The (mid- and far-) IR luminosity function of cluster galaxies & its evolution

Andrea Biviano, INAF/Osservatorio Astronomico di Trieste

in collaboration with:
Dario Fadda, Louise Edwards, NASA Herschel Science Center
Florence Durret, Institut d'Astrophysique de Paris
Francine Marleau, Toronto University

and with:
Paola Popesso, MPE Garching
& many others

Outline:

- What do we know about cluster IR luminosity functions (where 'IR' means $\lambda > 4$ μm):
  data from Spitzer, AKARI, Herschel (IRAS & ISO)
  cluster to cluster variance,
  evolution,
  dependence on the environment

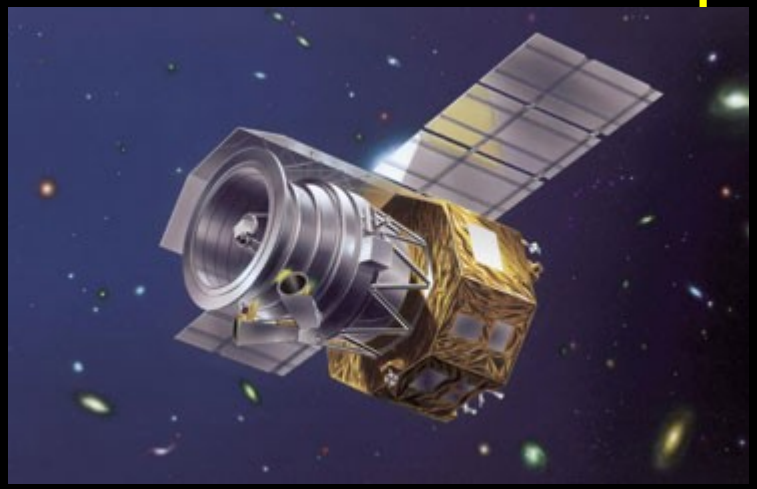
- The IR LF of the z=0.23 A1763 supercluster

- IR studies of clusters and groups in the GOODS and COSMOS fields

Mid- and Far-IR observations from space

IRAS

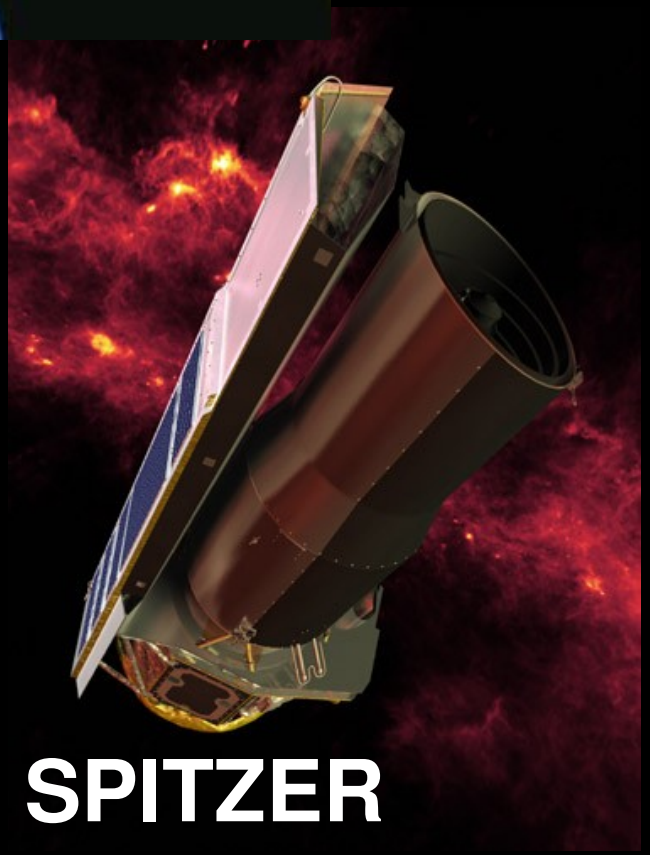




AKARI



ISO

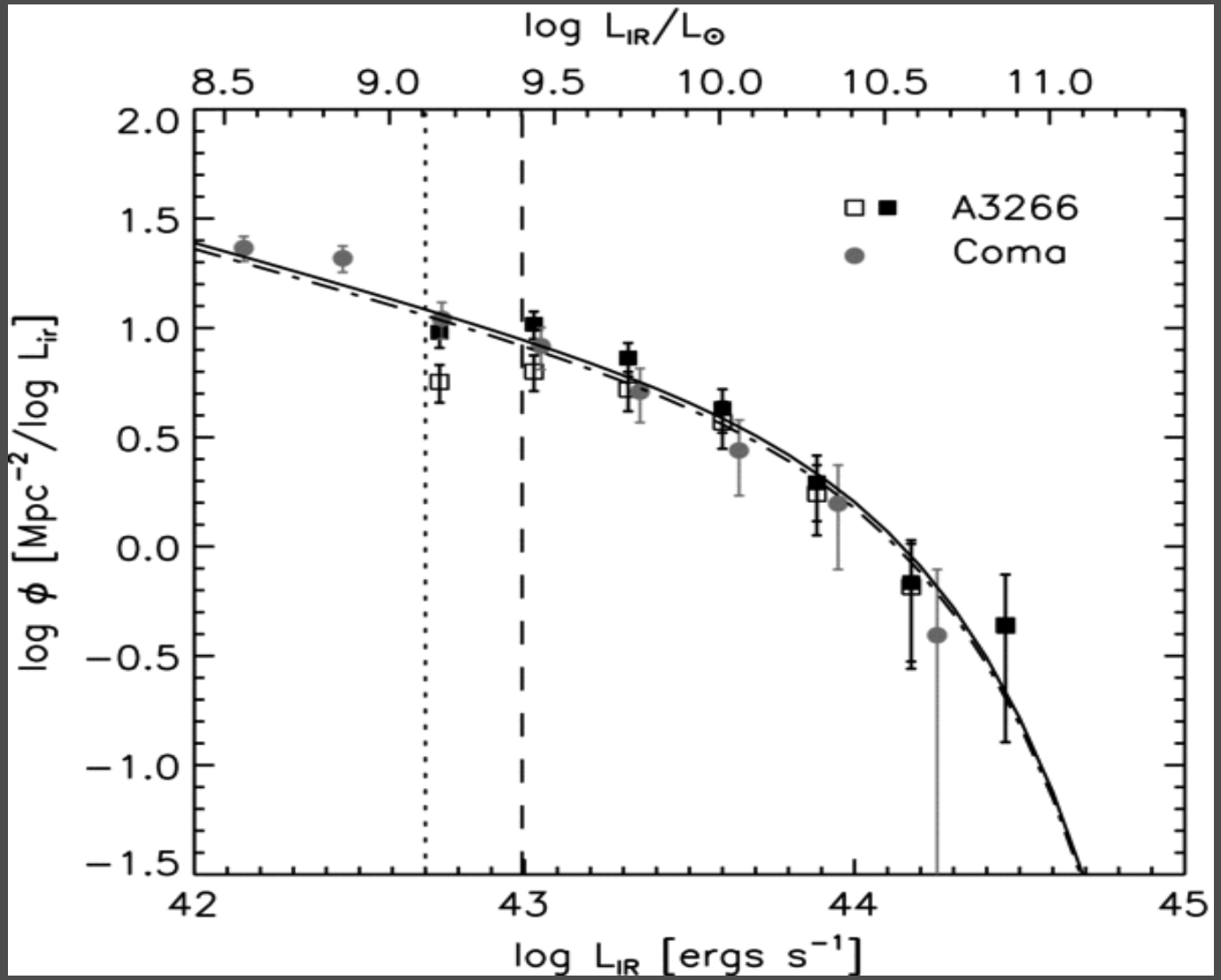


SPITZER



HERSCHEL

The distribution of galaxy L_{IR} (IR LF) in nearby galaxy clusters is "universal"

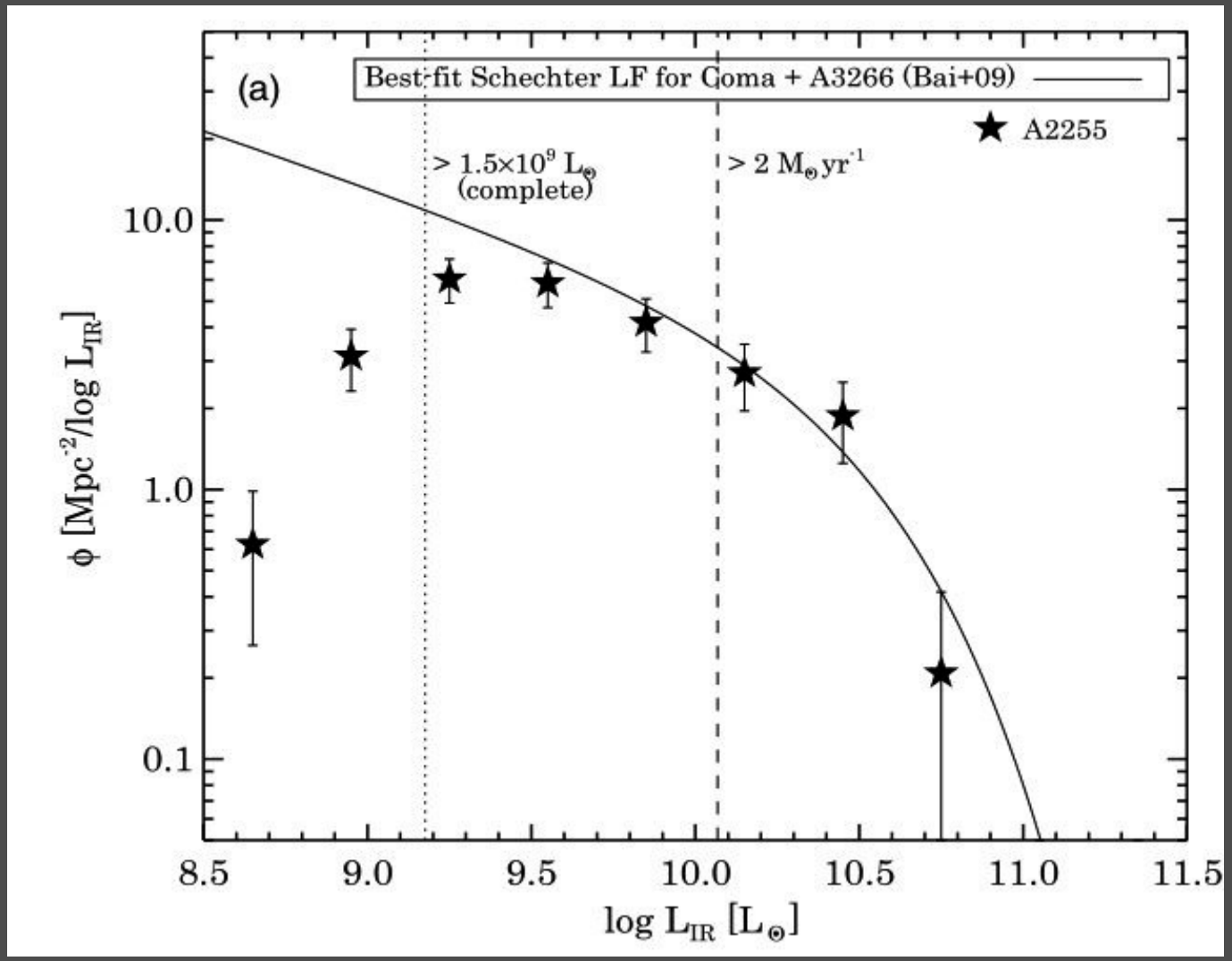


galaxy number density per bin of IR luminosity

(Bai+09)

IR luminosity

The distribution of galaxy L_{IR} (IR LF) in nearby galaxy clusters is "universal"

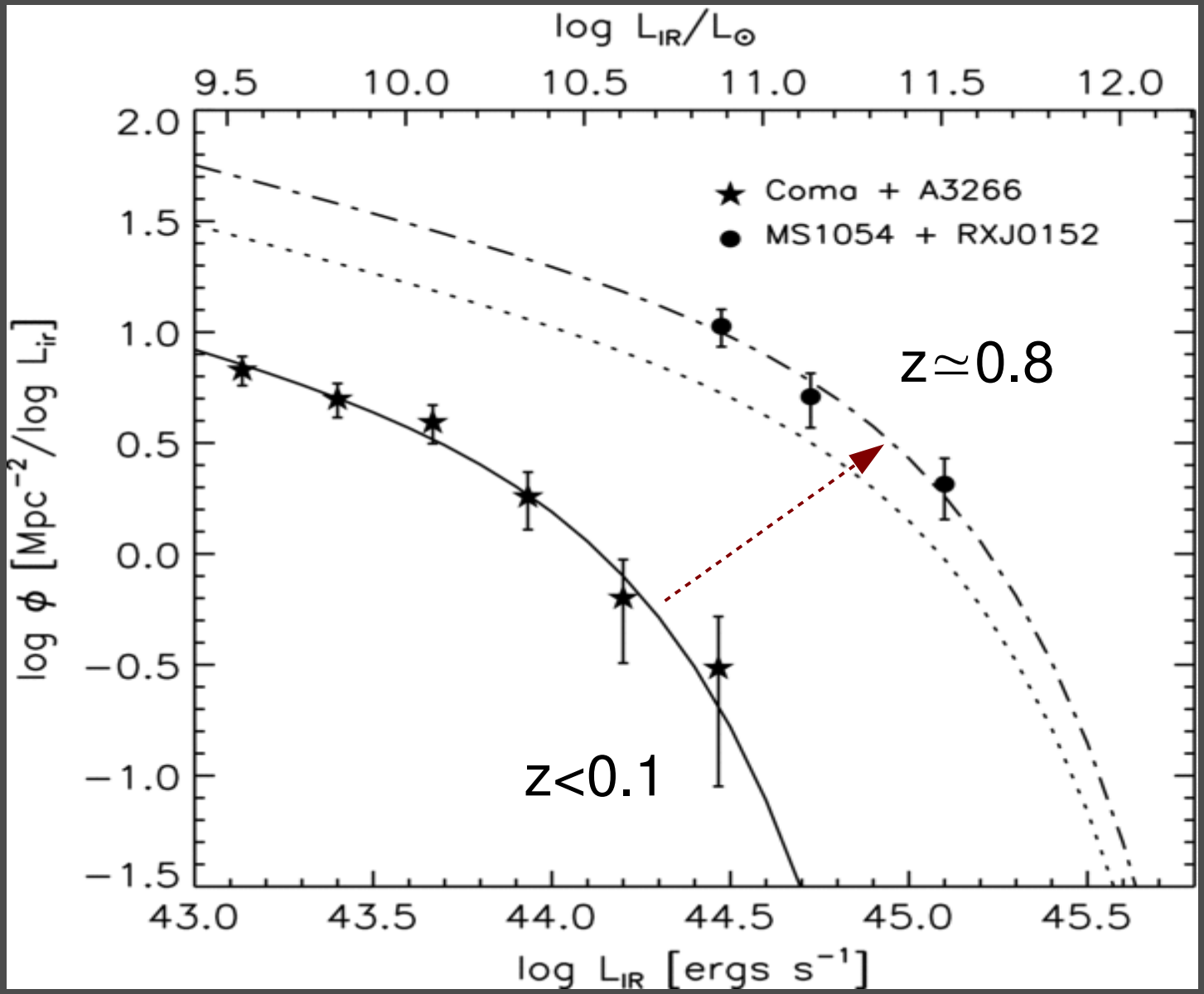


(Shim+11)

galaxy number density per bin of IR luminosity

IR luminosity

Evolution of the cluster IR LF



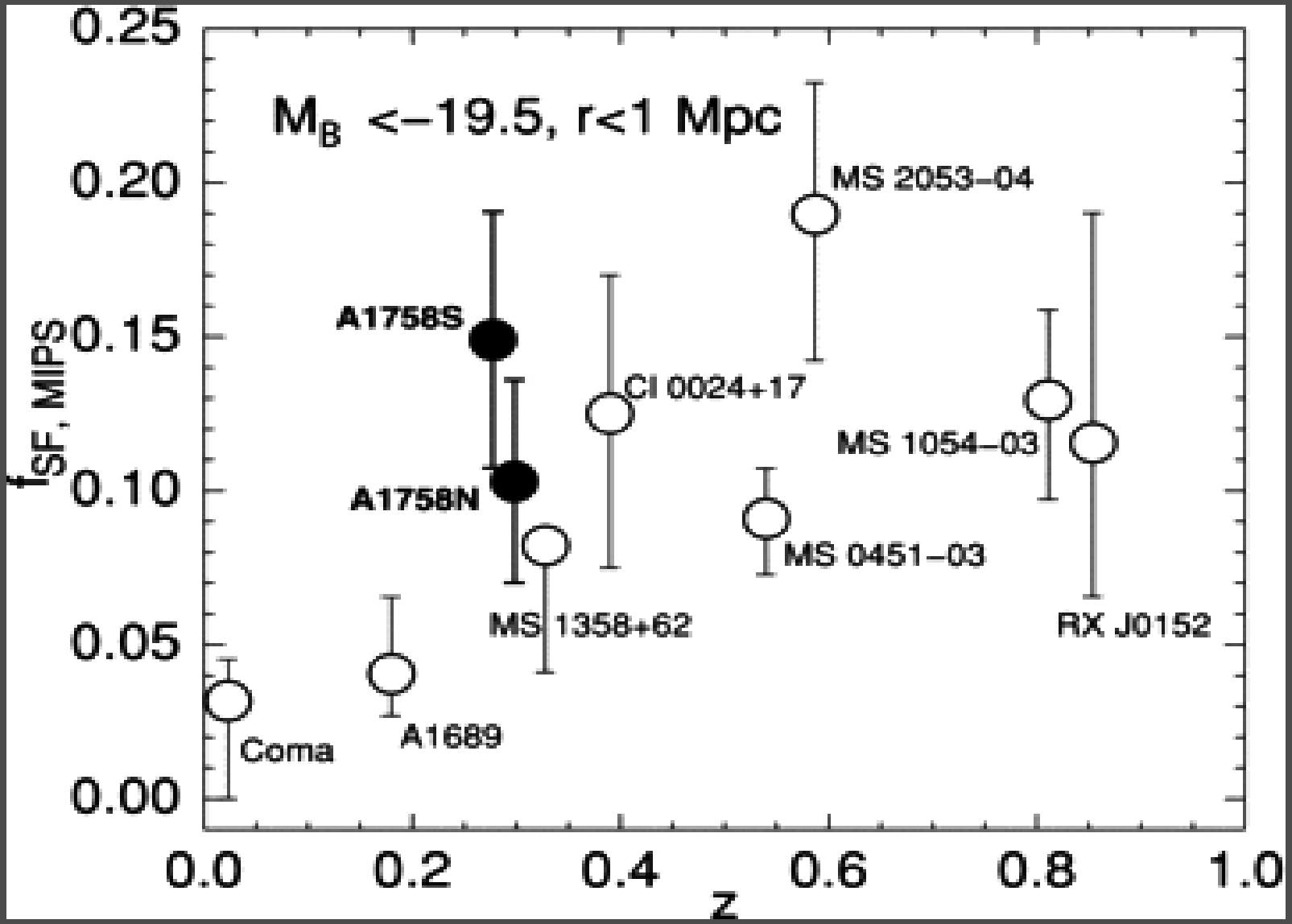
IR-emitter number density

IR luminosity

Higher number density and higher luminosity cutoff in higher redshift clusters

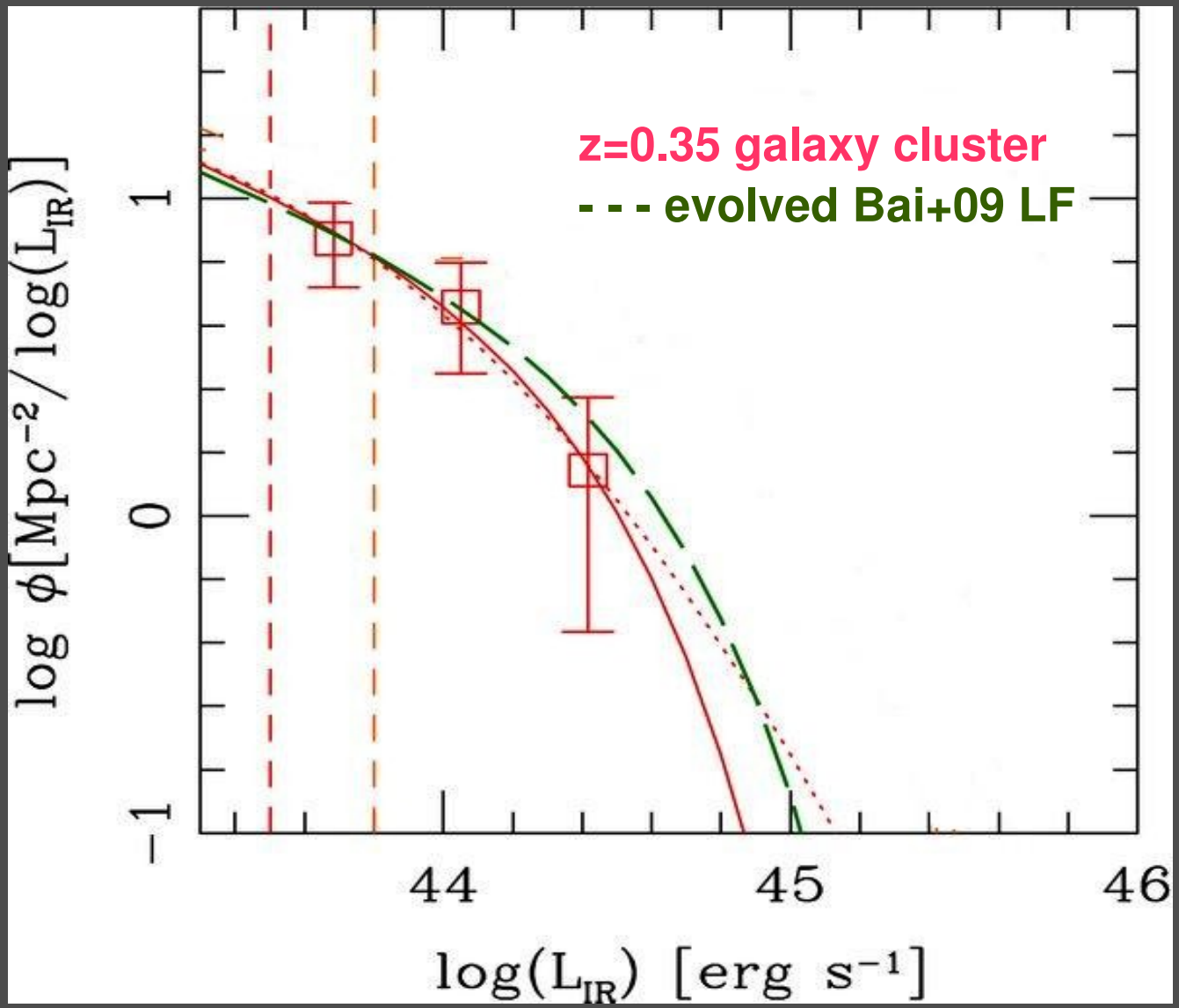
(Bai+09)

The fraction of IR-emitters in clusters ↑ with z: the “IR Butcher-Oemler” effect



(Haines+09)

The predicted evolution fits the IR LF of other clusters

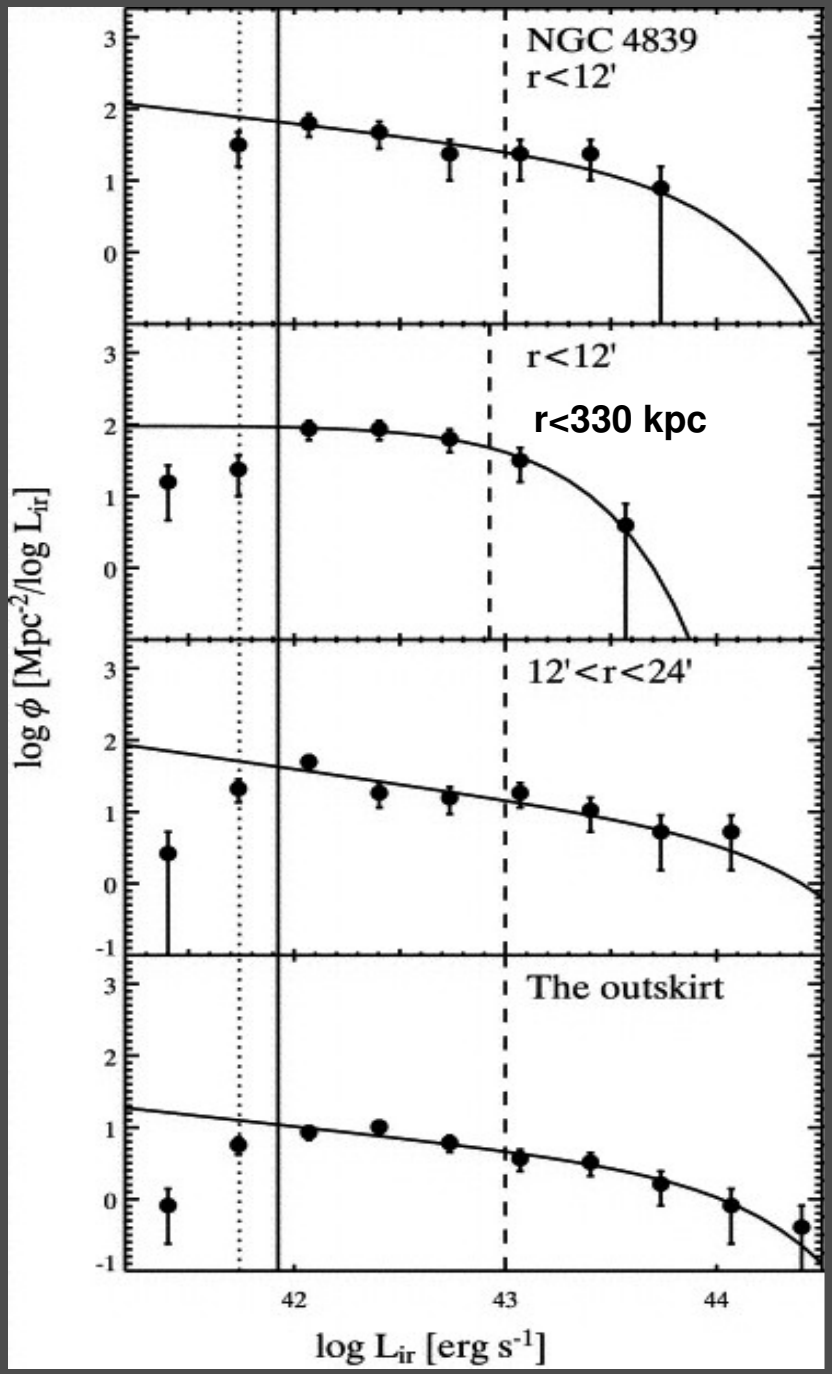


galaxy number density per bin of IR luminosity

(Tran+09)

IR luminosity

IR-emitter number density



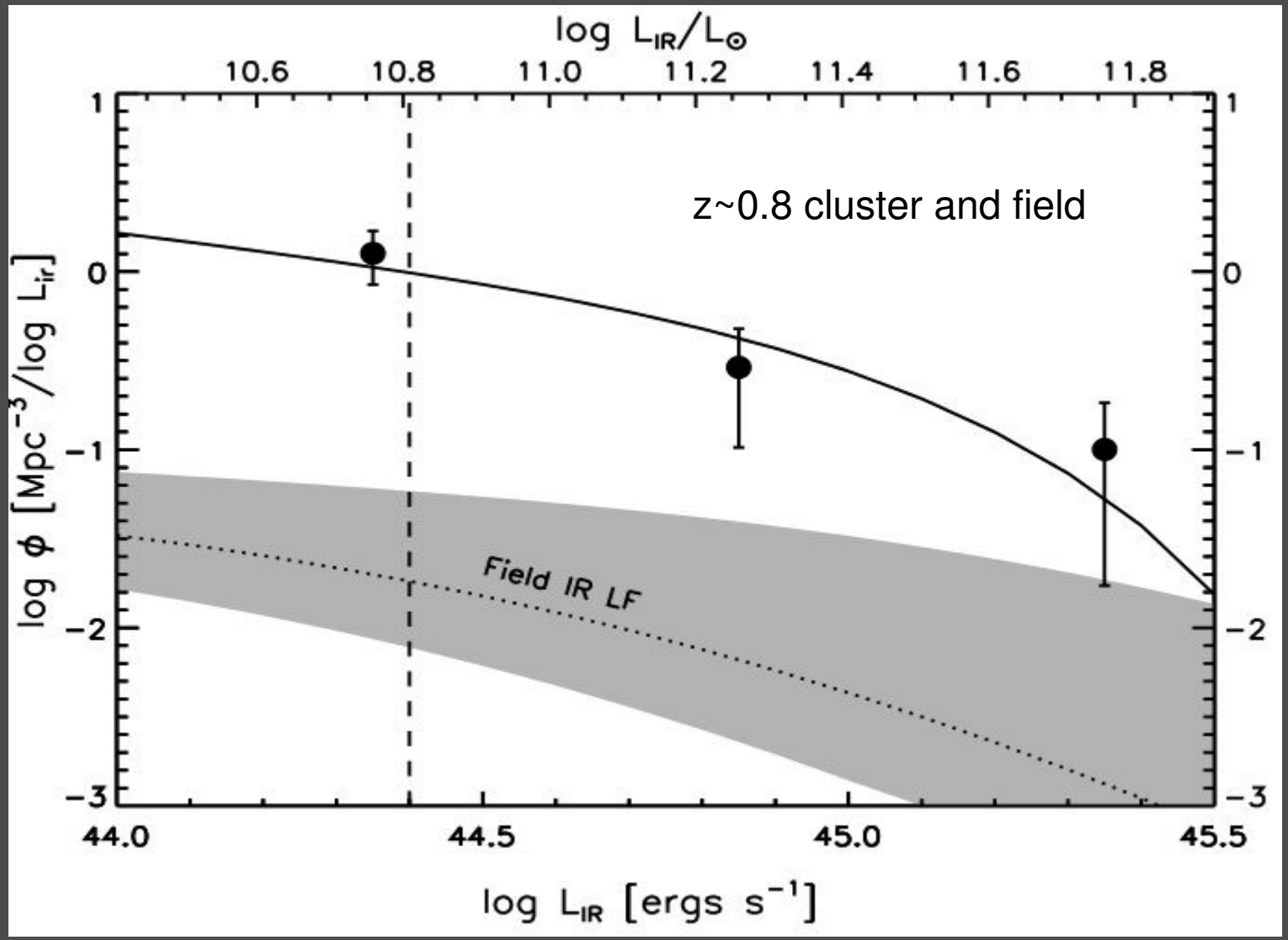
IR luminosity

The IR LF in clusters changes with distance from the cluster center

Higher ratio of bright/faint IR-emitters at large radii

(Bai+06)

IR LF in clusters ≠ IR LF of field galaxies

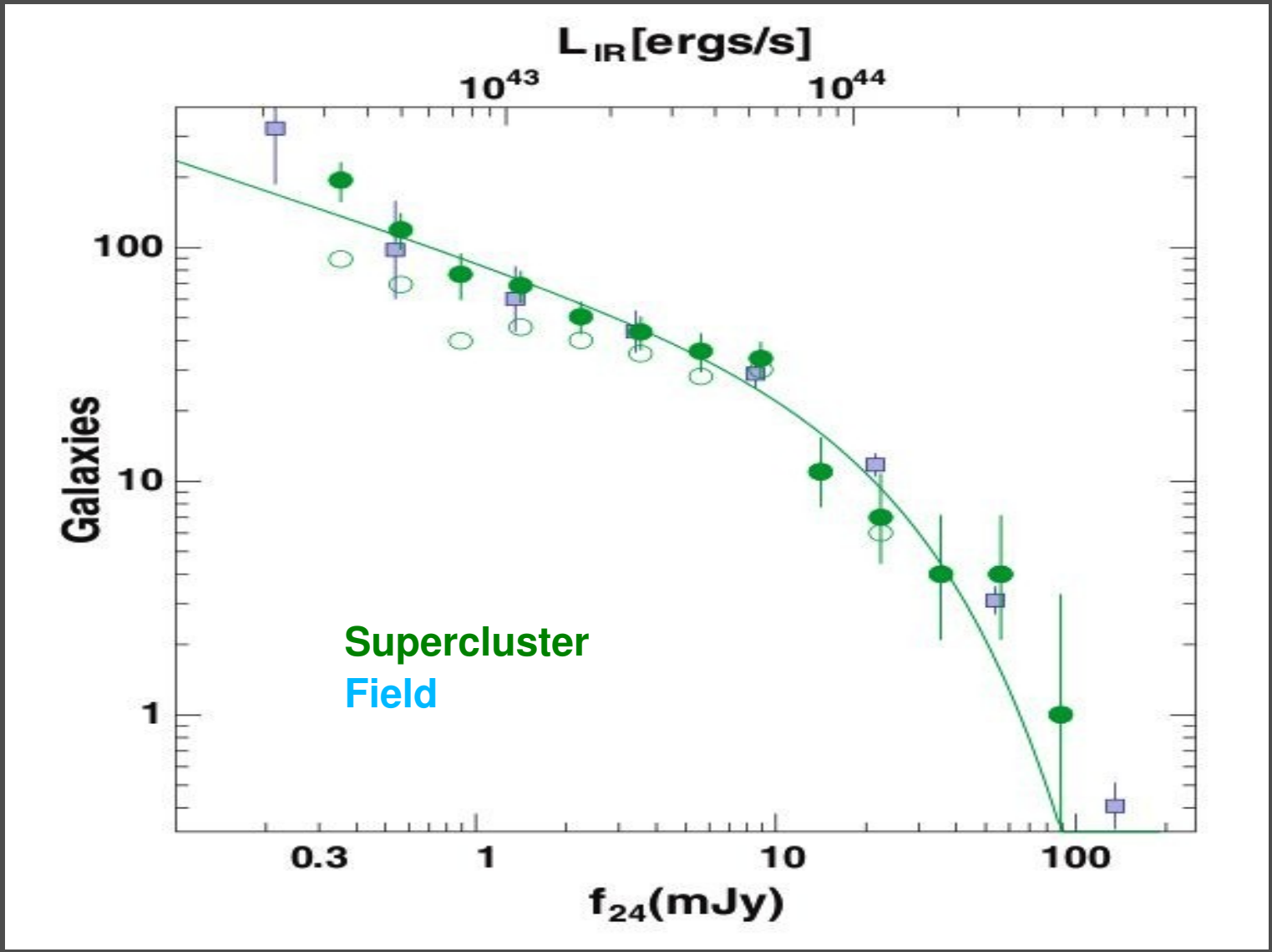


IR-emitter number density

IR luminosity

(Bai+07 & Le Floc'h+05)

Shapley supercluster IR LF ≈ field IR LF

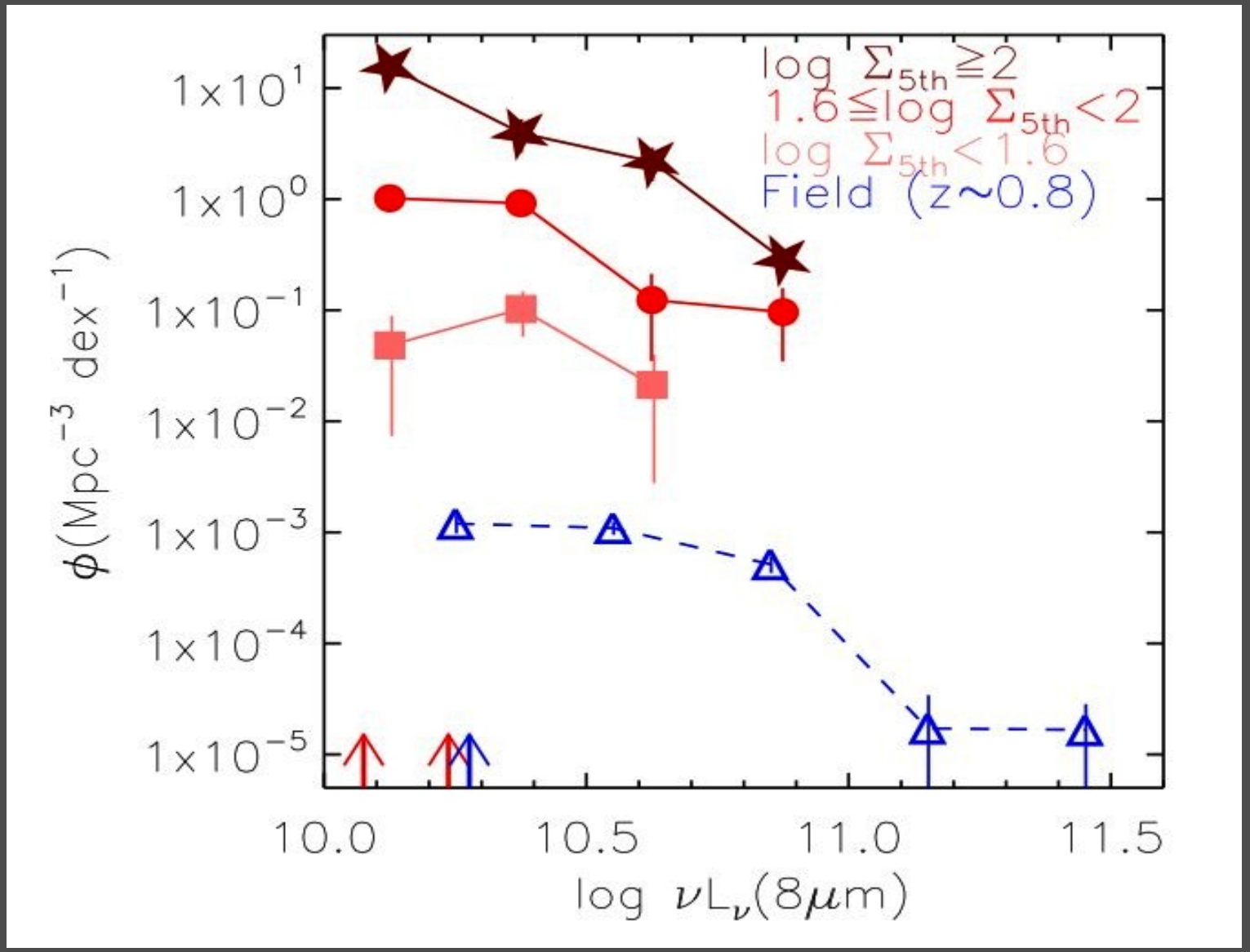


IR-emitter number density

IR luminosity

(Haines+11)

Environmental dependence of the cluster IR LF



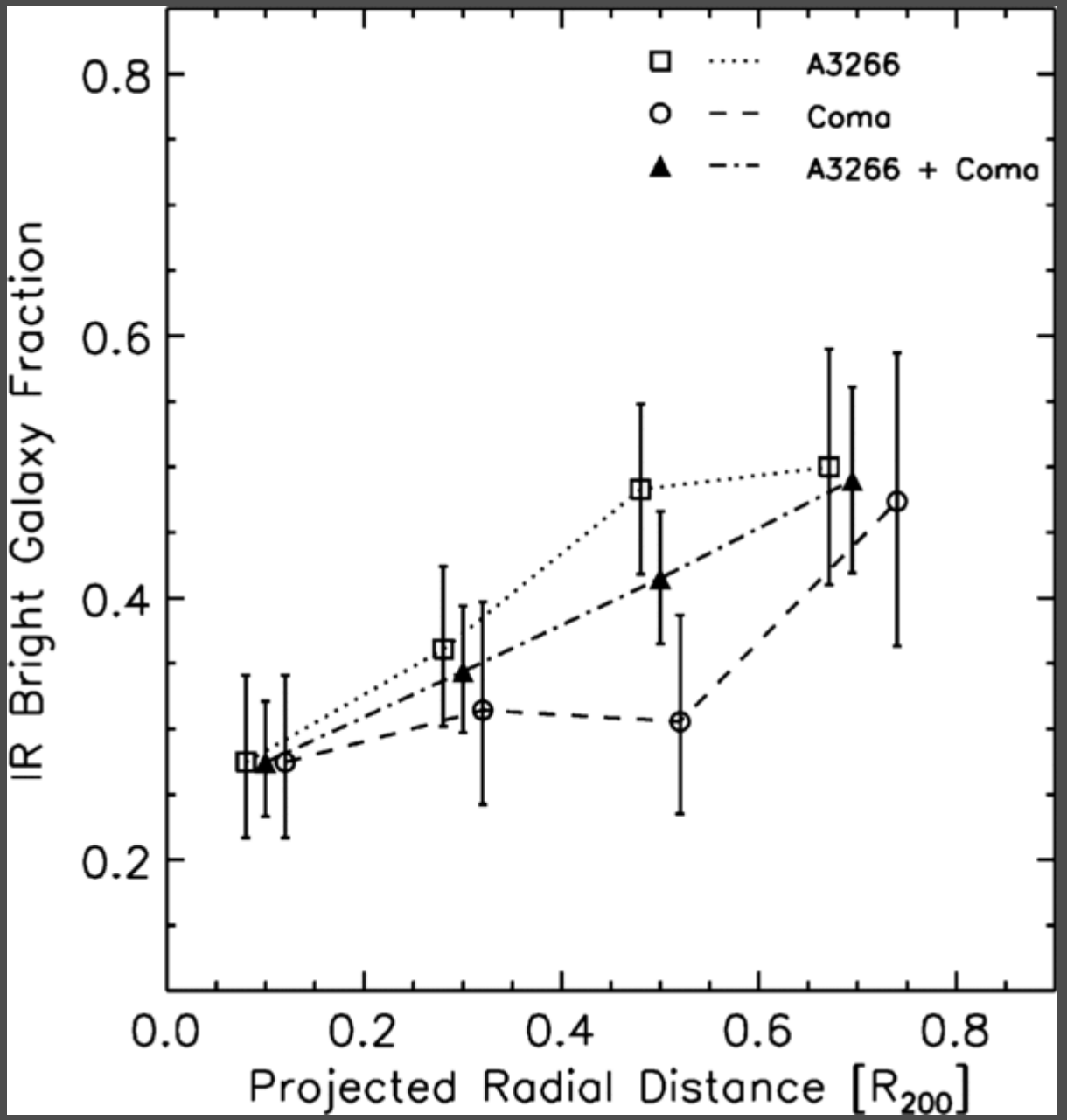
IR-emitter number density

IR luminosity

(Goto+10)

Higher fraction of high-SFR galaxies at larger radii

Fraction of $M_R \leq -20.15$ galaxies which have SFR $\geq 0.2\ M_\odot/yr$



(Bai+09)

Observational results:

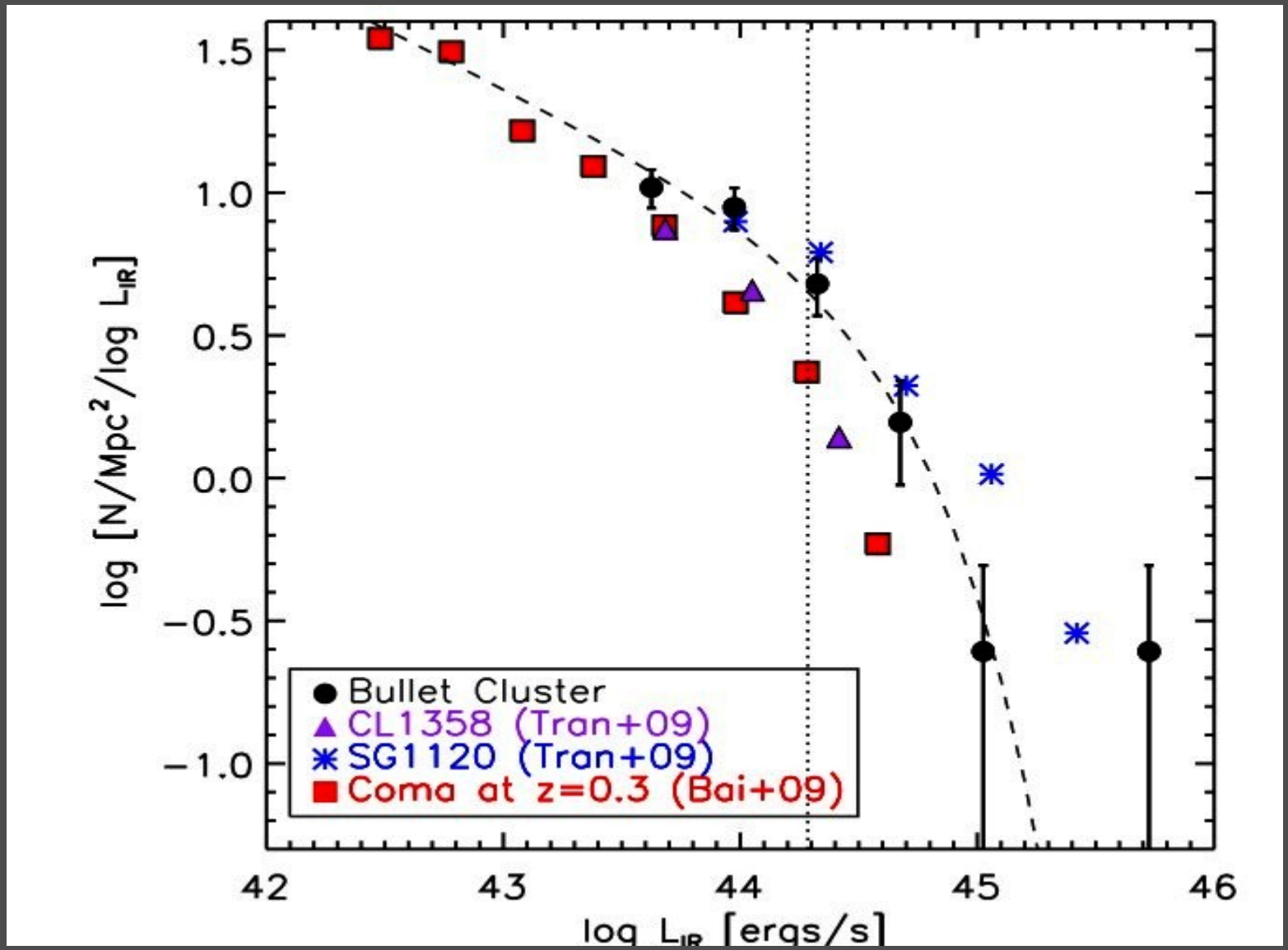
The cluster IR LF is “universal”

The cluster IR LF evolves rapidly but regularly with z

Denser environments have a higher fraction of IR-emitters and a flatter IR LF

...but... is everything OK?

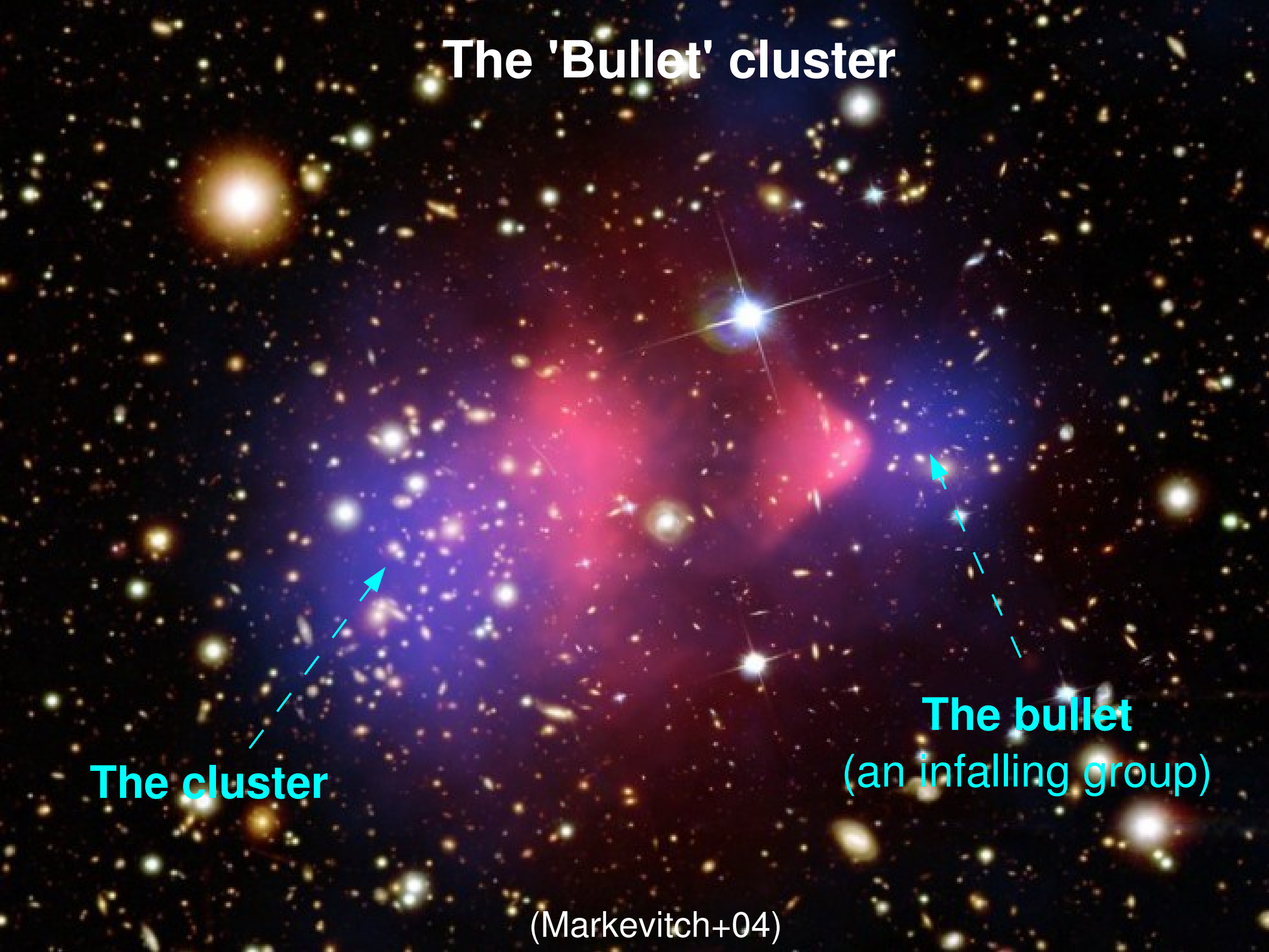
Is the cluster IR LF really “universal”?



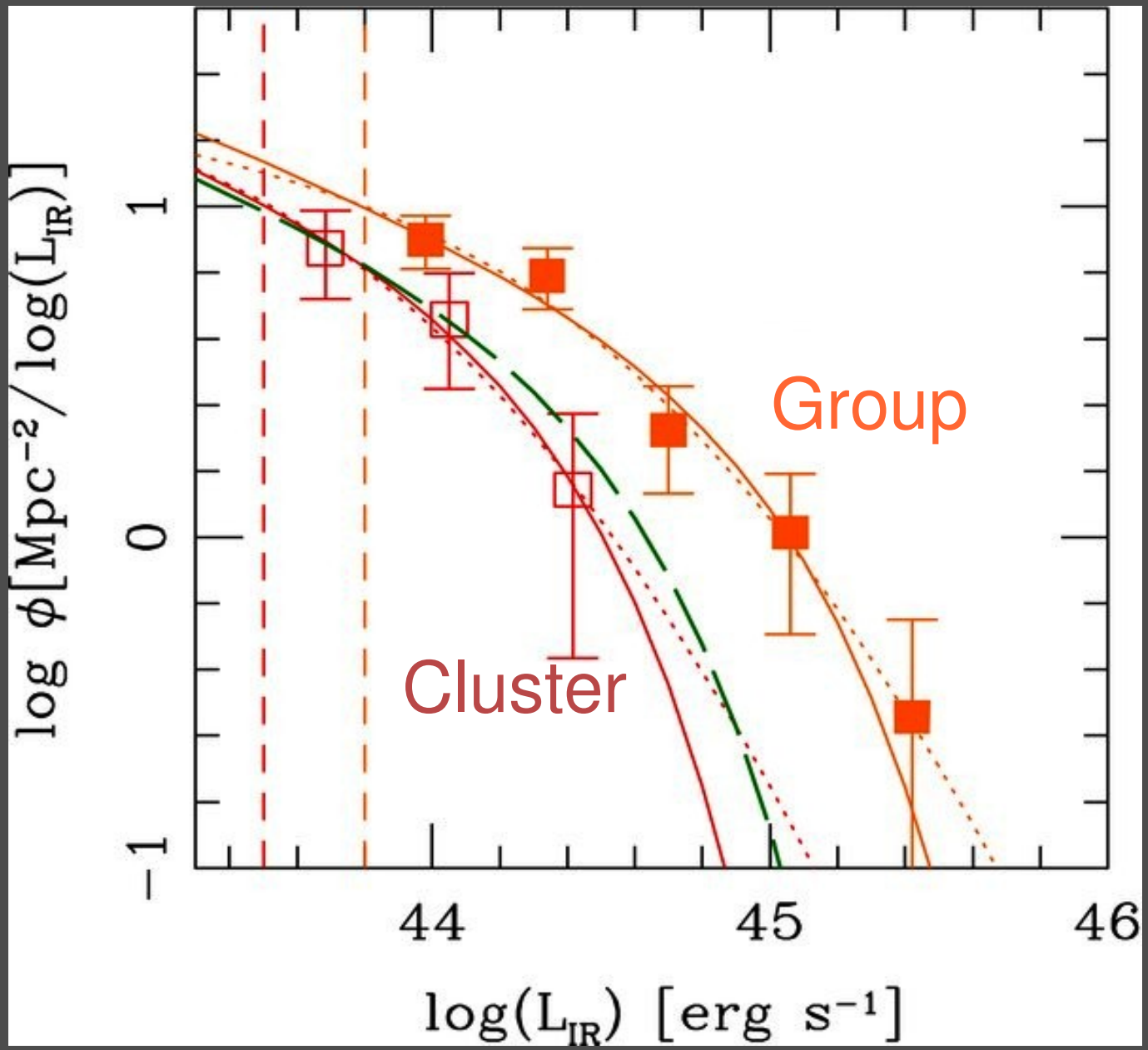
galaxy number density per bin of IR luminosity

IR luminosity

(Chung+10)


The 'Bullet' cluster
The cluster
The bullet
(an infalling group)
(Markevitch+04)

Is the cluster IR LF really “universal”?

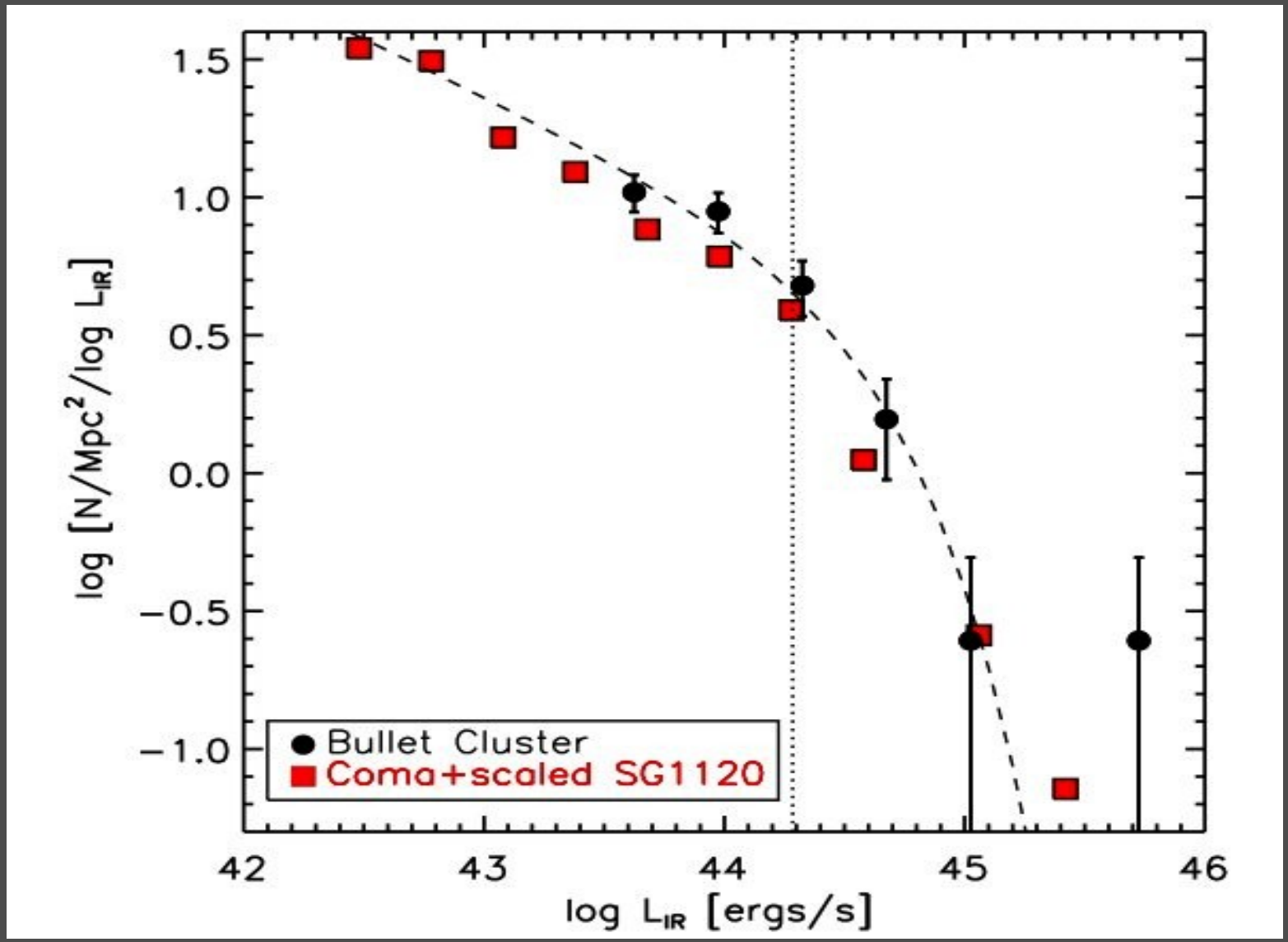


Density of
IR-emitters
&
ratio of
bright/faint
IR-emitters

higher
in groups
than in clusters

(Tran+09)

Is the cluster IR LF really “universal”?



IR luminosity

(Chung+10)

Is the cluster IR LF evolution as predicted?

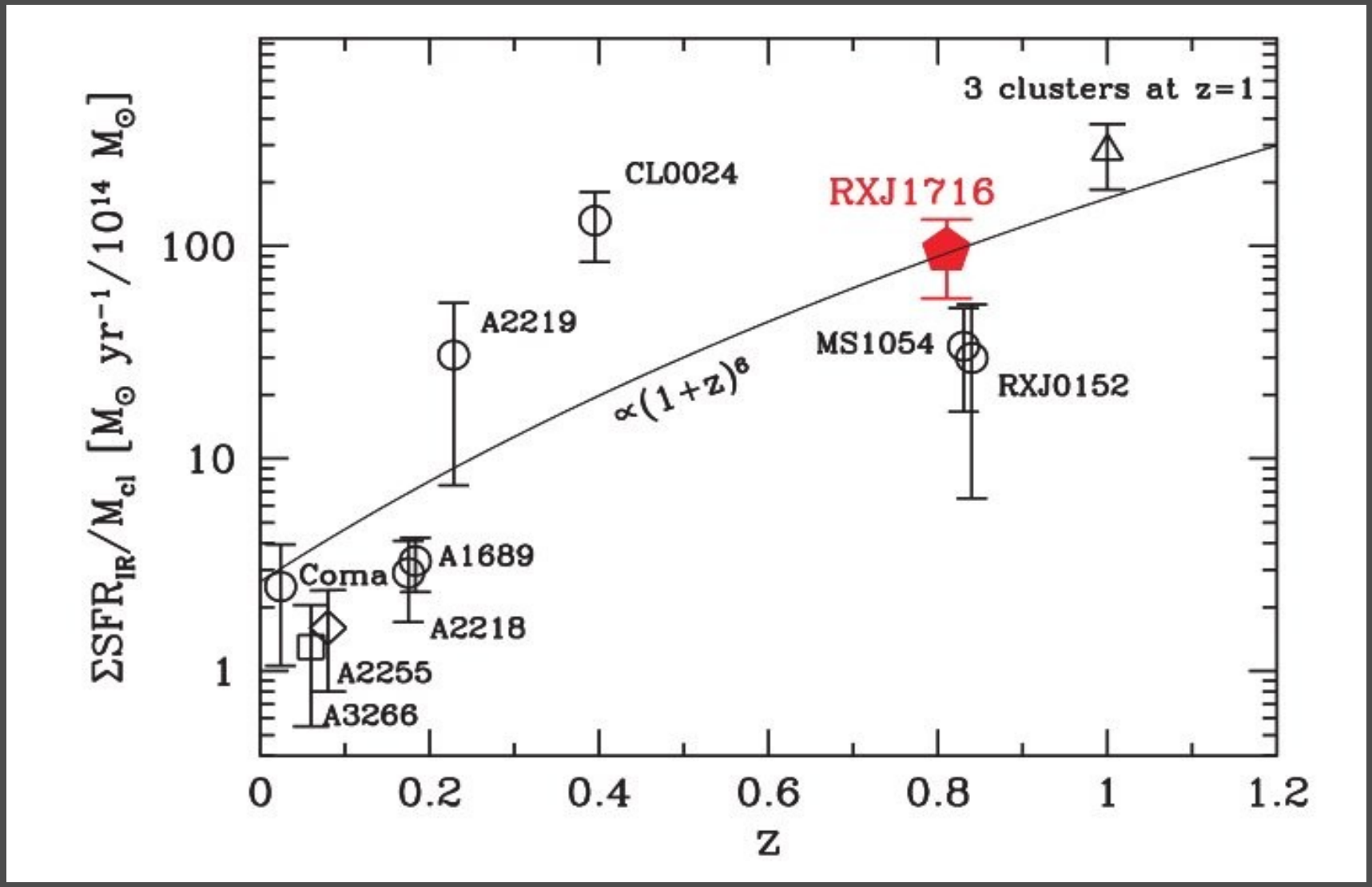
Look at the total cluster Star Formation Rate scaled by cluster richness or cluster mass as a function of redshift

ΣSFR:

Integrate IR LF (L_{IR})
and use Kennicutt's (1998) relation:

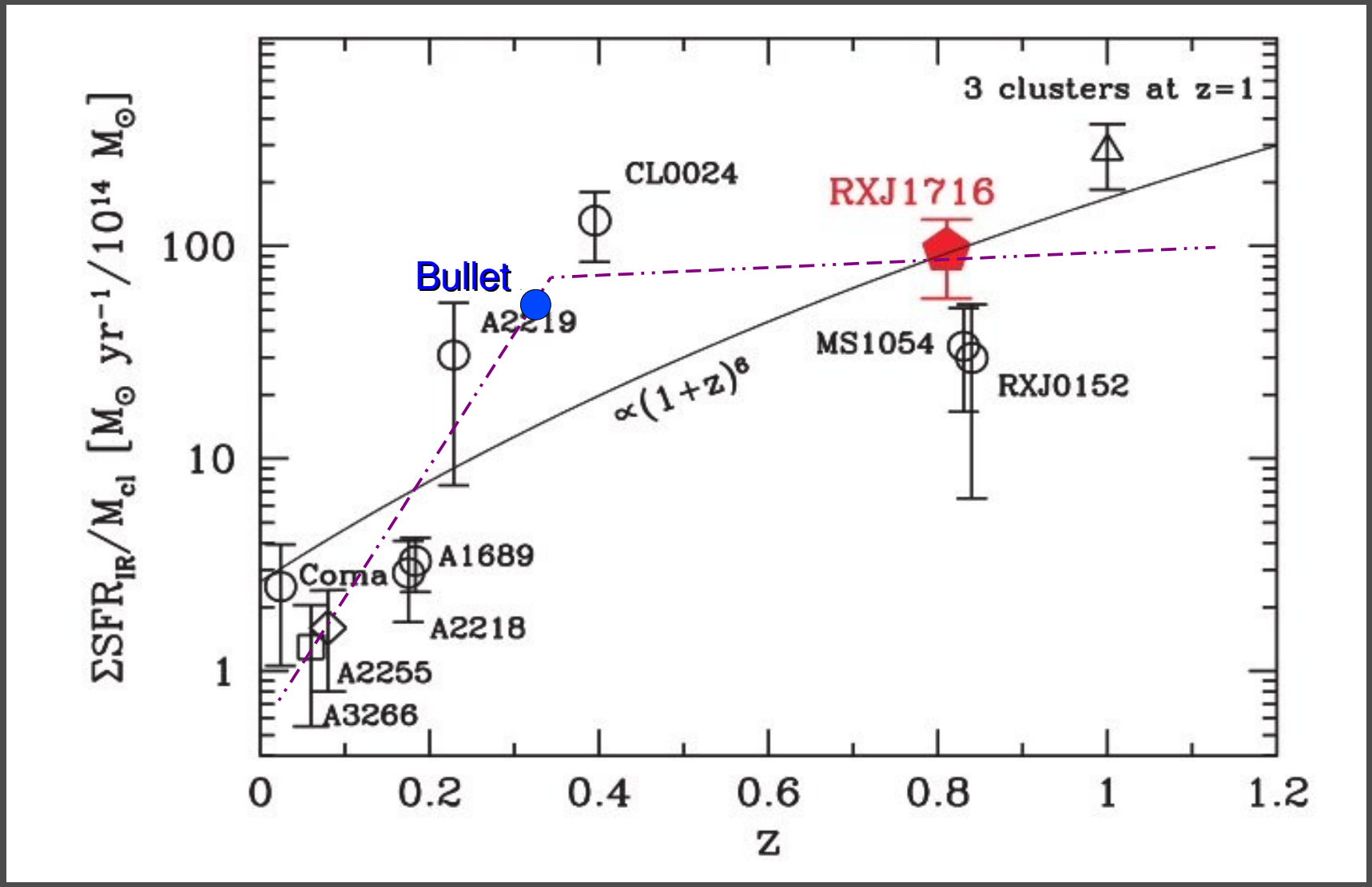
$$SFR\ [M_\odot/yr] = 1.7\ \ 10^{-10}\ L_{IR}/L_\odot$$

Total cluster SFR per unit (dynamical) mass vs. redshift



Steep evolution, $\Sigma SFR/M \propto (1+z)^6$ (Koyama +10)

Total cluster SFR per unit (dynamical) mass vs. redshift



Steeper evolution out to z~0.4?

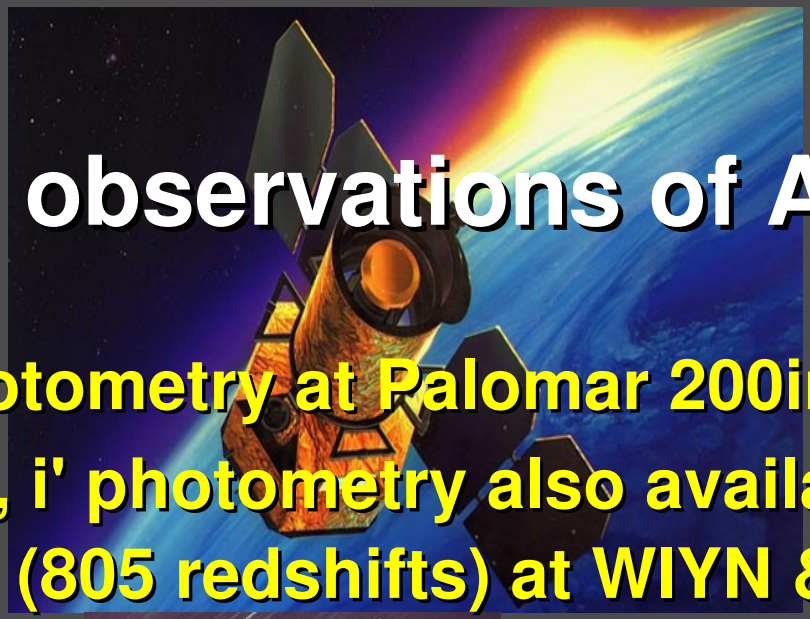
...or clusters at z~0.4 include groups (subclusters)?


Mid & Far-IR (3-160 μm)
Spitzer observations
of 3 galaxy clusters at z~0.2
Extensive follow-up observations
of one of them, A1763

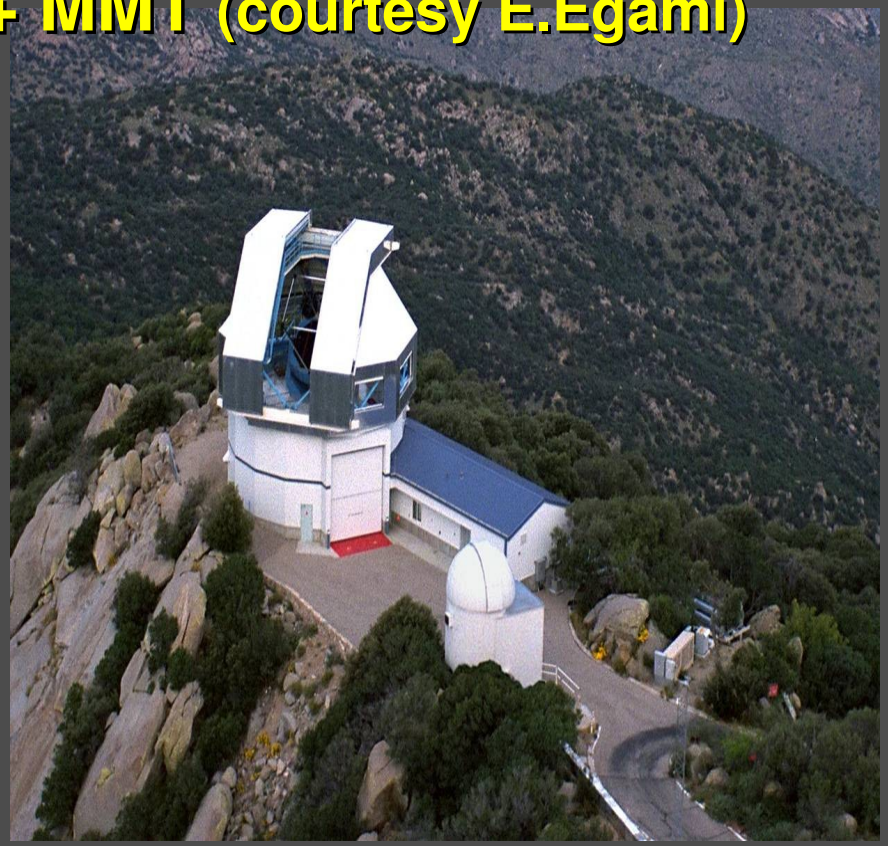
Follow-up observations of A1763:

r', J, H, K_s photometry at Palomar 200inch (LFC + WIRC)
SDSS u', g', r', i' photometry also available
spectroscopy (805 redshifts) at WIYN & TNG
+ MMT (courtesy E.Egami)

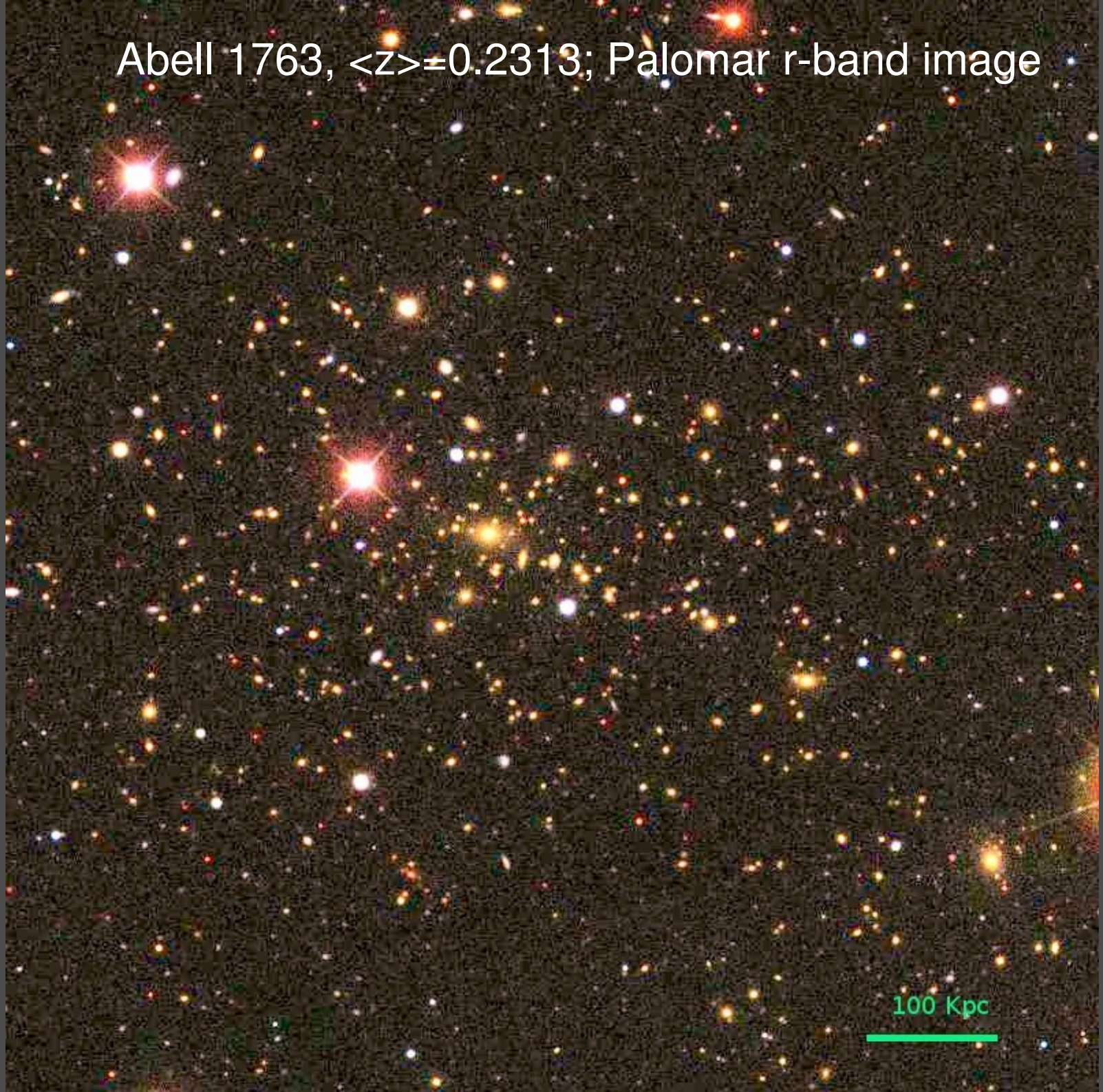
GALEX UV photometry
1.4 GHz VLA observations
XMM-Newton archive data

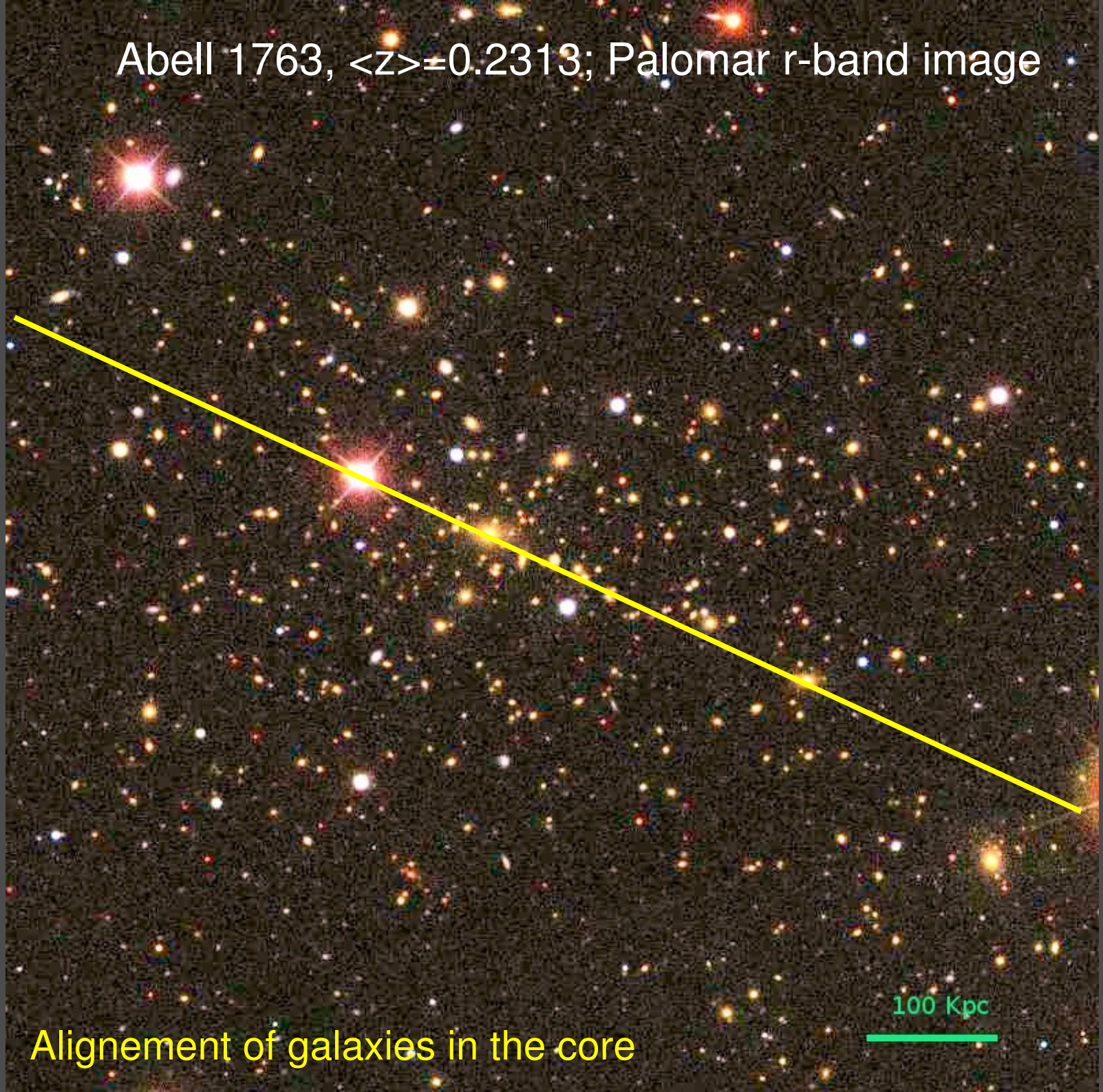





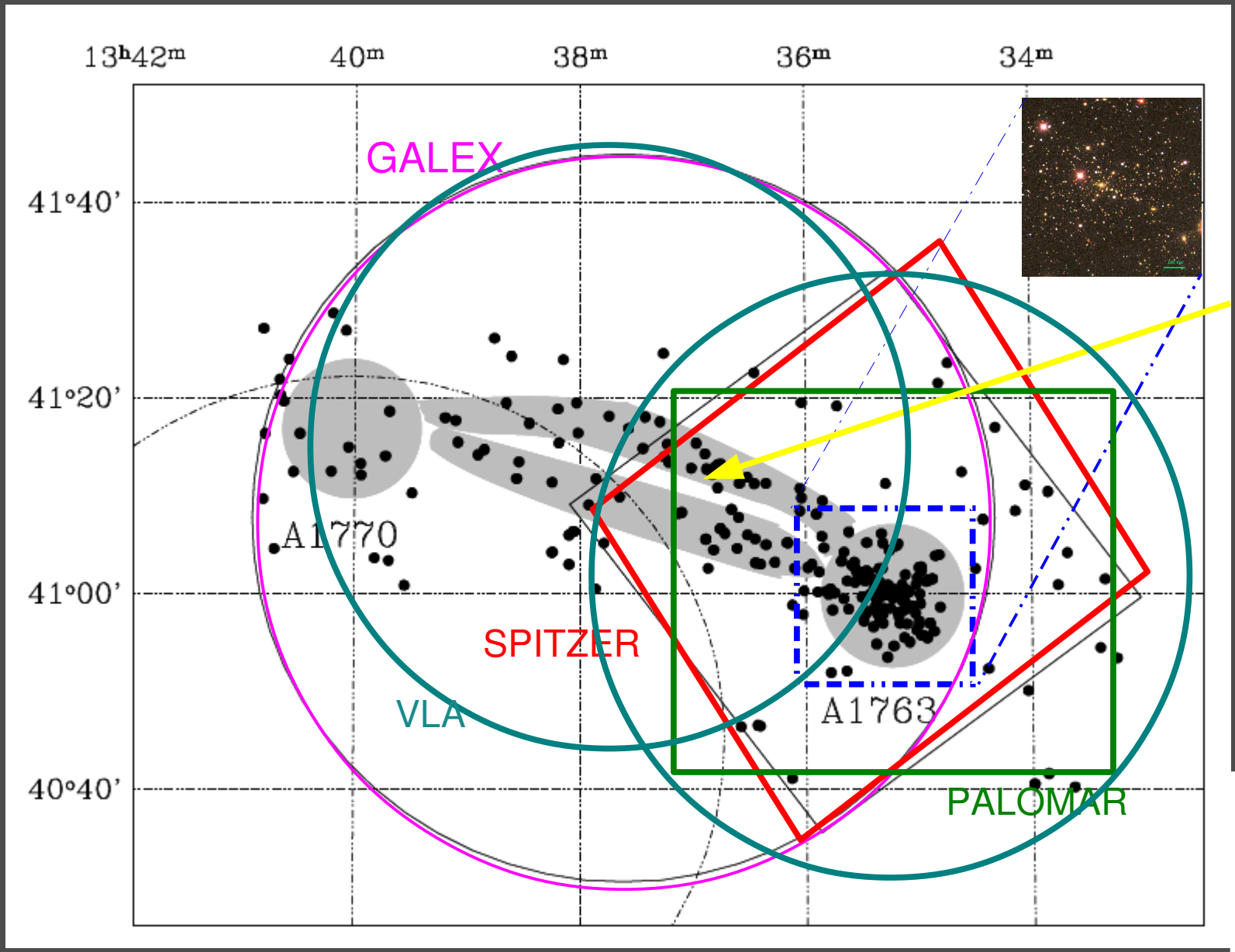





Abell 1763, <z>=0.2313; Palomar r-band image
100 Kpc


Abell 1763, <z>=0.2313; Palomar r-band image
100 Kpc
Alignement of galaxies in the core

Abell 1763, zooming out



1st LSS filament(s) discovered in the IR *(and confirmed spectroscopically)*

Dots: supercluster members (spectroscopically confirmed)

AIM: determine the galaxy IR luminosity function in different regions of the supercluster

⇒ galaxy star formation = f(environment)

...to achieve this aim:

Select sample of IR emitters members of the supercluster, 124 from z, 343 from z_{phot}

Base the selection on our 24 μm survey,

80% complete at 0.2 mJy

[deeper than 70 and 160 μm, emission at 24 μm closely related to recent star formation]

Fit galaxy Spectral Energy Distributions (SEDs) with model templates:

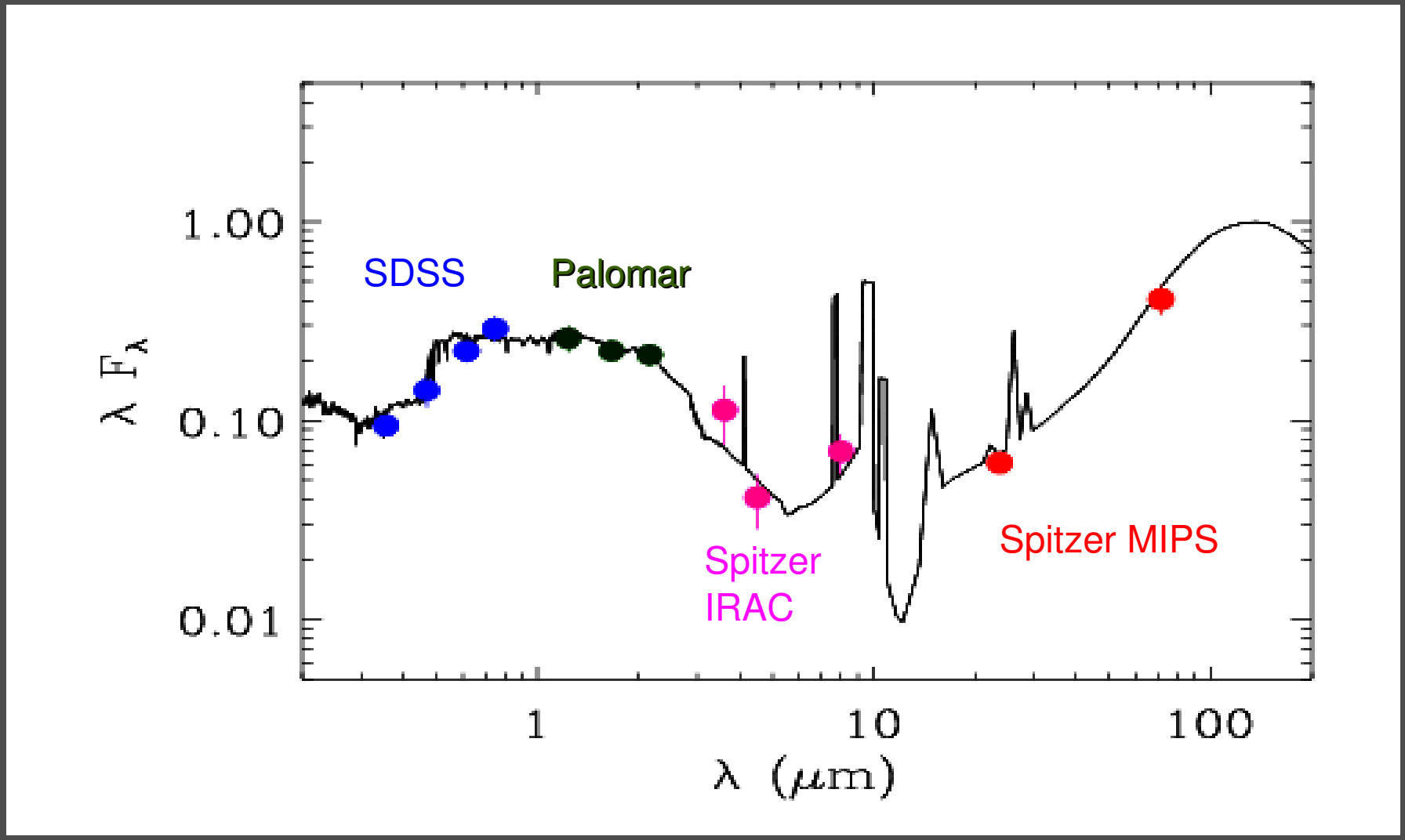
for L_{IR}:

Use GRASIL (Silva+98) & Polletta+07 models
and integrate best-fit model SEDs from 8 to 1000 μm

for $M_{\star}$:

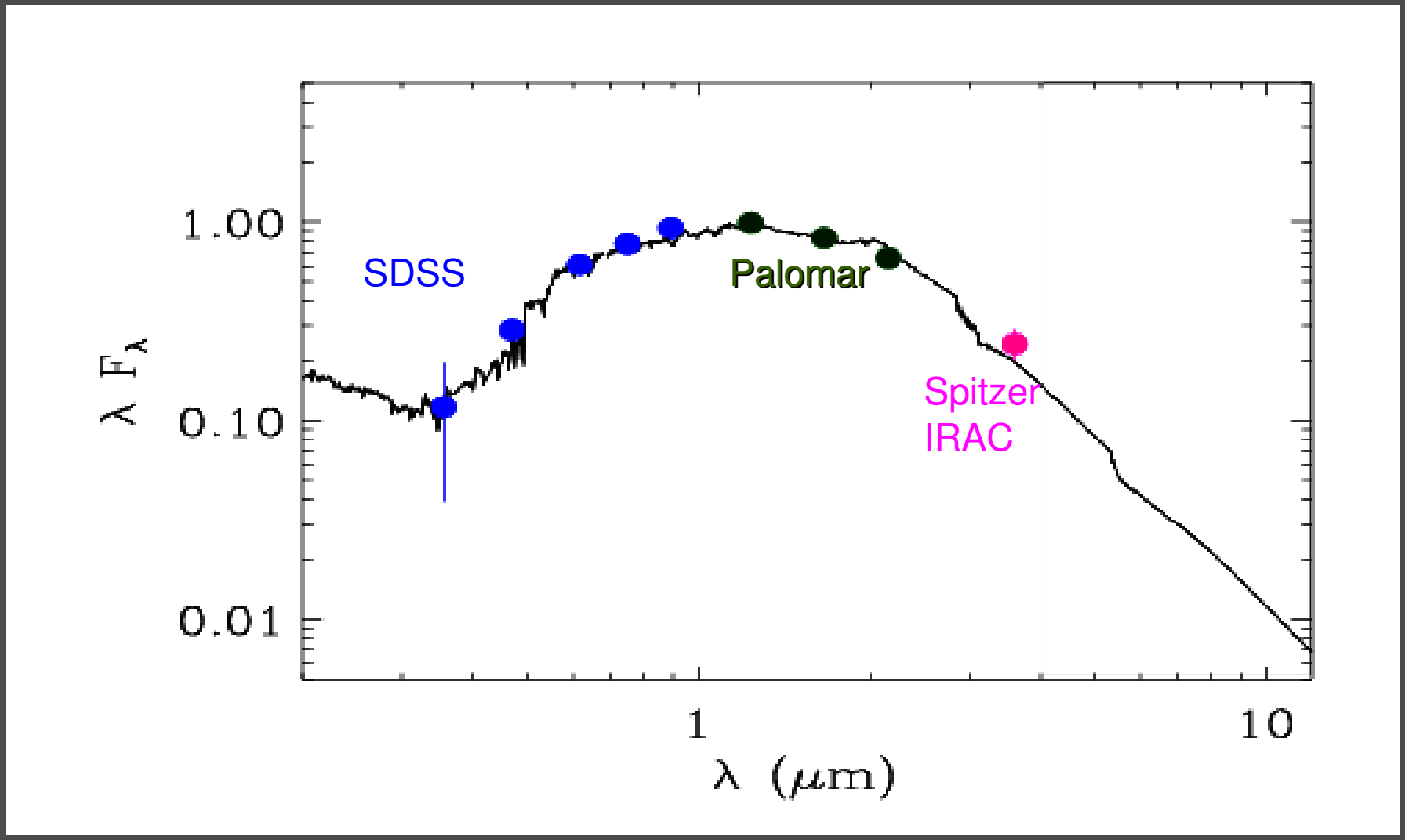
Use models of Maraston 05,
correct for absorption (Calzetti+00) with E(B-V) free to vary,
and restrict the fit to λ<4 μm

Example of full SED template fit:



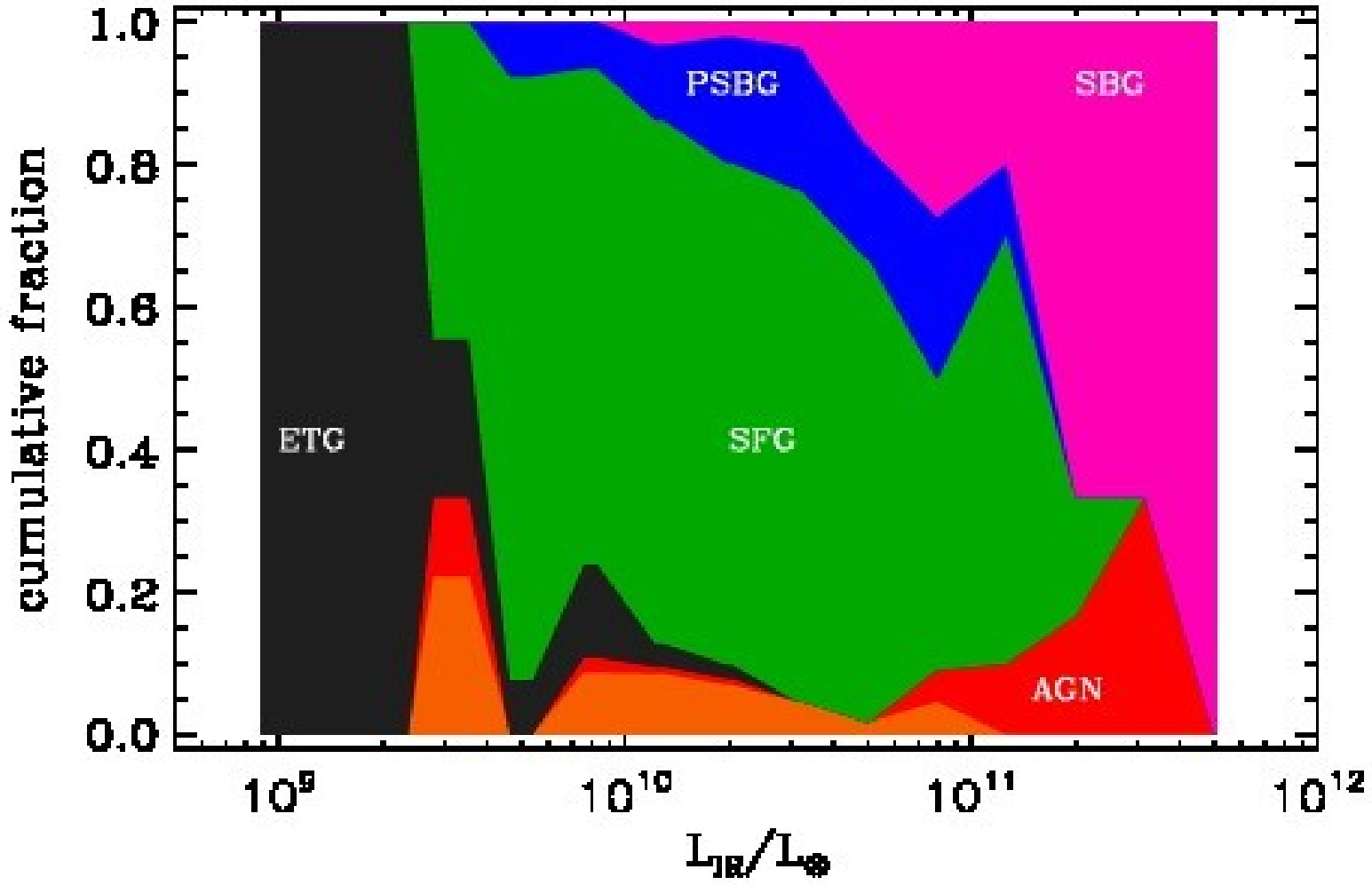
61 templates (GRASIL & Polletta's models) in 5 broad classes:
ETG, SFG, SBG, PSBG, AGN

Example of restricted (λ<4 μm) SED template fit:



Extinction E(B-V) is a free parameter, varying from 0 to1 mag, no dust emission in model ⇨ stop fit at λ<4 μm

The contribution of the different SED classes to the IR LF:



AGNs identified by their SED, and also using other diagnostics (from optical spectroscopy, X-ray and radio data, IRAC colors)

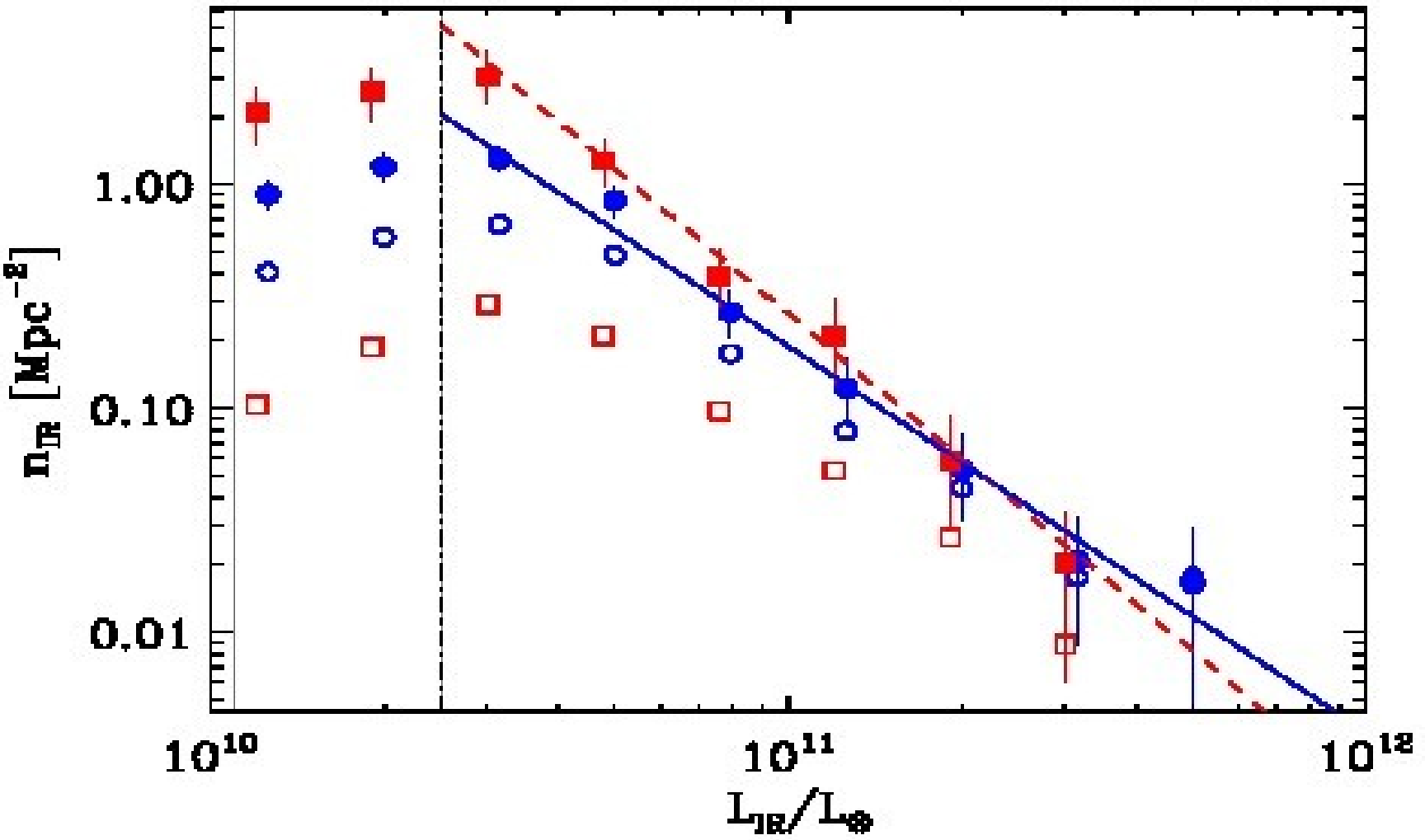
→ AGN contribution subtracted from IR LF

By counting the number of supercluster members
in bins of L_{IR} we do **not** obtain
the IR luminosity function (IR LF),
because our sample is neither complete nor pure
(contamination from non-members).

Therefore we evaluate:
Completeness = $C(f_{24})$
and Purity = $P(f_{24})$
for the spectroscopic sample
& the full (spectroscopic+photometric) sample.

Then we correct the IR counts to get the
pure & complete (P=1 & C=1) IR LF

The IR LF of the A1763 supercluster



Open/filled symbols = uncorrected/corrected counts

Red/blue symbols = spectroscopic only/full sample

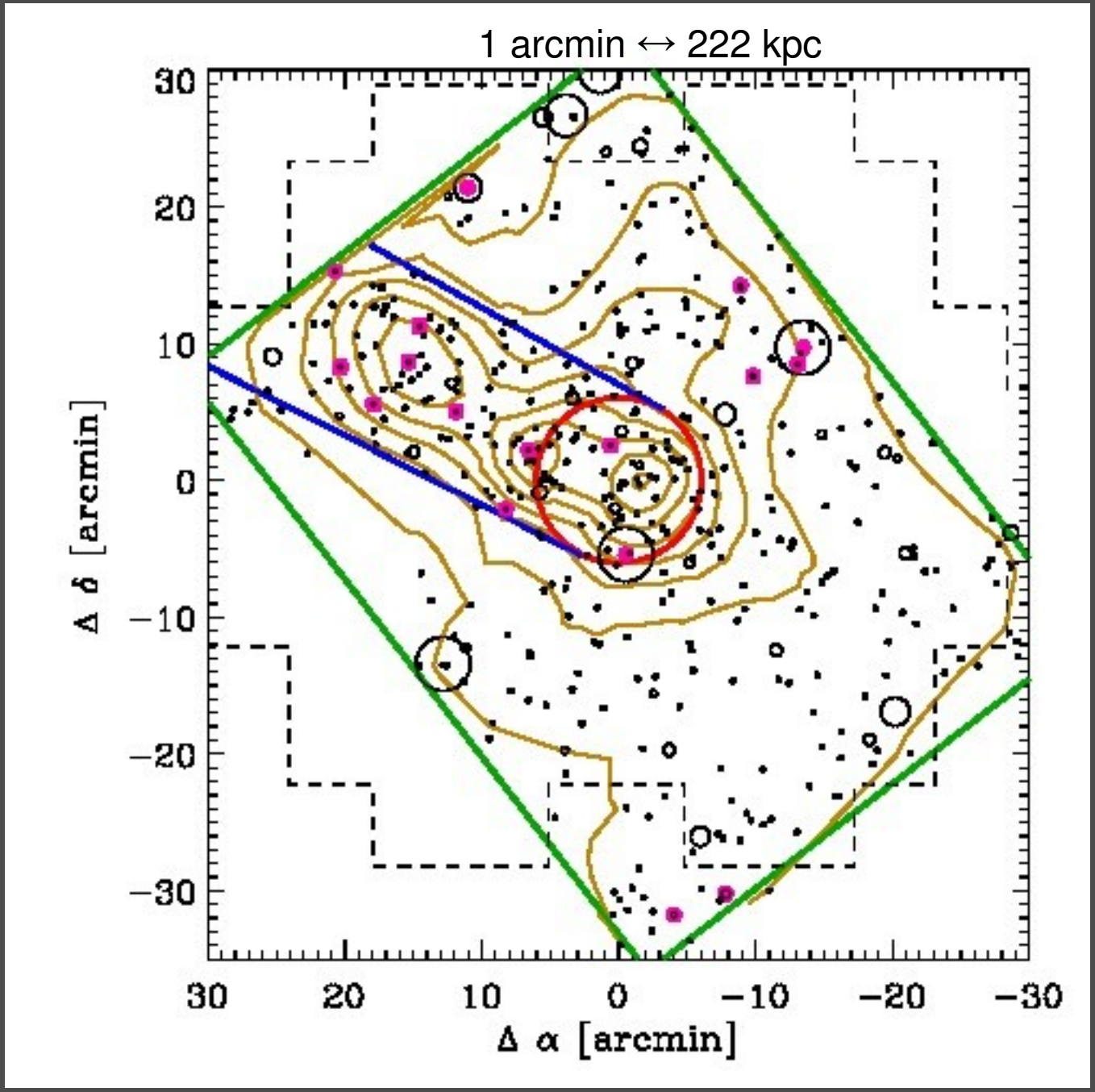
What is the effect of the environment?

We identify
3 environments:

core ($<r_{500}$)

large-scale filament

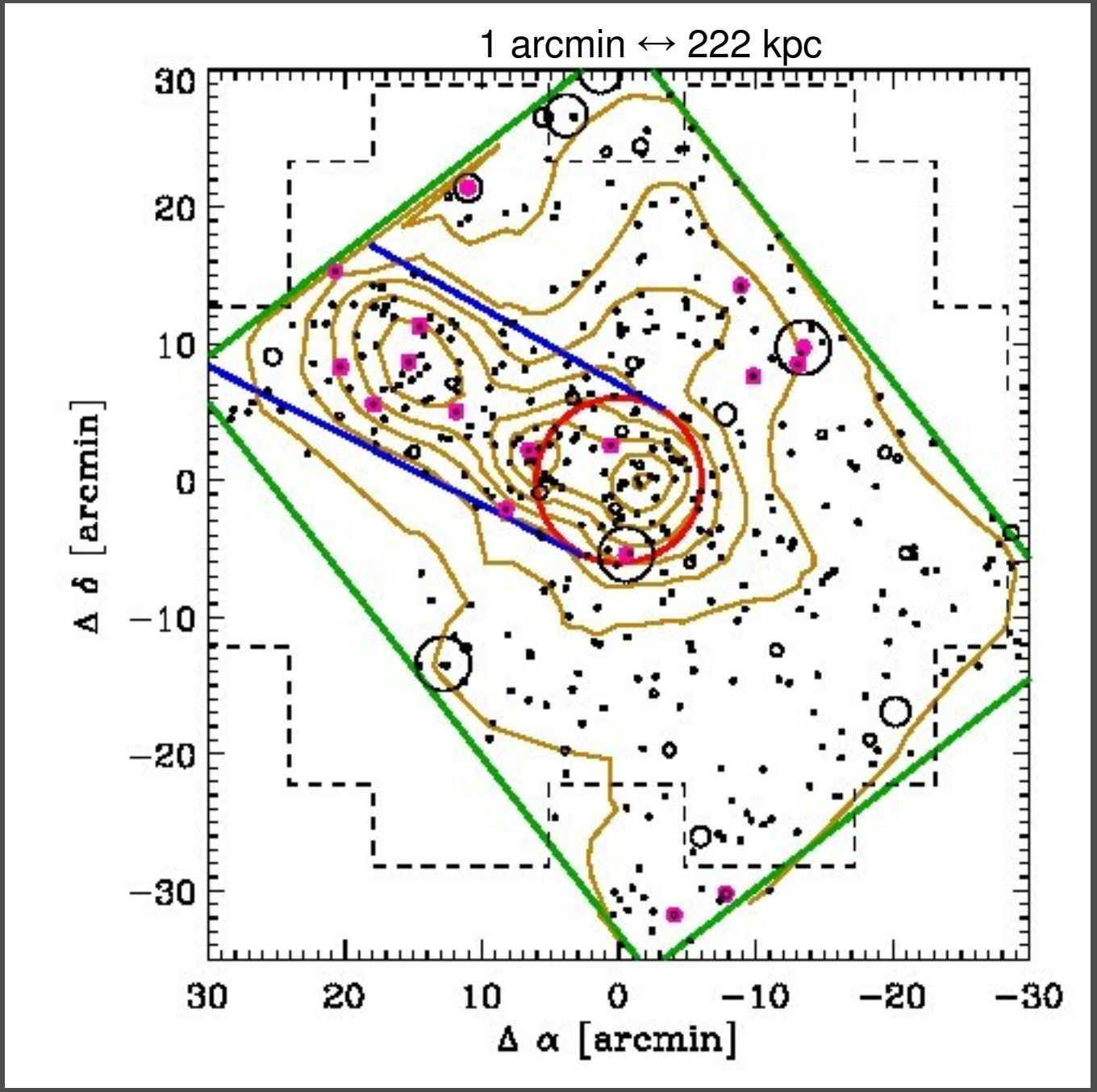
outskirts
(= the whole field except the core and the filaments)



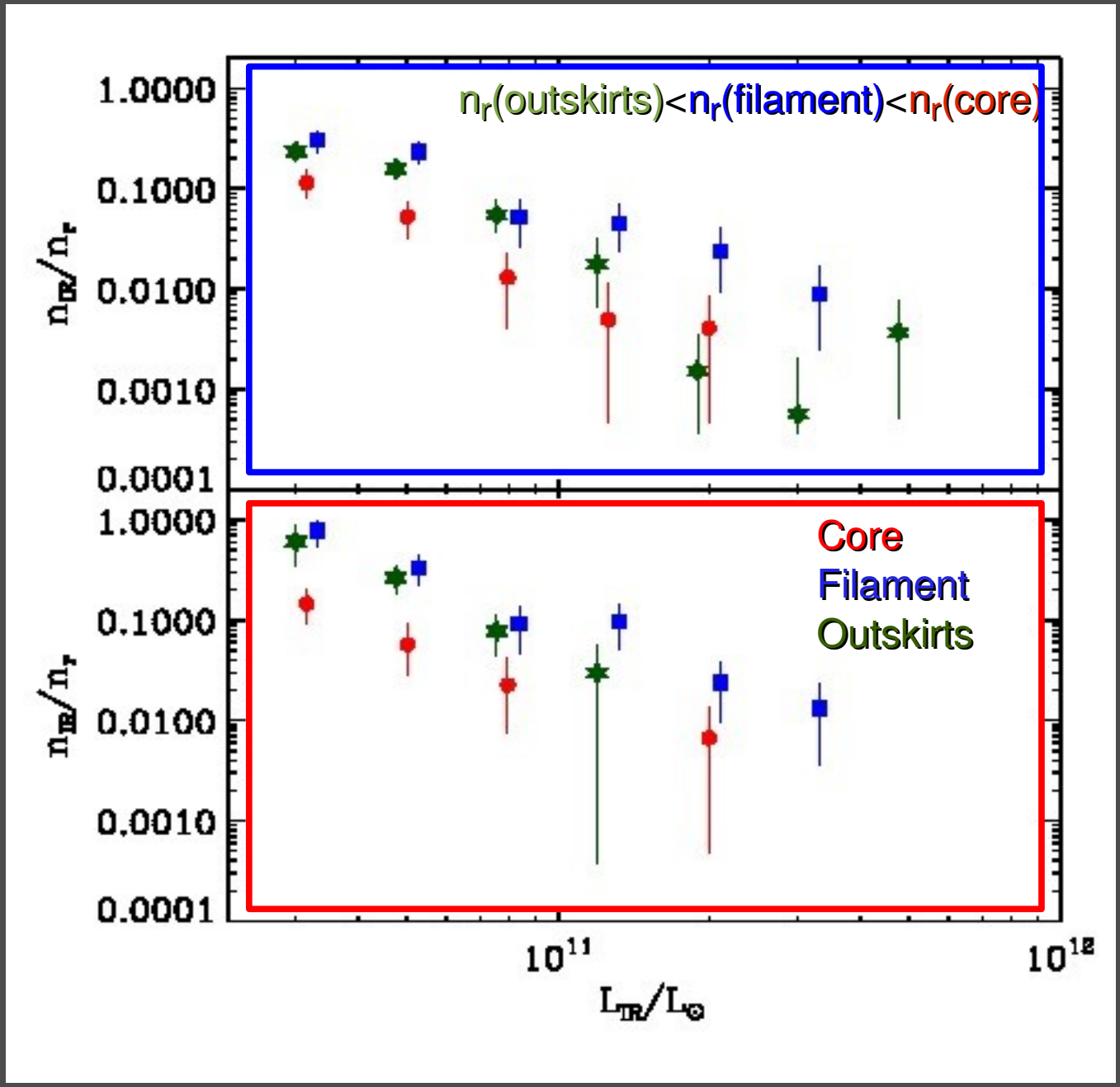
What is the effect of the environment?

LIRGs ($L_{IR}>10^{11}\ L_{\odot}$) are located mostly in the region of the filaments

They do *not* have high $SFR/M_{\star}$ ($\propto$ circle size)



The IR LFs in 3 different supercluster environments



The densities of IR-emitting galaxies, n_{IR}, are normalized by the densities, n_r, of normal, r-selected galaxies in the same regions

full sample

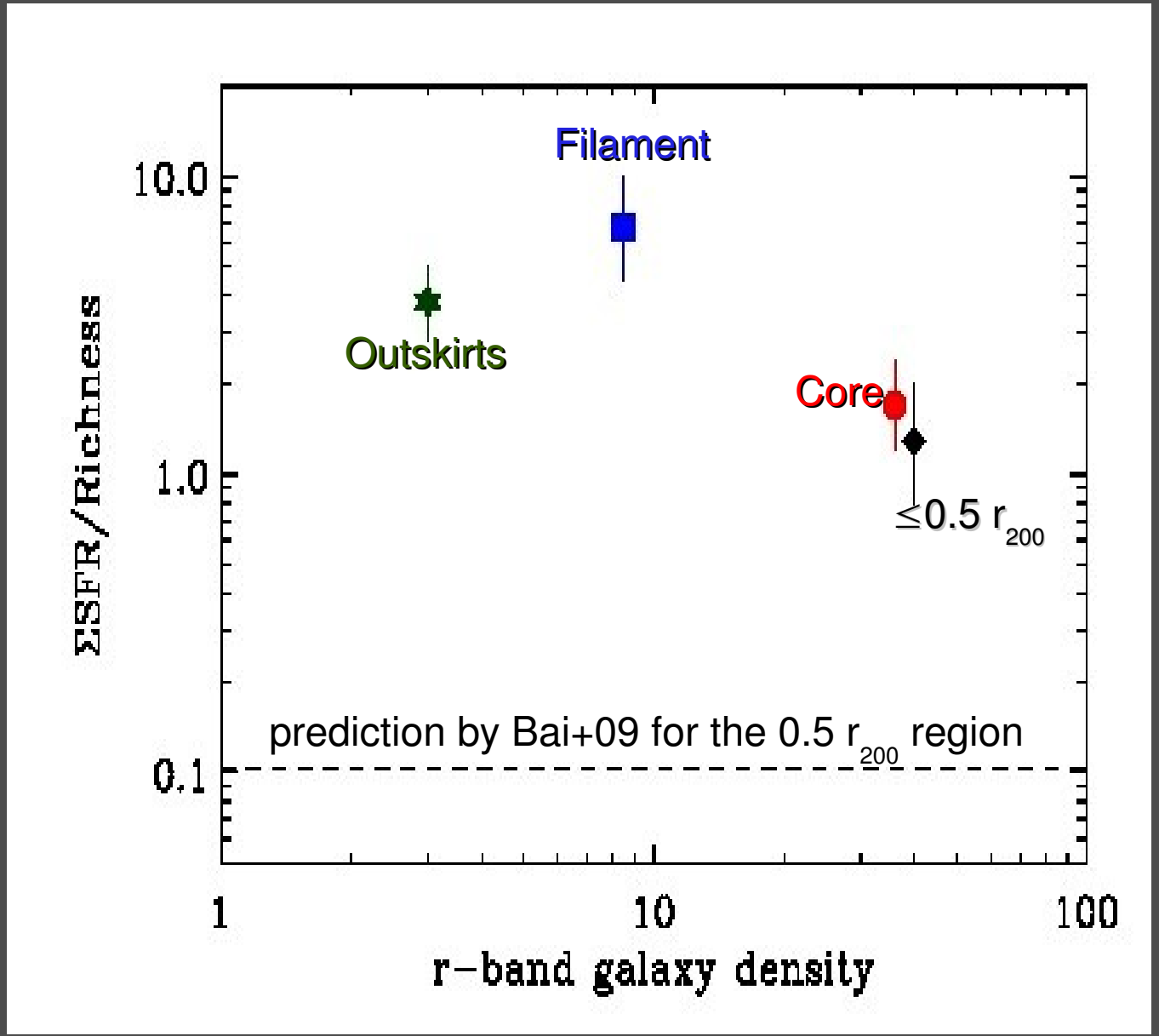
spectroscopic sample

What is the effect of the environment?

higher fraction of IR-emitters
&
milder decline of IR LF at bright end

↓

The filament is the supercluster region with the highest average SFR per galaxy



Comparison with previous works

Previous cluster IR LF determinations limited to core regions

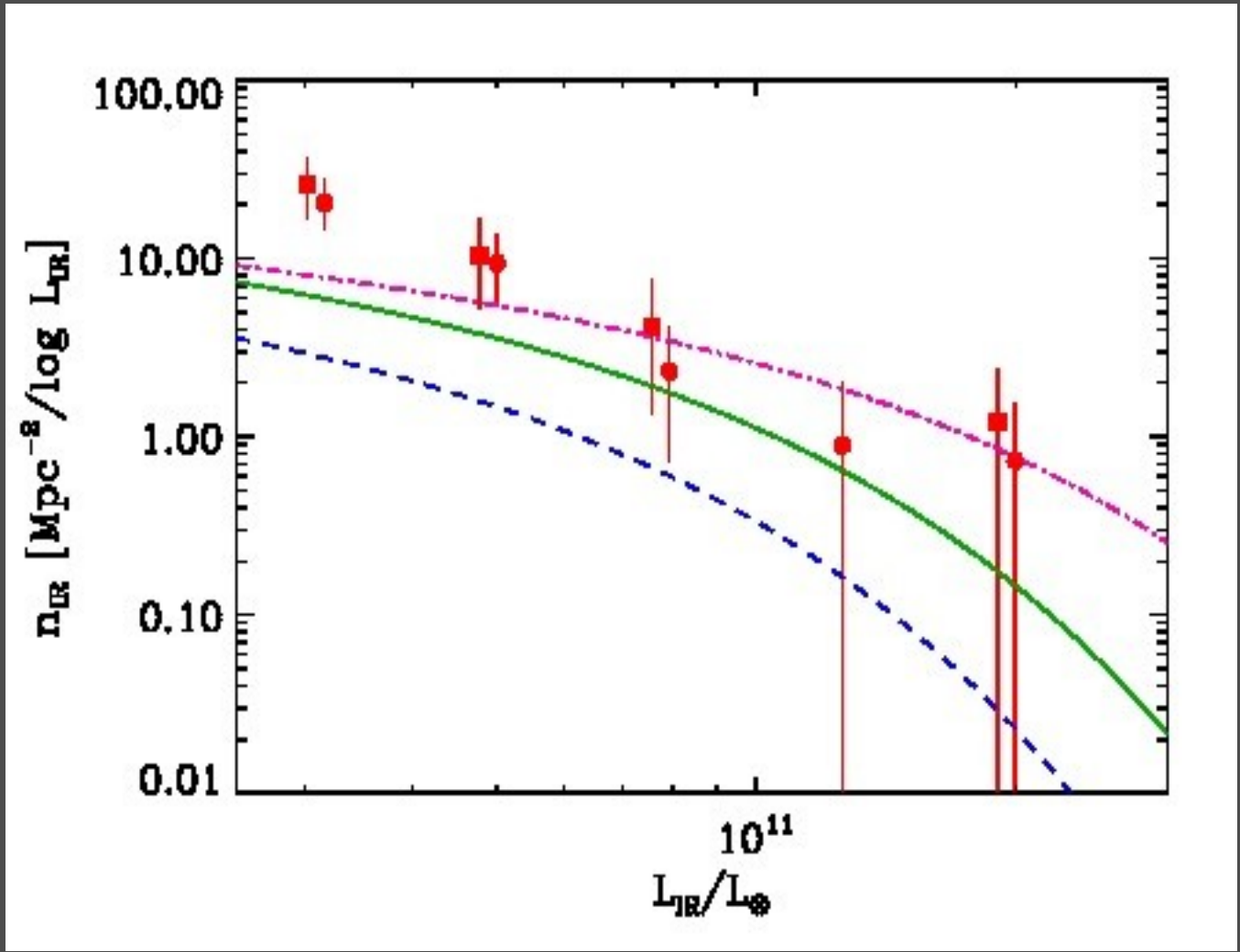
Dots: A1763 core, full
Squares: only z

Green line:
Coma IR LF
(Bai+09)

Blue line:
z=0.35 cluster IR LF
(Tran+09)

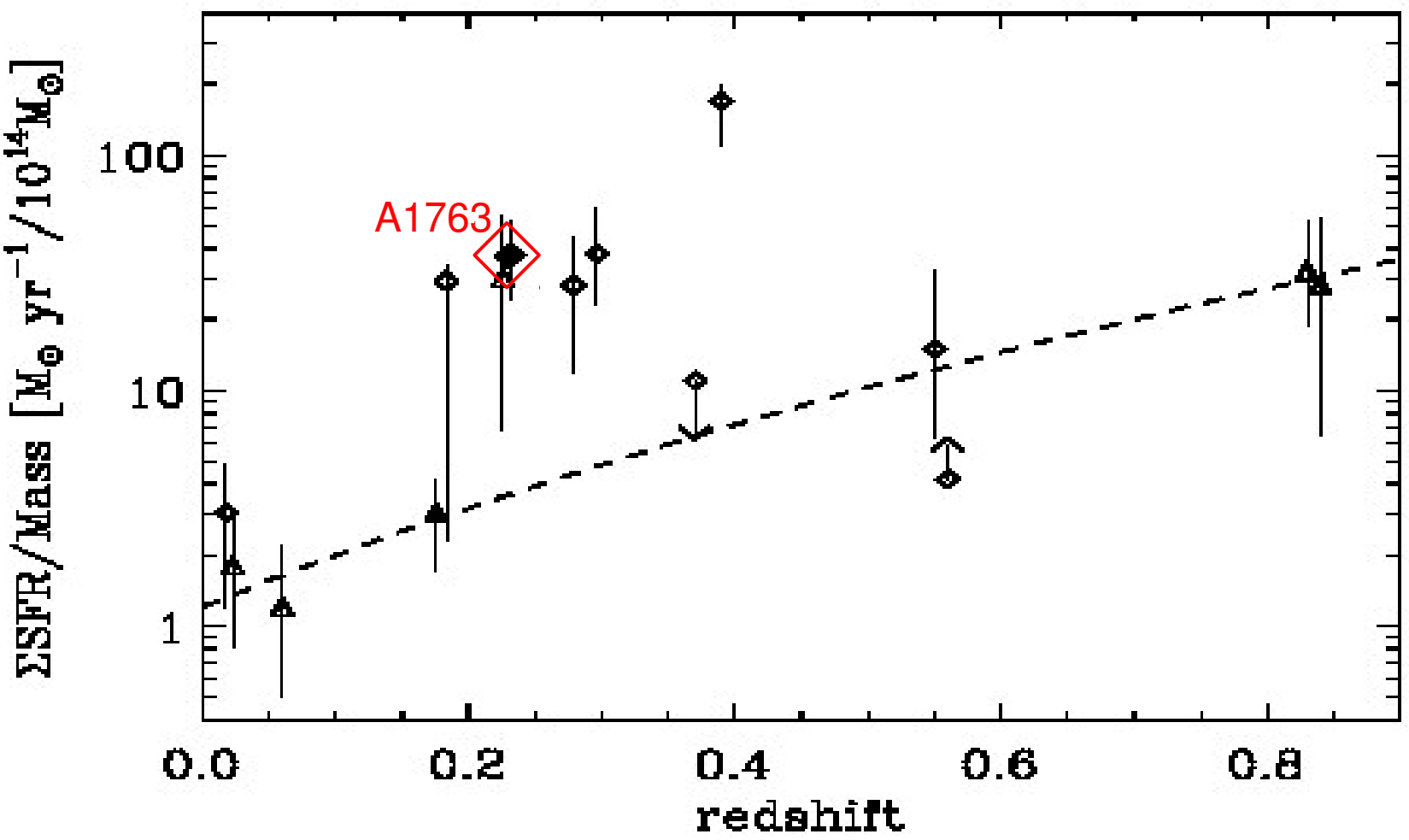
Pink line:
Bullet cluster IR LF
(<z>=0.3, Chung+10)

All other cluster LFs evolved to <z>=0.23 of A1763 following Bai+09



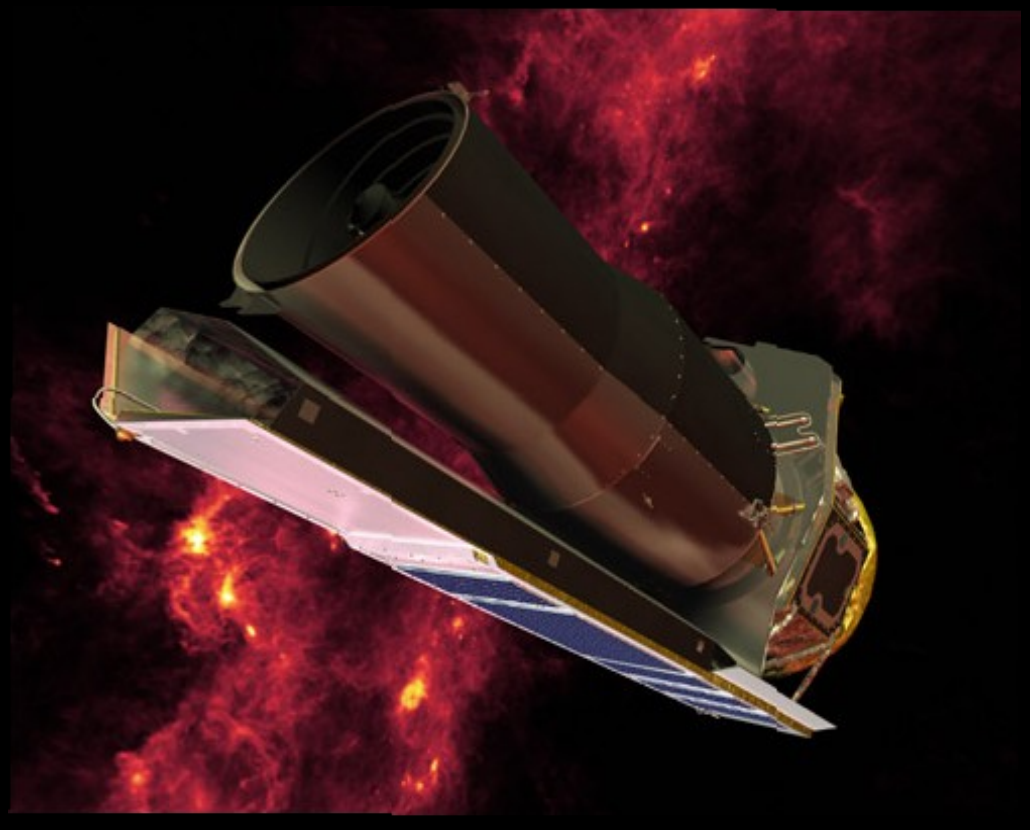
☛ IR LF of A1763 does not confirm the evolutionary relation of Bai+09

Comparison with previous works



The galaxy ∑SFR / total mass in cluster cores increases with z *(but not as predicted by Bai+09)*

Spitzer & Herschel observations of X-ray detected systems at $0 < z \leq 1.6$ in GOODS & COSMOS fields





Sample:

9 poor mass clusters/ groups at $M < 2 \times 10^{14}$ M

4 groups in GOODS fields at $0.7 < z < 1.6$

27 X-ray detected groups/clusters in COSMOS field:

➔ 4 stacked systems at $0.1 < z < 0.8$

8 clusters $> 2 \times 10^{14}$ $M_{\odot}$

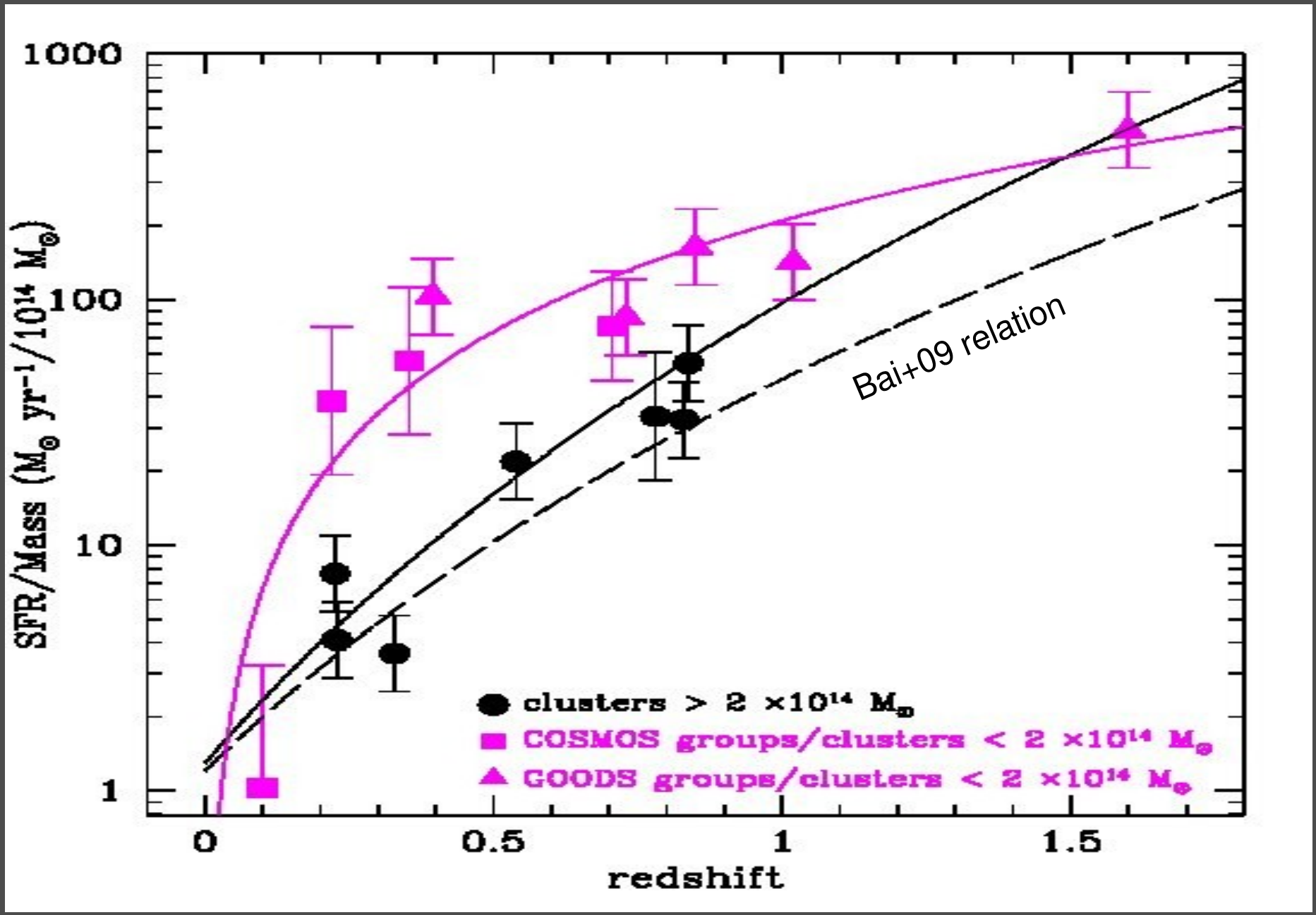
SFR: PACS 100 and 160 μm data:

GOODS-Herschel Program (PI D. Elbaz)

COSMOS: PEP PACS GT Program (PI D. Lutz)

Completeness: 50-85% for LIRGs

Total SFR ($<r_{200}$) / M_{200} vs. redshift



Summing up

- Galaxy star formation (as seen in the IR) depends on the environment and the redshift, but these dependences are not simple:
- intermediate-density environments (like filaments) are the preferred sites of galaxy star formation,
- the evolution of cluster SFR per unit mass is clear only up to $z \approx 0.4$.
- StarBurst in filaments, ram-pressure stripping in cluster cores, z-dependent accretion of star-forming galaxies from the field, together draw a plausible interpretation of the phenomenology of IR LFs in clusters and their surroundings.

What next?

➔ A1763: galaxy spectral line-indices & GALEX UV data

➔ Other clusters: Herschel data, evolution to z>1



High-z clusters:

48^{hrs} on 8 (proto)clusters (0.9<z<2.4)
(GT accepted, p.i. B. Altieri)

97^{hrs} on 8 clusters (1.4<z<1.8)
(OT accepted, p.i. P. Popesso)