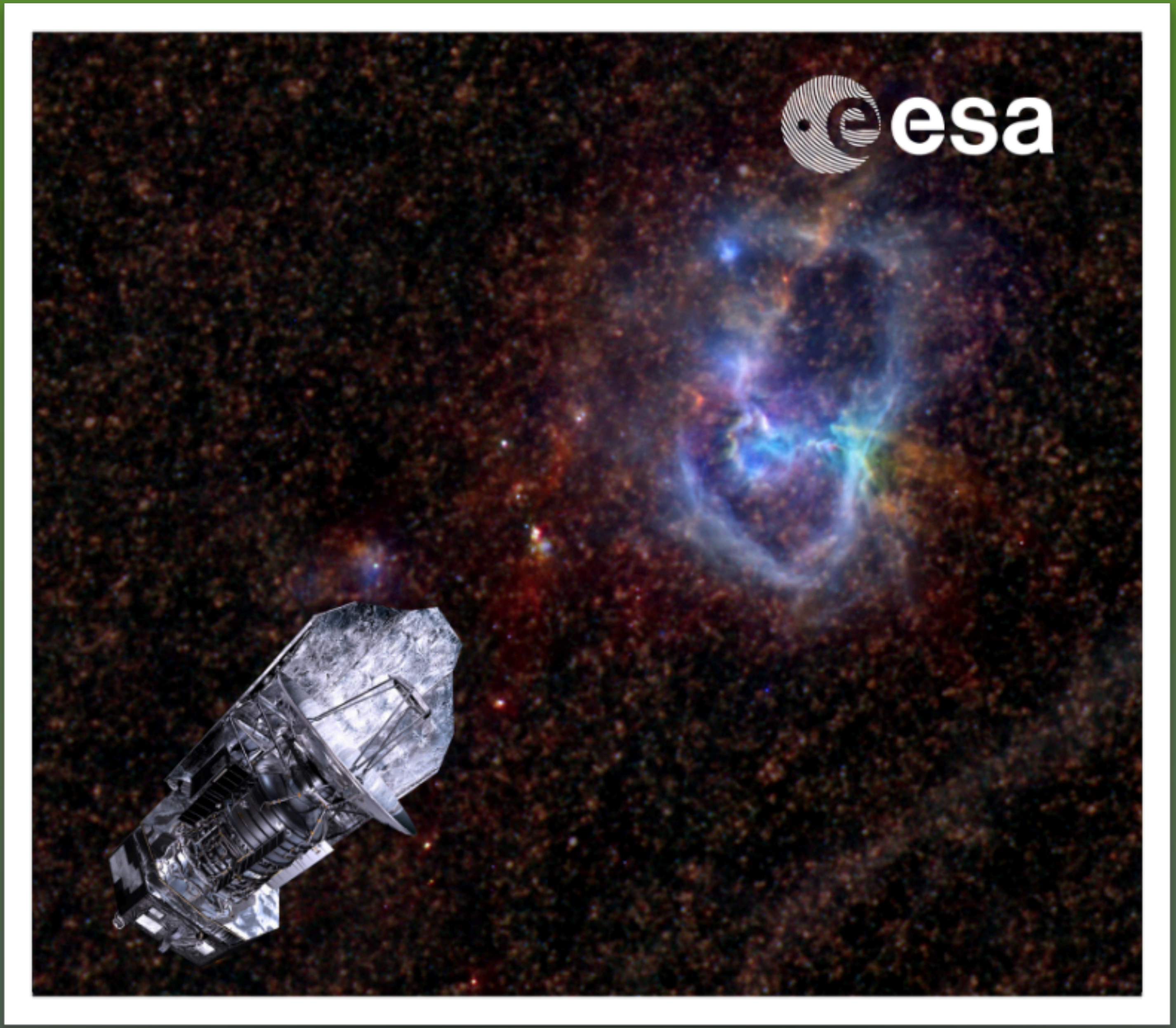
Herschel sheds light on Lyman Break Galaxies at z > 3

Outline:

- The importance of dust at high-z
- Star formation histories (SFHs) and optical/near-IR SED modelling
- Samples and data
- Stacking technique
- Pan-chromatic SEDs of z~3, 4, 5, 6 LBGs
- constraints on LIR/LUV, the IRX-β relation and SFHs
- Summary & Outlook

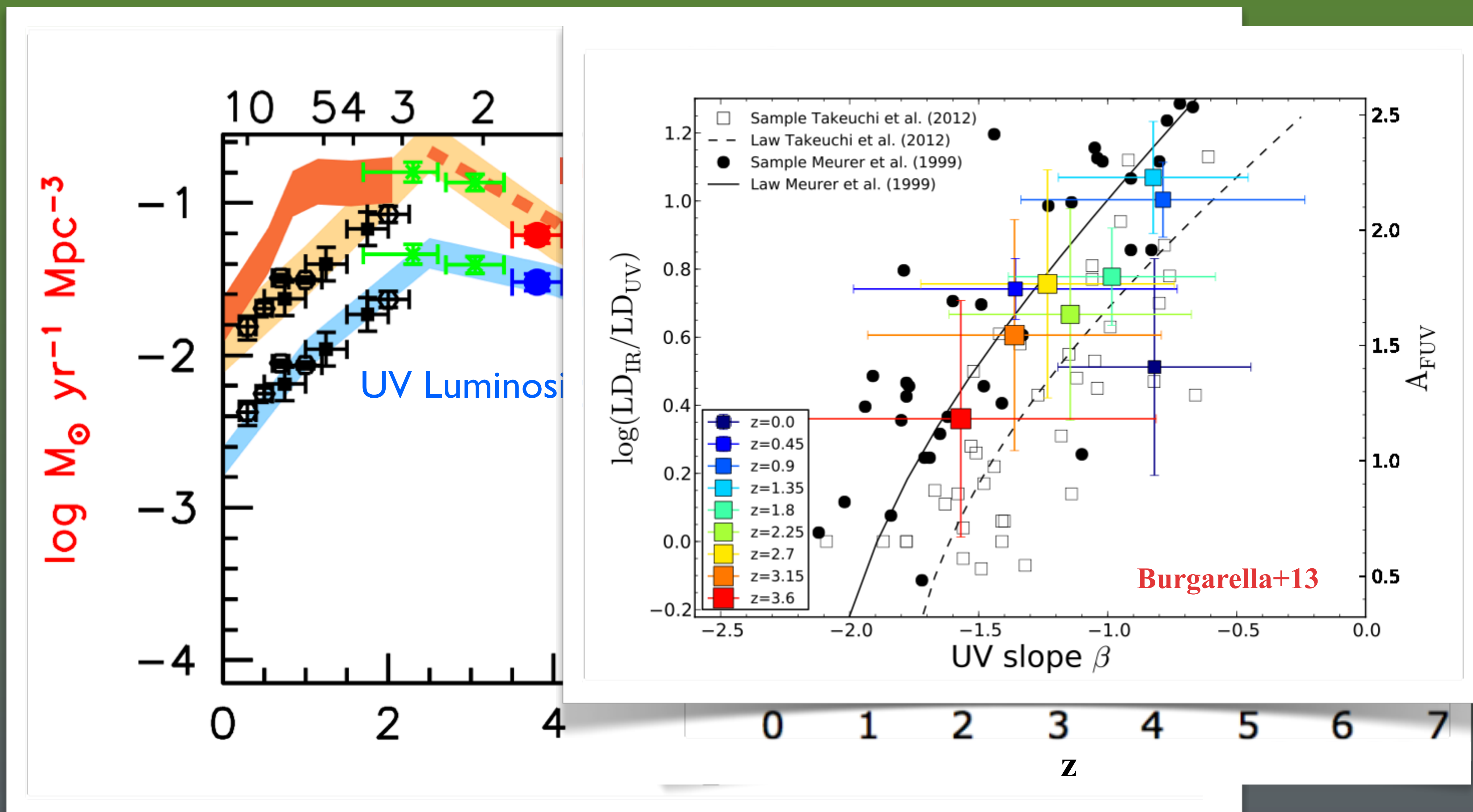


Thomas R. Greve (UCL)
Daniel Schaerer (Geneva)
Miroslav Zavadsky-Dessauges (Geneva) + LESS TEAM

ESA/ESTEC, Noordwijk, The Netherlands, Oct 2013

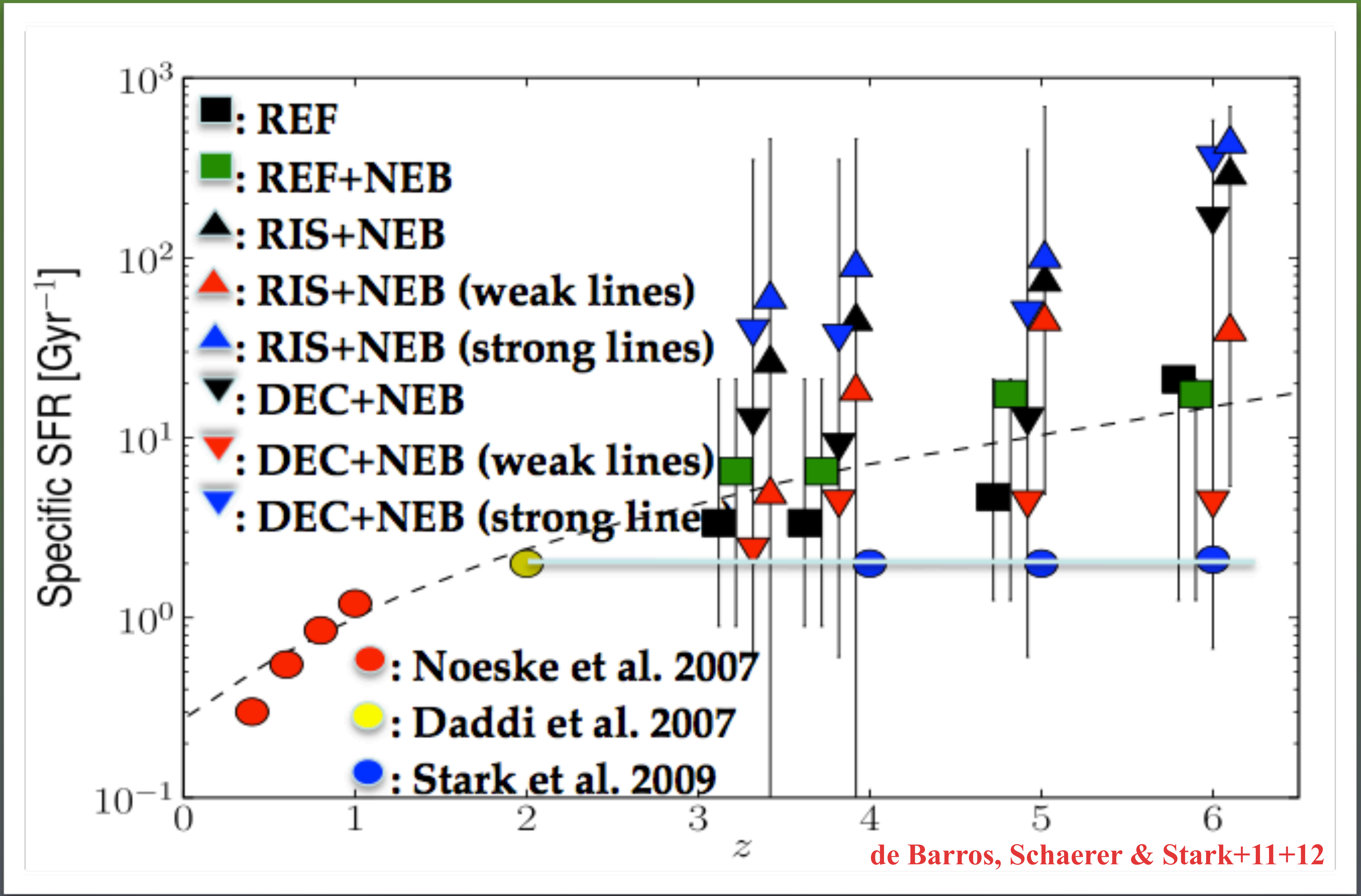
The importance of dust at high redshifts

- Inferring the total (obscured and unobscured) Cosmic SFRD(z)
- The dust-content of normal star forming galaxies at high-z
- Dust correction from rest-frame UV-colours (the IRX-β relation)



The importance of dust at high redshifts

- Delineating the evolution of the sSFR at z > 3
- Correct UV/Optical/Near-IR SED modeling is crucial - many pitfalls!



UV/optical/near-IR SED modeling of high-*z* LBGs

- Hyper-z SED/photo-z tool
  - includes nebular emission lines
  - Salpeter IMF 0.1-100$M_\odot$
  - GALEXV, Bruzual & Charlot (2003) synthesis models
  - Star formation histories (SFHs)

- Fit parameters:
  - redshift, z
  - metallicity, $Z/Z_\odot$ (of stars and gas)
  - Age, t
  - Dust attenuation, A_V
  - Stellar mass, M_{star}
  - Star formation rate, SFR

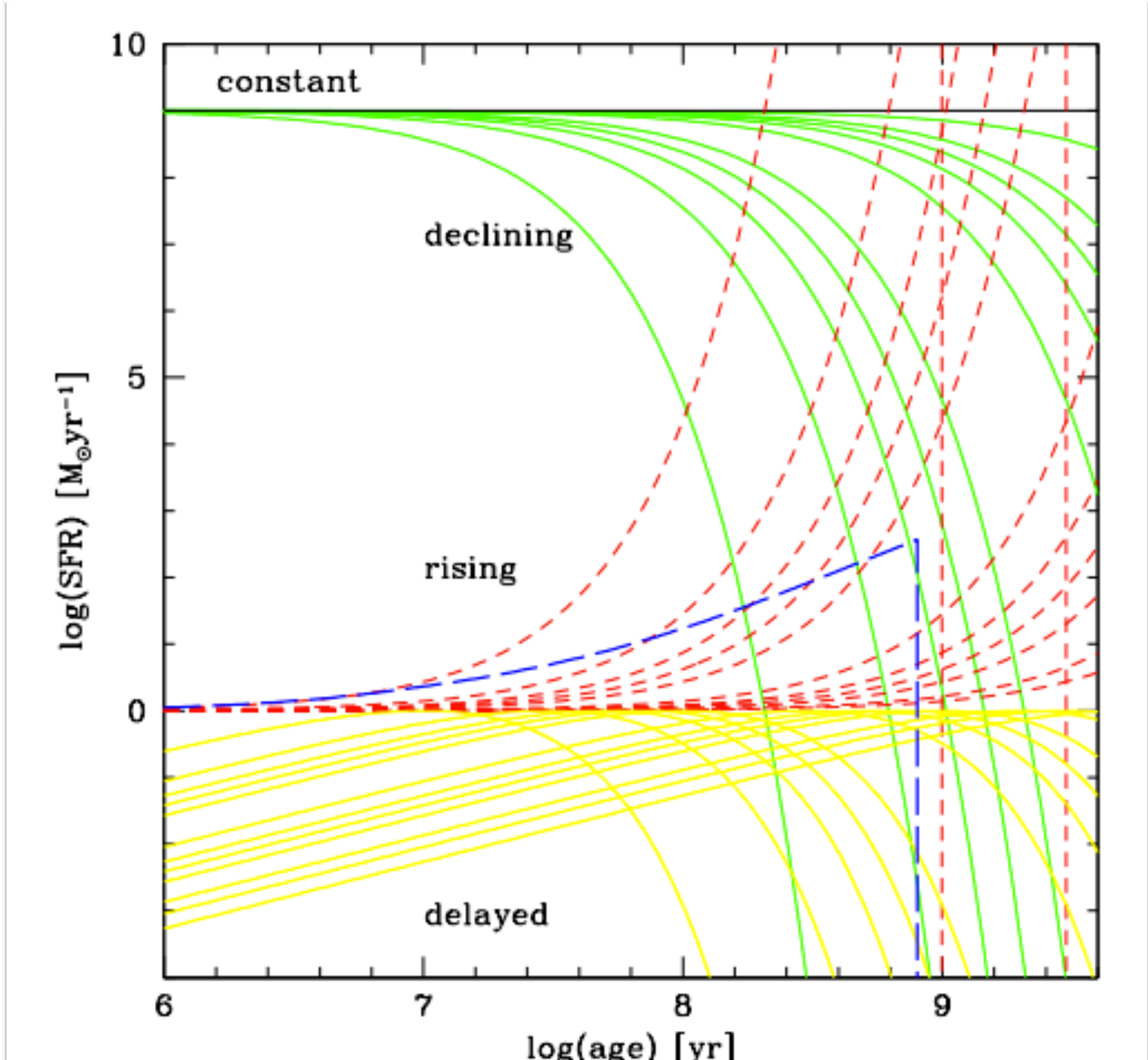
↓

L_{UV}, UV-slope(β), L_{IR}

<u>We can use observational constraints on L_{IR} to distinguish between SFHs</u>

Star formation histories (SFH)

ID	SF history	Functional form	Parameters	Color
A = DEC	exp. declining	SFR $\propto \exp^{-t/\tau}$	t, τ	green
B = REF	constant	SFR = const.	$t \geq 50$ Myr	black
C = RIS	rising	Finlator+2011	t	blue
D	exp. rising	SFR $\propto \exp^{+t/\tau}$	t, τ	red
E	delayed	SFR $\propto t \exp^{-t/\tau}$	t, τ	yellow

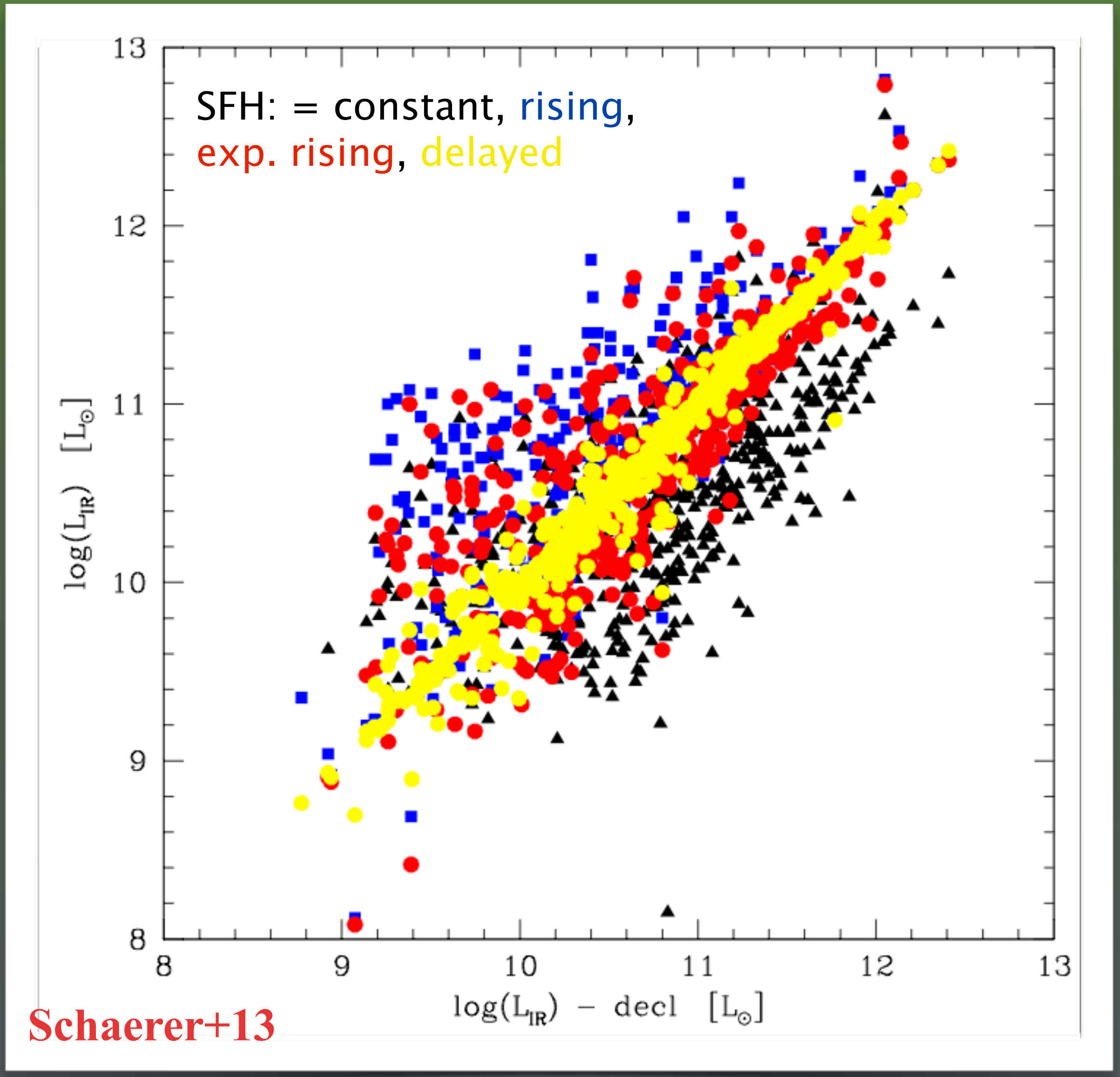


Schaerer & de Barros+10,+12+13

UV/optical/near-IR SED modeling of high-*z* LBGs

IR luminosity, L_{IR}:

- Modelling the SEDs of 705 B-dropouts (Schaerer+13)
- Accurate determination of L_{IR} may help us distinguish between SFHs

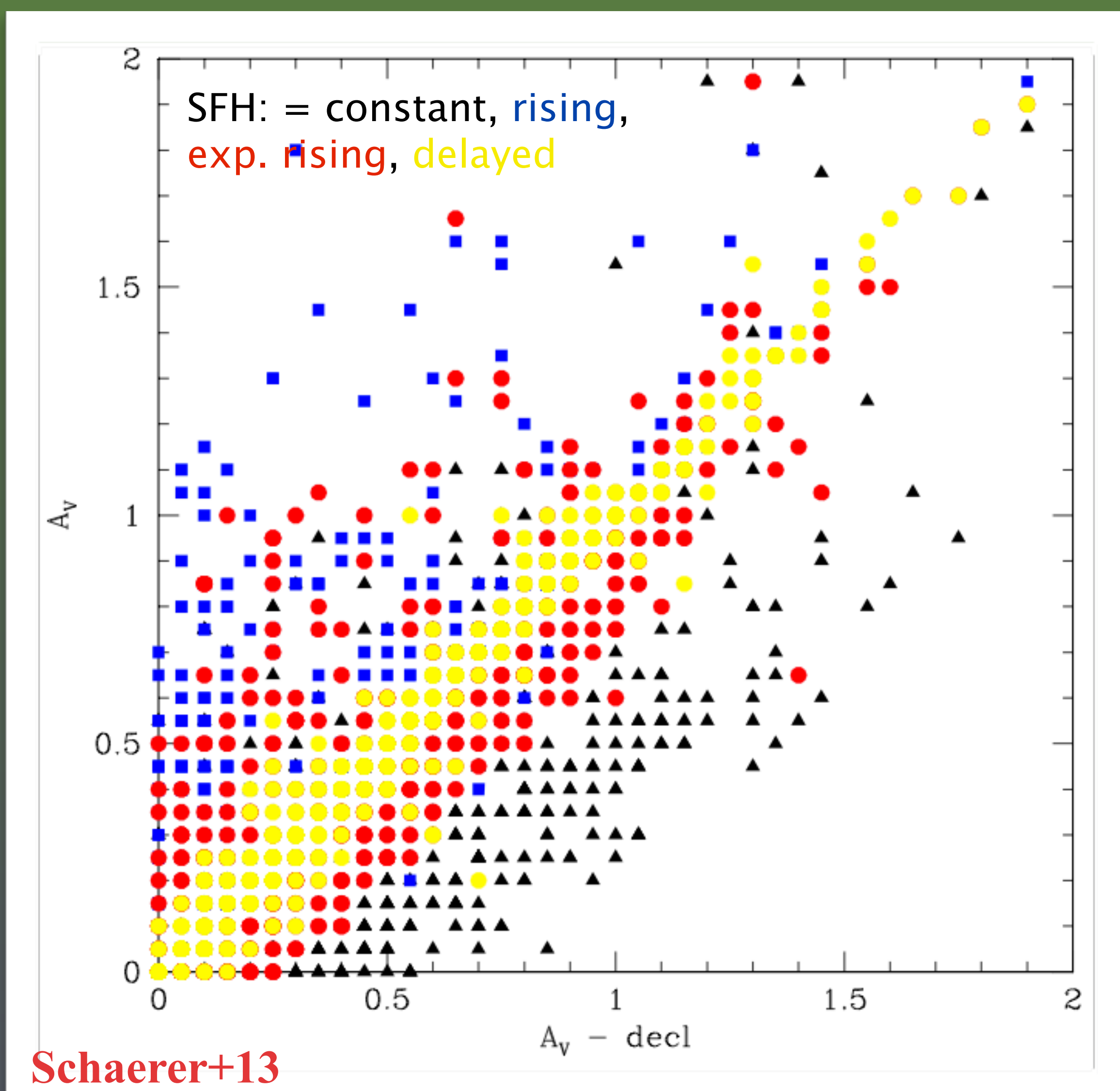


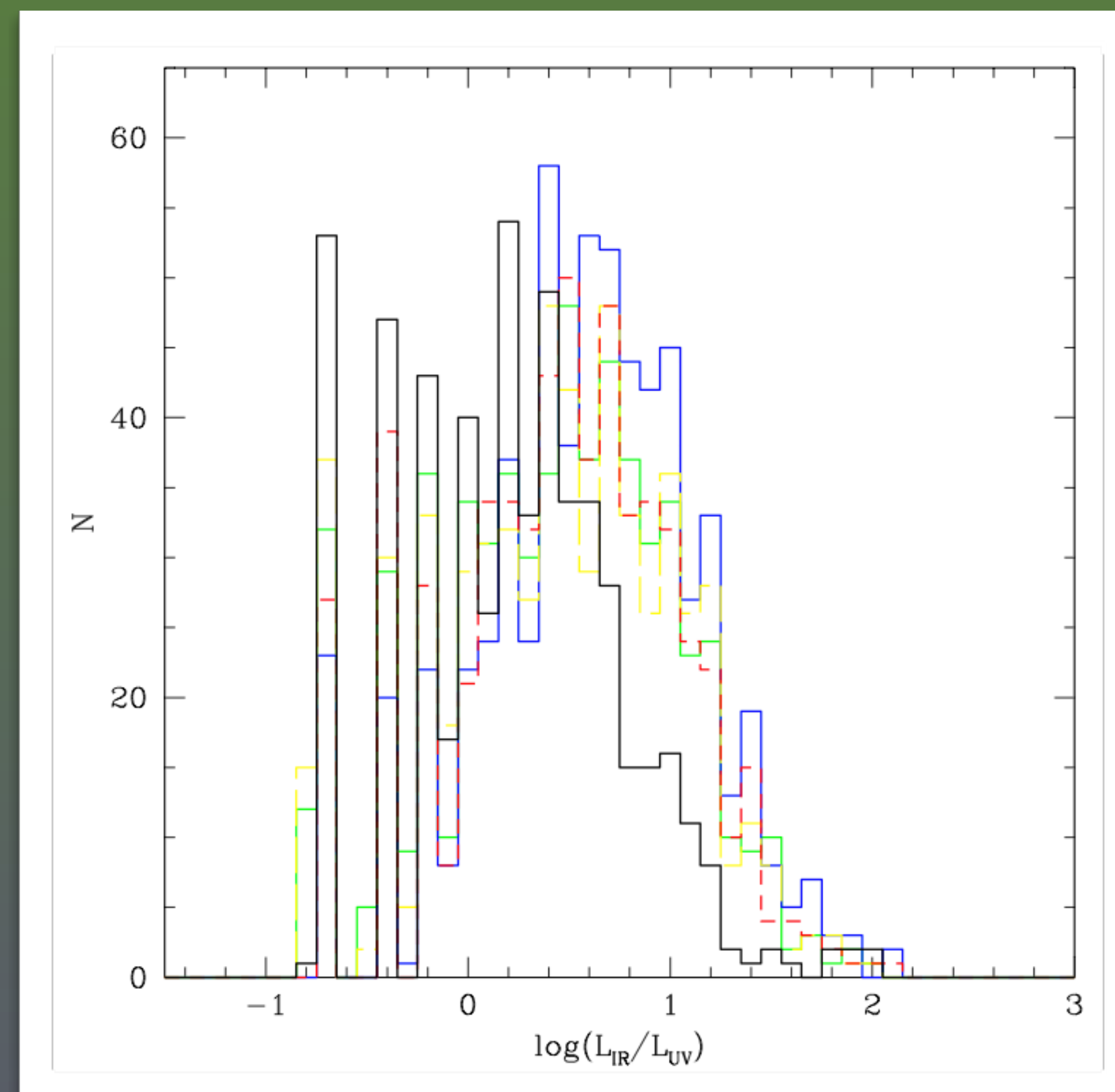
UV/optical/near-IR SED modeling of high-*z* LBGs

Dust exinction, A_V:

- Significant scatter in A_V and systematic dependencies on SFHs

- L_{IR}/L_{UV} measures the dust-attenuation, f_{UV}
- Measurements of L_{IR}/L_{UV} may allow us to distinguish between SFHs



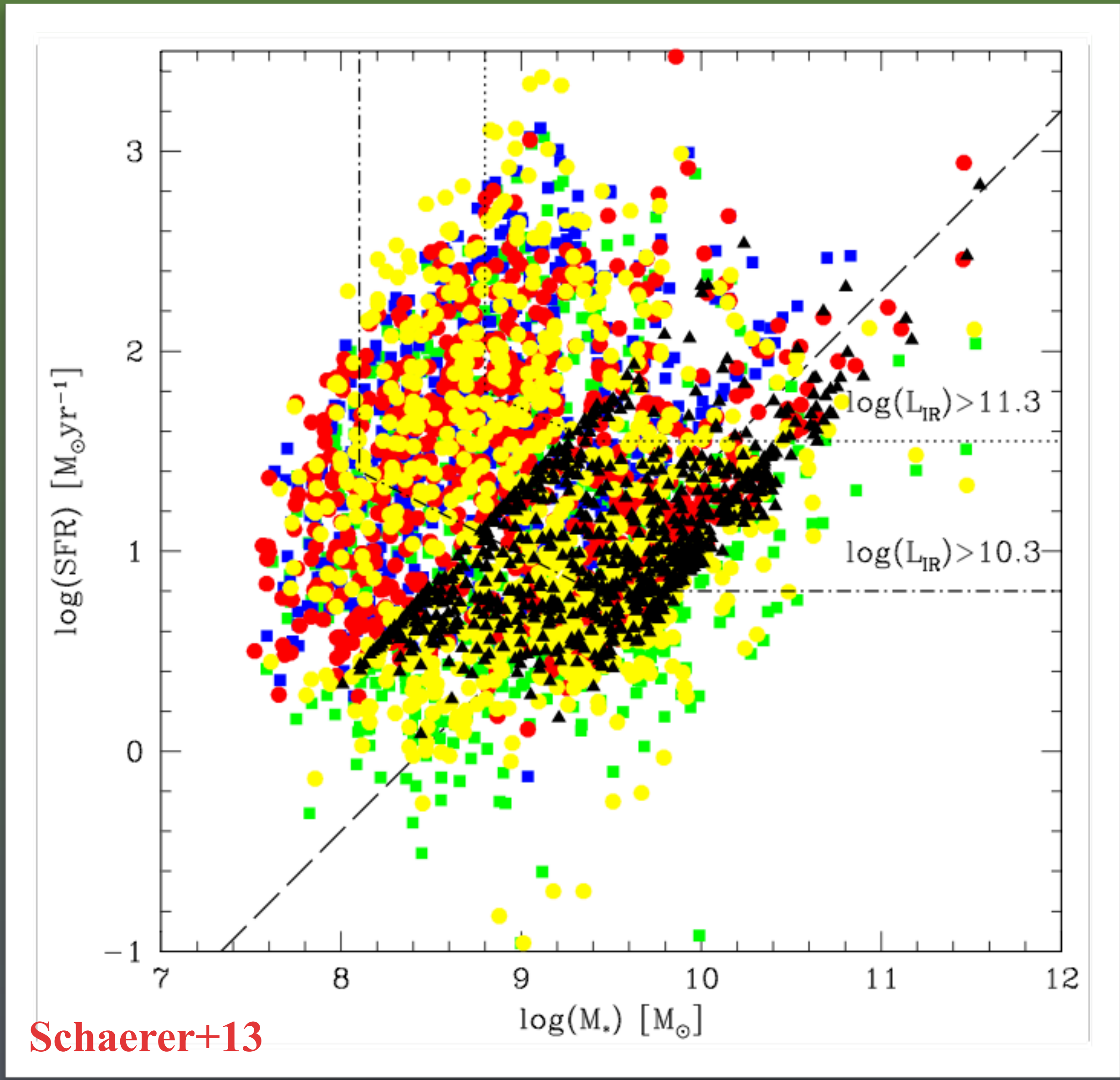


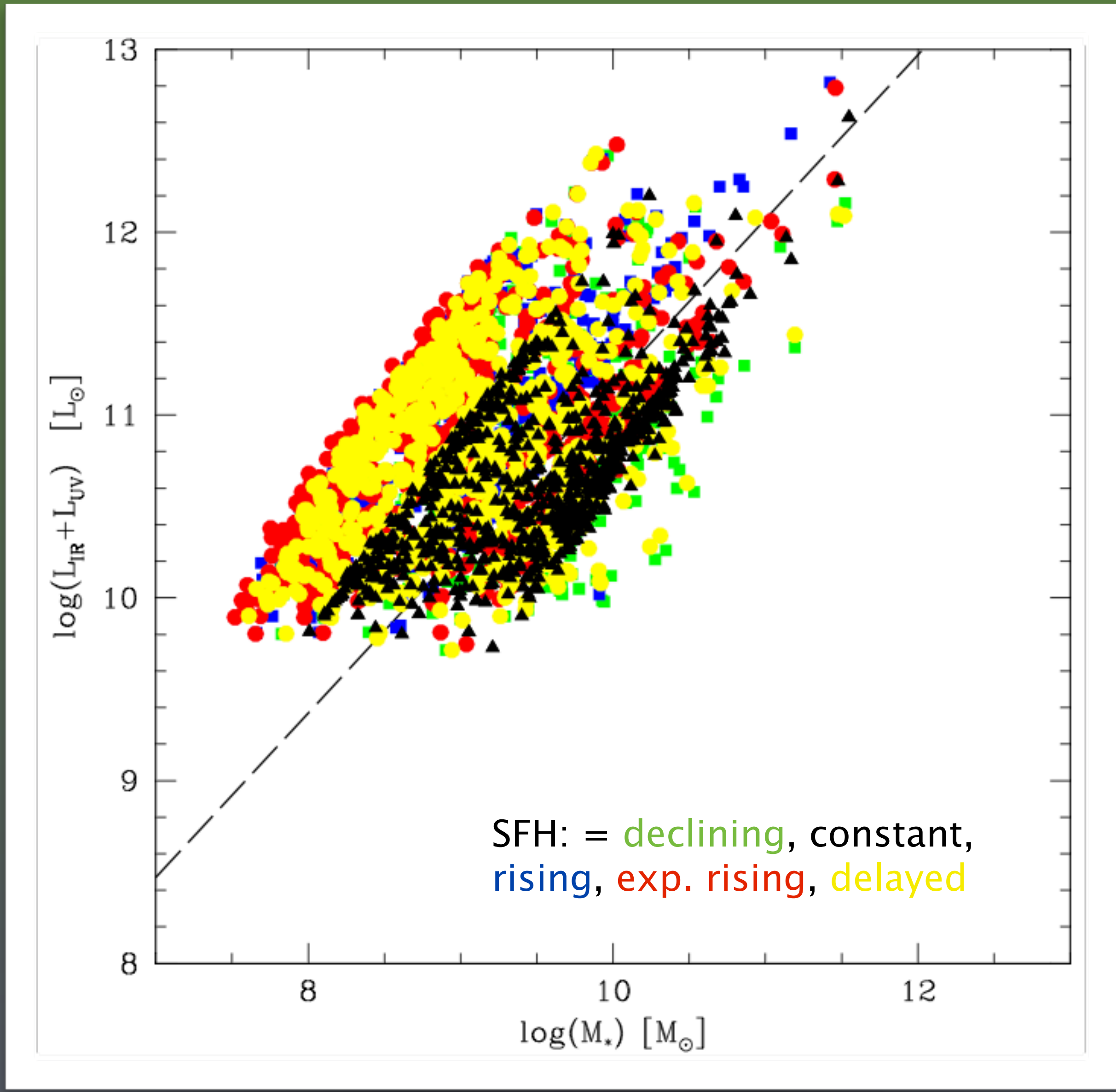
UV/optical/near-IR SED modeling of high-*z* LBGs

The SFR–Mstar relation:

- Large scatter and systematic dependencies on SFHs
- A well-defined 'main sequence' of star forming galaxies?

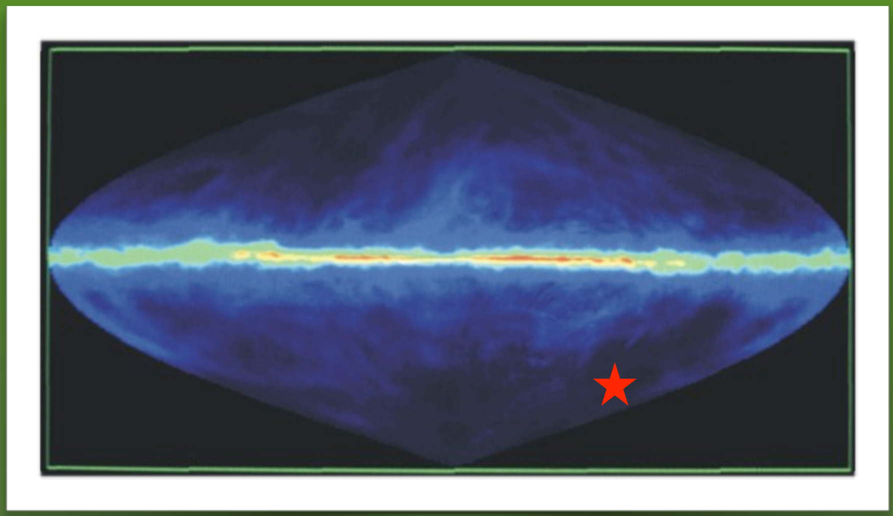
- Expressing SFR in terms of the observables L_{IR} and L_{UV}, the scatter diminishes

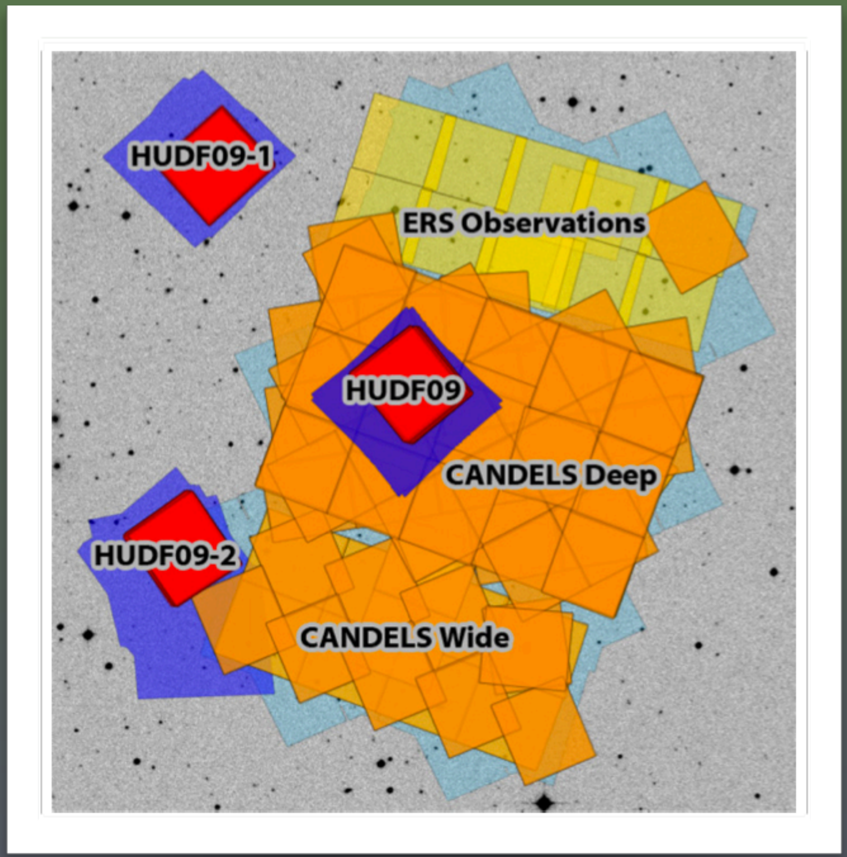


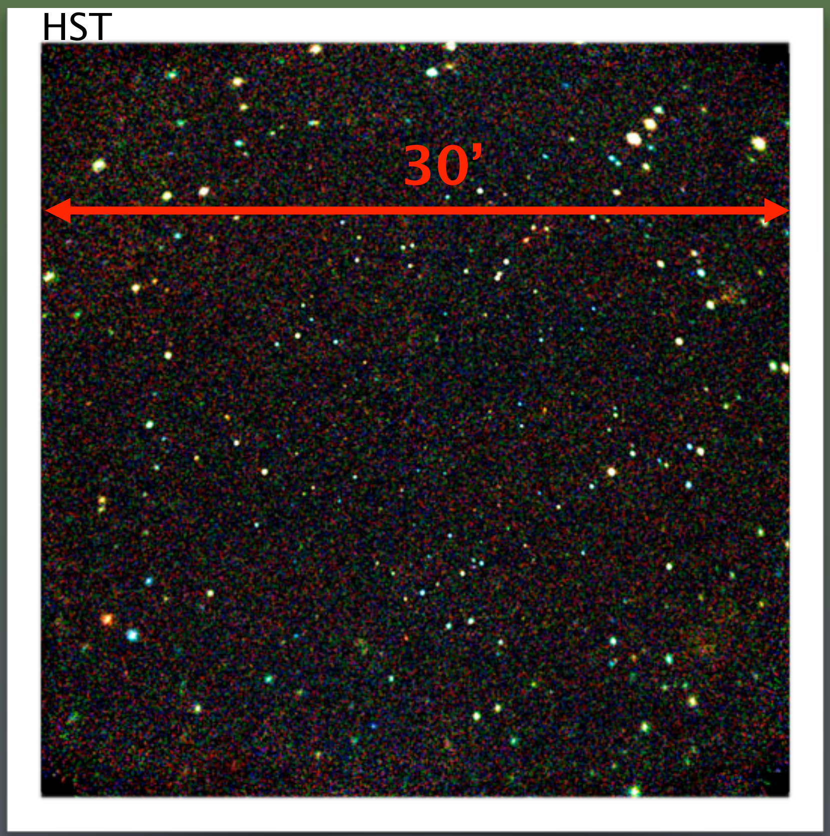


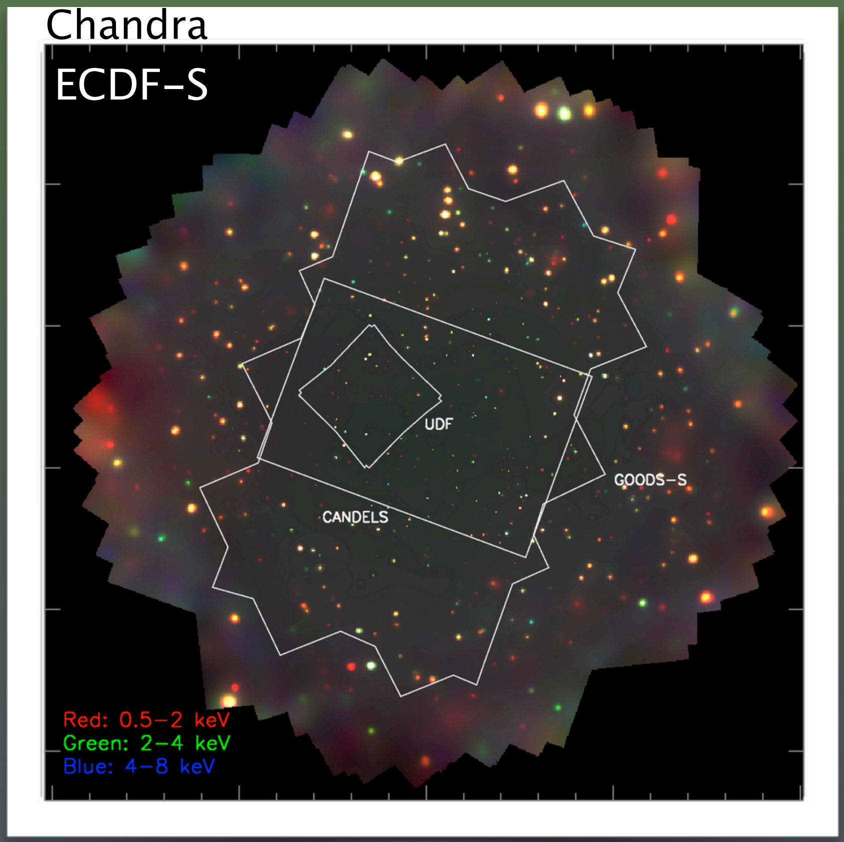
The Extended Chandra Deep Field South (ECDF-S)

- 30'×30' field (RA: 03h30m Dec: -27d40m)
- Multi-λ coverage:
  - UBVizJHK+IRAC GOODS-MUSIC catalogue (Santini+09) (K_s ~ 23.8)
  - Far/Mid-IR 24, 70, 160μm MIPS/Spitzer (FIDEL), and 70, 100, 160μm PACS/Herschel (PeP)
  - Submm: 250, 350, 500μm SPIRE/Herschel (HerMES) and LABOCA 870μm (Weiss+09)
  - Radio: VLA 1.4GHz, GMRT 610MGz (Ivision+10)



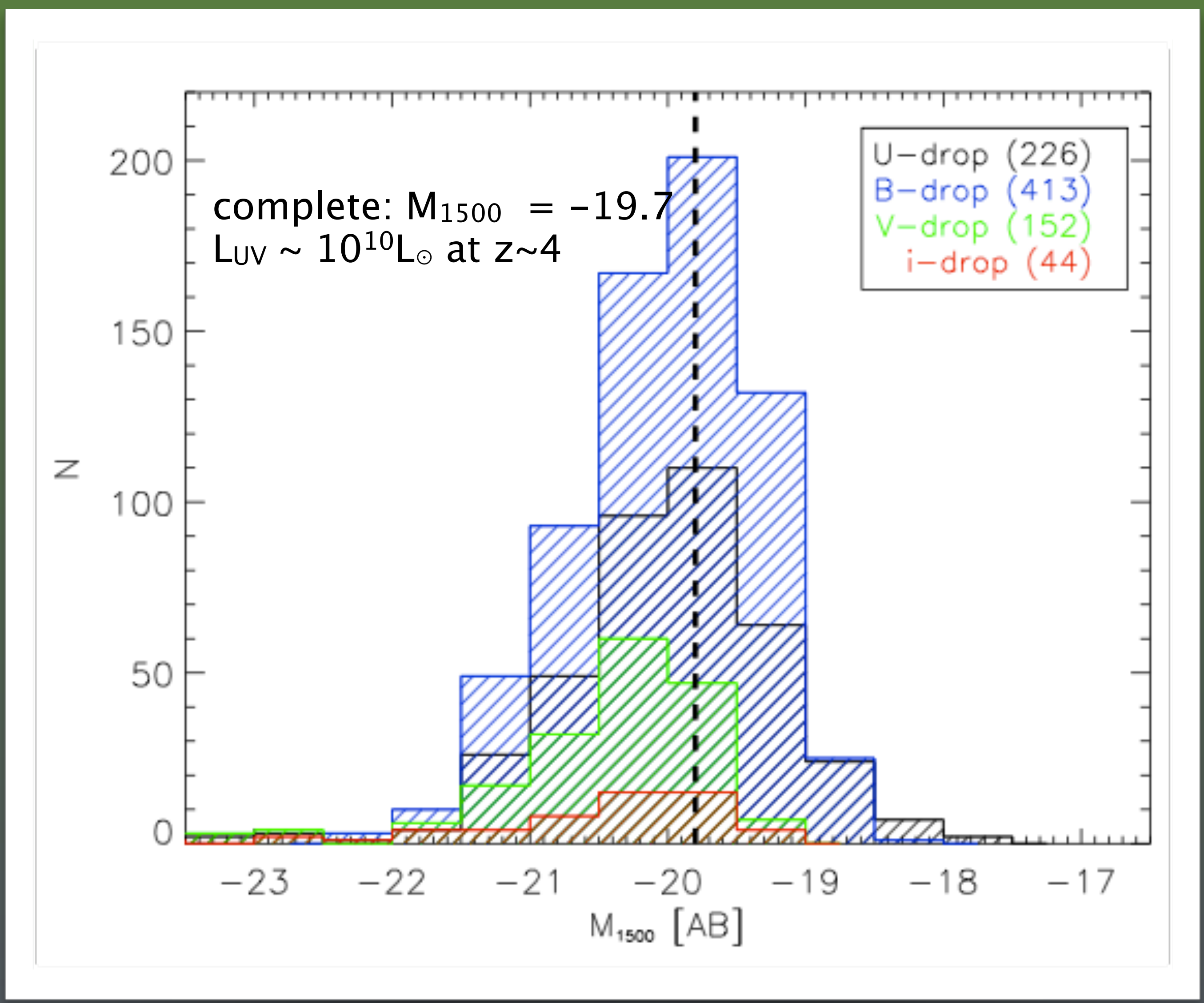


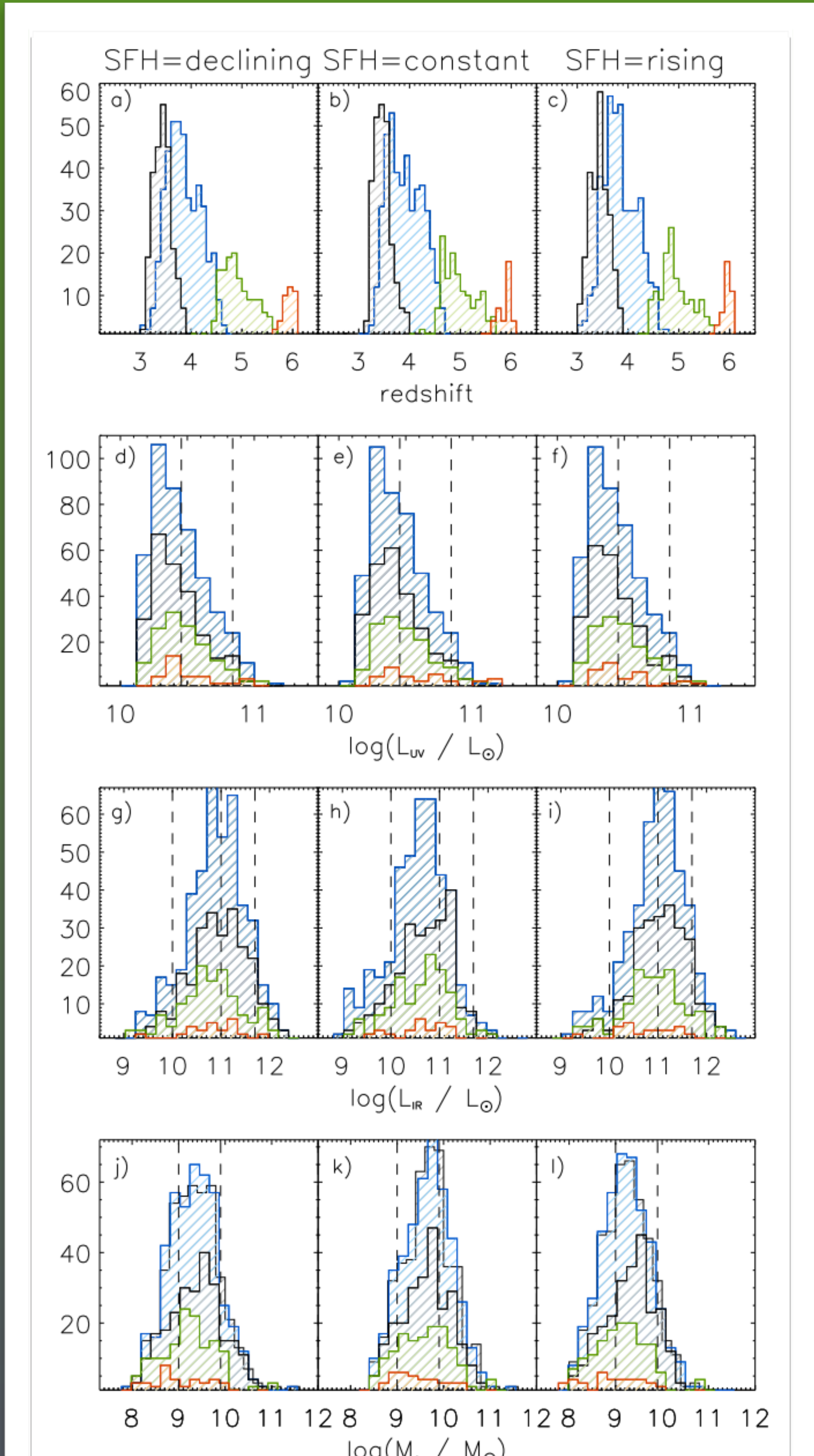




Sample selection

- UBVizJHK+IRAC GOODS-MUSIC catalogue
- Hyper-z SEDs/photo-z's (de Barros+12)
  - SFH = constant, declining, rising
  - z, M_{star}, L_{UV}, L_{IR}, β,...
- U-, B-, V-, and i-dropouts: $<z_{phot}>$ ~ 3.3, 3.9, 4.9, 6.0

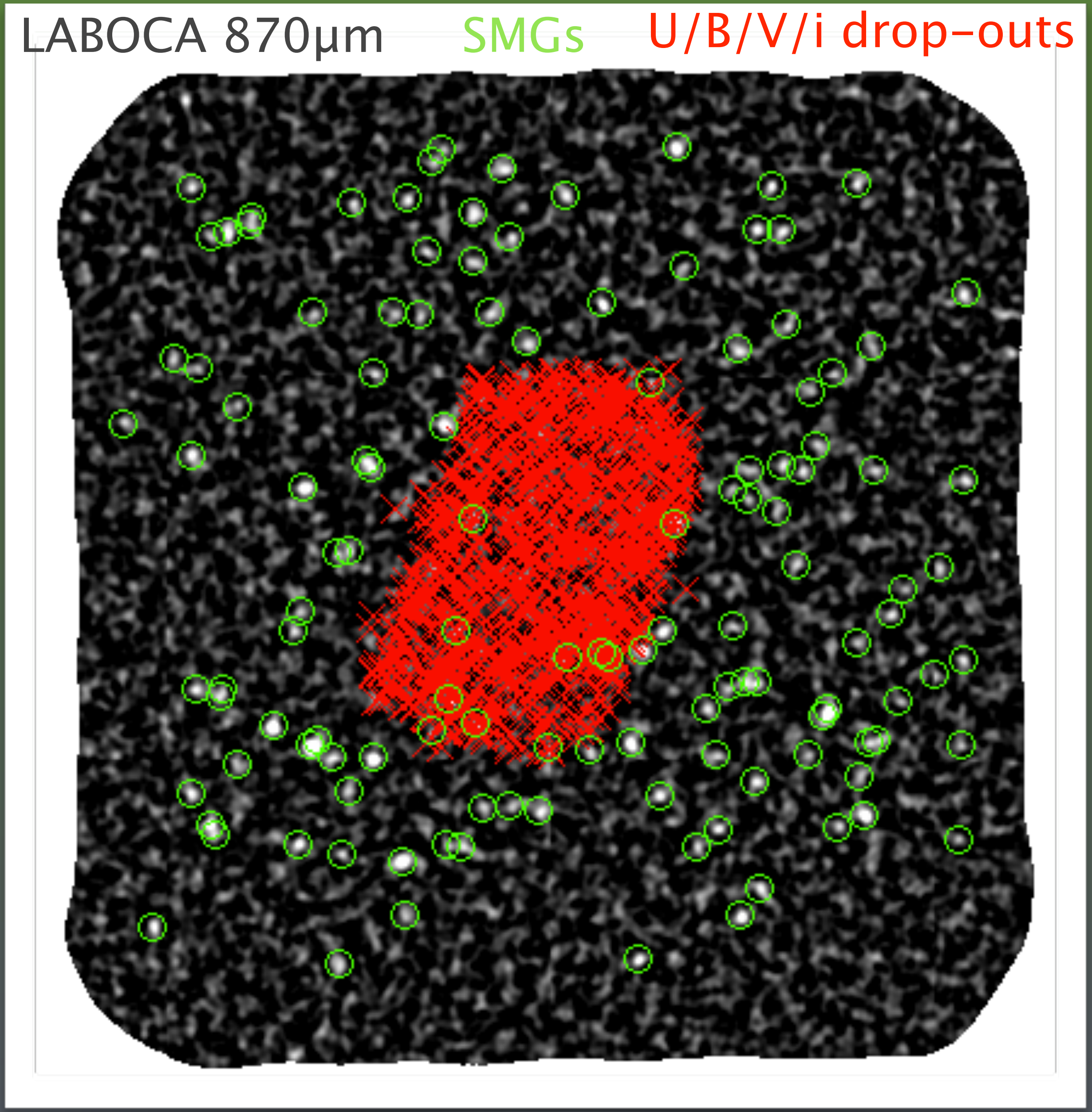


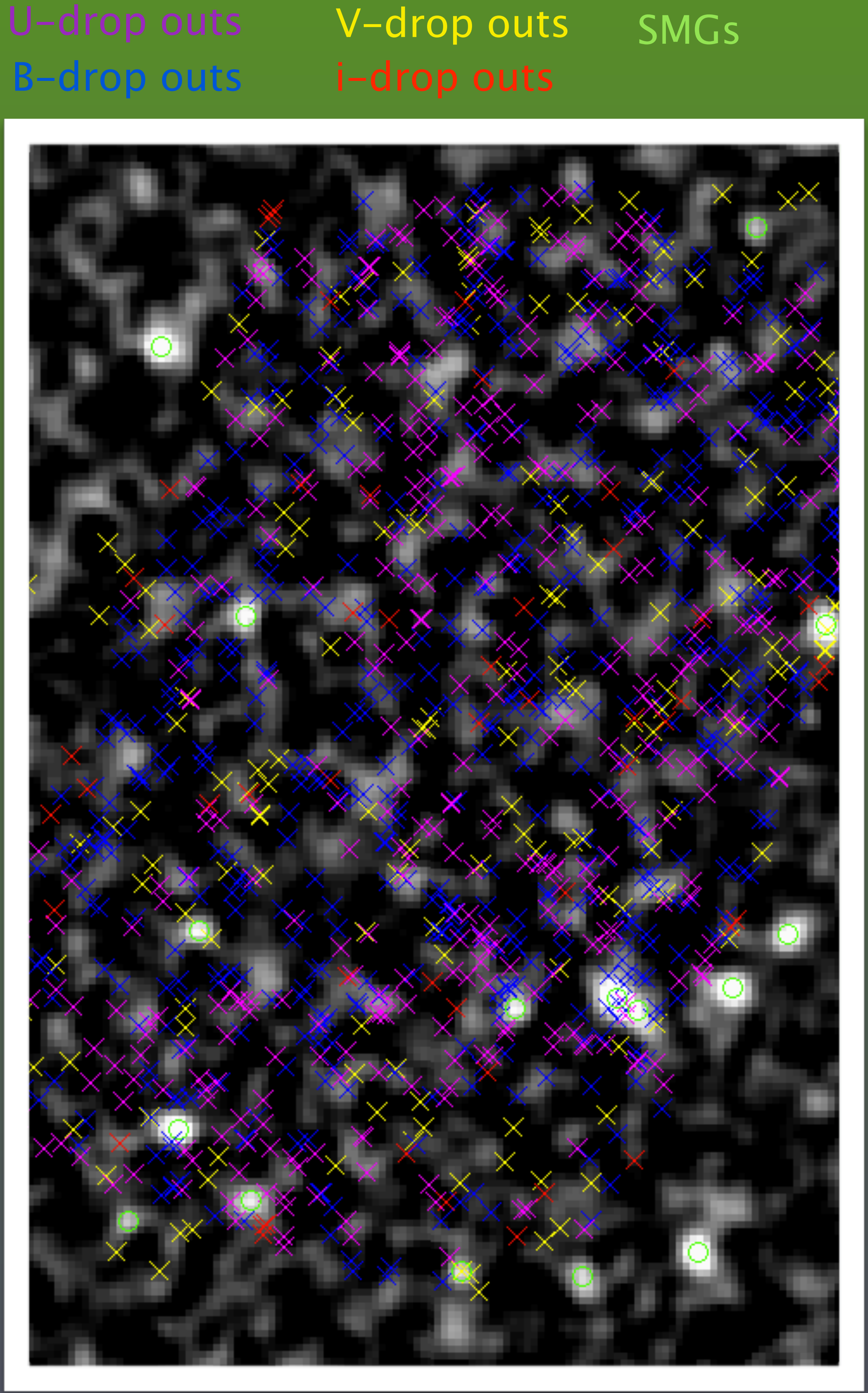


Greve, in prep.

Far-IR/submm imaging data

- 870μm: LABOCA map (LESS)
- σ ~ 1.1mJy/beam
- Beam FWHM~19.2”
- 126 submm sources (SNR>3.7)



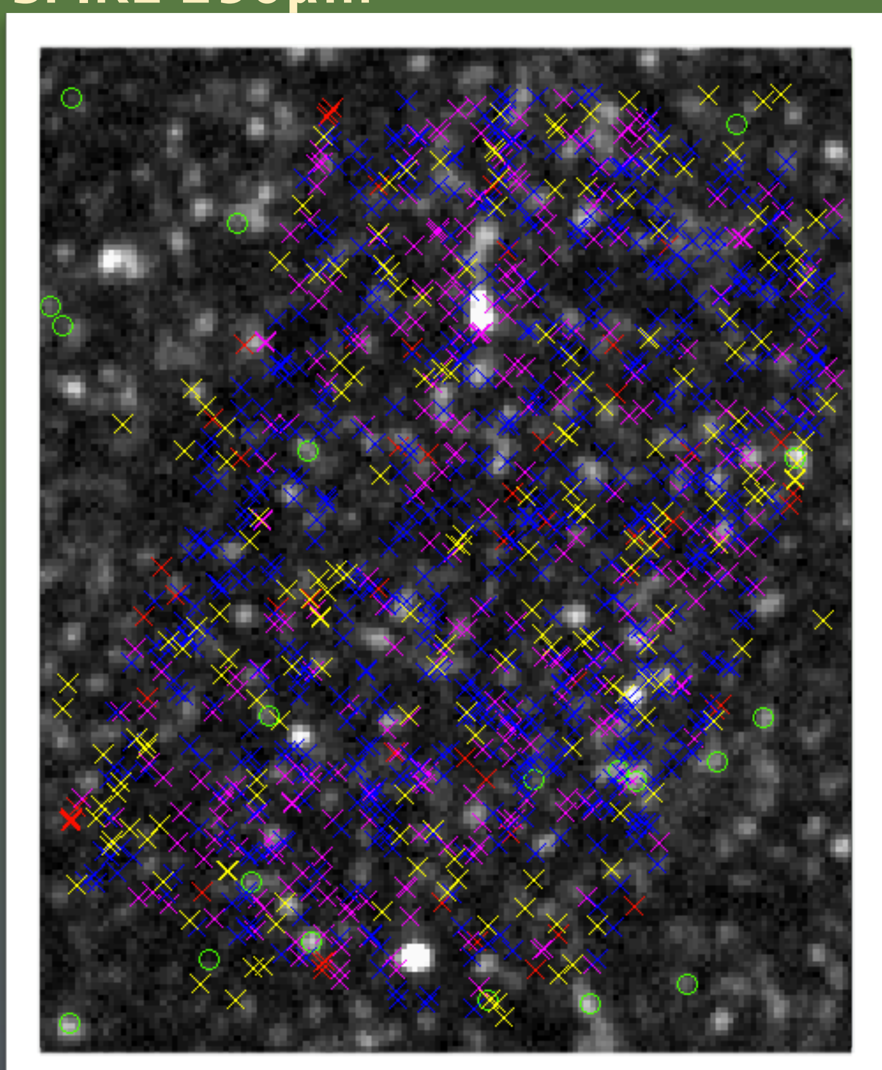


Far-IR/submm imaging data

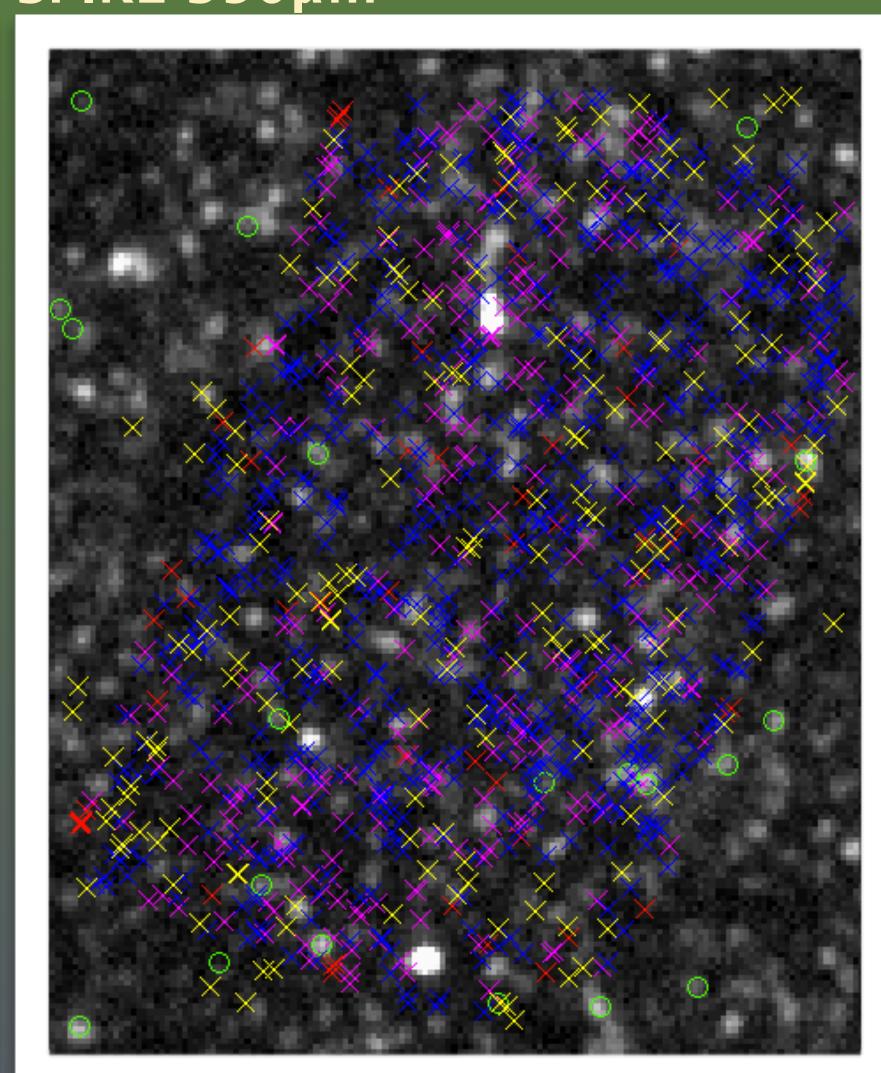
- 250, 350, 500μm: SPIRE maps (HerMES)
- σ ~ 4.8, 6.0, 6.3mJy/beam
- Beam FWHM~18.2, 24.9, 36.3”

U-drop outs V-drop outs SMGs
B-drop outs i-drop outs

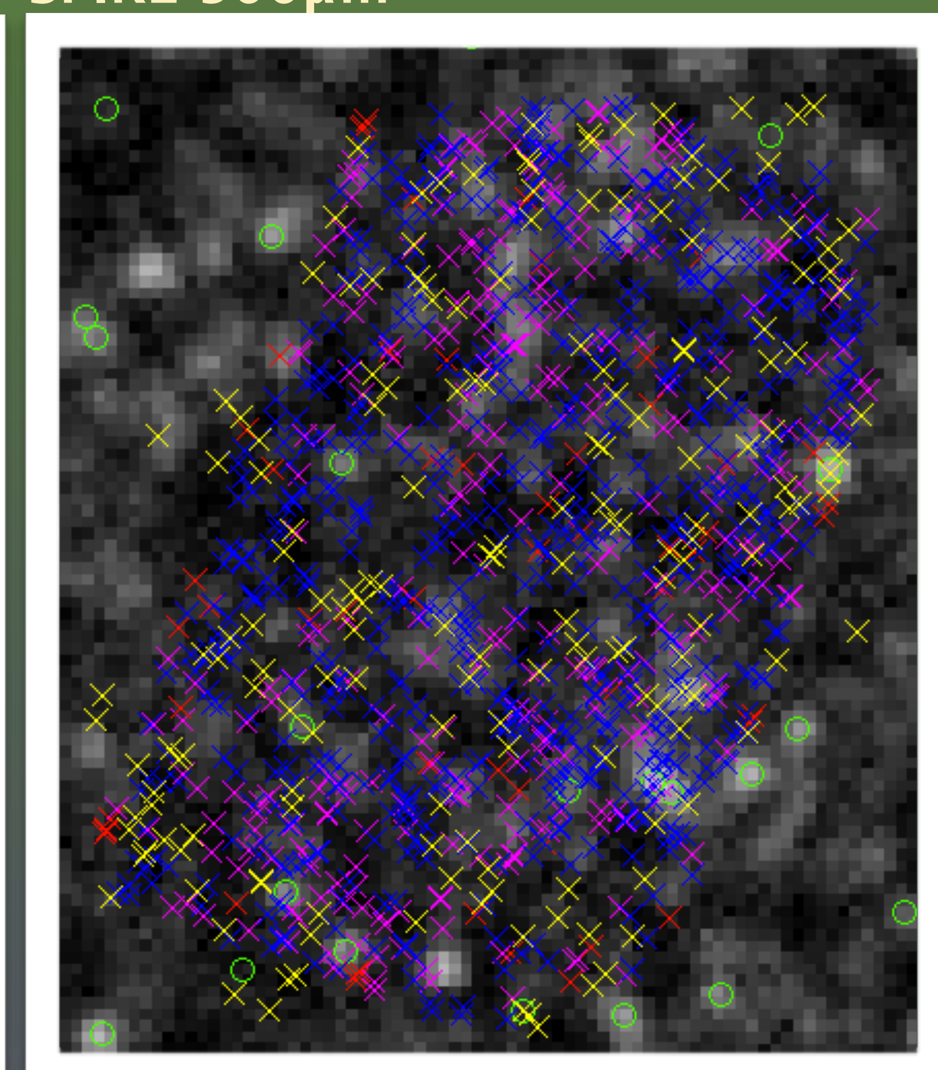
SPIRE 250μm



SPIRE 350μm



SPIRE 500μm

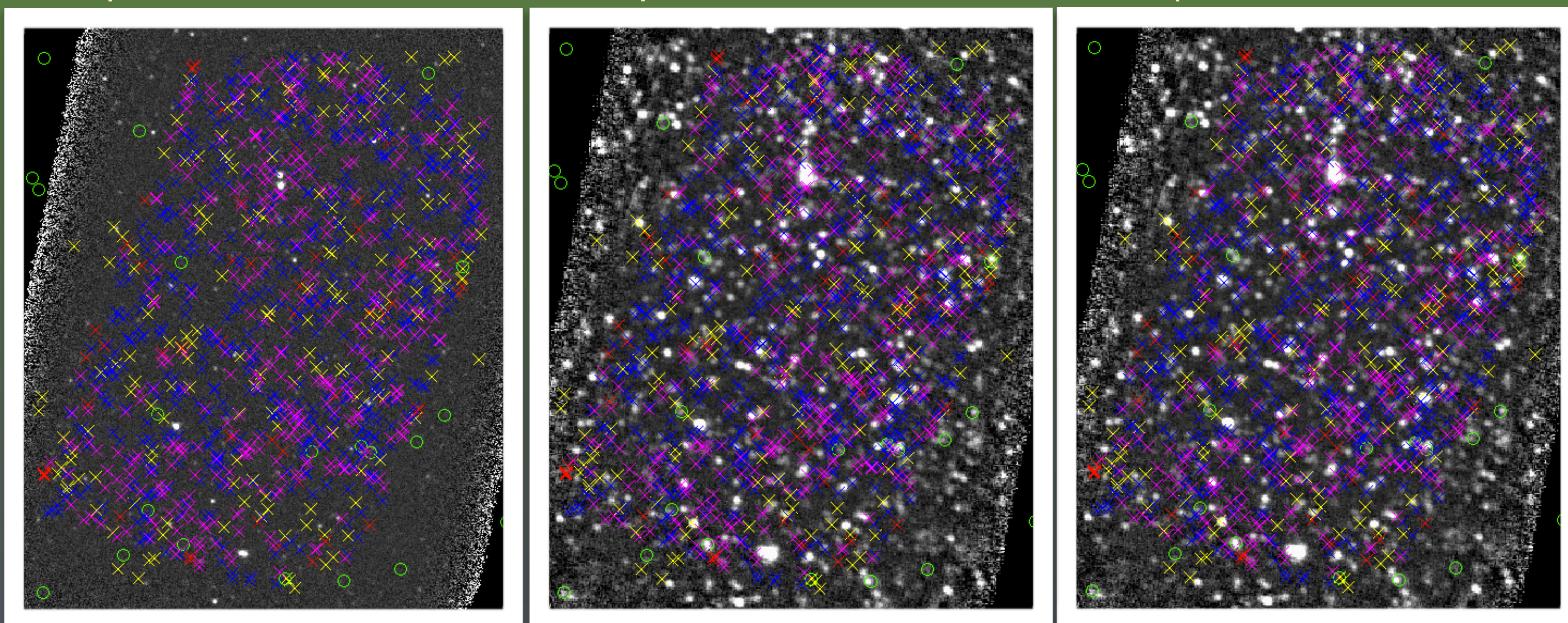


Far-IR/submm imaging data

- 70, 100, 160μm: PACS maps (PeP)
- σ ~ 0.2-0.6mJy/beam
- Beam FWHM~5.7, 6.7, 10.5”
- 468, 1189, 1240 sources with S/N > 3

U-drop outs V-drop outs SMGs
B-drop outs i-drop outs

PACS 70μm PACS 100μm PACS 160μm



Stacking

'Average' pixel values:

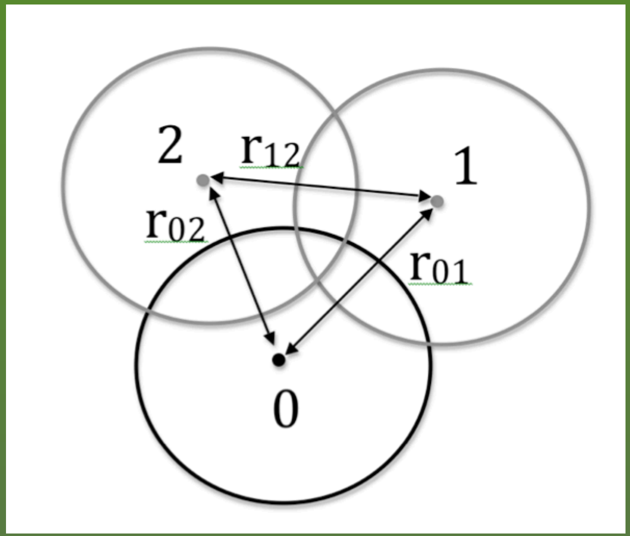
$$\langle I \rangle = \frac{\sum \frac{I_i}{\sigma_i^2}}{\sum \frac{1}{\sigma_i^2}}$$

$$\frac{1}{\sigma_{\langle I \rangle}^2} = \sum \frac{1}{\sigma_i^2}$$

Issues:

- Confusion of neighbouring sources will flux contaminate each other
- Clustering of sources on scales < beam can artificially boost the stacked signal

Global deblending:



$$n_0 + \alpha_{00} I_0 + \alpha_{01} I_1 + \alpha_{02} I_2 = f_0$$

$$n_1 + \alpha_{10} I_0 + \alpha_{11} I_1 + \alpha_{12} I_2 = f_1$$

$$n_2 + \alpha_{20} I_0 + \alpha_{21} I_1 + \alpha_{22} I_2 = f_2$$

$$\vdots$$

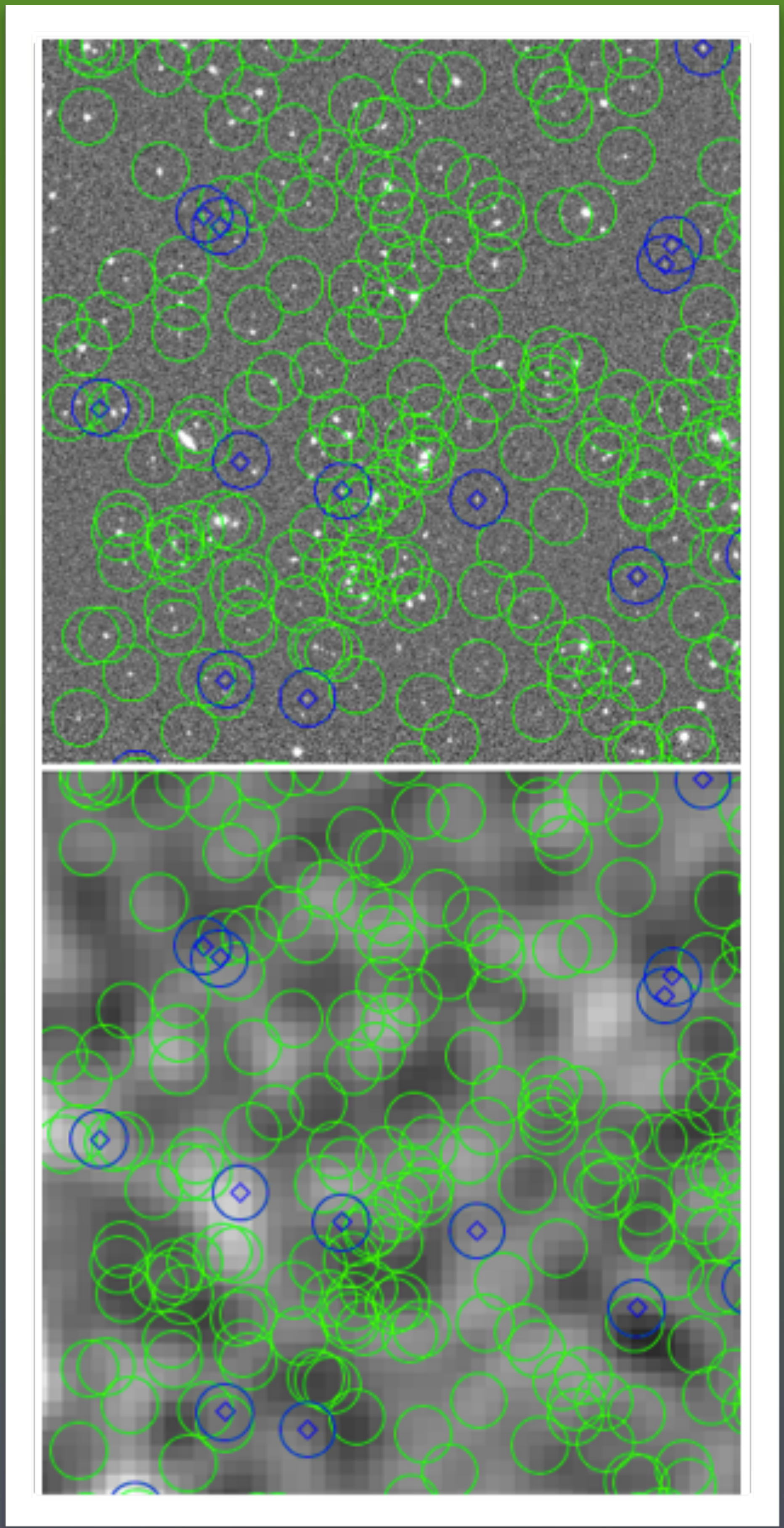
$$\alpha_{ij} = \exp(-r_{ij}^2/2\sigma^2)$$

$$\sigma = FWHM/2.3548$$

Webb+03; Greve+10, Kurczynski+10, Viero+11

targets

non-targets



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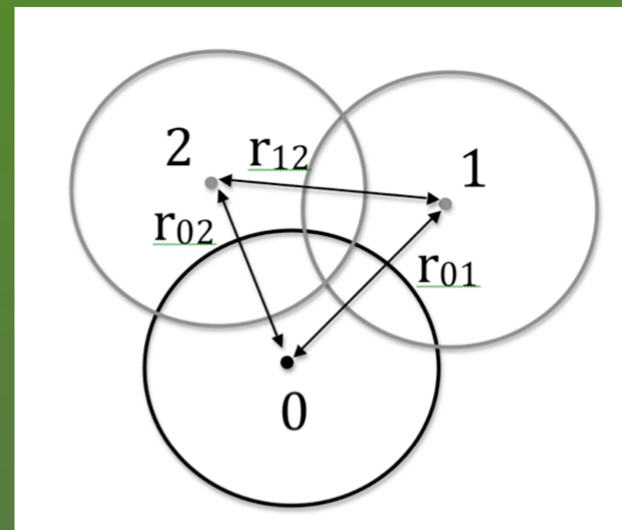

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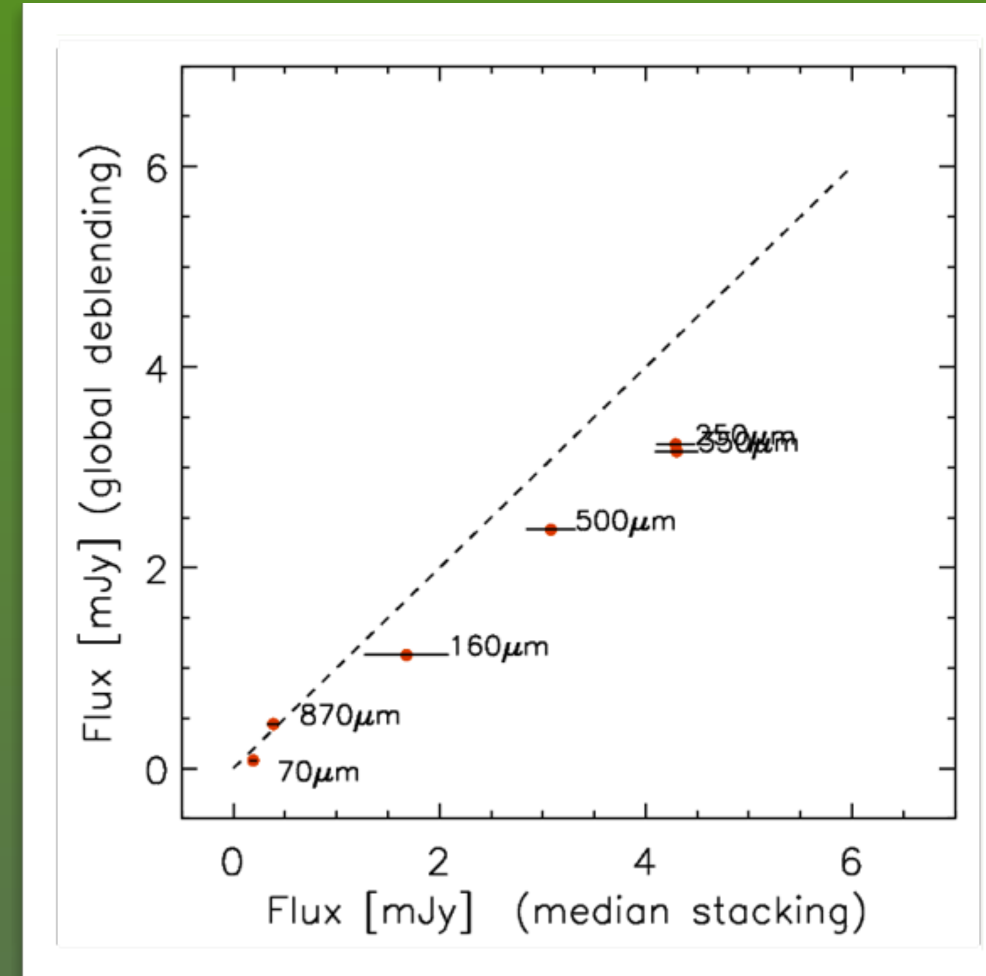
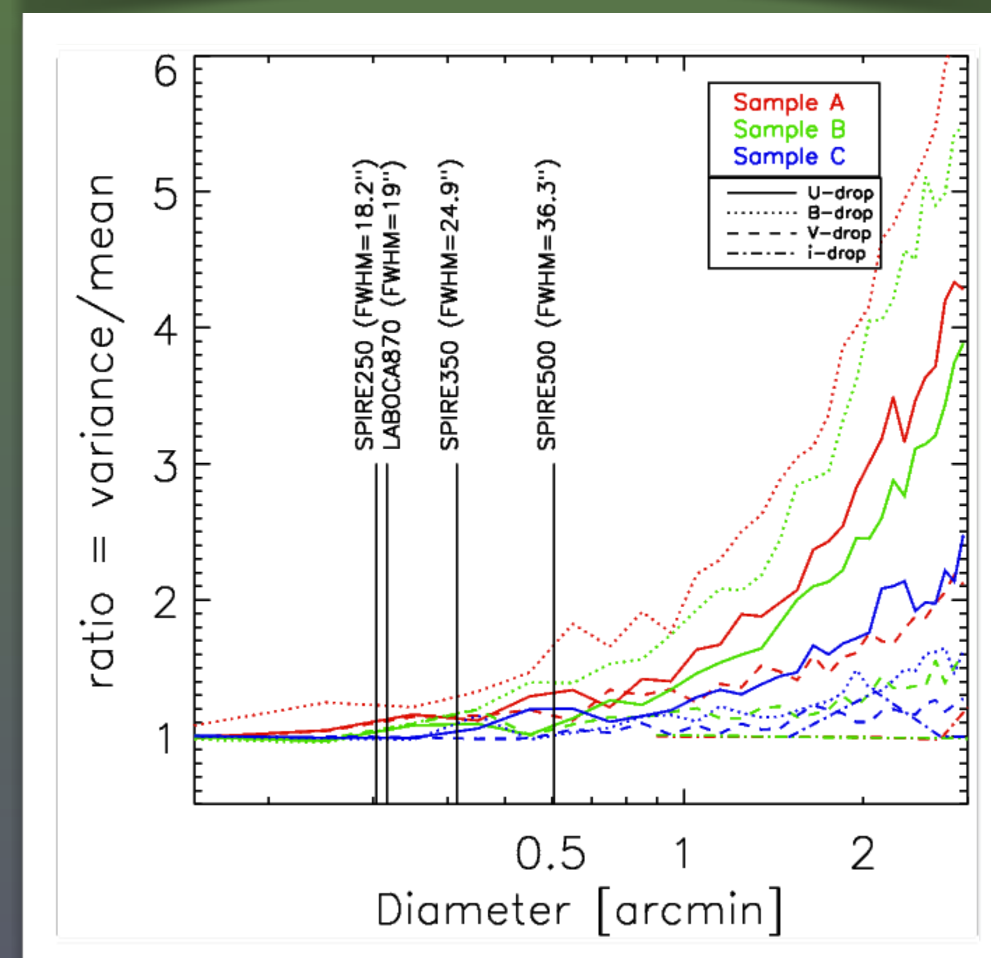
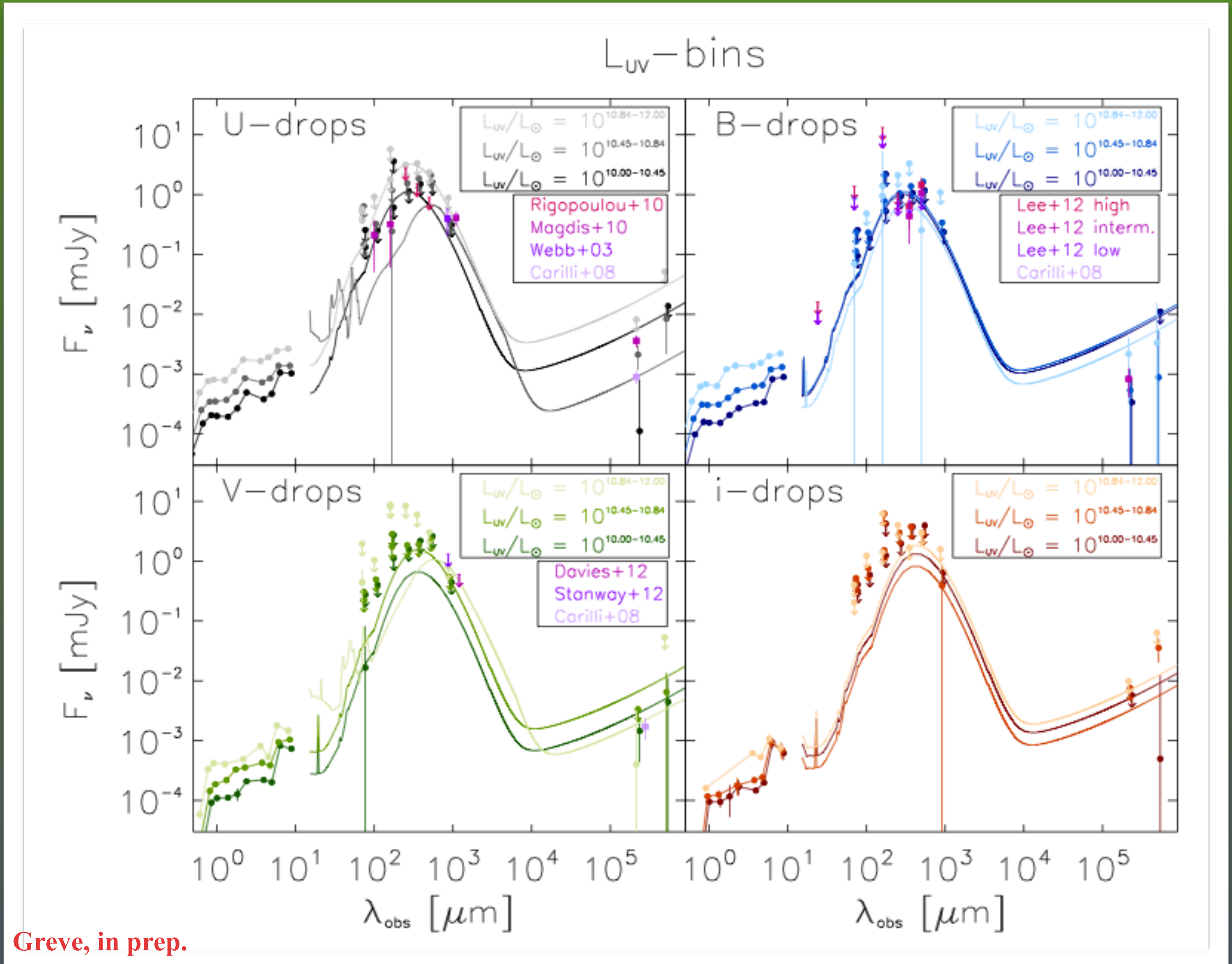
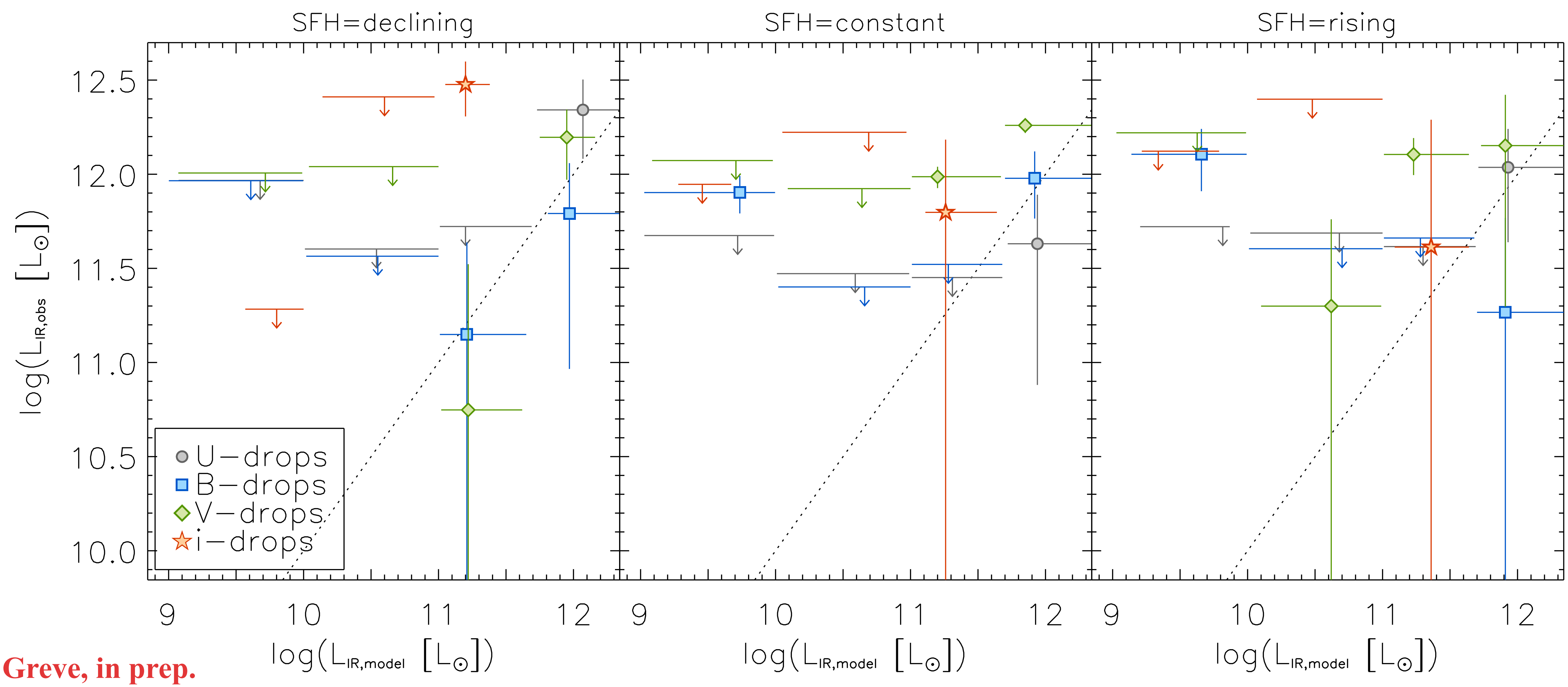




Pan-chromatic SEDs of LBGs at z~3,4,5,6

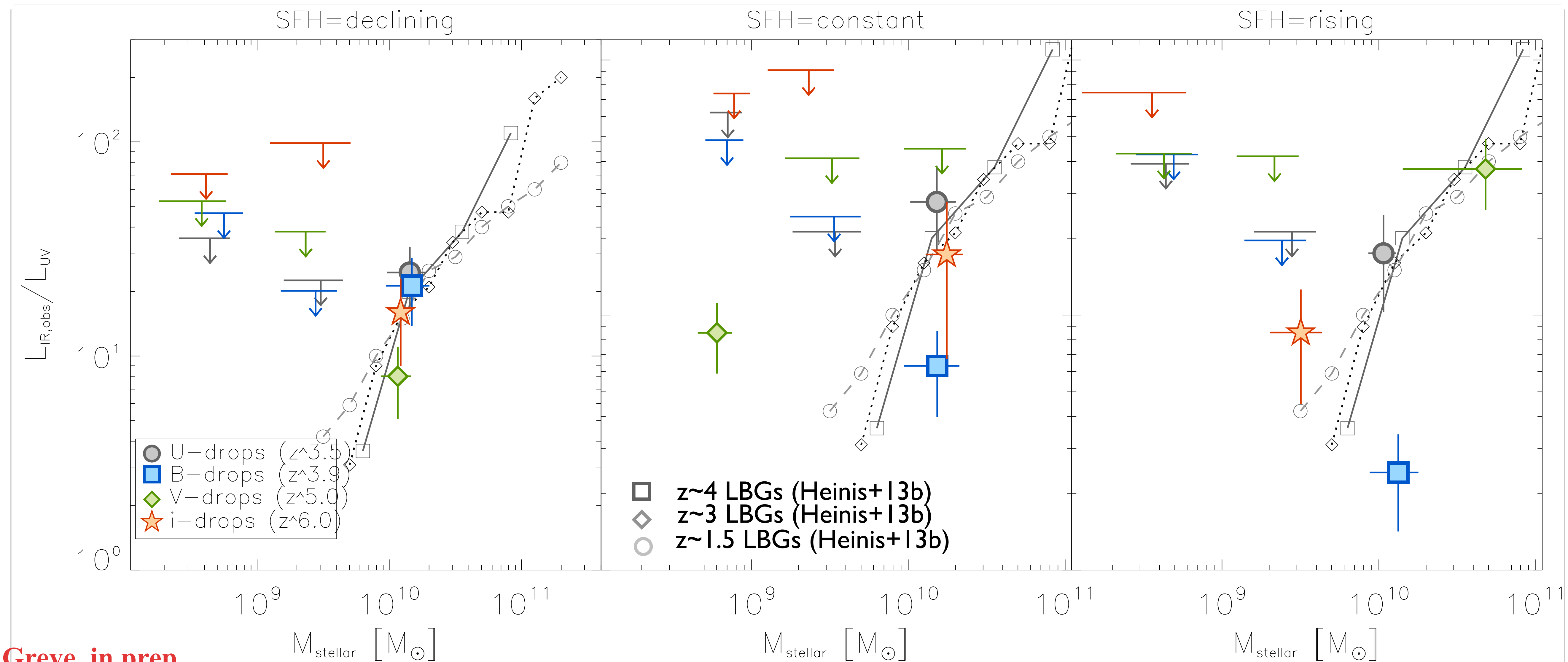


L_{IR}: stacking results vs. model predictions



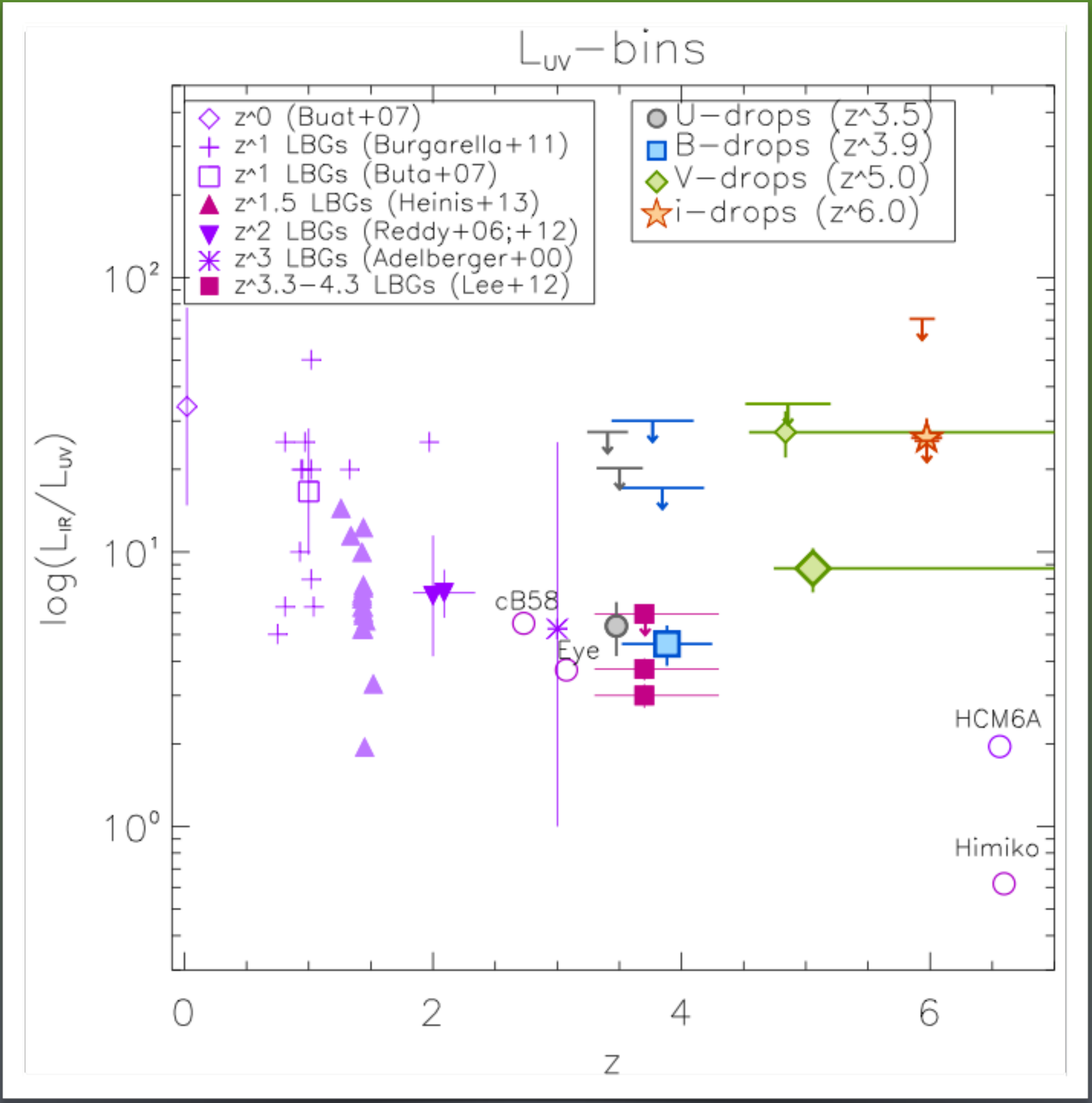
Greve, in prep.

Dust obscuration vs. M_{star}

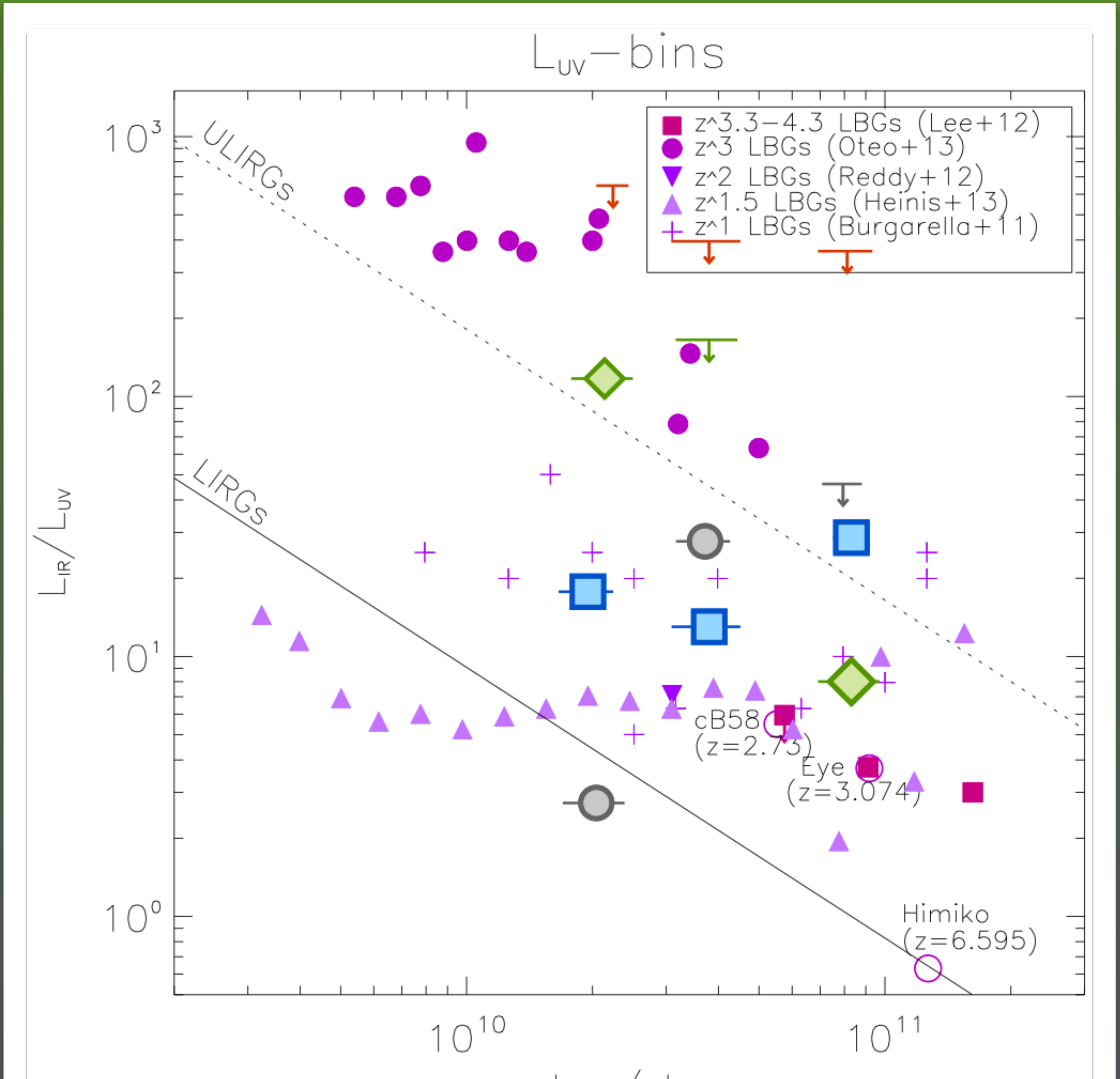


Greve, in prep.

Dust obscuration vs. z



Results: dust obscuration vs. L_{UV}



Greve, in prep.

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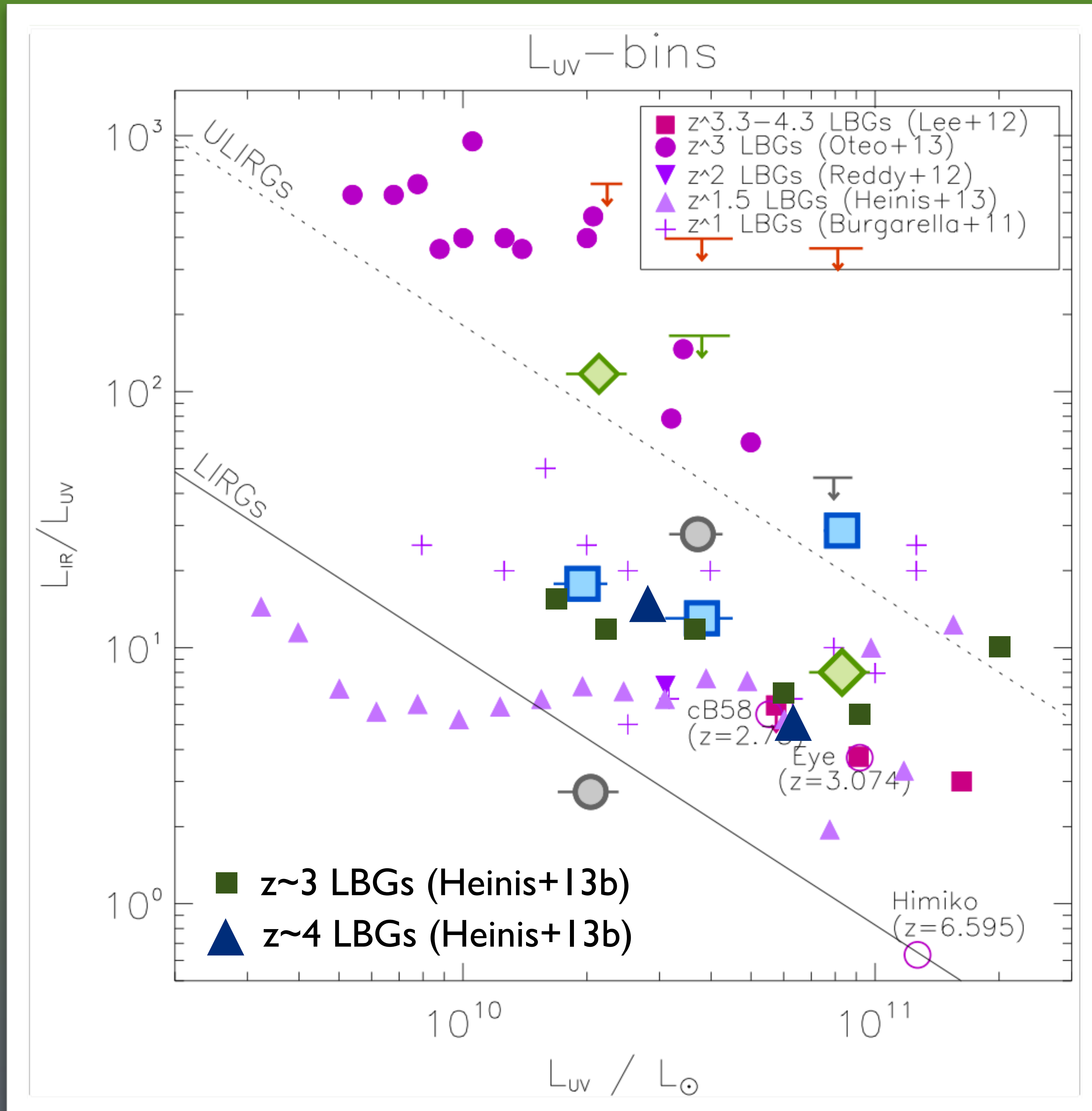
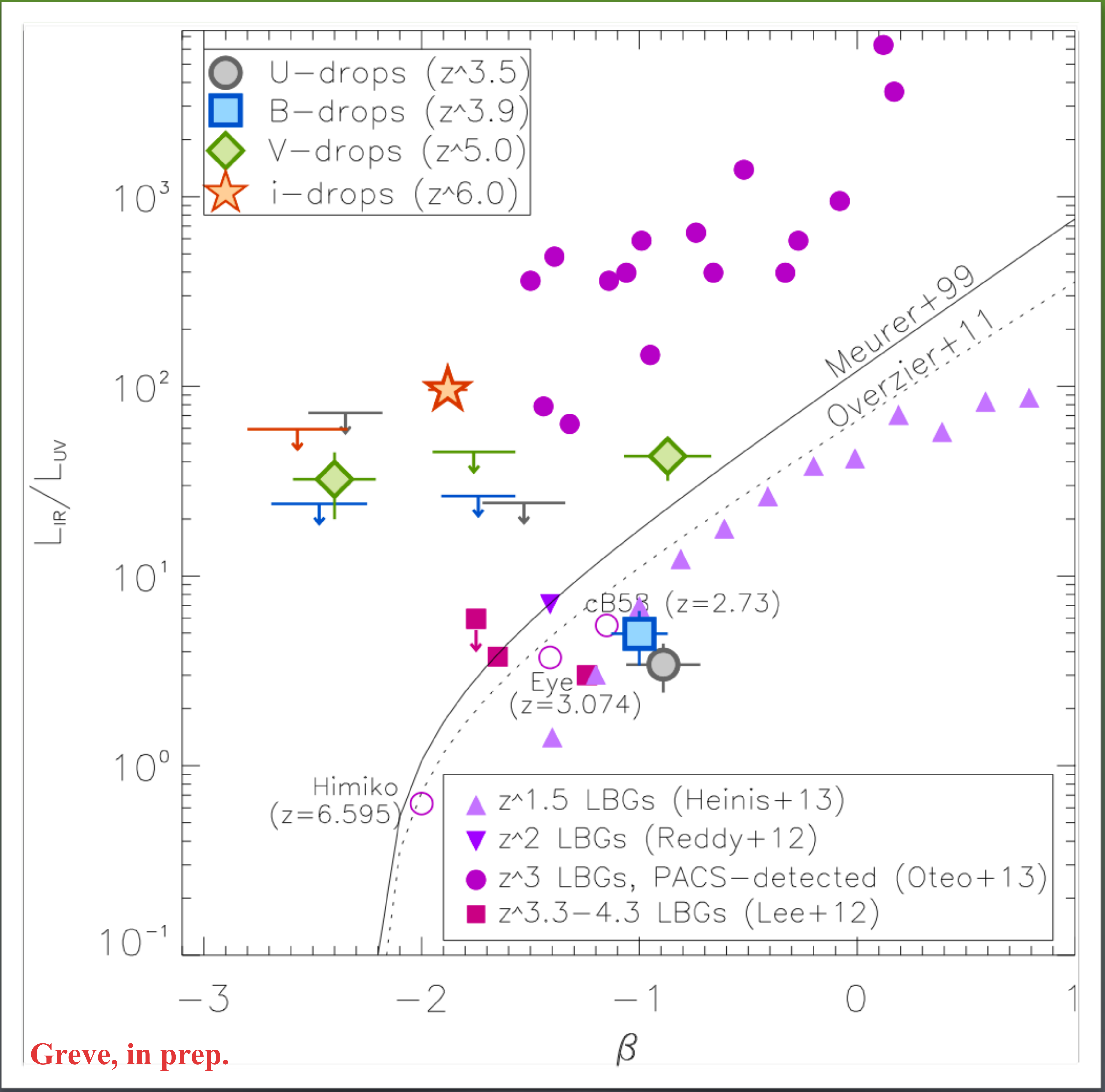


Results: dust obscuration vs. UV-slope



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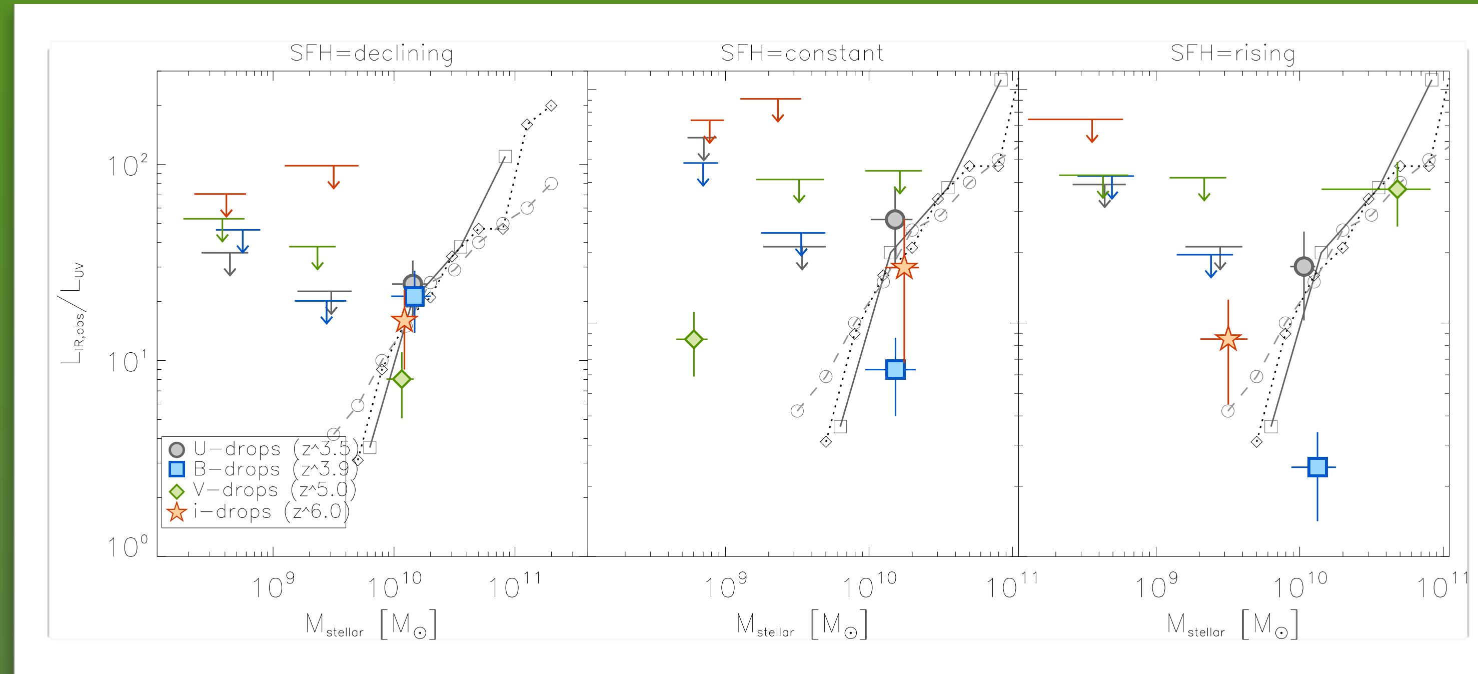
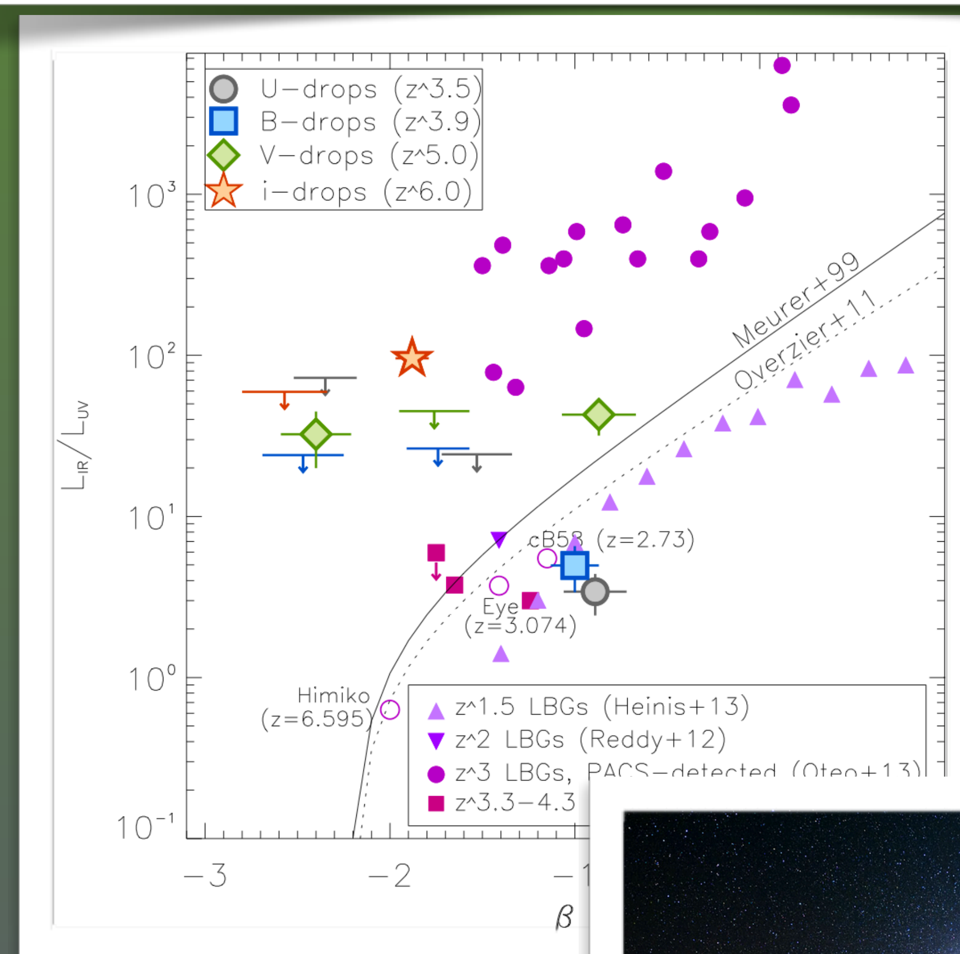
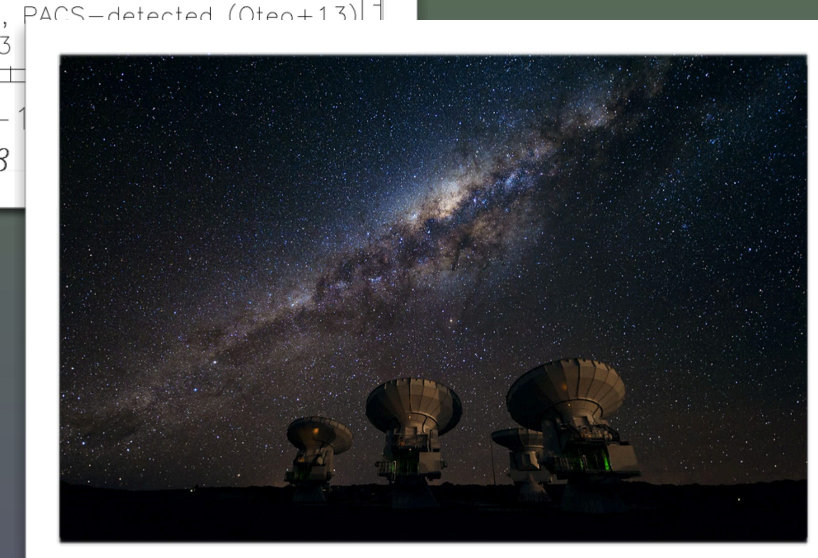
Summary

- Deep FIR/submm detections of z > 3 LBGs will play an important role in constraining their SFHs
- Despite significant challenges, stacking is a useful avenue to explore dust contents of z > 3 LBGs
- Via stacking we have obtained pan-chromatic SEDs of z~3, 4, 5, 6 LBGs
- We have made the first attemps at constraining their SFHs via stacking. This is very challenging!
- The stage is set for ALMA!







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