Dusty star-forming galaxies in the XMM-LSS cluster sample

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Context — Star formation in clusters

Local Universe

Well established results:
Star formation is suppressed in clusters (Kennicutt 1983, Gómez+ 2003).
No LIRGs are found in clusters.

Universe at z ~ 1

Enhanced star formation activity within higher density environments like groups (e.g. Elbaz+ 2007, Marcillac+ 2008).

Intermediate redshifts: the obscured side of star formation

LIRGs found in individual clusters
ISO observations: e.g. Duc+ 2002, 2004; Coia+ 2005;
Spitzer observations: e.g. Geach+ 2006; Marcillac+ 2007; Bai+ 2008; Haines+ 2009
AKARI observations: e.g. Koyama+ 2008
... suggest an **IR equivalent to the Butcher-Oemler effect**

Increasing fraction of 24 μm cluster galaxies with SFR > 4 Ms/yr from 3% @ z~ 0.02 to 13% @ z~0.8 (8 clusters, Spitzer data, Saintonge+ 2008). Evidence of excess of far-IR galaxies in 66 SDSS clusters @ <z> ~ 0.25 (Herschel-ATLAS, Coppin+ 2011).

Possible triggering mechanisms?
Pre-processing in infalling groups (e.g. Cortese+ 2006, Boué+ 2008);
Ram-pressure stripping combined with interactions (e.g. simulations by Kronberger+ 2008 and Martig & Bournaud 2008). ...

Investigating the IR Butcher-Oemler effect within the XMM-LSS C1 cluster sample: Is there a significant excess of mid-IR sources at given cluster radii?

Goal

Exploring **dust-enshrouded star formation** (and/or activity) out to the **cluster periphery** and its **evolution** with redshift as compared to the field.

Method: statistical approach

Studying the distribution of 24 μm-selected sources in a statistically significant, well-defined cluster sample and a sample of control fields extracted from the same dataset.

Single-band mid-IR emission correlates well with total L_{IR}
=> tracer of SF (e.g. Takeuchi+ 2005, Dale+ 2005).

We derive L_{IR} from F(24 μm) by using Chary & Elbaz (2001) templates → this is reasonable in our redshift range, up to z~1.

XMM-LSS cluster sample

"C1" sample (Pacaud+ 2007, Adami+ 2011, Clerc+ in prep.) over the 10 deg^2 of the XMM-LSS, a surface brightness limited survey.

Selection criteria: X-ray extension > 5"; extension likelihood > 33; detection likelihood > 32.
Cluster confirmation based on optical photometry and spectroscopy.

Redshift range: z ~ 0.05 – 1.05

Temperature range: ~ 0.6 – 4 keV

M_{500} range ~ 10^{13} – $2x10^{14}$ $M_{\odot}$

Advantages

- X-ray selected clusters over a contiguous area of the sky;
- Well known selection function (Pacaud+ 2007);
- Spitzer/SWIRE (Lonsdale+ 2003) IRAC+MIPS mapping (~ 9 deg^2)

=> Suited for statistical studies out to cluster periphery

- Sample of control fields from the same dataset;
- Availability of multiwavelength data, in particular:

CFHTLS u*g'r'i'z' photometry => photometric redshifts with Le_Phare (Ilbert+ 2006, McCracken+ 2008 using T03 release).

Enlarged C1 sample: 37 clusters over ~ 10 deg² of XMM-LSS out of which:

33 with Spitzer-MIPS data and **25** within CFHTLS W1 field with photo-z based on 5-bands (Ilbert, Le_Phare)

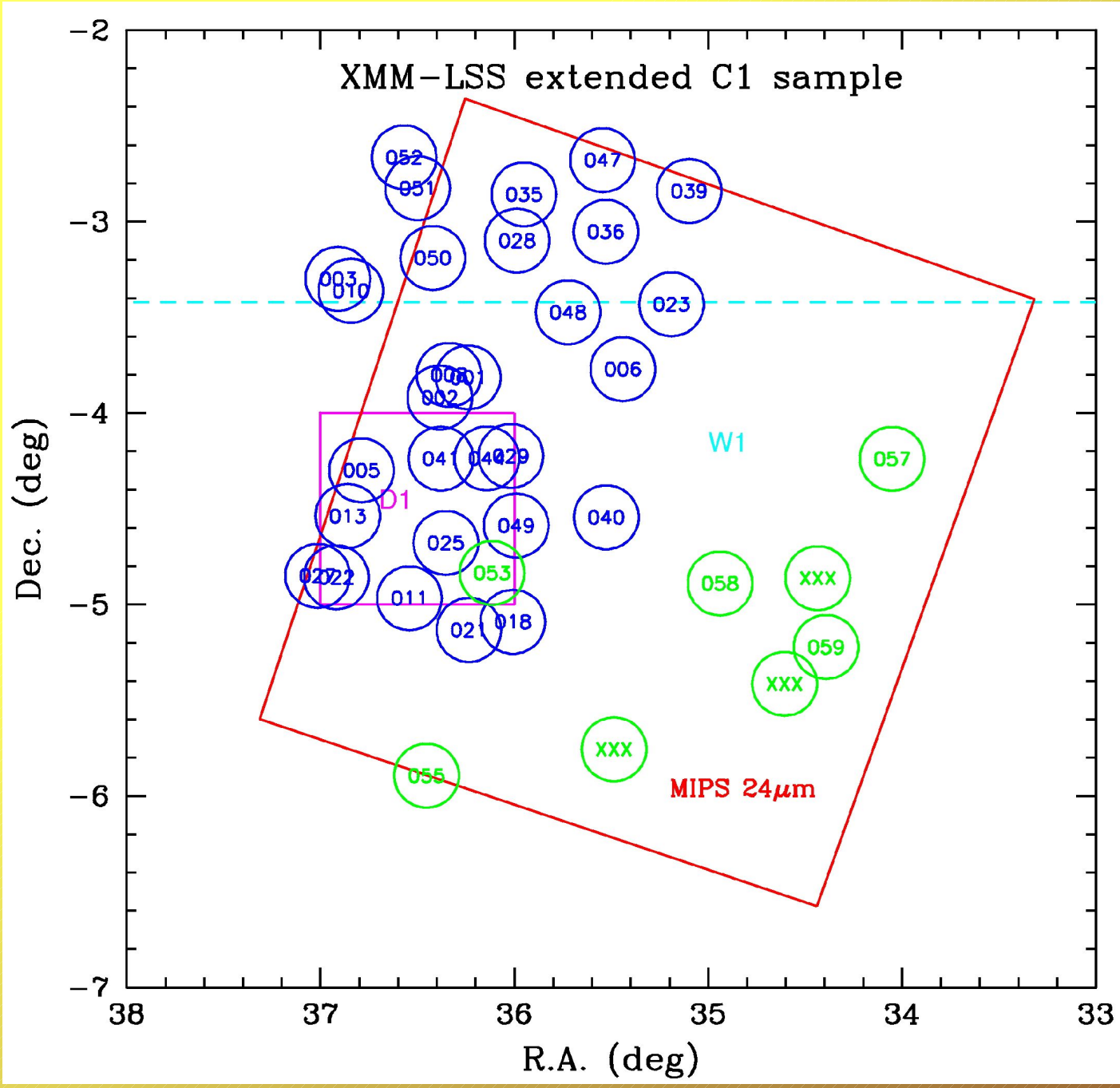
Selection of 24μm sources:

from SWIRE-XMM 2008 band-merged catalogue

F_{24} > 180 μJy (with optical or IRAC counterpart, otherwise F > 400 μJy)

r < 10' centered on X-ray position

Same selection applied to randomly chosen **control fields** with available photo-z over the survey area free of X-ray clusters.



Distribution of 24 μm sources

Azimuthally averaged, projected surface density profiles of 24 μm sources.
Surface densities are computed within 100 kpc-wide cluster-centric annuli.

Individual clusters: the profiles suggest the presence of an excess of sources in some cases, but the signal is too weak (Temporin+ 2008, arXiv: 0810.5499).

Improve the signal through stacking!

two alternatives:

1) Stacked density profiles with a statistical subtraction of fore/background sources (Temporin+ 2009, AN 330, 915).

2) Stacked density profiles after pre-selection of sources according to photo-z.

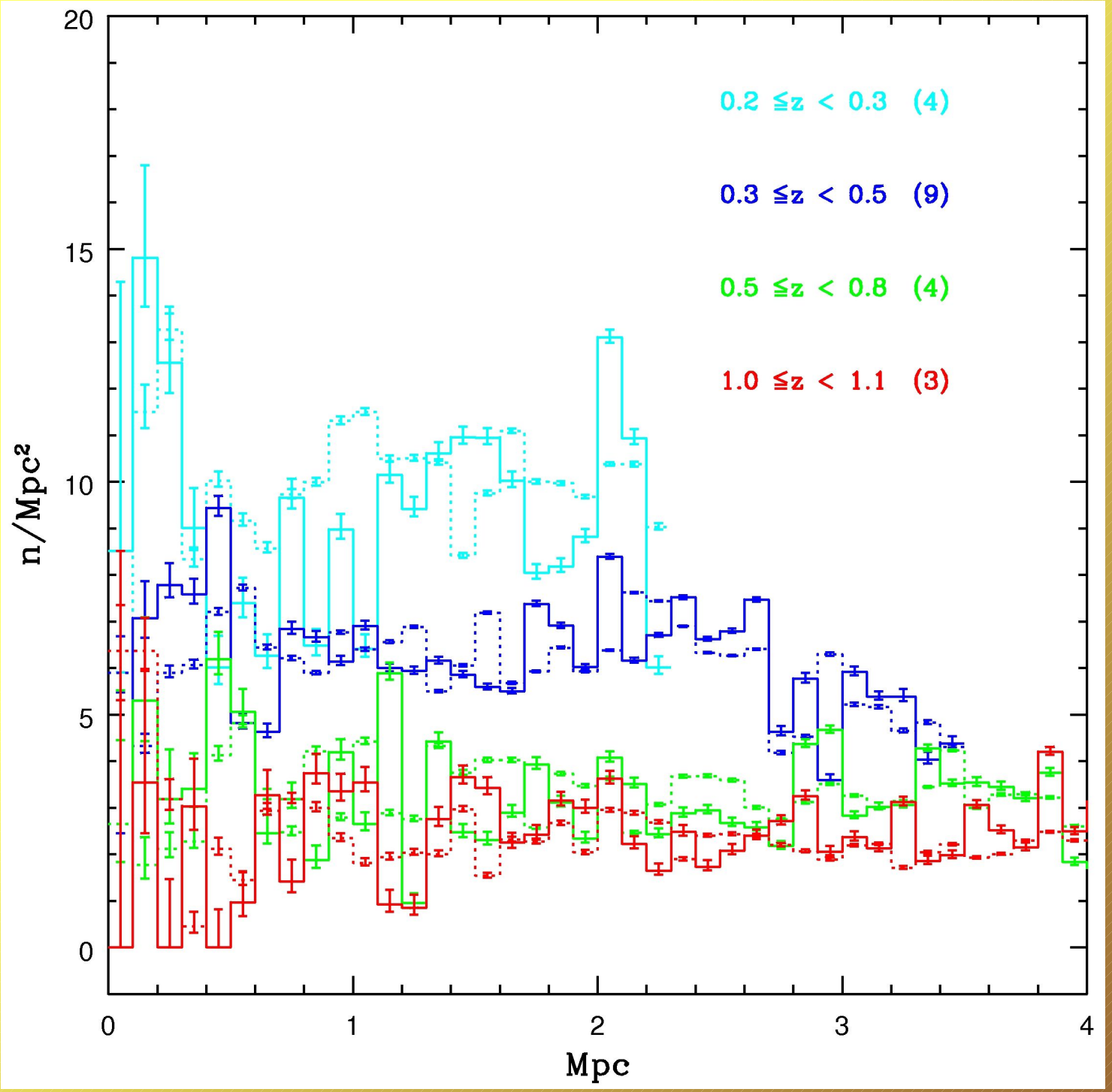
Results with method of statistical background subtraction

Stacked density profiles in 4 redshift bins for **clusters** (solid lines) and **field** (dashed lines)

Only mid-IR sources with flux > 5σ

Clusters whose areas significantly overlap have been discarded

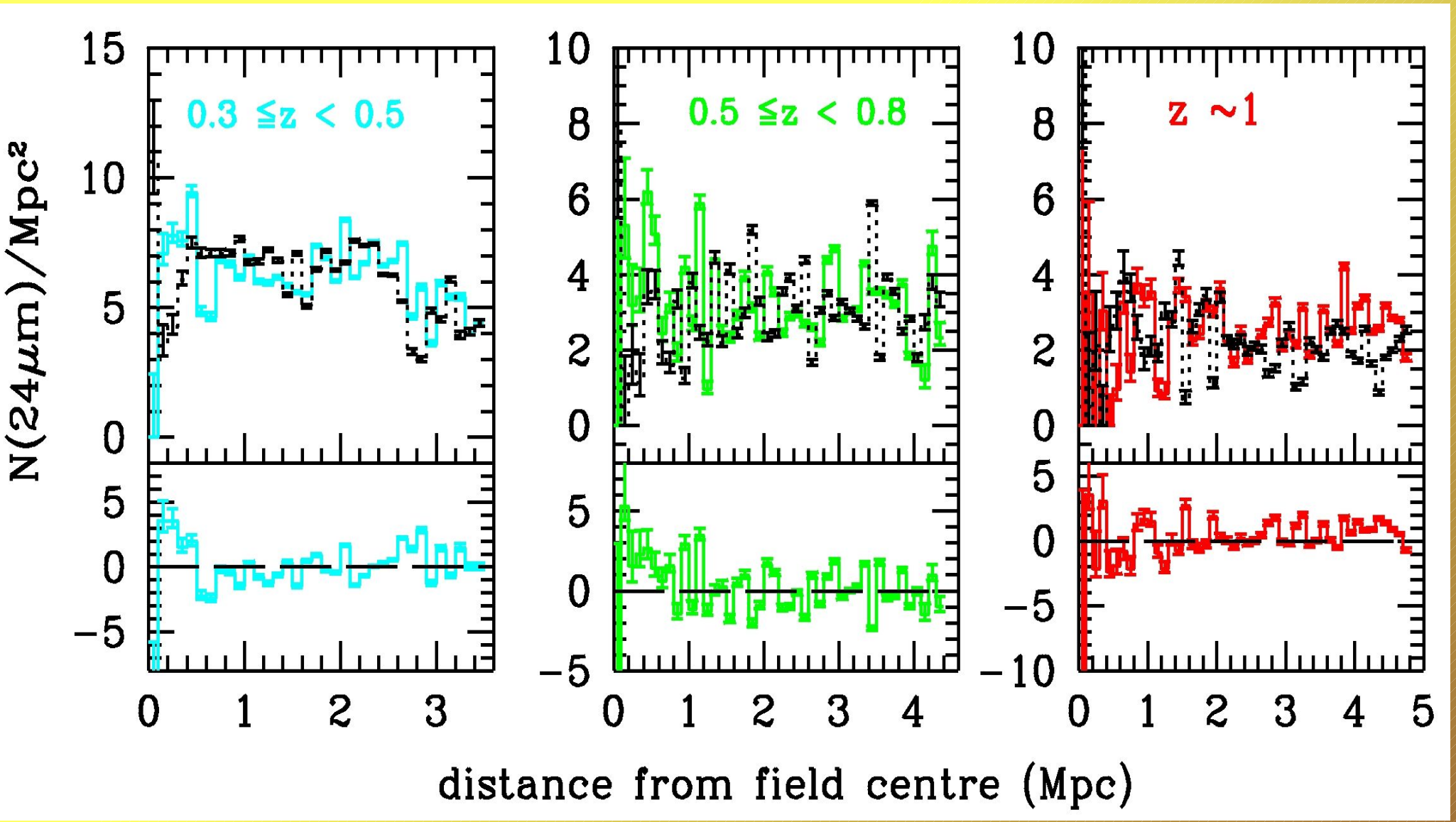
Weak **excess density of 24 μm sources at z > 0.3 for radii 200 – 500 kpc.**



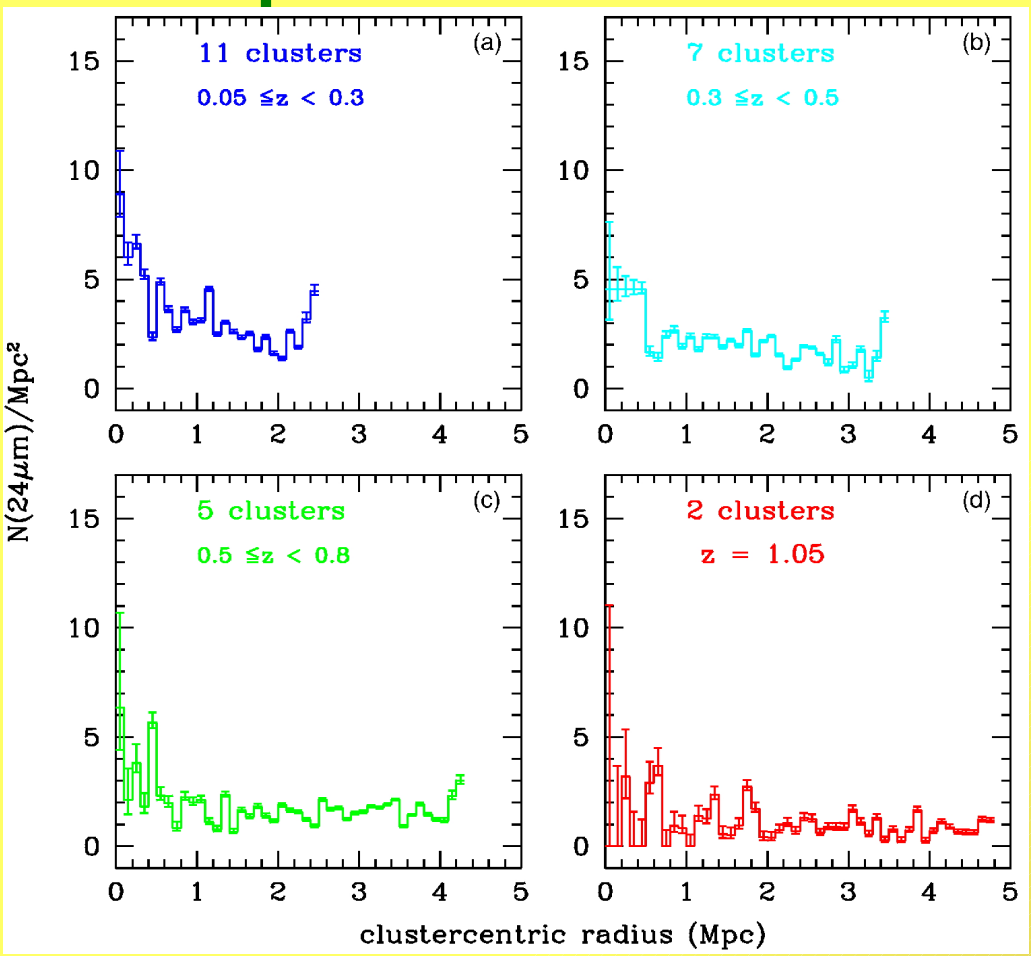
Temporin et al. 2009, AN 330, 915

Subtraction of statistical background from cluster profiles

Excess of ~ 3 sources/Mpc^2



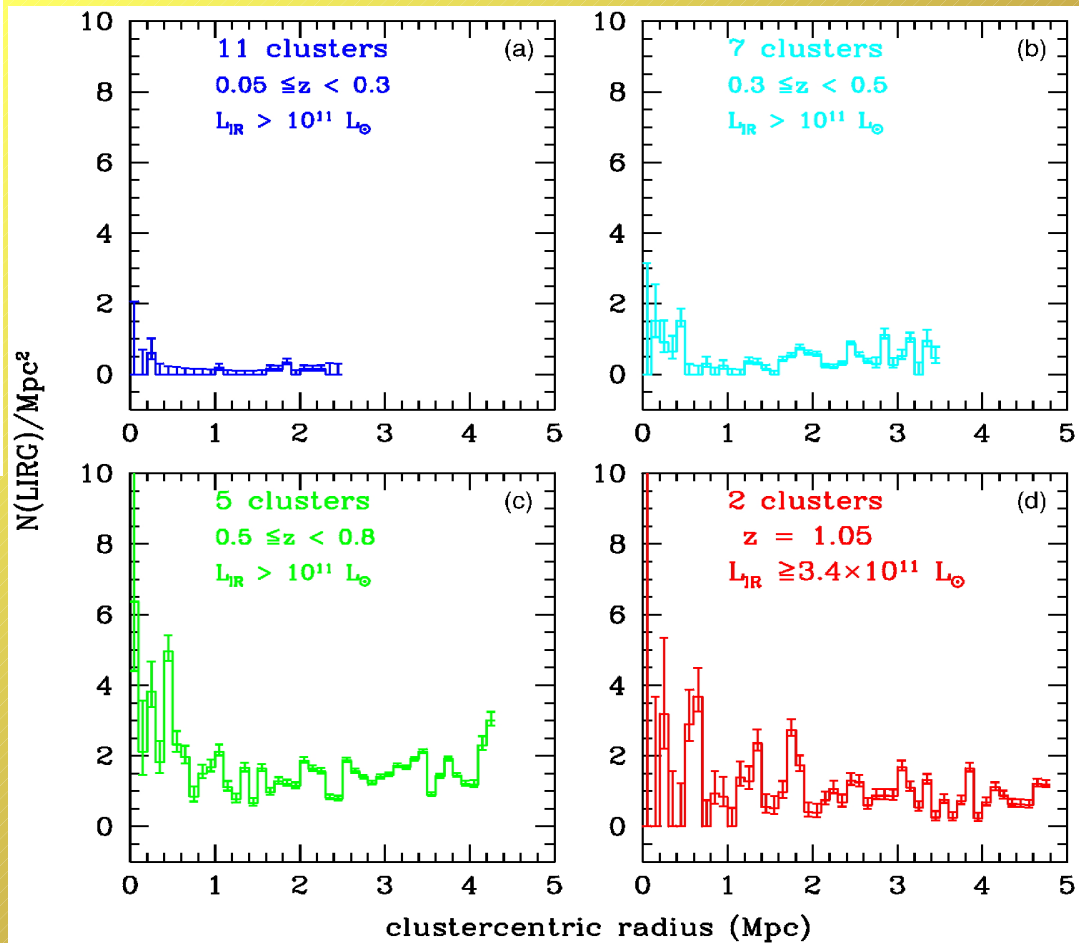
Stacked density profiles after **pre-selection** of candidate members **with photo-z**



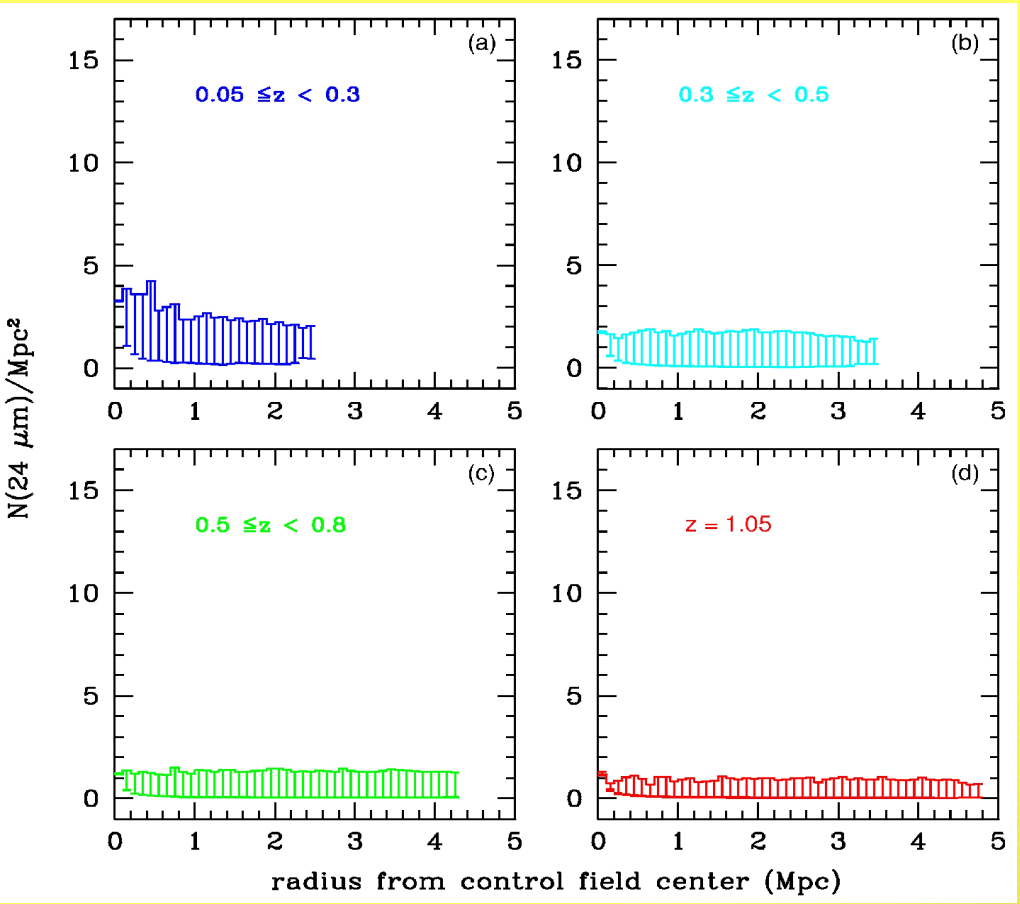
24 μm sources with photo-z compatible with cluster membership (accounting for $\sigma_{\Delta z/(1+z)}$ ~ 0.05 and 3000 km/s velocity dispersion) out to 10'-radius.

All sources

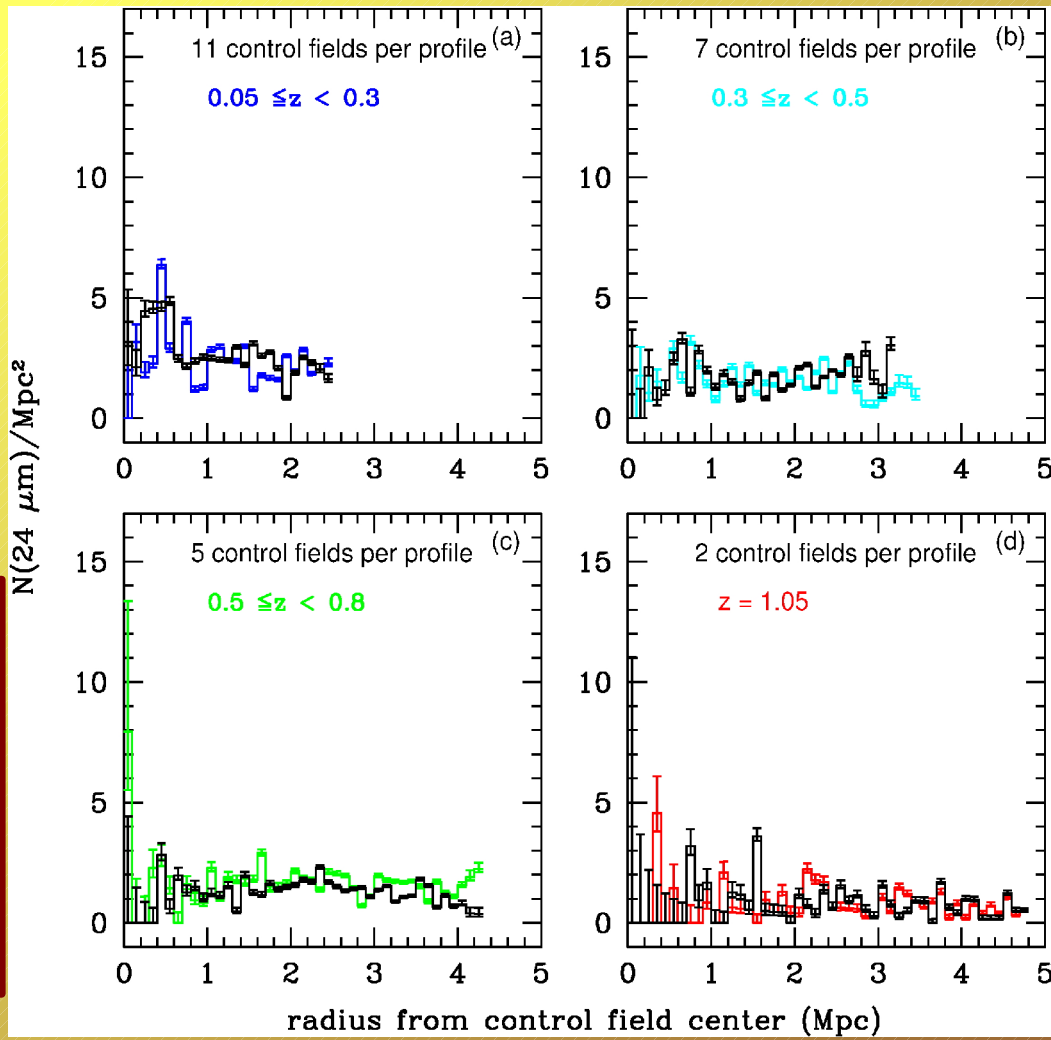
Only LIRGs and ULIRGs



Comparison with control fields



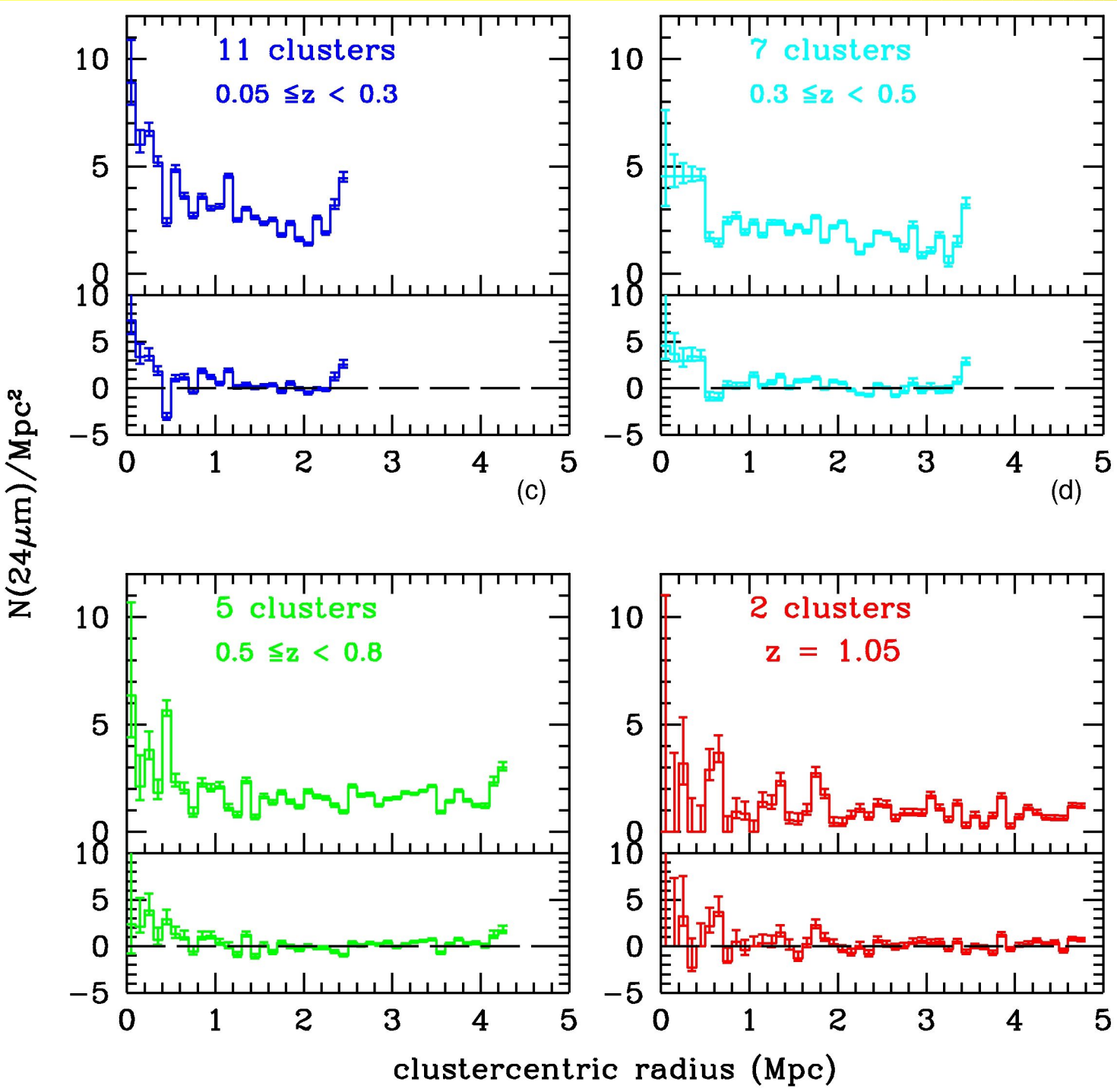
Stacked density profiles for 82 control fields after pre-selection of 24 μm sources within the same redshift intervals used for clusters. Distributions are flat with typical densities of 1 – 2 IR sources/Mpc^2



Stacked density profiles for 2 subsamples of 16 control fields (one in black, one in colour). The number of control fields and the redshift distribution match those of clusters in each redshift bin.

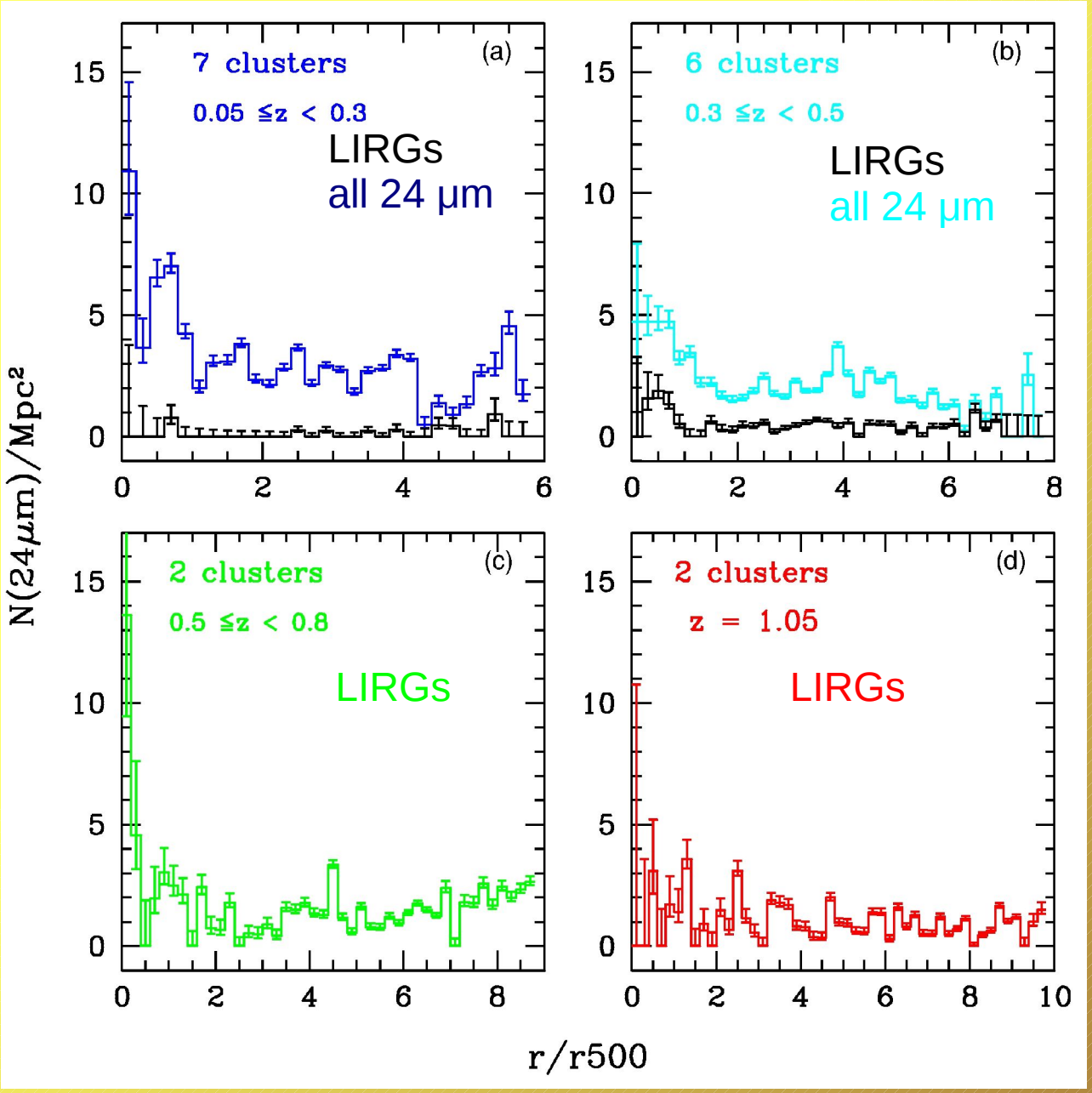
Oscillations are smaller than the density peaks @ r < 1 Mpc for clusters in the 2 medium-z bins.

Cluster profiles before and after subtraction of the average field distribution

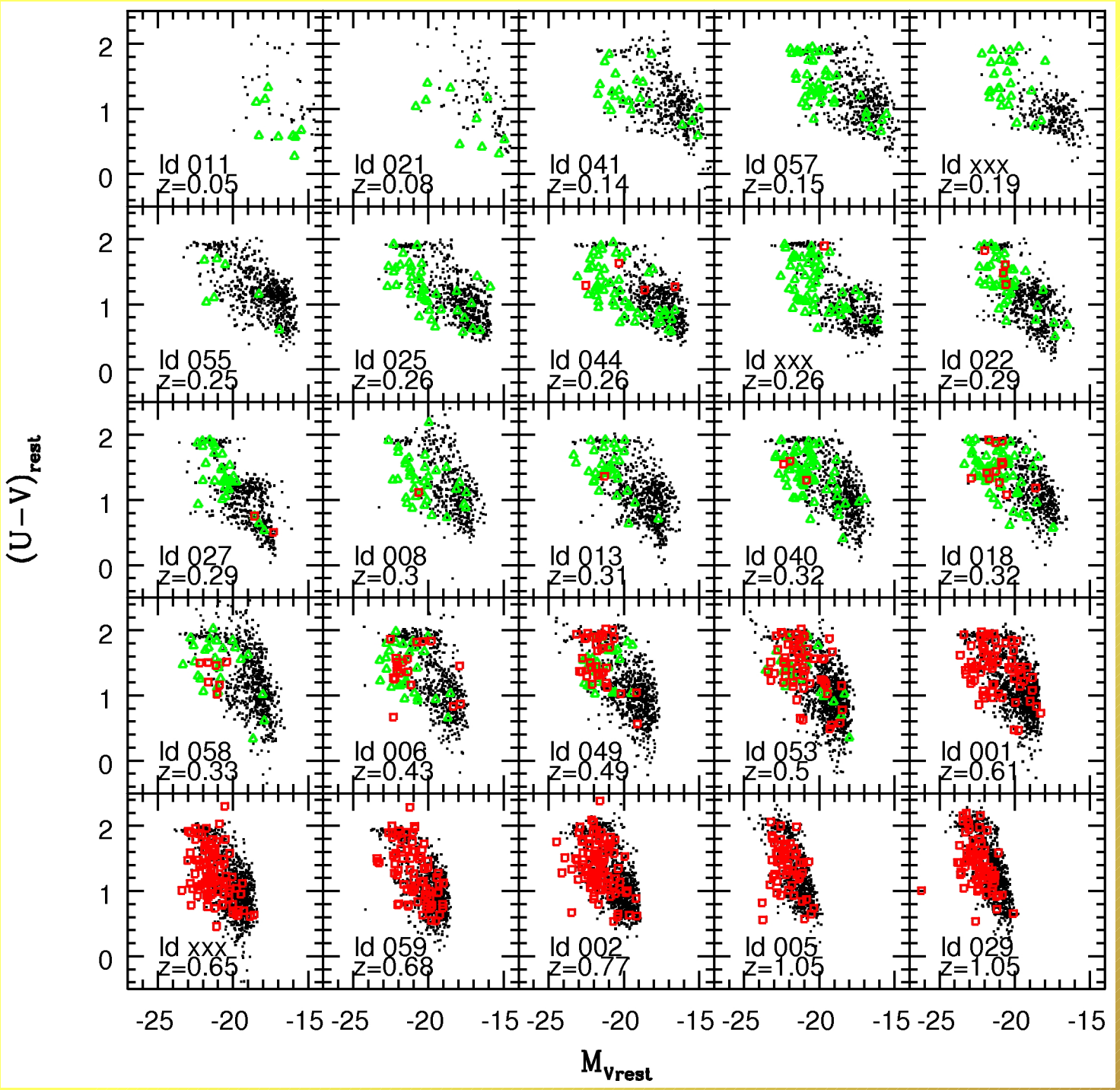


Density profiles on physical cluster scales

Mid-IR source counts in annuli of width 0.2 * r_{500} centred on cluster X-ray position.
Subsample of 17 clusters with completed X-ray analysis.



Rest-frame Color-Magnitude Diagrams



black: optical sources

green: 24 μm sources
$L_{IR} < 10^{11}$ Lsun

red: 24 μm sources
$L_{IR} > 10^{11}$ Lsun

Photo-z pre-selection reduces efficiently fore/background contamination.

MIR sources mainly in green valley.
Some MIR sources on red sequence.
Consistent with dusty, star-forming galaxies.

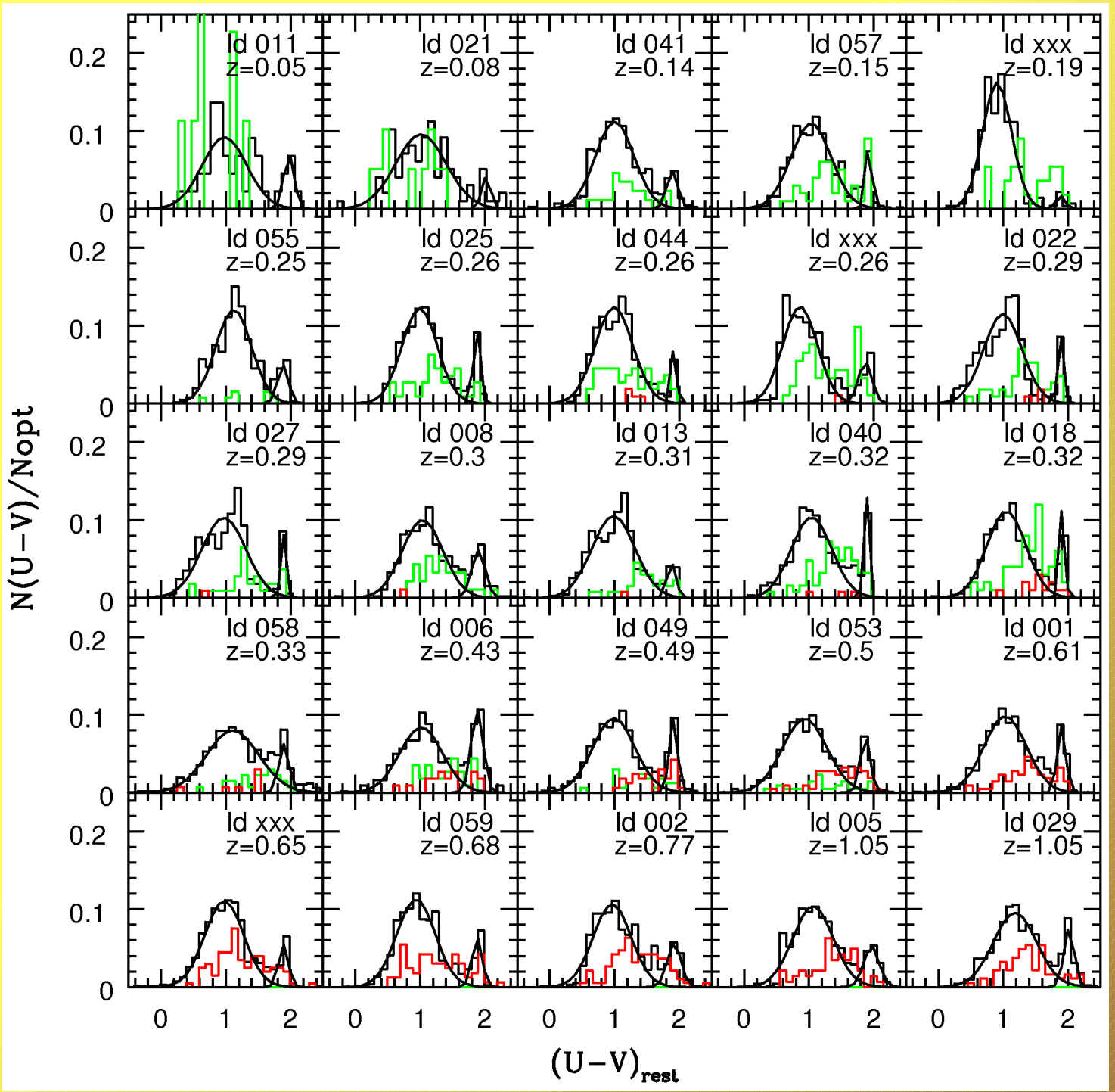
Fraction of LIRGs increases steeply with z

Population of CMD diagram (photo-z pre-selected sources)

Optical sources

24 μm L< $10^{11}L_{\odot}$

24 μm L> $10^{11}L_{\odot}$

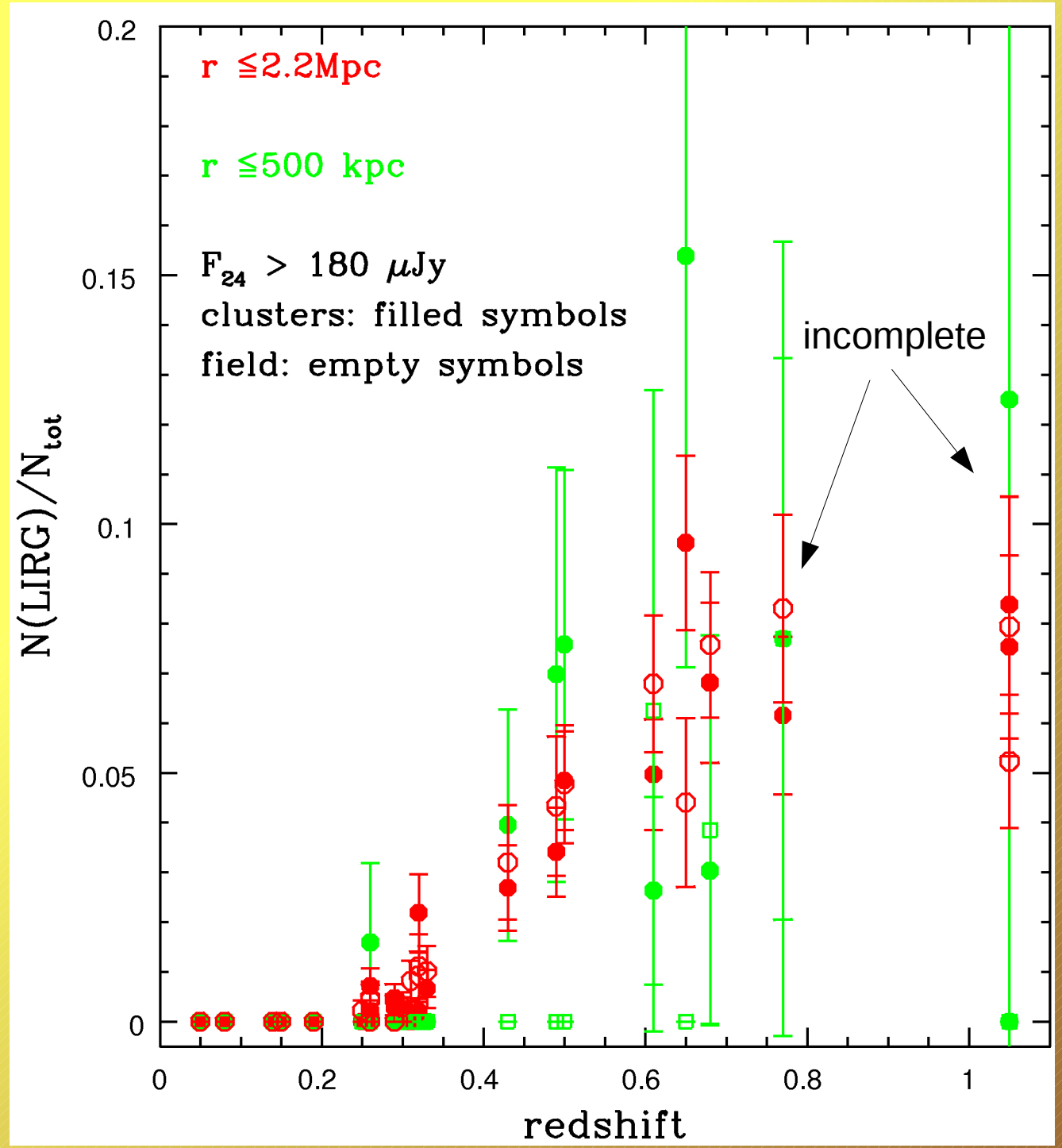


The fraction of LIRGs w.r.t the total number of galaxies in clusters within radii of 500 kpc and 2.2 Mpc increases with redshift.

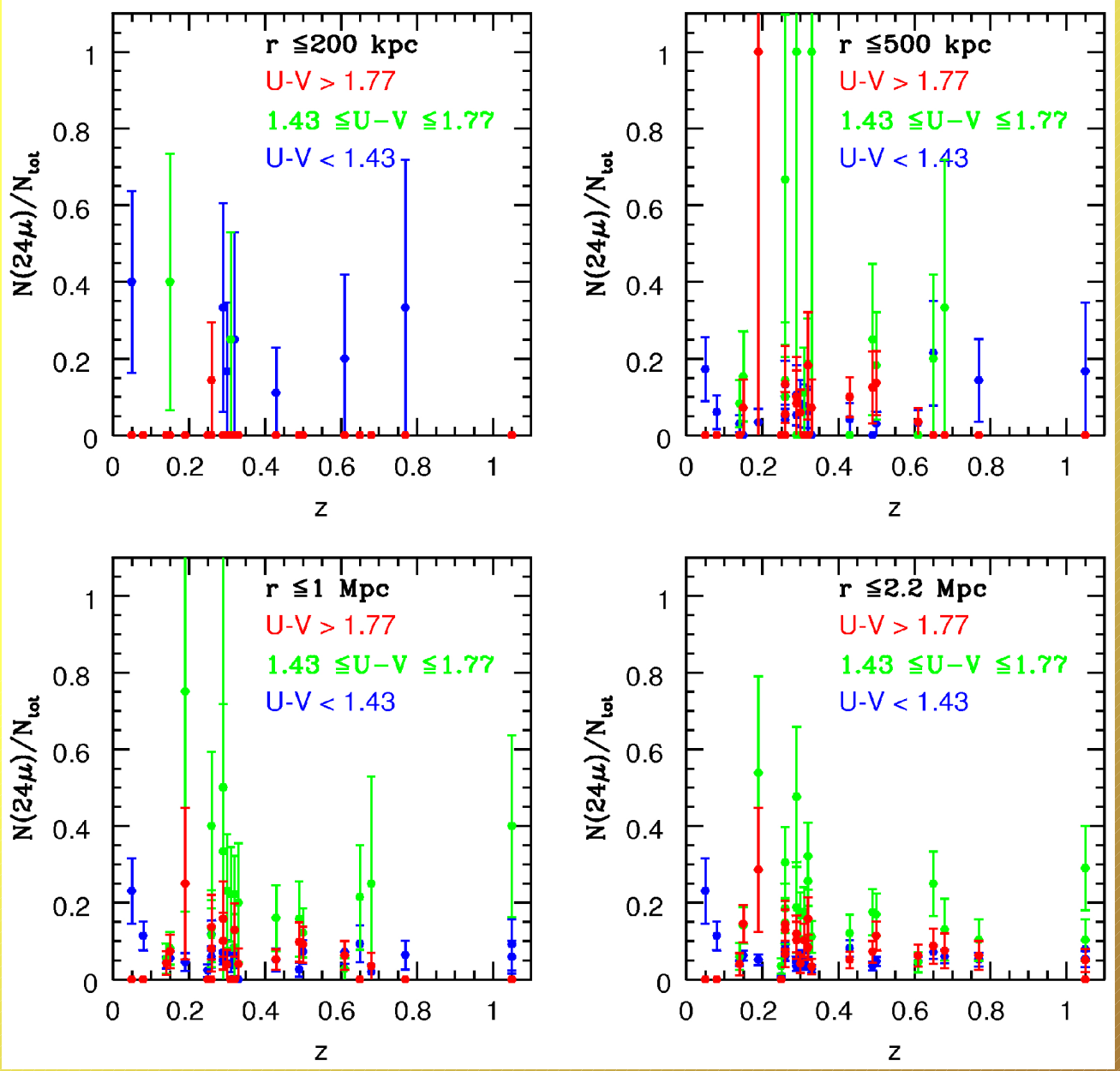
The trend for the 2.2 Mpc radius is similar to the one observed in the field (only a few individual clusters show a clearly higher fraction than the field).
Within 500 kpc radius, the fraction tends to be higher in clusters, though not in all of them.

There are large variations between clusters at similar redshifts... why?

Difference in mass?
Difference in dynamical state of the clusters?



Fraction of 24 μm sources per color interval in individual clusters as a function of redshift within radii of 200 kpc, 500 kpc, 1 Mpc, and 2.2 Mpc. "Green" sources dominate at r > 200 kpc, while "blue" sources dominate at r < 200 kpc.



Summary & Conclusions

First statistical study of the distribution of 24 μm-sources in clusters at **z = 0.05 – 1.05** out to cluster periphery.

Comparison of stacked, azimuthally averaged, surface density radial profiles of 24 μm sources for cluster sample and randomly selected control fields.

2 methods: statistical evaluation of bkg (27 clusters in 4 z-bins);
pre-selection with photo-z (25 clusters in 4 z-bins)

We find an excess of 24 μm sources (~ 3 sources/Mpc^2) w.r.t. the field at cluster-centric radii ~ 200 – 500 kpc @ z ~ 0.3 – 0.8.
At these intermediate redshifts the number of LIRGs in the explored region around clusters ranges between ~ 15 and 100 candidate cluster members.

Color-magnitude diagrams show that mid-IR sources in clusters mostly populate the "green valley", with a smaller number of objects falling on the red sequence, consistent with dusty star-forming galaxies.

Color distribution of 24 μm sources within clusters suggests that bluer 24 μm sources are found also at r < 200 kpc, while green / red sources dominate at r > 200 kpc.

These results need to be confirmed by spectroscopic follow-up.