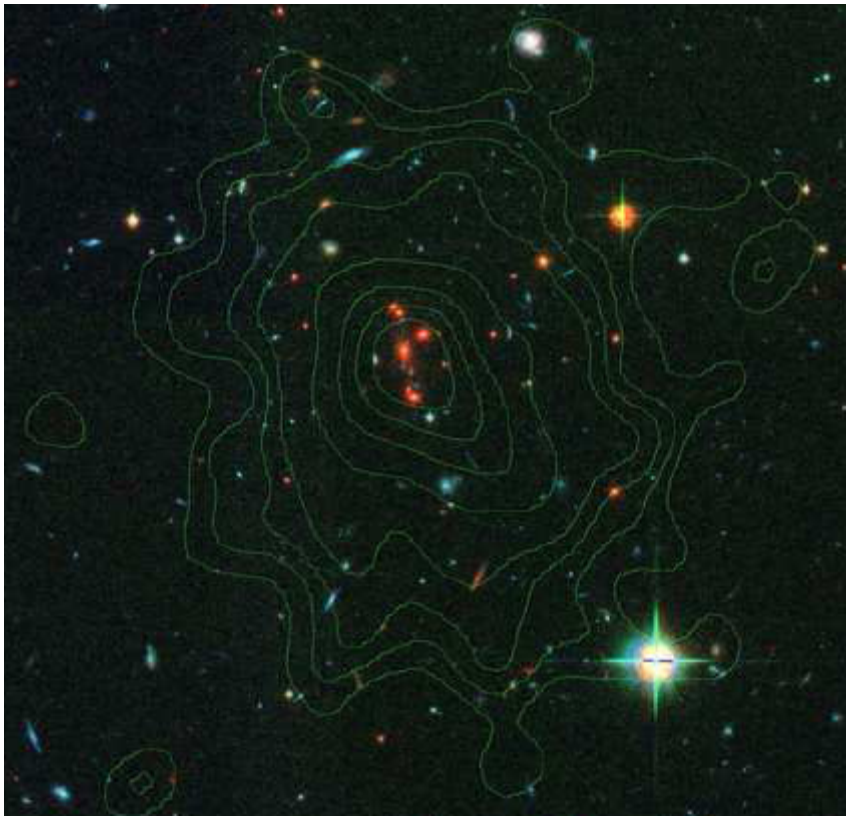
The most distant massive galaxy clusters



Rene Fassbender (MPE)

rfassben@mpe.mpg.de

KITP, 8 March 2011

Agenda

I. Selection and status of the most distant galaxy clusters

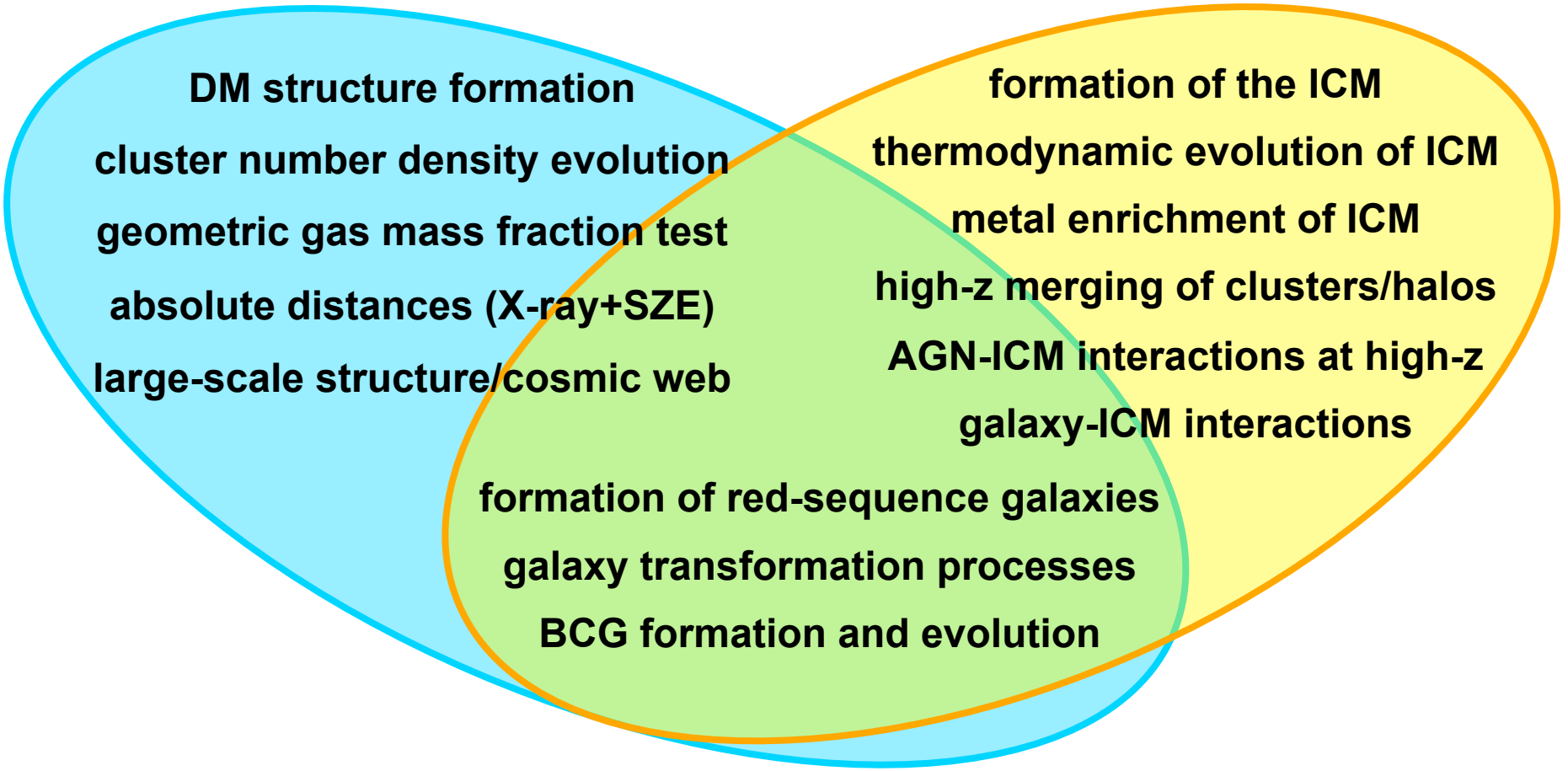
II. The most distant $M>10^{14}M_{sun}$ systems

III. What is a distant cluster?

IV. Summary and open questions

I. Selection and status of the most distant clusters

Tracing the High-z Evolution of X-ray Galaxy Clusters Observationally



Observational Possibilities at z>1

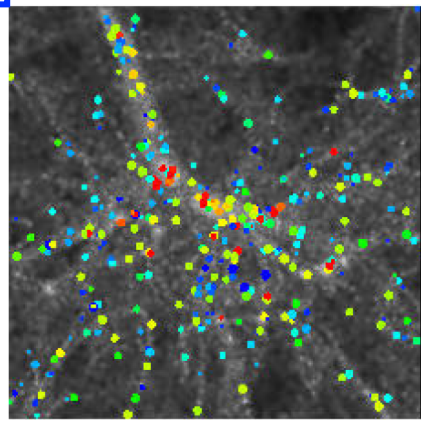
I) Cluster Galaxies

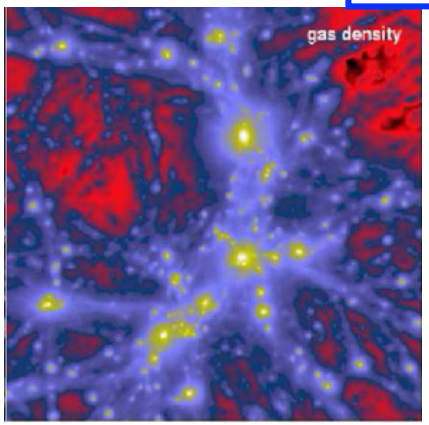
optical, NIR, MIR

detection: optical

detection: NIR / MIR

obs. limitations:
k-correction (optical)
PSF (MIR)





II) Intracluster Medium

X-ray

detection

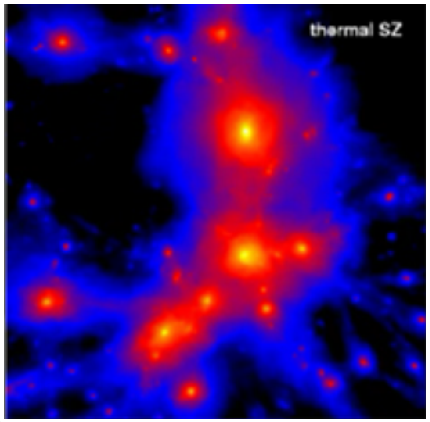
obs. limitations:
SB-dimming $(1+z)^{-4}$

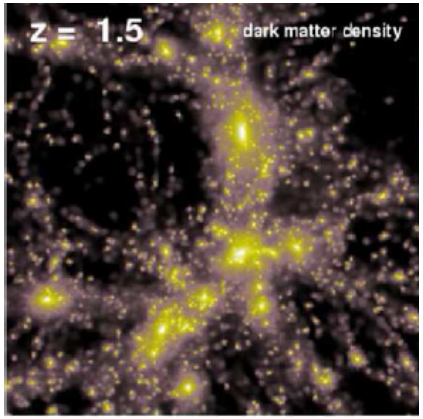
III) Sunyaev-Zeldovich Effect

mm

detection?

obs. limitations:
instrument sensitivity
signal contamination(?)





IV) Gravitational Lensing

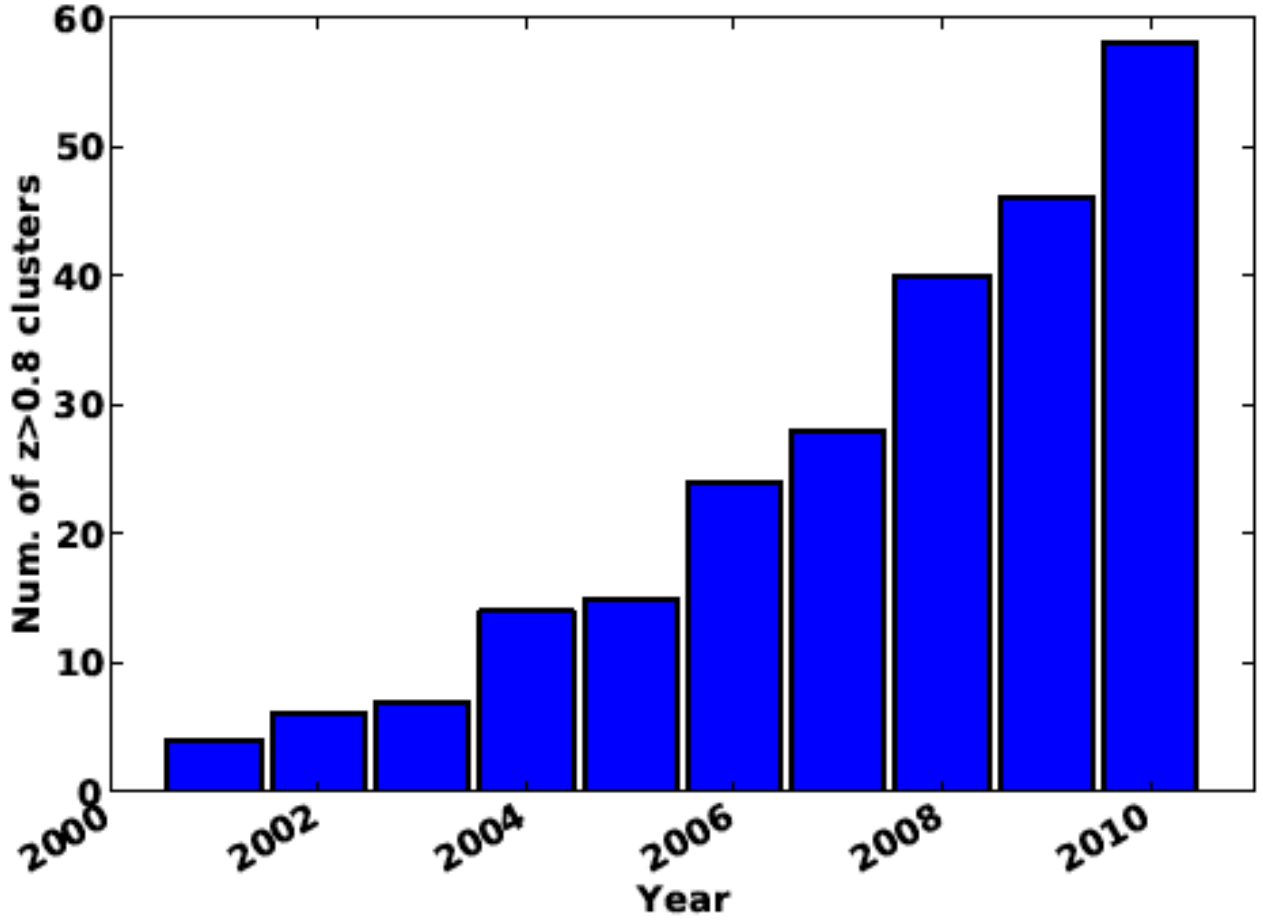
optical

not for detection

obs. limitations:
lack of background galaxies

Distant cluster studies are accelerating

Number of published, spectroscopically confirmed z>0.8 systems with L_X measurements



from Suhada et al., to be submitted

A XMM-Newton Distant Cluster Project (XDCP) Primer

Aim: find & study distant X-ray clusters at z>0.8

Science Goals:

- multi-wavelength studies of distant clusters
- galaxy evolution in the densest environments
- high-z scaling relations
- cluster number density evolution

XDCP Assets:

- >200 X-ray selected candidates at z>0.5 from 80deg^2
- follow-up imaging data for >80% of distant candidates and for >400 X-ray clusters over all redshifts
- spectroscopic follow-up of high-z candidates >50% complete
- largest sample of distant X-ray clusters to date (and for next 10 years)

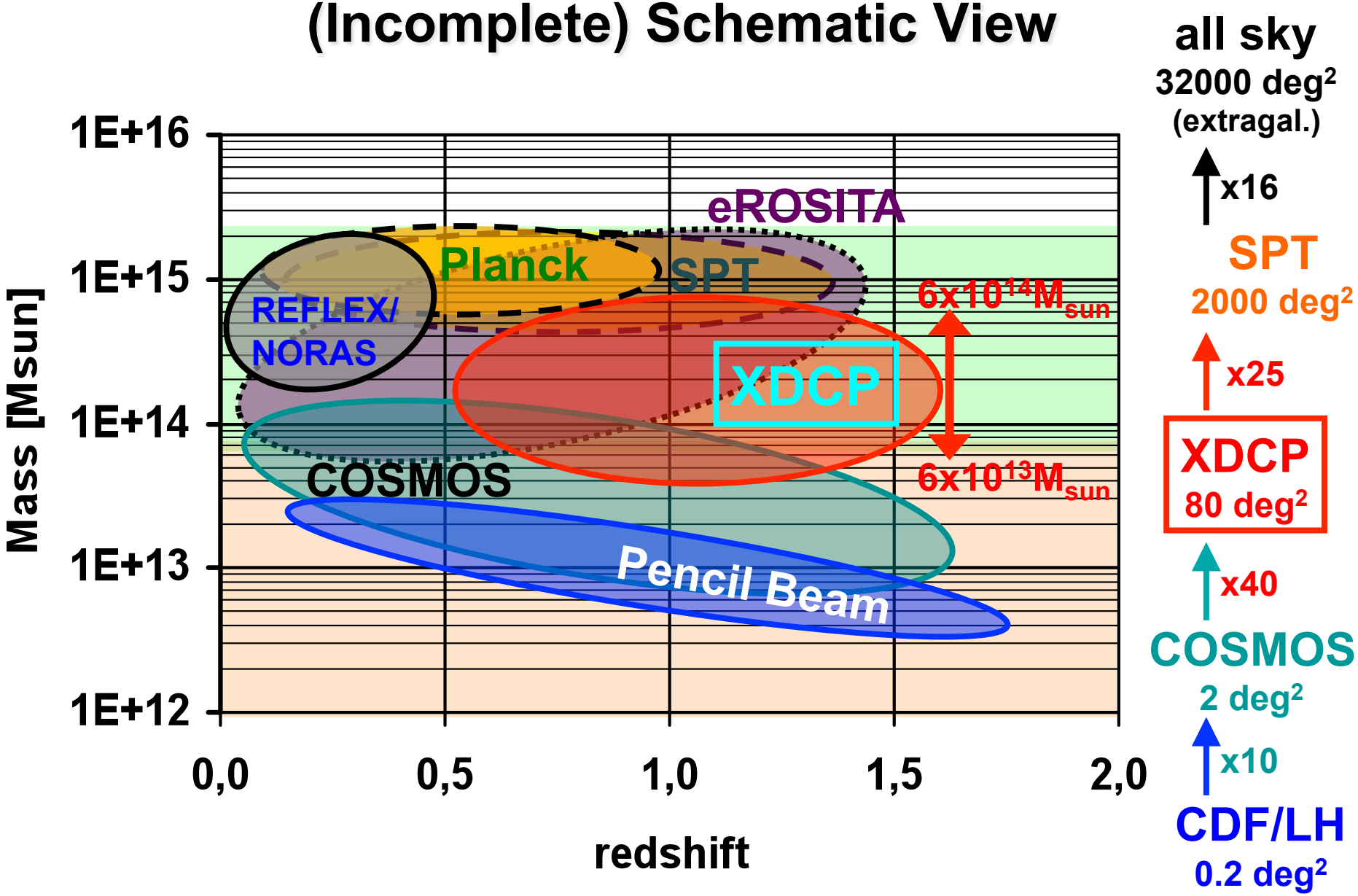
Fassbender 2008, arXiv:0806.0861
http://www.xray.mpe.mpg.de/theorie/cluster/XDCP/xdcp_index.html

The XMM-Newton Distant Cluster Project Team

Hans Böhringer (MPE)
Rene Fassbender (MPE)
Alessandro Nastasi (MPE)
Robert Suhada (MPE)
Martin Mühlegger (MPE)
Daniele Pierini (MPE)
Andreas Reichert (MPE)
Joana Santos (INAF Trieste)
Piero Rosati (ESO)
Arjen de Hoon (AIP)
Axel Schwope (AIP)
Georg Lamer (AIP)
Jan Kohnert (AIP)
Gabriel Pratt (Saclay)
Hernan Quintana (PUC)
Joe Mohr (USM Munich)

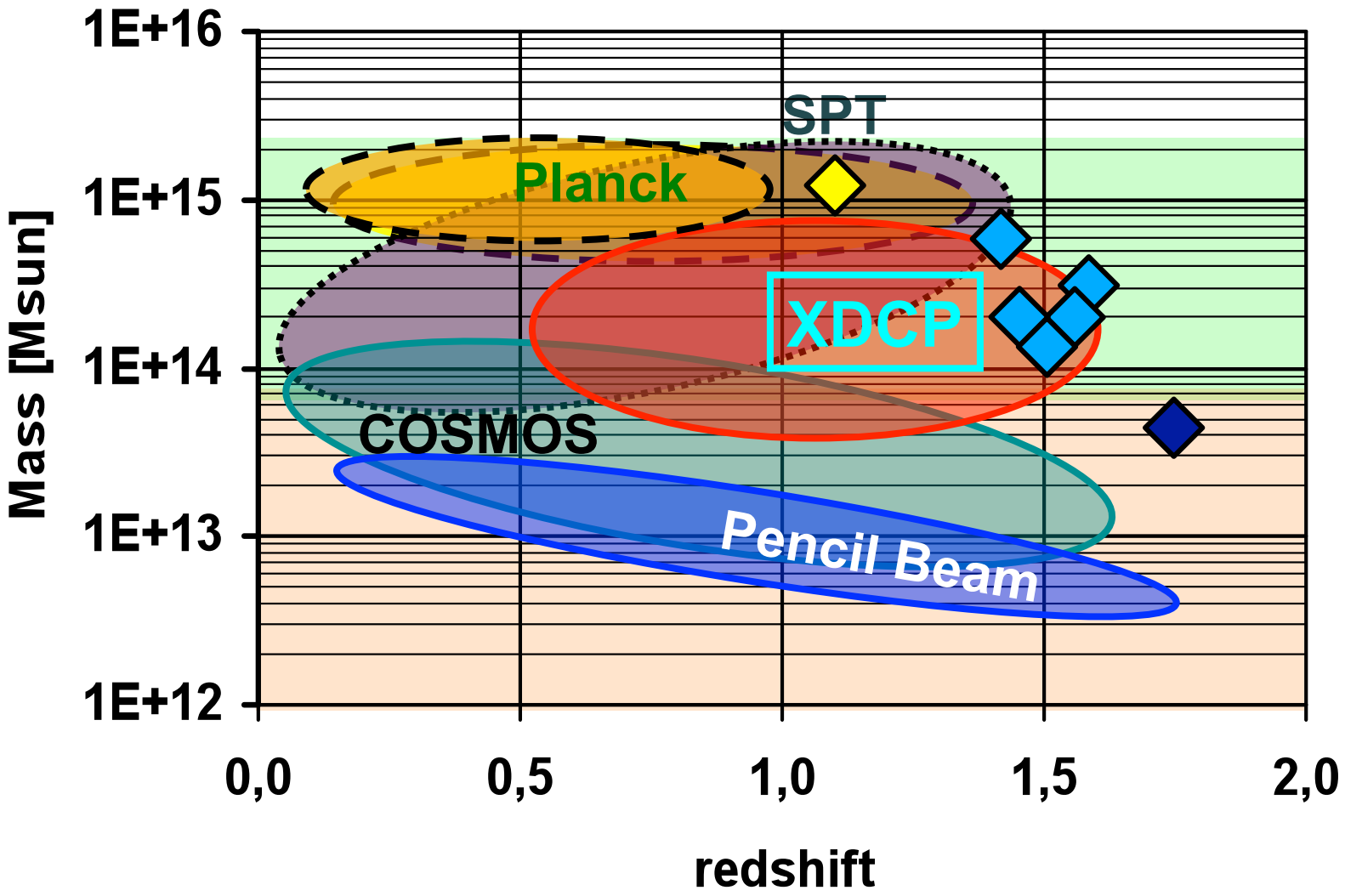
Galaxy Cluster Surveys based on ICM Signature

(Incomplete) Schematic View



Galaxy Cluster Surveys based on ICM Signature

Status of known clusters at highest z



The top 10 most distant clusters known
spectroscopically confirmed

z	Name	Sel.	$L_{X,bol}$ [10^{44} erg/s]	M200 [$10^{14} M_{sun}$]	References
2.07	CL J1449+0856	MIR	0.9	0.7	Gobat+11
1.75	XMMU J1053+5723	Xray	0.5	0.6	Henry+10
1.62	XCL J0218-0510	MIR	0.4	0.6	Tanaka+10, Papovich+10
1.58	**XMMU J0044-20**	**Xray**	**6.1**	**3.0**	Santos+to be subm.
1.56	**XMMU J1007.4+1237**	**Xray**	**2.1**	**2.0**	Fassbender+11
1.49	**XMMUJ 0338+00**	**Xray**	**1.2**	**1.4**	Nastasi+to be subm.
1.49	ISCS J1432.4+3250	MIR	3.5	2.5	Brodwin+10
1.46	**XCSJ2215.9-1738**	**Xray**	**2.2**	**2.0**	Hilton+10, Stanford+06, Bielby+10
1.41	ISCS J1438.1+3414	MIR	2.2	2.2	Brodwin+10, Stanford+05
1.39	**XMMU J2235.3-2557**	**Xray**	**10.0**	**6.0**	Rosati+09, Jee+09, Mullis+05

XDCP Search Method for Distant Galaxy Clusters

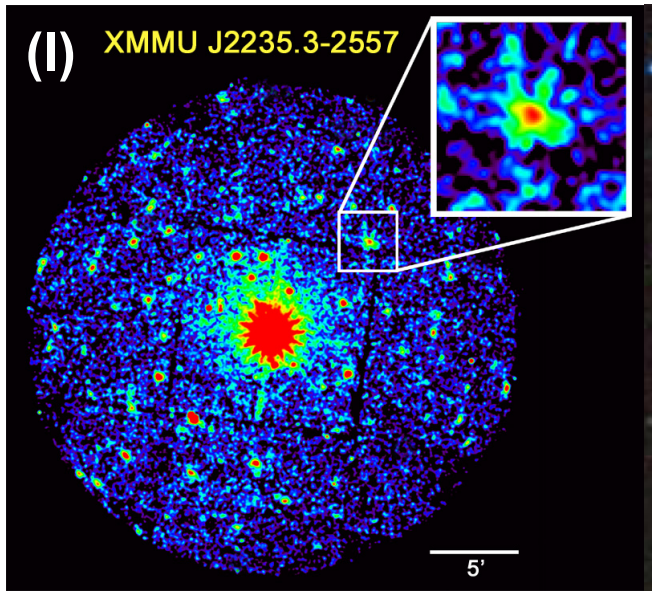
I) identification of (weak) extended X-ray sources in the XMM-Newton archive

II) imaging confirmation of a galaxy overdensity & red-sequence redshift estimate

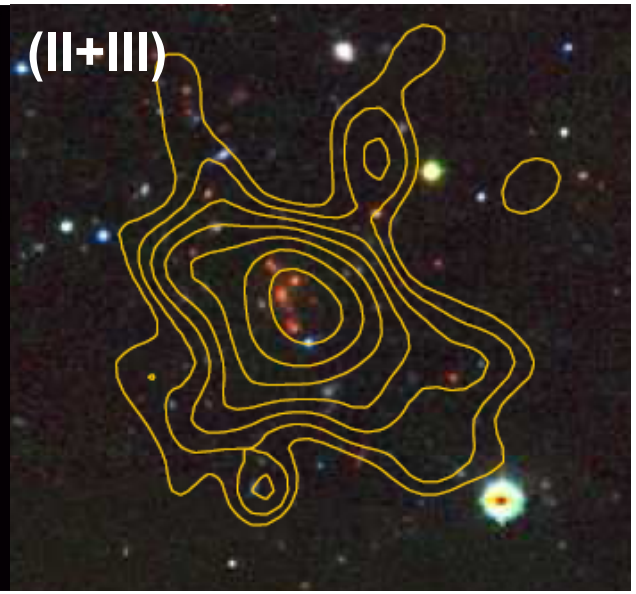
III) spectroscopic redshift determination with VLT FORS2

IV) detailed multi-wavelength follow-up of the most interesting clusters

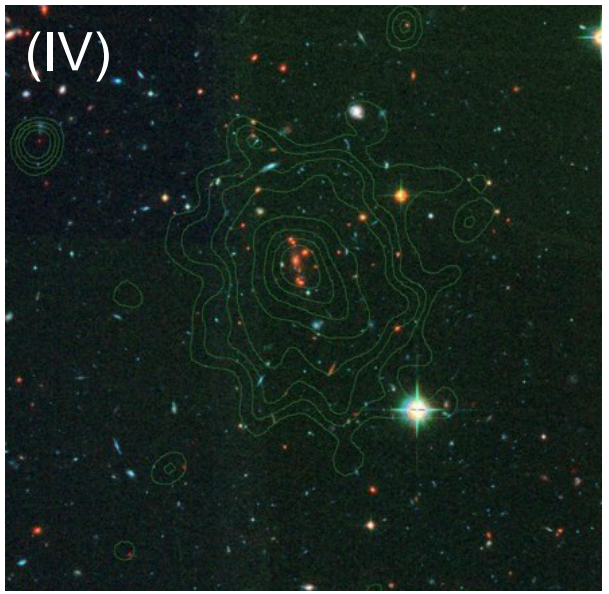
Example: XMMU J2235.3-2557 at z=1.39



XMM field-of-view



XMM X-ray contours
+RzK band color composite



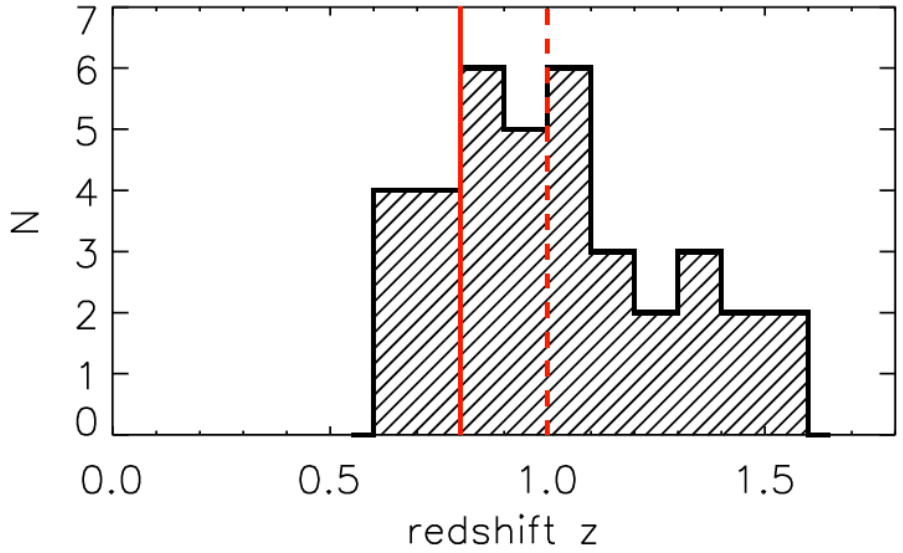
Chandra X-ray contours
+ HST(i,z)+VLT(K) image

Mullis et al. 2005, Rosati et al. 2009

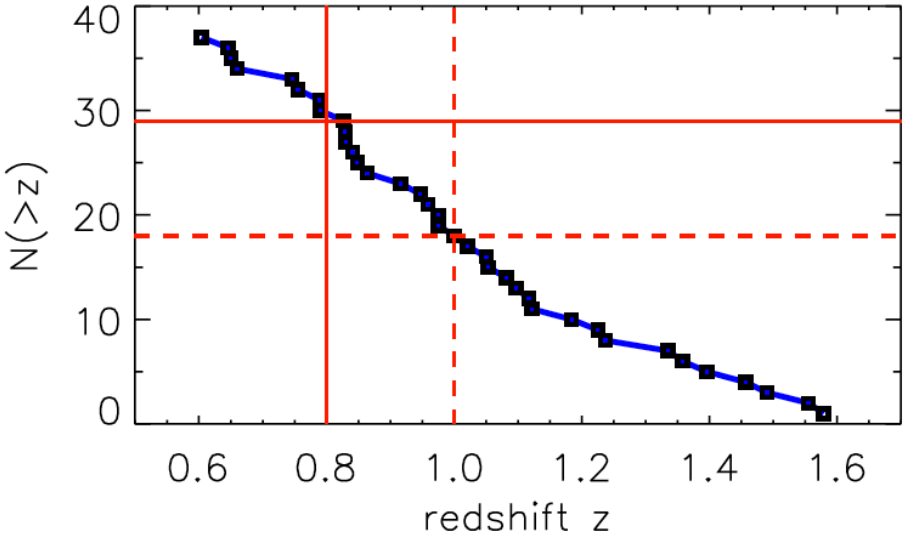
Current spectroscopic XDCP Cluster Sample

~50% of final sample

redshift histogram



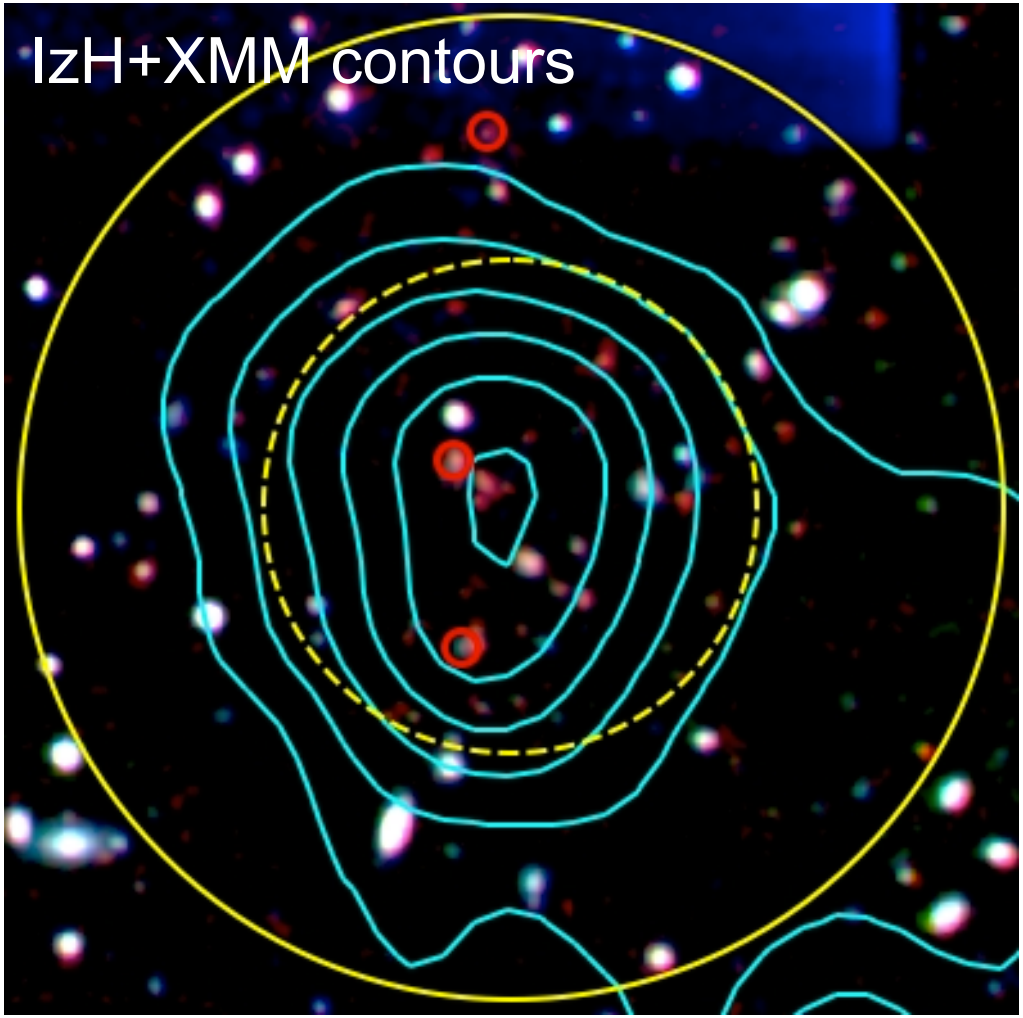
cumulative redshift distribution N(>z)



II. The most distant $M>10^{14}M_{sun}$ systems

I) XMMU J0044-20 at z=1.579

the most massive known cluster at z>1.5



$L_X^{(0.5\text{-}2keV)}=1.9\times10^{44}$ erg/s

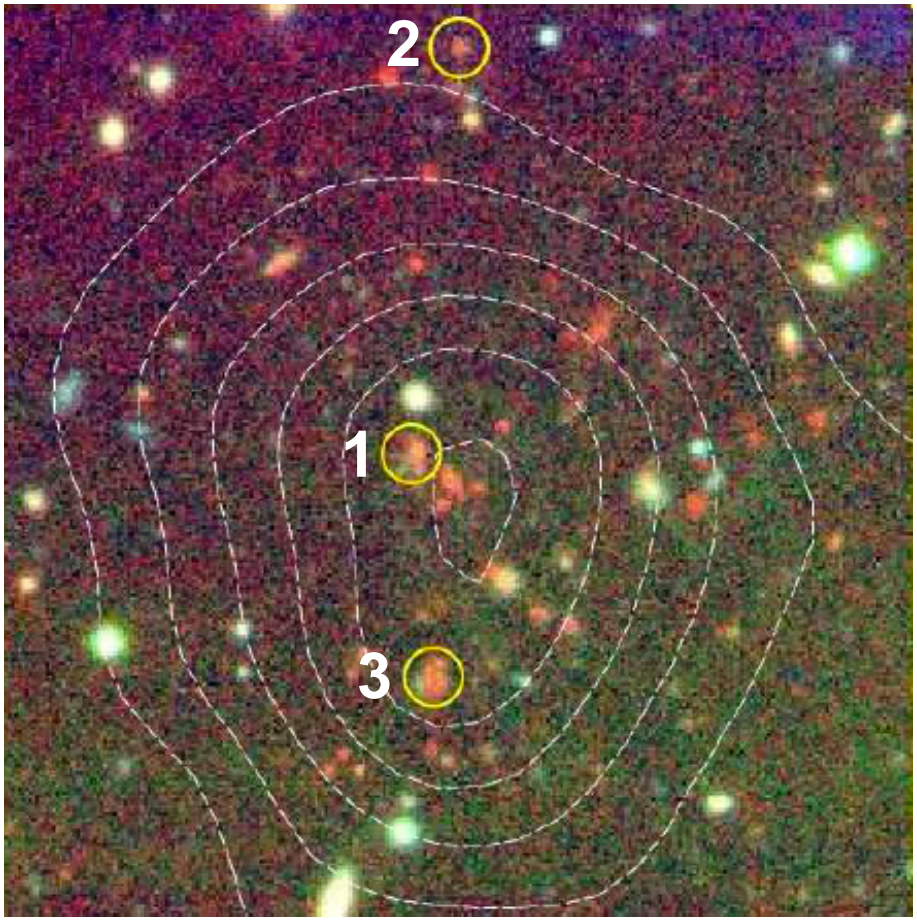
$L_{X,bol}=6.1\times10^{44}$ erg/s

$M_{200}\sim(3\pm1)\times10^{14}M_{sun}$

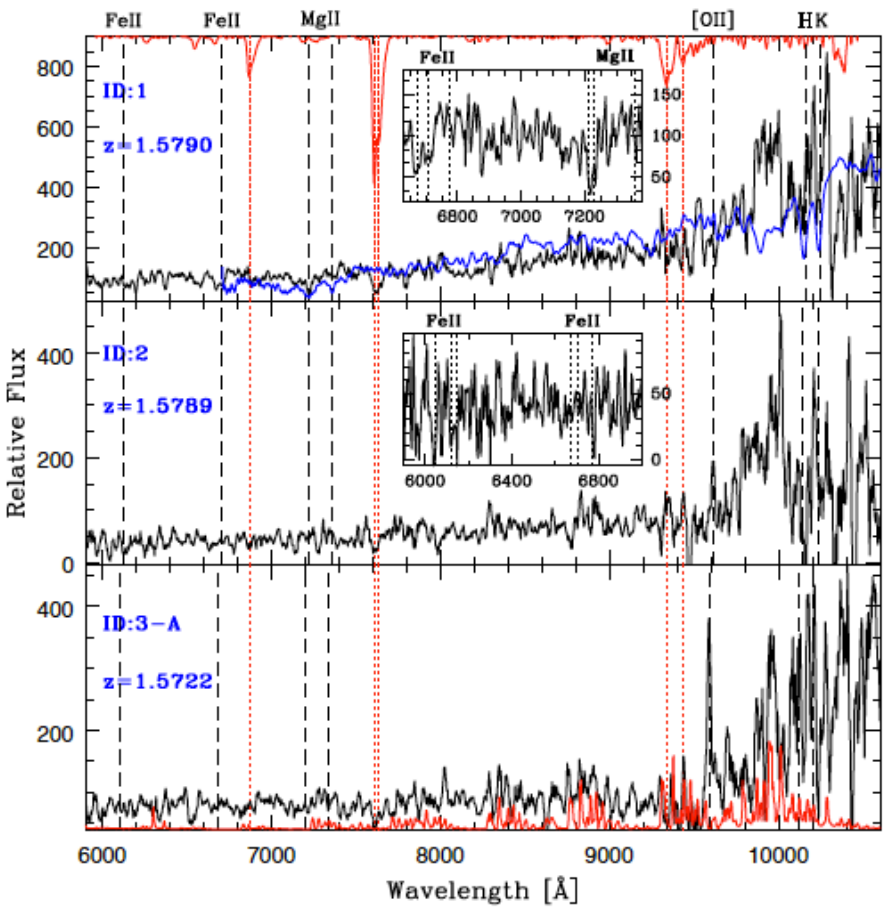
the 2nd least likely cluster in XDCP after XMMU J2235-2557

Santos et al., to be sumbitted

I) XMMU J0044-20 at z=1.579
massive galaxies in the making



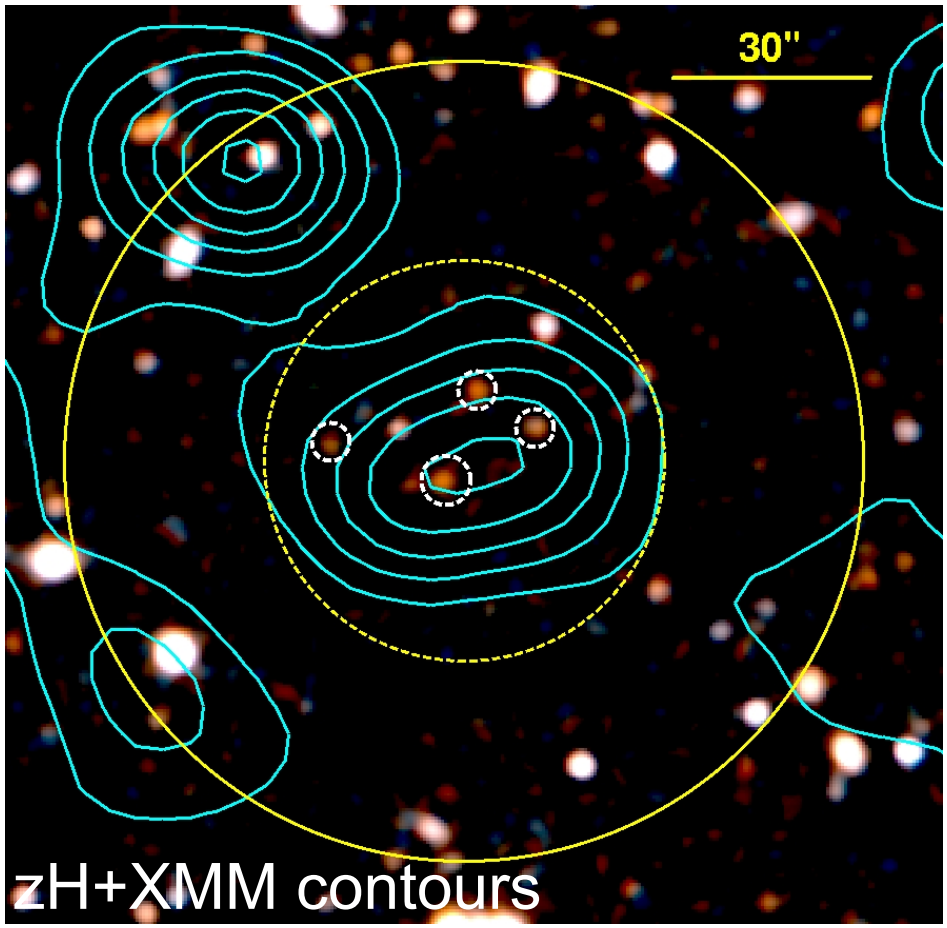
1.5'x1.5' IzH+XMM contours

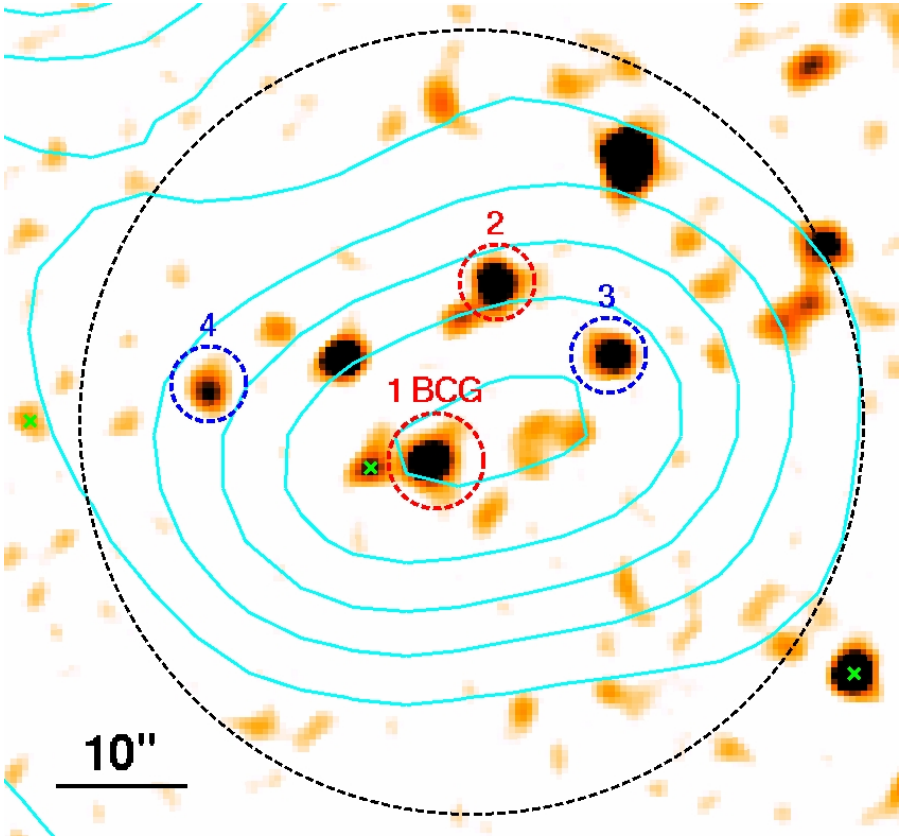


Santos et al., to be sumbitted

II) XMMU J1007.4+1237 at z=1.555

$L_{X,bol}=2.1x10^{44}$ erg/s, $M_{200}\sim2x10^{14}M_{sun}$



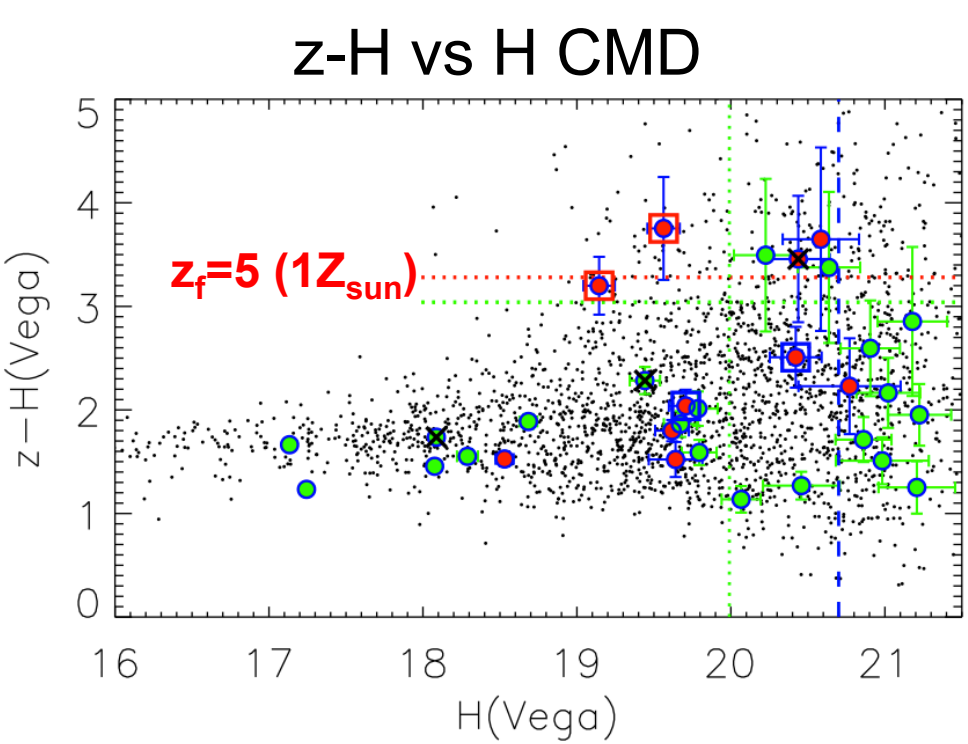


2.5'x2.5' z+H image with XMM contours

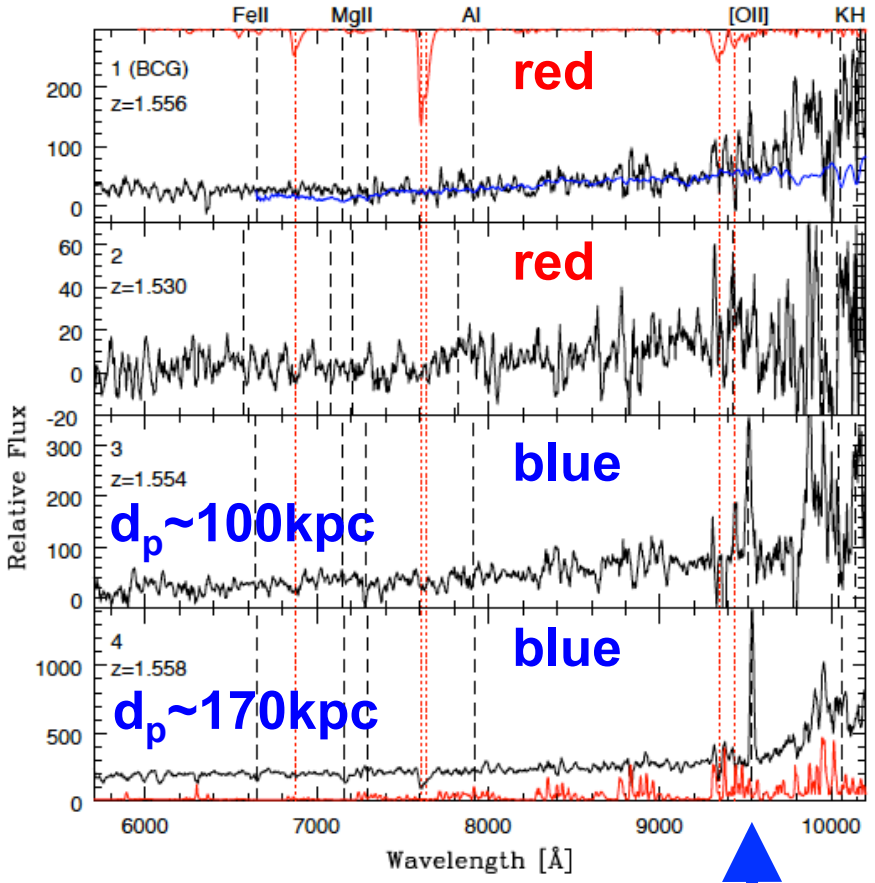
1'x1' H-band

Fassbender et al. 2011, A&A, arXiv:1101.3313

II) XMMU J1007.4+1237 at z=1.555
starburst activity in the cluster core



red: r<30” from X-ray center
green: 30” < r < 60”
squares: red/blue spectr. members

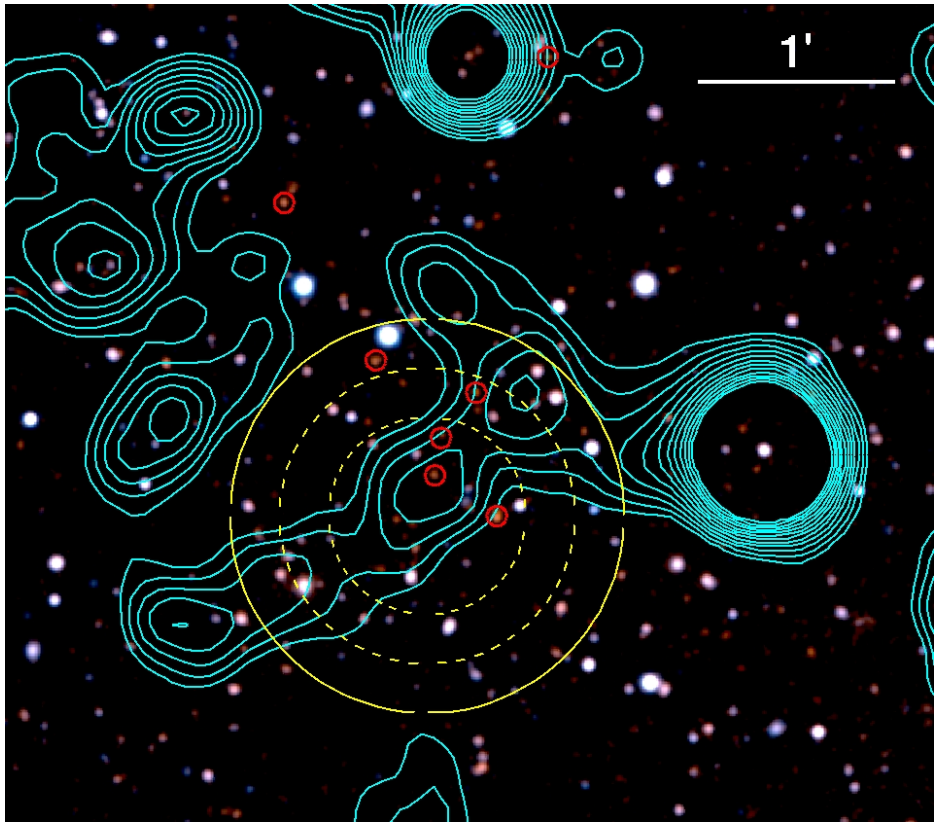


[OII]

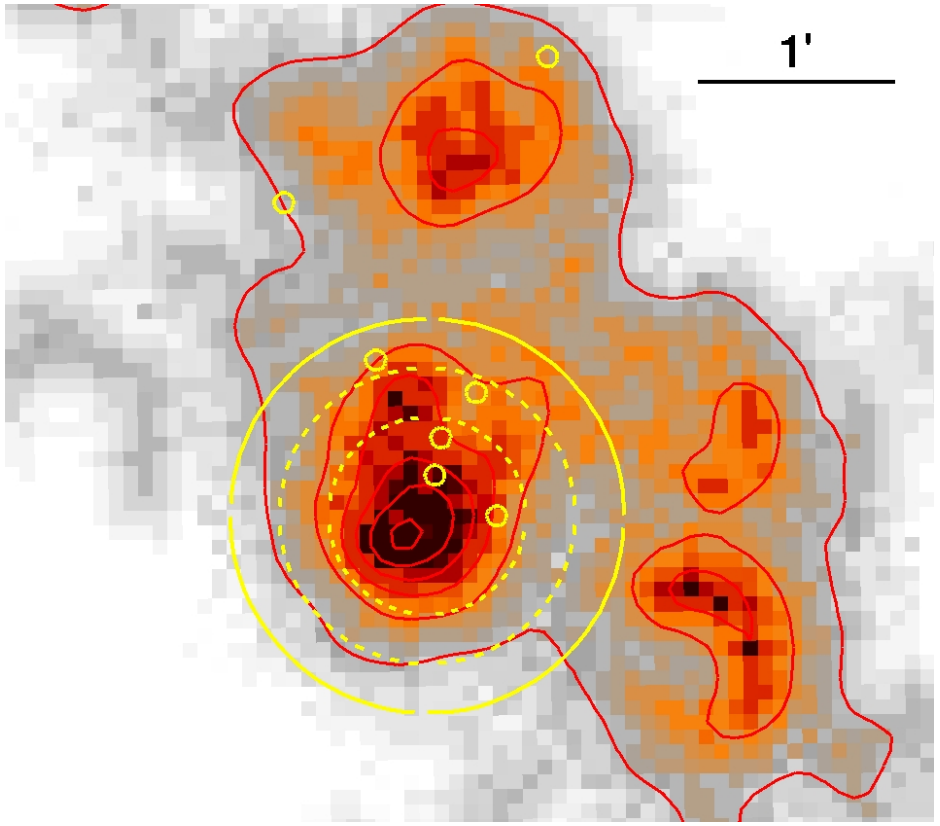
Fassbender et al. 2011, A&A, arXiv:1101.3313

III) XMMU J0338+00 at z=1.490

$L_{X,bol}$=1.2x10^{44} erg/s, M_{200}~1.4x10$^{14}M_{sun}$



4.5'x4' zH image
with XMM contours

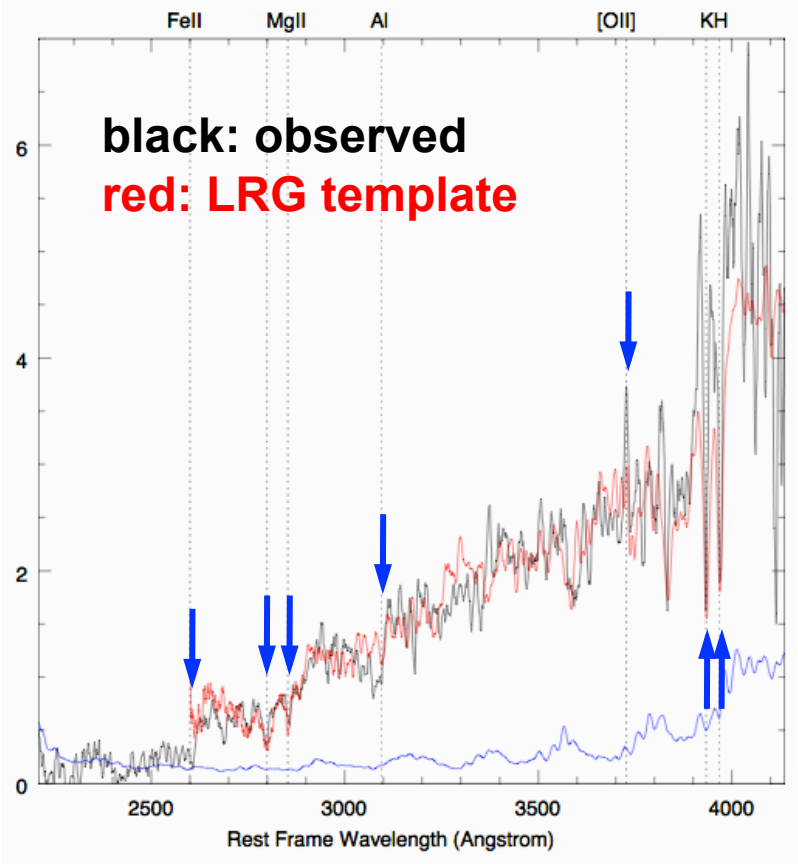


red galaxy density map with density contours (1-14σ significance)

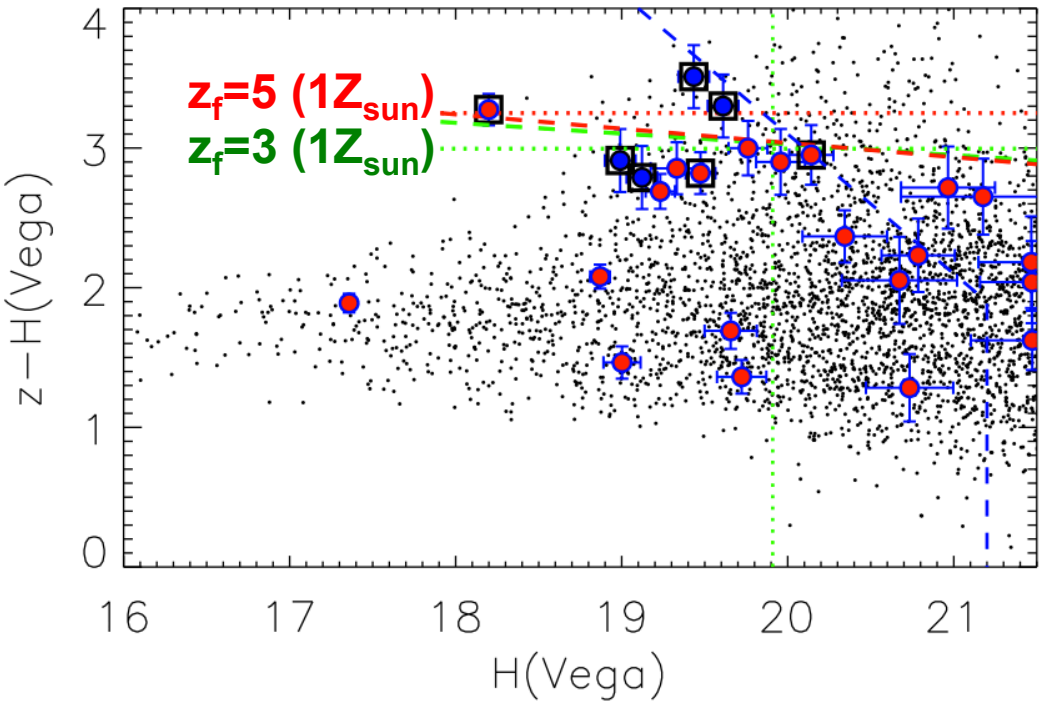
Nastasi et al., to be submitted

III) XMMU J0338+00 at z=1.490

stacked spectrum and color-magnitude diagram



restframe stacked spectrum of
7 secure members (black)

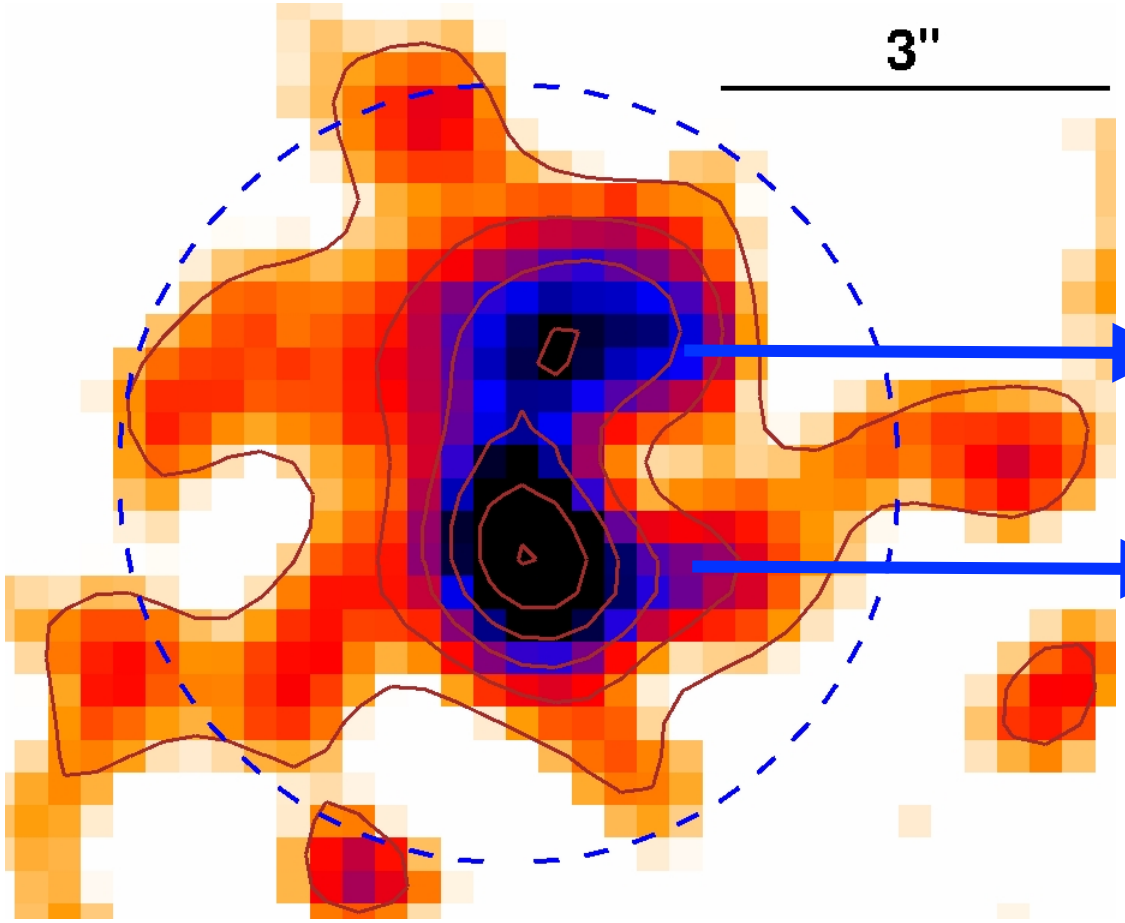


red: r<30” from X-ray center
blue: r>30” & spectr. member
black: spectroscopic members

Nastasi et al., to be submitted

III) XMMU J0338+00 at z=1.490

active assembly phase of the BCG



z=1.5053 (tentative)

z=1.5031

Δv~260km/s (tentat.)

VLT/FORS2 z band (0.7” smoothed)

Nastasi et al., to be submitted

III) XMMU J0338+00 at z=1.490
a 'light' cluster at the detection limit

Old & Evolved?	Young & Forming?
extended X-ray emission	weird morphology?
red-sequence present, low SFR for spectroscopic members	large color spread?
strong peak of red galaxy density	spatial density extensions out to r>1Mpc
bright passive BCG	BCG in assembly and off-center

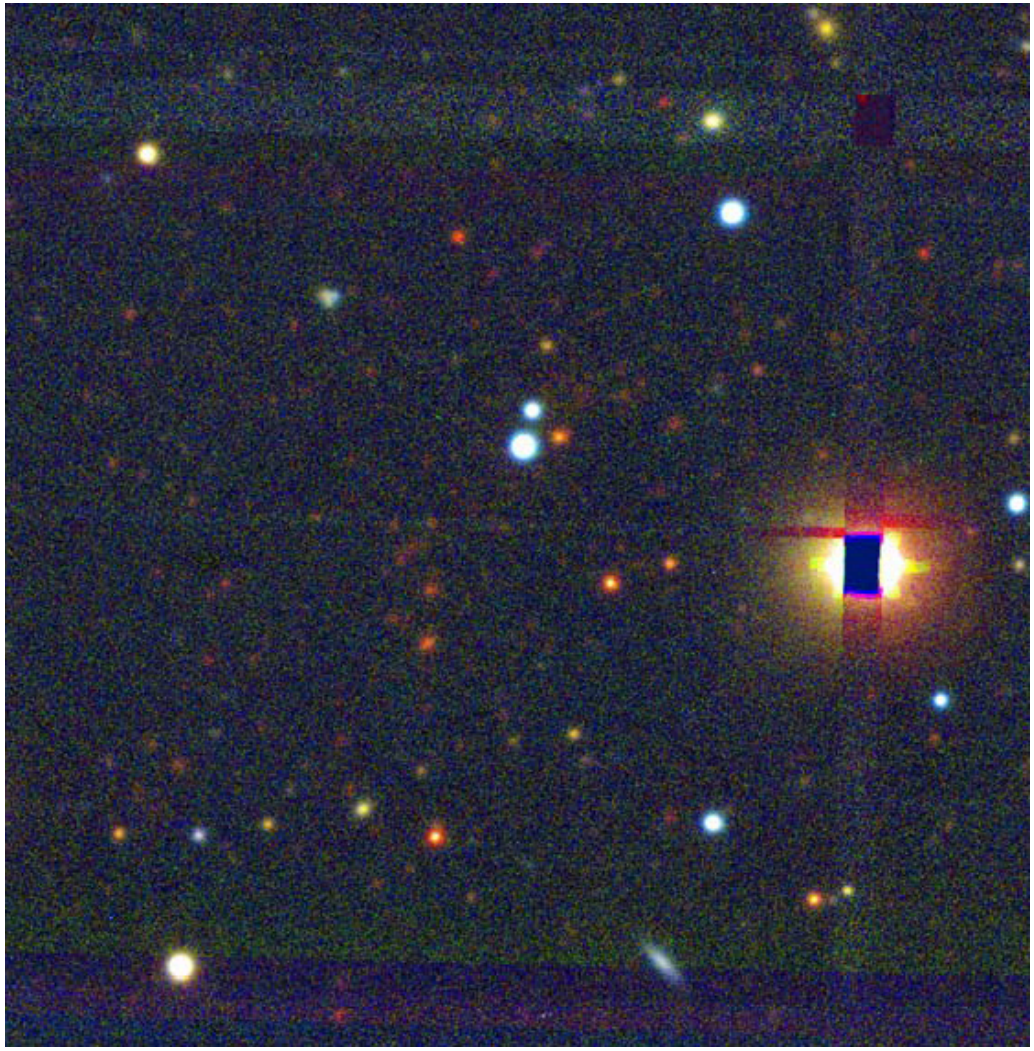
An evolved or a forming cluster???

Nastasi et al., to be submitted

III. What is a distant cluster?

Cluster Identification Exercise I

Who sees a z~0.8 cluster? How massive?

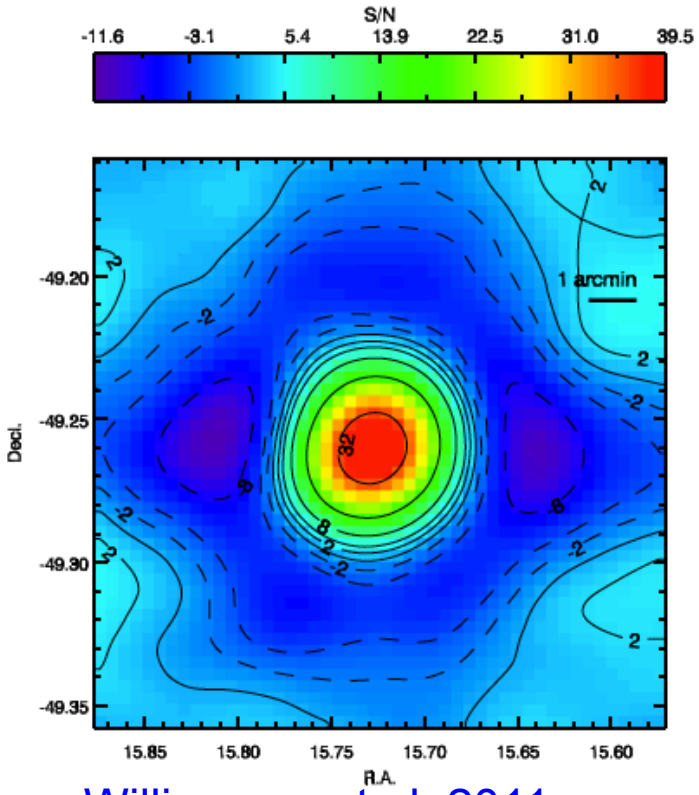


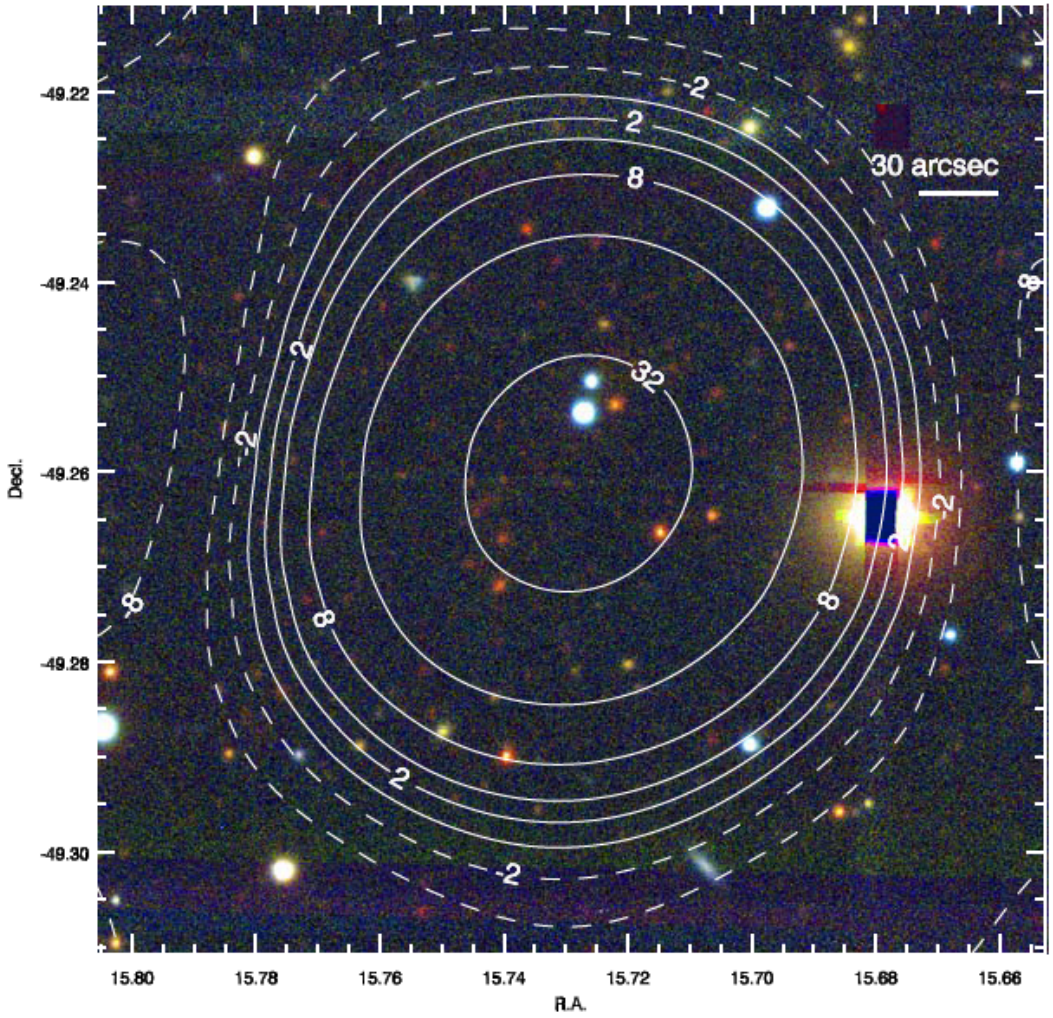
6’x6’ gri

SPT-CLJ0102-4915 at z_{phot}=0.78

$M_{SPT}=1.9x10^{15}\ M_{sun}$

How much of an optical counterpart would one expect or even require for massive systems?

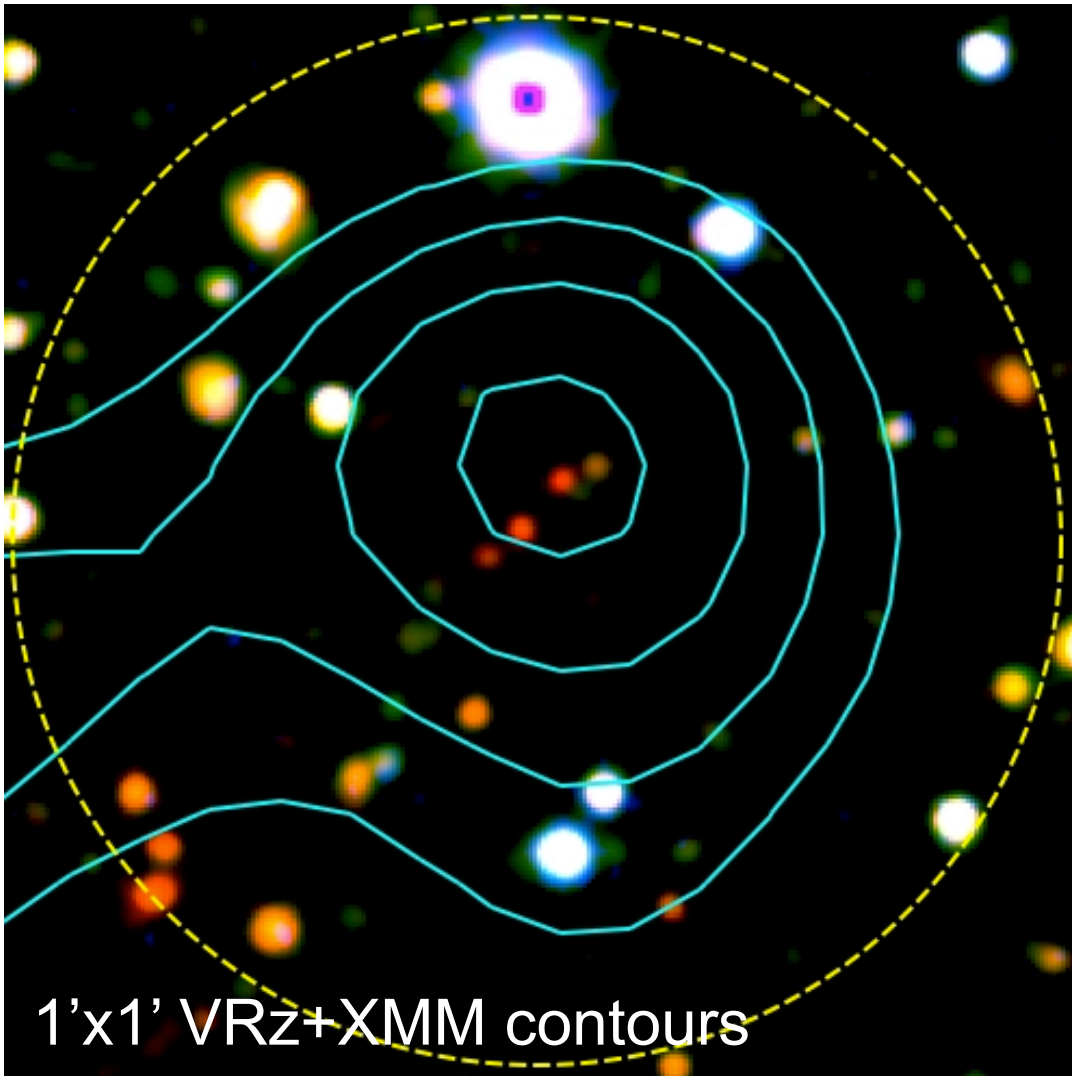




from Williamson et al. 2011

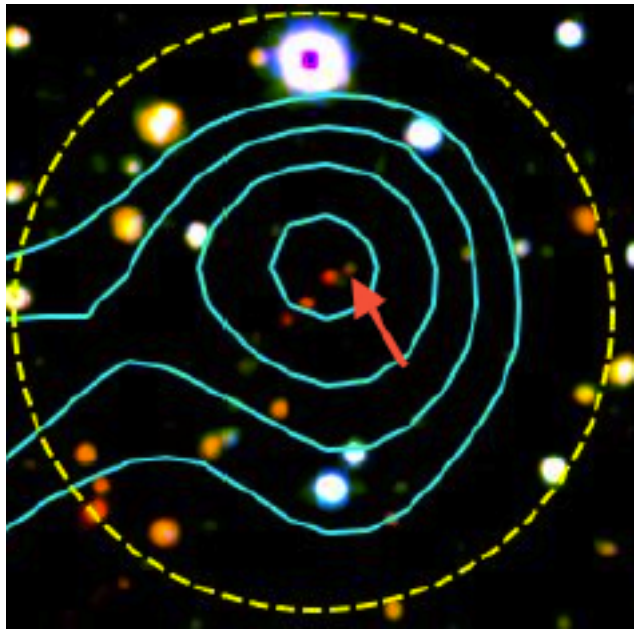
Cluster Identification Exercise II

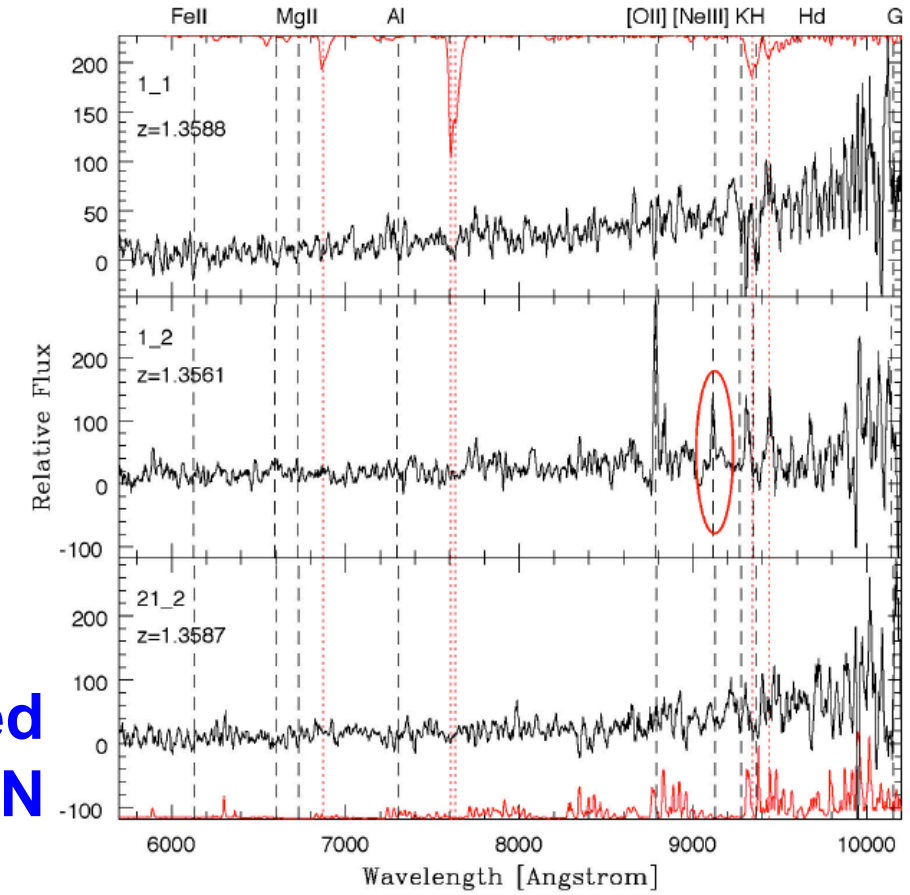
z=1.36: Cluster? Group? How massive?



Cluster Identification Exercise II

XMMU J1532.2-08 at z=1.358





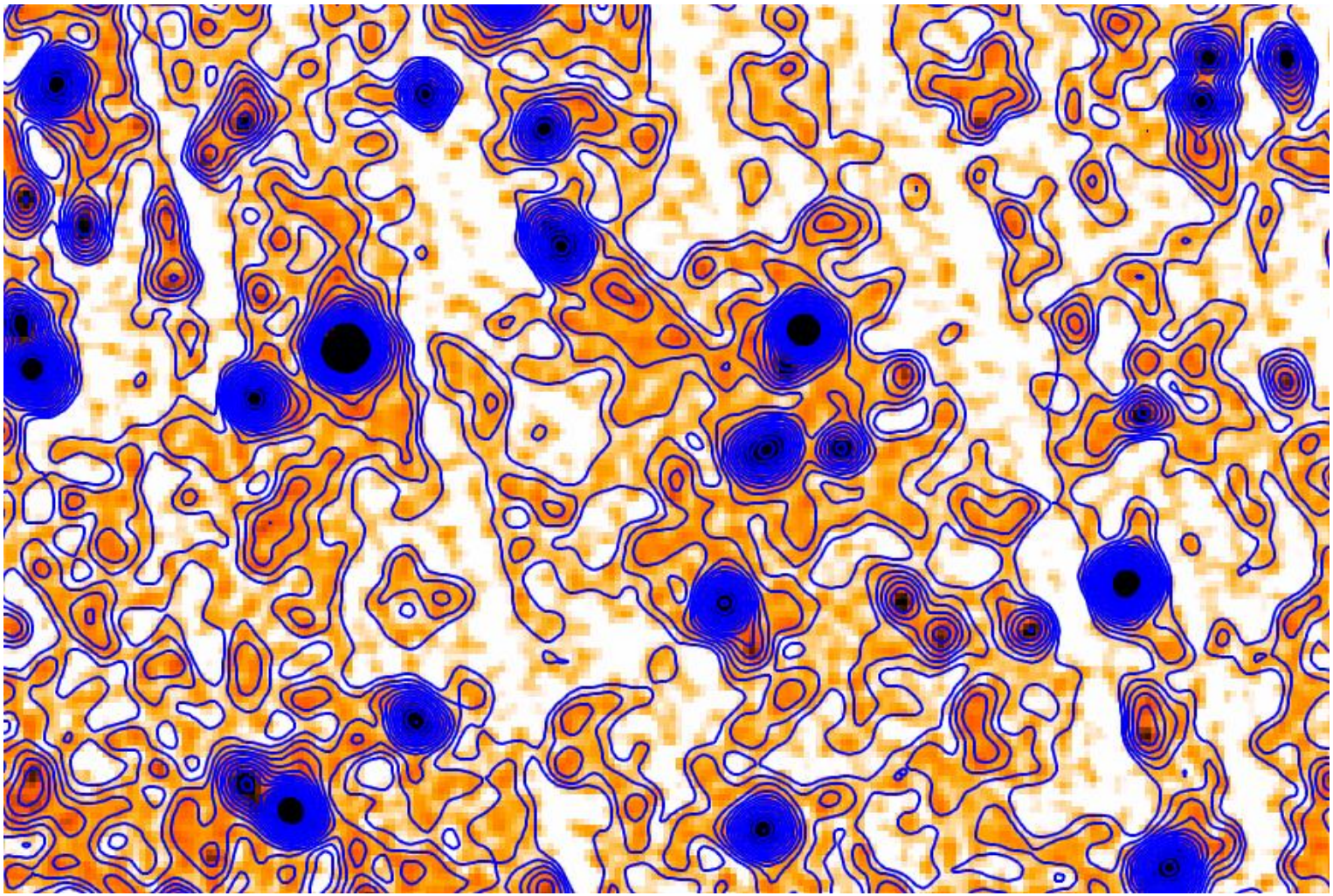
a spectroscopically confirmed system with an obscured AGN

$M_{200}<1.4x10^{14}\ M_{sun}$

Suhada et al., to be submitted

Cluster Identification Exercise III

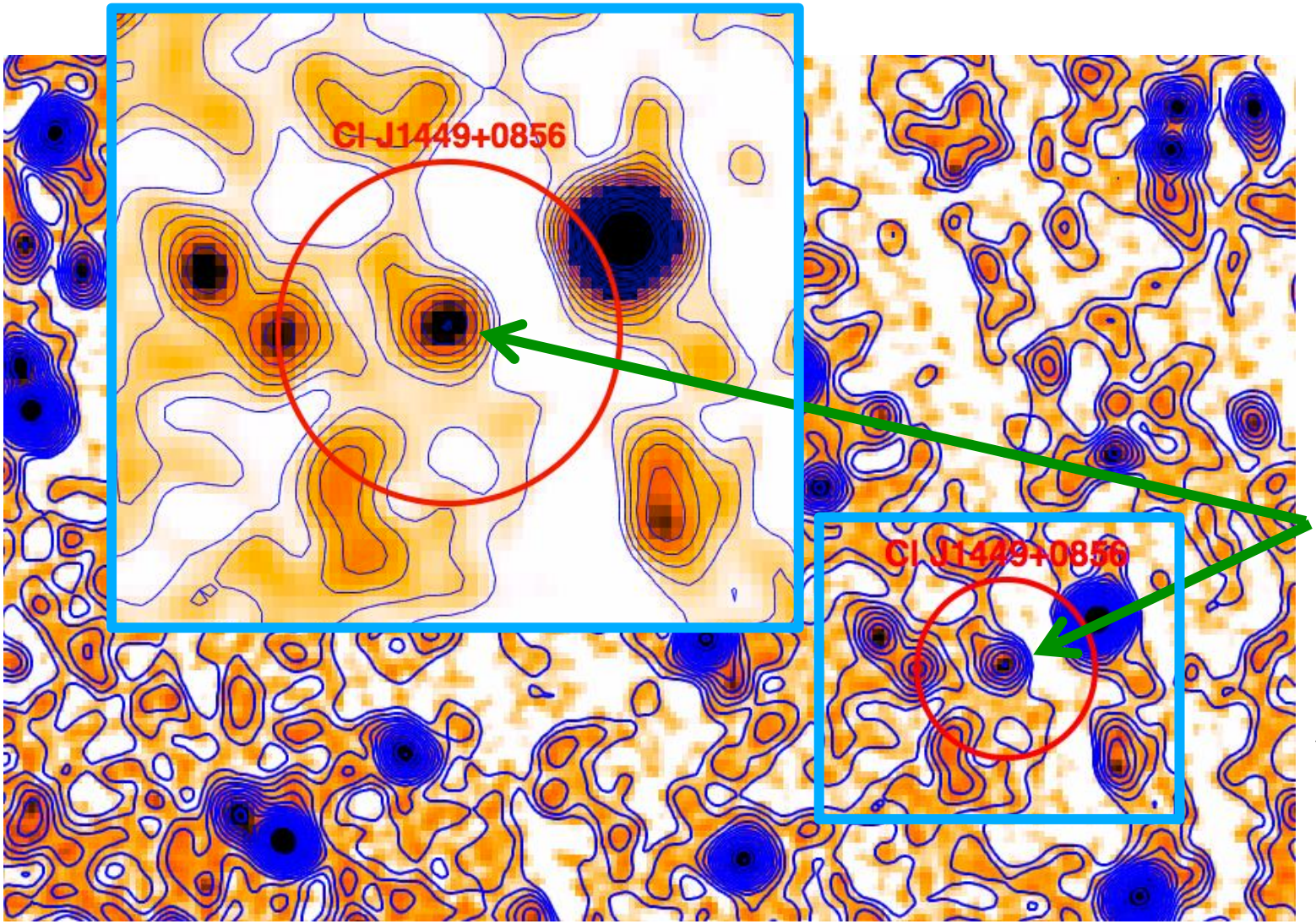
Selection of the z=2.07 cluster in X-rays?



35ksec XMM data 14'x10'

Cluster Identification Exercise III

X-ray selection not possible (f_X<10^{-15}erg/s/cm^2)



point source

35ksec XMM data 14'x10'

XDCP Working Definition
for a confirmed distant galaxy cluster

A cluster is confirmed when all of the following is true:

1. blind detection of (significantly) extended X-ray emission in XMM-Newton data
2. presence of an overdensity of red galaxies coincident with the X-ray emission
3. a minimum of 3 concordant spectroscopic redshifts of associated galaxies

What do people call a distant cluster? What should be called a proto-cluster?

- spectroscopic overdensities around z>1.5-2 radio galaxies → usually proto-cluster
- Kurk+09: overdensity of spectroscopic reshifts+ NO X-ray emission in CDFS →proto-cluster or future cluster
- photometric & spectroscopic overdensities with subsequent detection of extended X-ray (residuals) at any z →cluster
- Spitzer selected photo-z overdensities with spectroscopy at any z → cluster
- red sequence with photo-z at any z → often called cluster

When is a distant group a cluster, and when is it massive?

1. How much observational evidence should there be before a candidate system at z>1 is a confirmed cluster? (X-ray, spectroscopy, RS, photo-z, galaxy overdensity...)

2. When should z>1 systems be called clusters, when groups? ($M_{200}>10^{14}M_{sun}$ at any redshift for clusters?)

3. When is a distant z>1 (z>1.5) cluster to be called massive? ($M_{200}>3x10^{14}M_{sun}$, M>M*(z)?)

IV. Summary and open questions

Summary...

1. The XDCP has compiled the largest sample of z>0.8 X-ray luminous galaxy clusters to date, with currently 31 spectroscopically confirmed systems at 0.78<z<1.58 spanning about a factor of 10 in cluster mass
2. Currently around 60 z>0.8 confirmed galaxy clusters are in the literature, with accelerating discovery rates that will soon reach 100
3. The Top10 list of confirmed clusters/groups currently spans the redshift range 1.39≤z≤2.07 with XMMU J2235-2557 (z=1.39) and XMMU J0044-20 (z=1.58) being the most massive and unlikely systems
4. The most distant confirmed clusters with $M_{200}>10^{14}\,M_{sun}$ are currently the XDCP systems XMMU J0044-20 at z=1.58, XMMU J1007+1237 at z=1.56, and XMMU J0338+00 at z=1.49
5. At z≥1.5 the cluster galaxy population seems to be undergoing major changes compared to lower-z systems (SFR, galaxy assembly, RS,...)

...and Open Questions

The currently used terminology related to distant systems is very diffuse and confusing, some streamlining would definitely help to improve clarity:

1. How much overvational evidence should there be before a distant candidate systems is a confirmed cluster/group?
2. What should be called proto-cluster and what is a ‘real’ distant cluster based on the available observations?
3. At what mass should a z>1 galaxy system be called a cluster, when a group?
4. When is a cluster to be safely called ‘massive’ as a function of redshift?