Dust properties of LBGs at z ~ 3

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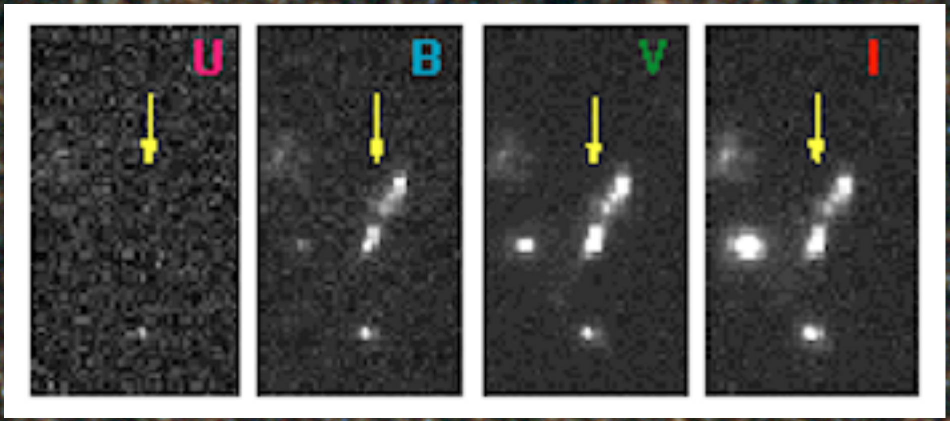
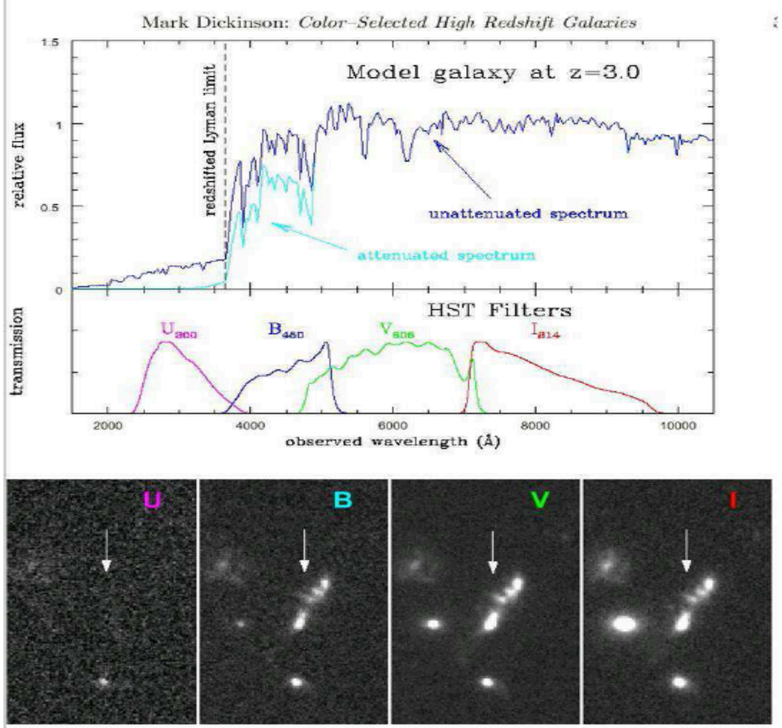
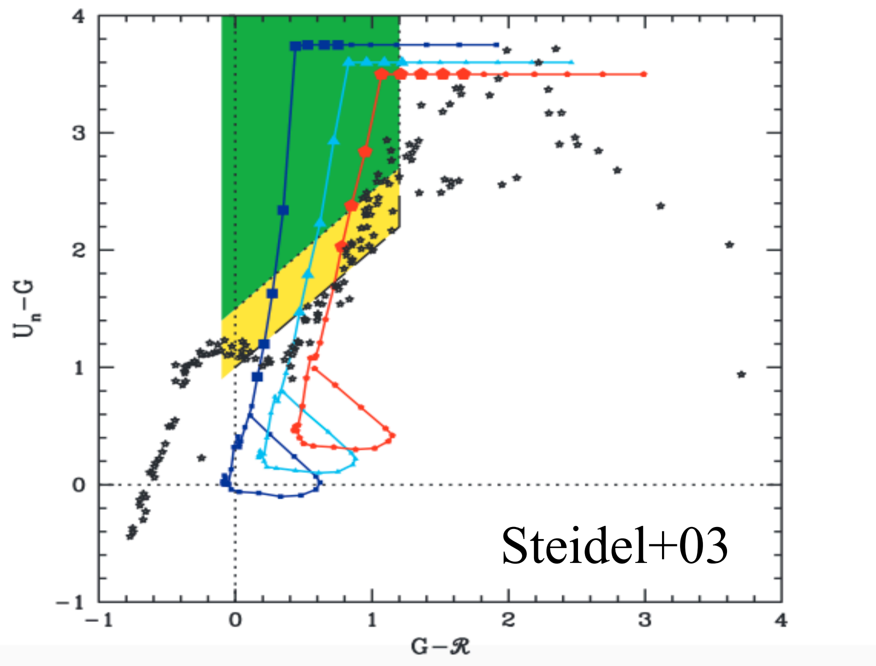
D. Burgarella, S. Heinis, B. Lo Faro, V. Buat and M. Béthermin et al.



Context: Lyman break galaxies (LBGs)



- **Lyman-break galaxies** are the largest population of star-forming galaxies known to be at z > 3. (Efficiency of the dropout technique)
- The **dropout technique** uses the drop of the UV flux due to the position of the Lyman break

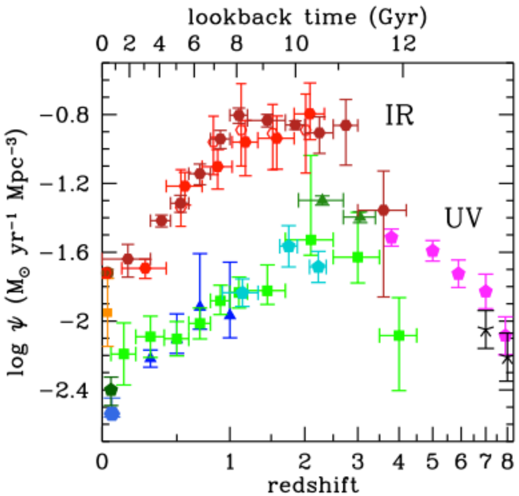


Steidel+03

- Only a small number of individual high-z LBGs are detected in the FIR / sub-mm
  - Low dust content
  - E(B-V) ~ 0.15

Context: SFRD and dustiness along the cosmic time

IR and UV uncorr SFRD



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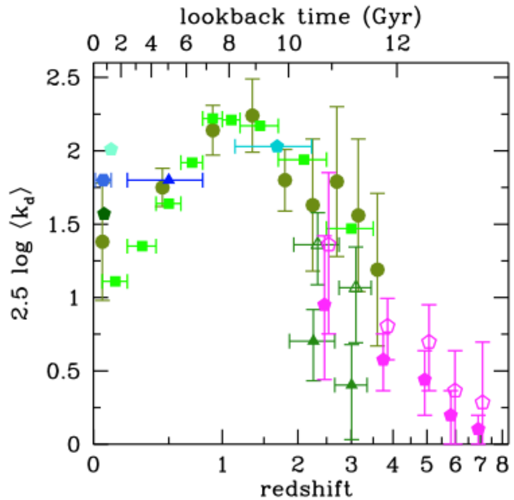
Attenuation (A)



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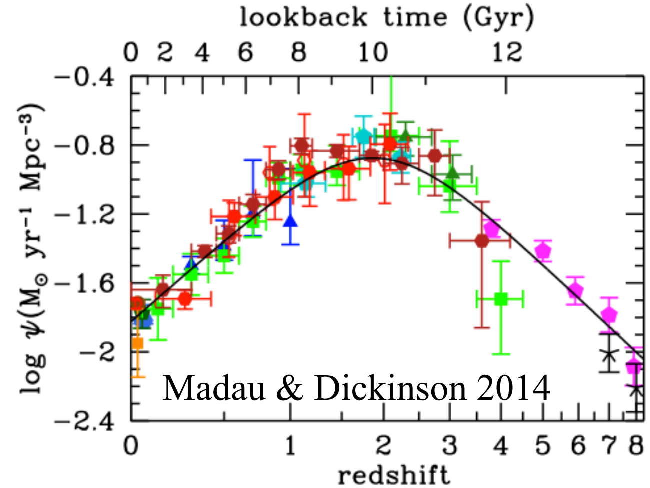
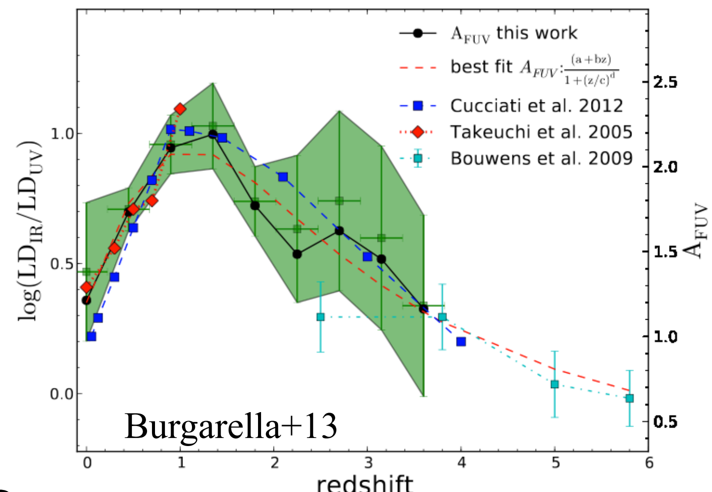
SFRD

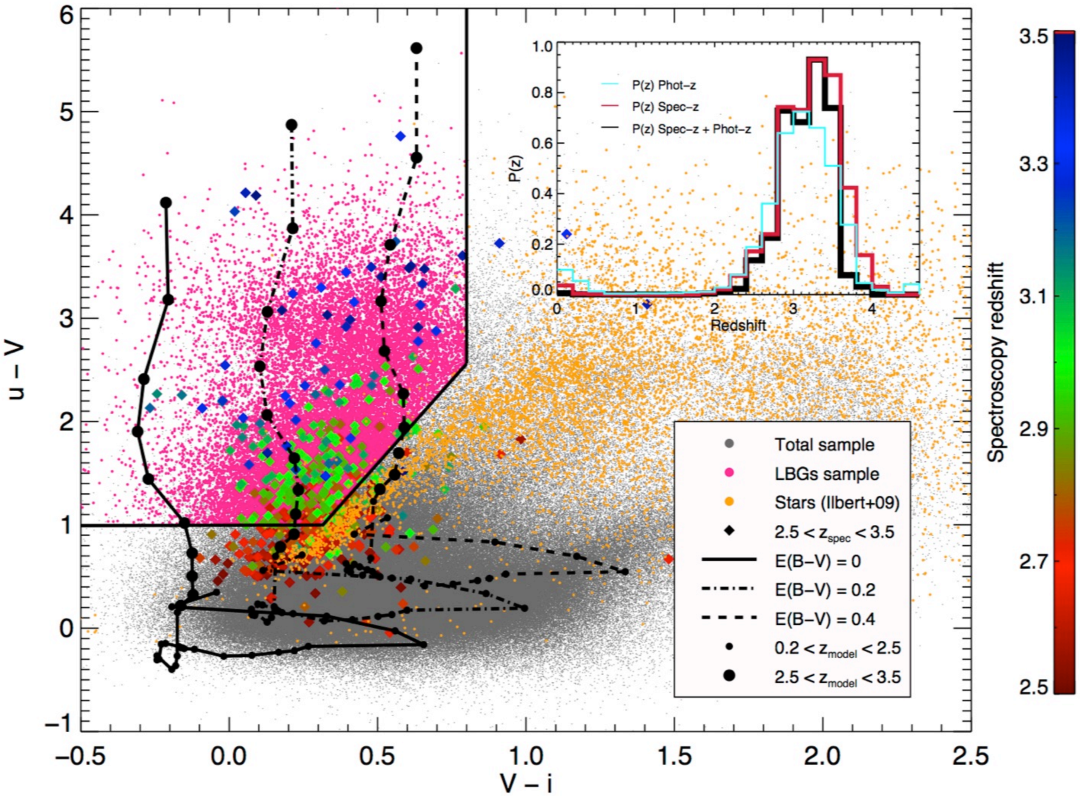


- The Attenuation corrections to the UV at high-z are only obtained from UV spectrum (e.g. UV slope, SED-fitting).
- UV slope degenerate (Attenuation, age, SFRH, metallicity, dust properties, …)
- Large dispersion in the dust attenuation at high-z



- **What about the IR information (L_{IR}/L_{UV})?**

LBG sample



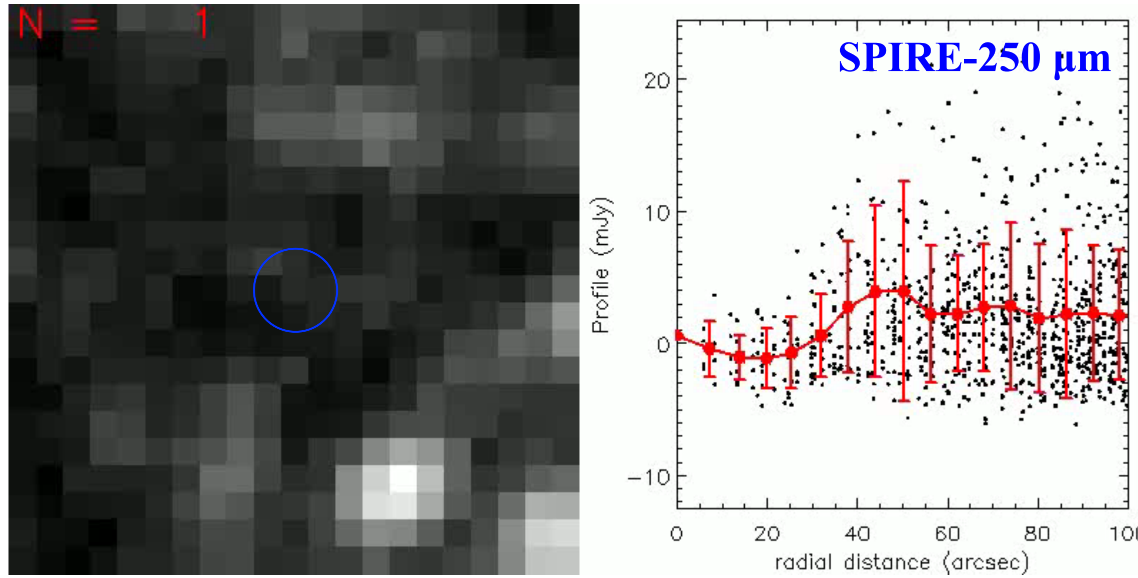
- **COSMOS field (2 deg^2)**
- **Eliminate the low-z interlopers:** $2.5 < z_{photo} < 3.5$
- **log(L_{FUV} [$L_\odot$]) > 10.20** (Completeness 75%)
- $< z_{photo} > = 3.02 \pm 0.25$
- **Sample = 22.000 LBGs**
- **Characterization of the sample as a function of:**
  - UV luminosity (L_{FUV})
  - UV slope (β_{UV})
  - Stellar mass (M_*)

	UV luminosity (L_{FUV})	UV slope (β)	Stellar mass (M_*)
Interval	10.2 < log(L_{FUV} [$L_\odot$]) < 11.4	-1.9 < β < 0.1	9.8 < log(M_* [$M_\odot$]) < 11.3
Nº of bins	4	5	6
Size of the bins	0.3 dex	0.4	0.25 dex

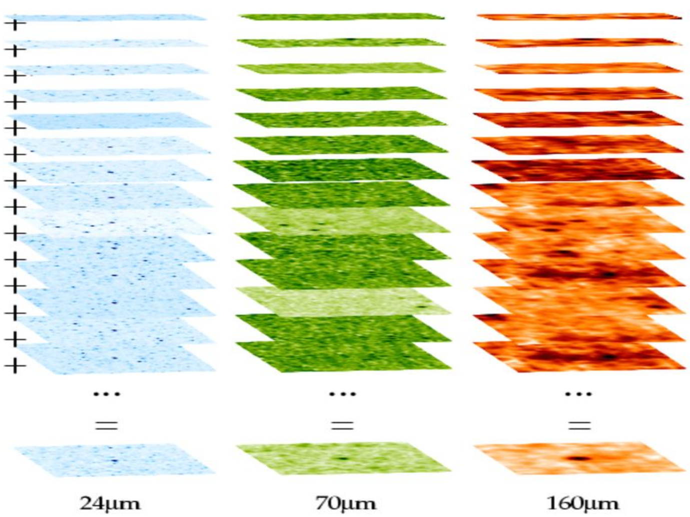
Stacking analysis

- **Only less than 0.05% detected in Far-IR observations**
- **We make a statistical study by using stacking analysis:**
  - PACS (100 and 160 μm)
  - SPIRE (250, 350 and 500 μm)
  - AzTEC (1.1 mm)

Stacking as a function of M_* ($10.25 < \mathrm{Log}(M_*) < 10.5$)

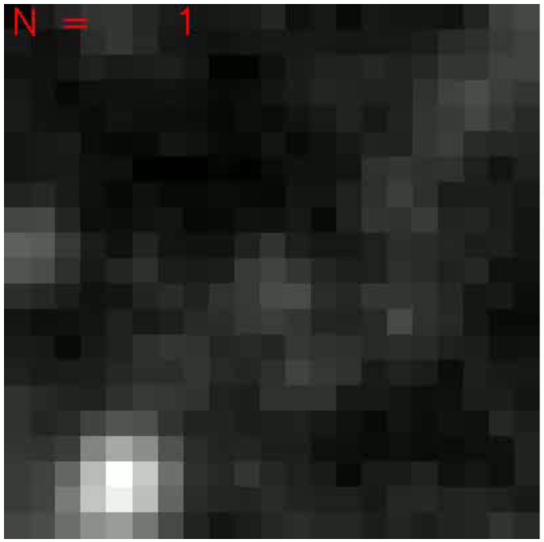


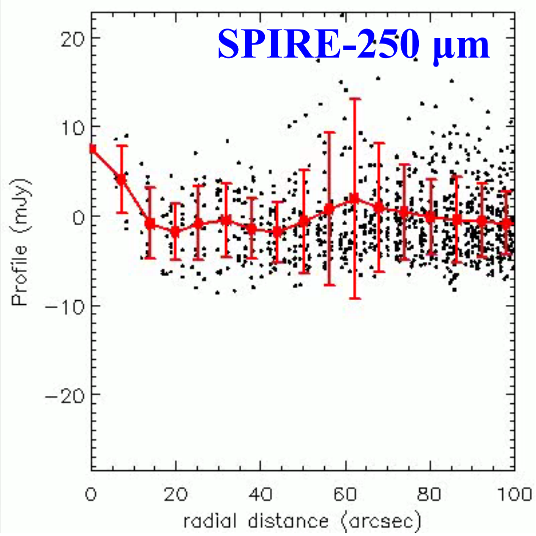
- **Must apply corrections in the stacking analysis due to a bias coming from:**
  - The incompleteness of our input catalogue in dense regions (Important for faint population)
  - The clustering of galaxies.



Stacking analysis: Incompleteness corrections

Stacking as a function of L_{FUV} ($10.2 < Log(L_{FUV}[L_\odot]) < 10.5$)





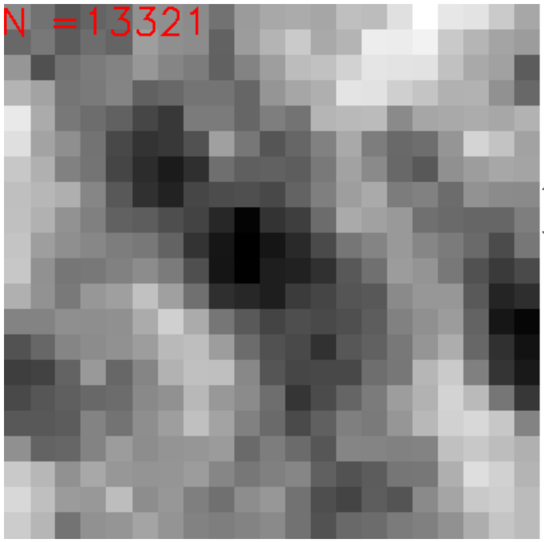
- **Completeness** ~ 75 %
- **We stack** ~ 13000 LBGs

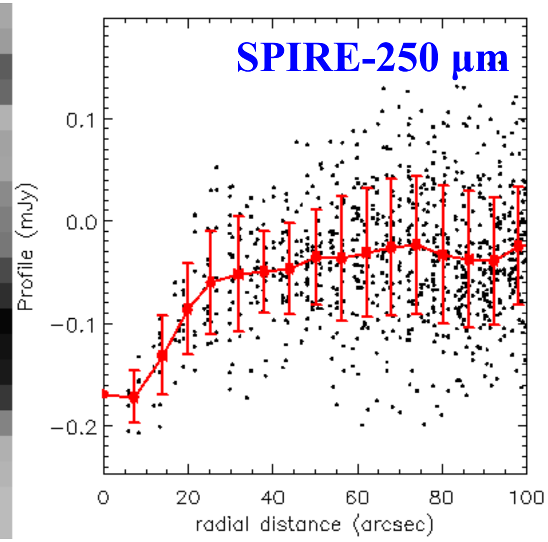
"In the detection process, we miss part of the faint objects located in the dense areas or close to bright objects. we lose the contribution of the dense background areas in the stacked image, causing a negative flux contribution near to the stacked object in relation to the global background."

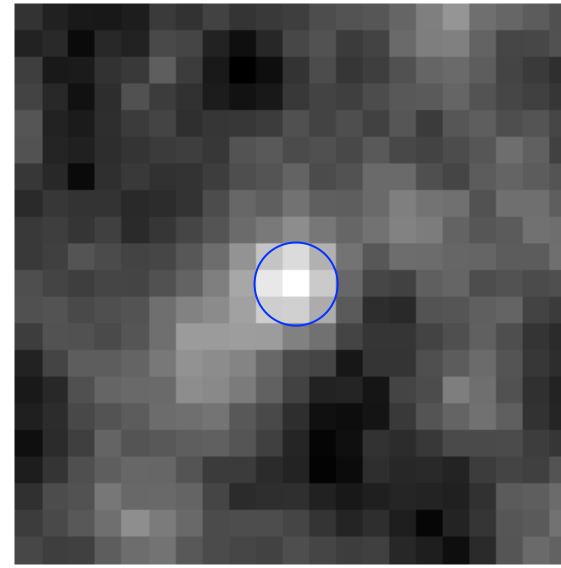
- **Correction of the bias coming from the incompleteness of the input catalog:**
  - We build a mock catalog (UV colors , L_{FUV}, β_{UV}, M_*).
  - We Simulate the mock catalog in i^+ and V_J bands from SUBARU (Where we selected the sample)
  - We recover the simulated galaxies using SExtractor.
  - We split the recover mock catalog as the original LBGs sample
  - We stack the position of the recover mock catalog in the Far-IR

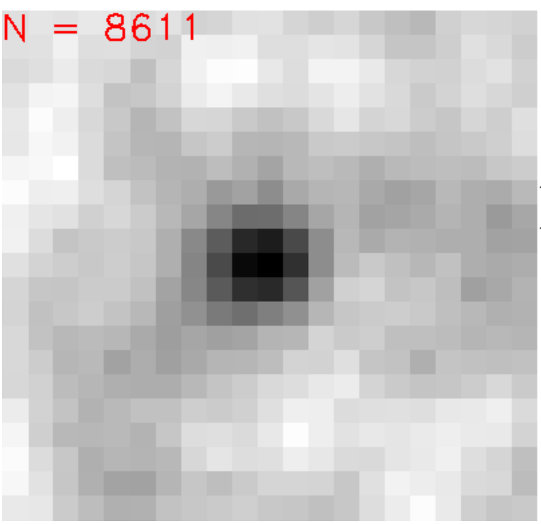
Stacking analysis: Incompleteness corrections

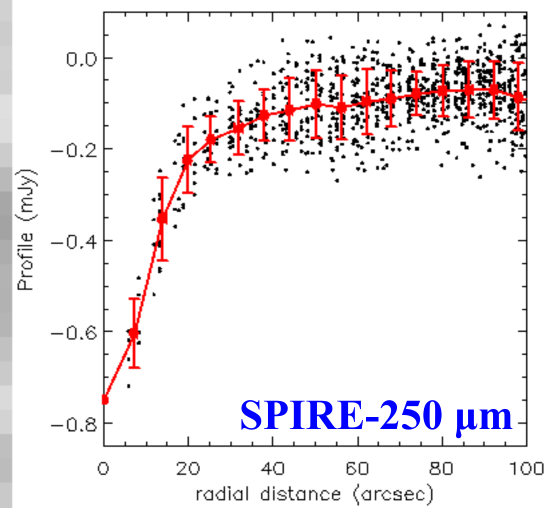
Stacking as a function of L_{FUV} ($10.2 < Log(L_{FUV}[L_{\odot}]) < 10.5$)

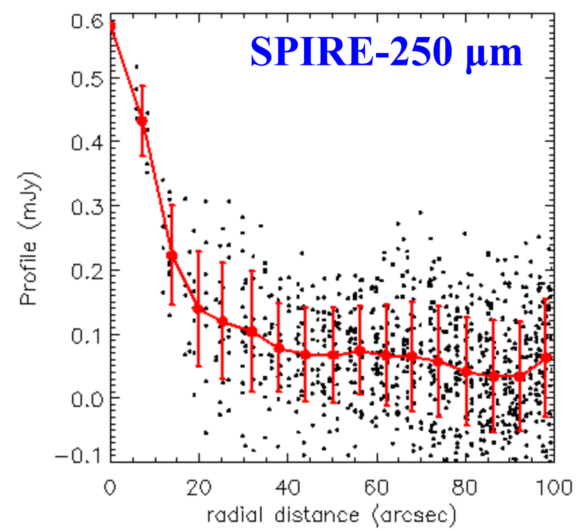




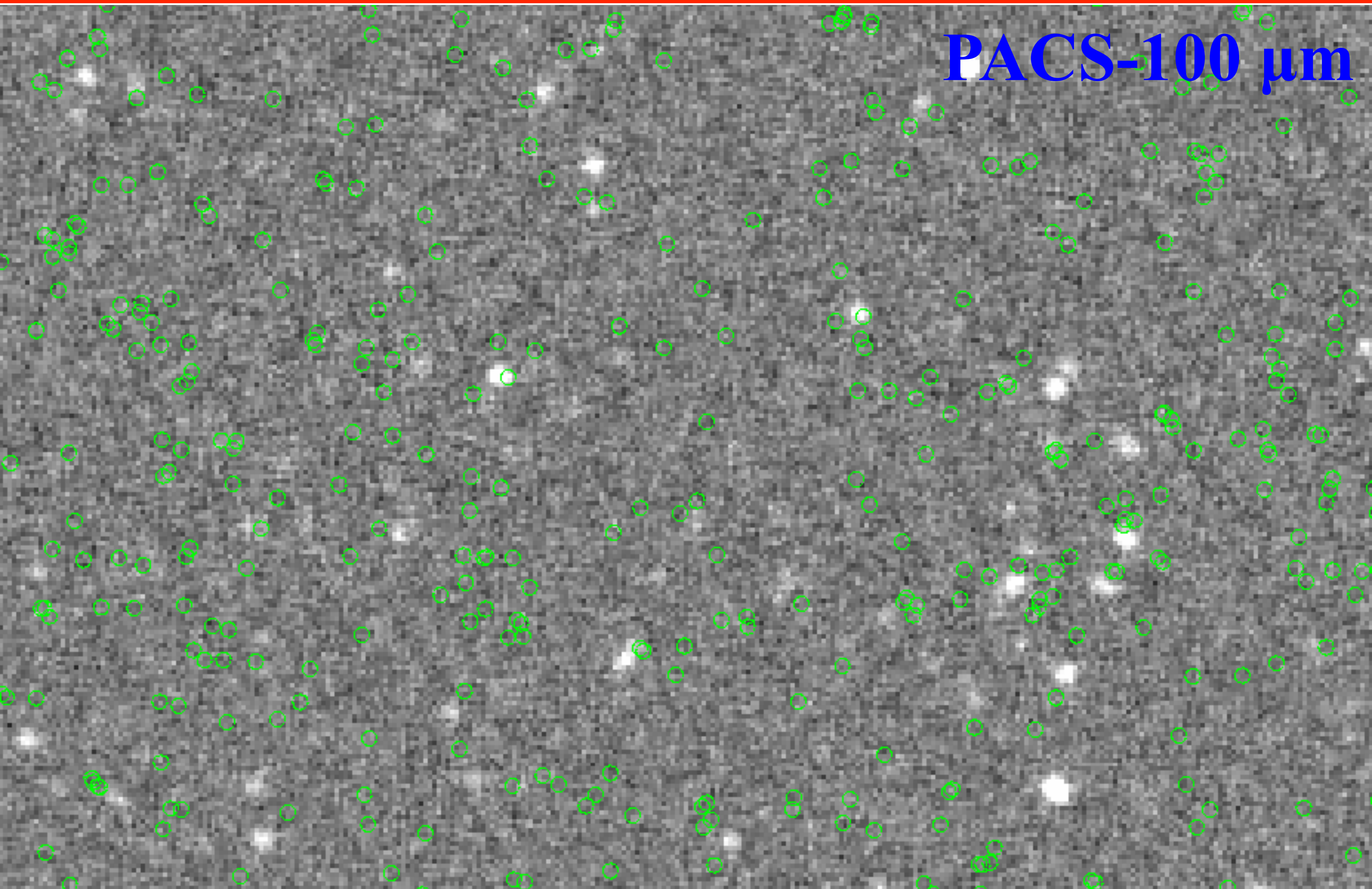




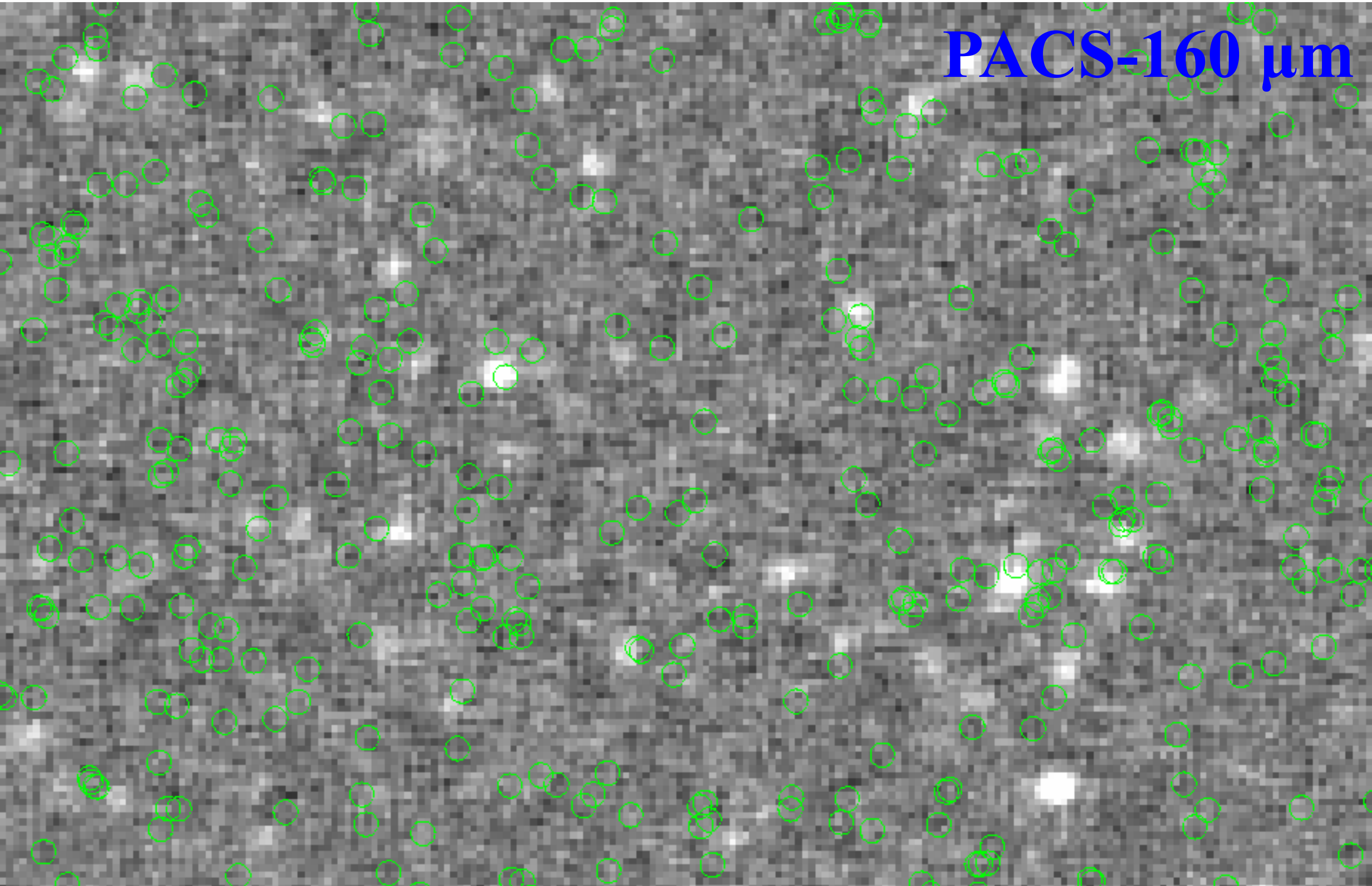




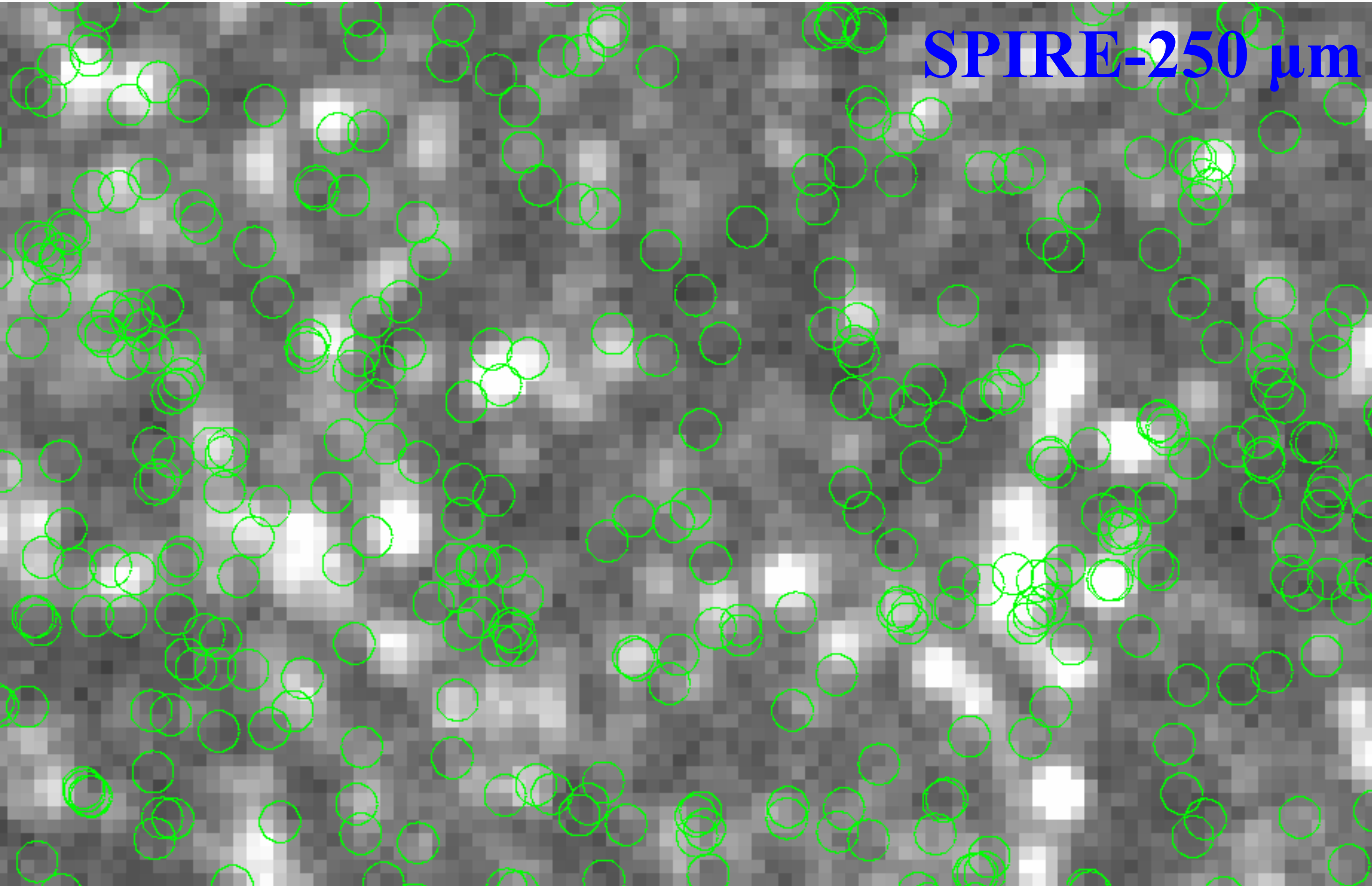
Stacking analysis: Cluster corrections



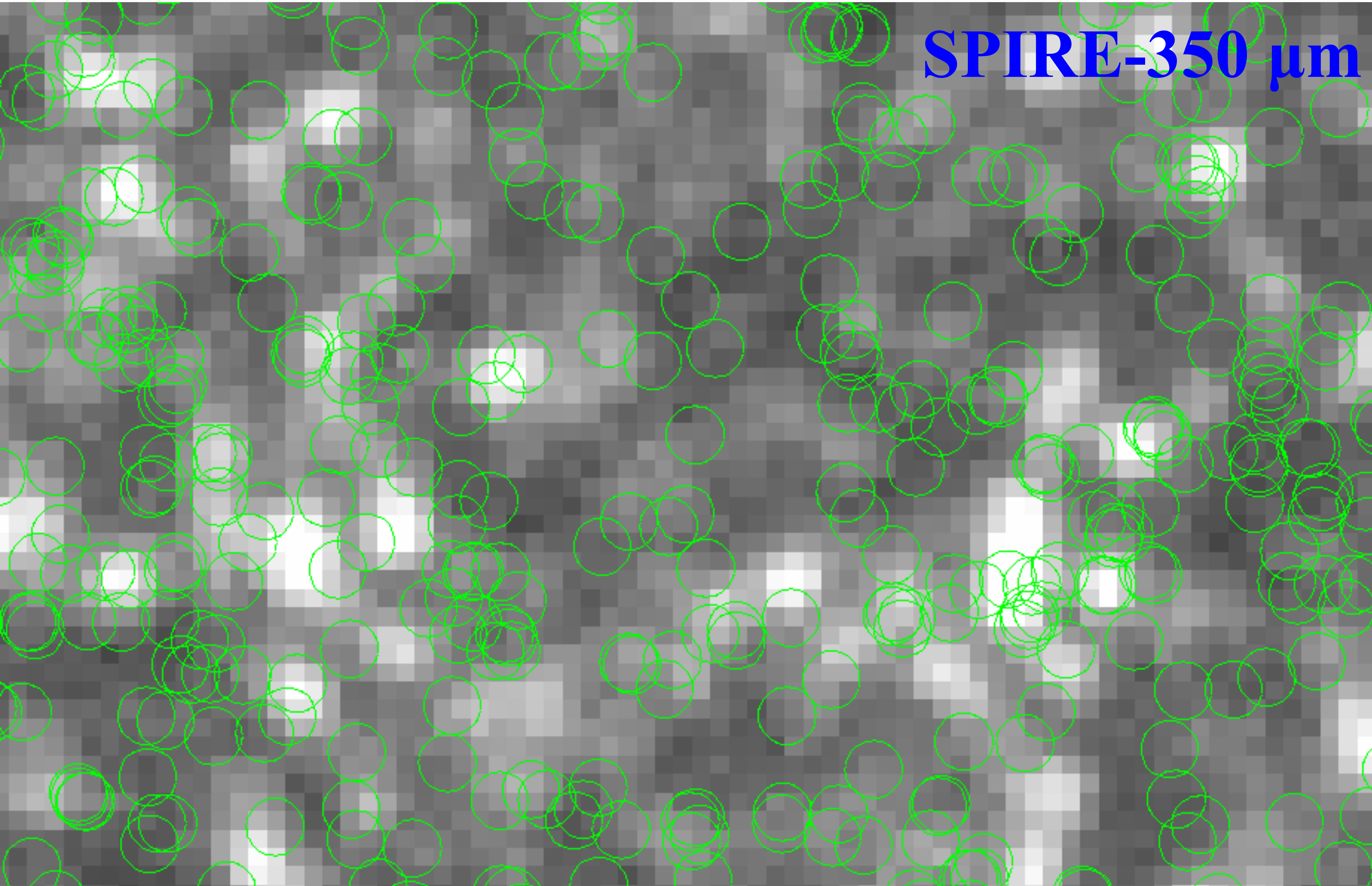
Stacking analysis: Cluster corrections



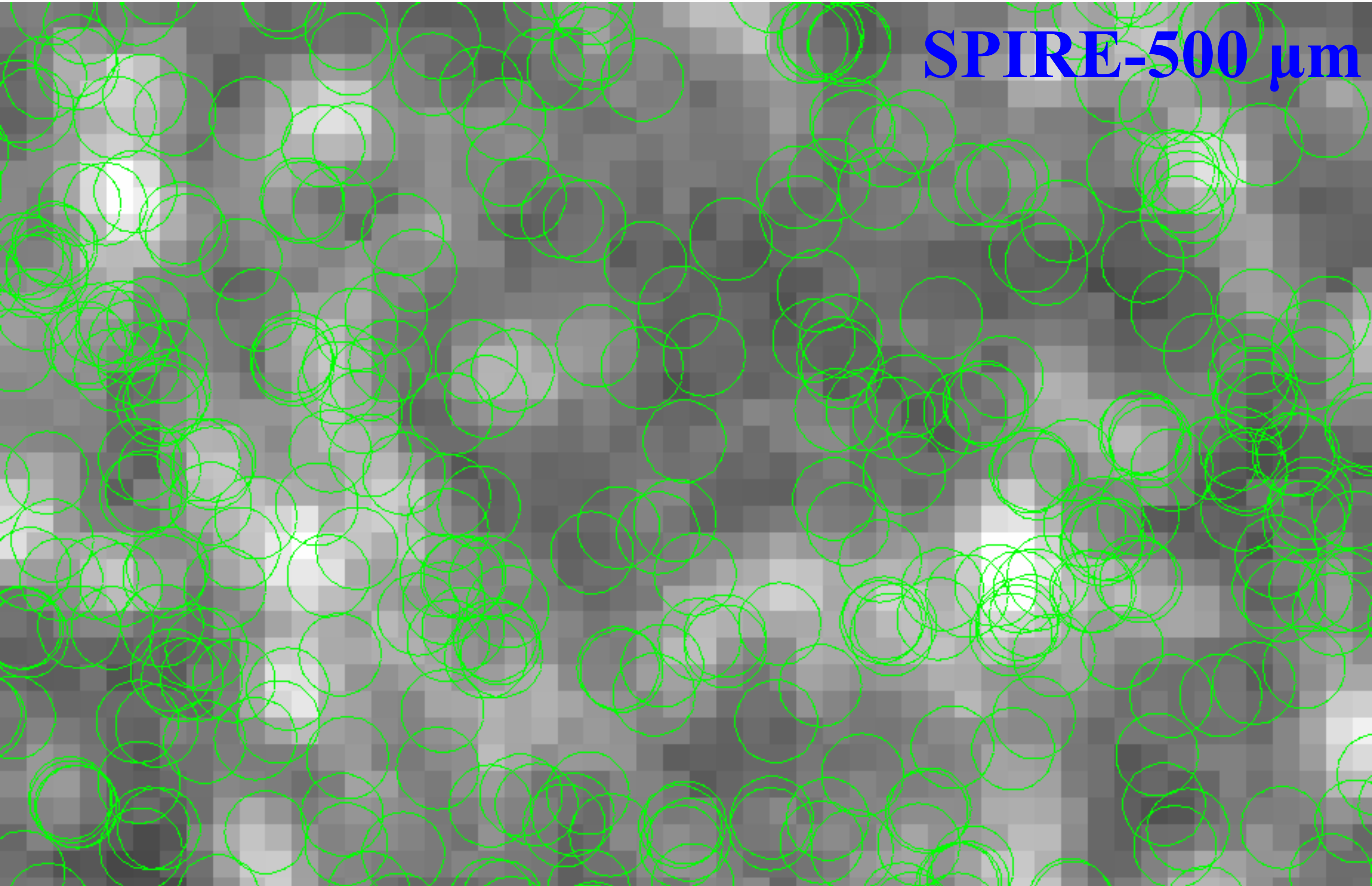
Stacking analysis: Cluster corrections



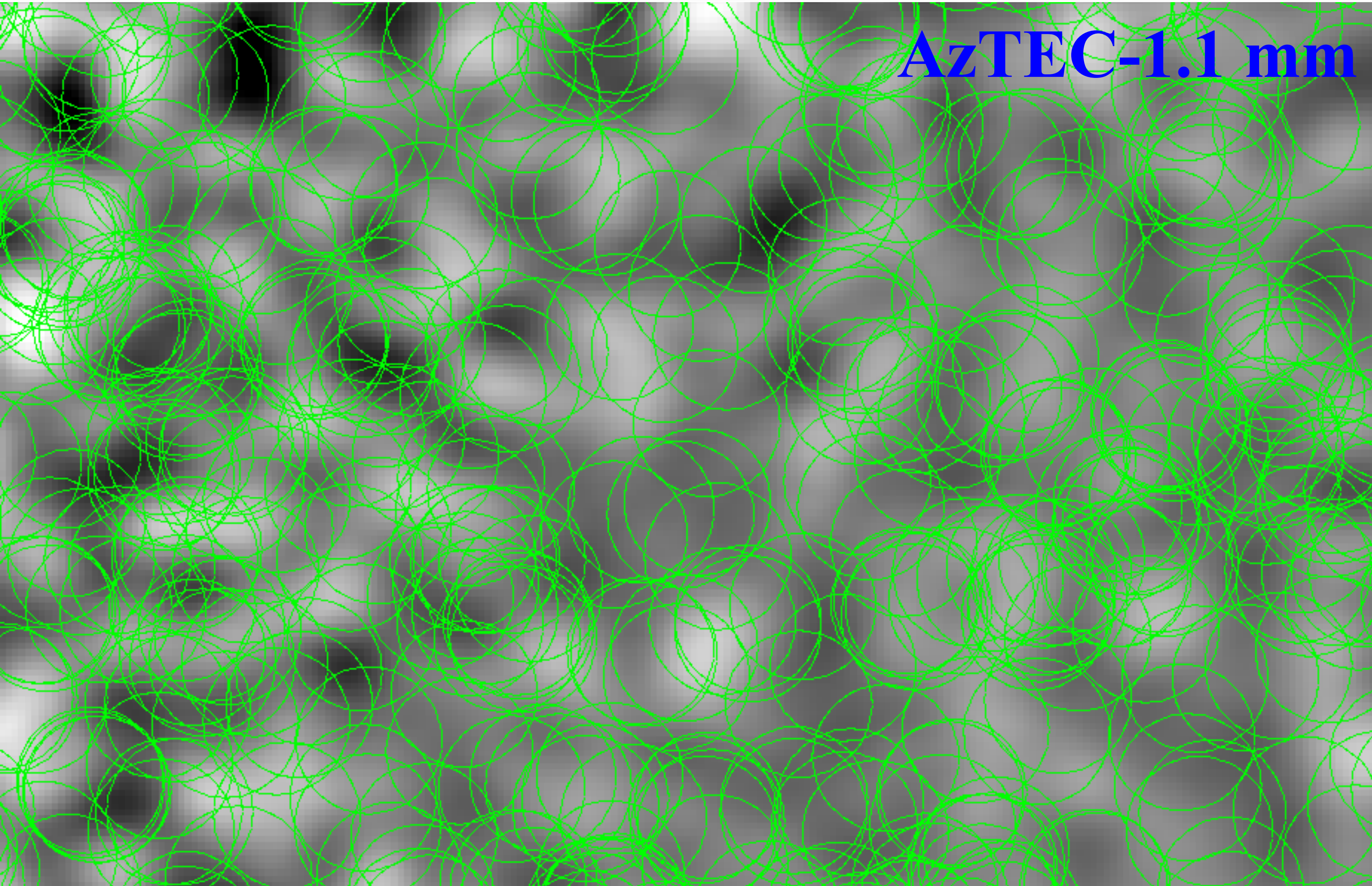
Stacking analysis: Cluster corrections



Stacking analysis: Cluster corrections



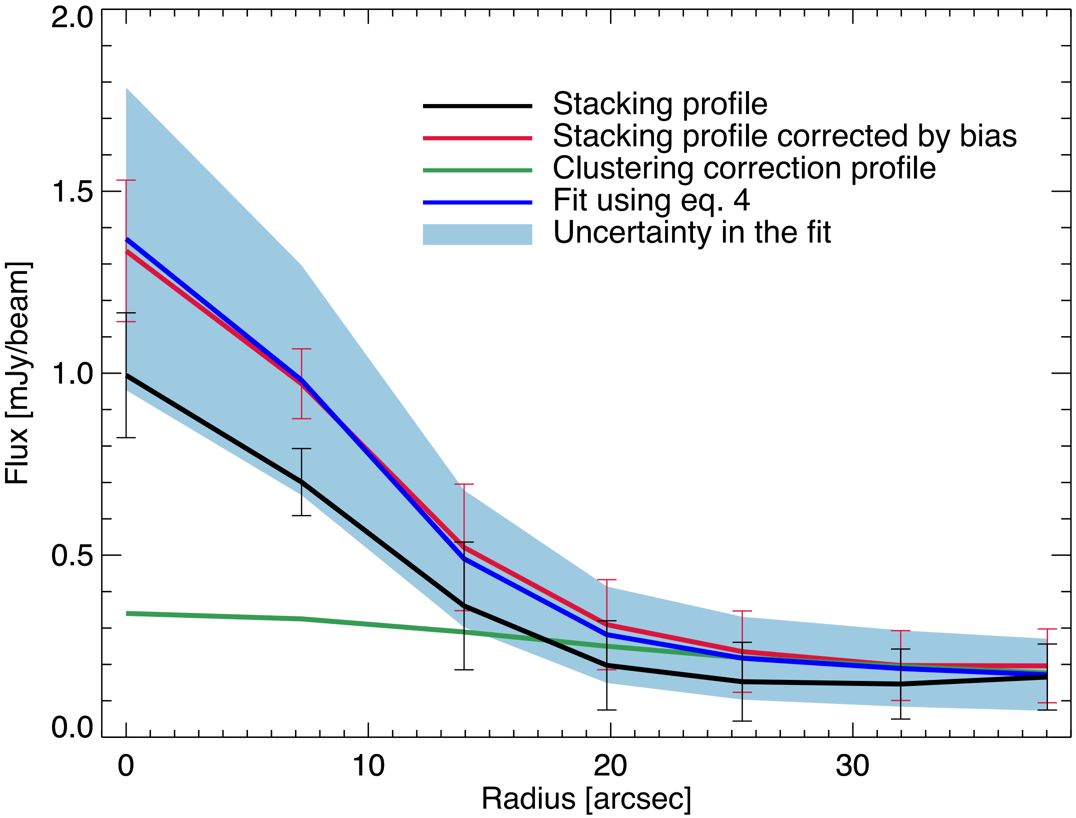
Stacking analysis: Cluster corrections



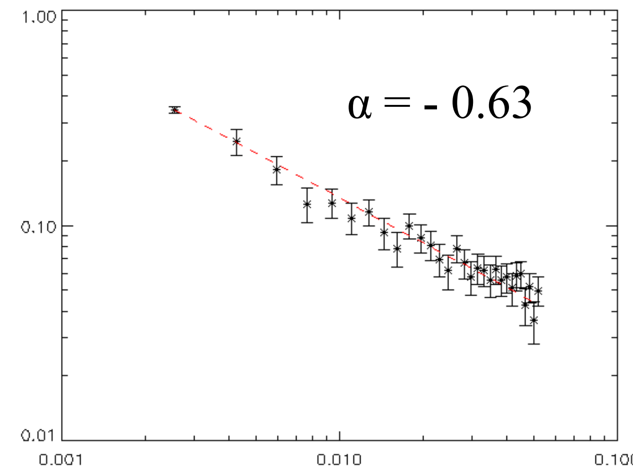
Stacking analysis: Cluster corrections

- The LBGs are clustered between them and other population of SF-galaxies.
- Confusion in the Far-IR observation due to the FWHM.

Stacking analysis: Cluster corrections

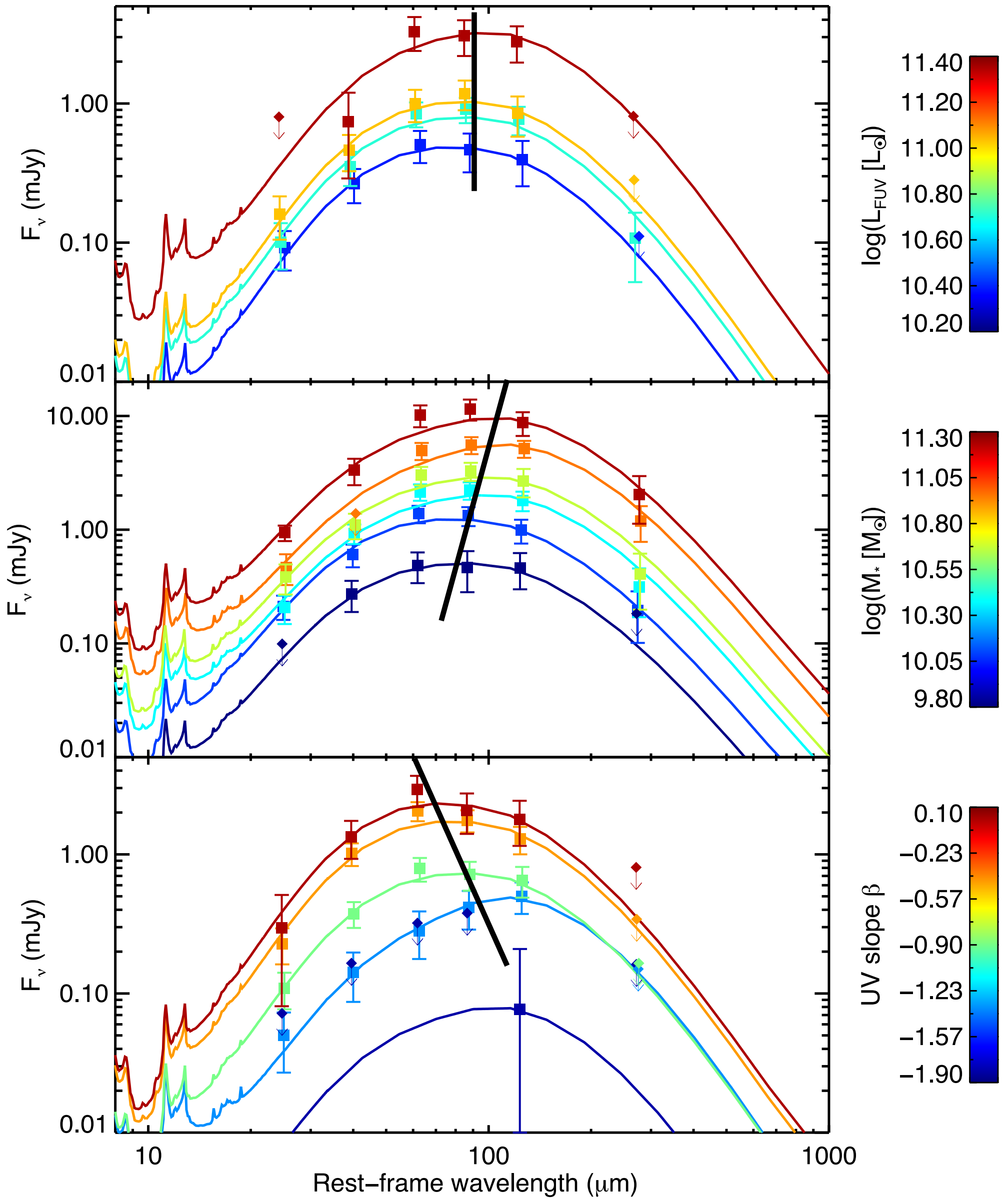


- Auto-correlation function of our LBGs sample.
  - Power-law: $\omega(\theta,\Phi)\ \alpha\ \theta^{\alpha}$



$$I(\theta,\phi) = \alpha \times PSF(\theta,\phi) + \beta \times w(\theta,\phi) * PSF(\theta,\phi) + \gamma$$

SEDs and IR Luminosity



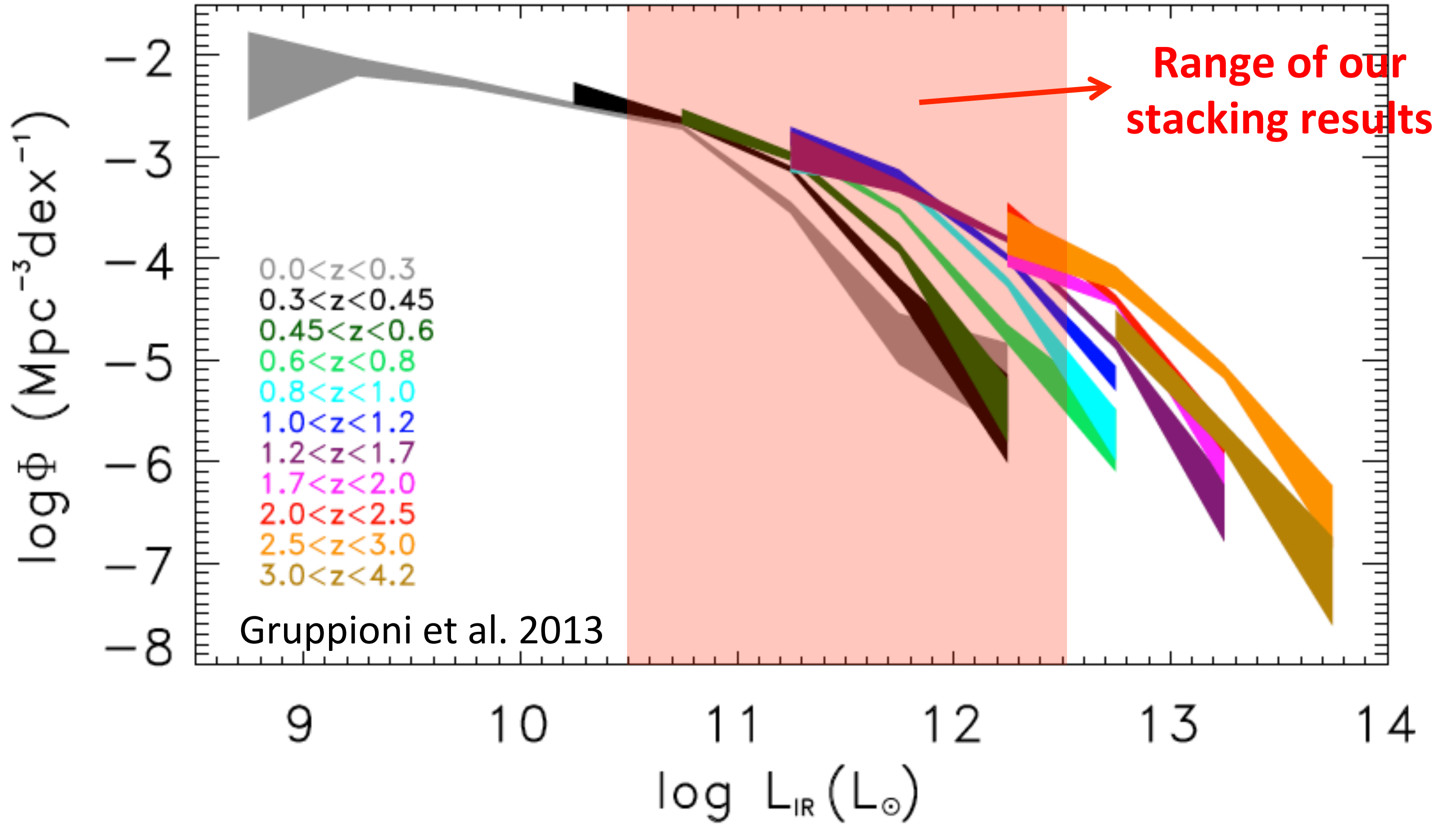
- **The total L_{IR} is estimated by integrating over the range $8 < \lambda < 1000$ μm of the best fit to the** Dale et al. (2014) **templates.**

- **We use SED-fitting code CIGALE** (Burgarella et al. 2005 and Noll et al. 2009)

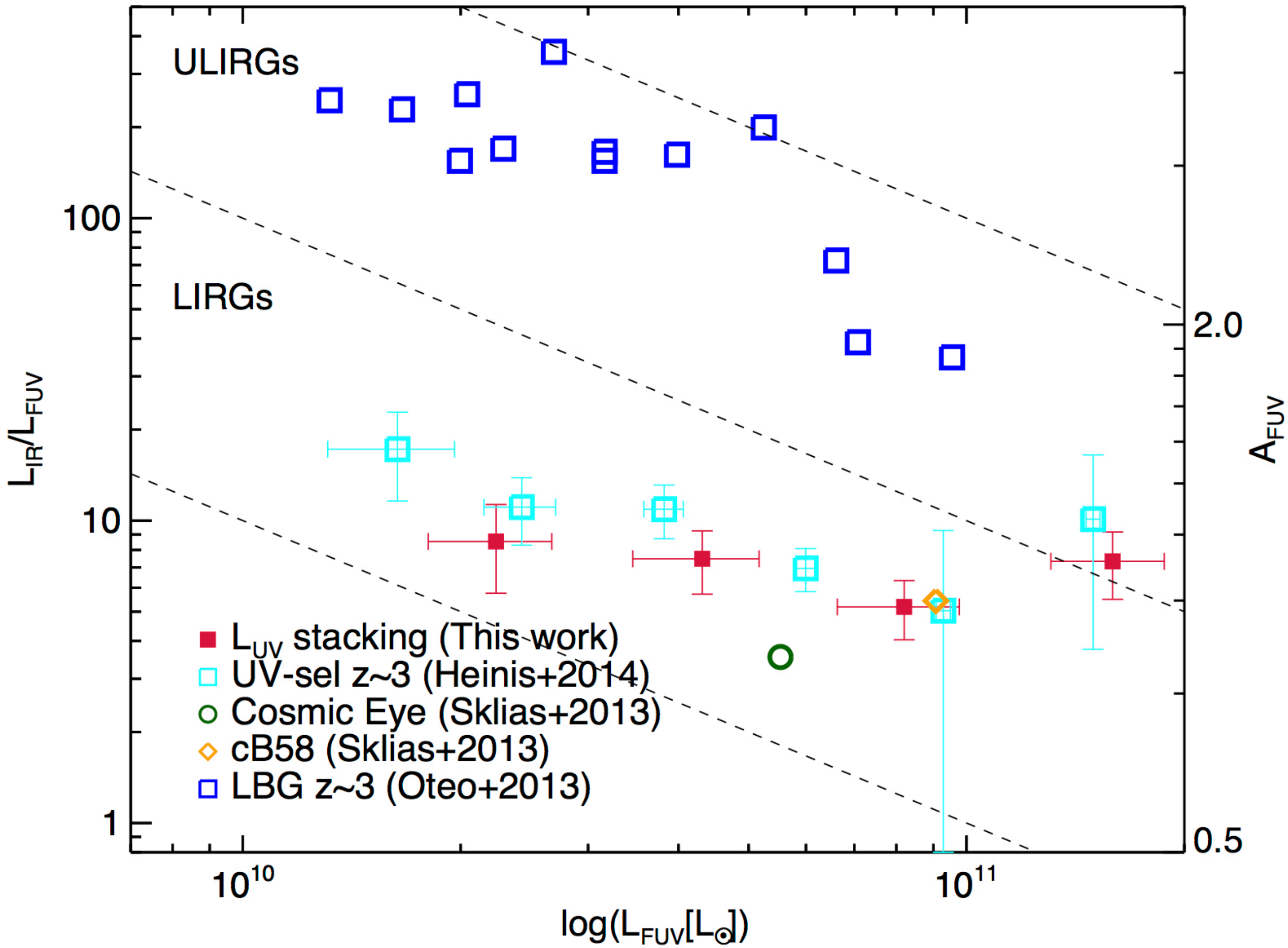
- Evolution of the peak in the IR emission as a function of the M_* and β_{UV}. The average of the dust temperature:
  - ○ ↑M_* - ↓T_d
  - ○ ↑β_{UV} - ↑T_d
  - ○ ↑L_{FUV} - ~T_d

IR Luminosity

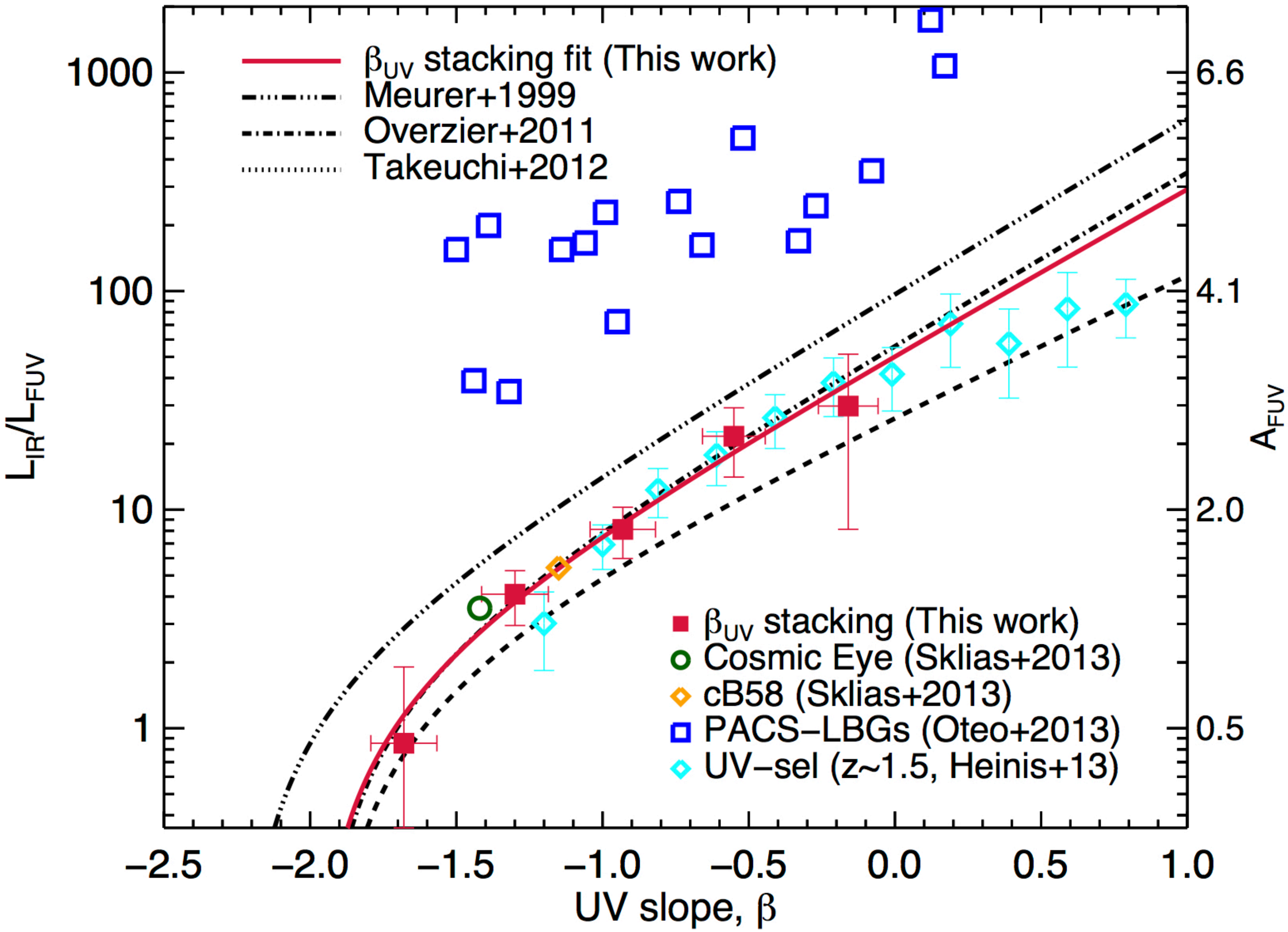
- **Using the stacking analysis we can study the fainter objects in the IR LF (Normal star forming galaxies), that we can not do it with direct detections.**



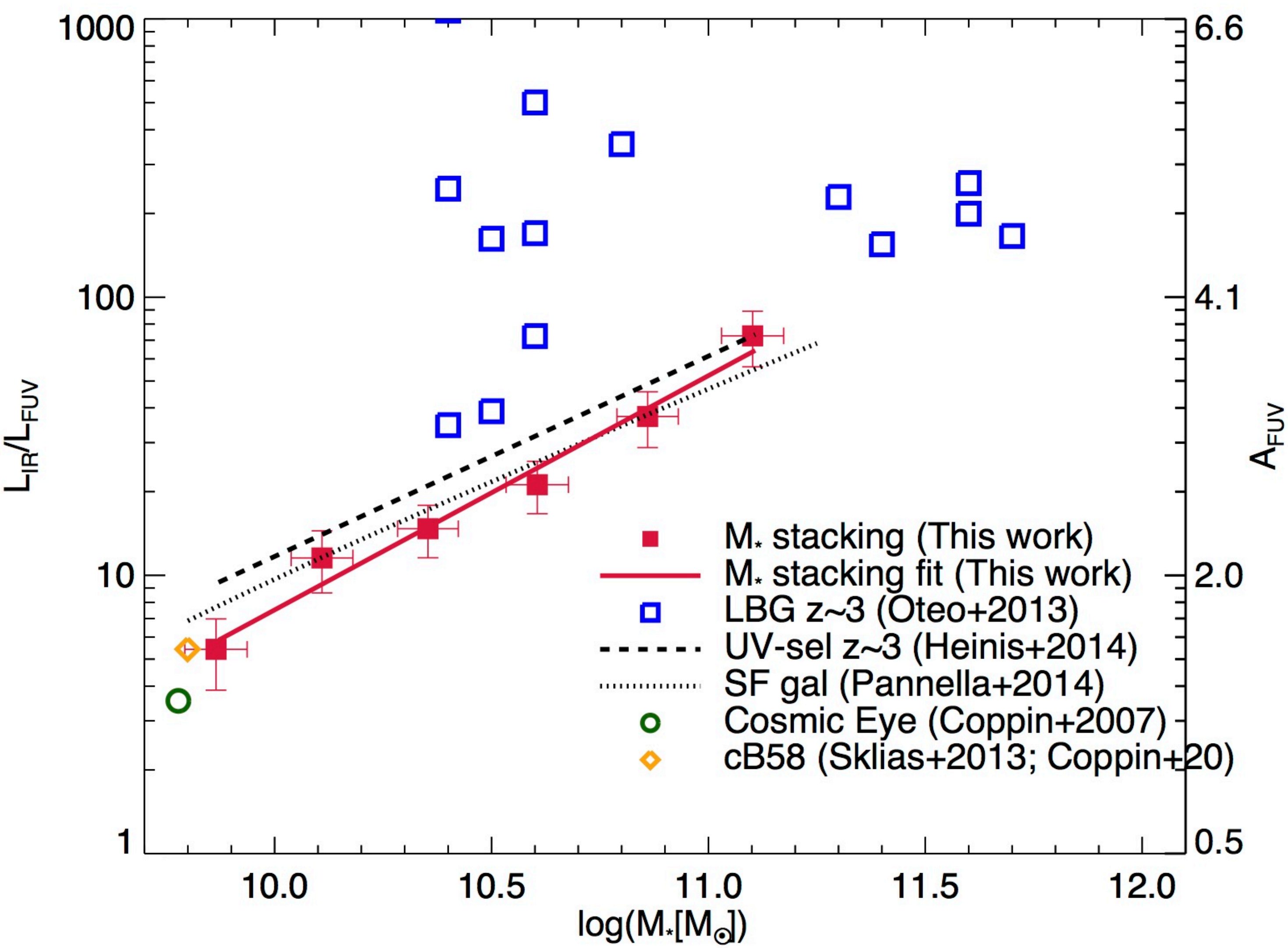
Dust attenuation as a function of L_{FUV}



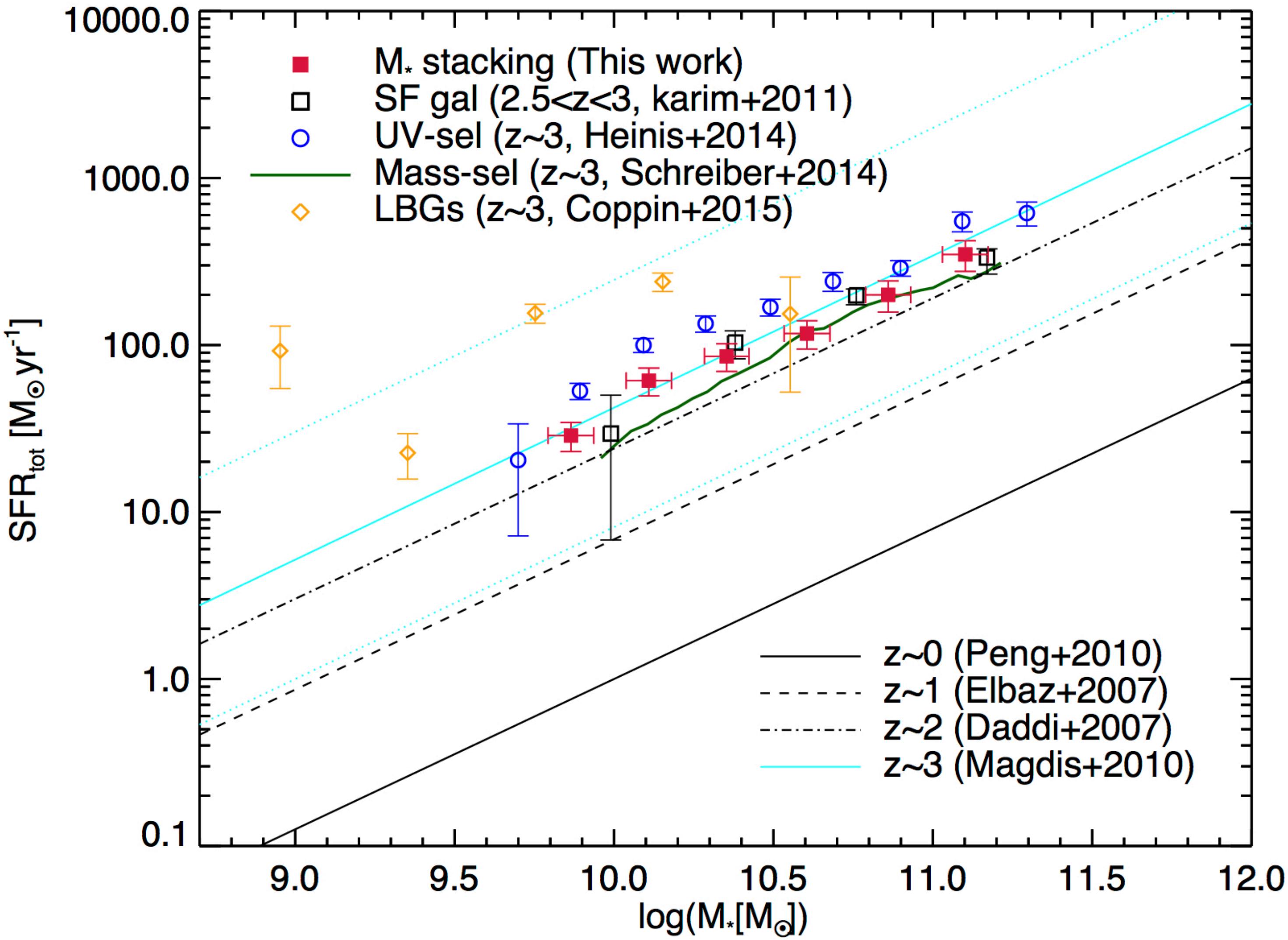
Dust attenuation as a function of β_{UV}



Dust attenuation as a function of M_*



SFR_{total} - M_*



M* stacking (This work)
SF gal (2.5<z<3, karim+2011)
UV-sel (z~3, Heinis+2014)
Mass-sel (z~3, Schreiber+2014)
LBGs (z~3, Coppin+2015)
z~0 (Peng+2010)
z~1 (Elbaz+2007)
z~2 (Daddi+2007)
z~3 (Magdis+2010)
SFR_tot [M⊙yr^-1]
log(M*[M⊙])
10000.0
1000.0
100.0
10.0
1.0
0.1
9.0
9.5
10.0
10.5
11.0
11.5
12.0

Summary

We perform a stacking analysis using large sample of LBGs (22.000) at PACS, SPIRE and AzTEC bands in the COSMOS field:

1. We obtain the full infrared SEDs and we derive the average IR luminosity for our LBGs as a function of their L_{FUV}, β_{UV} and M_*.

2. The average L_{IR} to L_{FUV} ratio (and dust attenuation) is roughly constant over the L_{FUV} range for the average population of LBGs.

3. The average L_{IR} to L_{FUV} ratio (or dust attenuation) is correlated to β_{UV} and M_*.

4. We show that our LBG sample is consistent with the main sequence of star forming galaxies.

Alvarez-Marquez et al. (in prep) ---- javier.alvarez@lam.fr