Dusty, vigorous star formation in clusters: The XMM-LSS sample

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Context — Star formation in clusters

Local Universe

Well established results:
Star formation is suppressed in clusters (e.g. 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

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
Is there 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).

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 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.

XMM-LSS cluster sample

"C1" sample (Pacaud+ 2007, Clerc+ in prep.) over the 11 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_{sun}

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:

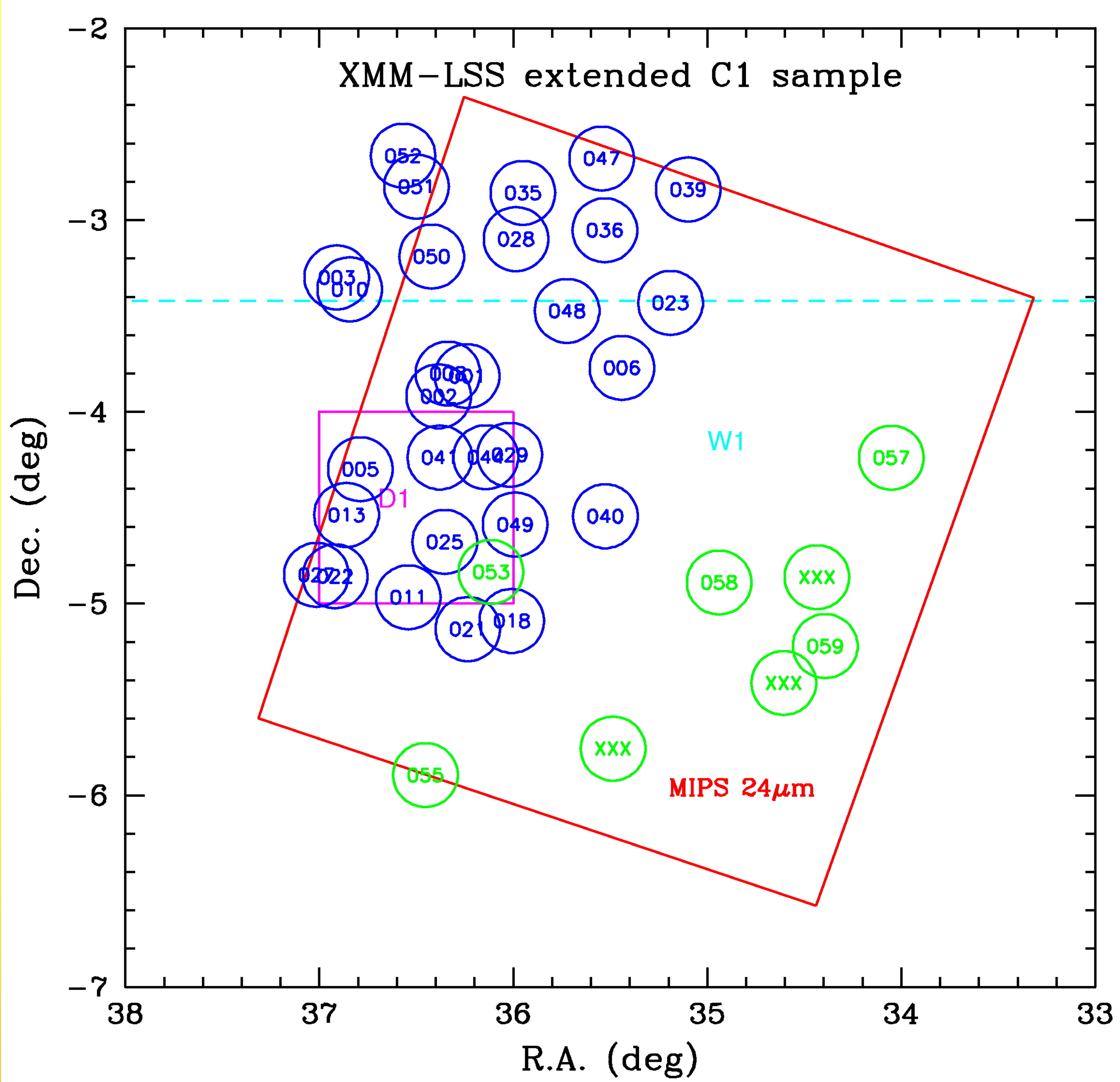
CFHTLS u*g'r'i'z' photometry => photometric redshifts with Le_Phare (Ilbert+ 2006, McCracken+ 2008).

C1 sample: 29 confirmed clusters in the first 5 deg² of XMM-LSS out of which:

22 with full MIPS coverage
+ 3 with partial coverage

17 with full CFHTLS coverage

Enlarged C1 sample:
37 clusters over 10 deg^2 out of which 33 with 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

r < 10' centered on X-ray position

Selection of control fields:

1) Generation of 20000 random positions uniformly distributed in the SWIRE-XMM area.
2) Rejection of all positions within 6 arcmin from XMM X-ray sources and/or within 6 arcmin from the borders of the MIPS image.
3) From the remaining positions, selection of uniformly distributed fields well separated from one another: 105 fields.
4) Rejection of fields with no or insufficient optical coverage.
   Final number of control fields, for which a pre-selection of sources in photo-z is possible: 82.
5) Extraction of 24 μm sources adopting the same criteria used for 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.

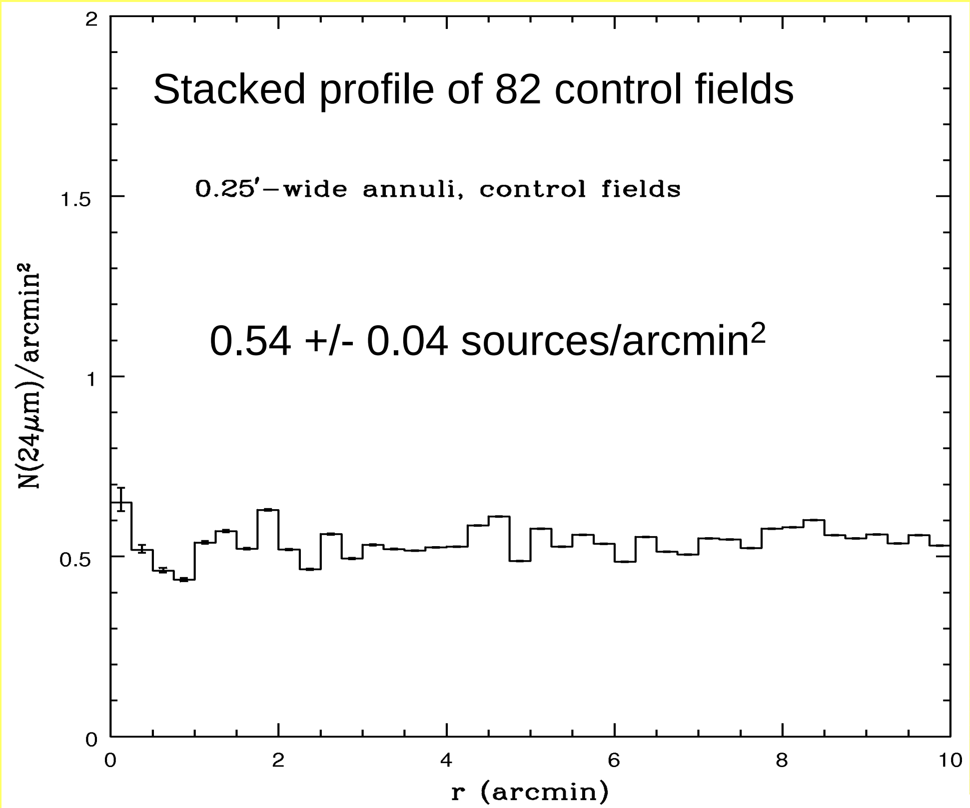
Individual clusters: the profiles suggest the presence of an excess of sources in some cases, but the signal is too weak (Temporin+ 2008, arXiv: 0810.5499).

Improve the signal through stacking!

1) Stacked density profiles with a statistical subtraction of fore/background sources.

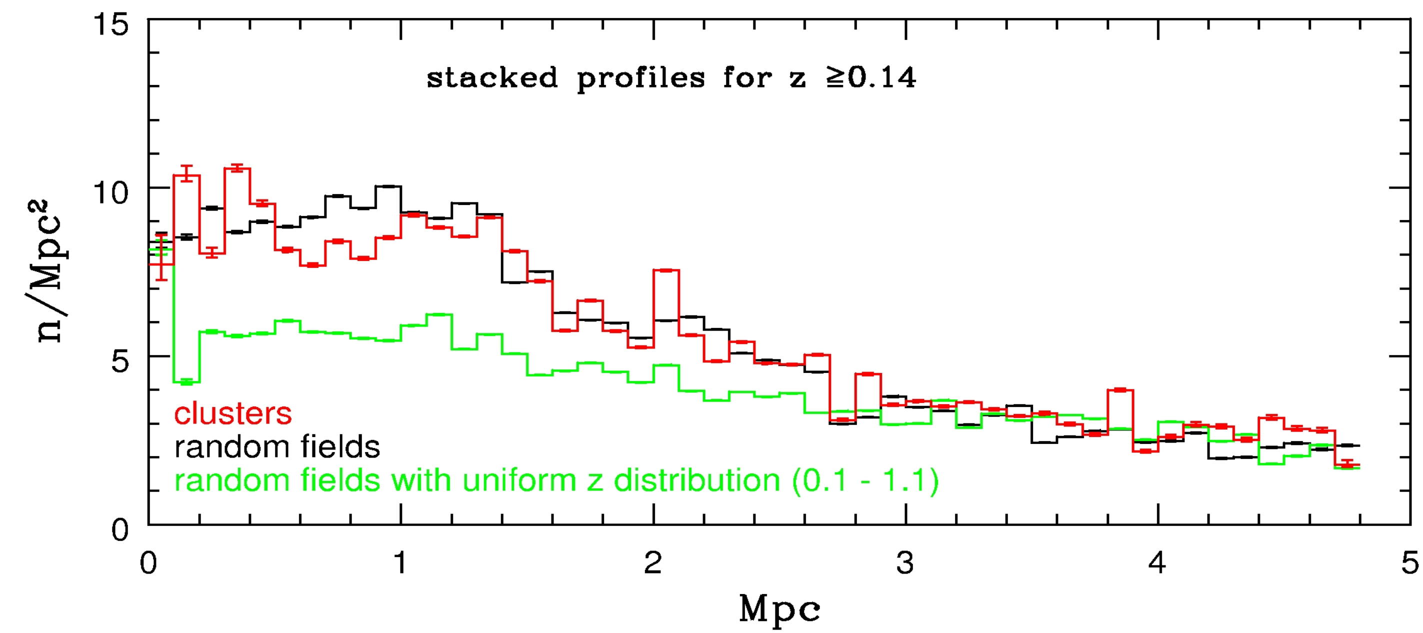
2) Stacked density profiles after pre-selection of sources according to photo-z.

Statistical evaluation of the background



Background looks flat...
but counts expressed in sources/arcmin^2!

What happens when annuli are defined in Mpc?



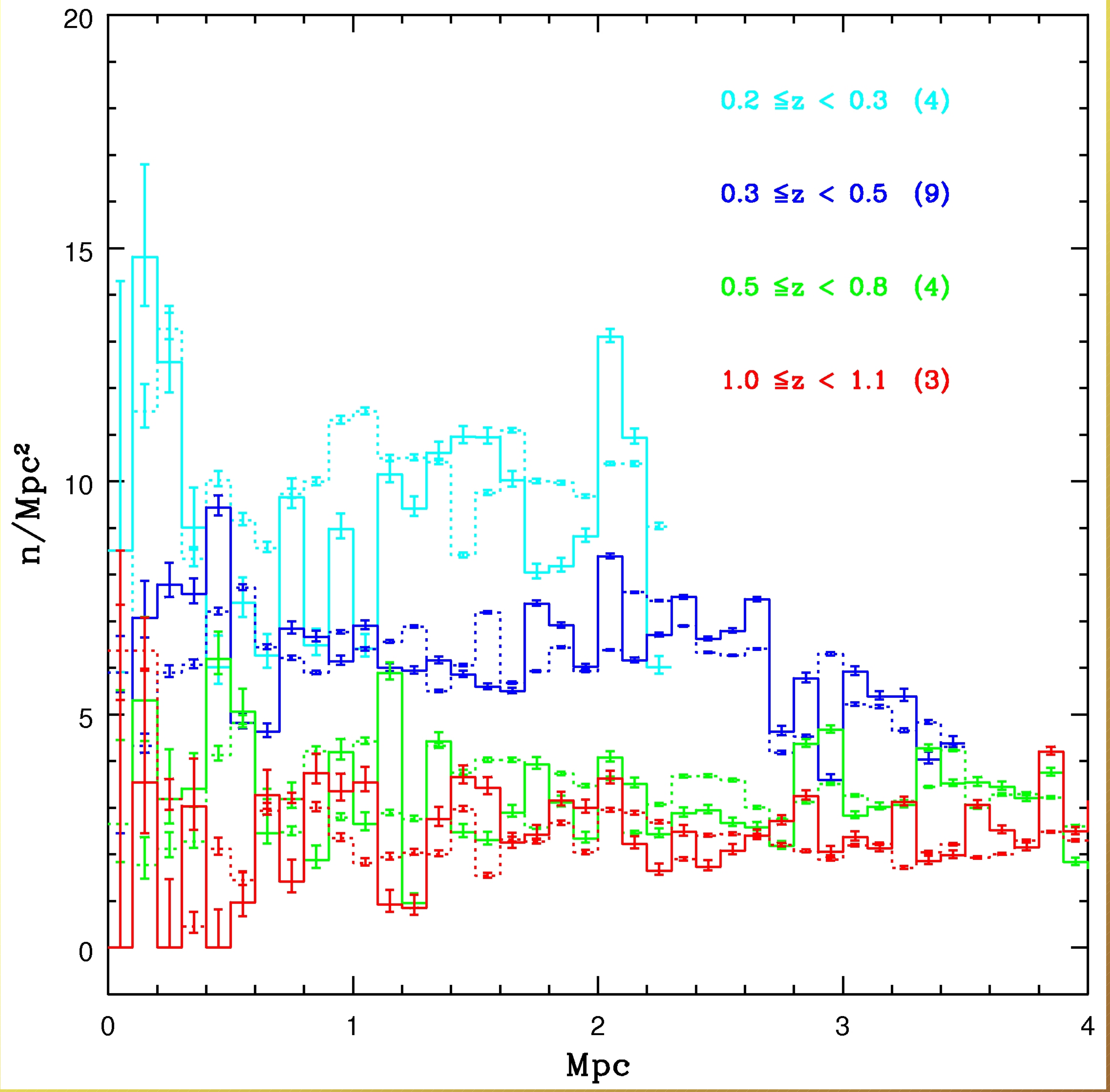
Shape of bkg depends on redshift distribution!

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

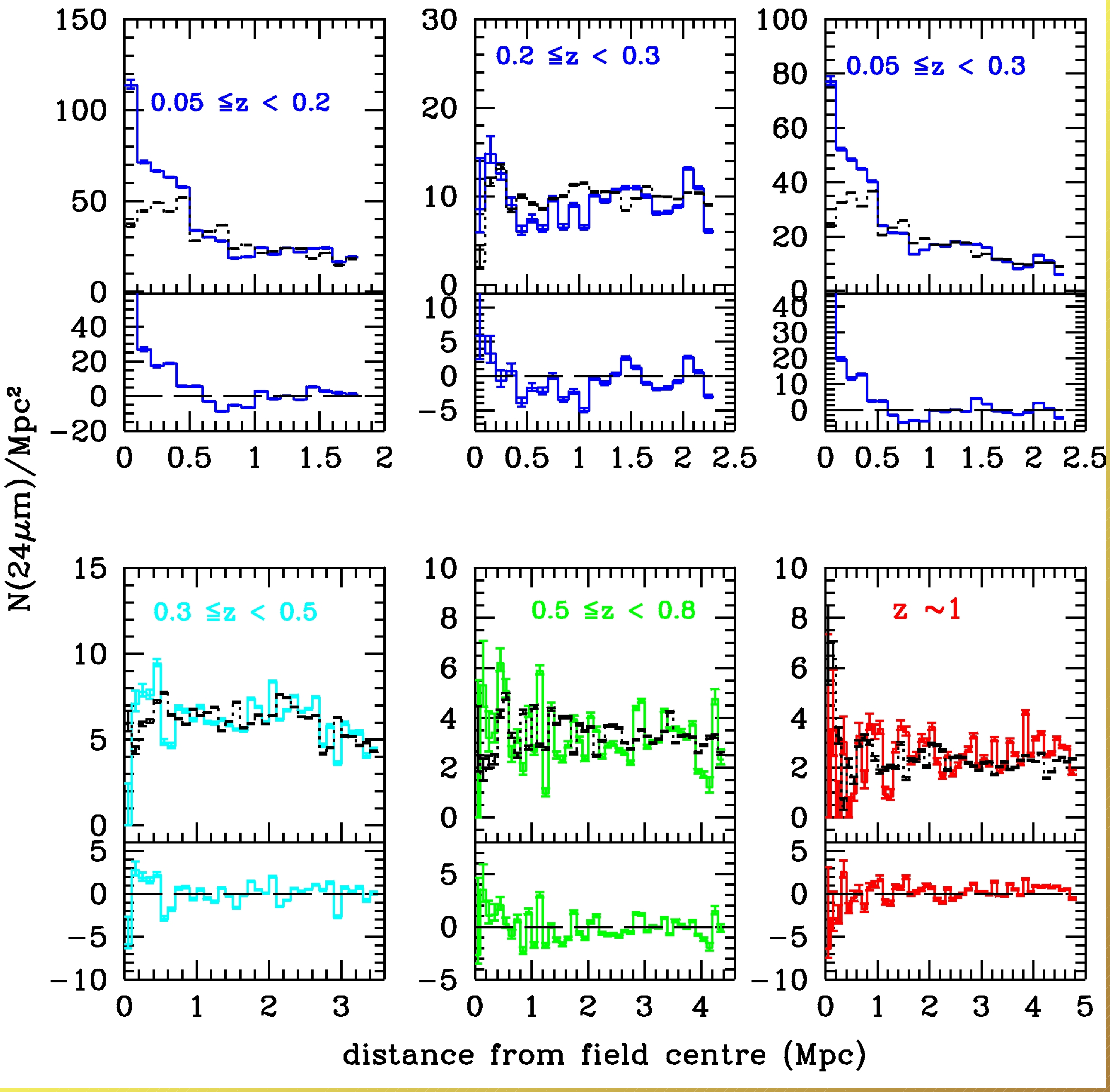
Only mid-IR sources with flux > 5σ

Clusters whose areas significantly overlap have been discarded

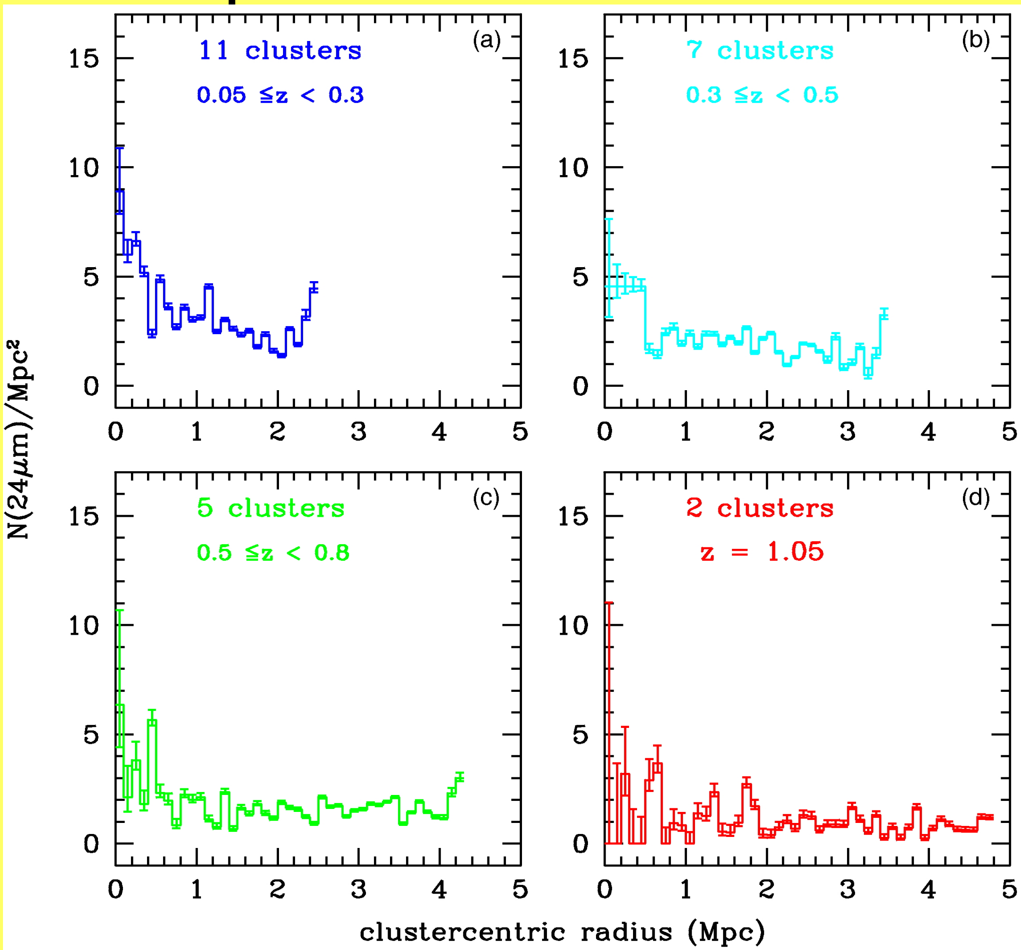
Weak excess at z > 0.3 for radii 200 – 500 kpc.



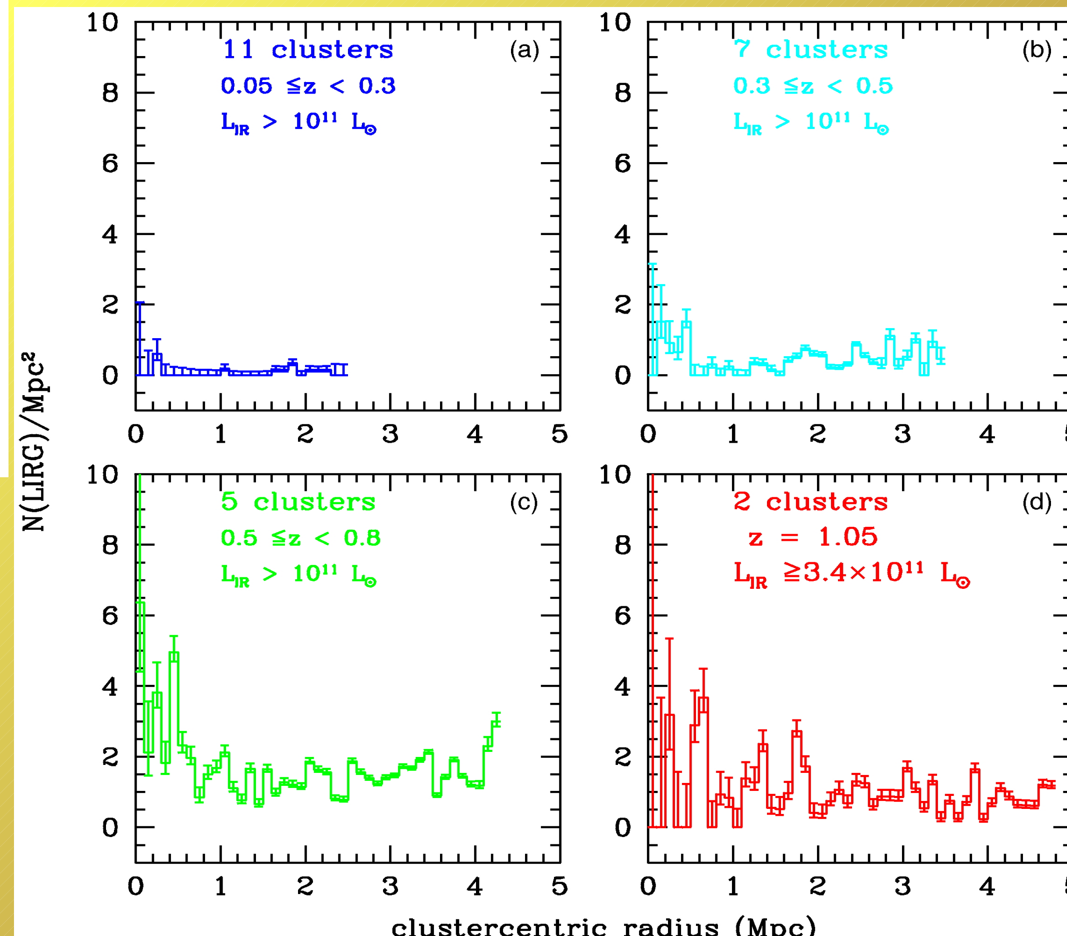
Subtraction of background from cluster profiles



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



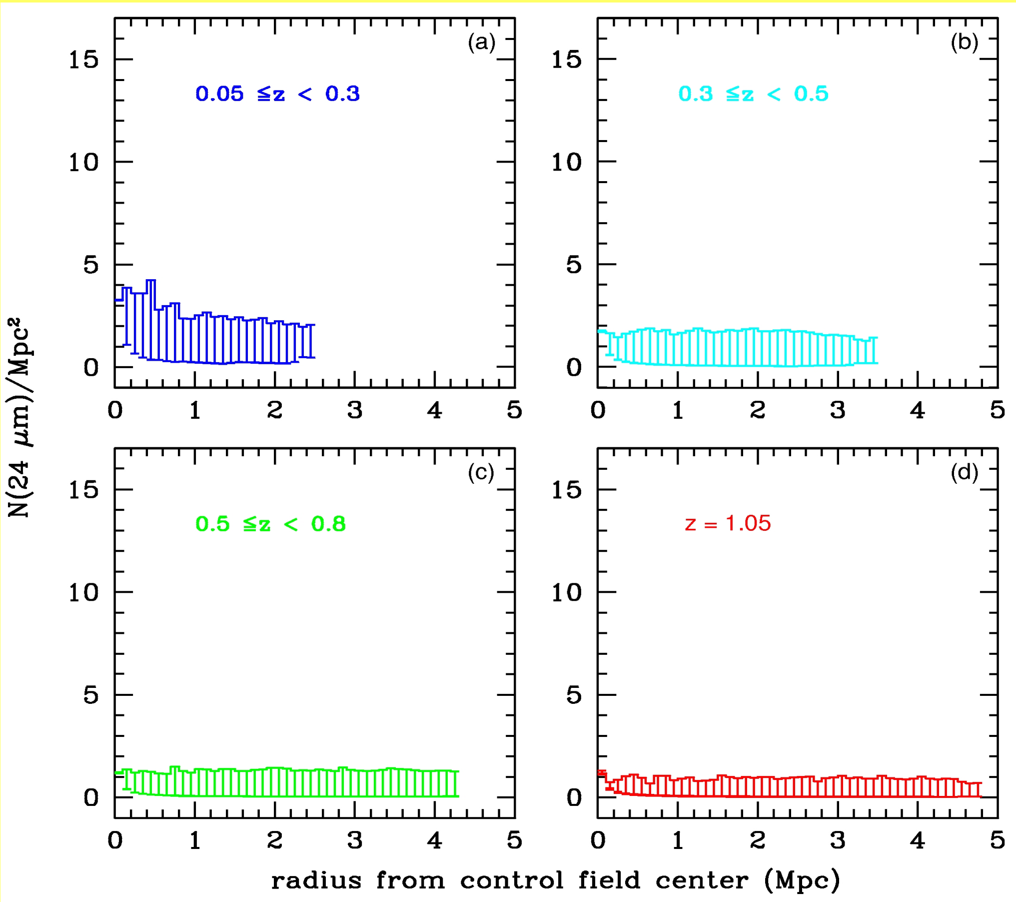
24 μm sources with photo-z compatible with cluster membership (accounting for $\sigma_{\Delta z/(1+z)}$ ~ 0.05 and 3000 km/s velocity dispersion) out to 10'-radius.



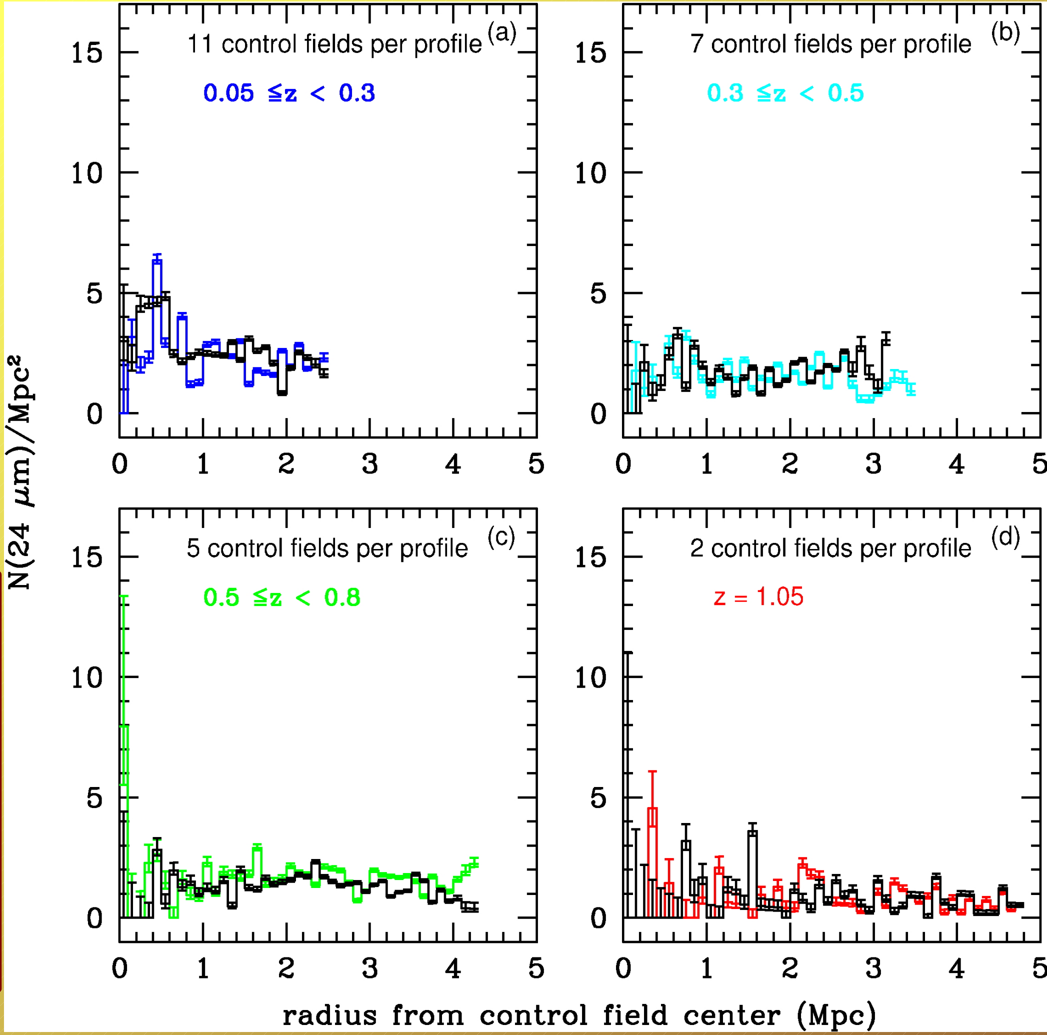
All sources

Only LIRGs and ULIRGs

Comparison with control fields



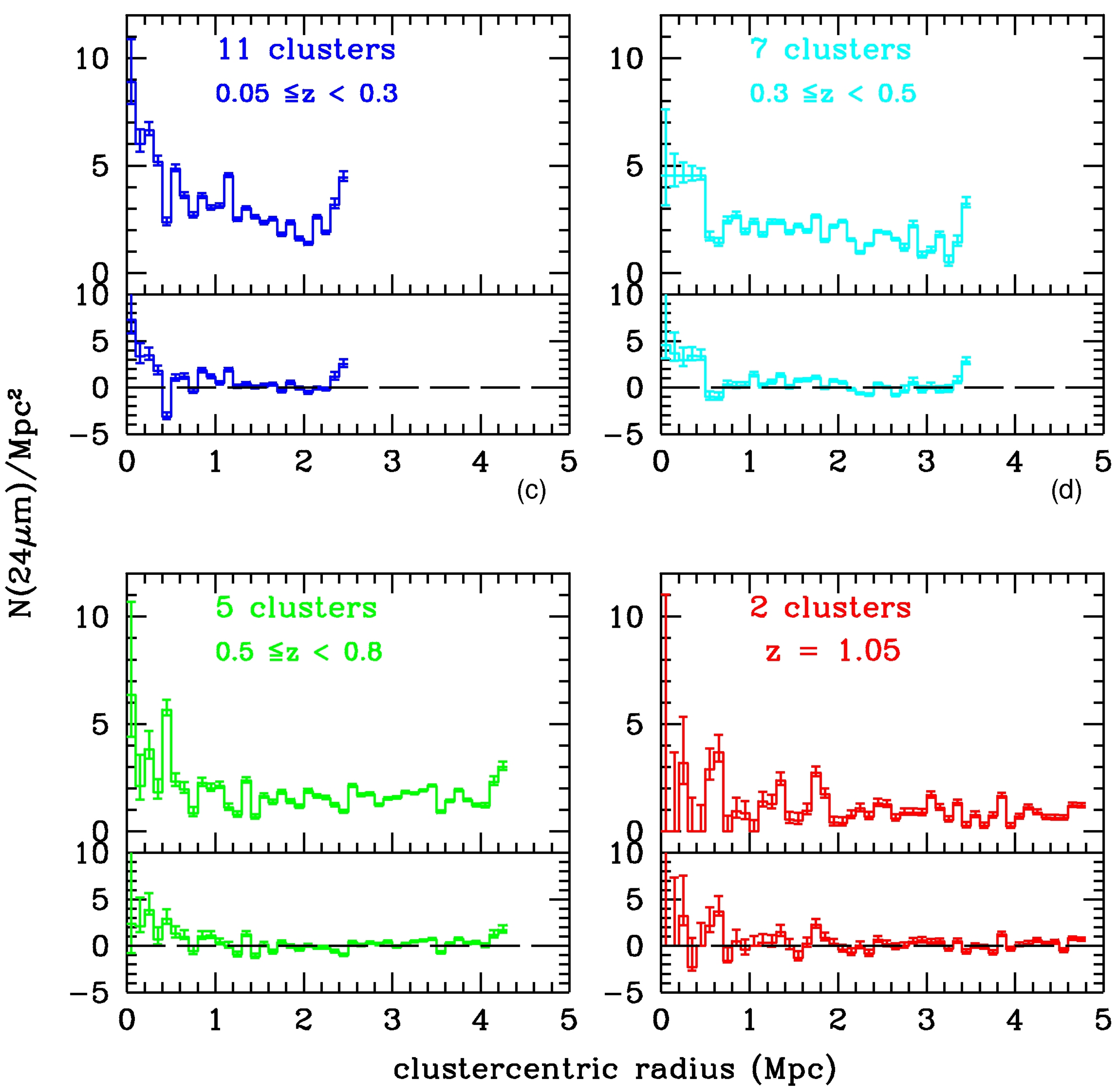
Stacked density profiles for 82 control fields after pre-selection of 24 μm sources within the same redshift intervals used for clusters. Distributions are flat with typical densities of 1 – 2 IR sources/Mpc^2



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.

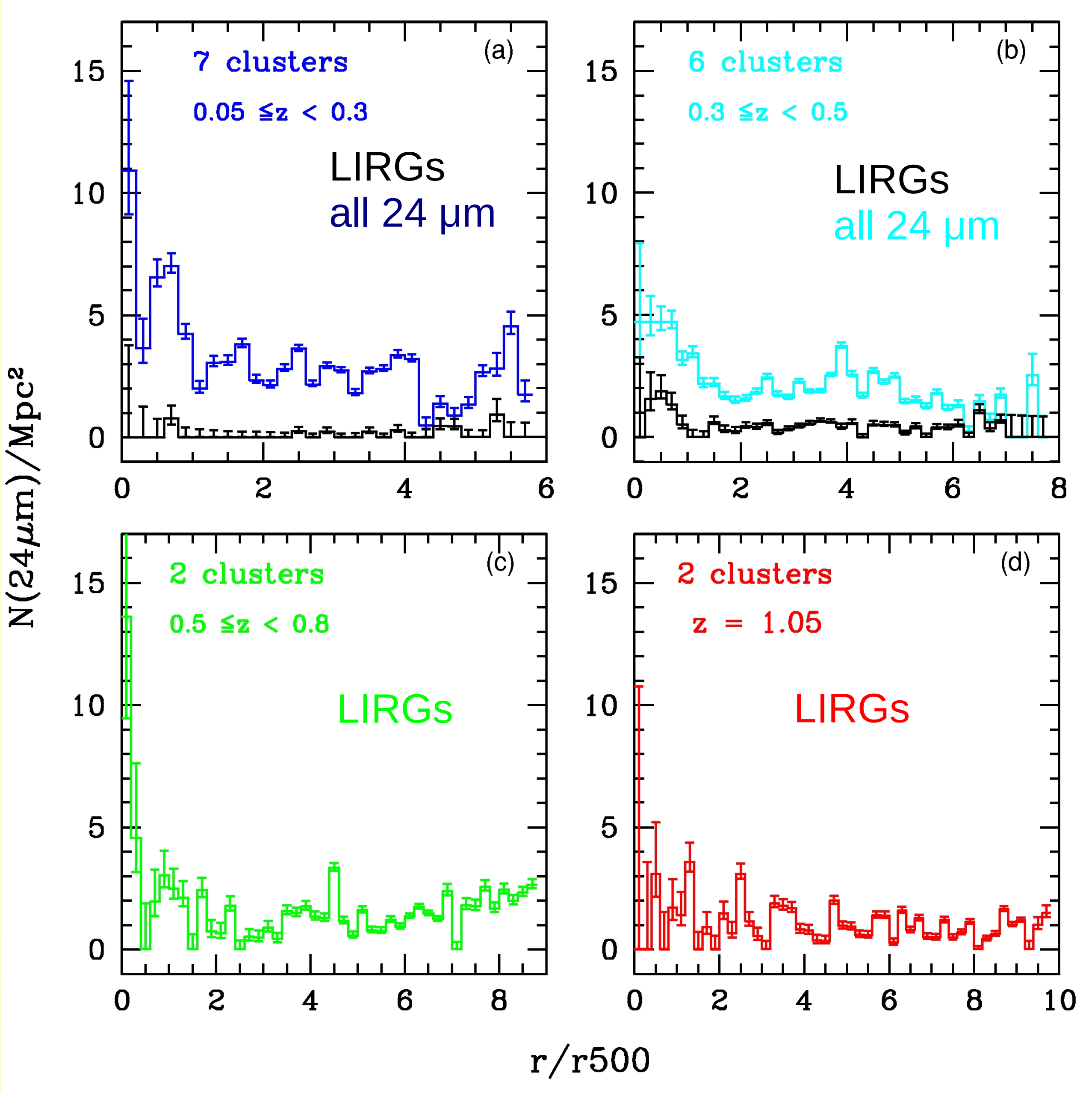
Oscillations are smaller than the density peaks @ r < 1 Mpc for clusters in the 2 medium-z bins.

Cluster profiles after subtraction of the average field distribution

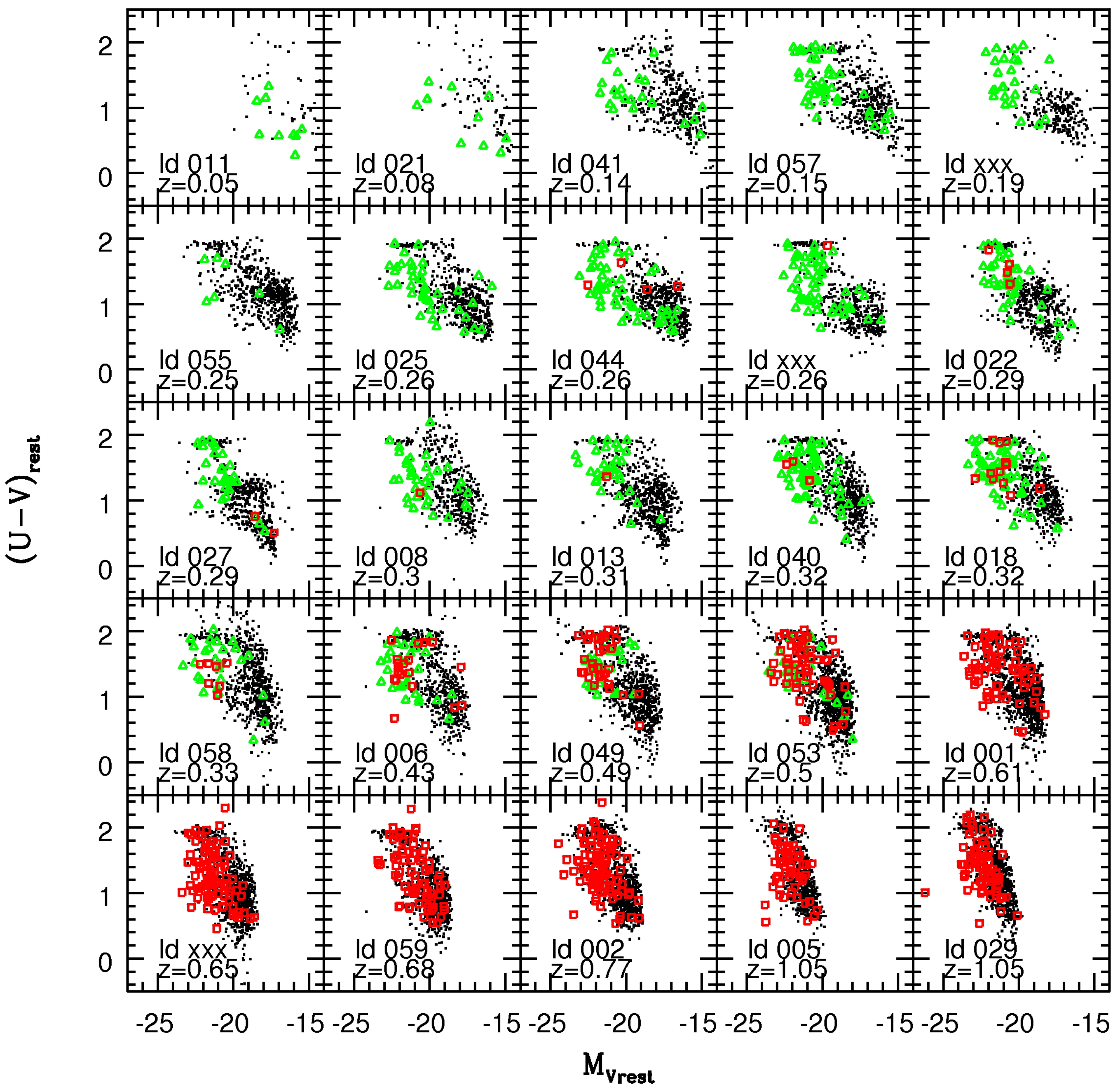


Density profiles on physical cluster scales

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

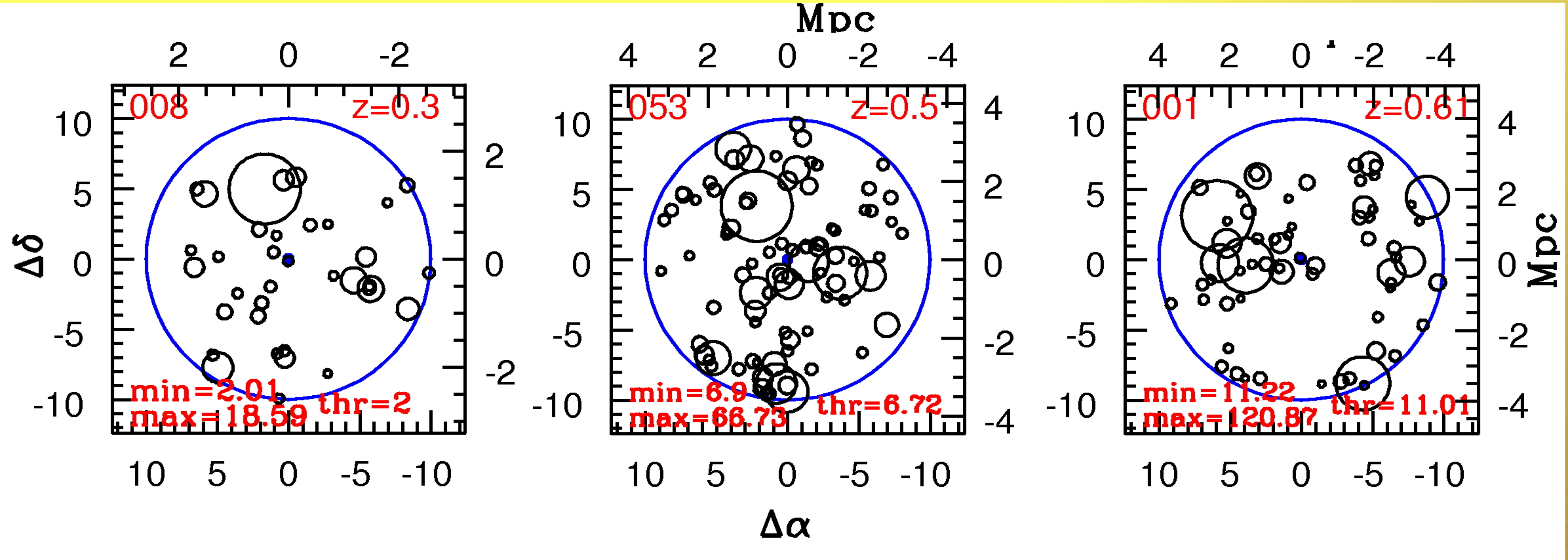
red: 24 µm sources $L_{IR} > 10^{11}$ Lsun

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

Spatial distribution of mid-IR sources within clusters



min, max = L_{IR} (10^{10} L_{sun})

Brightest mid-IR sources tend to avoid the very center of clusters

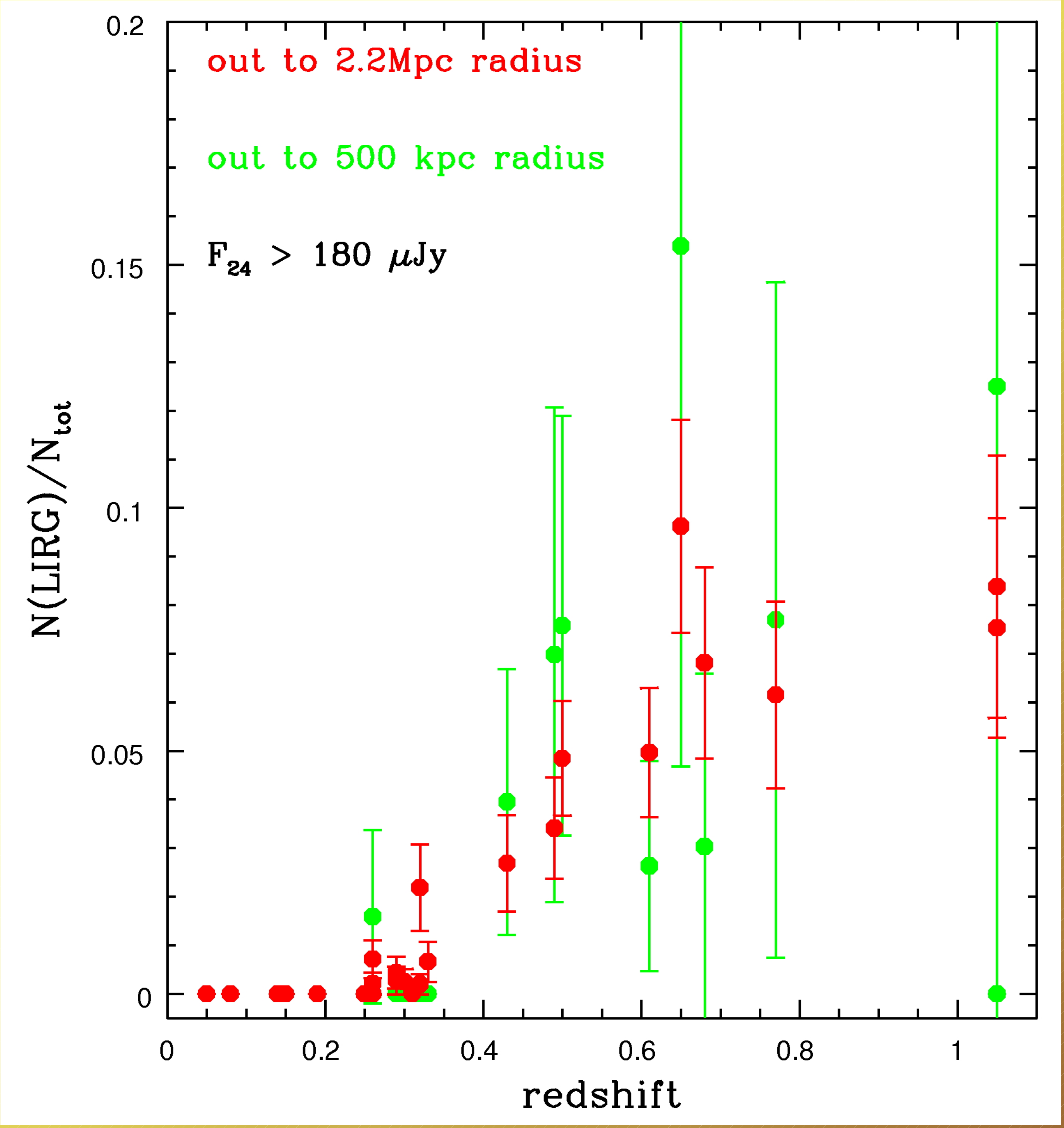
(in qualitative agreement with z=0.81 cluster studied by Koyama et al. 2008)

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.

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

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



Summary & Conclusions

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

Comparison of stacked, azimuthally averaged, surface density radial profiles of 24 µm sources for cluster sample and sample of 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 at cluster-centric radii ~ 200 – 500 kpc with respect to the field at 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.

The distribution of mid-IR sources within individual clusters shows that the brightest sources tend to avoid the very center of the clusters.
They rather concentrate in intermediate density cluster regions out to the periphery and are asymmetrically distributed.
The fraction of LIRGs in clusters appear to steeply increase with redshift.

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