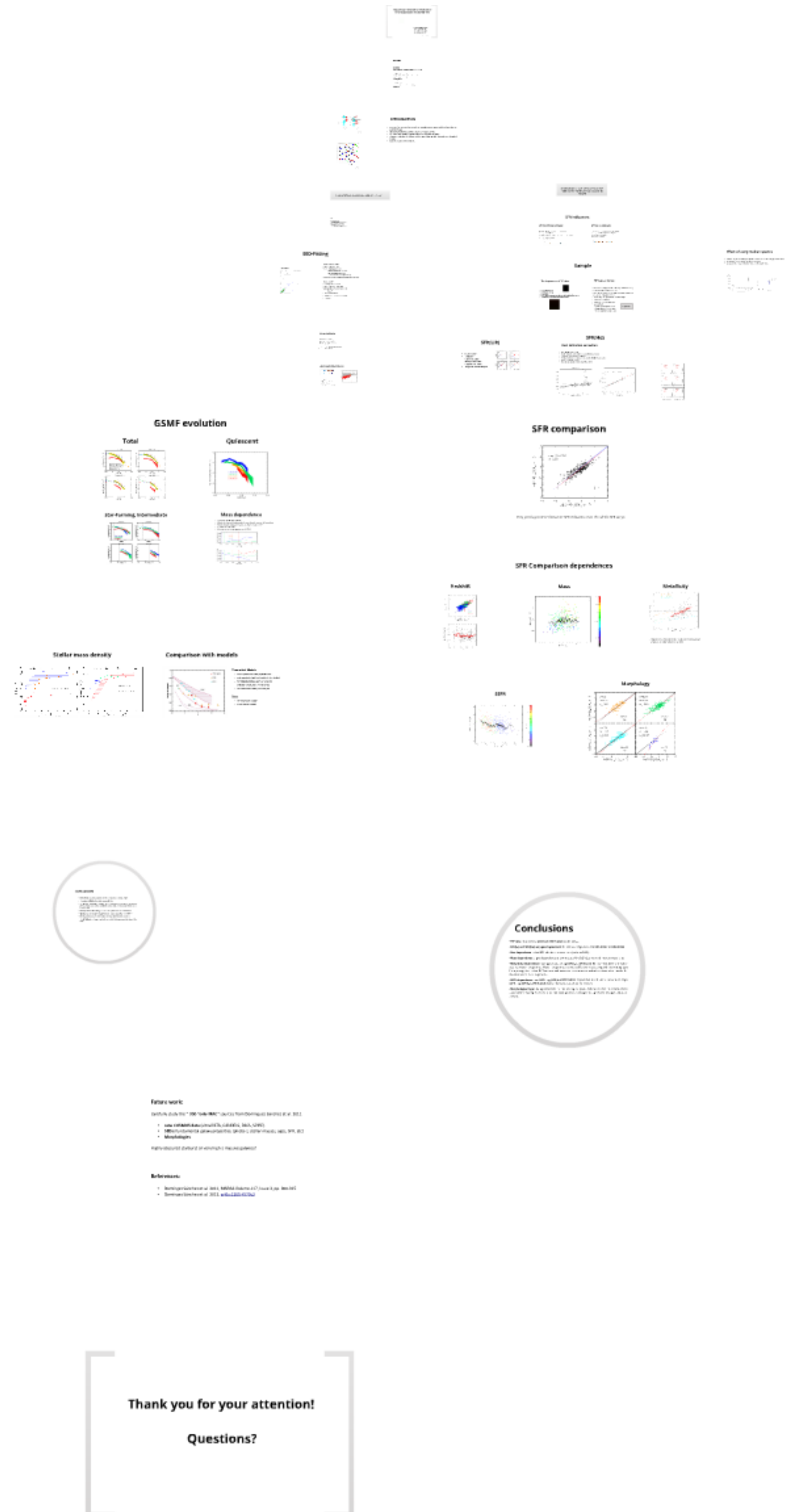

GSMF evolution
Total
Quiescent
Star-Forming, Intermediate
Mass dependence
SFR comparison
SFR Comparison dependences
Redshift
Mass
Metallicity
SSFR
Morphology
Stellar mass density
Comparison with models
Conclusions
Future work:
References:
Thank you for your attention!
Questions?

Mass and star formation rate evolution of infrared galaxies in the COSMOS field

Helena Domínguez Sánchez

Prof. Andrea Cimatti
Dra. Carlotta Gruppioni
Dra. Francesca Pozzi

ESAC, Madrid,19/07/2012

OUTLINE

- **Introduction**
- **Galaxy Stellar Mass Function Evolution (1.4 < *z* < 3.0)**

  -Sample

  -SED-fitting: photo-z, mass, SFR, etc

  -Galaxy Classification: star-forming, intermediate, quiescent

  -GSMF evolution & comparison with models
- **SFR comparison**

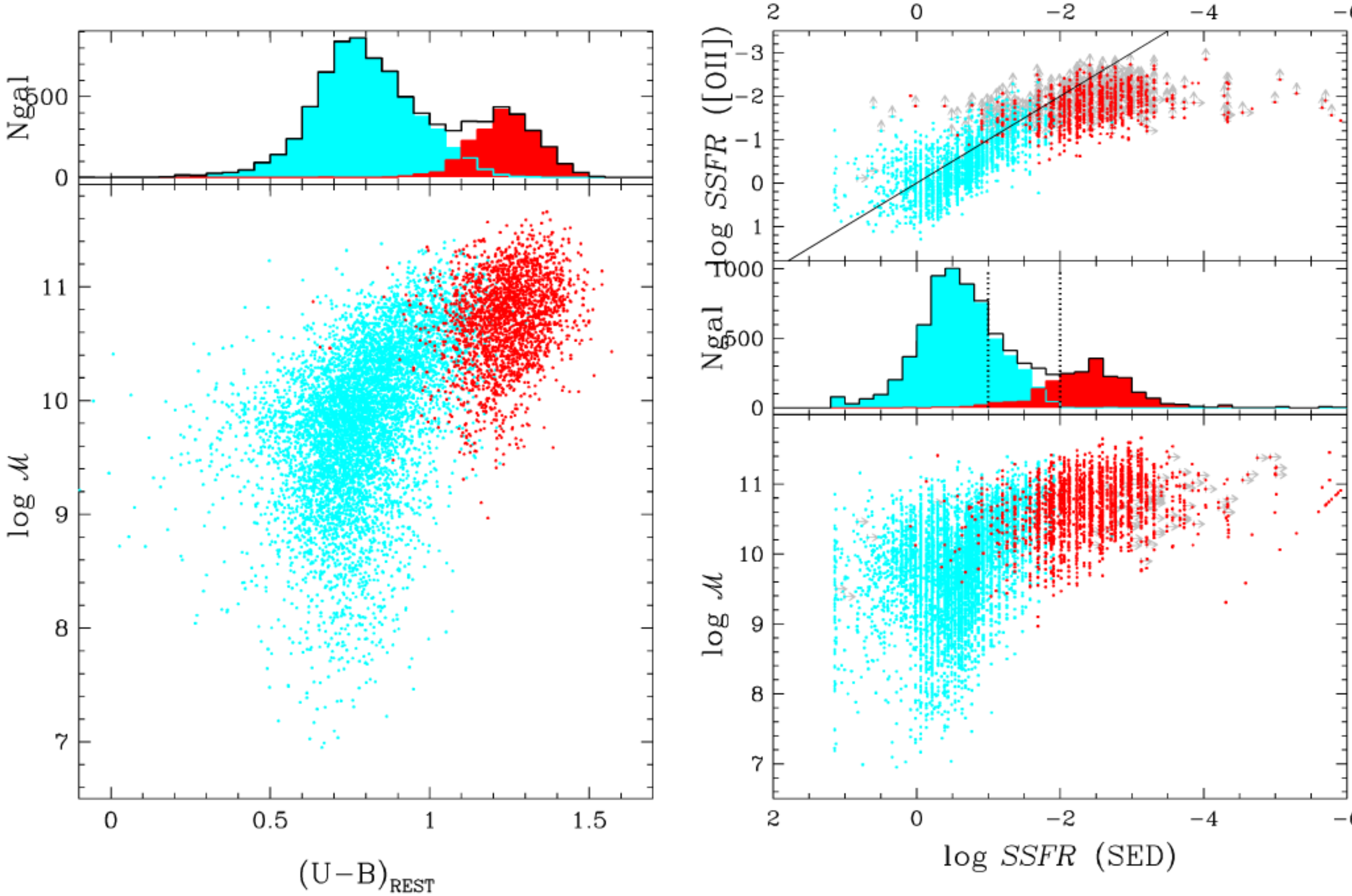
  -Sample

  -SFR(Hα) & SFR(LIR)

  -SFR comparison & dependences (z, mass, metallicity...)
- **Conclusions**

INTRODUCTION

- Mass and SFR are two fundamental and complementary aspects of galaxy formation and evolution theory.
- Bimodality of observed galaxies: Early and Late Type Galaxies.
- ETGs formation theories: Monolitc collapse vs Hierarchical merging.
- Observed evolution of different galaxy types helps putting constrains on theoretical models.
- Need of an accurate SFR estimate.



Pozzetti et al. (2010)

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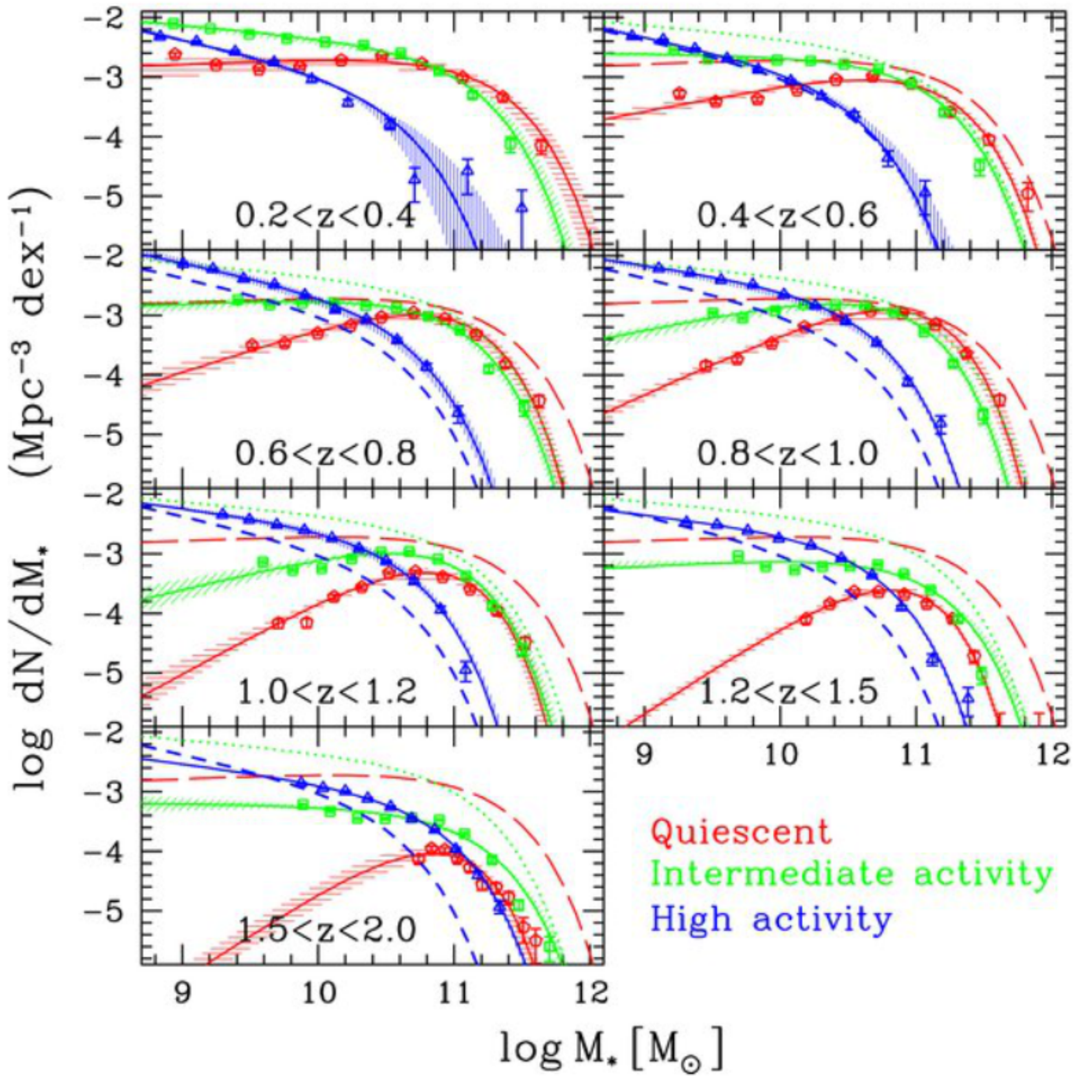

Ilbert et al. (2010)

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1. GSMF of infrared selected galaxies at high z (1.4 < z < 3.0)

Sample

- **IRAC selected** ($mag_{3.6}$ < 22 mag, 95% complete)
- **COSMOS** field: multiwavelength coverage, 2deg ^{2}
- **Multiwavelength catalog** with **Likelihood Ratio Technique** (Sutherland & Sanders 1992)

-**IRAC** (3.6,4.5,5.8,8.0 µm, Sanders et al. 2007): **78649**; 353 **only IRAC (0.5 %)**

-**MIPS** 24 µm (mag_{lim} =18.5 mag, Le Floc' h et al. 2009): 11352 sources; **14%**

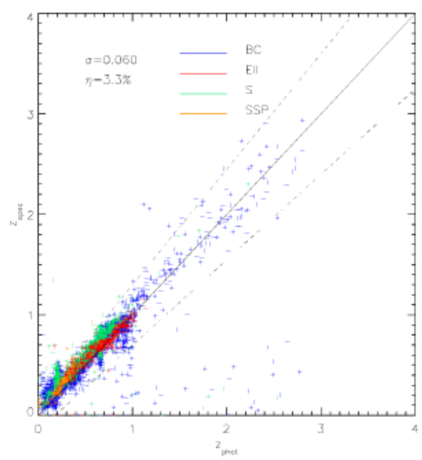
-**Optical** (i < 26.5 mag; u^*, B_J, g^+, v_J, r^+, i^+, z^+, J, K; Capak et al. 2007): 74742 sources; **95%**

-**K_s** : (B_J, i^+, z^+ , J ; 23 mag, McCracken et al. 2010): 3554 sources; **4.5%**

SED-Fitting

z-phot accuracy

- **Comparison with 8176** sources with high confidence **z-spec** (zflags 3.1, 3.5, 4.1, 4.5).
- Accuracy: $\sigma_{\Delta z/(1+z)}$**=0.06**
- Catastrophic errors: **η=3.3 %**



Photometric redshifts

- LePhare code (Ilbert et al. 2006)
- COSMOS SED library (Ilbert et al. 2009)
  - -**Ellipticals & Spirals** (Polletta et al. 2007)
  - -**Blue galaxies** (Bruzual&Charlot 2003)
  - -We also included **SSP** 0.05-3 Gyr (Maraston 2005)
- **Extinction Laws: Calzetti et al. (2000), Calzetti modified, Prevot et al. (1984)**

Mass and SFR

- ~ 20,000 high-z sources: **1.4 <z <3.0**
- LePhare code (Ilbert et al. 2006): **U-5.8μm**
- **Maraston (2005)** models: better treatment TP-AGB

  $SFR \propto e^{-t/\tau}$

- Solar metallicity, Chabrier IMF
- 9 values τ (0.1, 0.3, 1.0, 2.0, 3.0, 5.0, 10.0, 30.0 Gyr)
- 221 steps in age

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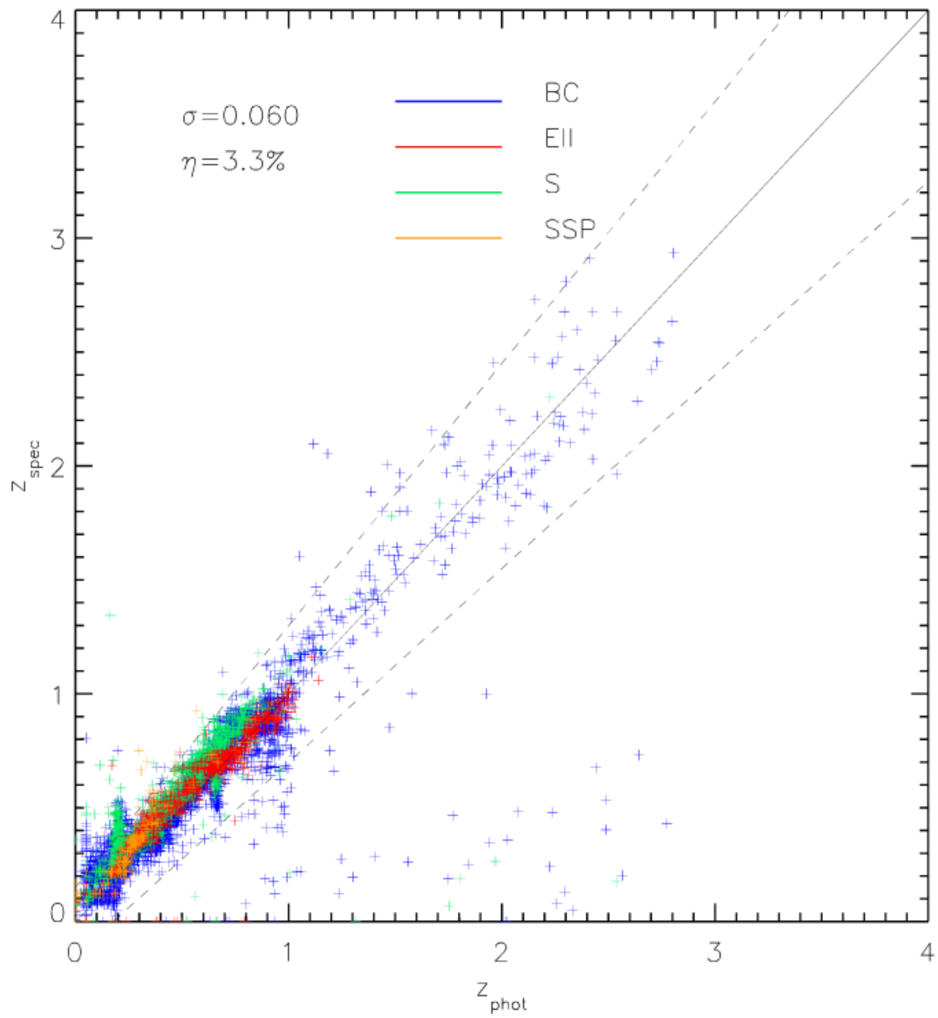

Prezi

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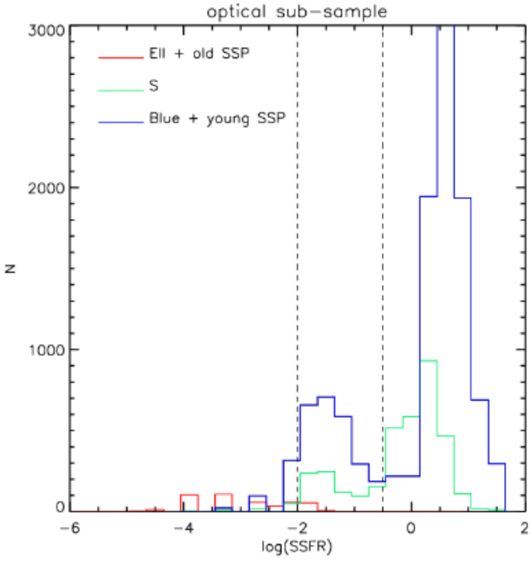
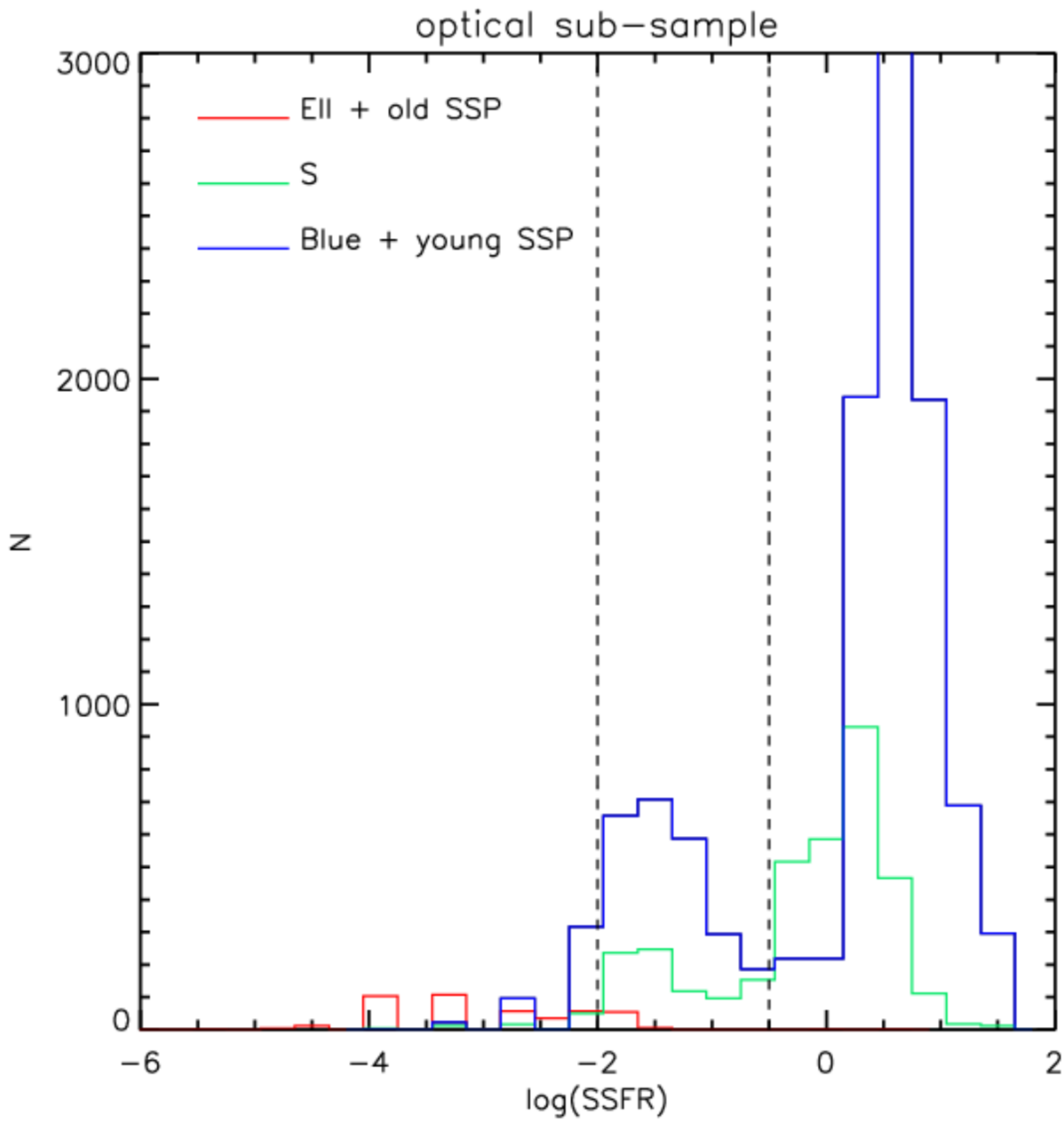
Galaxy Classification



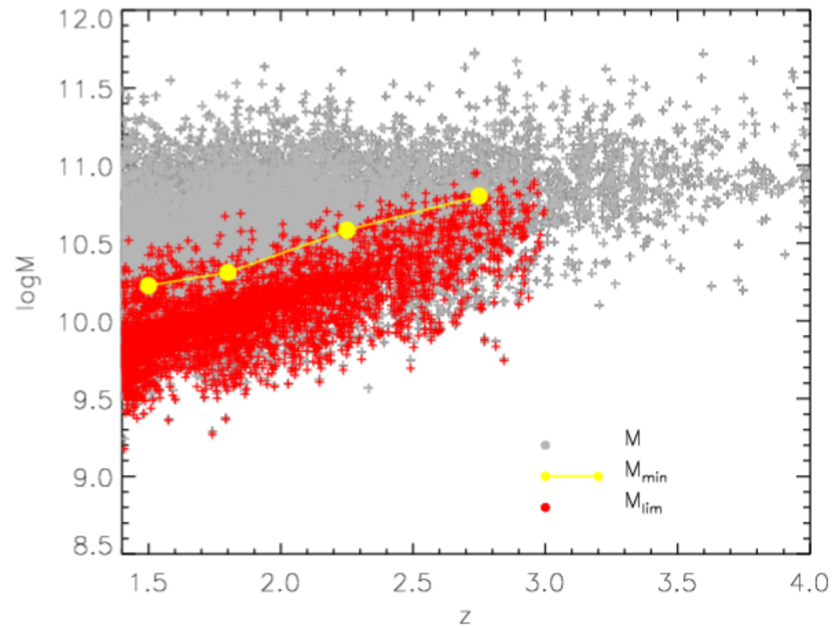
- **Star-forming:** log(SSFR[Gyr^{-1}]) > -0.5
- **Intermediate:** -2.0 < log(SSFR[Gyr^{-1}]) < -0.5
- **Quiescent:** log(SSFR[Gyr^{-1}]) < -2.0 (no MIPS)

Similar classification as in **Pozzetti et al. (2010), Ilbert et al. (2010).**
In agreement with BzK (**Daddi et al. 2004**)


optical sub−sample
Ell + old SSP
S
Blue + young SSP
3000
2000
1000
0
N
−6
−4
−2
0
2
log(SSFR)
Prezi

Galaxy Stellar Mass Function

z	all	quiescent	intermediate	star-forming	MIPS
1.4-1.6	5142	515	1325	3302	261
1.6-2.0	6303	512	1445	4346	1286
2.0-2.5	4693	287	914	3492	1178
2.5-3.0	1794	77	415	1302	272



- 1/Vmax Method
- Mass limit (Pozzetti et al. 2010)
- Errors:

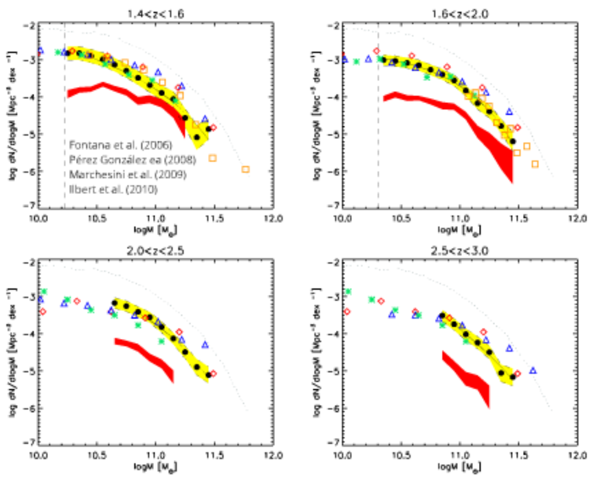
  -Poissonian errors

  -Montecarlo Simulations

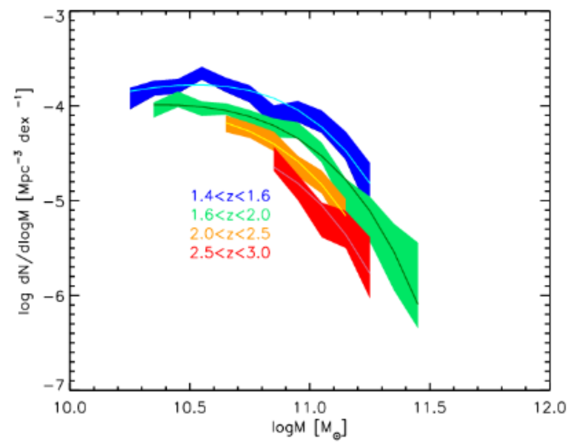
  -Cosmic variance (Somerville et al. 2004)

GSMF evolution

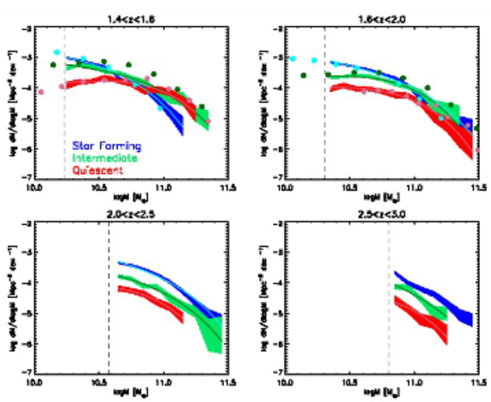
Total



Quiescent

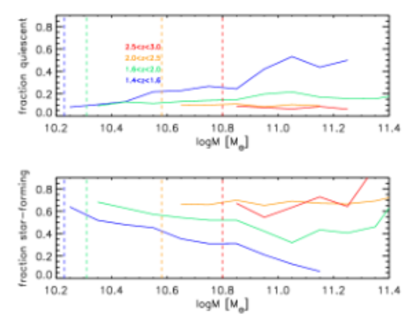


Star-Forming, Intermediate

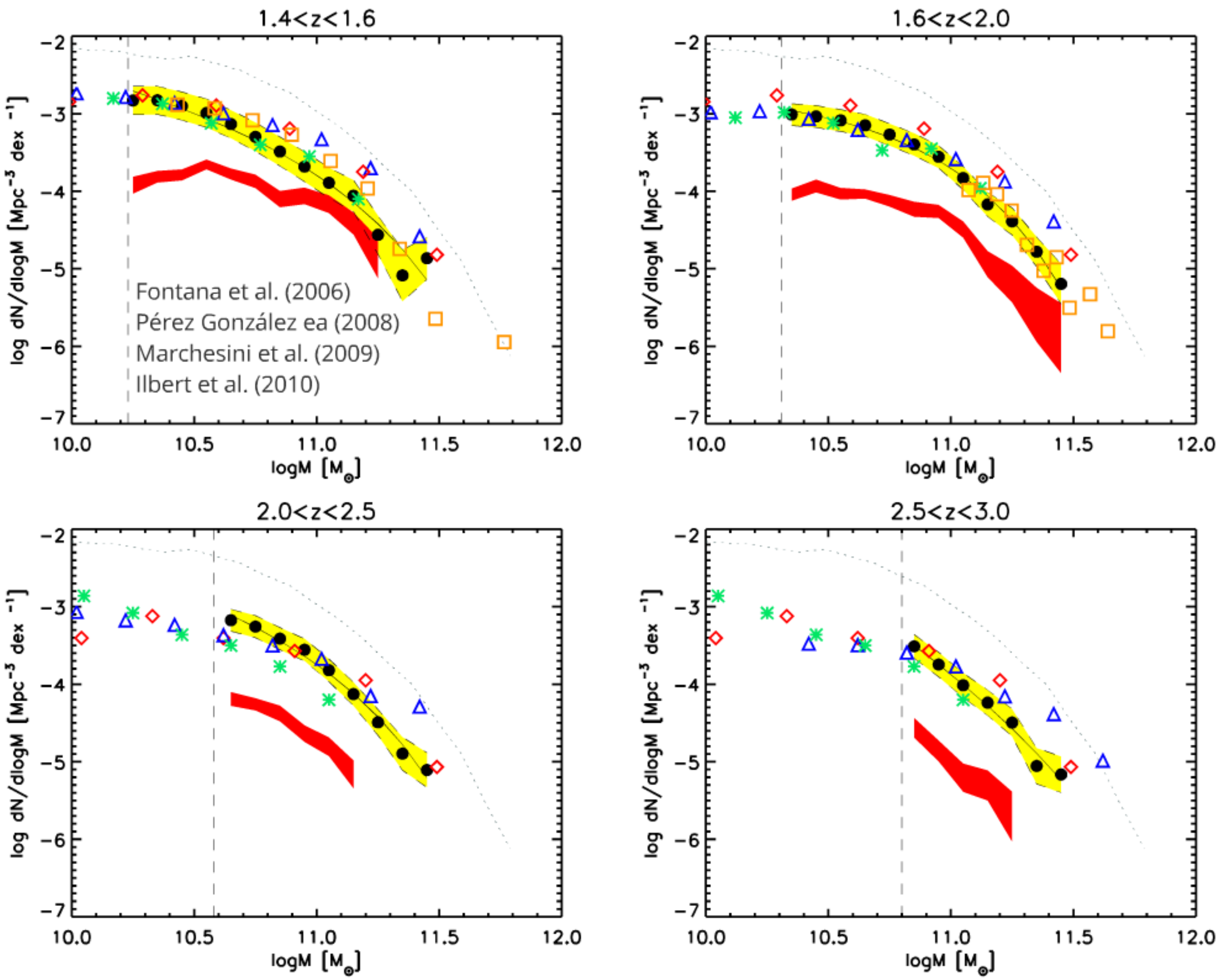


Mass dependence

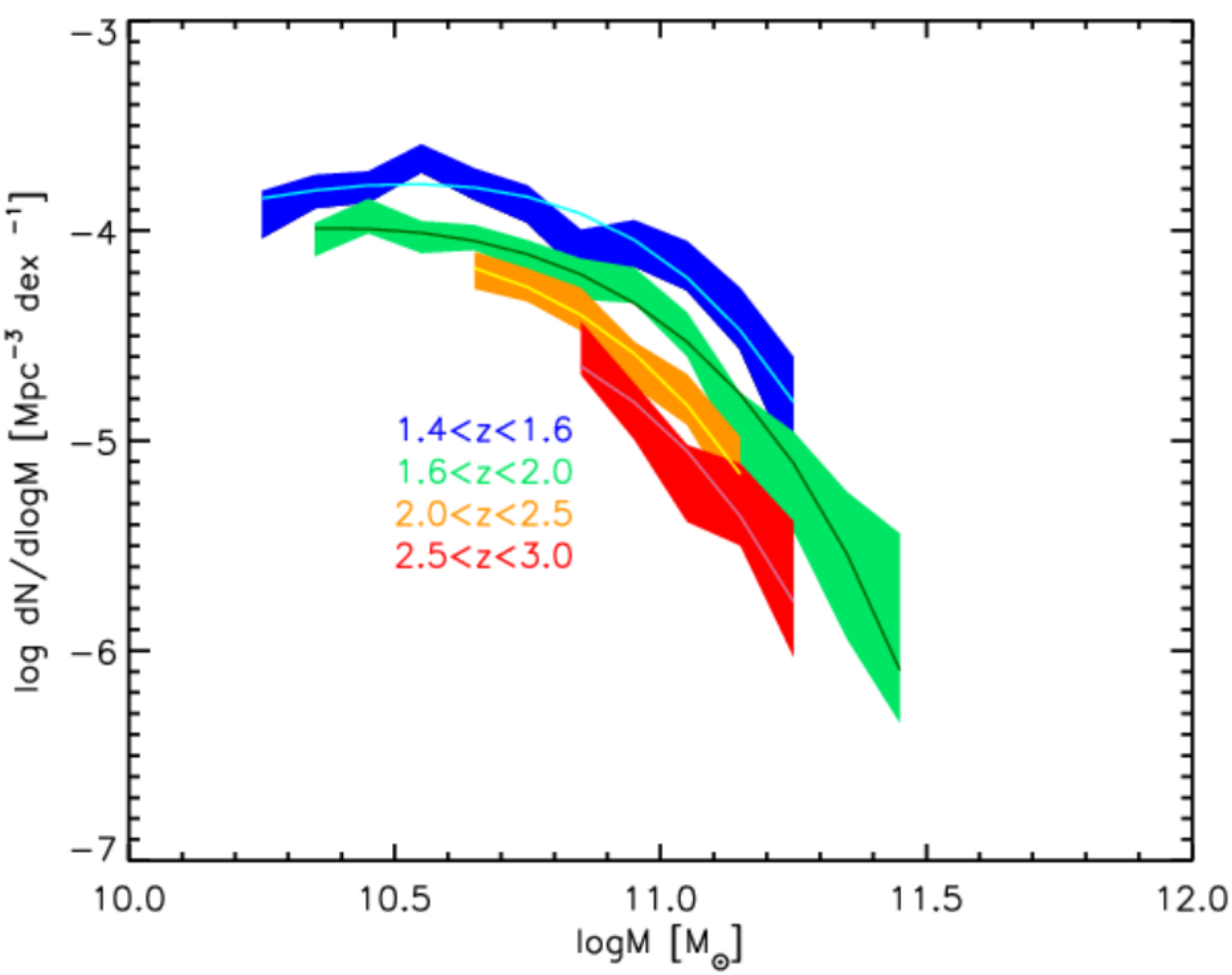
- Agreement with **Ilbert et al. (2010)**.
- Number of **Quiescent & intemediate** galaxies continuosly **increase** with cosmic time.
- Number of **Star-forming** galaxies **decrease** at high mass since z ~ 1.5
- **z ~ 1.5 epoch of transition**
- Mass dependence: **downsizing** (Cowie et al. 1996)



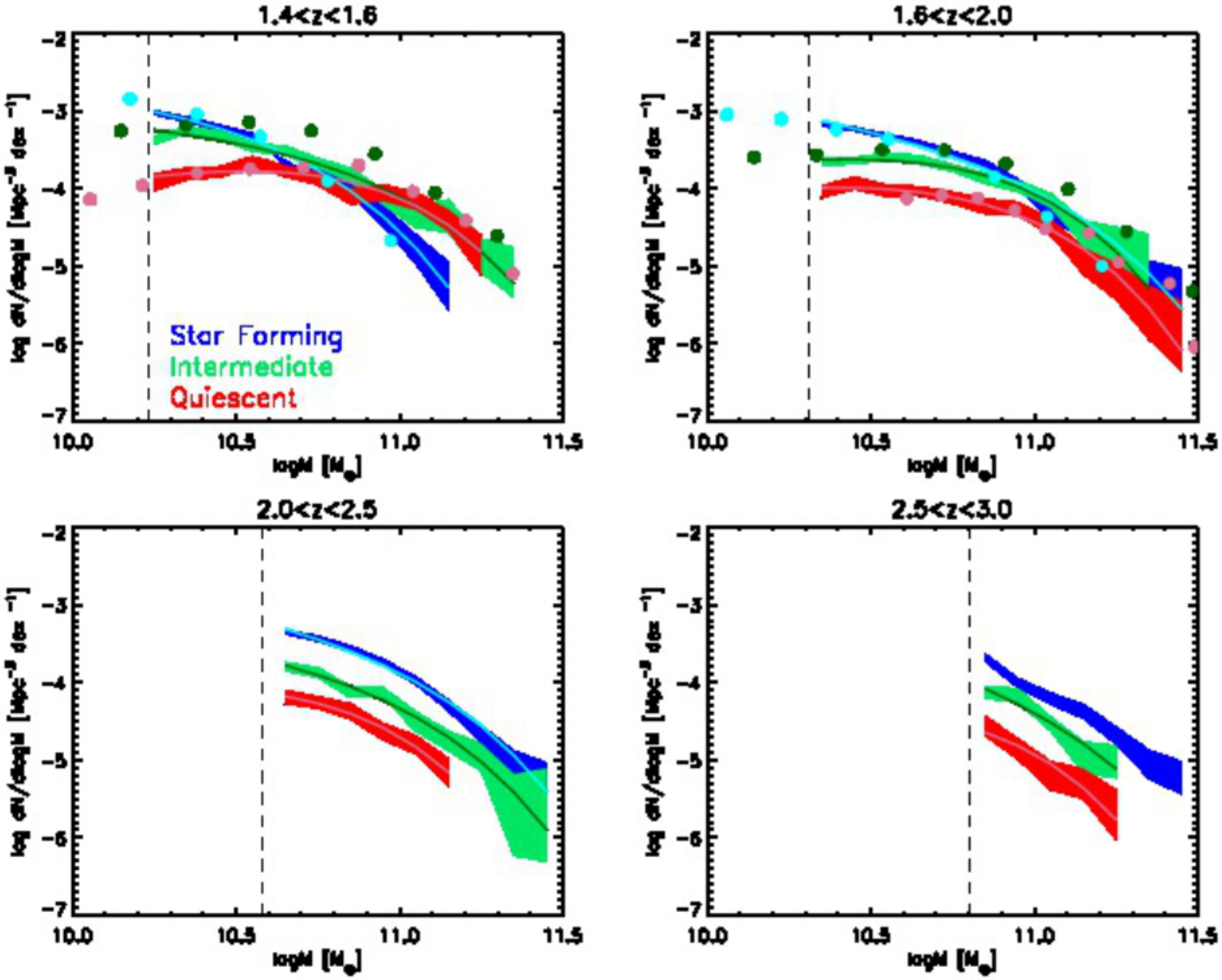
Total


1.4<z<1.6
1.6<z<2.0
2.0<z<2.5
2.5<z<3.0
Fontana et al. (2006)
Pérez González ea (2008)
Marchesini et al. (2009)
Ilbert et al. (2010)
log dN/dlogM [Mpc^{-3} dex $^{-1}$]
logM [M$_\odot$]
10.0
10.5
11.0
11.5
12.0
−2
−3
−4
−5
−6
−7

Quiescent



Star-Forming, Intermediate



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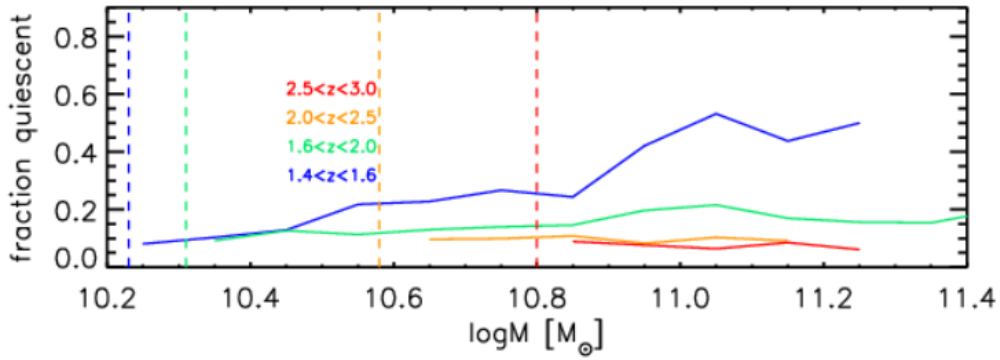
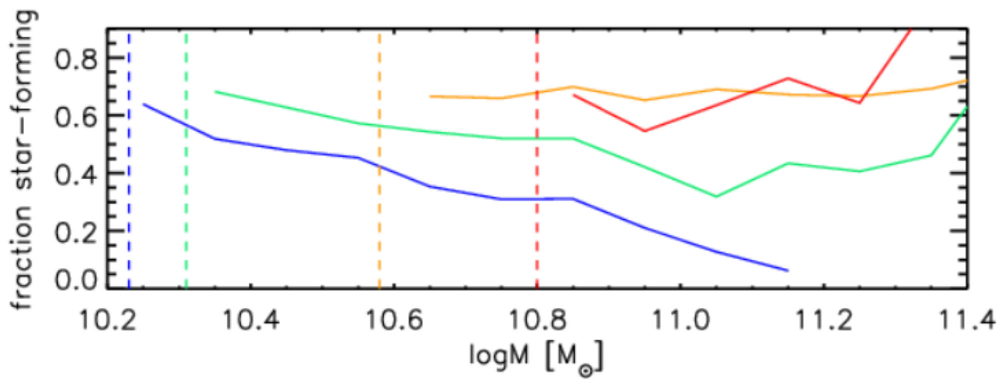
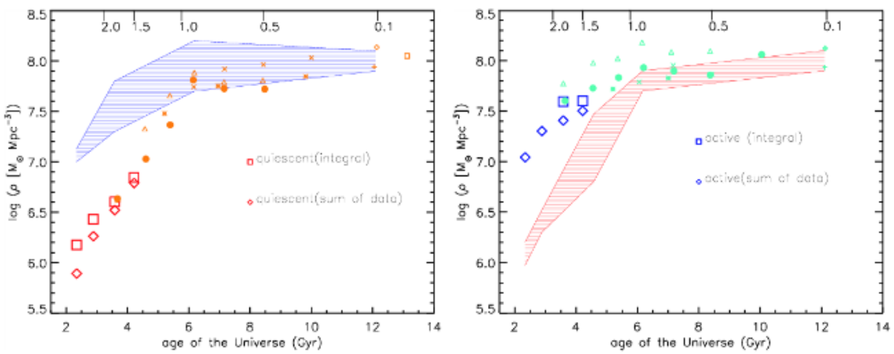


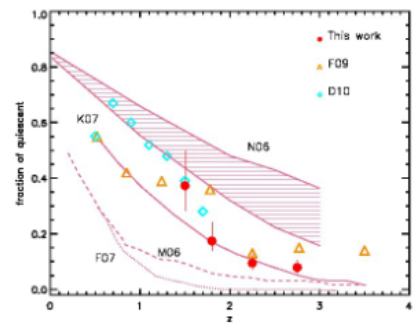


Prezi

Stellar mass density



Comparison with models



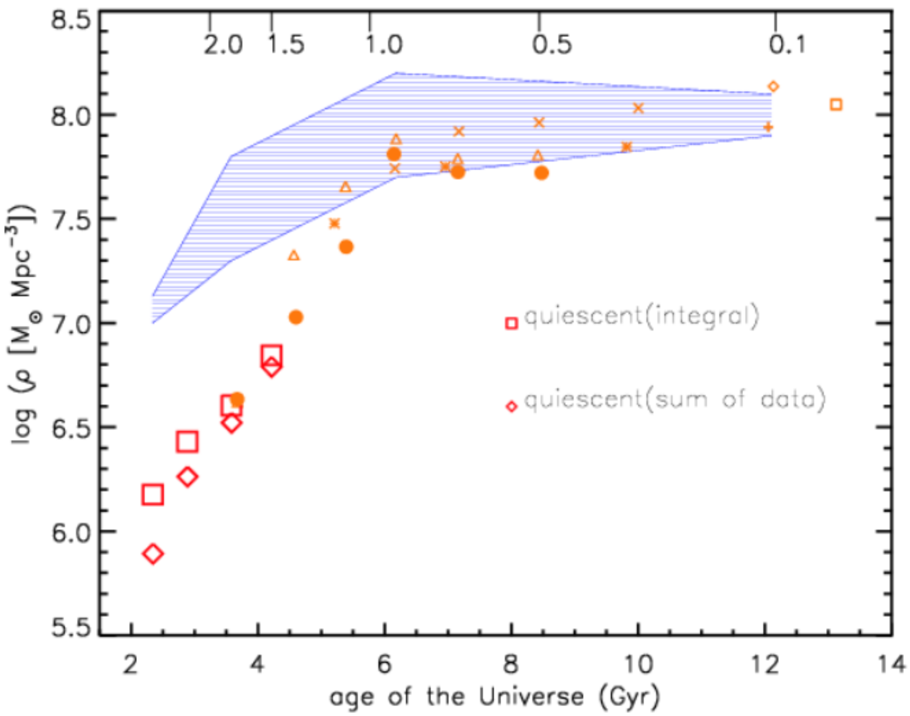
Theoretical Models

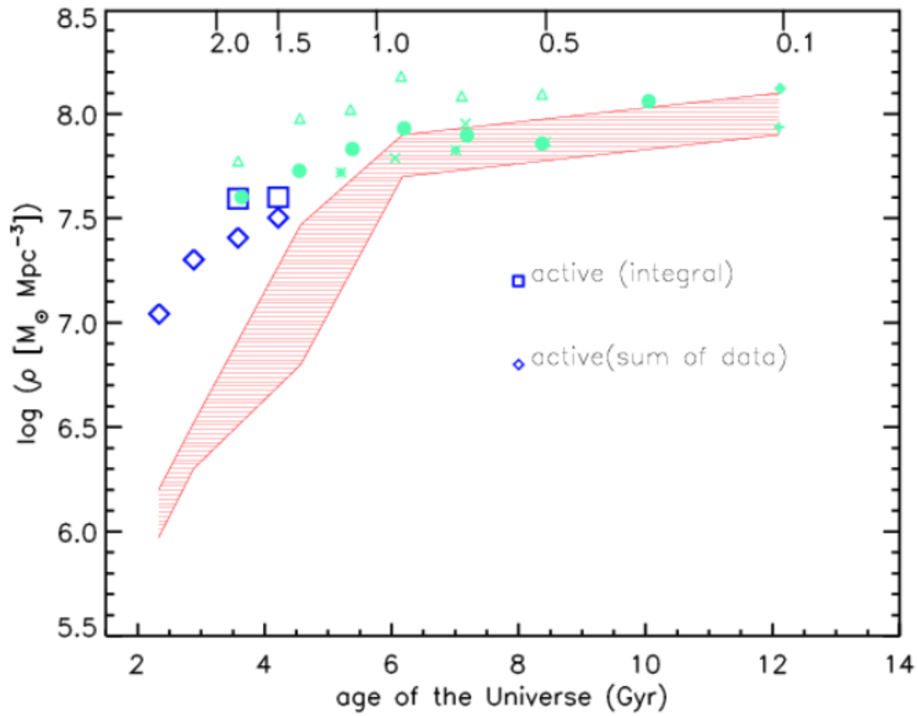
- N06: **Nagamine et al. (2006)**, hydrodinamical.
- M06: **Menci et al. (2006)**, semi-analytical , AGN feedback.
- K07: **Kitzbichler&White (2007)**, semi-analytical Milleniuum N-body dark matter simulation.
- F07: **Fontanot et al (2007)**, semi-analytical.

Data

- F09: **Fontanot et al. (2009)**
- D10: **Damen et al. (2010)**

Stellar mass density





Prezi

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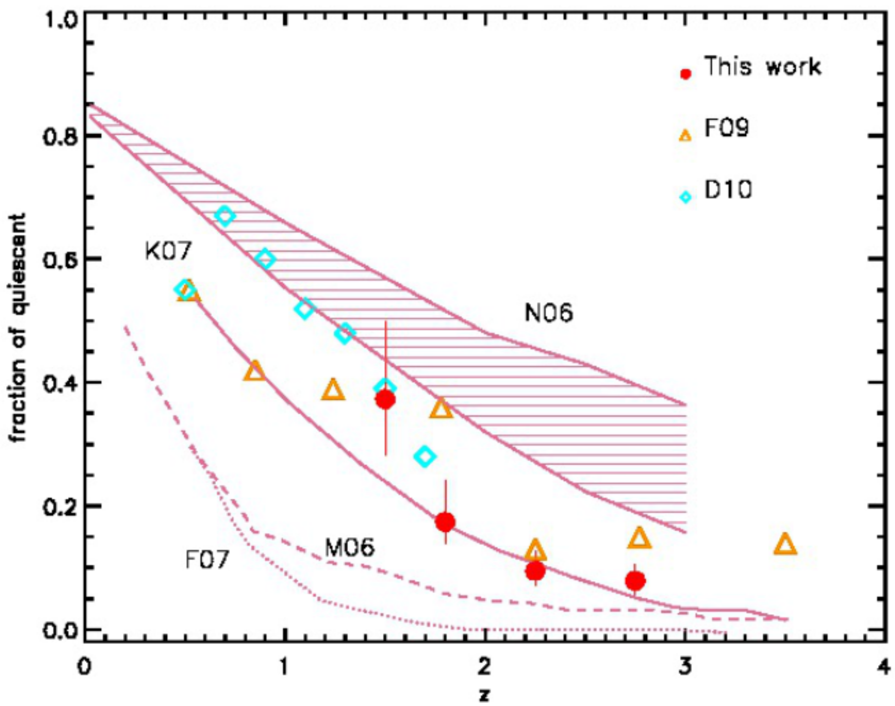

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CONCLUSIONS

- **IRAC selected** sample **important** to study the mass function evolution at high z.
- The **quiescent GSMF continously increases with time**.
- **z ~ 1.5 epoch of transition**: At higher z the mass function is dominated by star-forming galaxies at all masses. At lower redshifts the intermediate and quiescent galaxies become more important.
- **Mass dependence: Downsizing**, *i.e.* more massive galaxies become quiescent first.
- **Significant number of quiescent galaxies** already in place **at z > 2.5** ($\rho \sim 6.0\ M_{\odot} Mpc^{-3}$).
- Models predict an increase in the fraction of quiescent galaxies with cosmic time.

  The **K07 Milleniumm based mode**l is the one which better **reproduces the shape of the data.**

2. Comparison of star formation rates from Halpha and infrared luminosity as seen by Herschel

Herschel

SFR Indicators

SFR from Infrared Luminosity

- **Dust absorbes light** emitted by young stars and re-emitts in the IR.
- Commonly used **Kennicutt (1998)**
- **Theoretical derivation**: Leitherer & Heckman (1995), continuos burst, Salpeter IMF, solar abundances.
- Valid only for **young (10^8 yr) starbursts**.

$$\mathrm{SFR}\,(M_\odot\,yr^{-1}) = 4.5 \times 10^{-44}\,L_{FIR}\,(\mathrm{ergs\,s^{-1}})$$

SFR from Hα luminosity

- Young (< 20 Myr) massive (> 10 $M_\odot$) OB **stars ionize the molecular gas**
- Commonly used **Kennicutt et al. (1994), Madau et al. (1998)**
- Direct **probe of the young population**
- **Must correct for dust extinction**

$$\mathrm{SFR}\,(M_\odot\,yr^{-1}) = 7.9 \times 10^{-42}\,L(H\alpha)\,(\mathrm{ergs\,s^{-1}})$$

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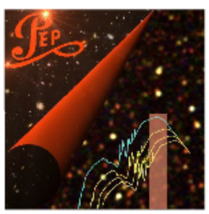
Sample

The importance of PEP data

- PACS Evolutionary Probe
- Herschel Space Telescope
- P.I. Dieter Lutz
- Data at **100 and 160 µm** in some of the most widely studied fields (COSMOS).
- Very important to constrain the **peak of the IR emission**



PEP Selected Sample

- **PEP selected** 100, 160 µm (~7000 sources, blind catalog, 3σ limit 5 and 10.2 mJy)
- **COSMOS** field: multiwavelength coverage, 2deg 2
- **MIPS** 24 µm (S_{lim}=80 µJy, Le Floc' h) + **3.6 µm selected** multiwavelength catalog (S_{lim}=1 µJy, NUV-8.0 µm Ilbert et al. 2010)
- **zCOSMOS 20k** spectroscopic information: **23% of thePEP sample**
- **z < 0.46** to observe Hα (6562.8 Å)
- -High zflag (> 2.1), **Hα** emission line **S/N=3**
- **No AGN emission** :

  Diagnostic Diagrams Bongiorno et al. 2009

  SED-fitting with Polleta et al. 2007 templates

  X-Ray detection (Chandra or XMM-Newton)

474 galaxies

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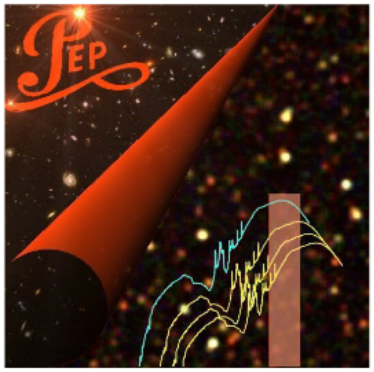

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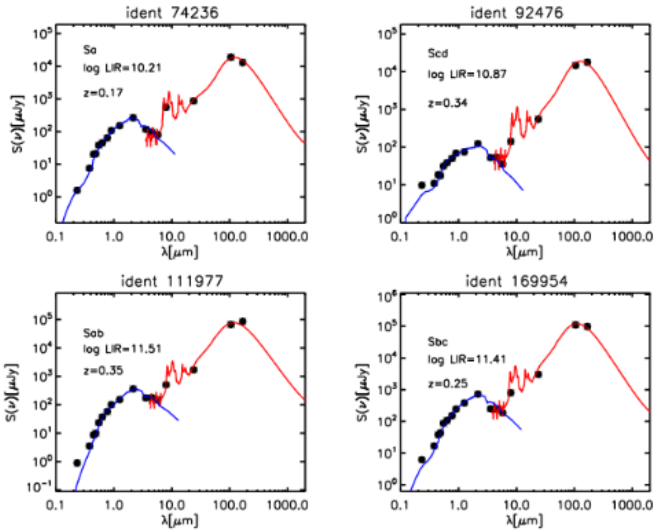
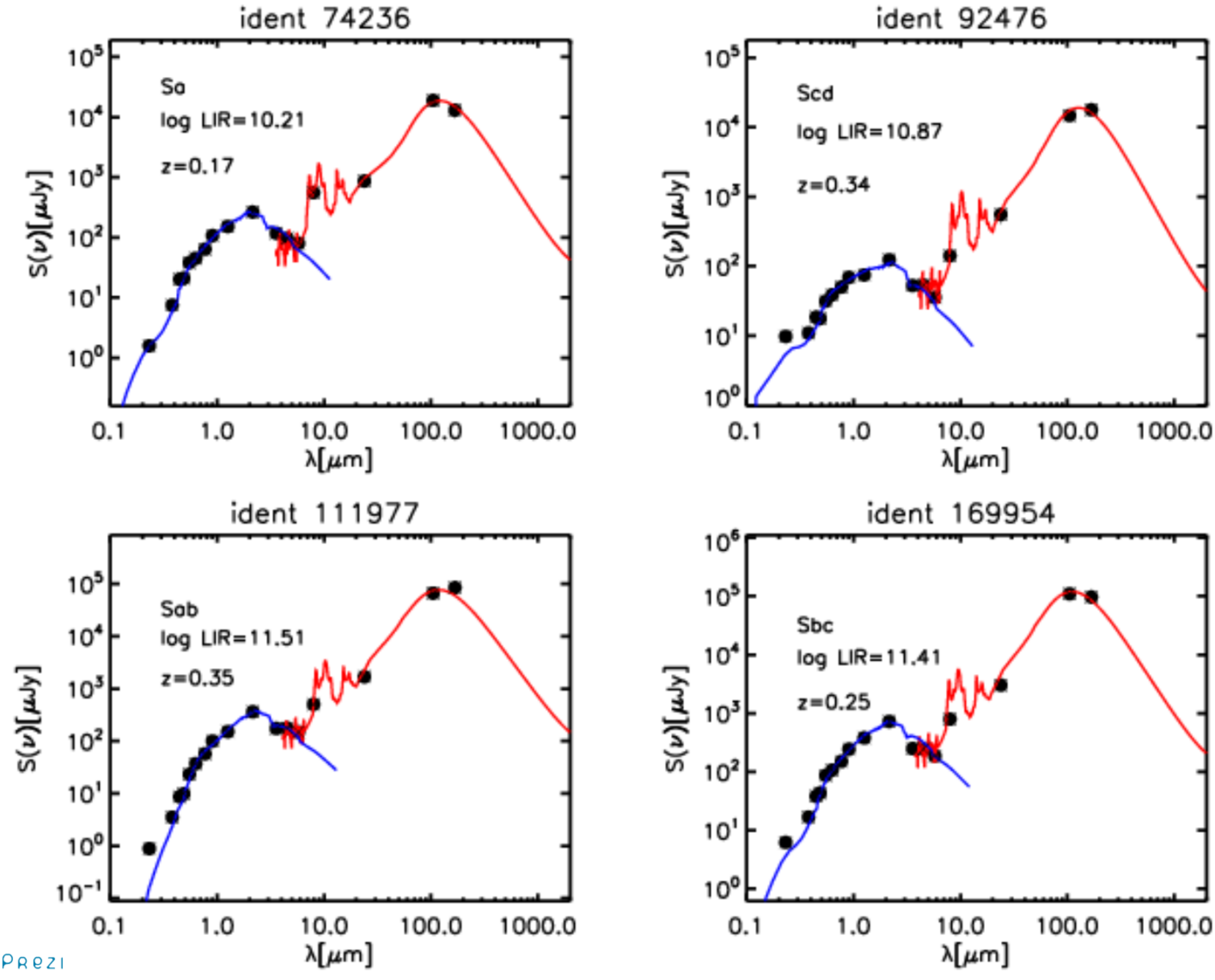
474 galaxies

SFR(LIR)

- *LePhare* code
- IR libraries:
  -Dale et al. (2001)
  -Chary& Elbaz (2001)
  -Lagache et al. (2004)
- Integrated from 8-1000 μm

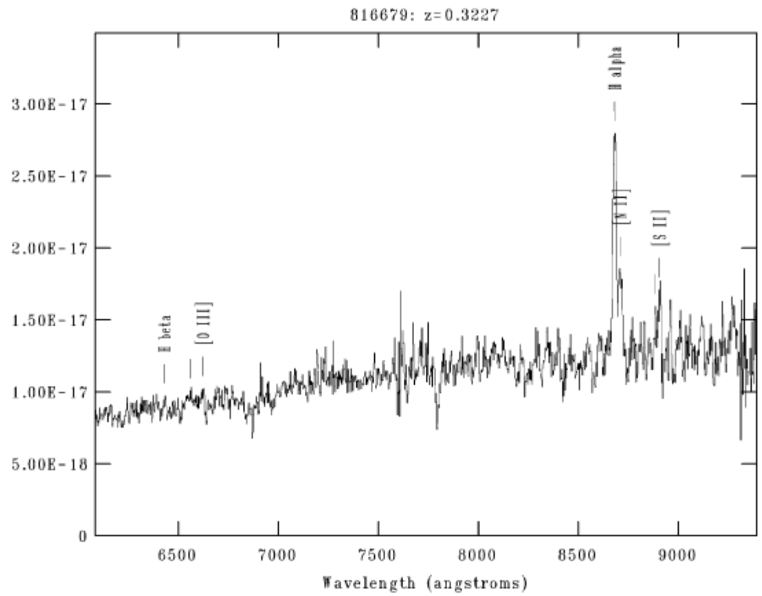


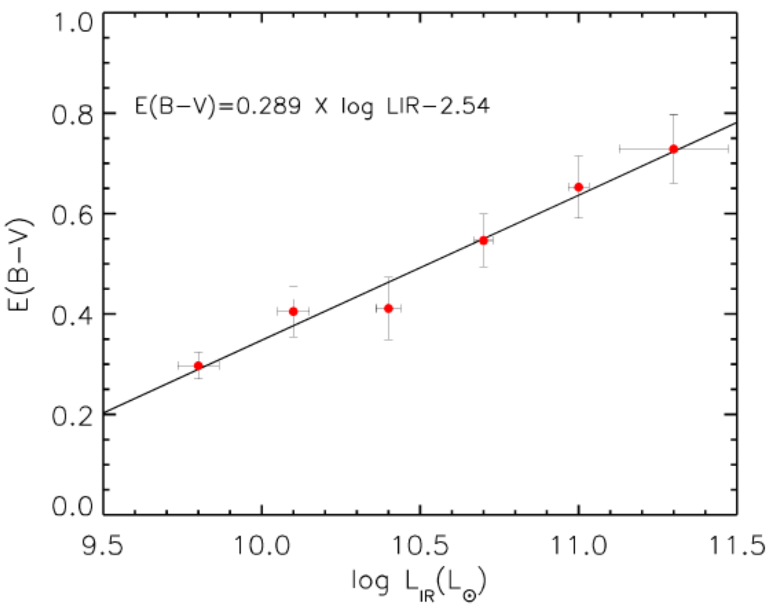

ident 74236
Sa
log LIR=10.21
z=0.17
ident 92476
Scd
log LIR=10.87
z=0.34
ident 111977
Sab
log LIR=11.51
z=0.35
ident 169954
Sbc
log LIR=11.41
z=0.25
S(ν)[μJy]
λ[μm]
0.1
1.0
10.0
100.0
1000.0

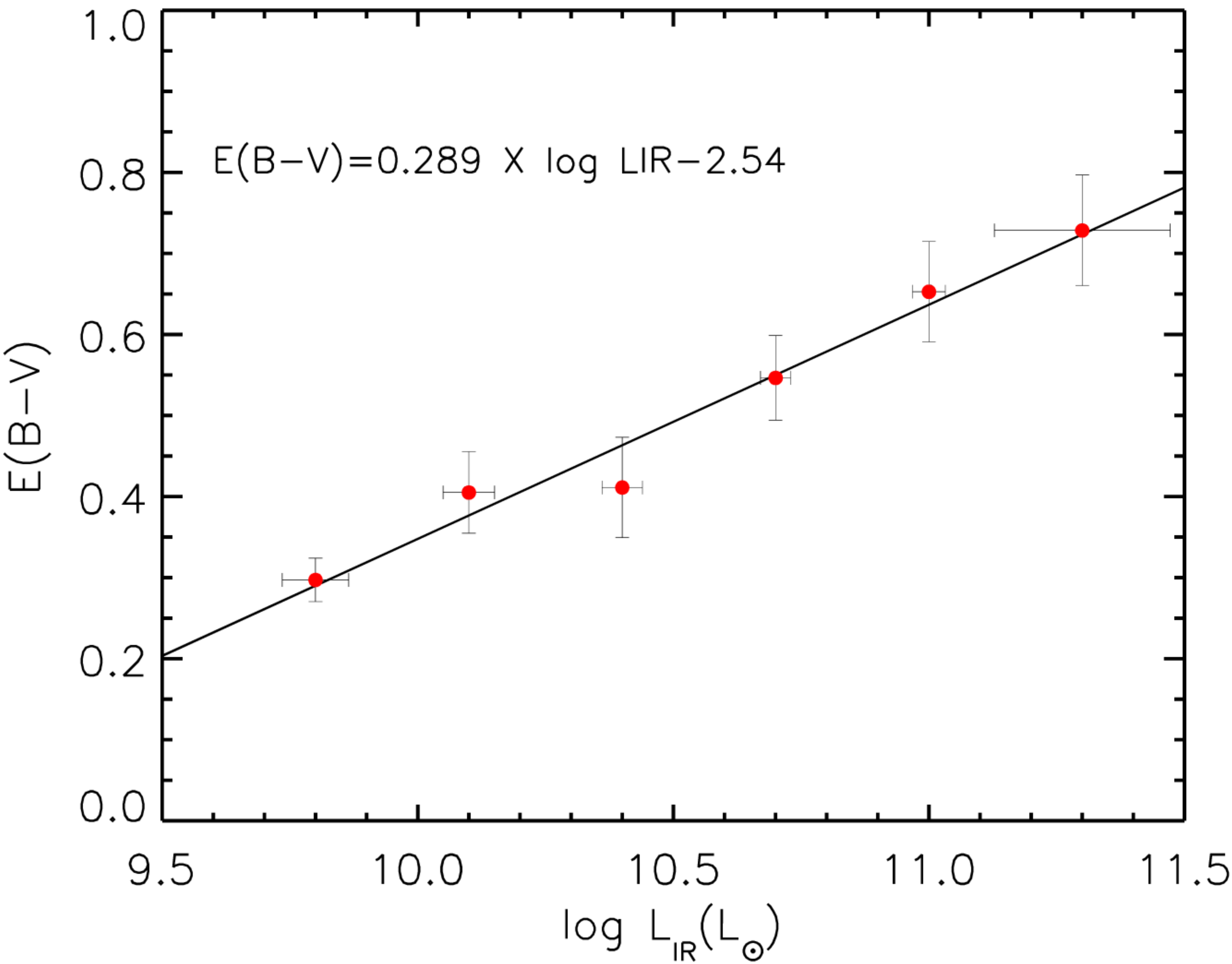
SFR(Hα)

Dust Extinction correction

- From Hα/Hβ observed ratio.
- Quality of spectra not enough to measure Hβ for each source.
- Construct average spectra in 6 LIR bins.
- Substract continuum emission and measure the Hα/Hβ observed ratio.
- Derive average E(B-V) values.
- Find strong correlation between log LIR and E(B-V)





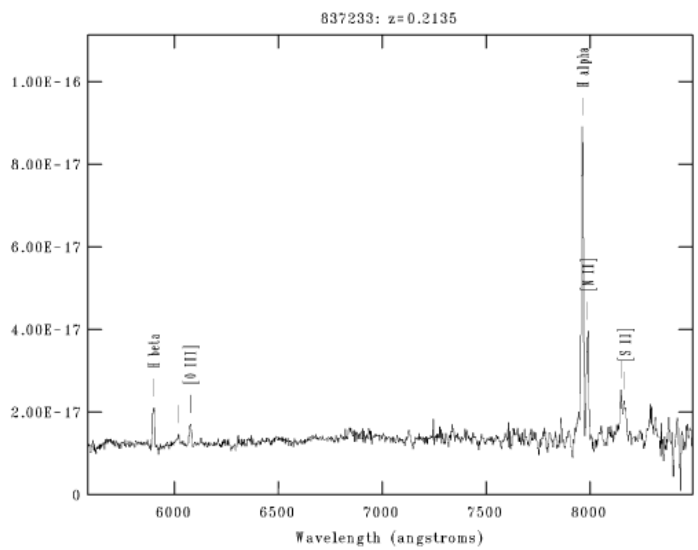


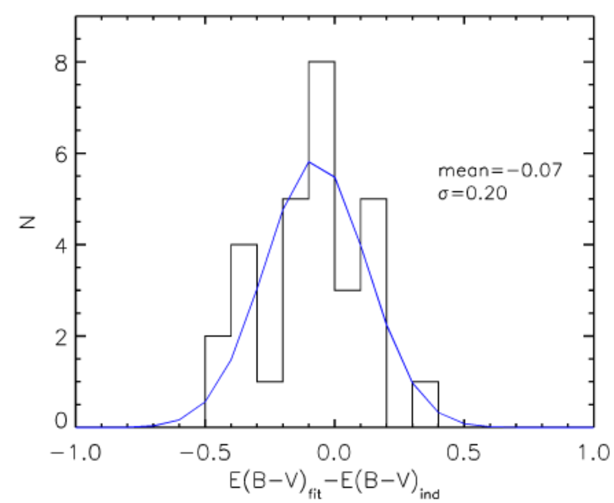
E(B−V)=0.289 X log LIR−2.54
E(B−V)
1.0
0.8
0.6
0.4
0.2
0.0
9.5
10.0
10.5
11.0
11.5
log $L_{IR}(L_{\odot})$

Prezi

Effect of using median spectra

- Selected 31 galaxies with high S/N in the continuum near the Hα, Hβ emission lines.
- Constructed average spectra for these 31 sources.
- Compared the average extinction value and the single value.





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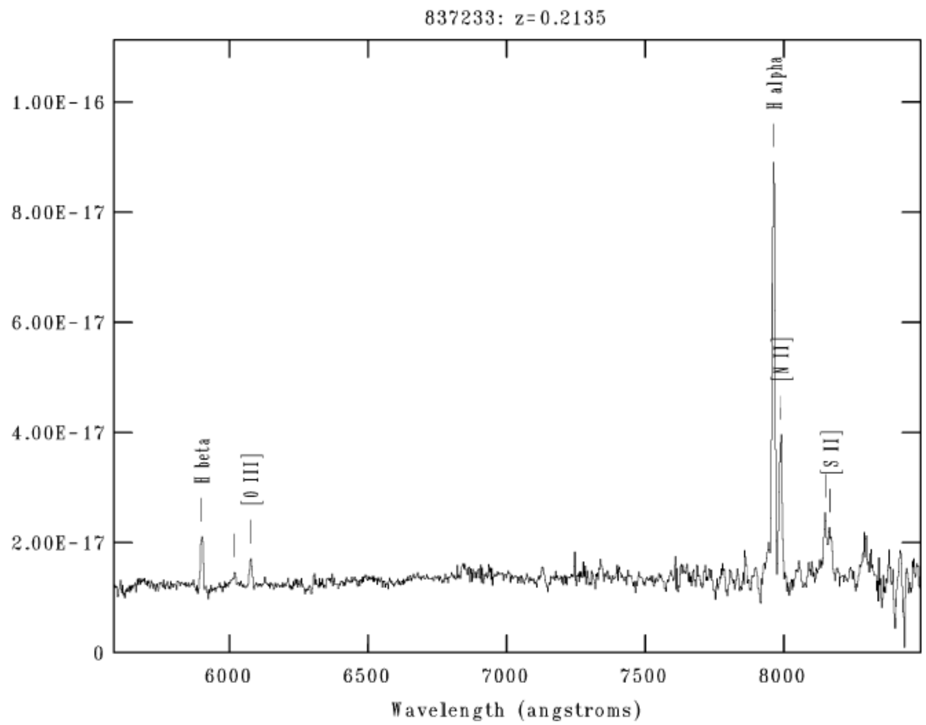
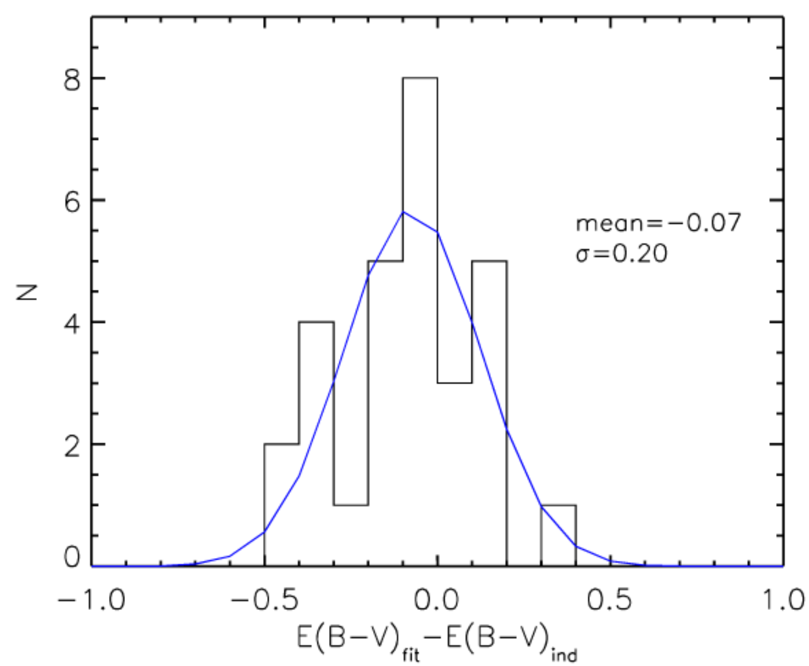
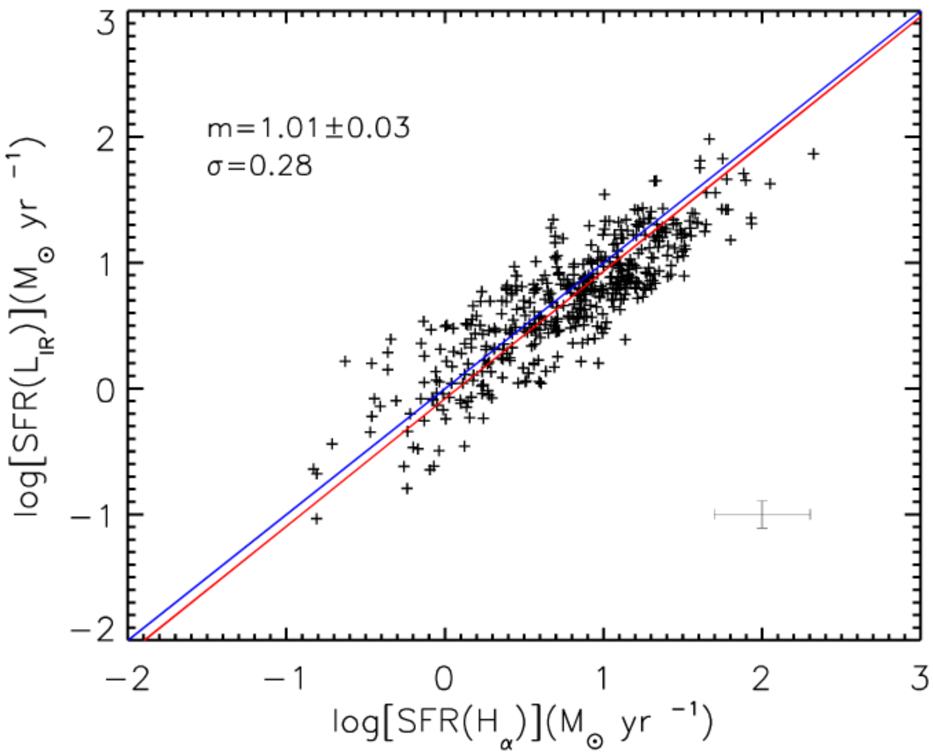
- Compared the average extinction value and the single value.





Prezi

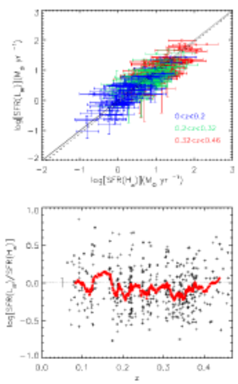
SFR comparison



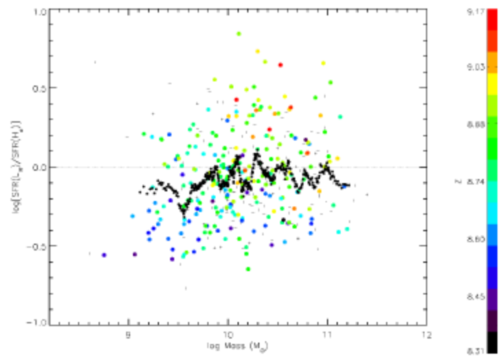
Very good agreement between SFR indicators over the whole SFR range.

SFR Comparison dependences

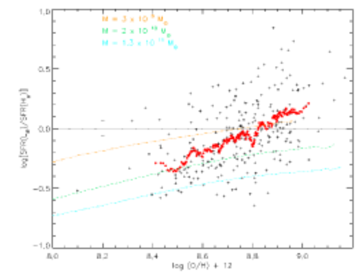
Redshift



Mass

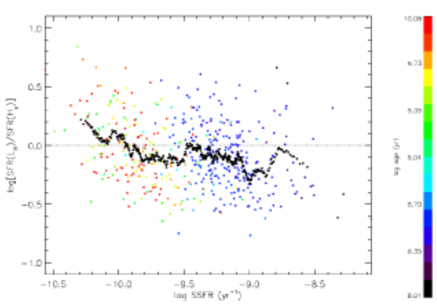


Metallicity

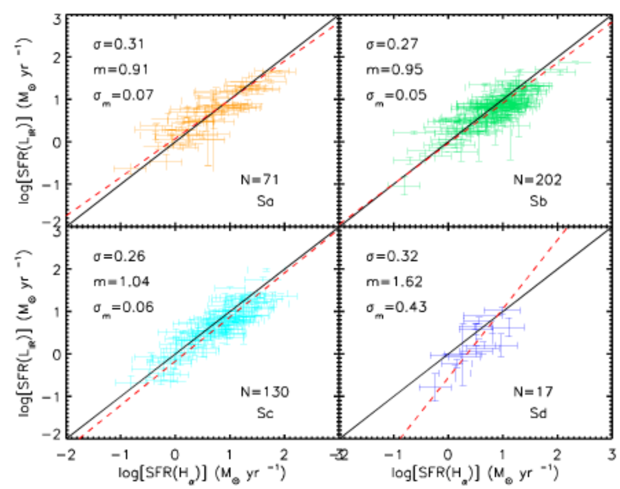


Comparison with model for dust evolution in spiral galaxies
(Calura et al. 2009, Schurer et al. 2009)

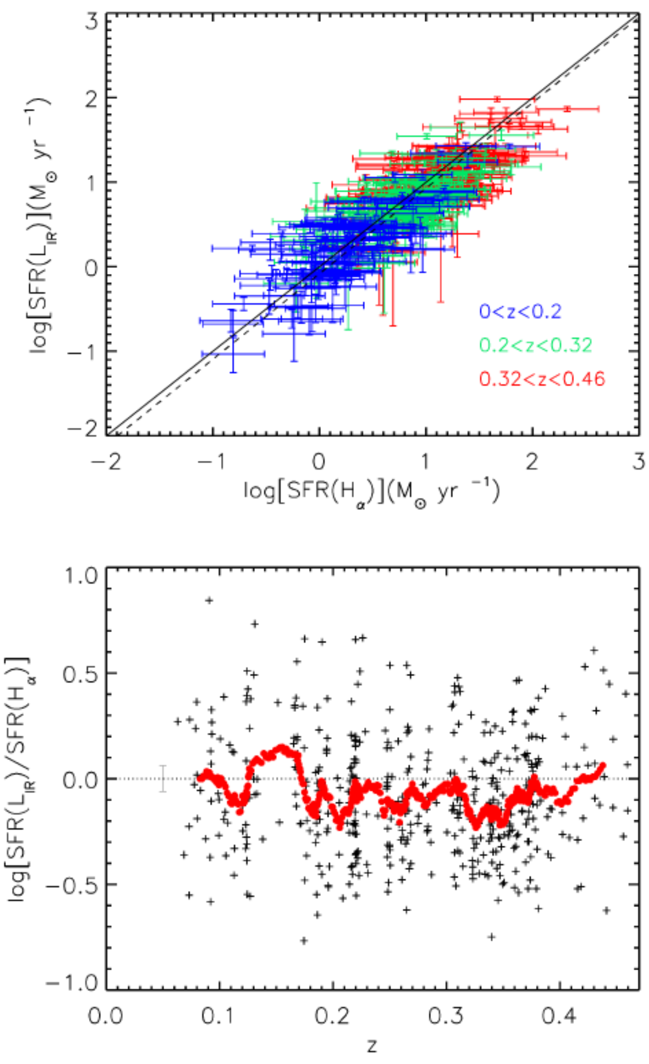
SSFR



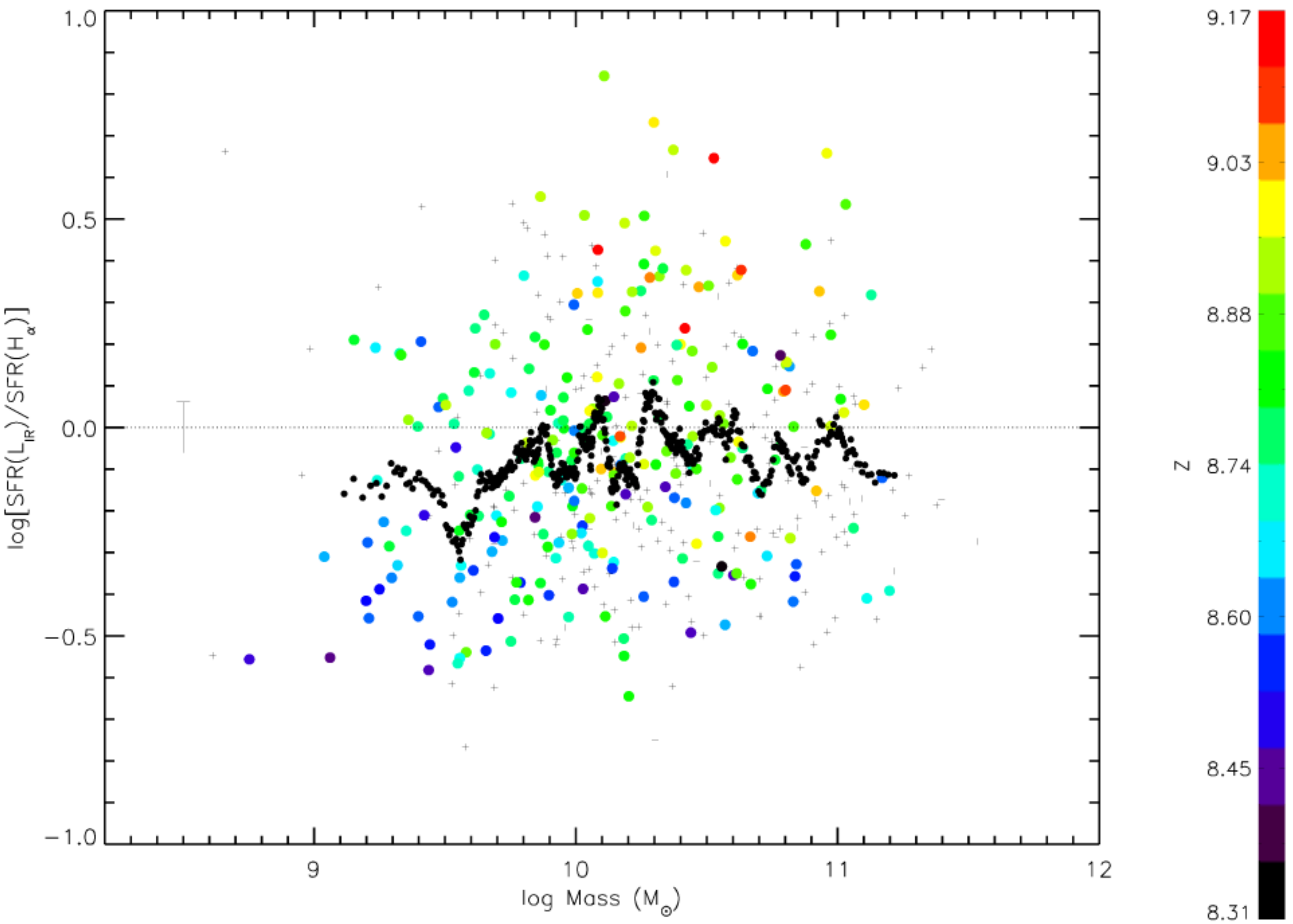
Morphology



Redshift

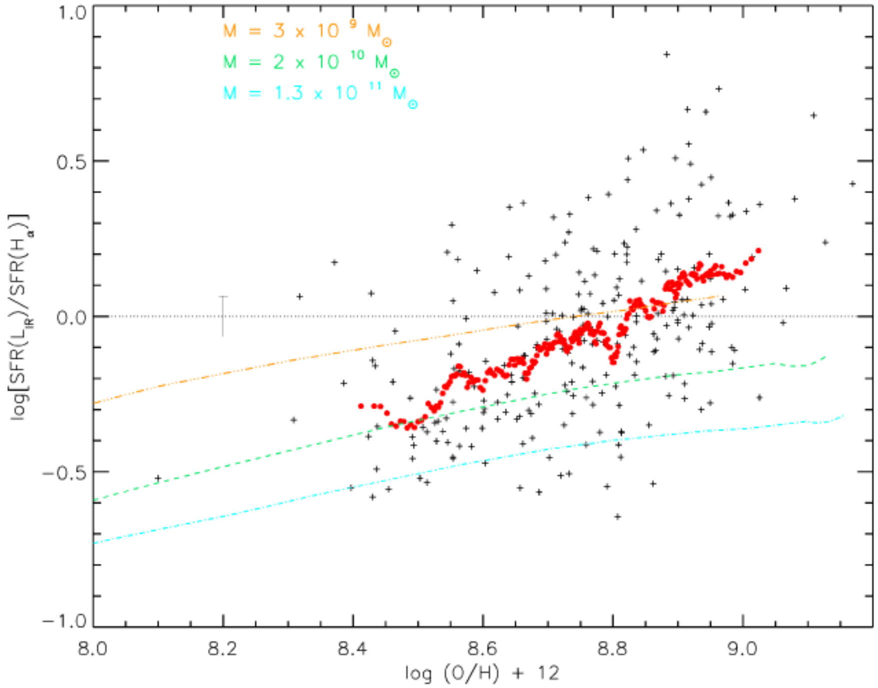

3
2
1
0
−1
−2
log[SFR(L_IR)](M_⊙ yr ^−1)
0<z<0.2
0.2<z<0.32
0.32<z<0.46
−2
−1
0
1
2
3
log[SFR(H_α)](M_⊙ yr ^−1)
1.0
0.5
0.0
−0.5
−1.0
log[SFR(L_IR)/SFR(H_α)]
0.0
0.1
0.2
0.3
0.4
z

Mass



1.0
0.5
0.0
−0.5
−1.0
9
10
11
12
log Mass ($M_\odot$)
log[SFR(L_{IR})/SFR(H_α)]
9.17
9.03
8.88
8.74
8.60
8.45
8.31
Z

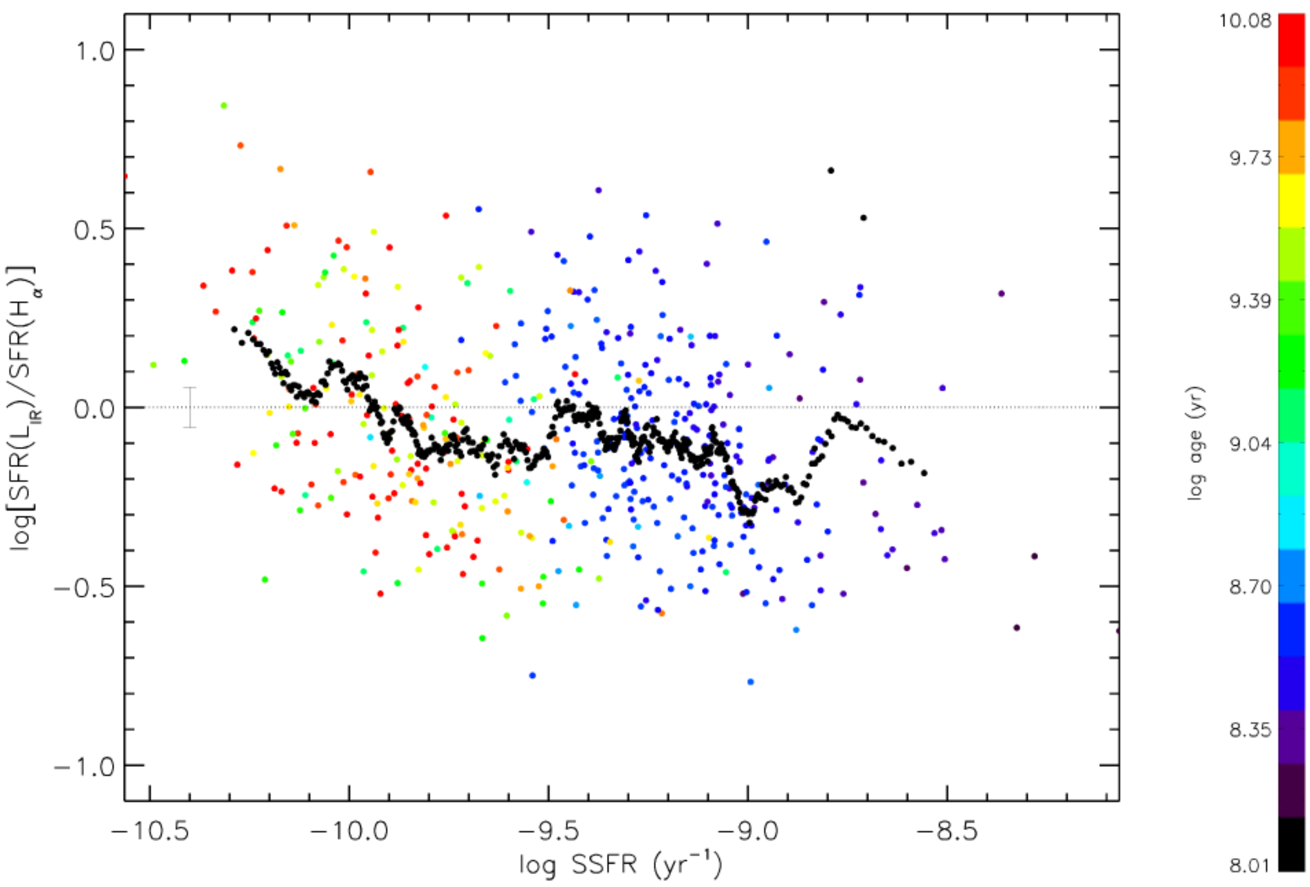
Metallicity



Comparison with model for dust evolution in spiral galaxies
(Calura et al. 2009, Schurer et al. 2009)

Prezi

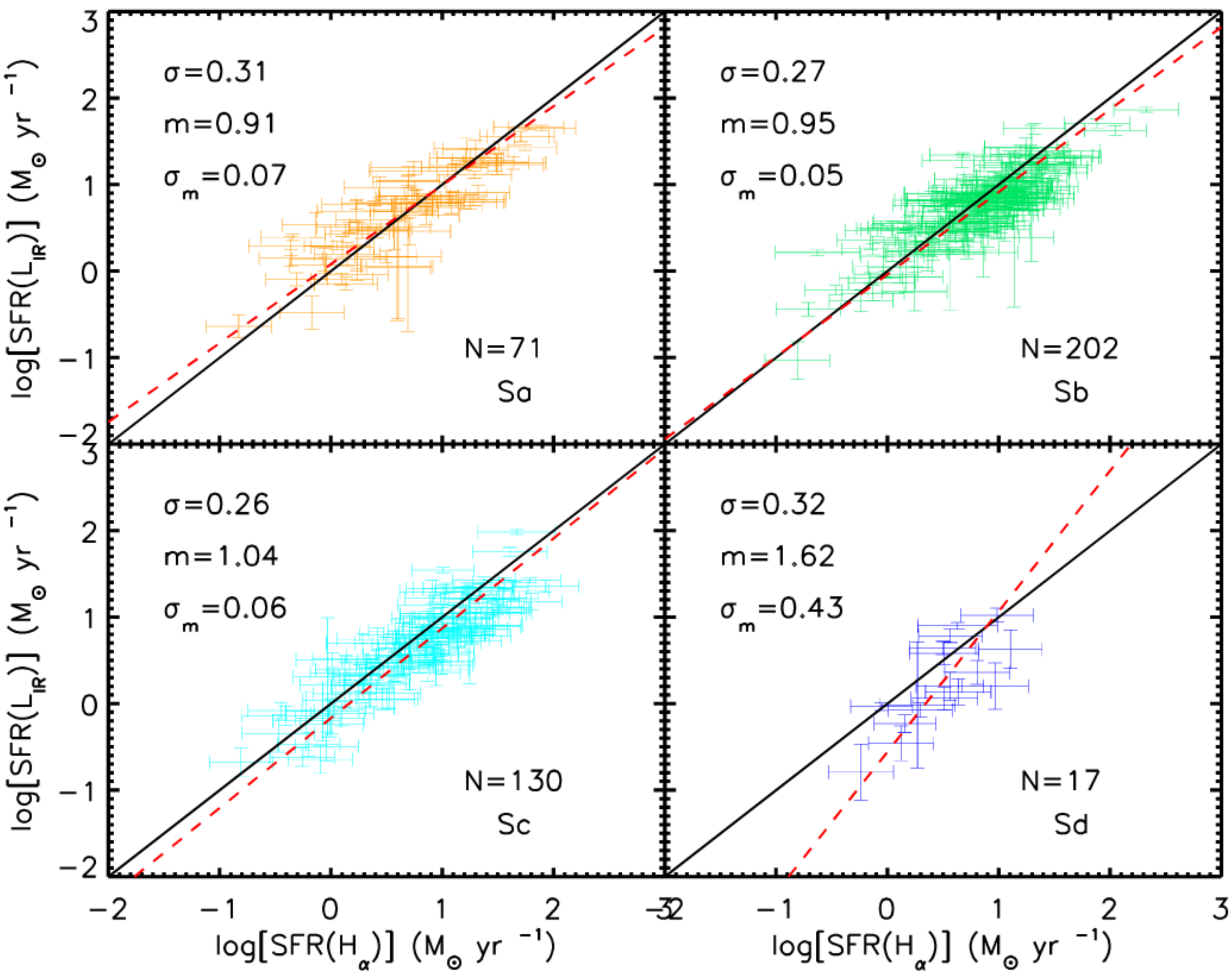
SSFR



1.0
0.5
0.0
−0.5
−1.0
log[SFR(L_IR)/SFR(H_α)]
−10.5
−10.0
−9.5
−9.0
−8.5
log SSFR (yr⁻¹)
10.08
9.73
9.39
9.04
8.70
8.35
8.01
log age (yr)

Prezi

Morphology


σ=0.31
m=0.91
σ m=0.07
N=71
Sa
σ=0.27
m=0.95
σ m=0.05
N=202
Sb
σ=0.26
m=1.04
σ m=0.06
N=130
Sc
σ=0.32
m=1.62
σ m=0.43
N=17
Sd
log[SFR(L IR)] (M⊙ yr −1)
log[SFR(H α)] (M⊙ yr −1)

Conclusions

-PEP data important to **constrain the IR peak** to derive L_{IR}.

-SFR(L_{IR}) and SFR(Hα) very good agreement for the bulk of galaxies (m=1.01±0.03, a=-0.08±0.03)

-No z dependence in the SFR indicators comparison (up to z= 0.46).

-Mass dependence: slight dependence at low masses ($M < 9.3\ M_{\odot}$), mainly driven by metallicity.

-Metallicity dependence: average values of log [SFR(L_{IR}) /SFR(Hα)] differ by ~ 0.6 dex from metal-poor to metal-rich galaxies. Metal rich galaxies are more efficient in absorbing and re-emitting light from young stars in the IR. The observed behaviour can be explained with a theoretical model for dust evolution in spiral galaxies.

-SSFR dependence: low SSFR, log [SFR(L_{IR})/SFR(Hα)]>0, maybe due to old stellar population. High SSFR, log [SFR(L_{IR})/SFR(Hα)]<0 due to intense bursts of star formation.

-Morphological type: 3σ agreement for all morphological types. Indication of an increment of the slope when moving from early to late type galaxies although no significant enough statistical sample.

Future work:

Carefully study the ~ **300 "only IRAC"** sources from Domínguez Sánchez et al. 2011

- **new COSMOS data** (ultraVISTA, CANDELS, PACS, SPIRE).
- **SEDs:** fundamental galaxy properties (photo-z, stellar masses, ages, SFR, etc)
- **Morphologies**

Highly obscured starburst or very high-z massive galaxies?

References:

- Domíngez Sánchez et al. 2011, MNRAS Volume 417, Issue 2, pp. 900-915
- Domíngez Sánchez et al. 2012, arXiv:1205.4573v2

Thank you for your attention!

Questions?