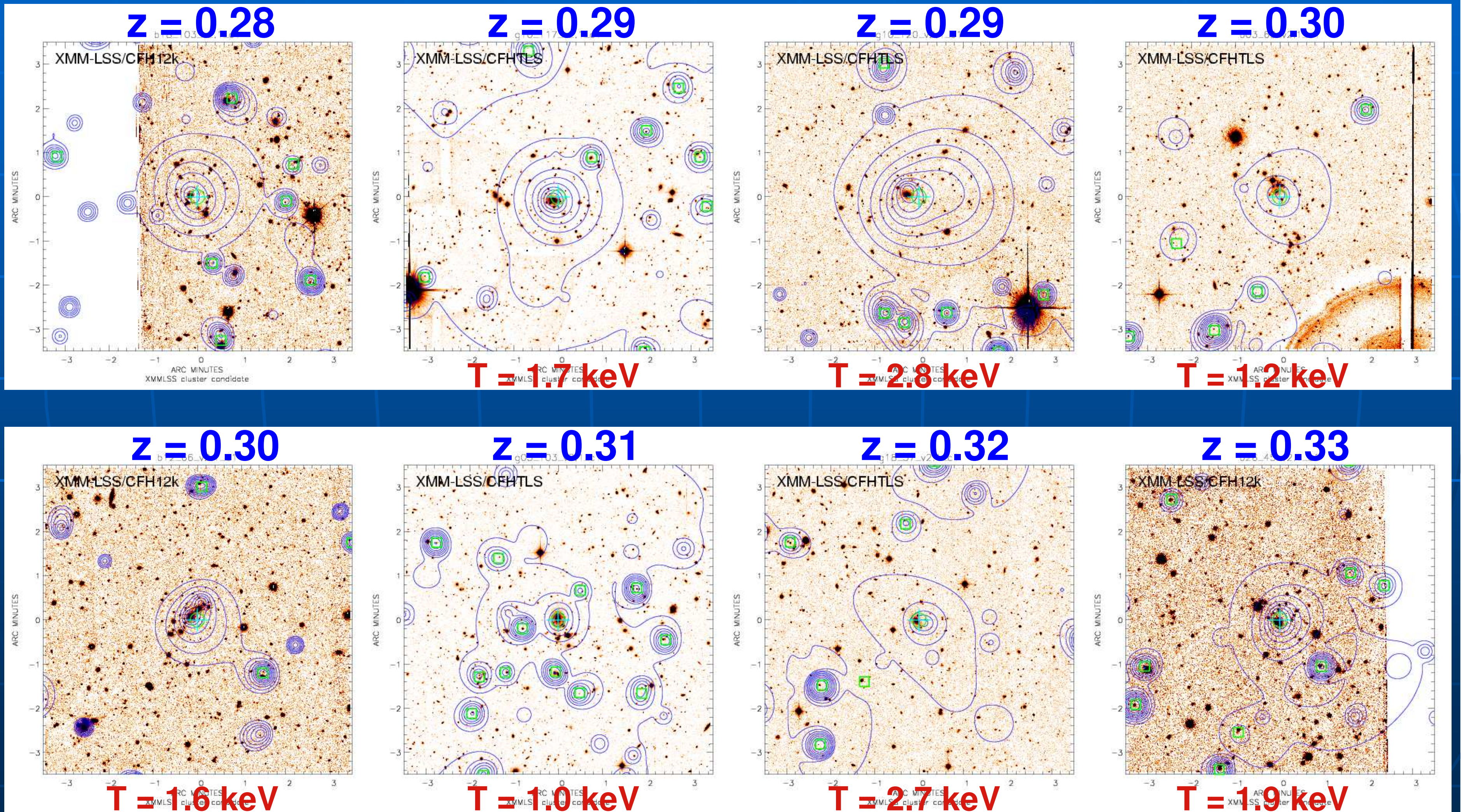
The C1 cluster sample (z < 0.3)

Small volume, high sensitivity ⇒ low T



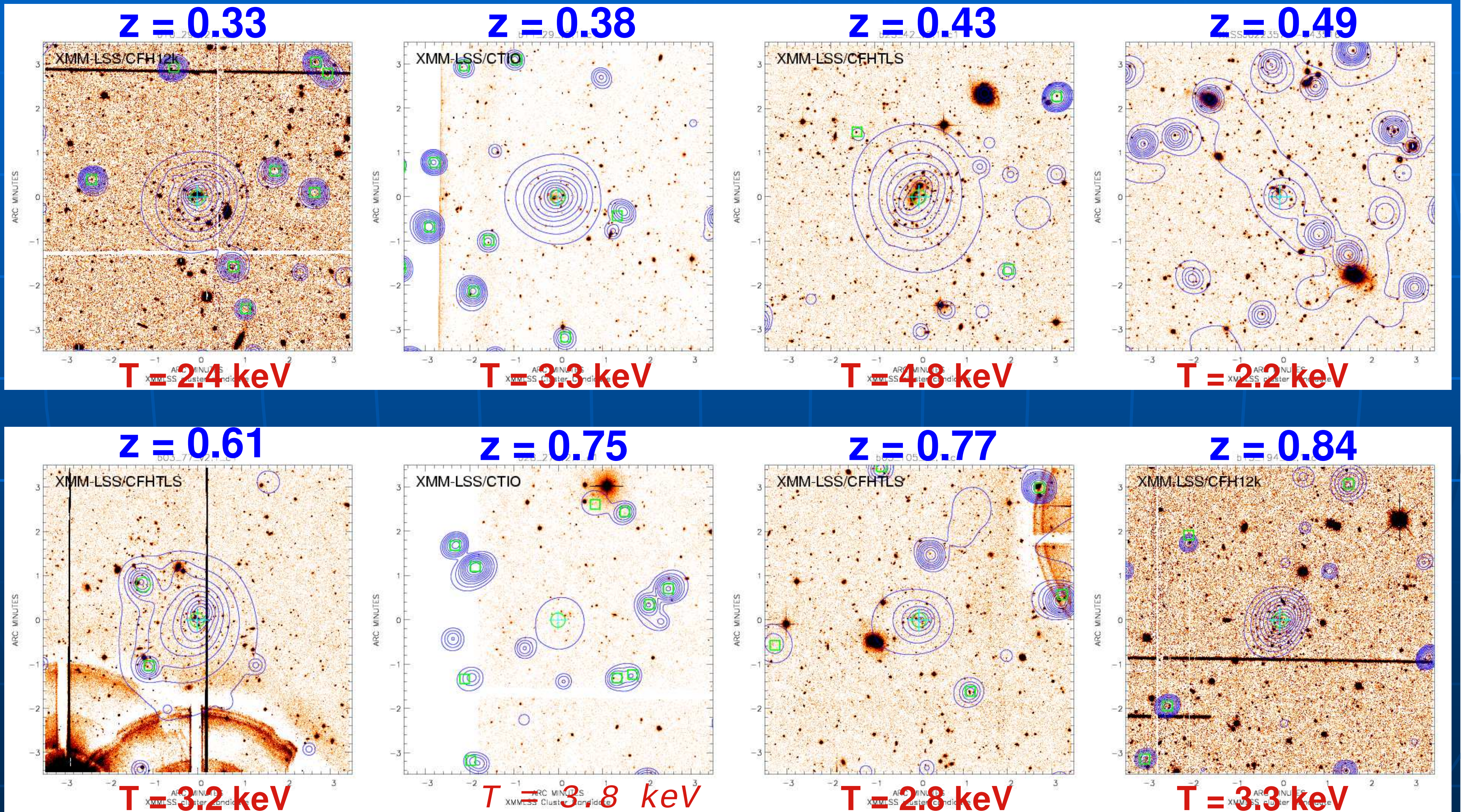
The C1 cluster sample (z ~ 0.3)

… and 1 < T < 3 keV bulk of XMM-LSS population

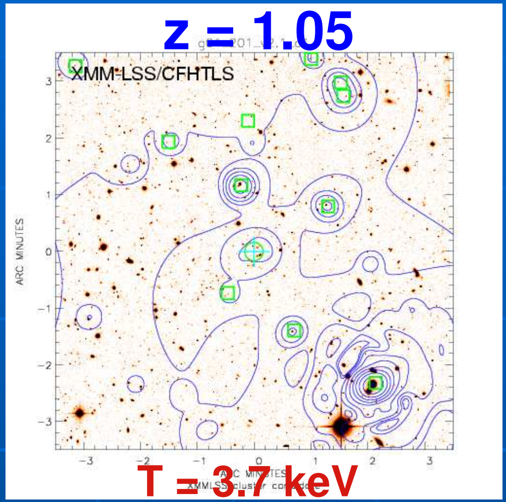


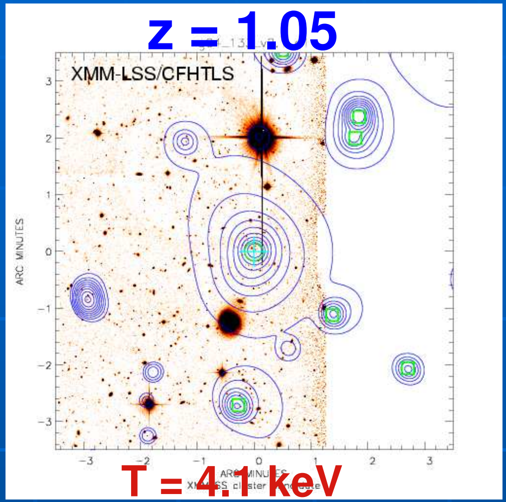
The C1 cluster sample (0.3 < z < 1.0)

… finally detecting clusters

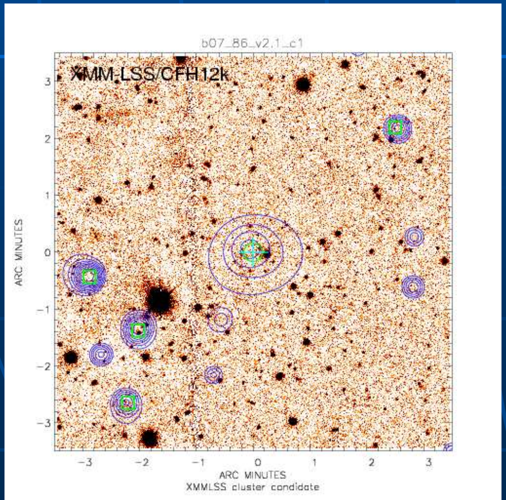


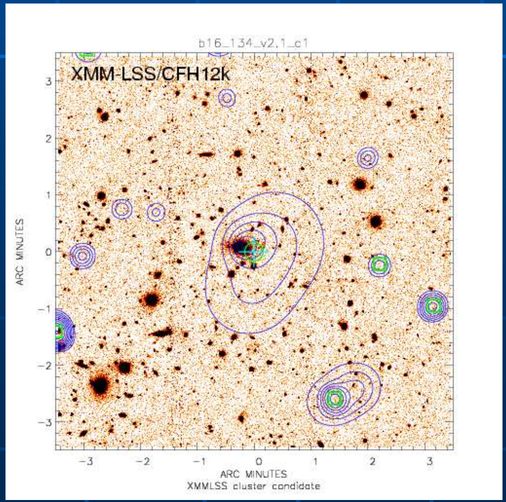
The C1 cluster sample (z > 1.0)

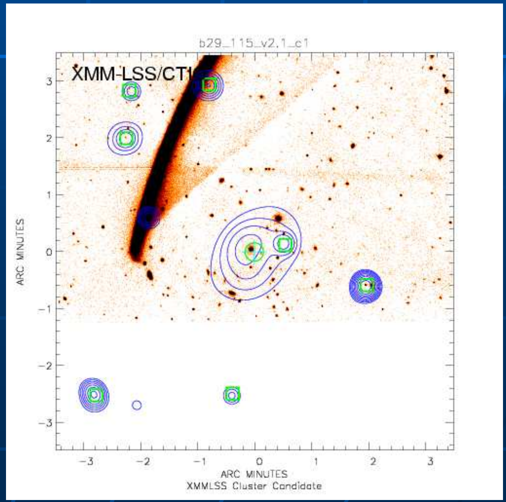




Pending sources …

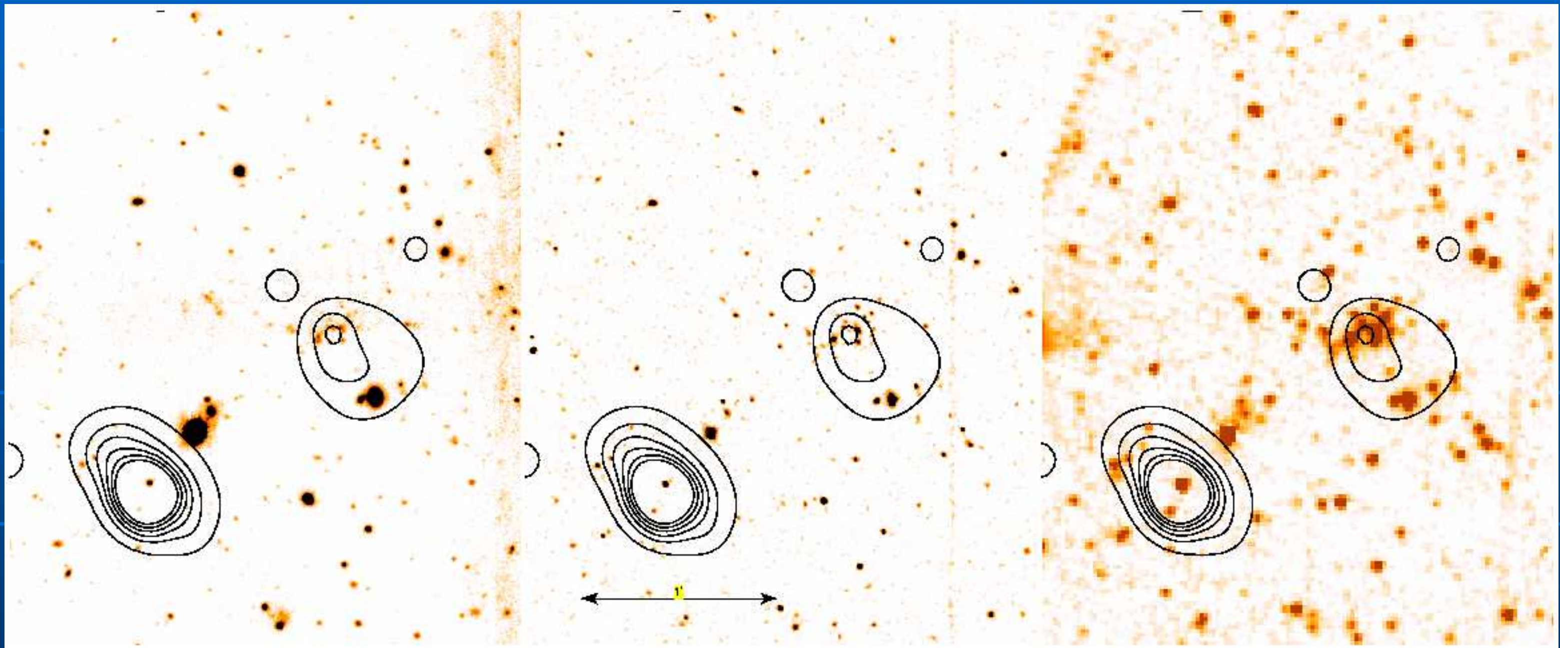






Distant cluster search (example)

XLSSC-046 (C2)



I (CFHT) K (NTT) 3.6 μm(Spitzer)

measured z = 1.22

Modele cosmologique

Cosmological modeling

- ΛCDM + P(k) (WMAP+BBKS)
- Mass Function (Sheth & Tormen 1999)
- Halo profile model (NFW 1995 + Bullock et al 2001)
- M_{500}-T relation (Arnaud et al 2005)
- L-T relation (Arnaud & Evrard 1999)

+

- Redshifted plasma model (APEC)

  ⇒ Fluxes (M,z)
- Convolution with XMM response

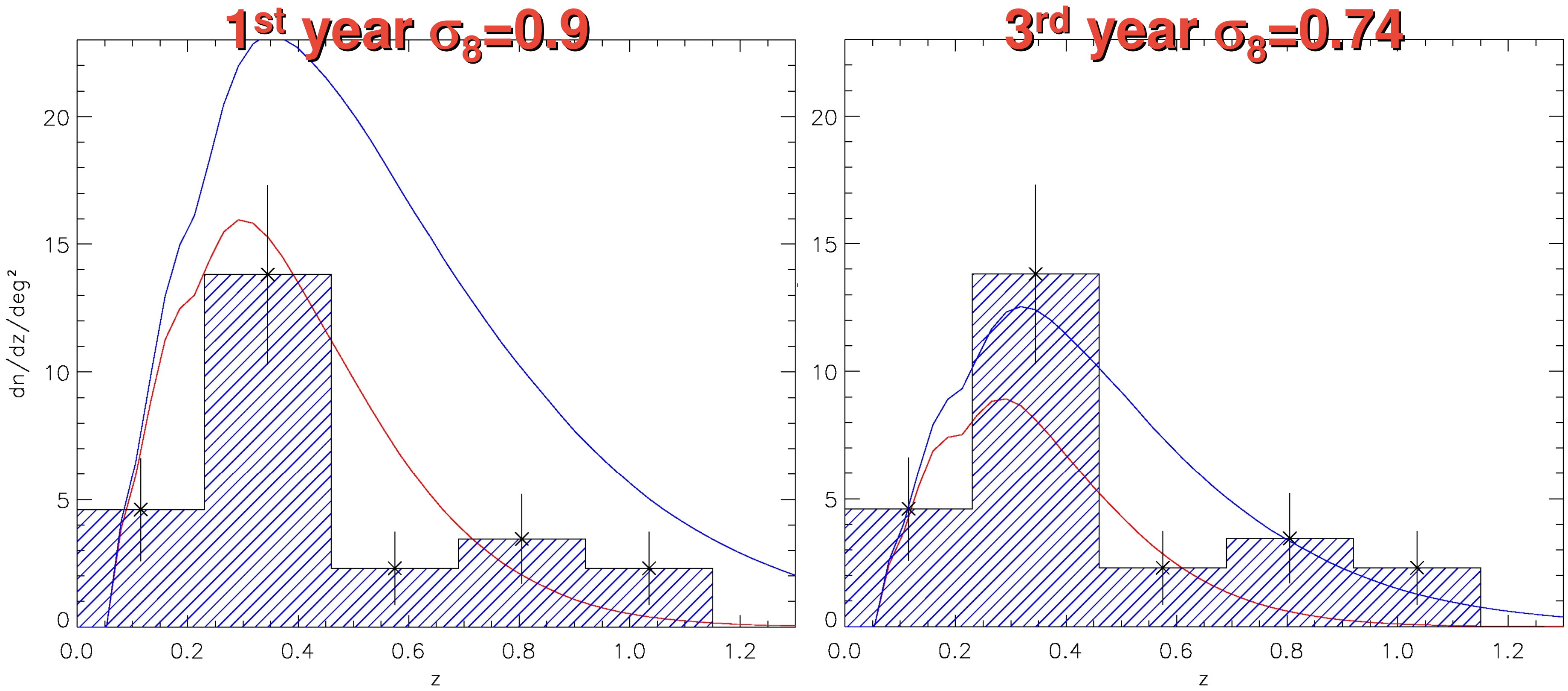
  ⇒ Count-rate
- β-profile (β=2/3 and Rc=180kpc)

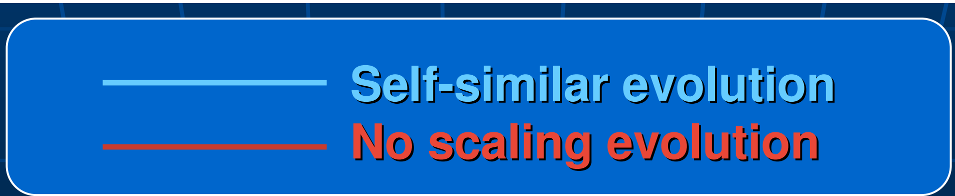
  ⇒ Folding with simulated detection rates

… and finally dn/dz !

The C1 redshift distribution

… compared with WMAP 1st and 3rd year



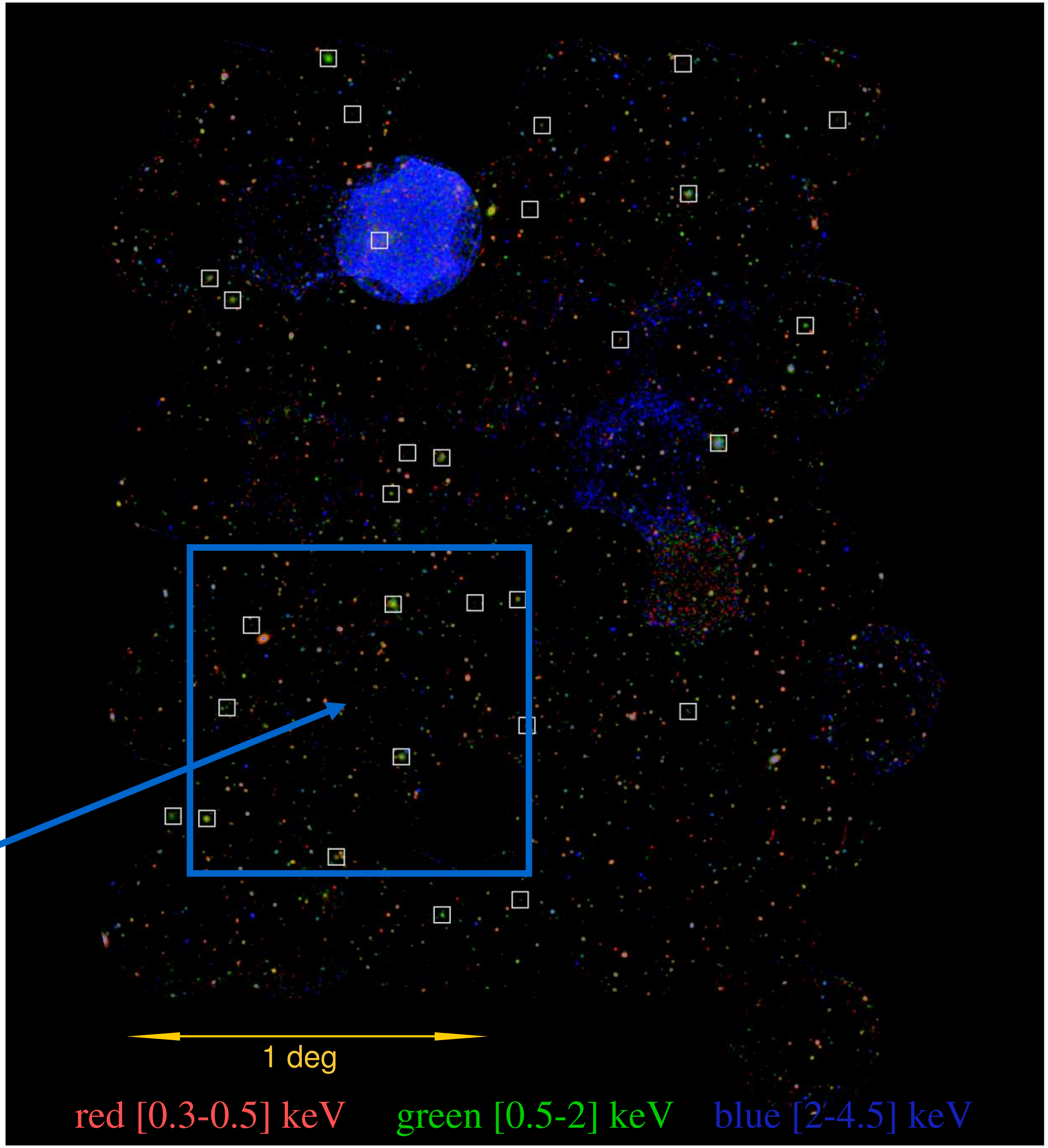


Constraining the cluster scaling laws

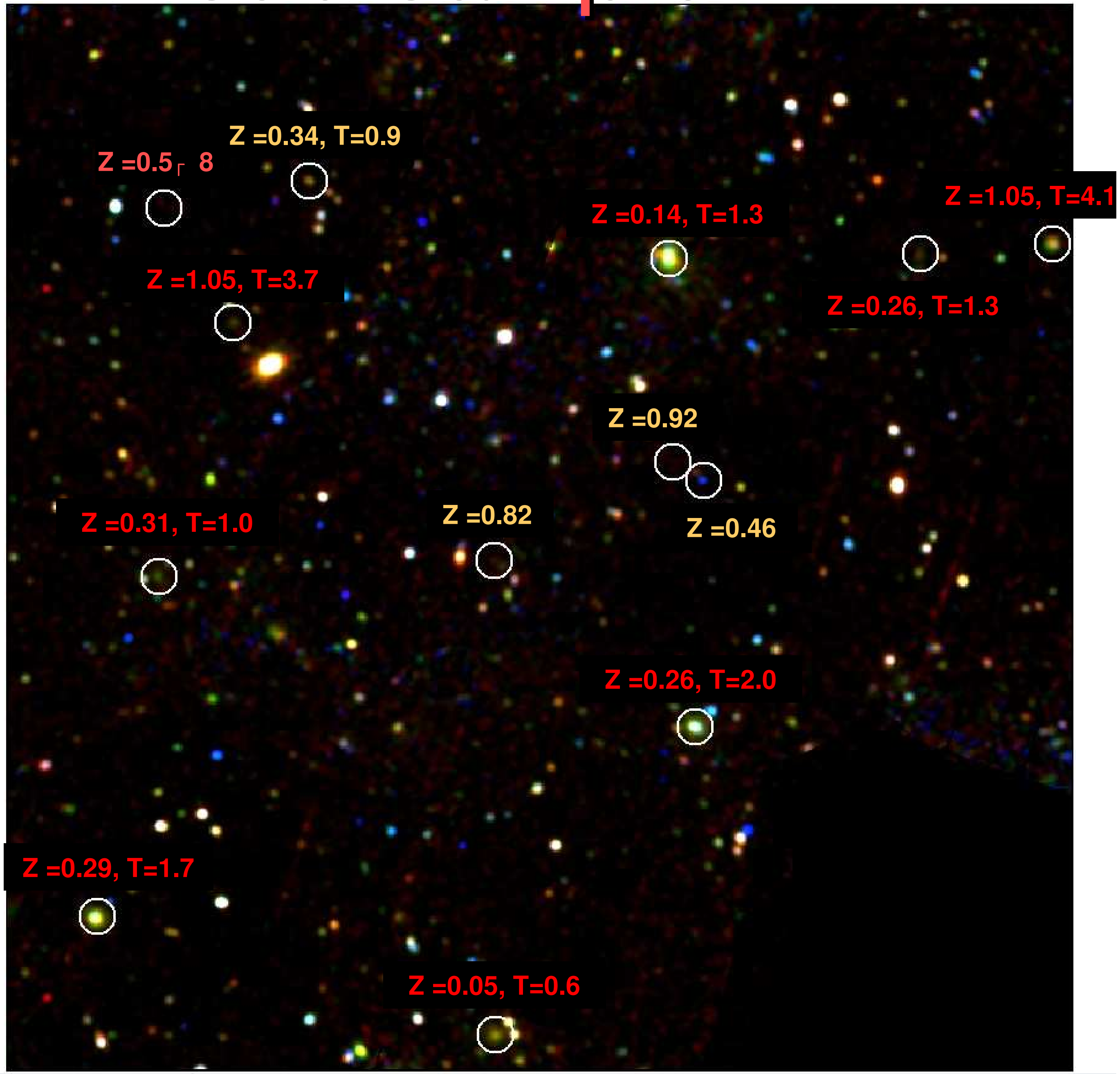
… over the D1 sub-sample

The D1 area

Here !



The D1 sub-sample



1 deg² - 20ks

CFHTLS Deep

VVDS

8 C1

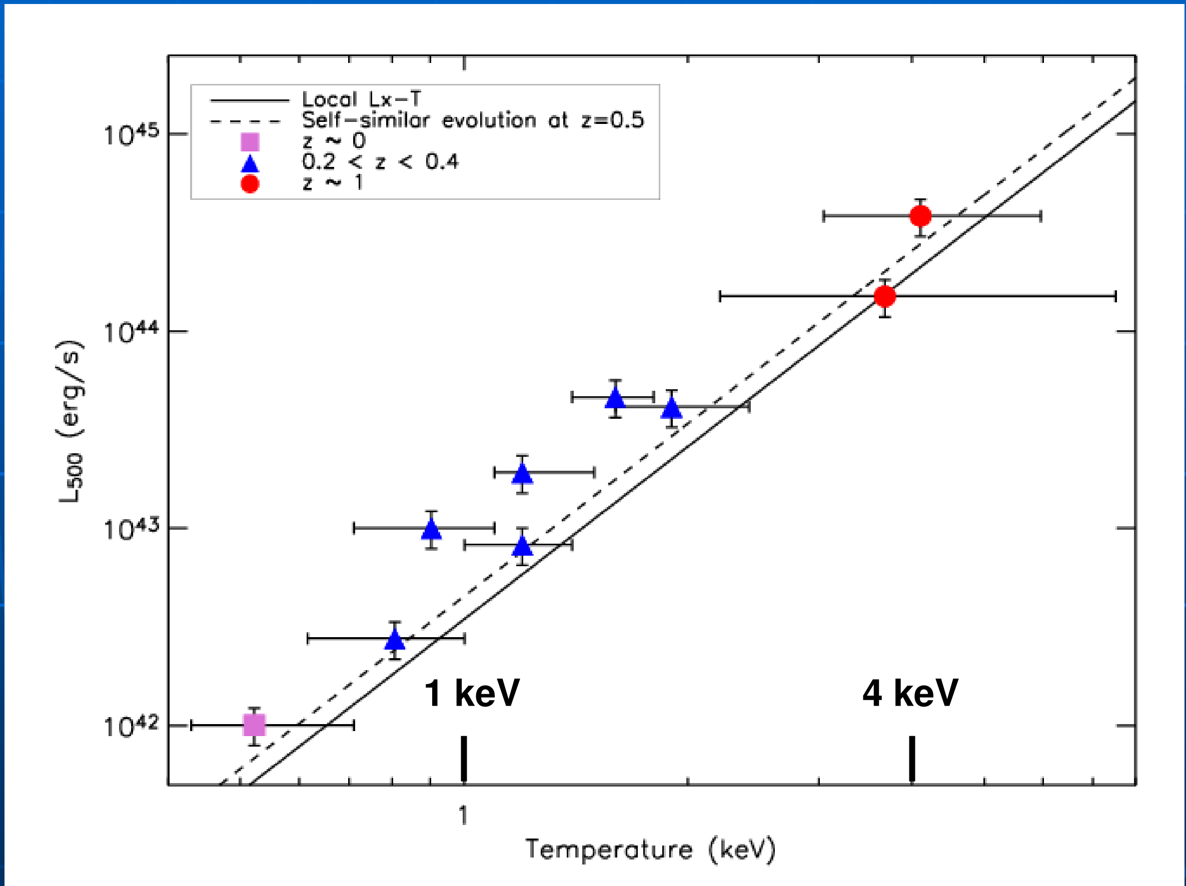
1 C2

4 C3

Pierre, Pacaud, Duc et al. 2006

The D1 L-T relation

The first L-T relation for intermediate redshift groups



L-T at z=0

L-T at z=0.5 (self-similar evolution)

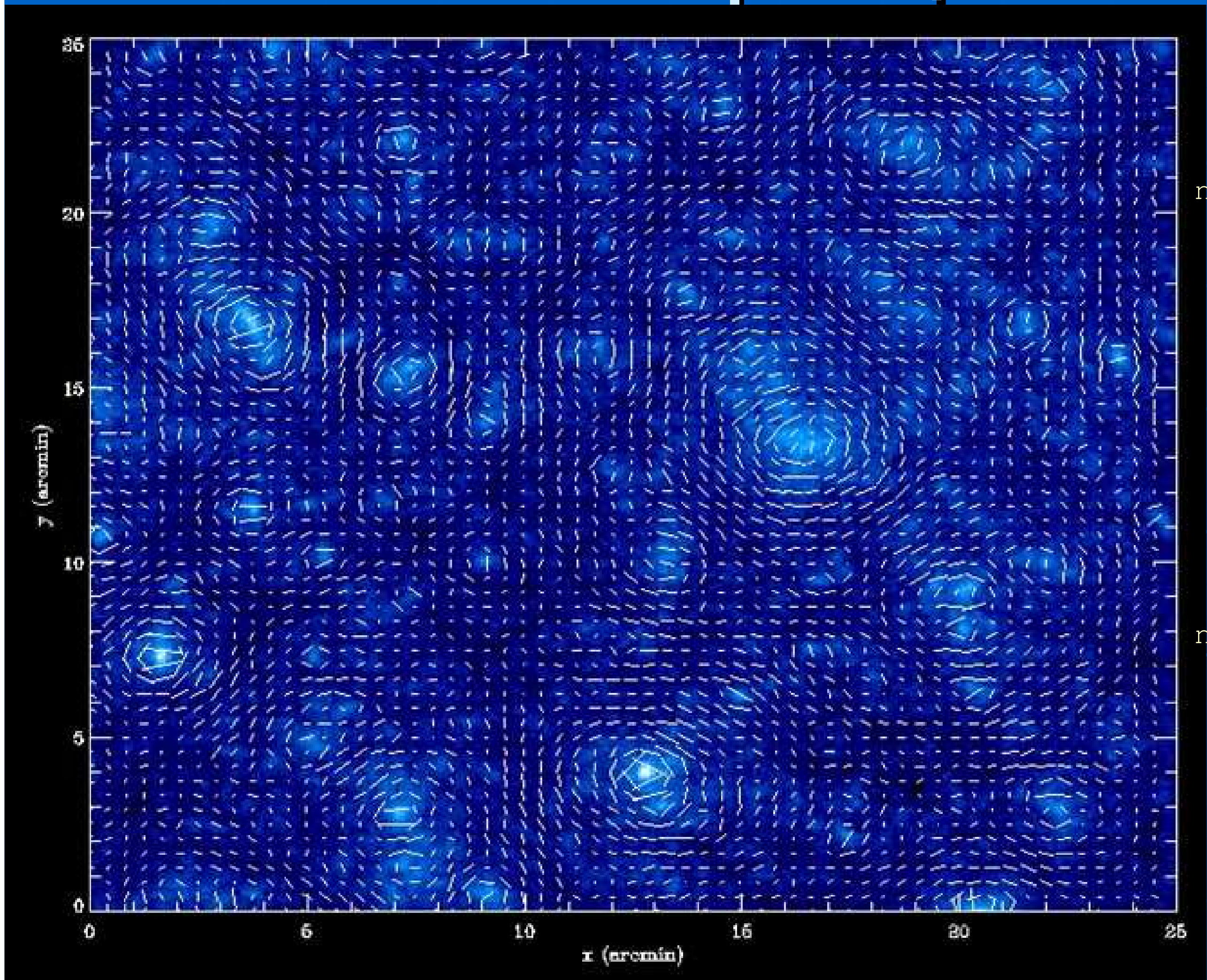
FUTURE

Insights from other wavelengths:

Weak lensing

Sunyaev-Zel'dovich effect

Weak



Jain, Seljak & White 1997, 25'x25', SCDM

- Measures the distortion of background galaxy shapes due to foreground matter distribution
- Enables direct reconstruction of the projected mass map

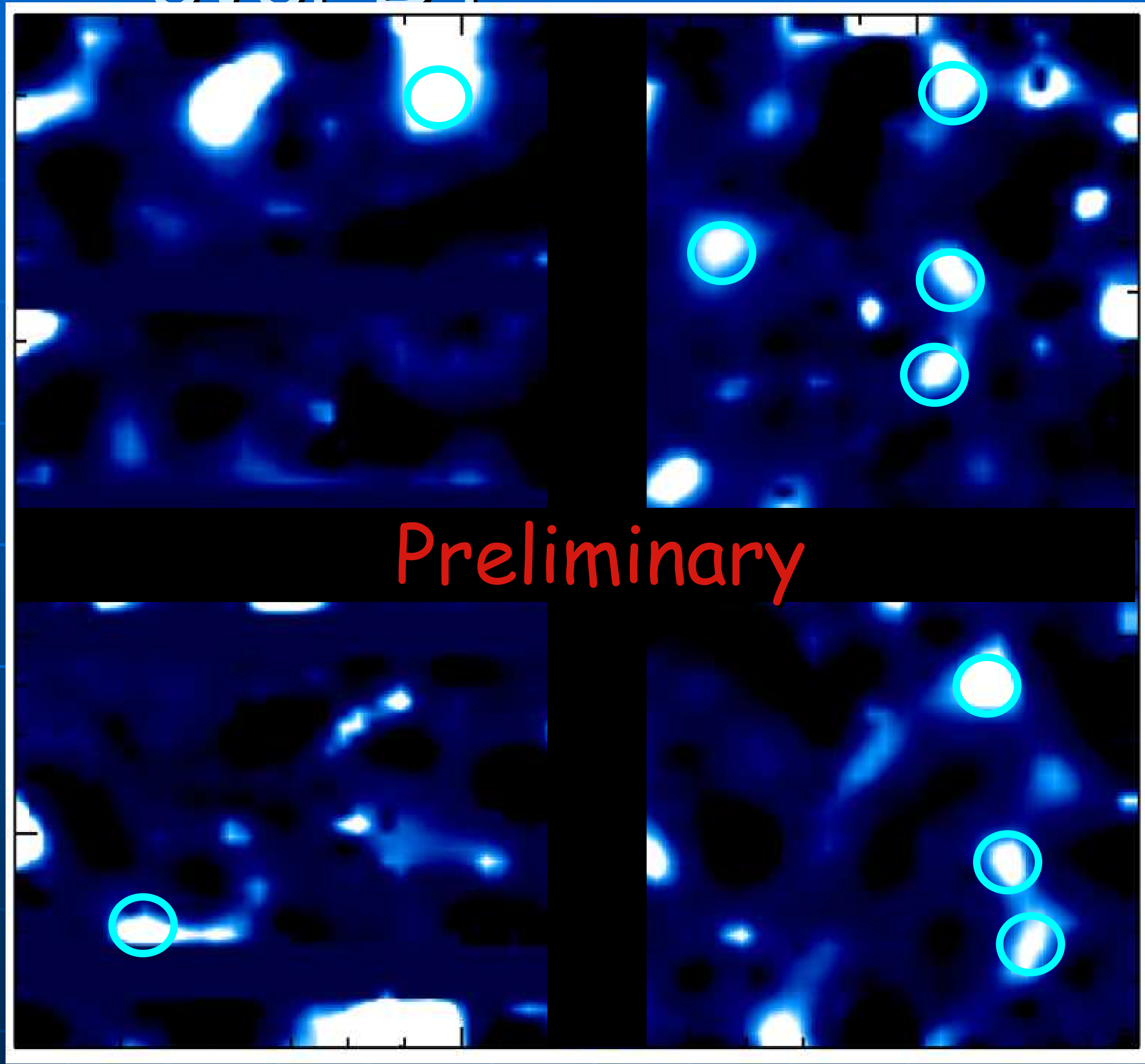
Theory

Weak Lensing over D1

Shapelet shear map with wavelet mass inversion

By Joel Bergé

Starck, Pires & Refregier 2005



Preliminary X-ray/Lensing comparison

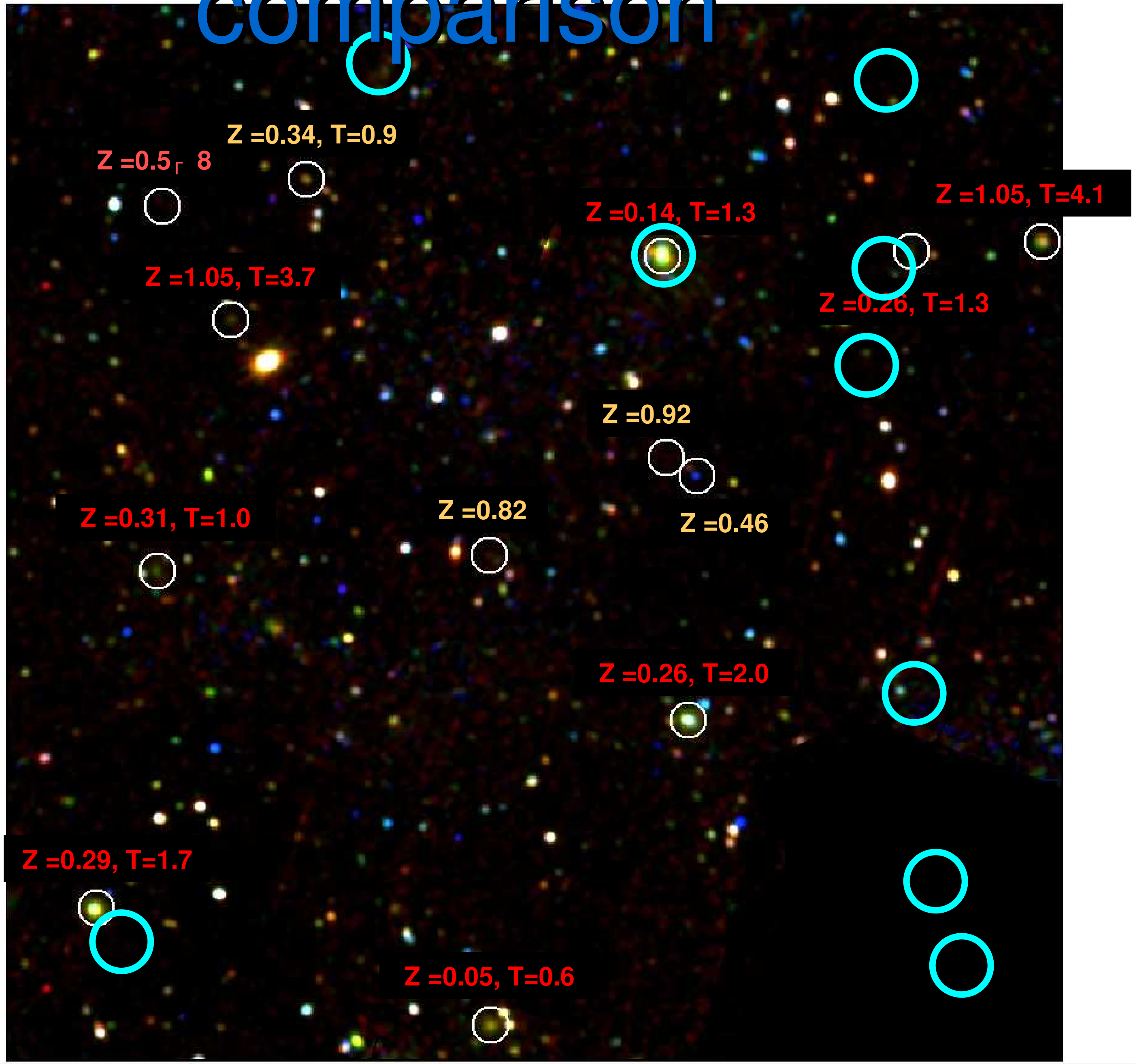
X-ray:

8 C1

1 C2

4 C3

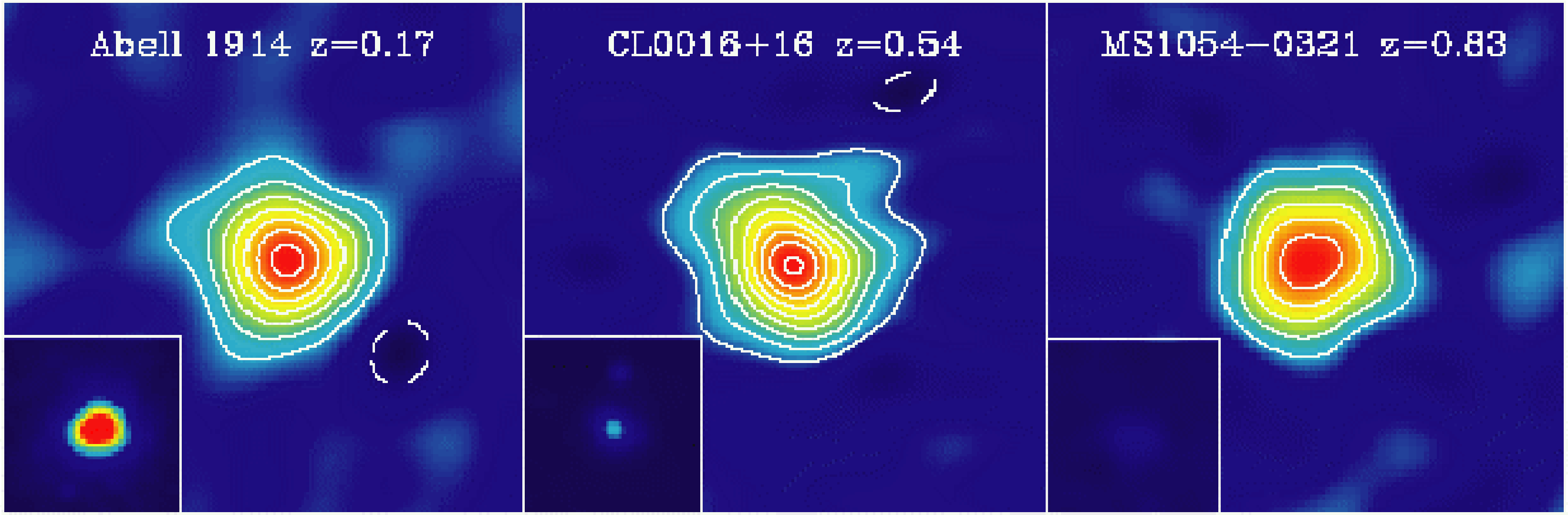
Lensing:



Sunyaev-Zel'dovich versus X-ray

- S-Z : $\Delta T_{CMB} \approx \int n_e T_e \; dl$
  (independent of z – integrated pressure)

- X-ray luminosity : $L_X \approx \int n^2 T^{1/2} \; dV$



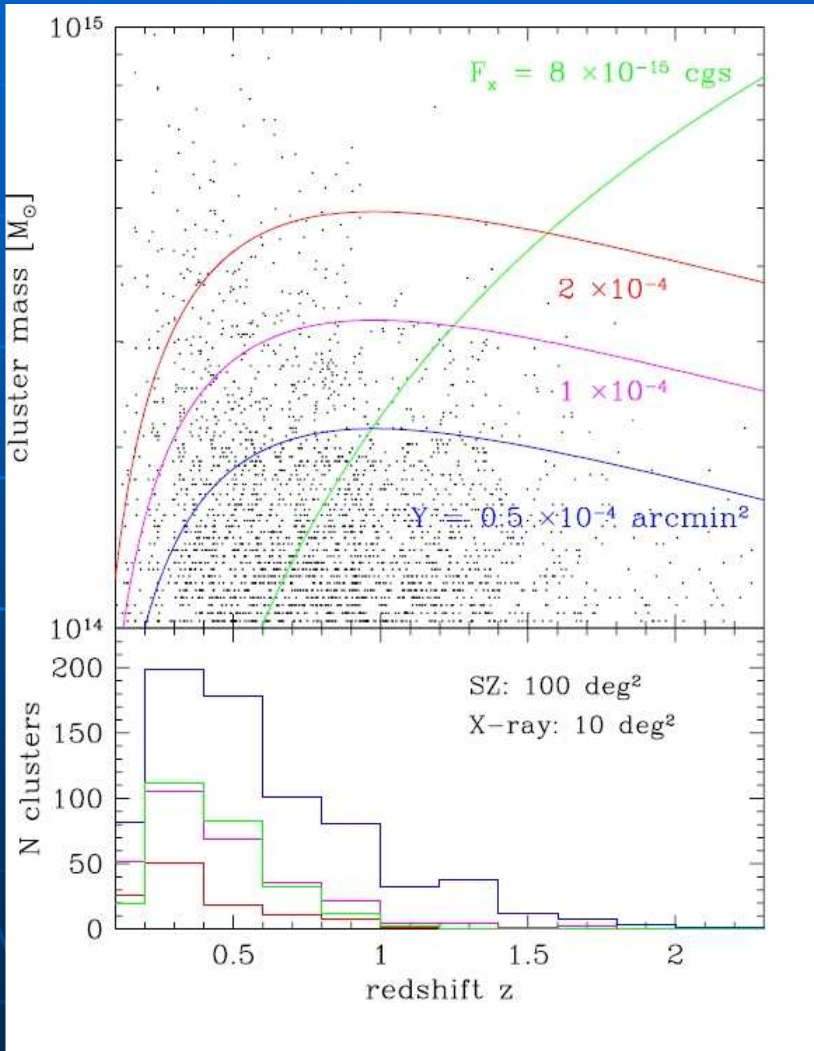
Courtesy of J. Carlstrom et al.

S-Z observations of the XMM-LSS field

- APEX-SZ survey :
  - Resolution: 50'' @ 150 GHz
  - Coverage: 4 clus./deg^2 over the whole field
  - Sensitivity: 10μK (y = 5.10^{-4} arcmin^2)
- OCRA :
  - Resolution: 70'' @ 30 GHz
  - Coverage: pointed observations
- AMIBA (interferometer):
  - Resolution: ~ 10'' @ 95 GHz
  - Coverage: pointed observations

All about to start !

Combining XMM and Apex



XMM: 12 / deg^2

APEX: 4 / deg^2

Lensing: few / deg^2

Courtesy:
Rüdiger Kneissl

Combining wavelengths

- Joint analysis of number density and space distribution of clusters using all three methods
  (i.e. with differing selection process)

- Use the joint X-ray/S-Z data sets to get insights into the evolution of the ICM physics

- Get mass information from the weak lensing survey on the CFHTLS data

- **The redundancy between the various observables allows:**
  - **Calibration of the mass-observables relations**
    AND
  - **Constraints on the cosmology**

Conclusions

Résumé

- Avec 10^4s d'XMM on détecte ~ 12 clusters per deg^2 (3 fois plus que les DS ROSAT)
  - Bientôt ~120 amas dans la région SWIRE ($10deg^2$)
  - Contraintes cosmologiques données par la distribution des amas jusqu'a z~1
- On détecte les groupes a $0.3 < z < 0.5$ pour la première fois (pièces des amas z~0)
  - La relation L-T est une source d'information sur la physique des baryons

Perspectives

Etudes multi-λ avec

APEX-SZ et CFHTLS weak lensing

Ł

- Meilleure comprehension de la physique de l'ICM
- vers la cosmologie de précision …

FIN