Massive galaxies at high redshift

A. Fontana
A. Grazian, E. Merlin, P. Santini, M. Castellano
+ CANDELS

Outline of the talk

- About the accuracy/reliability of stellar masses: the CANDELS exercise
- The impact on the estimate of the Mass Function

- The evolution of the MF at z>4

- Are we missing SF galaxies at z>4?
- Quiescent galaxies at z>4 (??)

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The strength of CANDELS: an arena to compare different recipes

ASTRODEEP

A CRITICAL ASSESSMENT OF PHOTOMETRIC REDSHIFT METHODS: A CANDELS INVESTIGATION

TOMAS DAHLEN[1], BAHRAM MOBASHER[2], SANDRA M. FABER[3], HENRY C FERGUSON[1], GUILLERMO

STELLAR MASSES FROM THE CANDELS SURVEY: THE GOODS-SOUTH AND UDS FIELDS

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A CRITICAL ASSESSMENT OF STELLAR MASS MEASUREMENT METHODS

BAHRAM MOBASHER [1], TOMAS DAHLEN [2], HENRY C. FERGUSON [2], VIVIANA ACQUAVIVA [3], GUILLERMO BARRO [4], STEVEN L. FINKELSTEIN [5], ADRIANO FONTANA [6], RUTH GRUETZBAUCH[7], SETH JOHNSON[8], YU LU [9], CASEY J. PAPOVICH [10], JANINE PFORR[11], MARA SALVATO[12], RACHEL S. SOMERVILLE [13], TOMMY WIKLIND [14], STIJN WUYTS [12], MATTHEW L. N. ASHBY [15], ERIC BELL [16], CHRISTOPHER J. CONSELICE [17], MARK E. DICKINSON [11], SANDRA M. FABER [4], GIOVANNI FAZIO [15], KRISTIAN FINLATOR[18], AUDREY GALAMETZ[6], ERIC GAWISER [13], MAURO GIAVALISCO[8], ANDREA GRAZIAN [6], NORMAN A. GROGIN [2], YICHENG GUO [4], NIMISH HATHI [19], DALE KOCEVSKI[20], ANTON M. KOEKEMOER [2], DAVID C. KOO [4], JEFFREY A. NEWMAN [21], NAVEEN REDDY [1], PAOLA SANTINI[6], RISA H. WECHSLER [9]

Draft version October 11, 2014

Santini +15

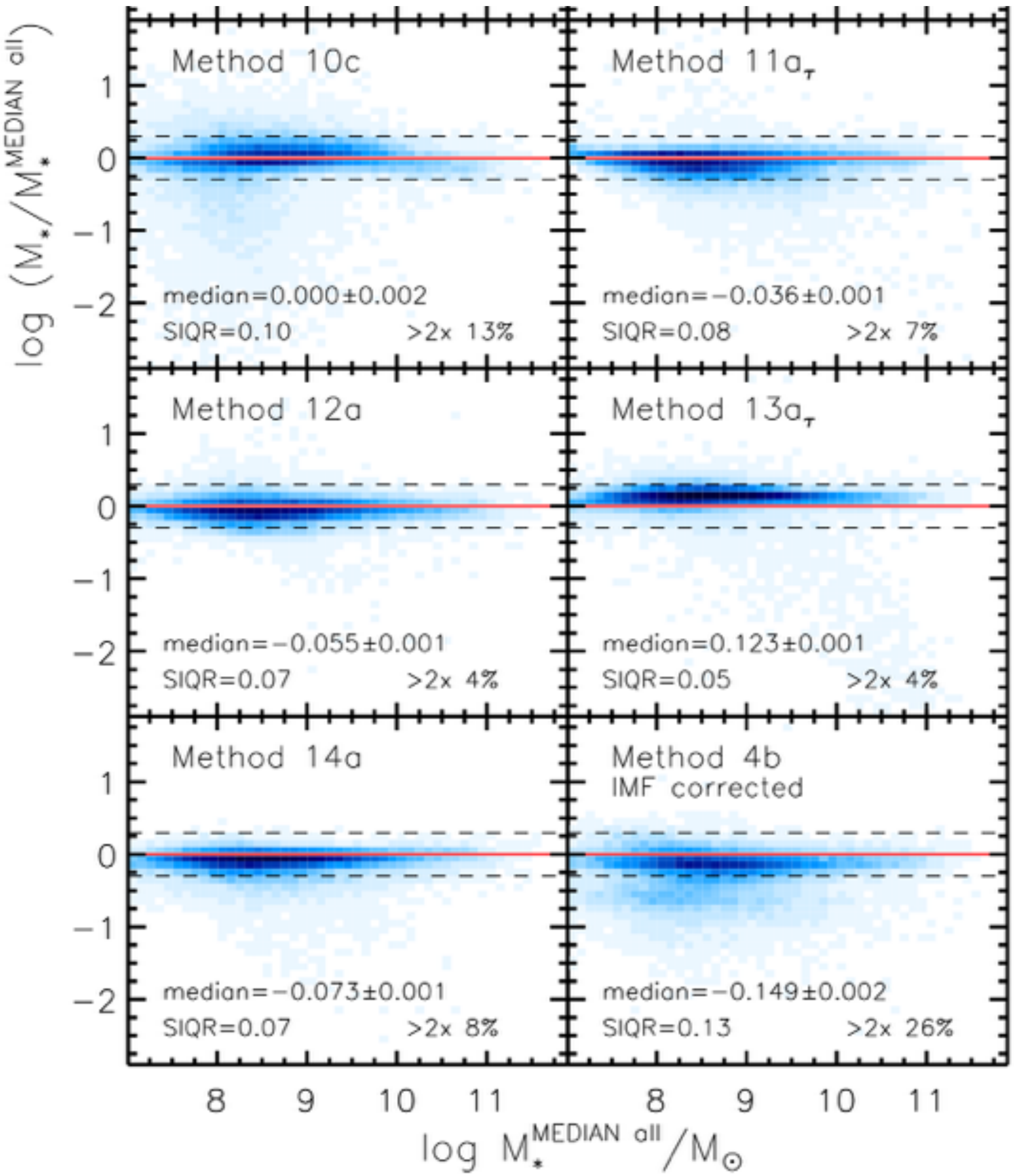
Table 1
Summary of the assumptions adopted to compute the stellar masses in CANDELS.

	Method 2a$_\tau$	Method 2d$_\tau$	Method 4b	Method 6a$_\tau$	Method 10c
PI	G. Barro	G. Barro	S. Finkelstein	A. Fontana	J. Pforr
fitting method	min χ^2	min χ^2	min χ^2	min χ^2	min χ^2
code	FAST[a] v0.9b	Rainbow[b]	own code	zphot[c]	HyperZ[d]
stellar templates	BC03[e]	PEGASE[f] v1.0	CB07[g]	BC03[e]	M05[h]
IMF	Chabrier	Salpeter	Salpeter	Chabrier	Chabrier
SFH	τ[i]	τ[i]	τ[i] + inv-τ[j] + const.[l]	τ[i]	τ[i] + trunc.[k] + const.[l]
log (τ/yr) step[m]	8.5–10.0 0.2	6.0–11.0 0.1	5.0–11.0 6 steps	8.0–10.2 9 steps	8.0, 8.5, 9.0
log (τ^{INV}/yr)[n]			8.5, 9.0, 10.0		
log (t_0/yr)[o]					8.0, 8.5, 9.0
metallicity [$Z_\odot$]	1	0.005, 0.02, 0.2, 0.4, 1, 2.5, 5	0.02, 0.2, 0.4, 1	0.02, 0.2, 1, 2.5	0.2, 0.5, 1, 2.5
log (age/yr) step[m]	7.6–10.1 0.1	6.0–10.1 60 steps	6.0–10.1 40 steps	7.0–10.1 110 steps	8.0 – 10.3 221 steps
extinction law	Calzetti	Calzetti	Calzetti	Calzetti + SMC	—
extinction E(B-V) step	0.0–1.0 0.025	0.00–1.24 0.025	0.0–0.8 0.02	0.0–1.1 0.05	0.0
nebular emission	no	no	yes	no	no
priors	[p]	[p]	[p]	[p q]	[p r]
reference	1	2	3	4	5

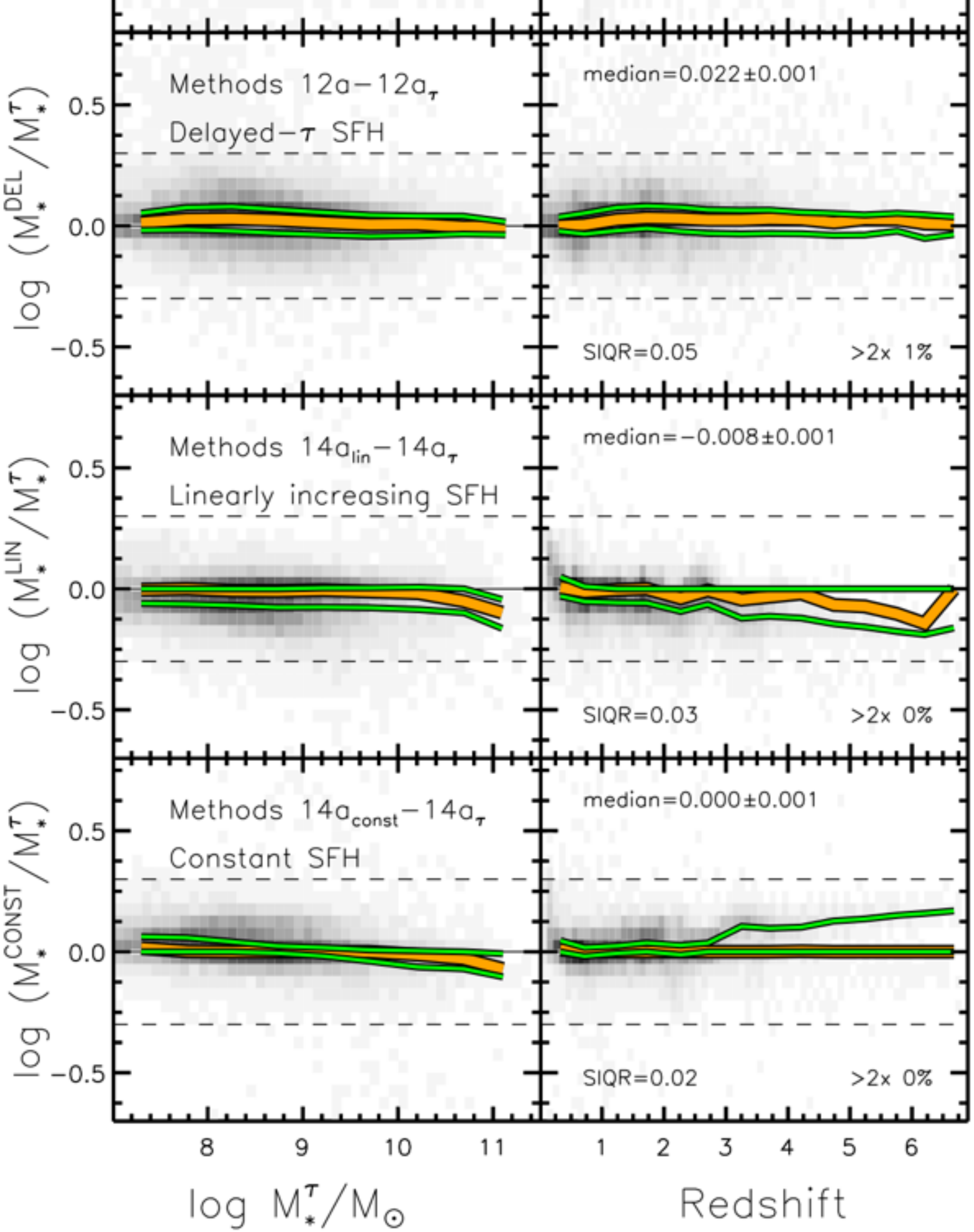
Table 1
(*continued*)

	Method 11a$_\tau$	Method 12a	Method 13a$_\tau$	Method 14a	Method 15a
PI	M. Salvato	T. Wiklind	S. Wuyts	B. Lee	S.-K. Lee
fitting method	median of the mass PDF[s]	min χ^2	min χ^2	MCMC	min χ^2
code	Le Phare[t]	WikZ[u]	FAST[a] v0.8b	SpeedyMC[v]	own code
stellar templates	BC03[e]	BC03[e]	BC03[e]	BC03[e]	BC03[e]
IMF	Chabrier	Chabrier	Chabrier	Chabrier	Chabrier
SFH	τ[i]	del-τ[w]	τ[i]	τ[i] + del-τ[w] + const.[l] + lin. incr.[x]	del-τ[w]
log (τ/yr) step[m]	8.0–10.5 9 steps	-∞[y] – 9.3 9 steps	8.5–10.0 0.1	7.0–9.7 —	8.0–10.0 14 steps
metallicity [$Z_\odot$]	0.4, 1	0.2, 0.4, 1, 2.5	1	1	0.2, 0.4, 1, 2.5
log (age/yr) step[m]	7.0–10.1 57 steps	7.7–9.8 24 steps	7.7–10.1 0.1	8.0–10.1 —	7.7–10.1 64 steps
extinction law	Calzetti	Calzetti	Calzetti	Calzetti	Calzetti
extinction E(B-V) step	0.0–0.5 0.1	0.0–1.0 0.025	0.0–1.0 0.025	0.0–1.0 —	0.0–1.5 0.025
nebular emission	yes	no	no	yes	no
priors	[p z]	[p]	[p]	[p]	[p]
reference	6	7	8	9	10

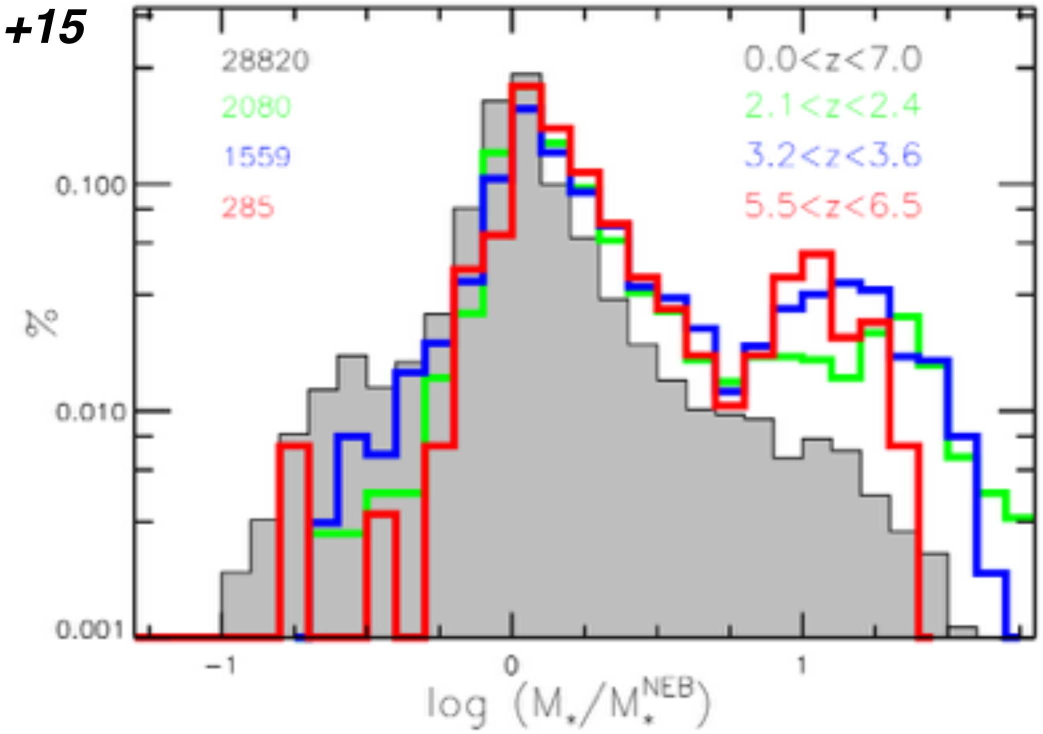
Santini +15


Method 10c
median=0.000±0.002
SIQR=0.10 >2x 13%
Method 11a_τ
median=−0.036±0.001
SIQR=0.08 >2x 7%
Method 12a
median=−0.055±0.001
SIQR=0.07 >2x 4%
Method 13a_τ
median=0.123±0.001
SIQR=0.05 >2x 4%
Method 14a
median=−0.073±0.001
SIQR=0.07 >2x 8%
Method 4b
IMF corrected
median=−0.149±0.002
SIQR=0.13 >2x 26%
1
0
−1
−2
8 9 10 11
log (M*/M*MEDIAN all)
log M*MEDIAN all/M⊙

Dependence on SFH : limited impact

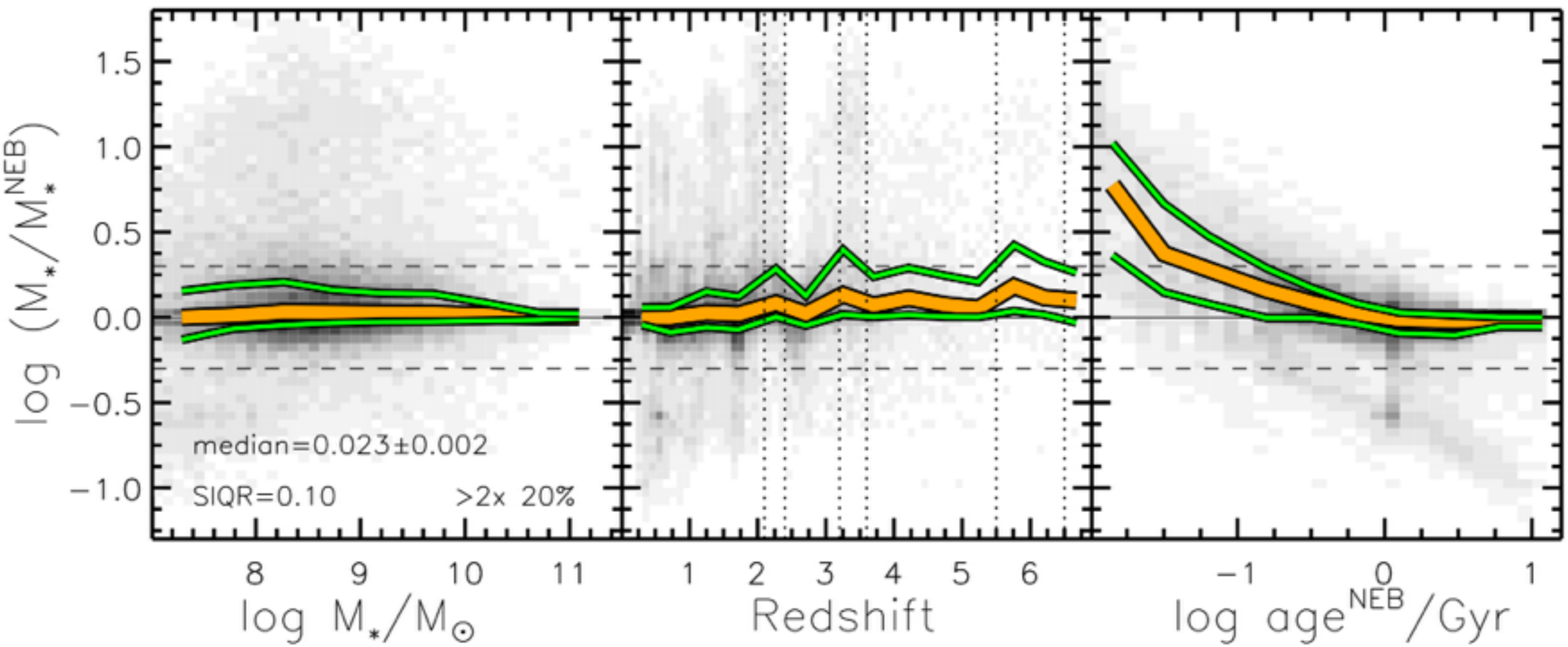


Santini +15



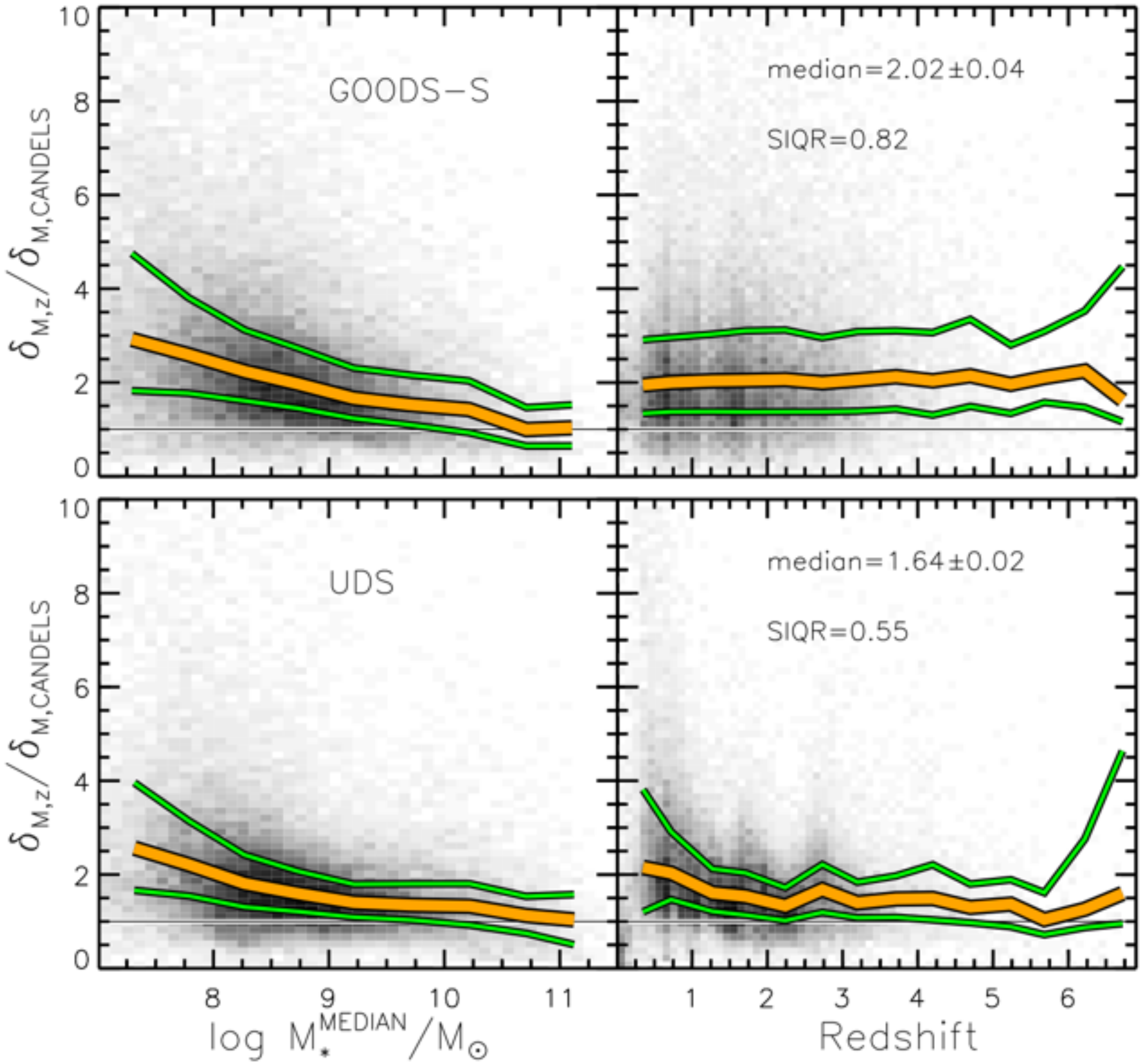
The treatment of nebular emission is important for 15% of the sample.

Specific redshift ranges, young/star-forming objects.



Santini +15

Dominant uncertainty: photometric redshift, not choice of models



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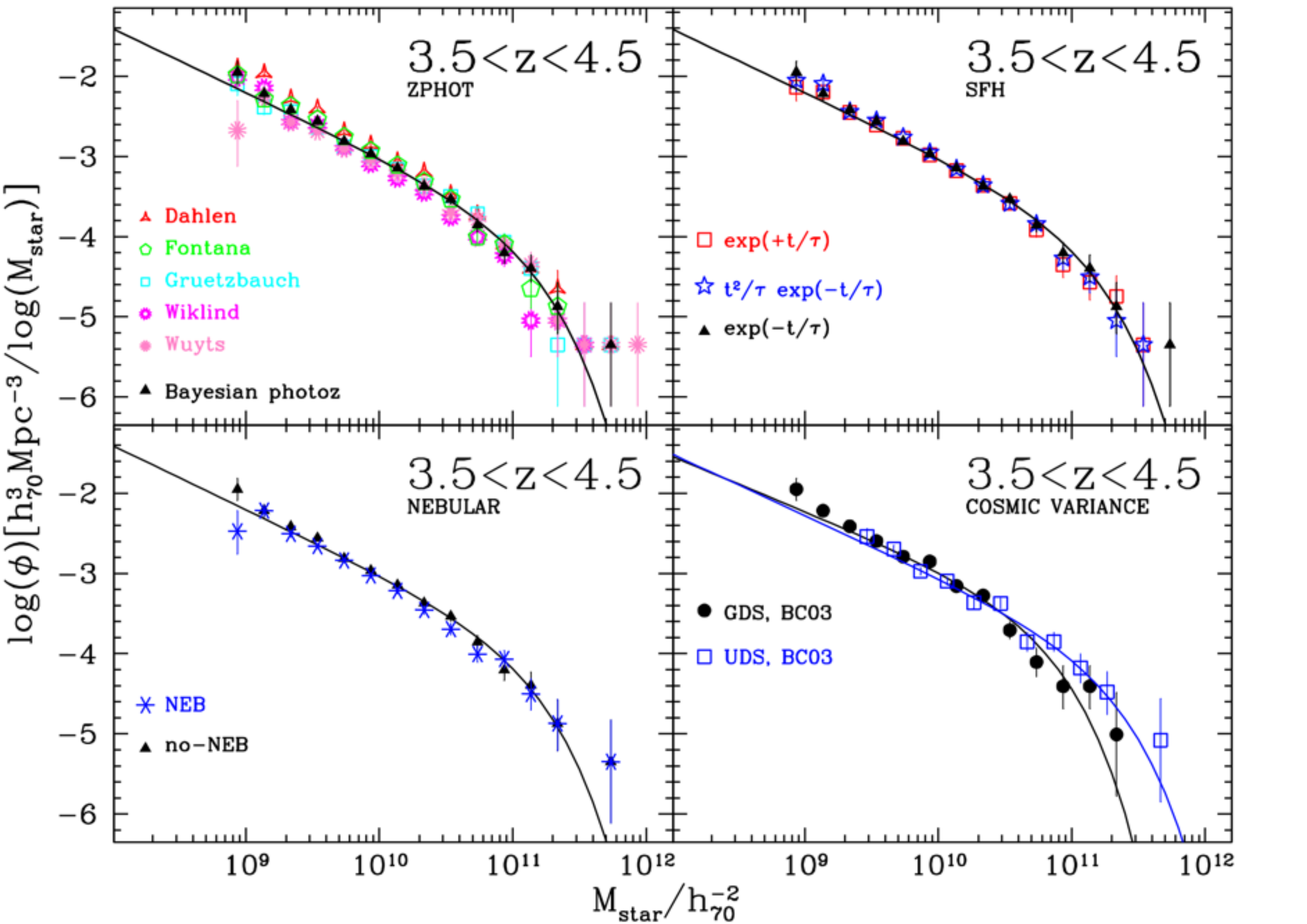
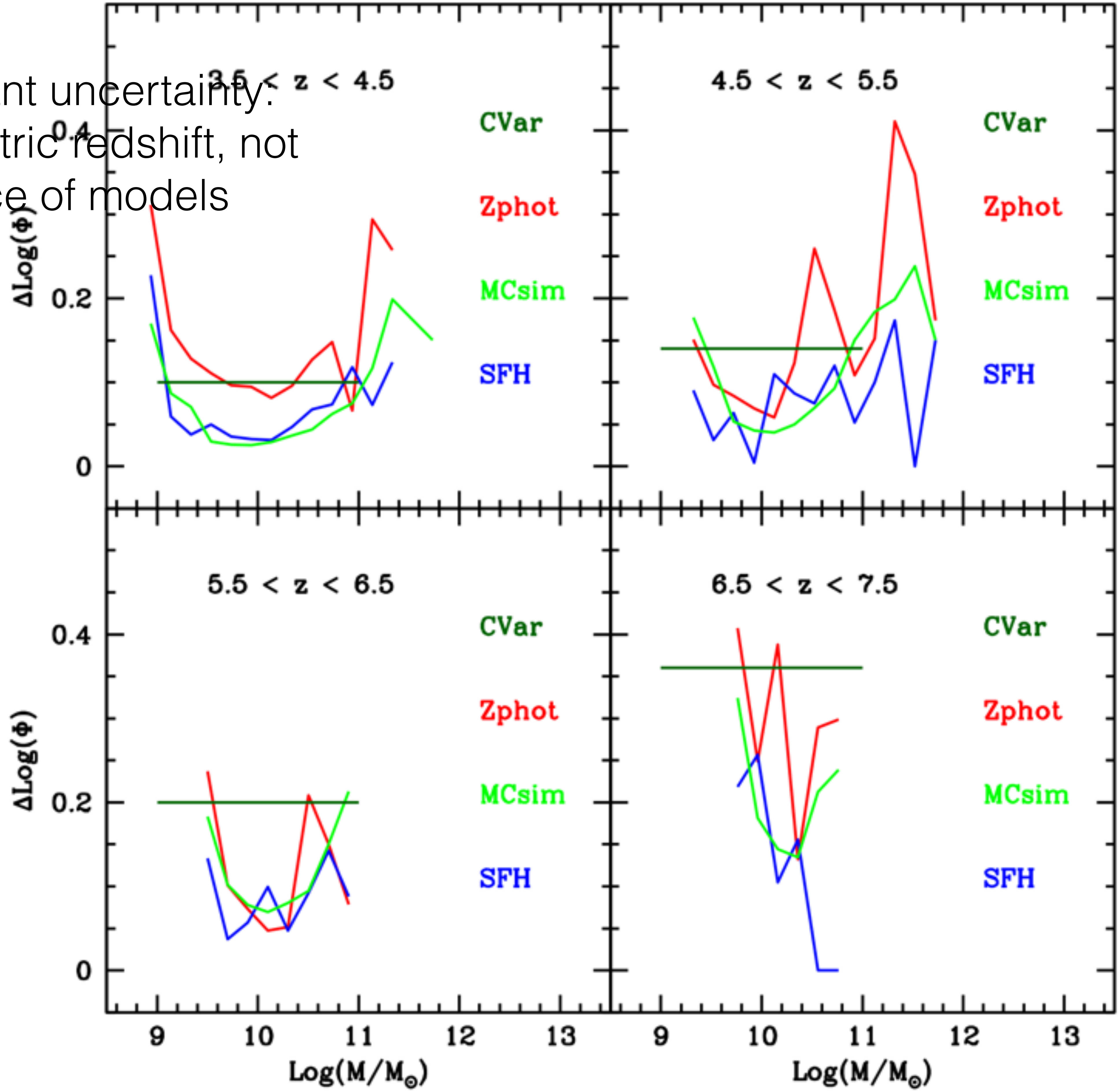
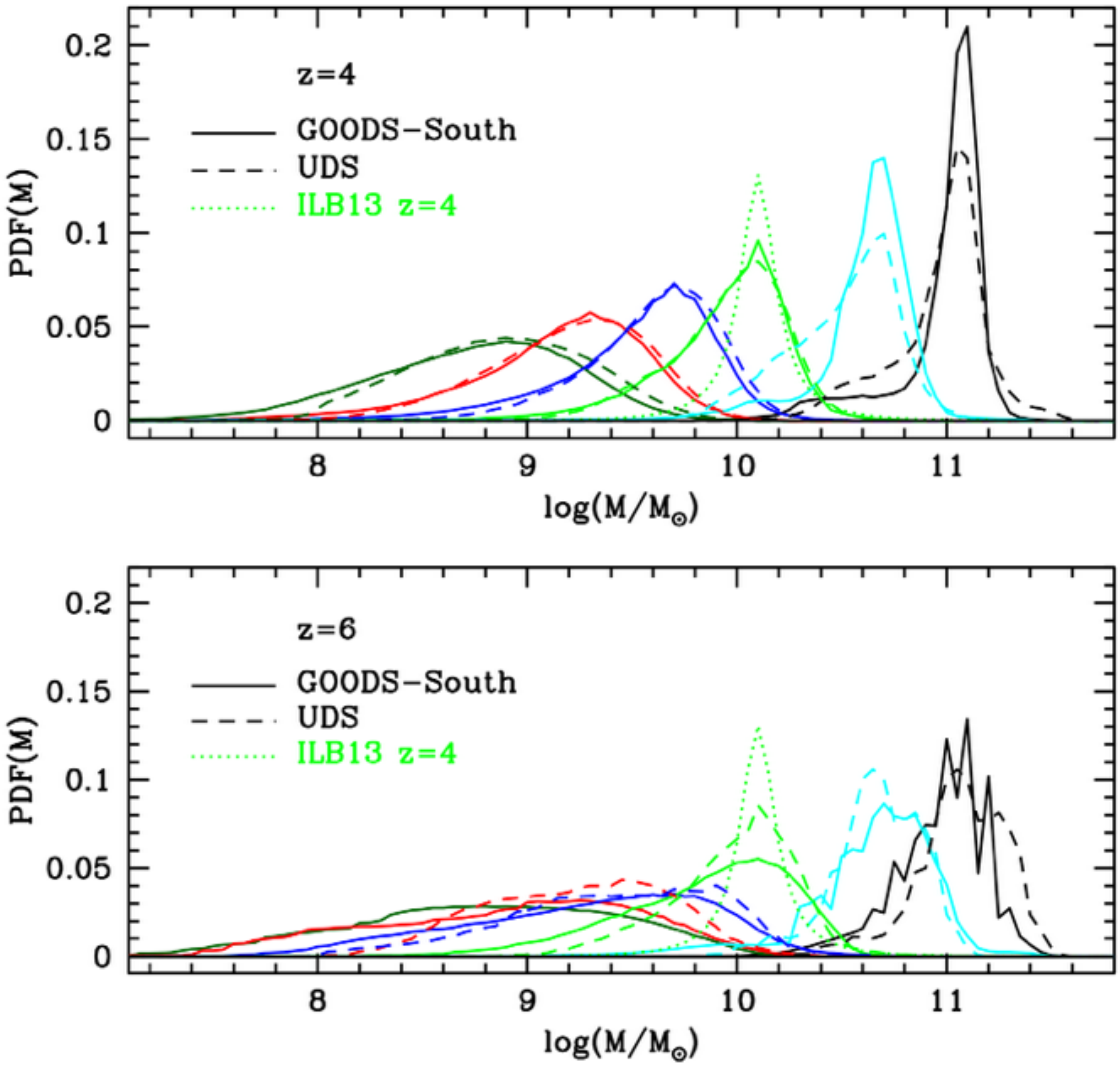

3.5<z<4.5
ZPHOT
Dahlen
Fontana
Gruetzbauch
Wiklind
Wuyts
Bayesian photoz
3.5<z<4.5
SFH
exp(+t/τ)
t²/τ exp(−t/τ)
exp(−t/τ)
3.5<z<4.5
NEBULAR
NEB
no−NEB
3.5<z<4.5
COSMIC VARIANCE
GDS, BC03
UDS, BC03
log(ϕ)[h³₇₀Mpc⁻³/log(M_star)]
M_star/h⁻²₇₀
−2
−3
−4
−5
−6
10⁹
10¹⁰
10¹¹
10¹²

Grazian +15

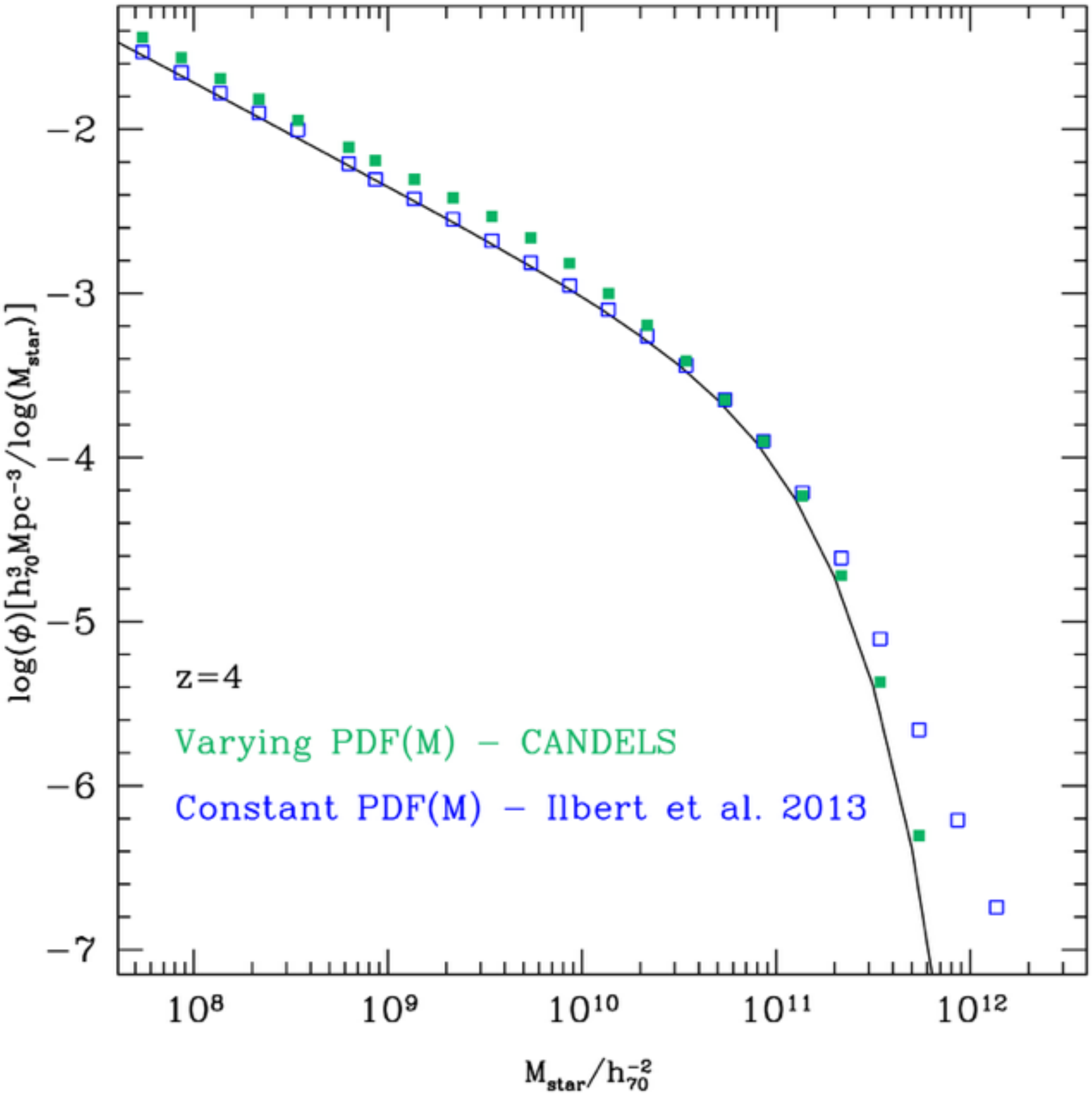
Dominant uncertainty: photometric redshift, not choice of models



Grazian +15



z=4
GOODS−South
UDS
ILB13 z=4
PDF(M)
0.2
0.15
0.1
0.05
0
8
9
10
11
$\log(M/M_\odot)$
z=6
GOODS−South
UDS
ILB13 z=4
PDF(M)
0.2
0.15
0.1
0.05
0
8
9
10
11
$\log(M/M_\odot)$



log(ϕ)[h³₇₀Mpc⁻³/log(M_star)]
M_star/h₇₀⁻²
z=4
Varying PDF(M) – CANDELS
Constant PDF(M) – Ilbert et al. 2013

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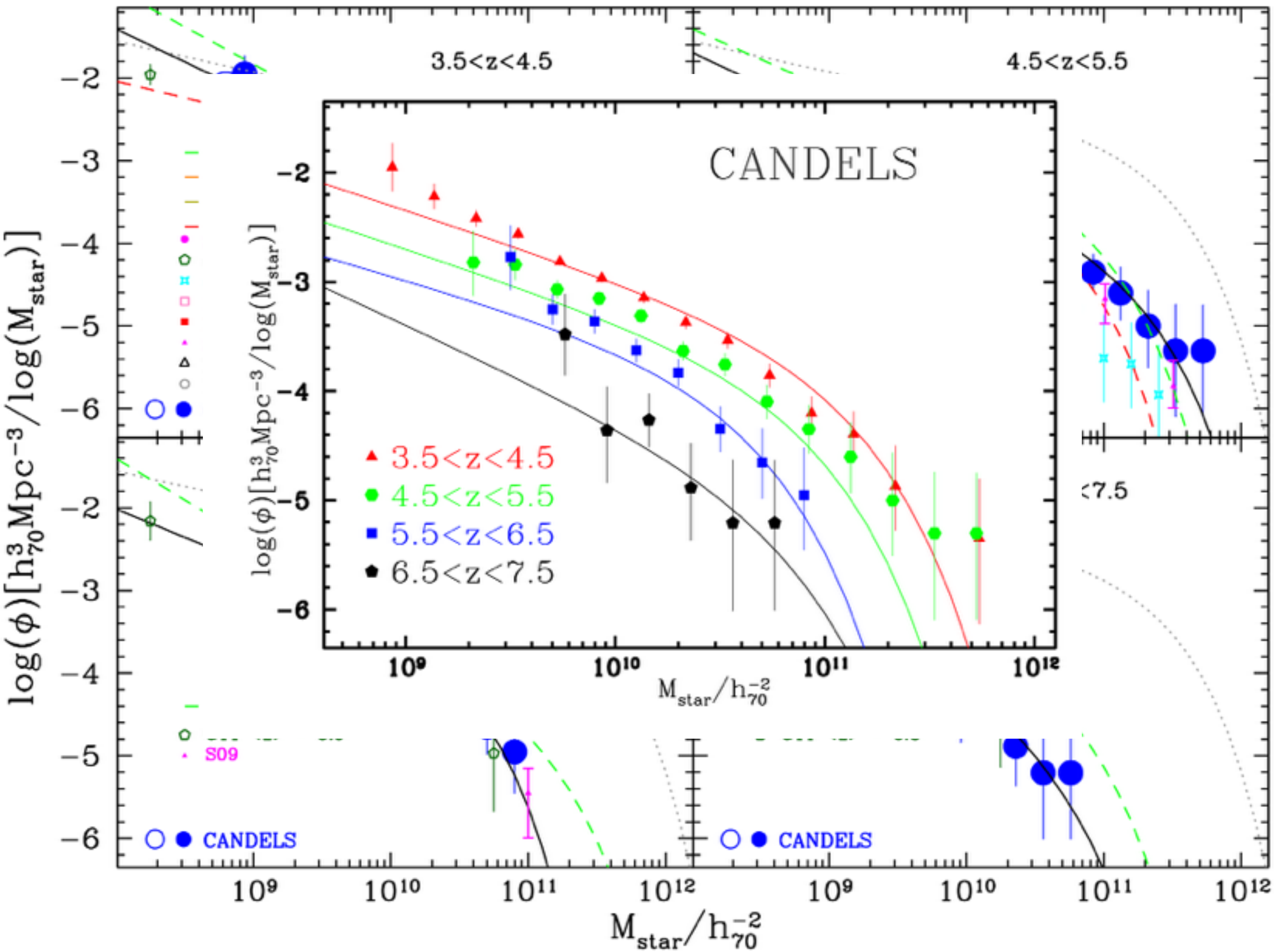
CANDELS - GOODS-S+UDS. (Grazian, AF+15, astro-ph)
H-selected sample, full photo-z selection



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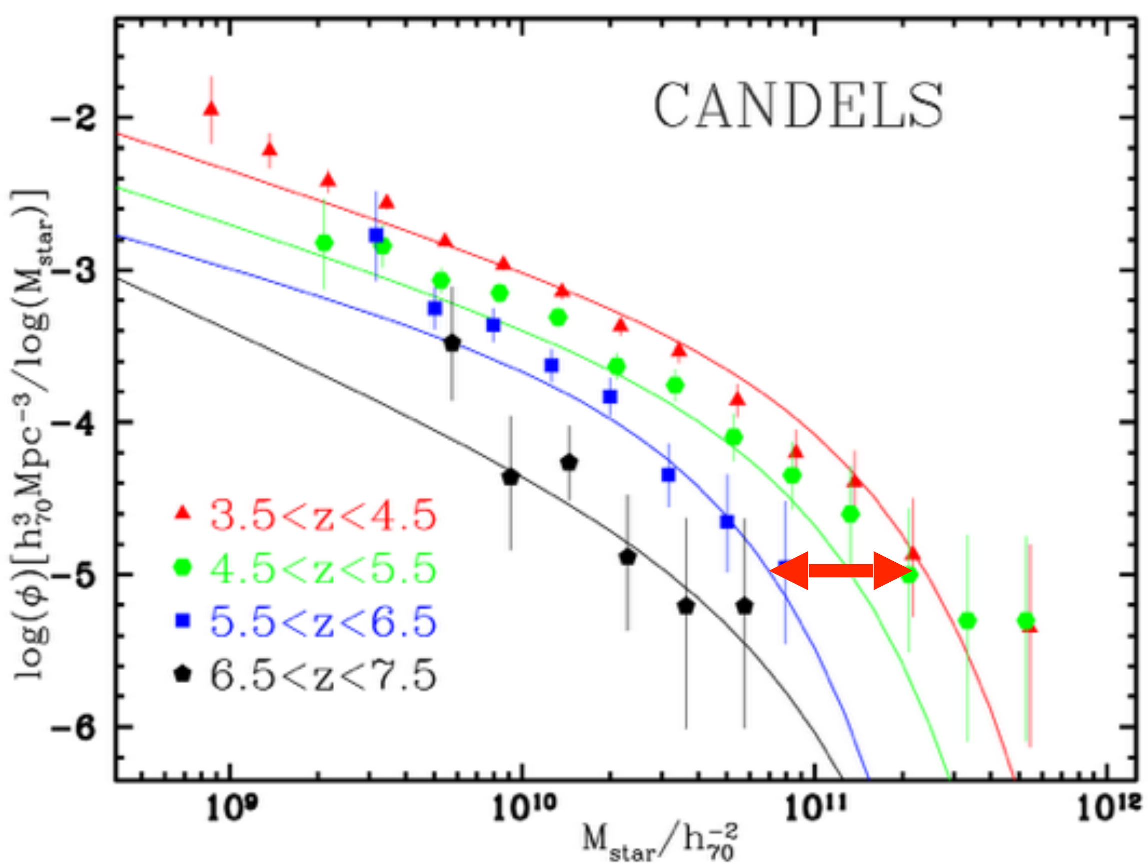
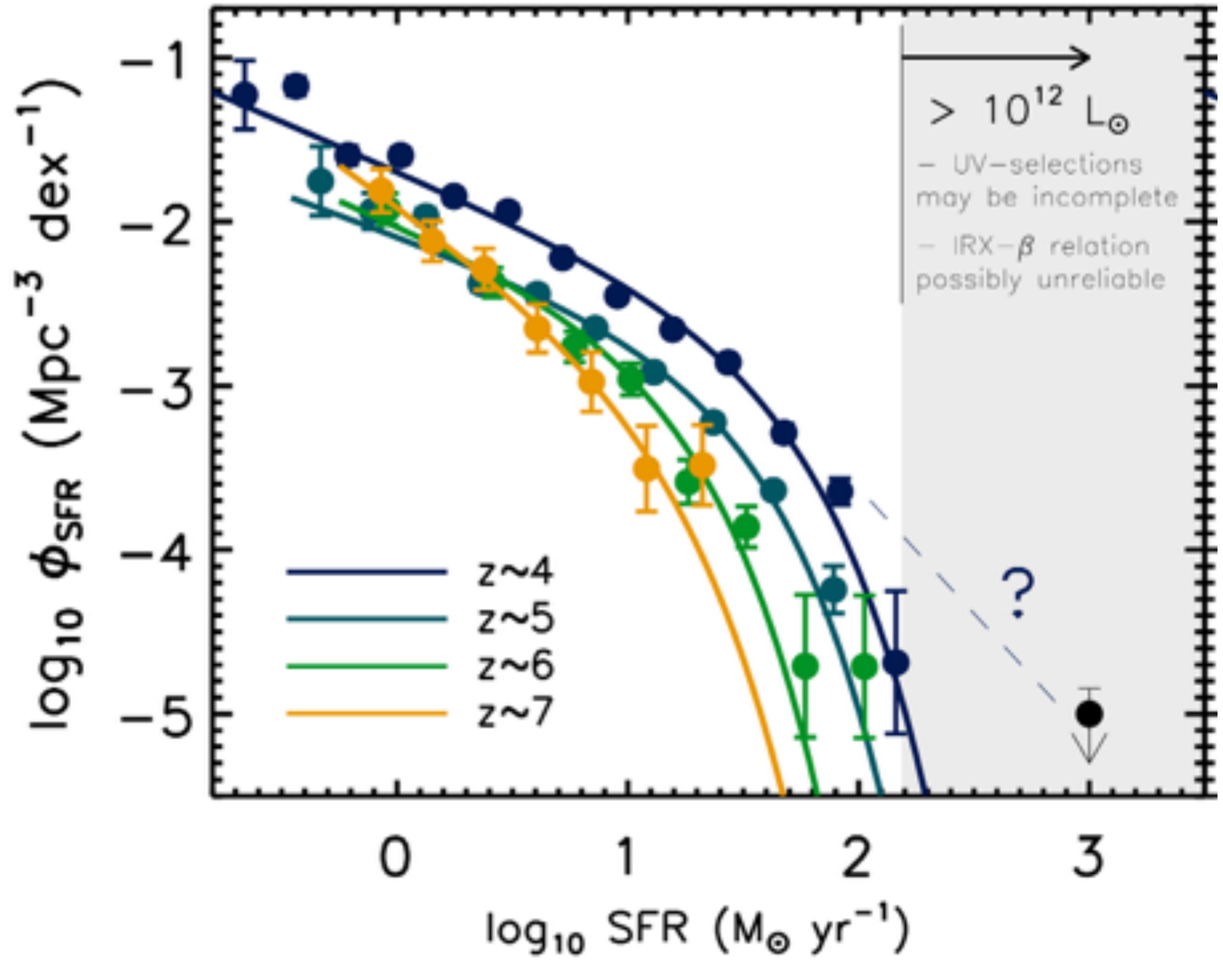
Is the overall picture consistent?

Grazian+14 *Smit+12*

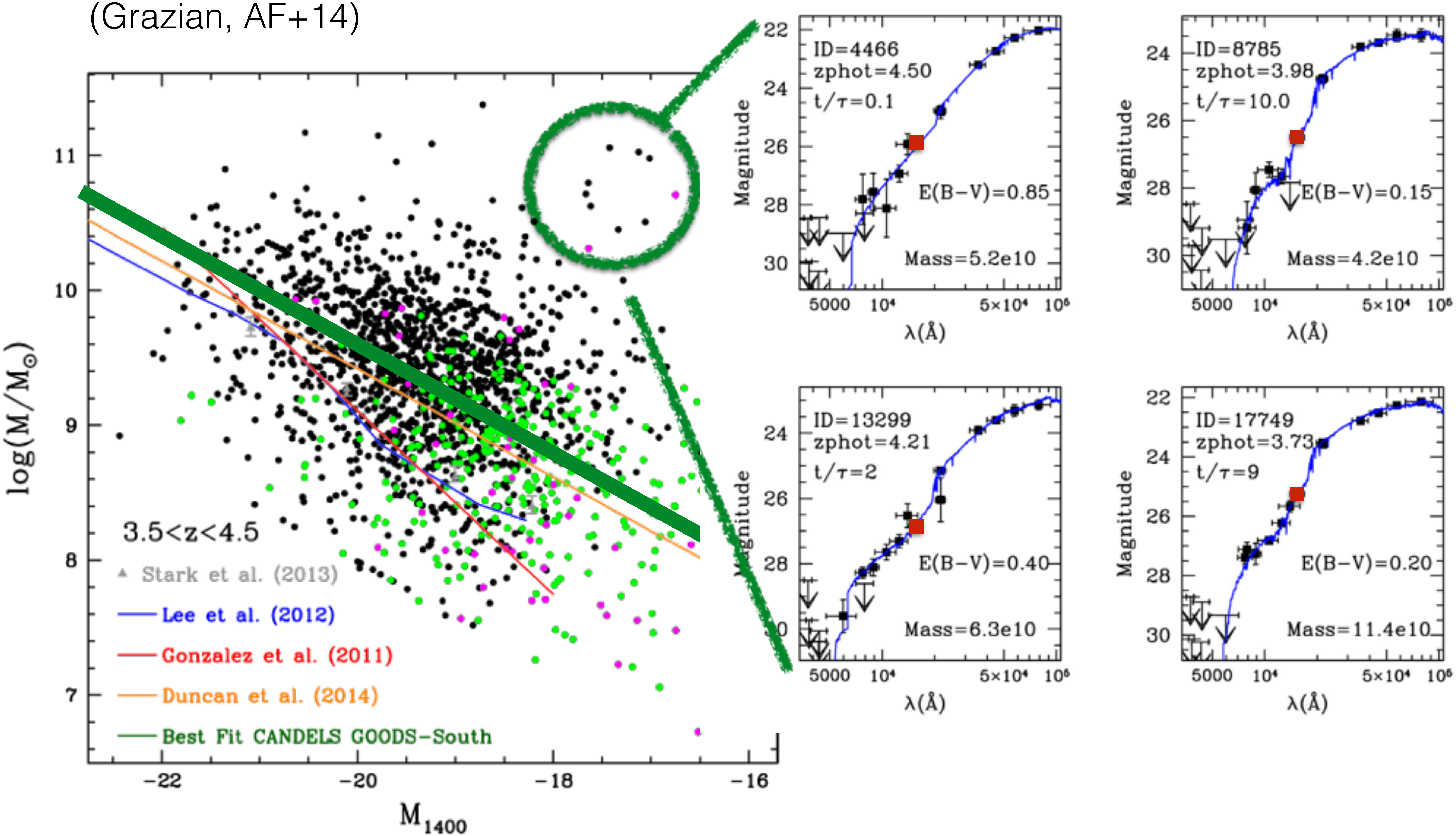




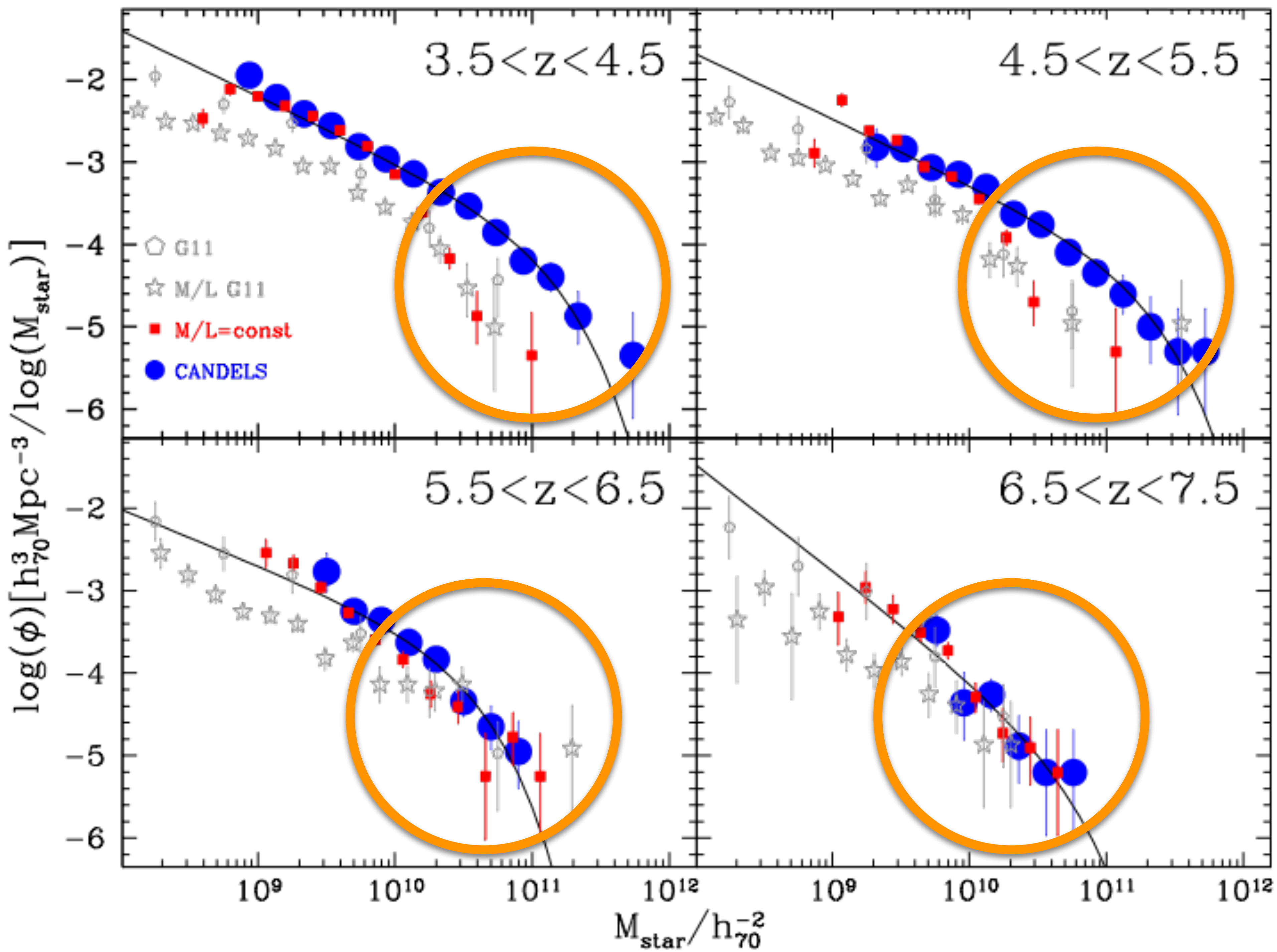
z=6 ->4 ΔM / Δt: ~290 Msun/yr

- To fix, 3 options
  - Revises (upward) SFR estimates in LBG (Castellano+14);
  - Imply large merging
  - A missing population of dusty sfr-ing galaxies at z>4

(Grazian, AF+14)



Grazian, AF,+14,



Real decrease or selection effects playing against?
We need JWST for NIRCam/MIRI-selected samples

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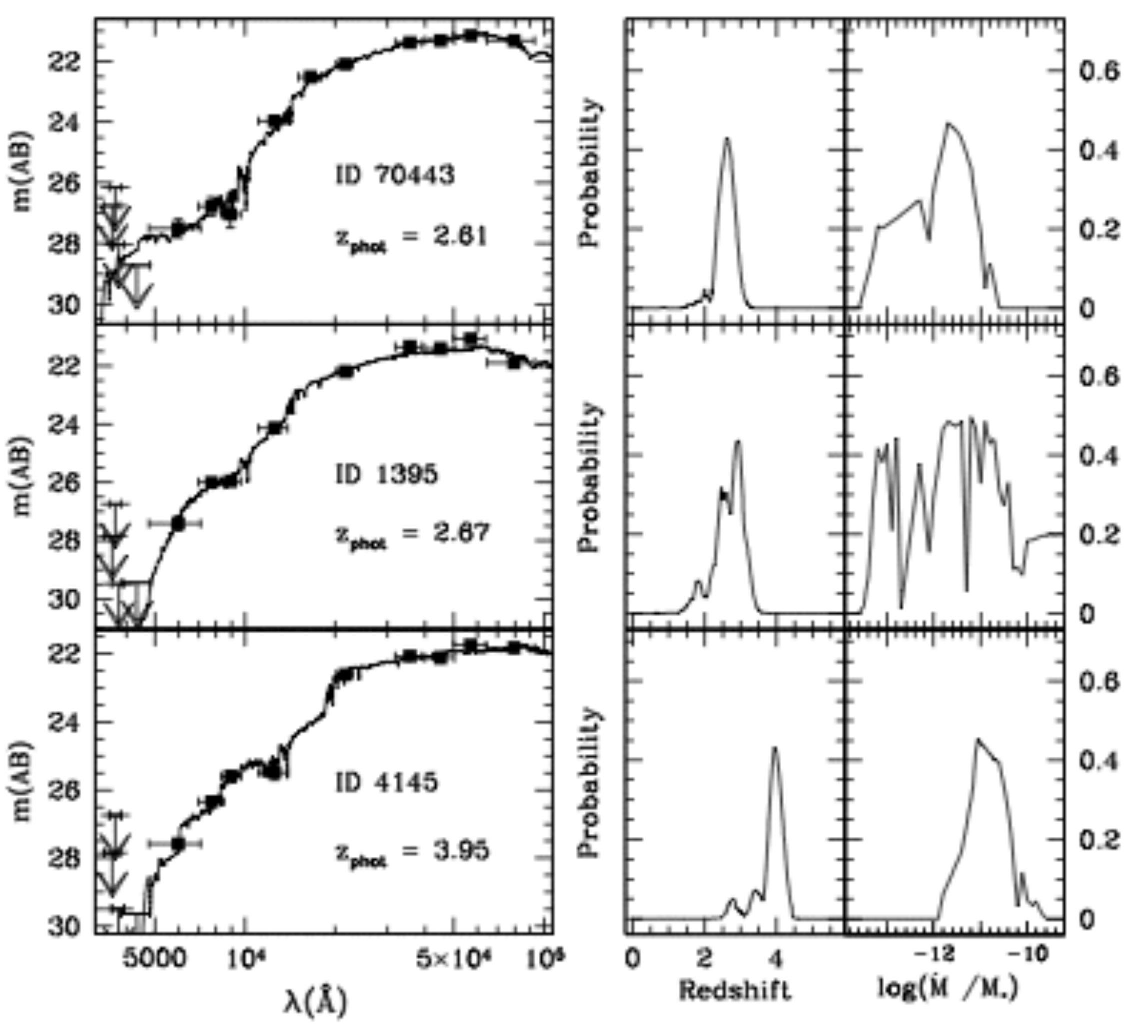
Passive galaxies at z>>2

Fontana et al 2009

SED fitting + no 24μm emission

A. Fontana et al.: The fraction of quiescent massive galaxies in the early Universe 19



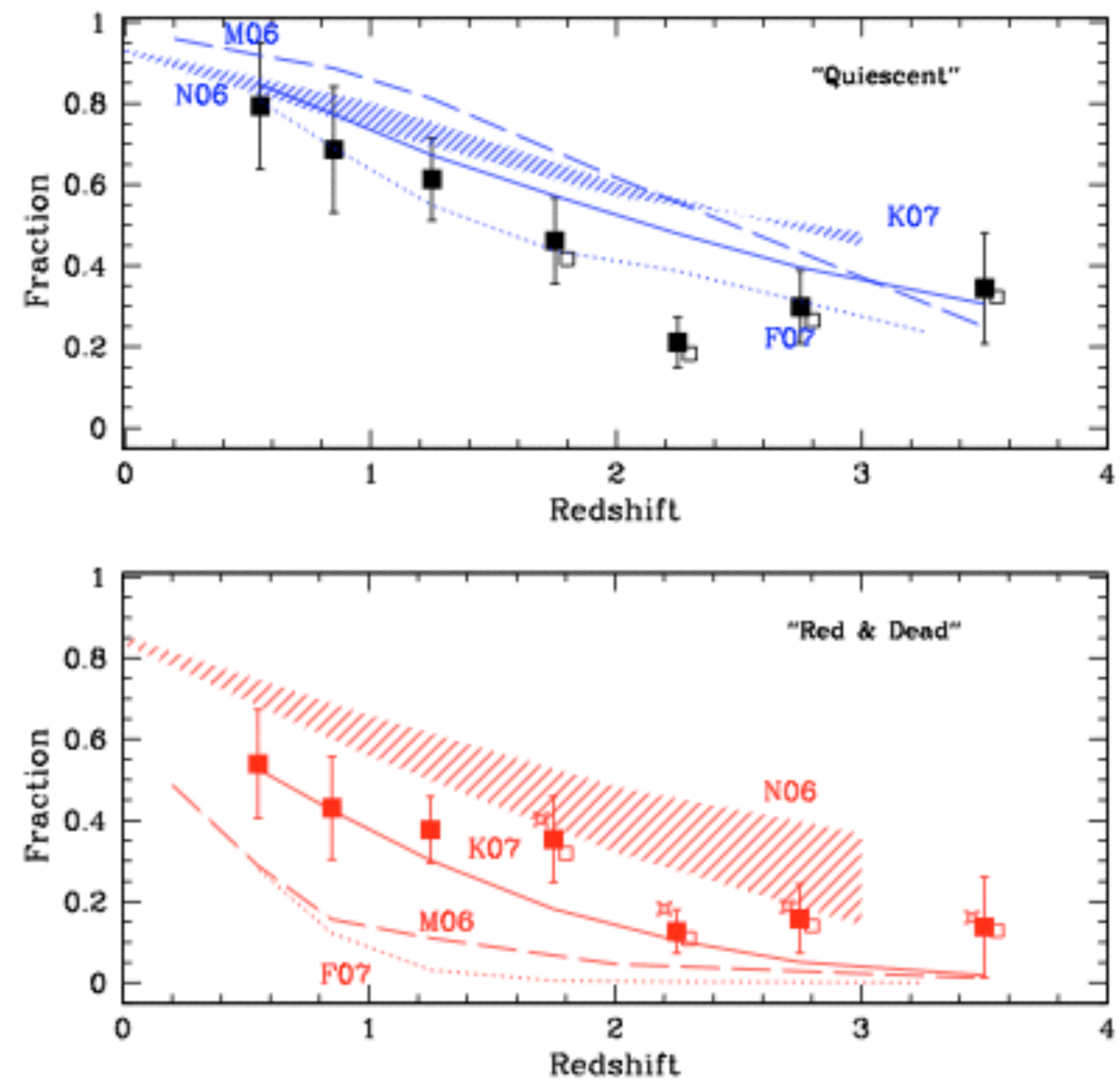
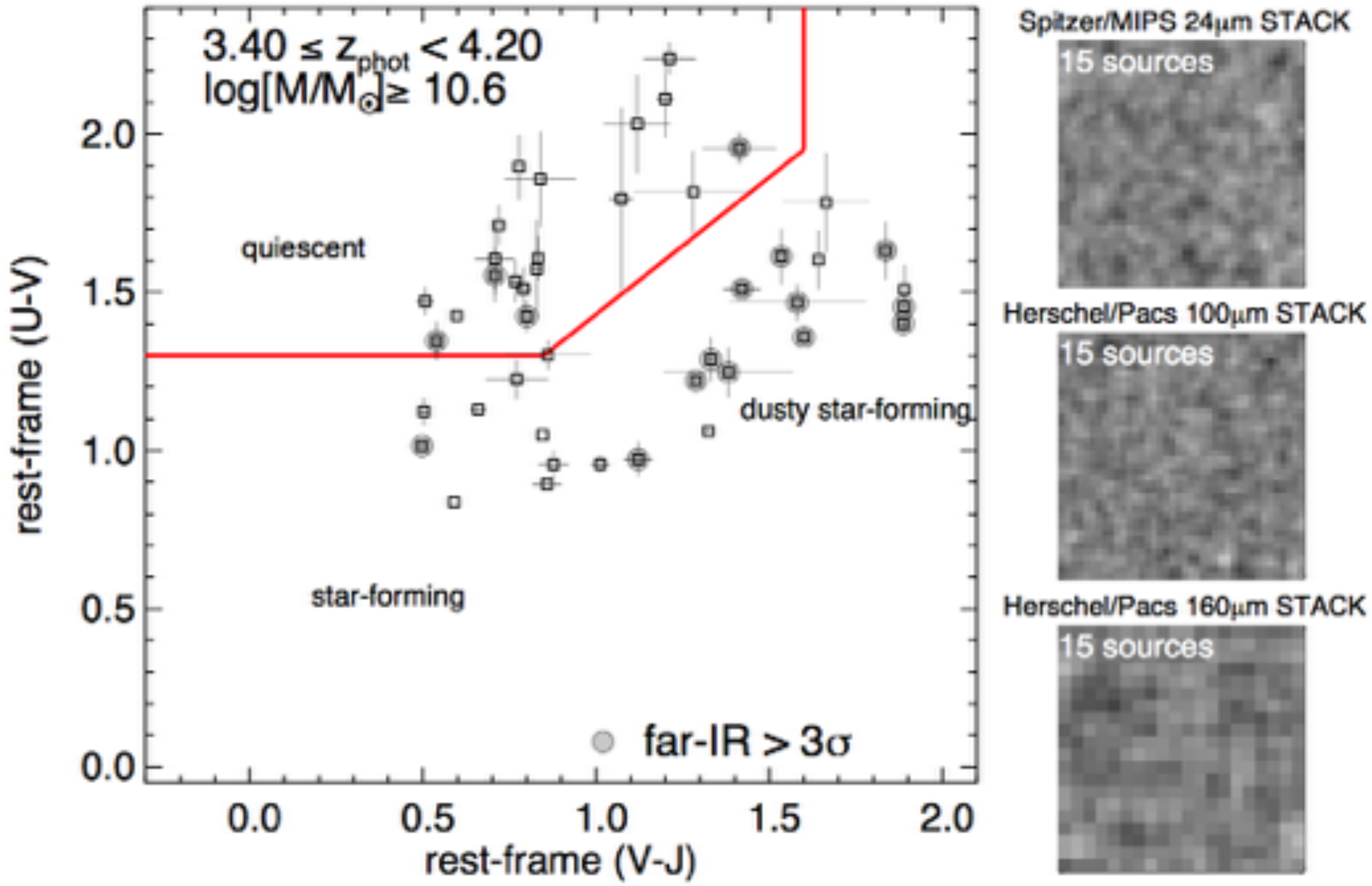
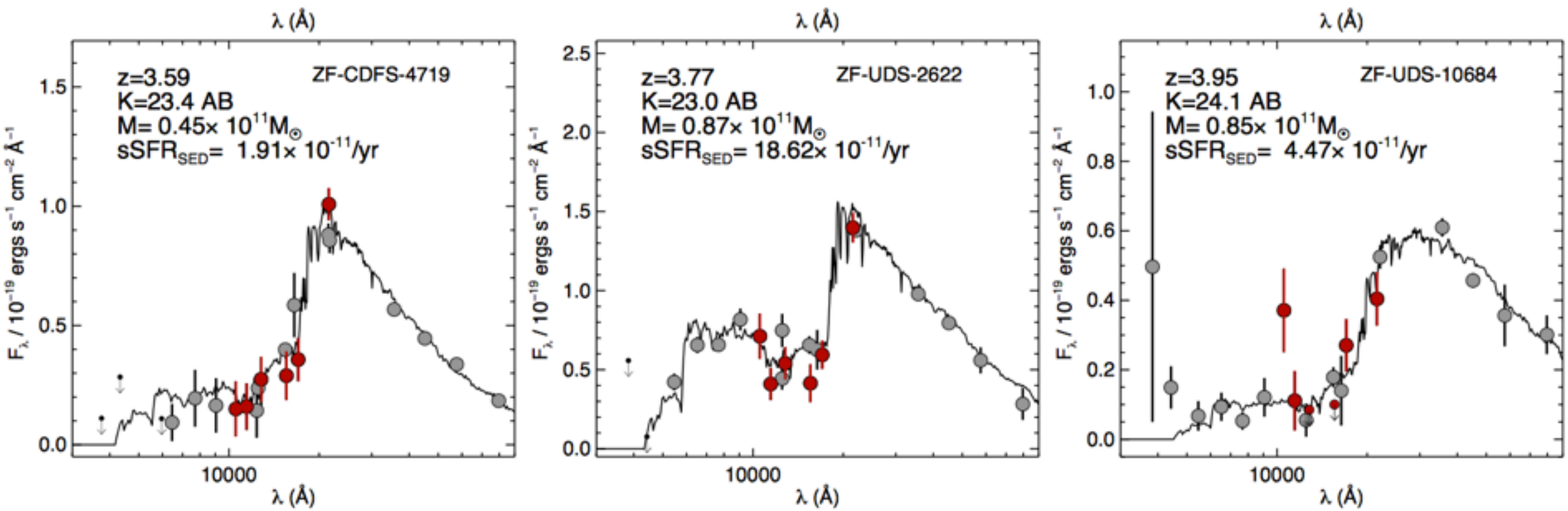


Fig. 4. Examples of "red and dead" galaxies at $z > 2.5$. For each object, from left to right: the observed flux in the GOODS band and the best-

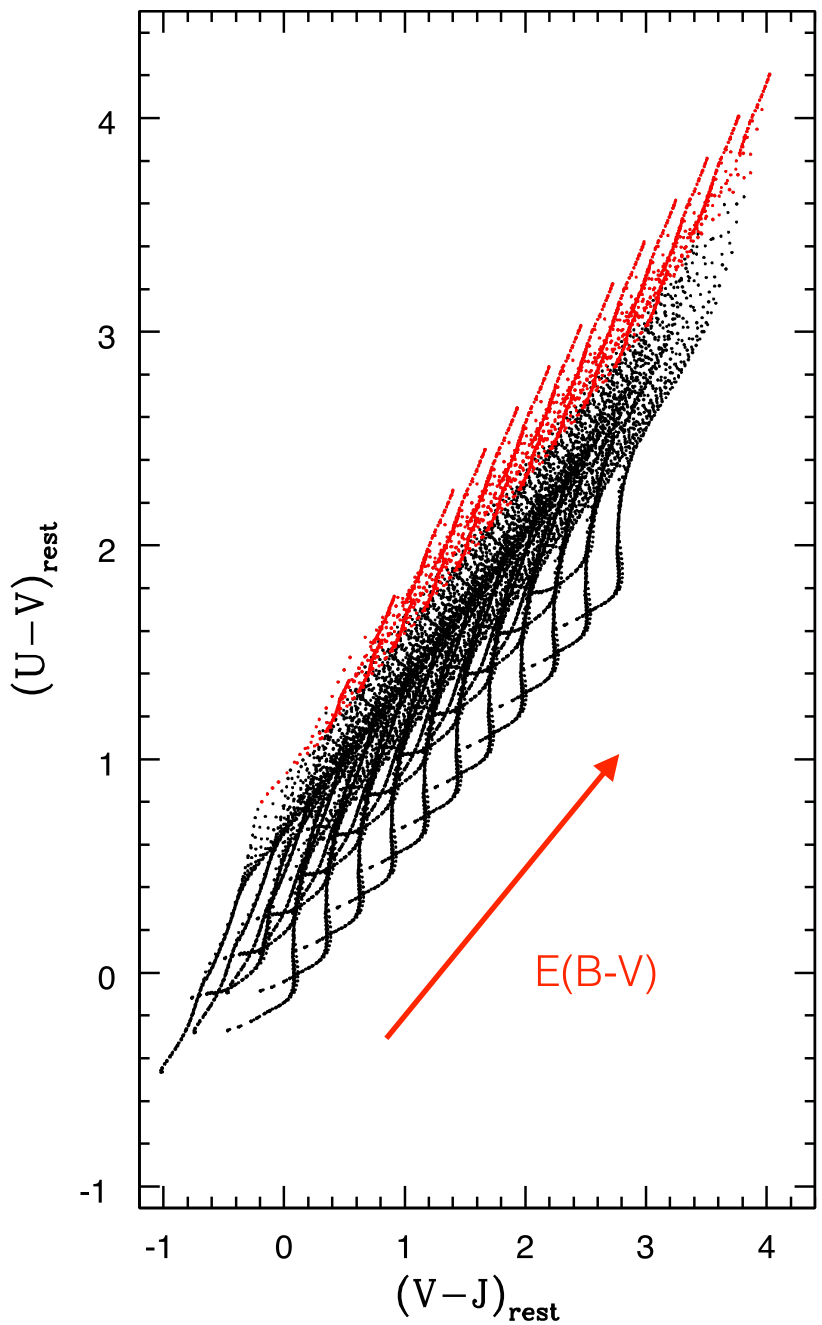
Straatman+ 14

z~4 massive quiescent galaxies from ZFOURGE

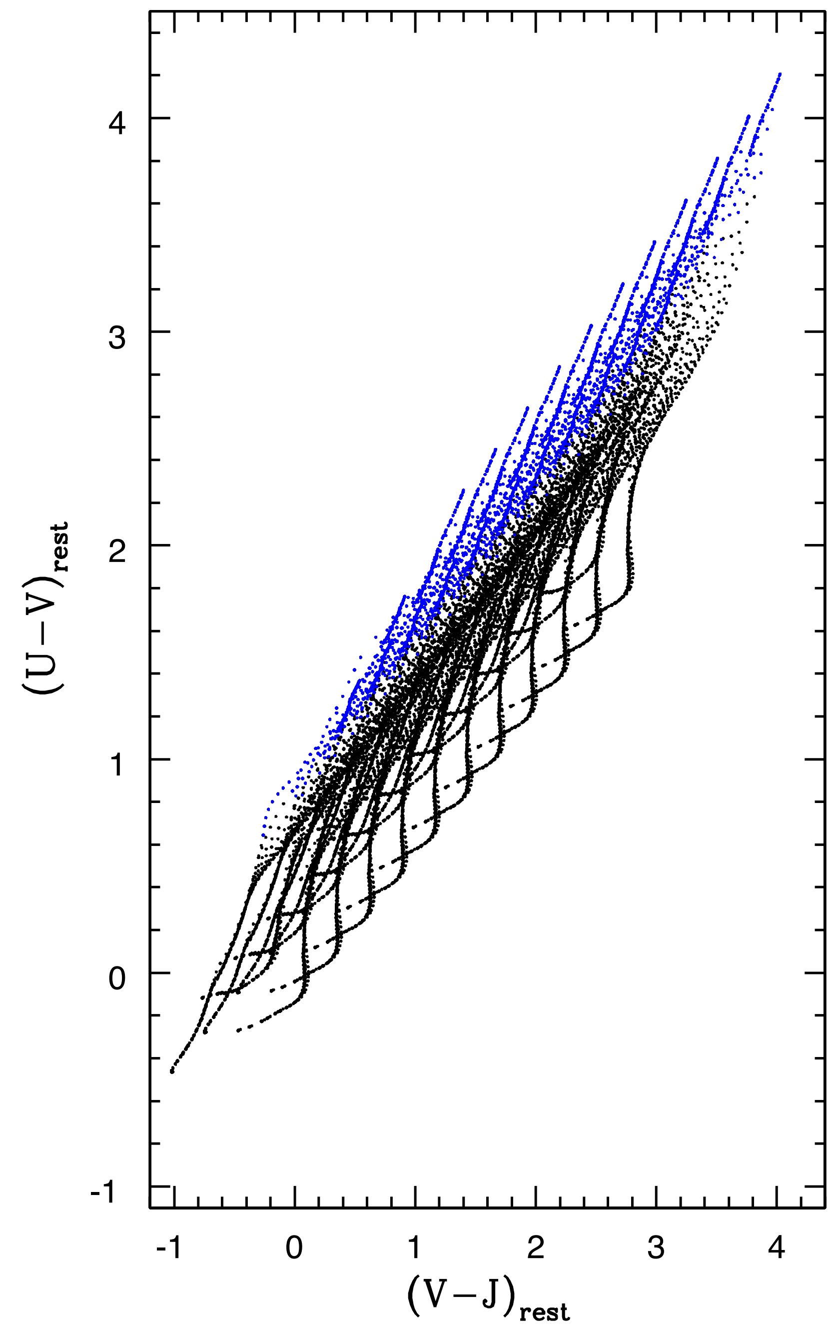




SSFR<1E-11



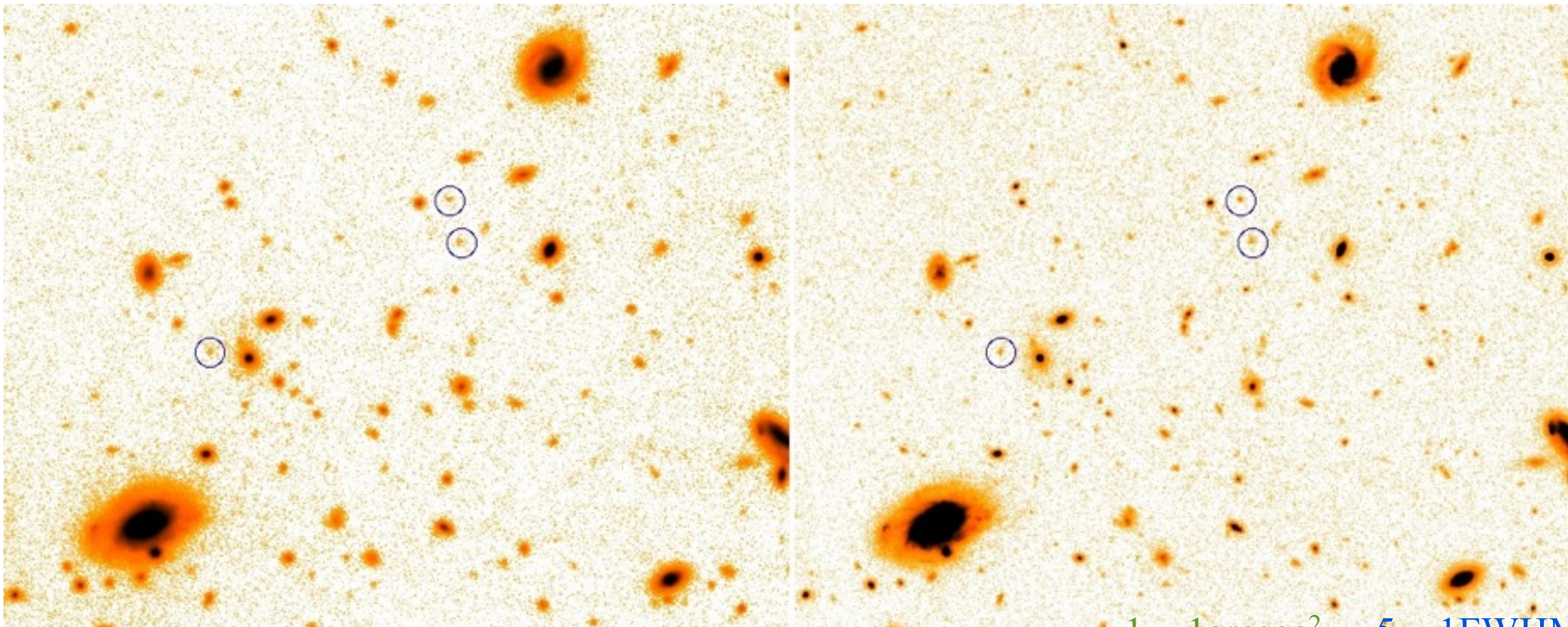
Age/τ>4



HUGS (Hawk-I UDS and GOODS Survey):

A.Fontana (PI), J. Dunlop, Faber, Ferguson et al...

Large Hawk-I@VLT program (250hr)



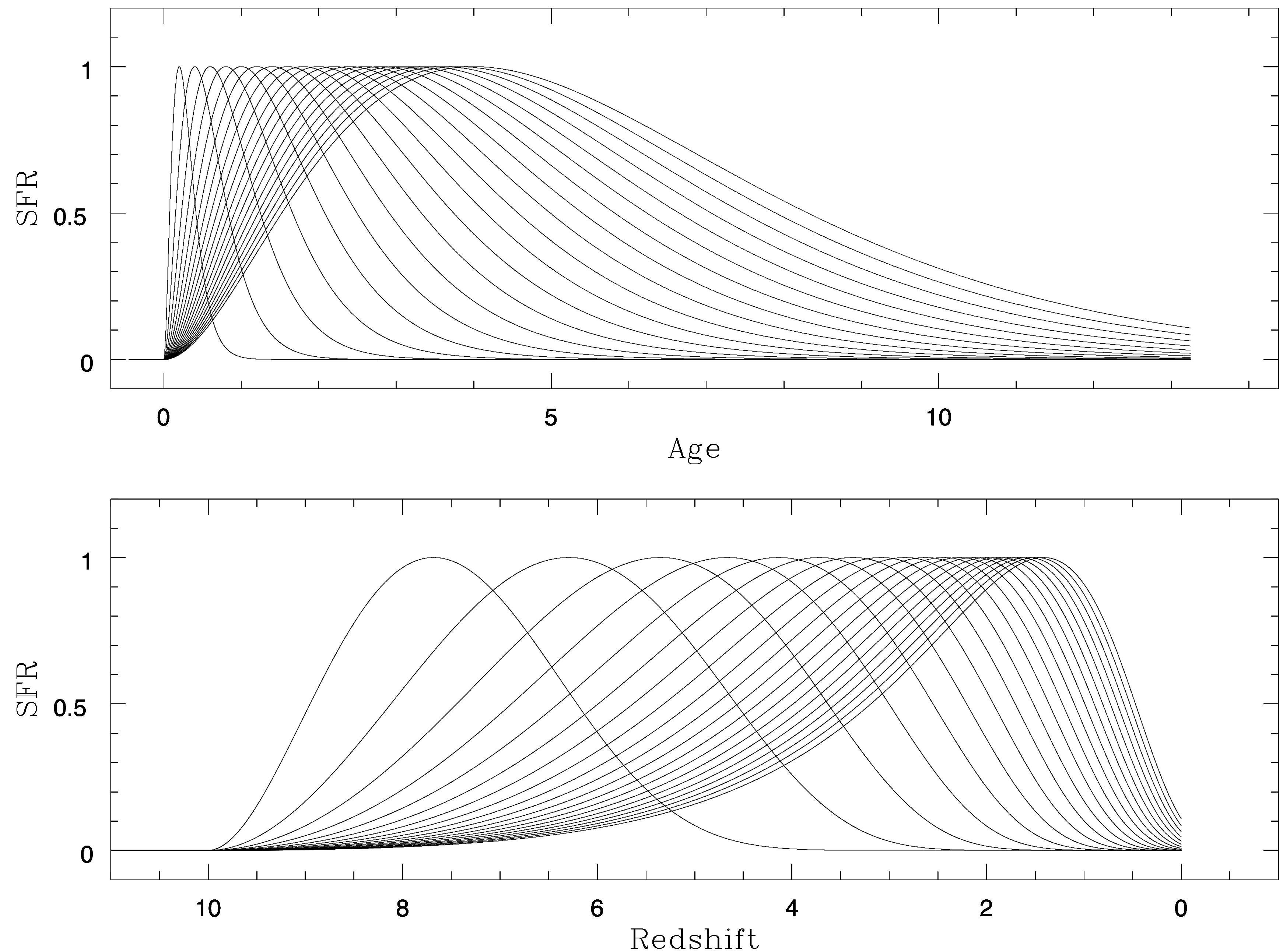
1σ, 1arcsec^2 5σ, 1FWHM^2

Layout and summary of observations for the GOODS-S field. We note that each pointing has been rotated with PA=-19.5degrees

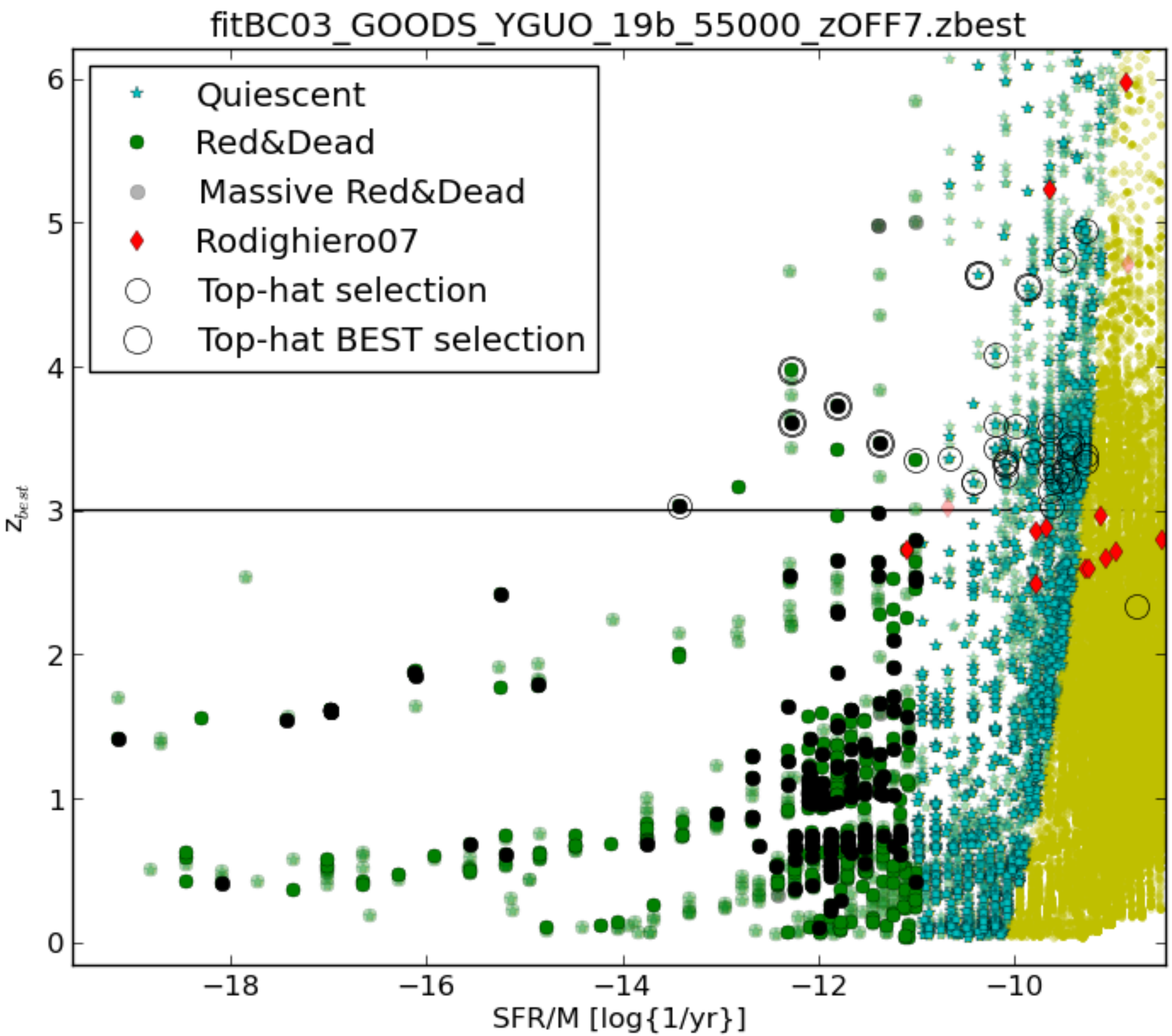
Pointing	Central RA	Central DEC	Exposure time (Sec)	Final seeing	maglim(1)	maglim(2)
			K band			
GOODS-D1	03:32:36.835	-27:47:45.24	113520	0.39	27.8	26.5
GOODS-D2	03:32:24.890	-27:48:33.22	112800 31h	0.38	27.8	26.5
GOODS-W1	03:32:41.080	-27:51:44.32	47220	0.43	27.4	26.0
GOODS-W2	03:32:29.650	-27:44:37.26	40800	0.38	27.3	26.0
GOODS-W3	03:32:31.796	-27:51:01.74	37320	0.38	27.3	25.9
GOODS-W4	03:32:20.242	-27:44:59.97	41880	0.42	27.3	25.8

Traditional tau-model stink

1) Inclusion of a variety of SFH:
constant, exp. declin, inverted tau, **t^2exp-t/τ**



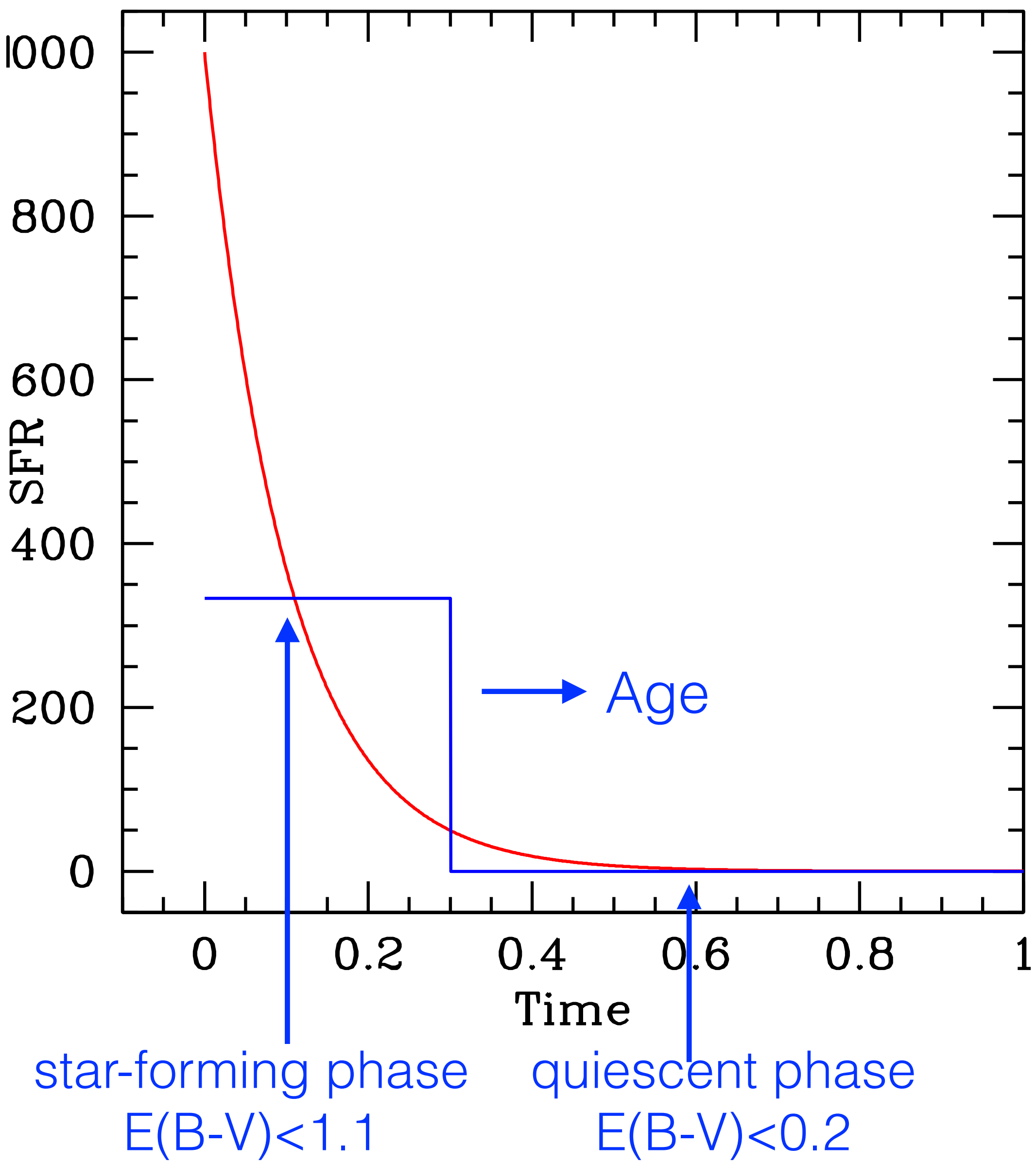
Merlin+15

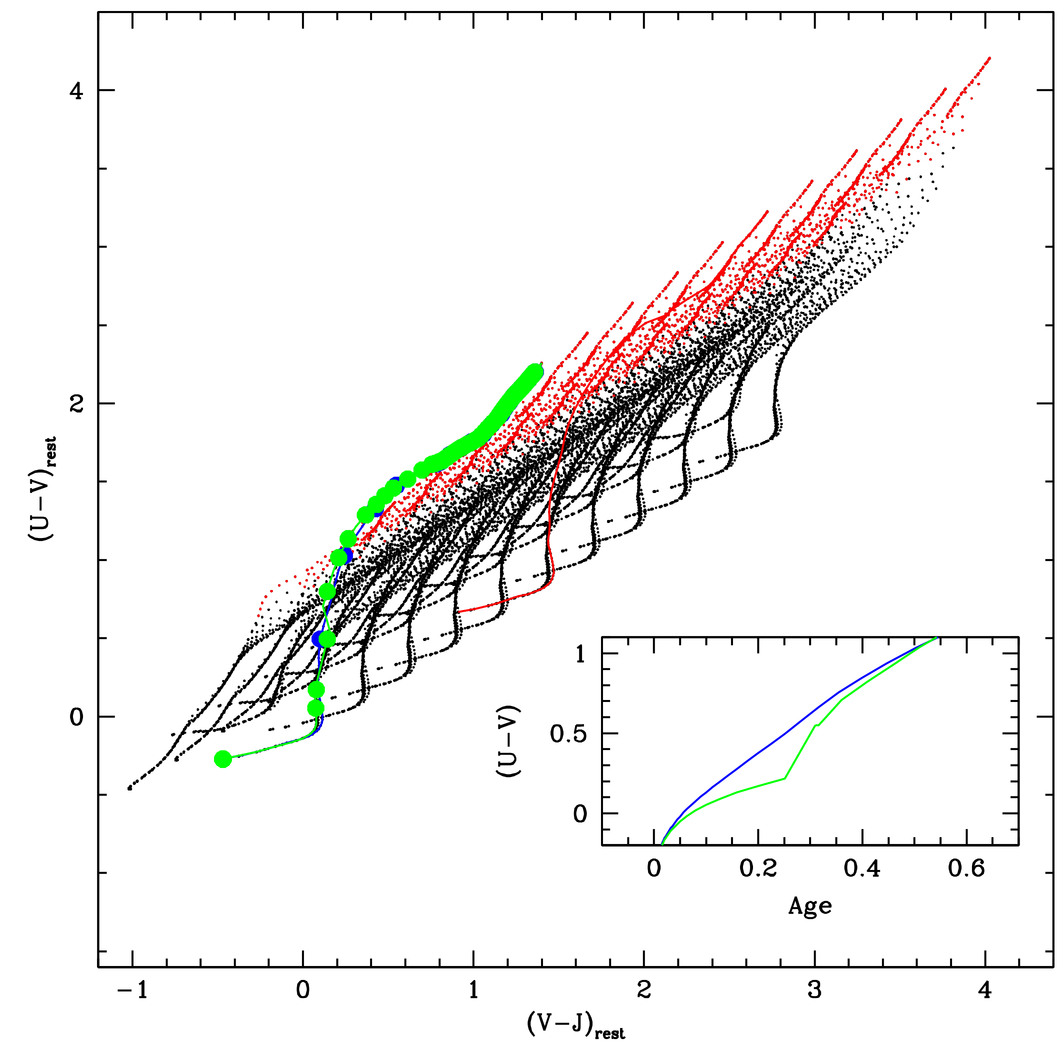


fitBC03_GOODS_YGUO_19b_55000_zOFF7.zbest
Quiescent
Red&Dead
Massive Red&Dead
Rodighiero07
Top-hat selection
Top-hat BEST selection
z_{best}
SFR/M [log{1/yr}]
−18
−16
−14
−12
−10
0
1
2
3
4
5
6

“Top-hat” (aka truncated) SFH

BC03 + all metallicities + Calzetti law





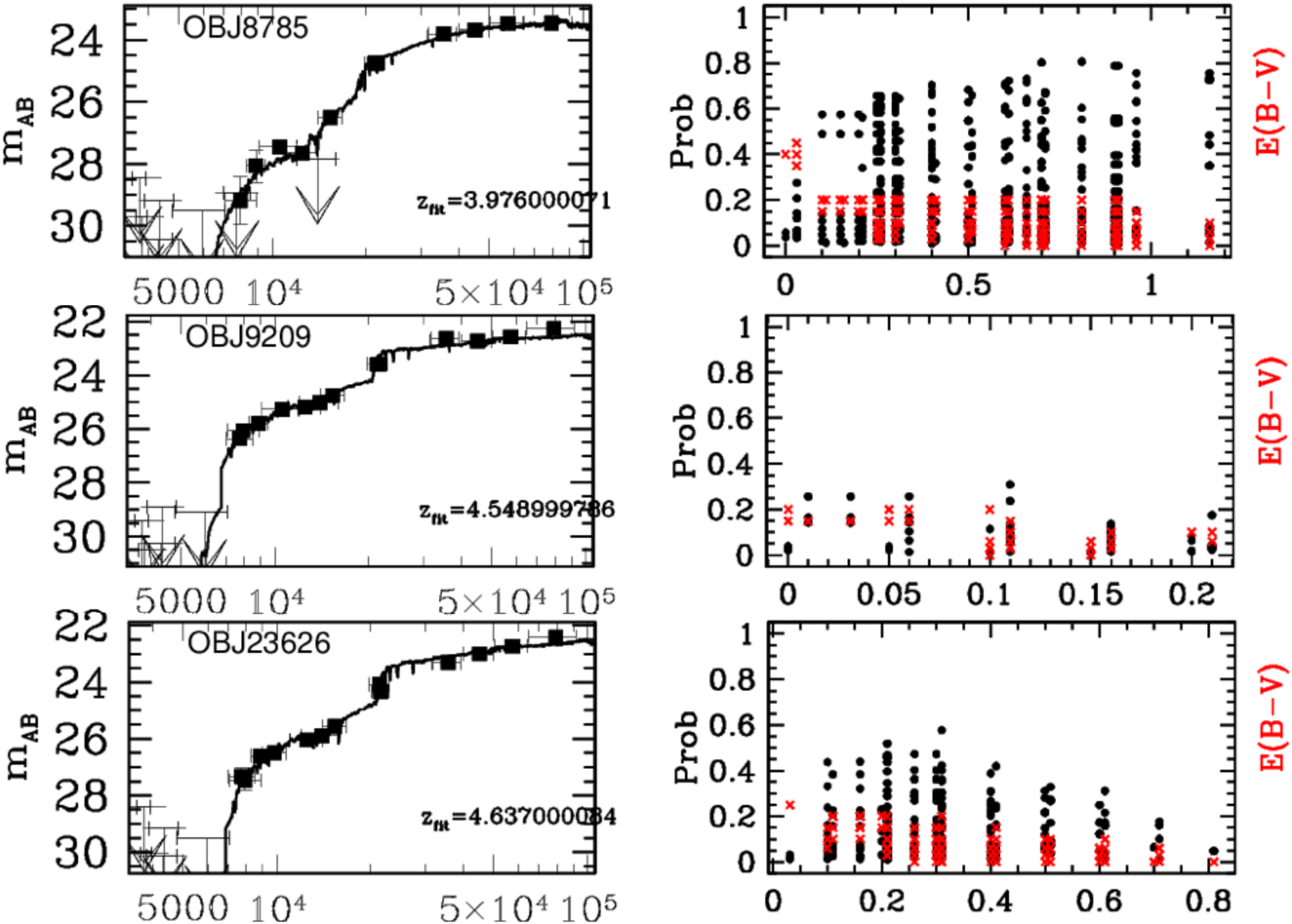
New selection:

Use top-hat libraries with varying durations of the burst (tau parameter) from 0.3 to 3 Gyrs + dust reduced after burst max(E(B-V))=0.2 using CANDELS official photo-z

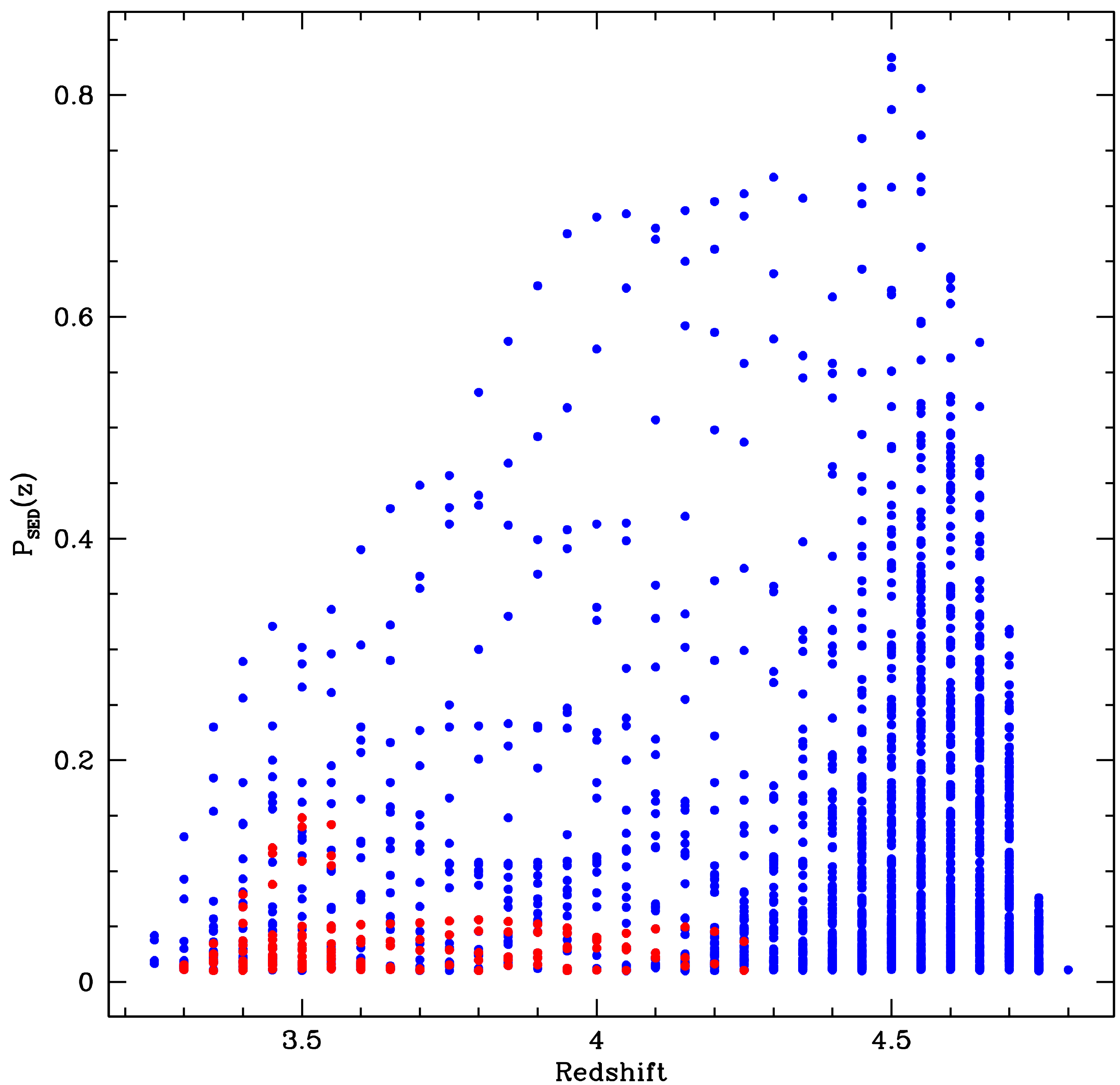
Models with age > 0 are after burst, passively evolving; models with age < 0 are still star forming ("age" has no sense)

K+IRAC1,2(,3,4) detected objects, z_off > 3,
quiescent (sSFR<1/t_U(z));
fit them with the top-hat library and select sources which have NO star forming solutions with prob > 2%

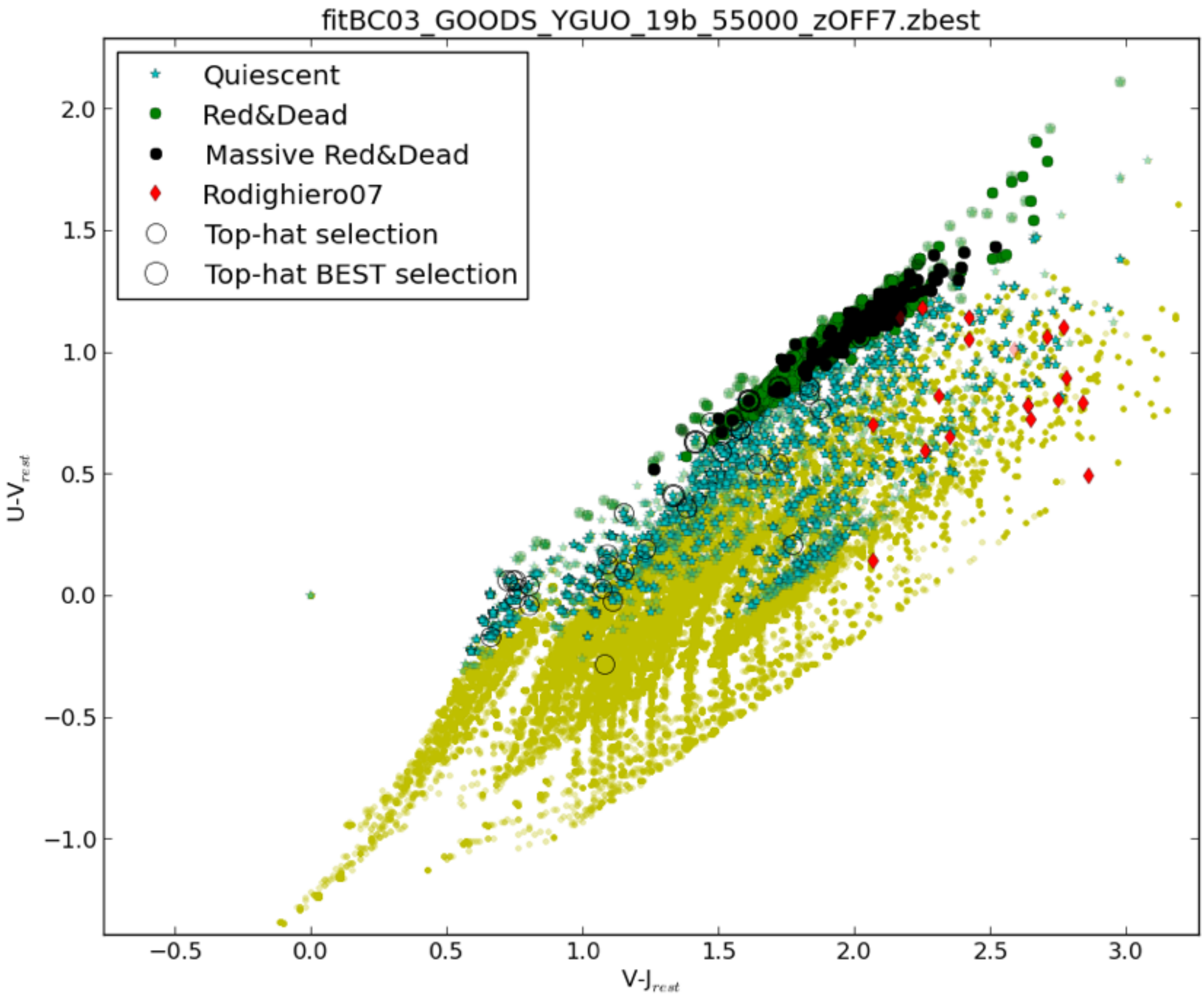
IRAC1234 detected (193 sources):
p*=2%: 34 sources
p*=5%: 51 sources
p*=10%: 67 sources
p*=20%: 193 sources (ALL)


OBJ8785
OBJ9209
OBJ23626
m_AB
Prob
E(B−V)
5000 10^4 5×10^4 10^5

P(z)



Redshift



fitBC03_GOODS_YGUO_19b_55000_zOFF7.zbest
Quiescent
Red&Dead
Massive Red&Dead
Rodighiero07
Top-hat selection
Top-hat BEST selection
U-V$_{rest}$
V-J$_{rest}$
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0

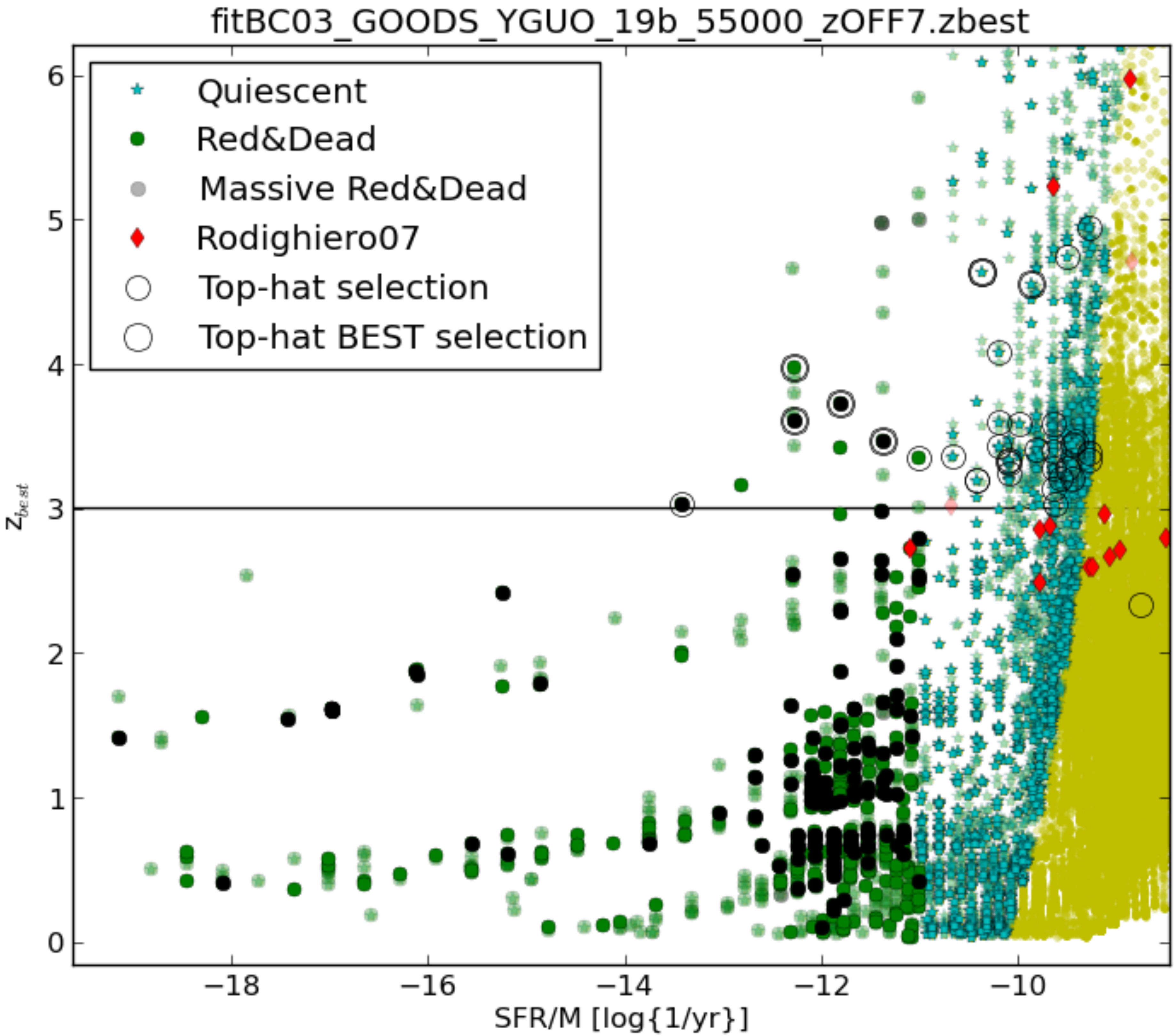
Take-away lessons:

- mass estimates are reasonably consistent against model uncertainty;
- impact on MF must be estimated and taken into account;

- Strong evolution in the MF from z=4 to 7

- Apparently inconsistent with naive SFR estimates from LBG: what are we missing?

- Excellent candidates of quiescent galaxies up z~5 are being found in CANDELS+HUGS on GOODS.


fitBC03_GOODS_YGUO_19b_55000_zOFF7.zbest
Quiescent
Red&Dead
Massive Red&Dead
Rodighiero07
Top-hat selection
Top-hat BEST selection
z_{best}
SFR/M [log{1/yr}]
−18
−16
−14
−12
−10
0
1
2
3
4
5
6