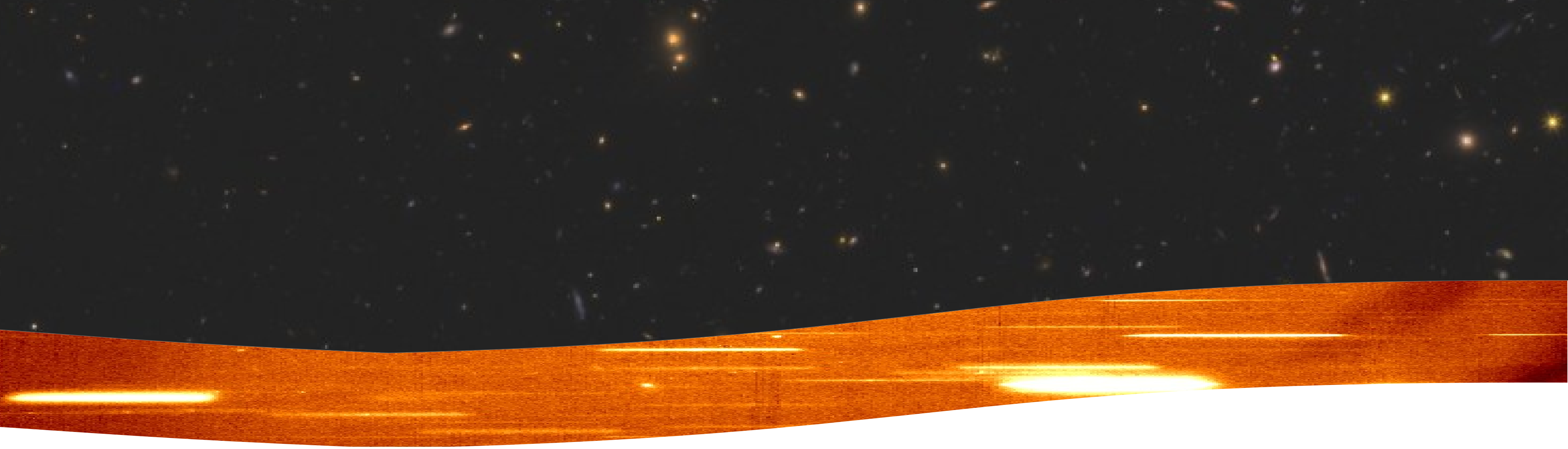


Dust attenuation in $z \sim 1$ galaxies from *Herschel* and 3D-HST Hα measurements

A. Puglisi, G. Rodighiero, A. Franceschini, M. Talia, A. Cimatti, I. Baronchelli, E. Daddi, A. Renzini, K. Schawinski, C. Mancini, C. Gruppioni, D. Lutz, S. Berta and S. J. Oliver

paper close to submission

GDSF2015

Star Formation Rate estimate

(Kennicutt 1998)

- **Ultraviolet continuum:** **1500 Å ≤ λ ≤ 2500 Å**

$$SFR_{UV}[M_{\odot}/yr] = 1.4\, x\, 10^{-28}\, L_{\nu}[erg/s/Hz]$$

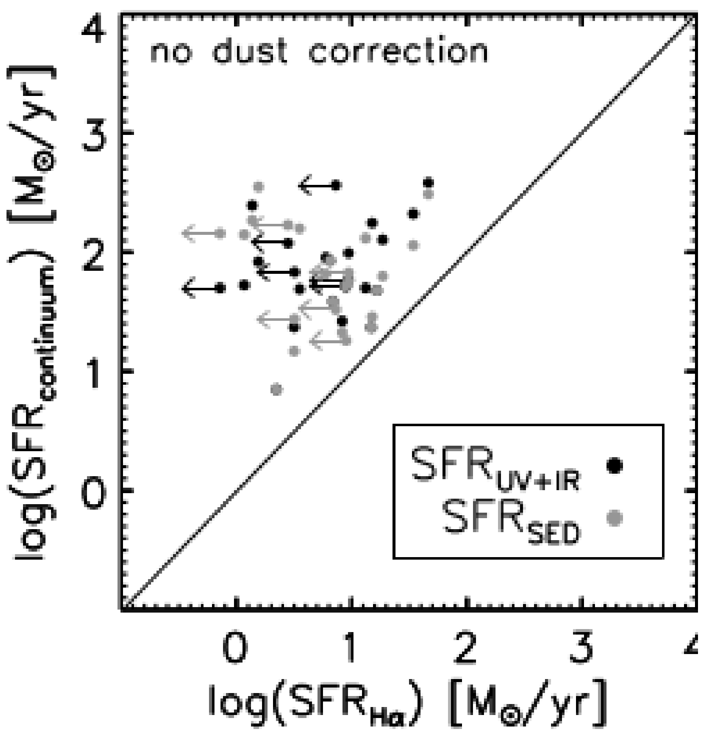
- **Far-Infrared emission:** **8 μm ≤ λ ≤ 1000 μm**

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

- **Recombination lines (Hα emission):** **λ=6562.8 Å**

$$SFR_{H\alpha}[M_{\odot}/yr] = 7.9\, x\, 10^{-42}\, L_{H\alpha}[erg/s]$$

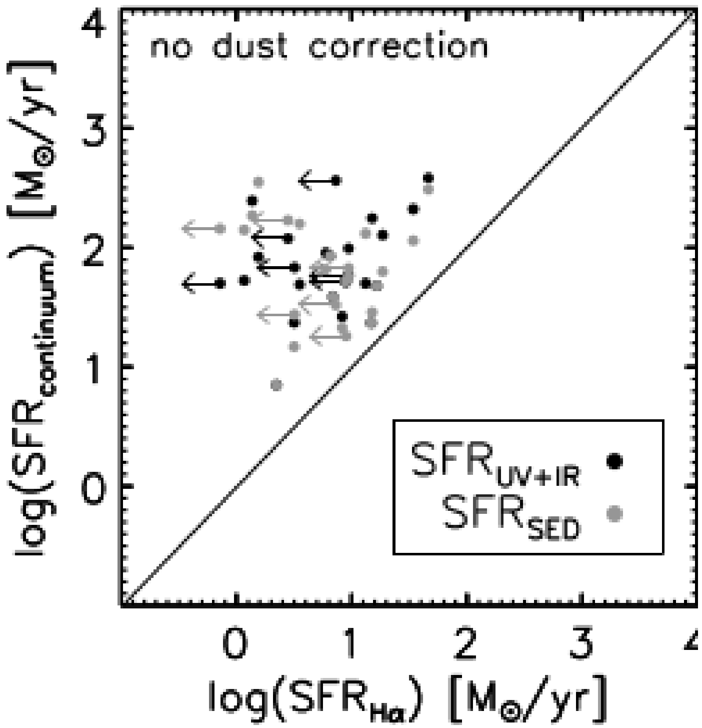
Star Formation Rate estimate



(from **Wuyts+2011**)

Star Formation Rate estimate

Main uncertainty @ UV-optical λ: dust extinction



(from **Wuyts+2011**)

DUST EXTINCTION

MAIN FEATURES of dust:

- Absorption in the UV-optical spectrum
- Thermal emission at far-IR λ
- Located in the Star Forming Regions

$$F(\lambda)_{obs} = F(\lambda)_{intr}\, x10^{-0.4A_{\lambda}}$$

Two components model

e.g. Charlot & Fall, 2000
Silva+1998

Diffuse dust → Attenuates the light of **all the stellar populations**

Birth cloud **$\tau \sim 10^7$ yrs** → Attenuates the light of **the youngest stars**

DUST EXTINCTION

The classical recipe (Calzetti+2000)

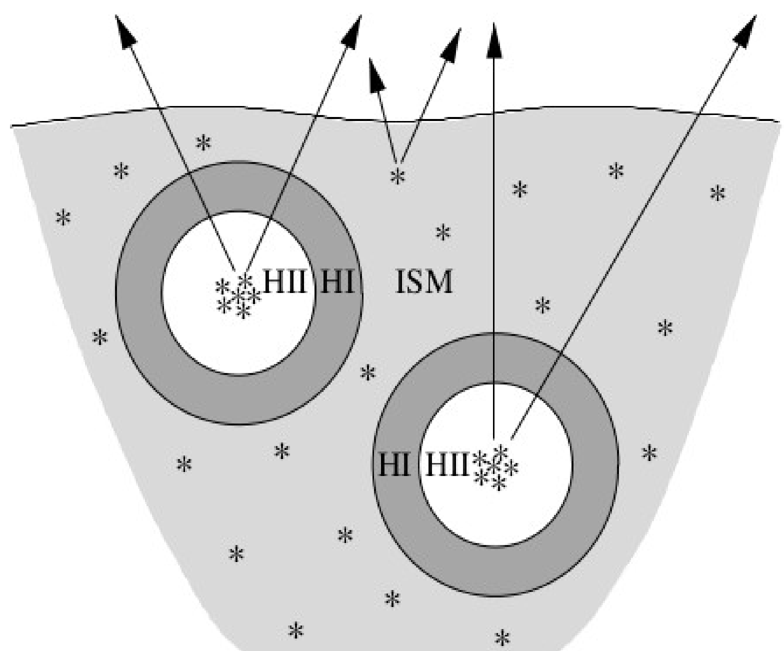
LOCAL UNIVERSE:

Evidence of **differential extinction** between **stellar continuum** and **nebular lines**

k(λ) for $E_{neb}(B\text{-}V)$
Fitzpatrick+1999

$$E_{neb}(B-V) = E_{star}(B-V)/f$$
$$f = 0.44$$

k(λ) for $E_{star}(B\text{-}V)$
Calzetti+2000



from **Charlot & Fall, 2000**

DUST EXTINCTION

The classical recipe (Calzetti+2000)

LOCAL UNIVERSE:

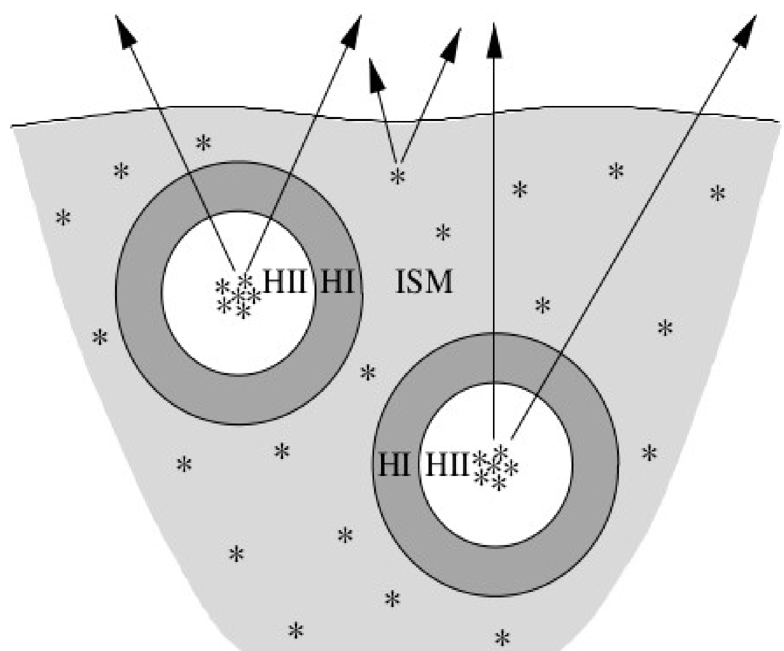
Evidence of **differential extinction** between **stellar continuum** and **nebular lines**

k(λ) for $E_{neb}(B\text{-}V)$
Calzetti+2000

$$E_{neb}(B-V) = E_{star}(B-V)/f$$

$$f = 0.58$$

k(λ) for $E_{star}(B\text{-}V)$
Calzetti+2000



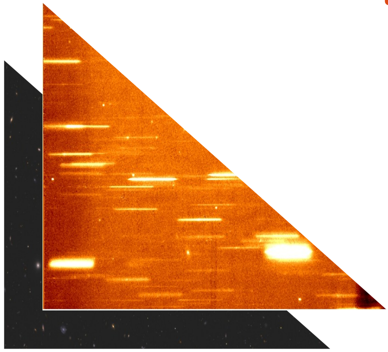
from **Charlot & Fall, 2000**

DUST EXTINCTION

Is the Calzetti law still valid in high redshift galaxies?

$$E_{neb}(B-V) = E_{star}(B-V)/f$$

Author	*f*	*z range*	*Sample*	*Method*
Calzetti et al. (2000)	0.44	0.003-0.05	starburst galaxies	Balmer decrement
Kashino et al. (2013)	0.83±0.10	1.4-1.7	sBzk galaxies	Balmer decrement (stacked spectra)
"	0.69±0.02	"	"	Hα to UV SFRs
Wuyts et al. (2011)	0.44	0-3	K_s selected galaxies	SFR indicators
Price et al. (2014)	0.55±0.16	1.36-1.5	MS star forming galaxies	Balmer decrement (stacked spectra)
Pannella et al. (2014)	0.58	< 1	UVJ selected galaxies	comparison between A_{UV}-$M_\star$/$A_{H\alpha}$-$M_\star$
"	0.77	1	"	"
"	1	> 1	"	"
Valentino et al. (2015)	0.74±0.05	2	CL J1449+0856	Balmer decrement (stacked spectra)
Erb et al. (2006)	1	2	rest-frame UV selected galaxies	matching UV and Hα SFRs
Reddy et al. (2010)	1	1.5-2.6	Lyman Break Galaxies	matching X-ray, UV and Hα SFRs
This work	0.93±0.06	0.7-1.5	far-IR selected galaxies	Hα to UV SFRs



***f*?**

GOAL:

- Deriving the **attenuation** on the **Hα** emission line from **near-IR spectroscopy** and **multi-wavelength photometry**

SAMPLE:

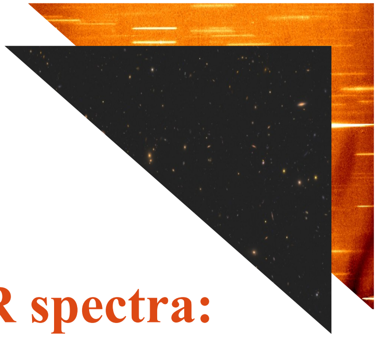
79 normal star forming galaxies
detected in the **GOODS-S field** in the **far-IR**
by the *Herschel* Space Telescope (PACS instrument).

$z \in [0.7\text{-}1.5]$

OUTLINE

- **Sample selection**
- **Spectral analysis**
- **Measure of the physical quantities of the sample**
- **Dust extinction corrections**
- **Results**

SAMPLE SELECTION



Far- IR selection:

PEP/*Herschel* survey (P.I. Lutz)
λ: 100, 160 μm
3σ limits: 1.2, 2.4 mJy
591 sources

IRAC coordinates
GOODS-MUSIC catalog
(Grazian+2006)

Near-IR spectra:

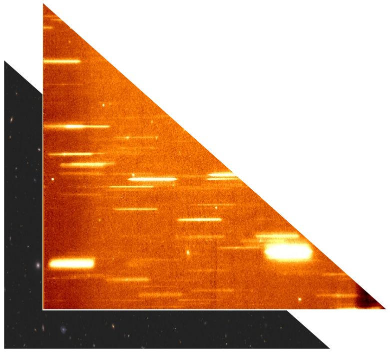
3D-HST survey (Brammer+2012)
WFC3/G141: λ ~ [1.1 – 1.65] μm
5σ line limit: 2.3×10^{-17} erg/s/cm^2
21005 sources

↓

378 PACS/3D-HST counterparts
144 with z_{MUSIC} **∈ [0.7-1.5]** (**Hα** emission)

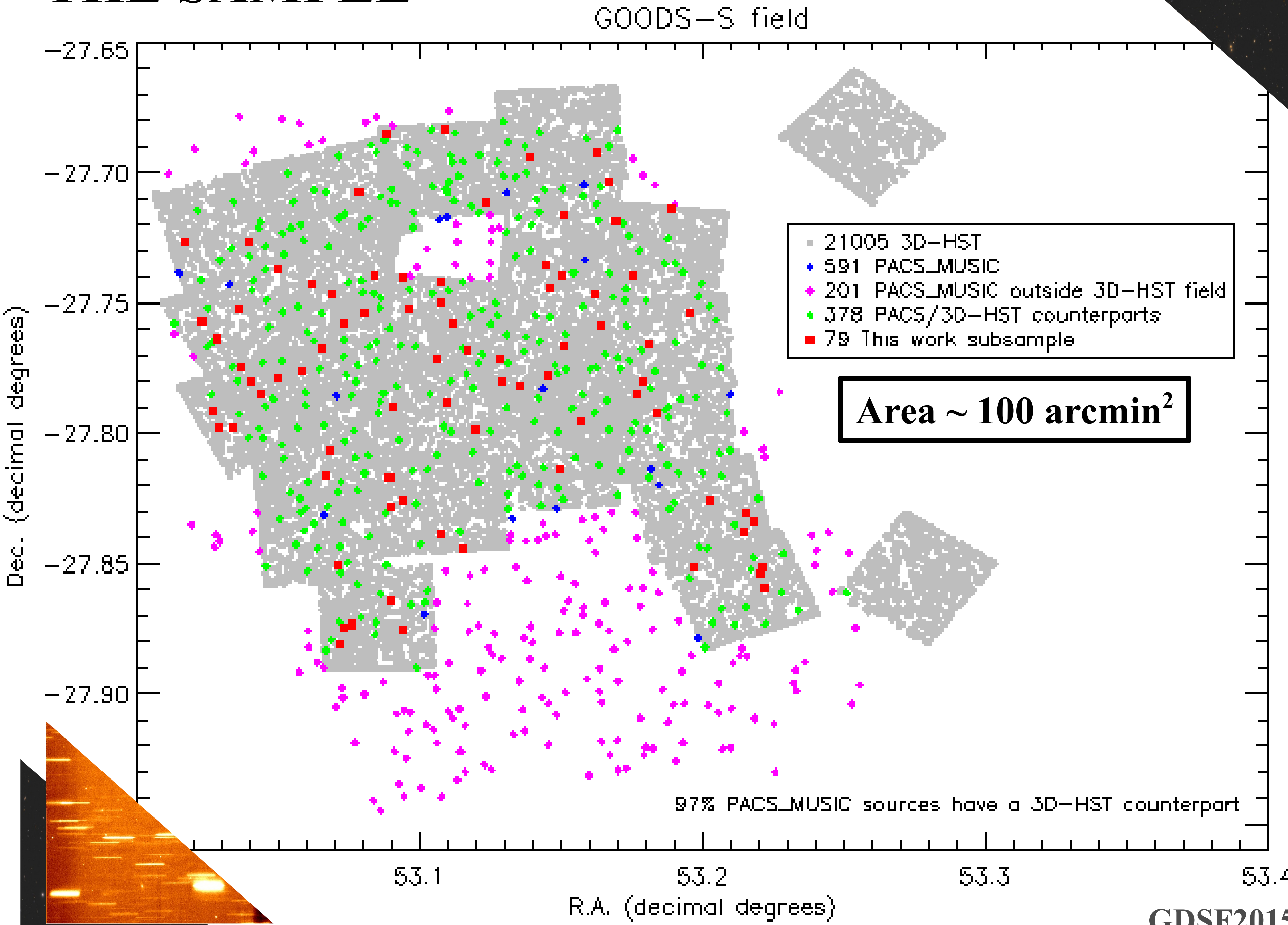
CLEANING
and
AGN EXCLUSION
(X-ray catalog Xue+2011)
$L_X \geqslant 3\times10^{42}\, erg/s$

↓

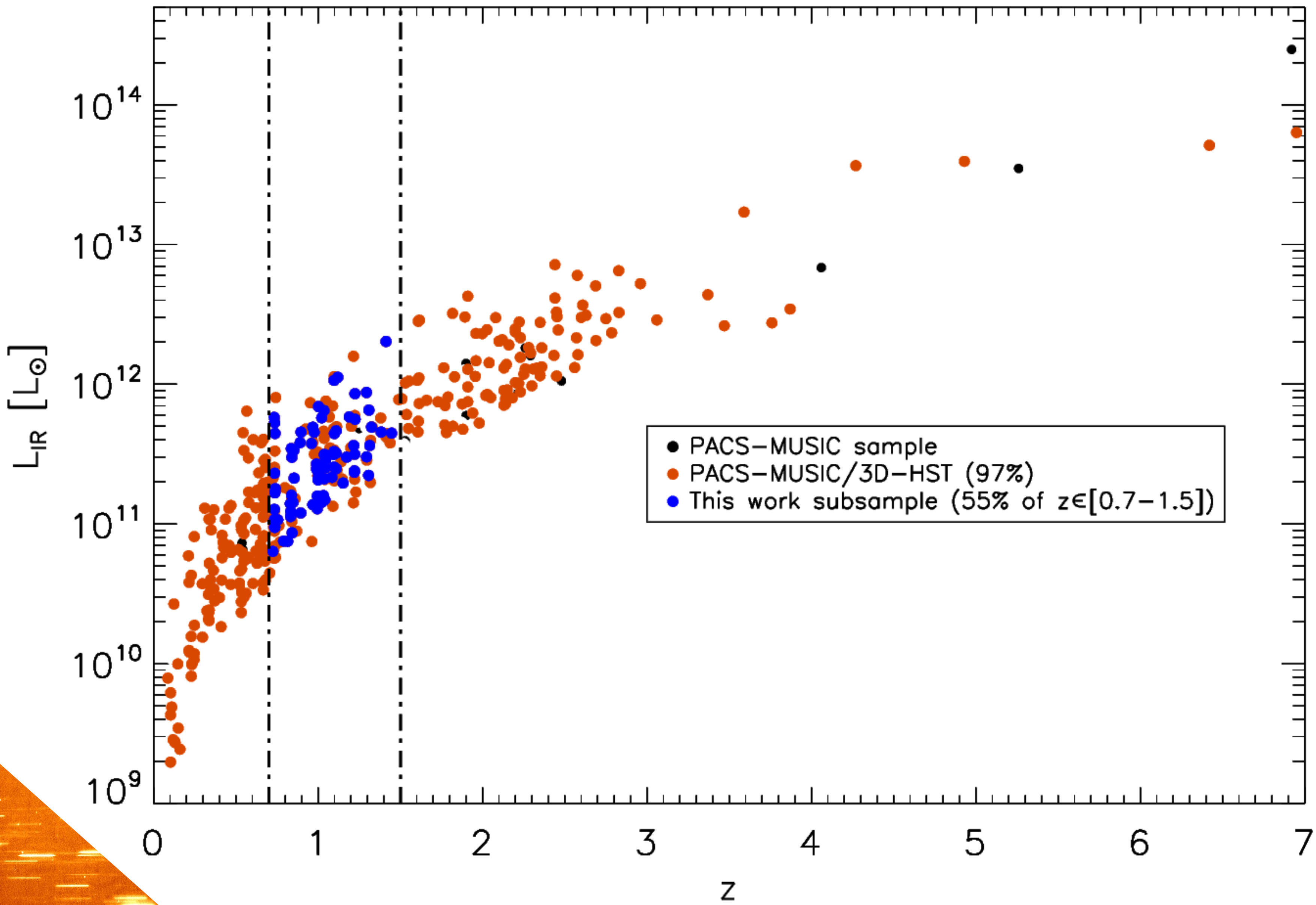


79 sources with ***Herschel*/PACS detection**
and strong **Hα emission line**

THE SAMPLE


GOODS-S field
-27.65
-27.70
-27.75
-27.80
-27.85
-27.90
Dec. (decimal degrees)
53.1
53.2
53.3
53.4
R.A. (decimal degrees)
21005 3D-HST
591 PACS_MUSIC
201 PACS_MUSIC outside 3D-HST field
378 PACS/3D-HST counterparts
79 This work subsample
Area ~ 100 arcmin²
97% PACS_MUSIC sources have a 3D-HST counterpart

THE SAMPLE

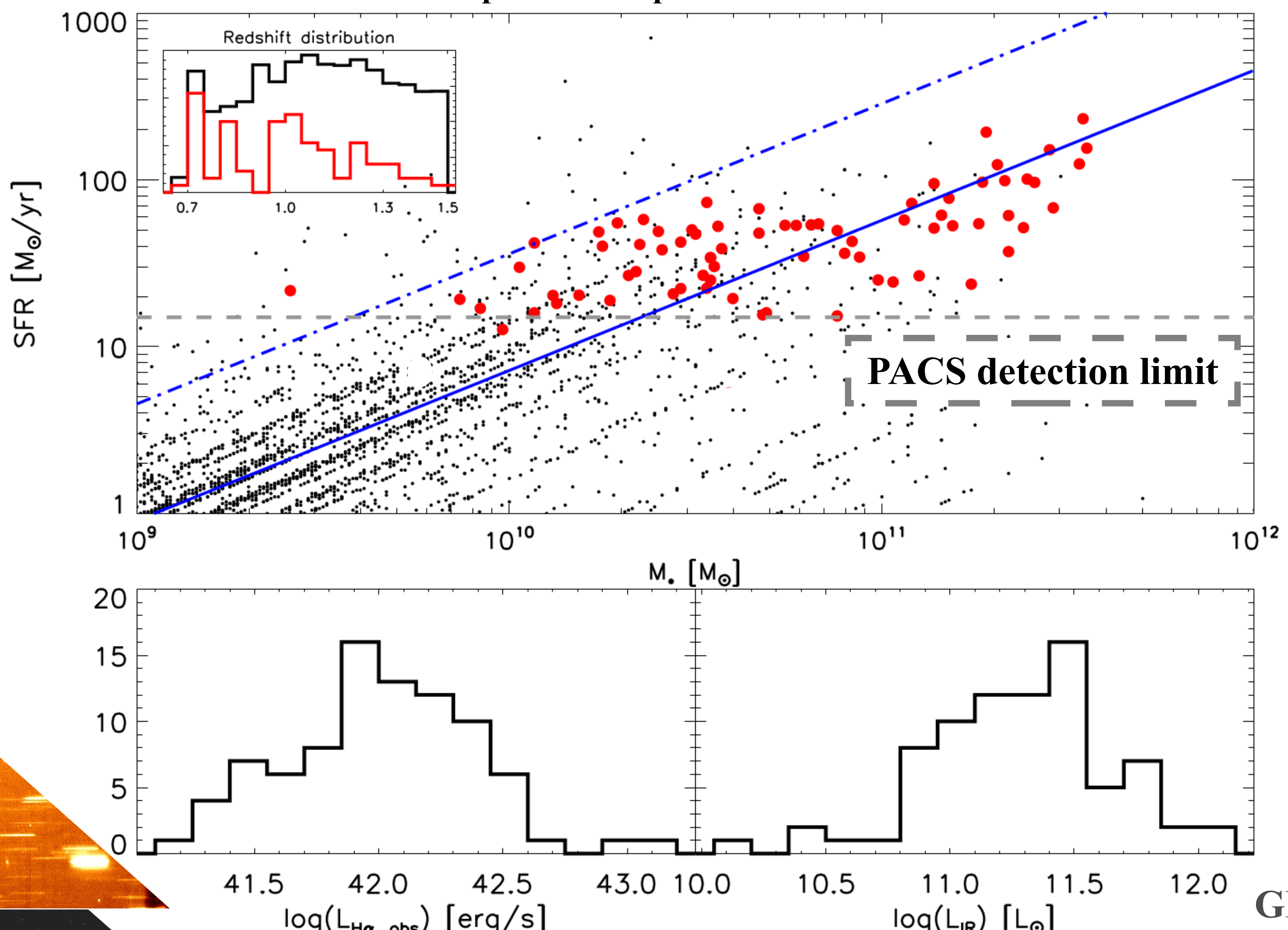


L_{IR} [$L_\odot$]
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
1
2
3
4
5
6
7
z
PACS−MUSIC sample
PACS−MUSIC/3D−HST (97%)
This work subsample (55% of z∈[0.7−1.5])

THE SAMPLE

$z \in [0.7 - 1.5] \quad L_{IR} \geqslant 1.2\,x\,10^{10}\,L_{\odot} \quad L_{H\alpha,obs} \geqslant 1.4\,x\,10^{41}\,[erg/s]$

Comparison sample from Skelton+2014

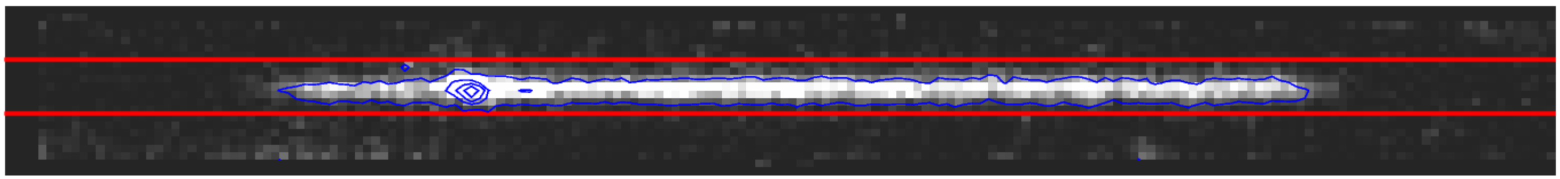


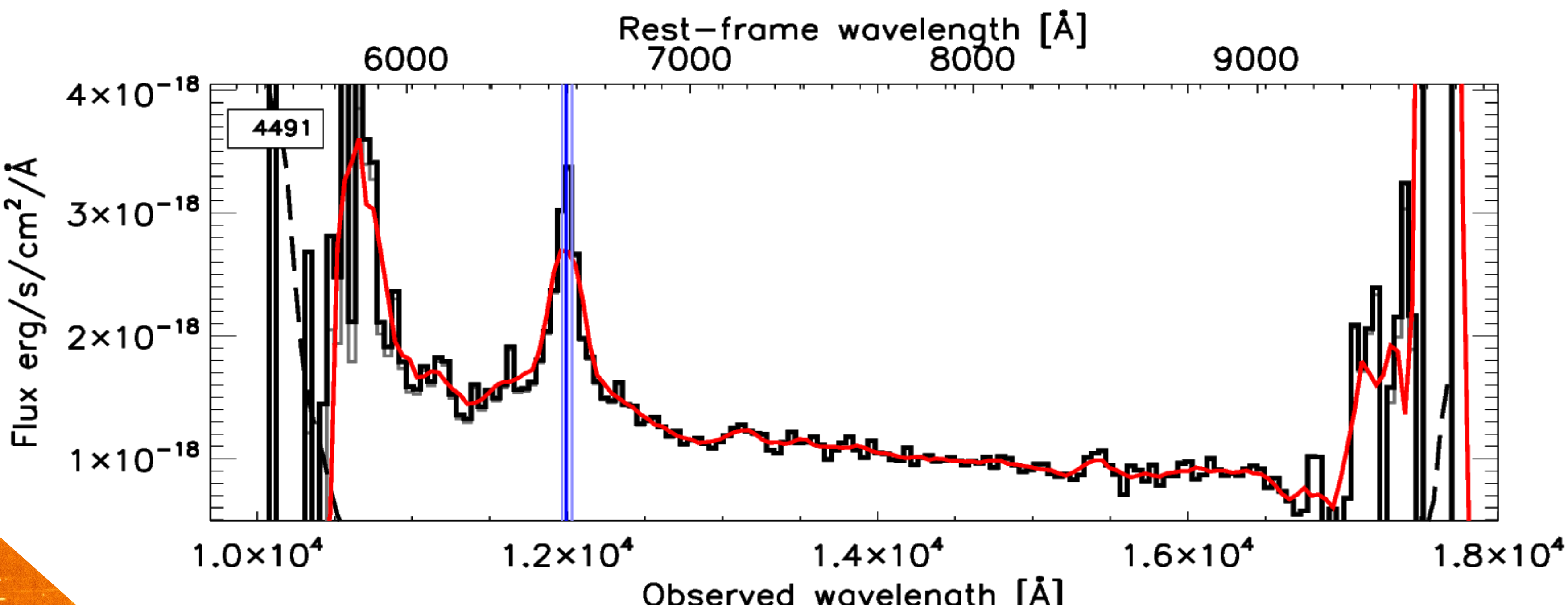
MS @ $z \sim 1$
Elbaz+2007

SPECTRAL ANALYSIS

- **Hα fluxes**
- **Redshifts**

Extraction window



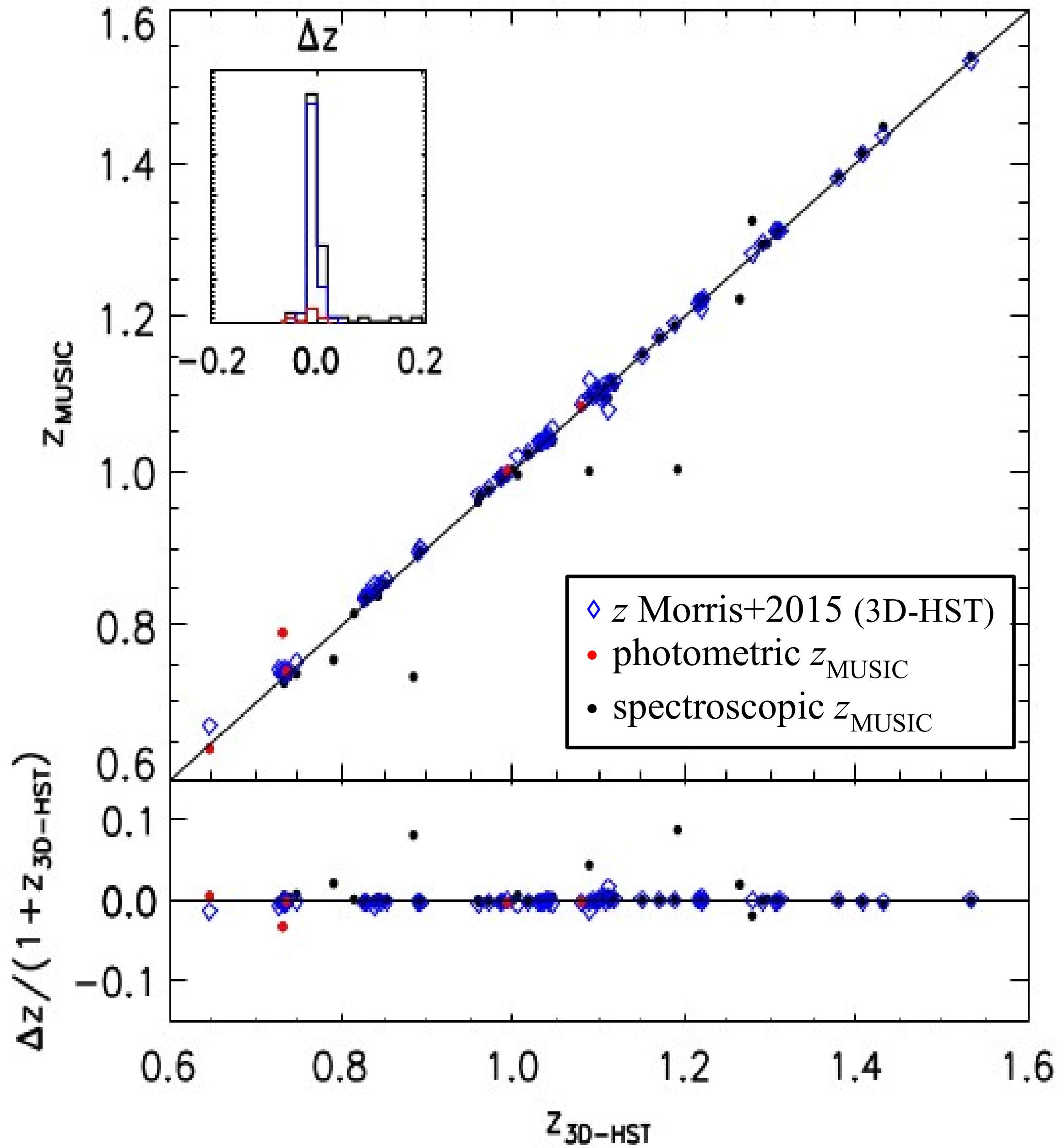


R ~ 130

- **[NII] contamination:** observed flux/**1.2** (Wuyts+2013)
- **Aperture correction:** scaling the continuum to the SED continuum

SPECTRAL ANALYSIS

Redshift correlation

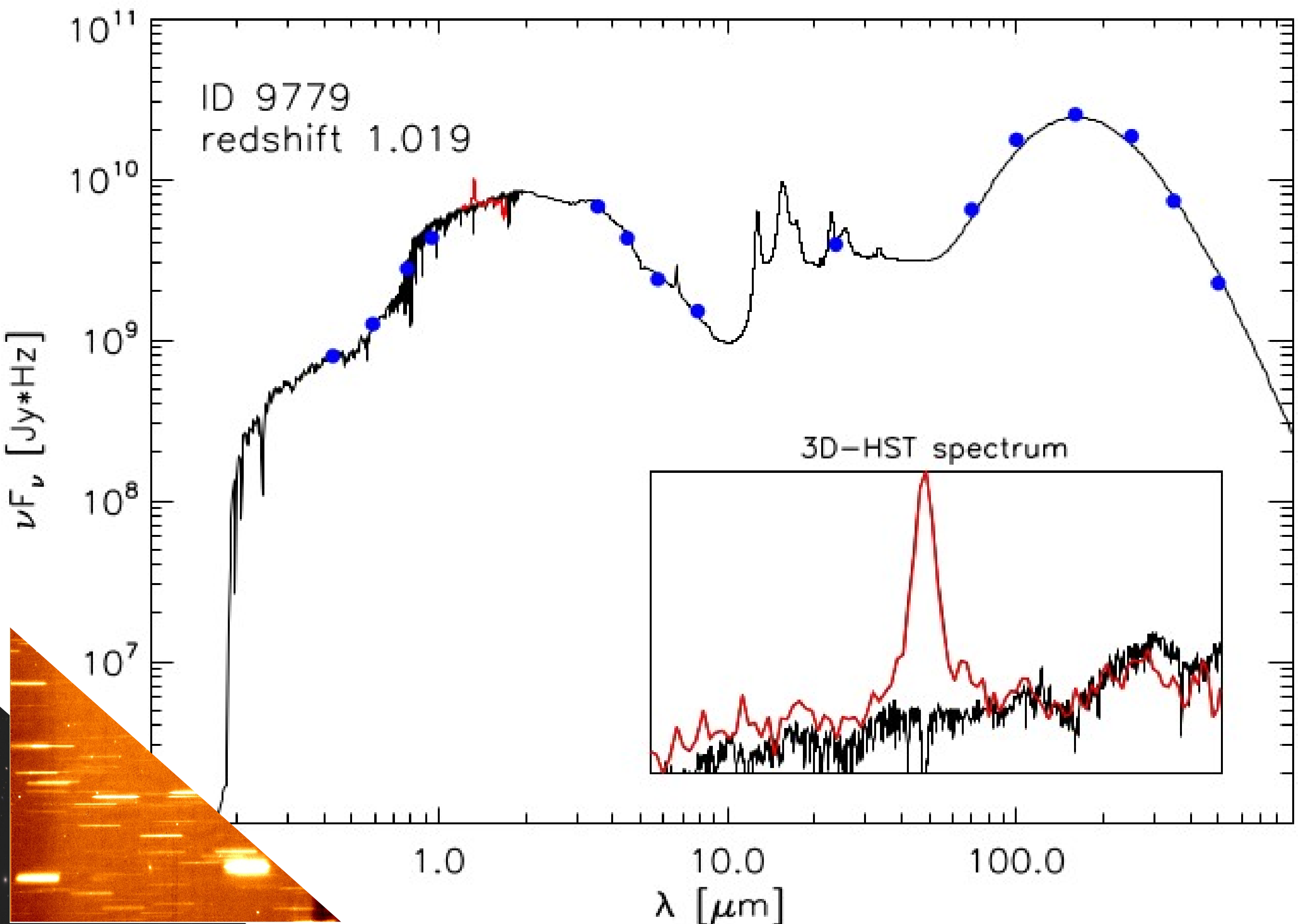


SED FITTING

(MAGPHYS, da Cunha+2008)

Bruzual&Charlot (2003) SPS, $z_{\text{3D-HST}}$, 21 bands

- **β**
- **M_*, L_{IR}, L_{UV}**



Filter	λ_{eff} [μm]
GALEX_NUV	0.2310
U	0.346
ACSF435W	0.4297
ACSF606W	0.5907
ACSF775W	0.7774
ACSF850LP	0.9445
ISAACJ	1.2
ISAACH	1.6
ISAACK	2.2
IRAC1	3.55
IRAC2	4.493
IRAC3	5.731
IRAC4	7.872
IRS16	16
MIPS24	23.68
PACS70	70
PACS100	100.
PACS160	160
SPIRE250*	250
SPIRE350*	350
SPIRE500*	500

* from HerMes consortium (Oliver+2012)

Measuring the SFRs

$$SFR_{H\alpha}[M_{\odot}/yr] = 7.9\,x\,10^{-42}\,L_{H\alpha}[erg/s]$$

$$SFR_{UV}[M_{\odot}/yr] = 1.4\,x\,10^{-28}\,L_{1600}[erg/s]$$

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

(Kennicutt, 1998)

"Total" SFR:

$$SFR_{IR+UV}[M_{\odot}/yr] = [1.7\,L_{IR} + 2.8\,L_{1600}]\,x\,10^{-10}\,[L_{\odot}]$$

(Kennicutt, 1998)

Dust extinction: continuum attenuation

$$A_{1600\,\mathring{A}} = 4.43 + 1.99\beta$$

Meurer+1999

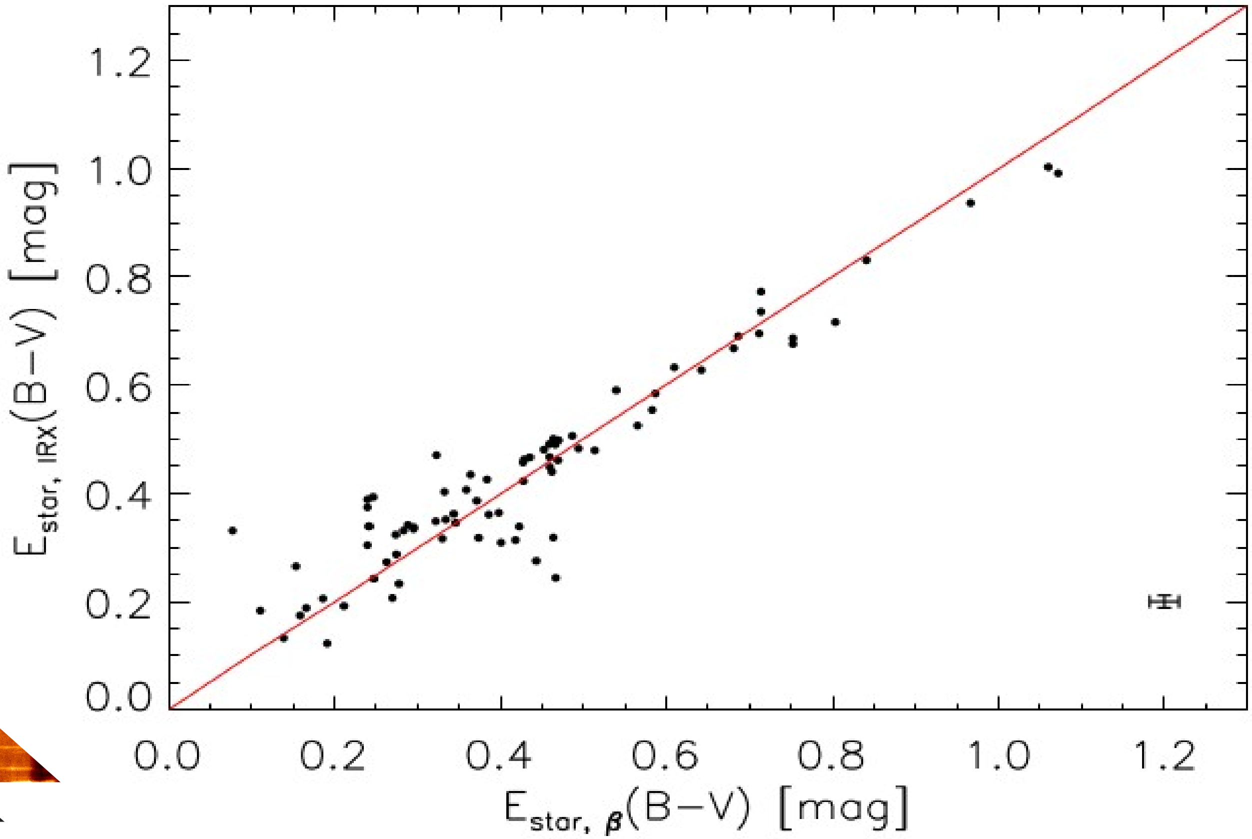
$$A_{IRX} = 2.5\log\left[1 + \frac{SFR_{IR}}{SFR_{UV}}\right]$$

e.g. Nordon+2012

$k(\lambda)$ Calzetti+2000

$$E_{star,\beta}(B-V)$$

$$E_{star,IRX}(B-V)$$



Dust extinction: *f*-factor

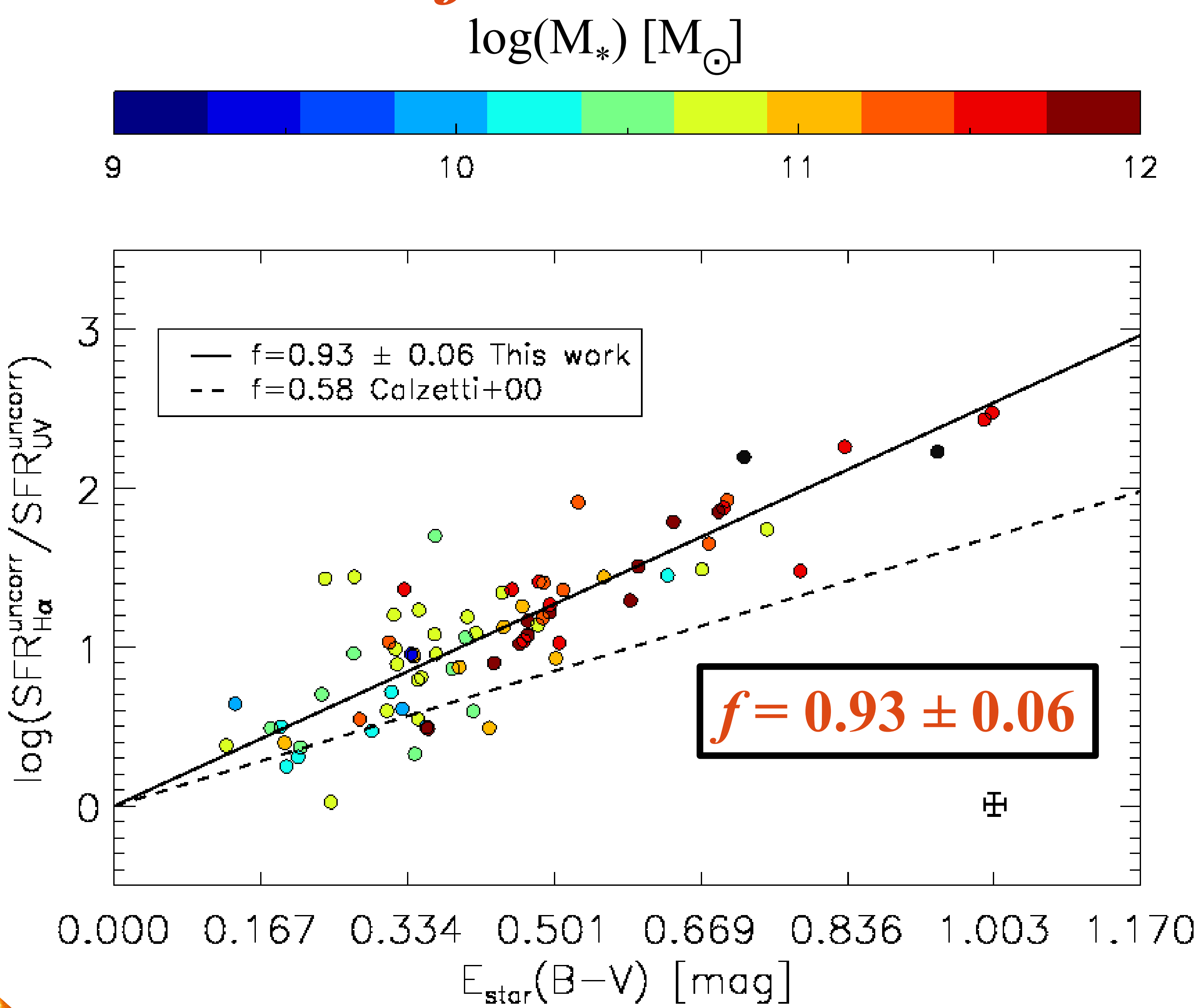
f **from Hα to UV SFR indicators:**

$$\frac{SFR_{H\alpha,uncorr}}{SFR_{UV,uncorr}} = \frac{10^{-0.4A_{H\alpha}} \times SFR_{tot}}{10^{-0.4A_{UV}} \times SFR_{tot}}$$

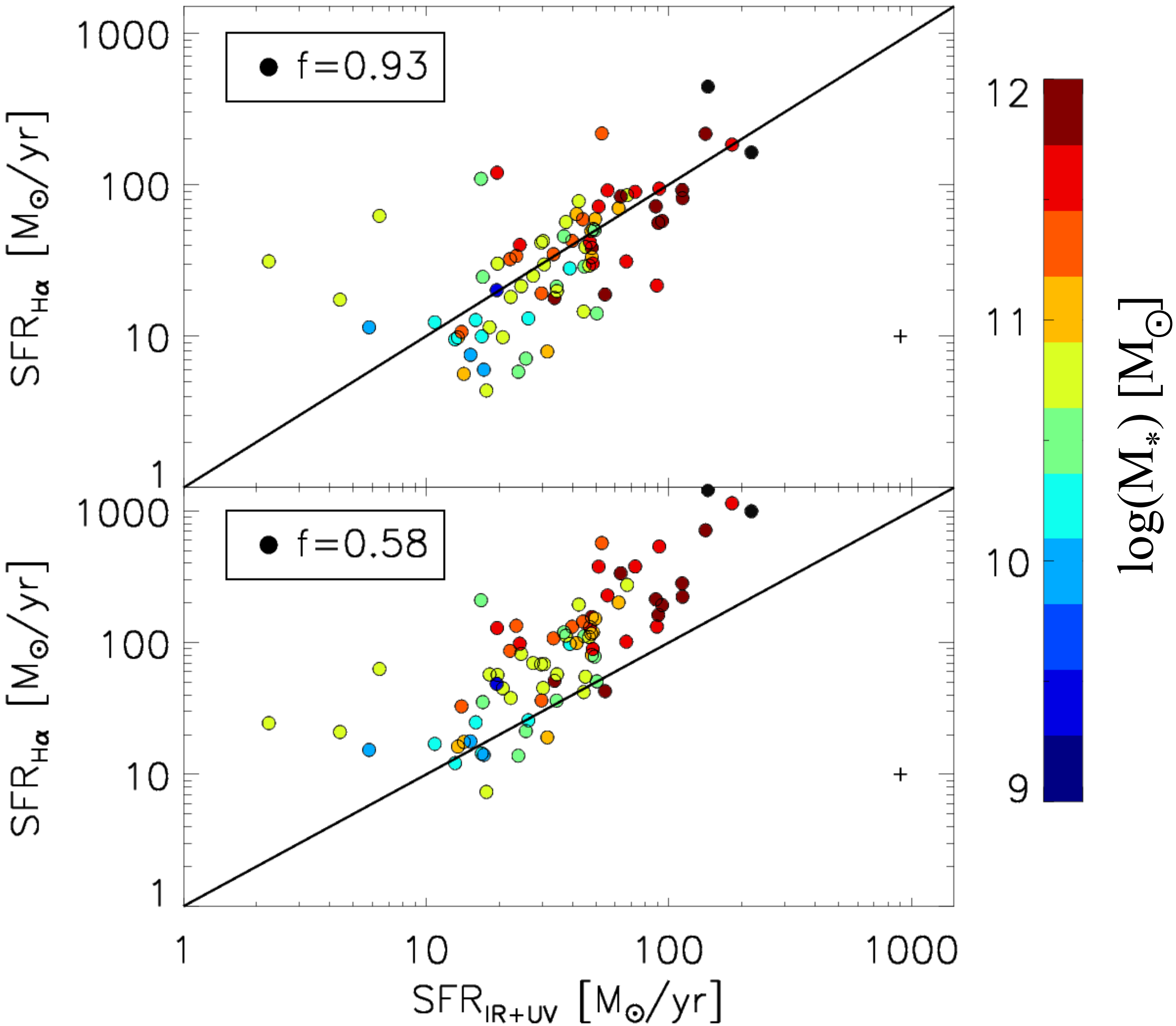
$$log[\frac{SFR_{H\alpha,uncorr}}{SFR_{UV,uncorr}}] = -0.4[\frac{k(H\alpha)}{f} - k(UV)] \times E_{star}(B-V)$$

$$f = E_{star}(B-V) / E_{neb}(B-V)$$

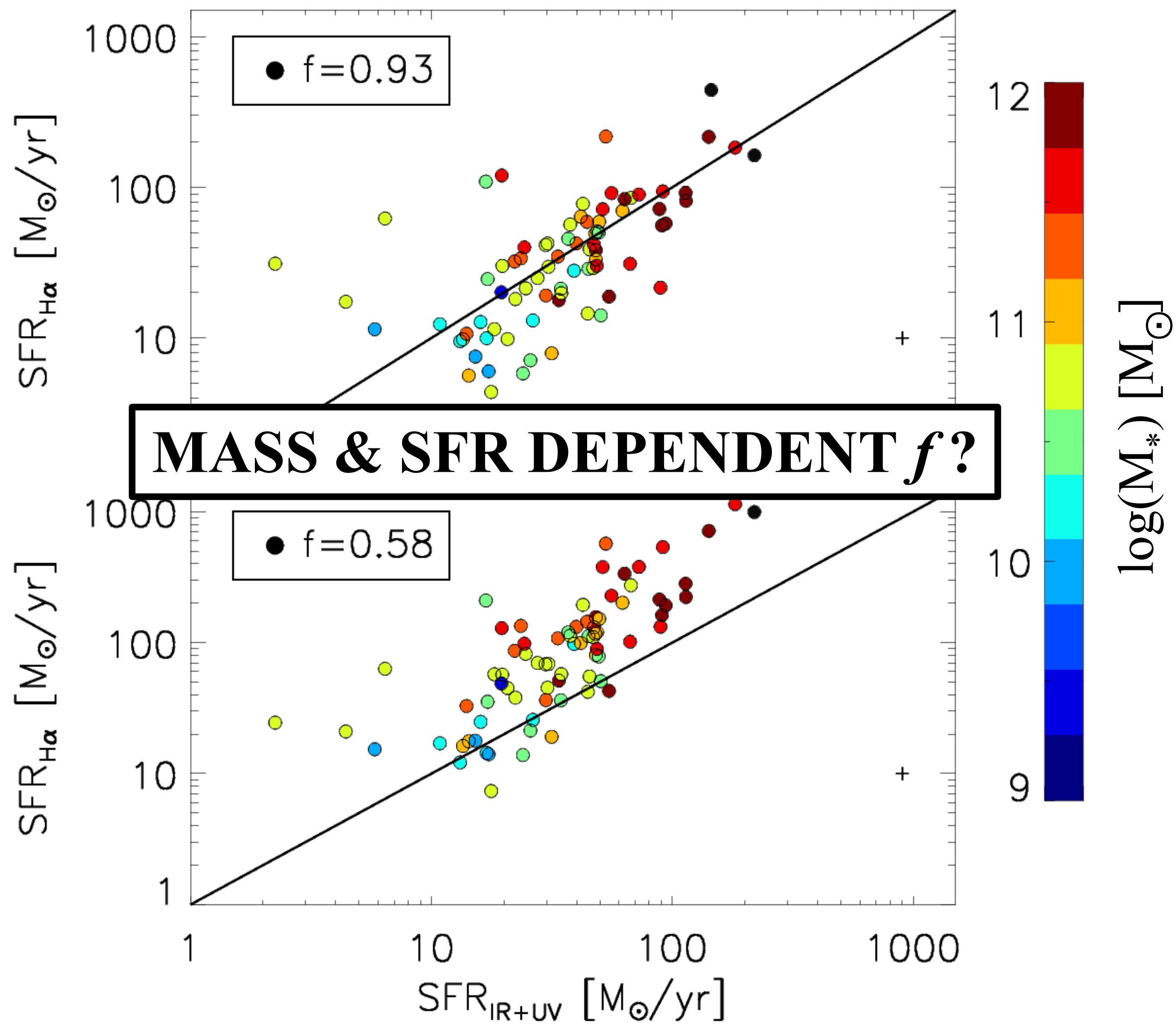
Dust extinction: *f*-factor



Dust extinction: the "BEST" *f*-factor

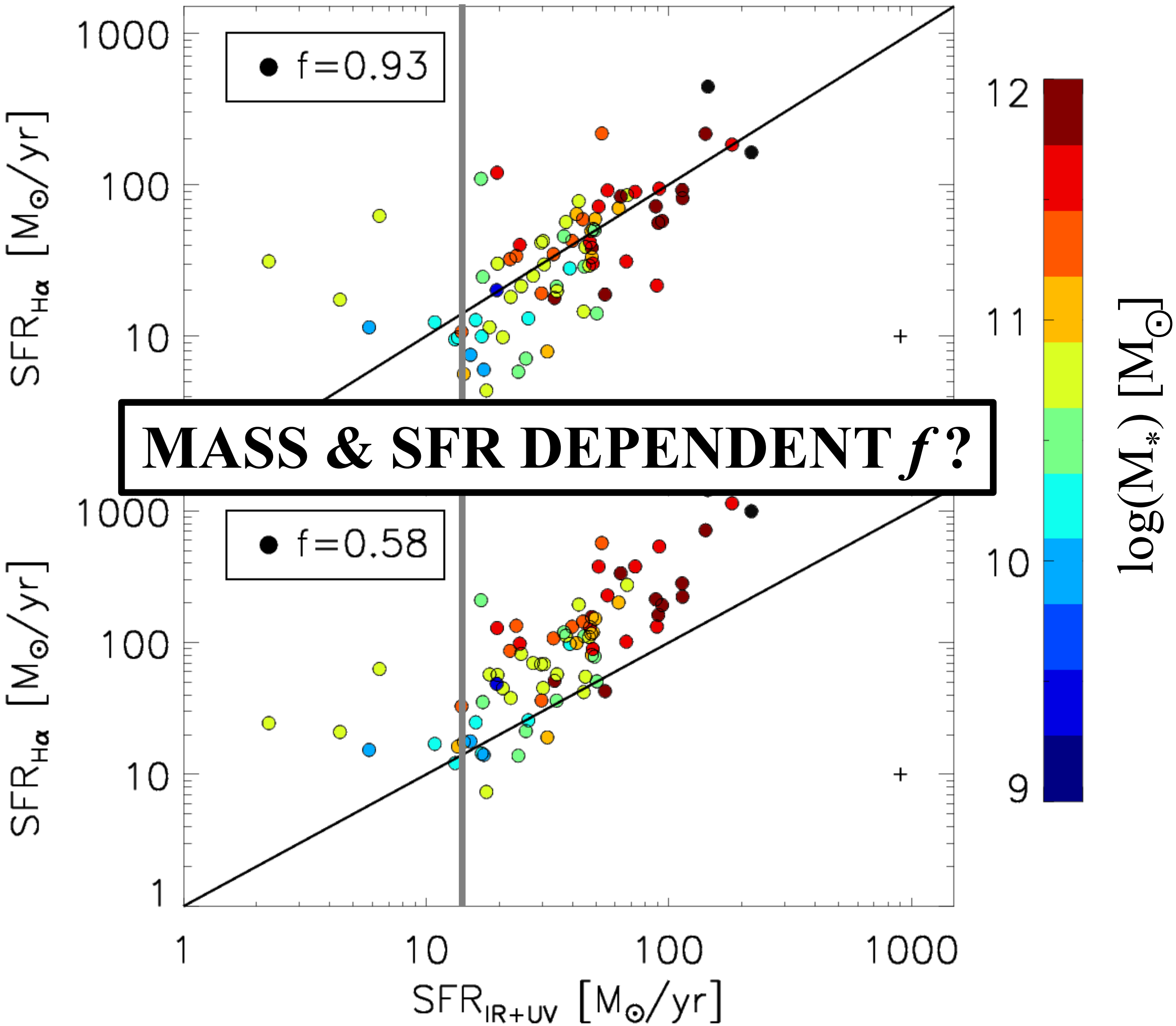


Dust extinction: the "BEST" *f*-factor



MASS & SFR DEPENDENT *f* ?

Dust extinction: the "BEST" *f*-factor



MASS & SFR DEPENDENT *f* ?

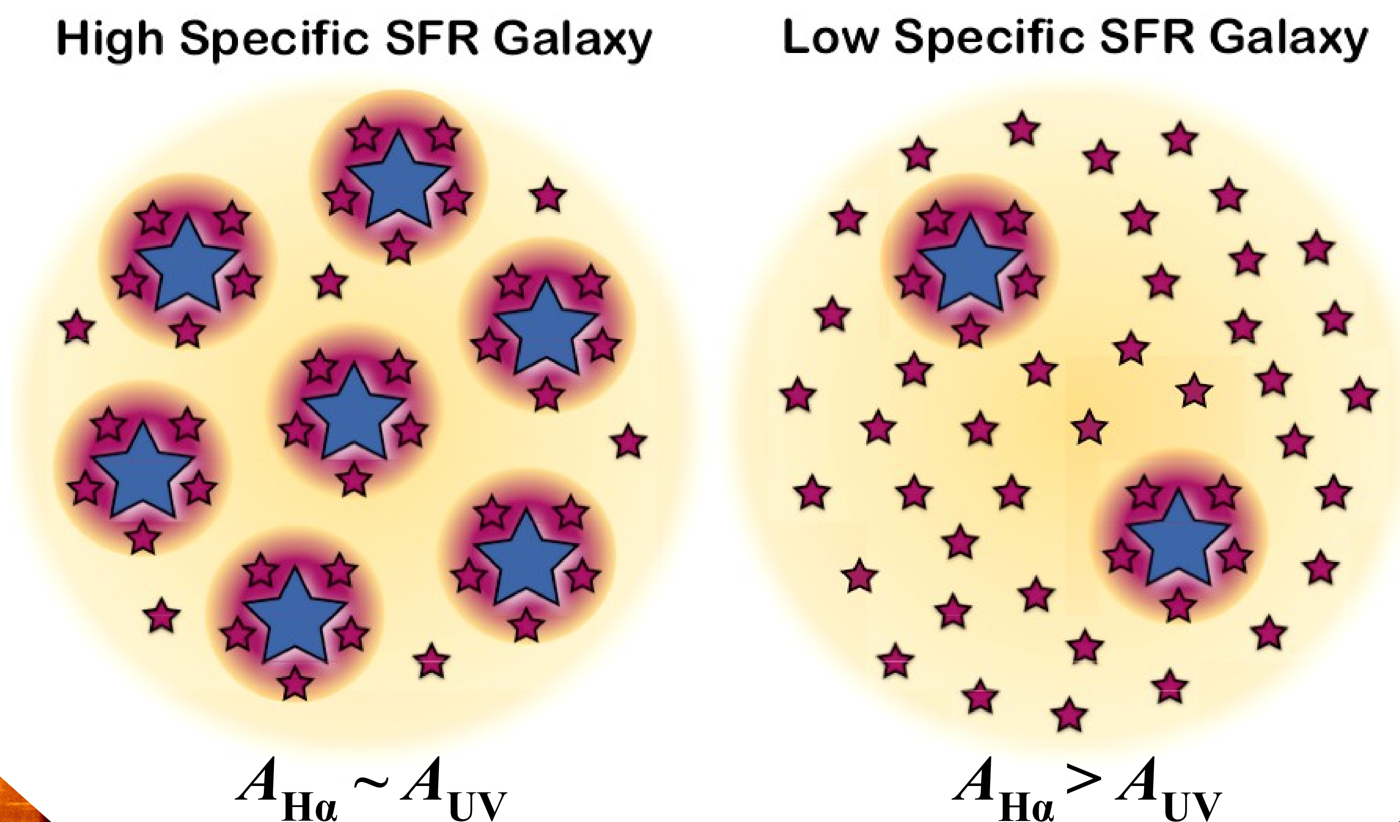
Selection bias for **SFR_{IR+UV} < 16 $M_\odot$/yr**

- 3σ flux limit at 160 μm for a MS galaxy at z ~ 1 (Magdis+2012)

FINAL RESULTS

- $f = 0.93 \pm 0.06 \rightarrow A_{H\alpha} \sim A_{UV}$
- $f = f(M_*, SFR)$ **?** (Reddy+2015, Pannella+2014, Price+2014, Wuyts+13, Reddy+2010...)

- **FUTURE PROSPECTS:** investigate the dependences of the *f*-factor using FMOS high quality spectroscopy (FMOS "Intensive Program" S12B-045, PI J. Silverman)



(Figure from **Price+2014**)

FINAL RESULTS

- $f = 0.93 \pm 0.06 \rightarrow A_{H\alpha} \sim A_{UV}$
- $f = f(M_*, SFR)$ **?** (Reddy+2015, Pannella+2014, Price+2014, Wuyts+13, Reddy+2010...)

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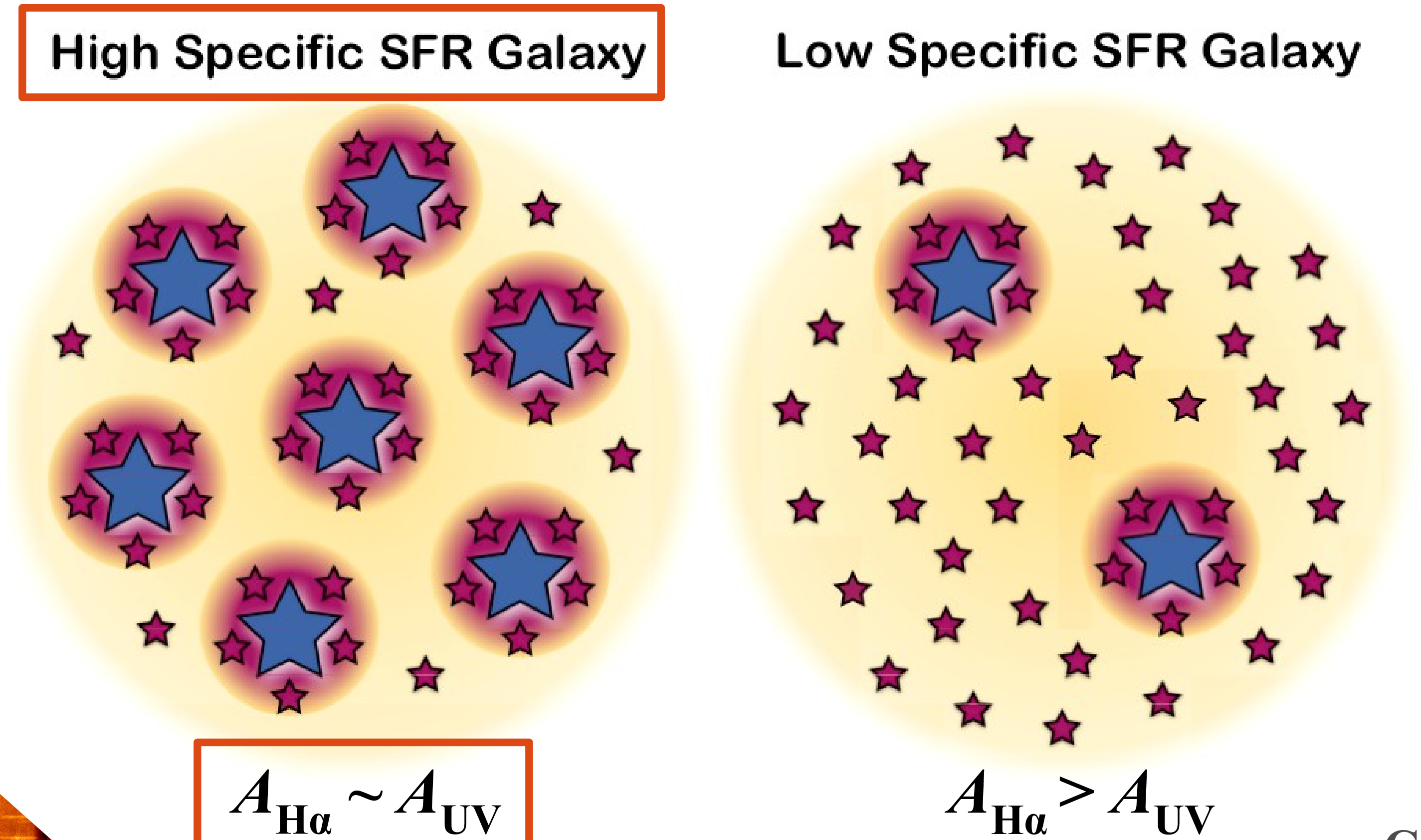
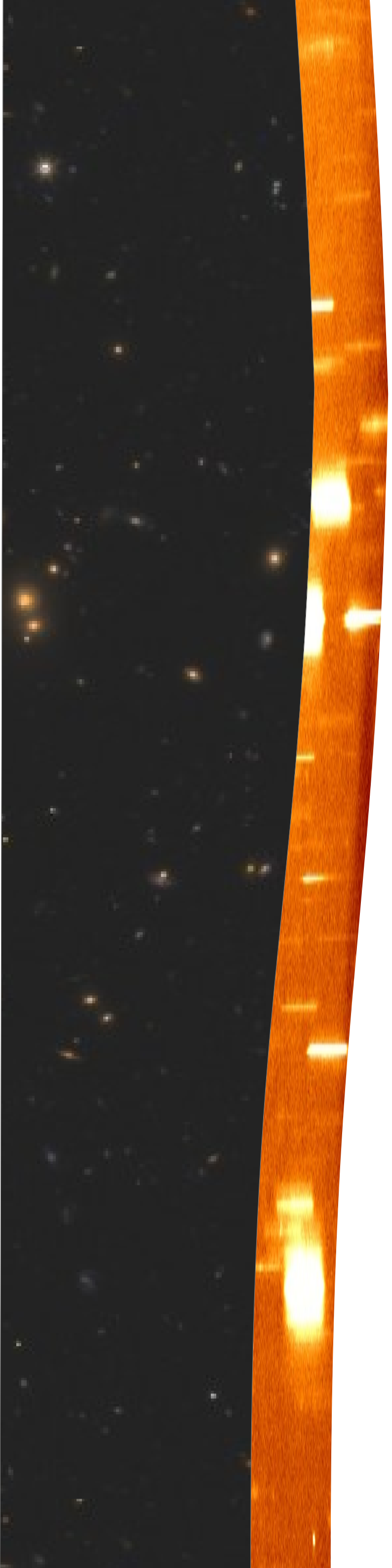


(Figure from **Price+2014**)



SUMMARY

THE SAMPLE

79 sources

Far-IR selection (**$L_{IR} > 1.38 \times 10^{10}\ L_{\odot}$**)

strong emission lines (**Hα >1.4×10^{41} erg/s**)

$0.7 < z < 1.5$

WHAT WE DID:

Spectral Analysis:

- Redshifts
- Hα fluxes

SED fitting:

- L_{IR}, L_{UV}, M_*

SFRs:

- Hα, UV, IR, IR+UV

Continuum dust attenuation:

- $E_{star,IRX}$(B-V) from IRX ratio
- $E_{star,\beta}$(B-V) from β slope

Differential extinction from Hα to UV SFR indicators

- *f*-factor as a function of E_{star}(B-V)

Test of the dust correction by comparing $SFR_{H\alpha}$ and SFR_{IR+UV}

WHAT WE FOUND: → **$f = 0.93 \pm 0.06$**