Search and confirmation of passive galaxies in the early Universe

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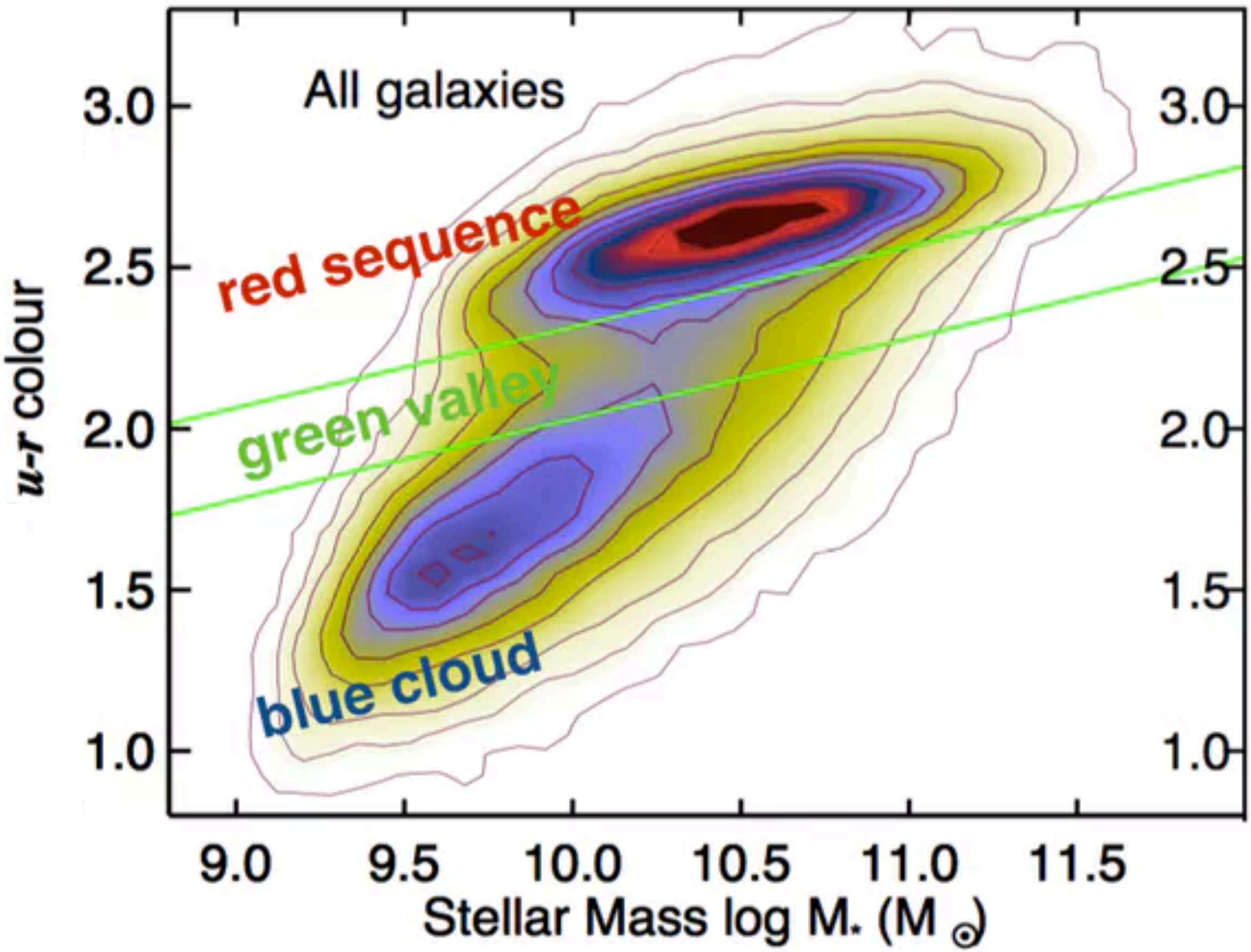
"Extremely Big Eyes on the Early Universe", 9-13 Sep 2019

Outline

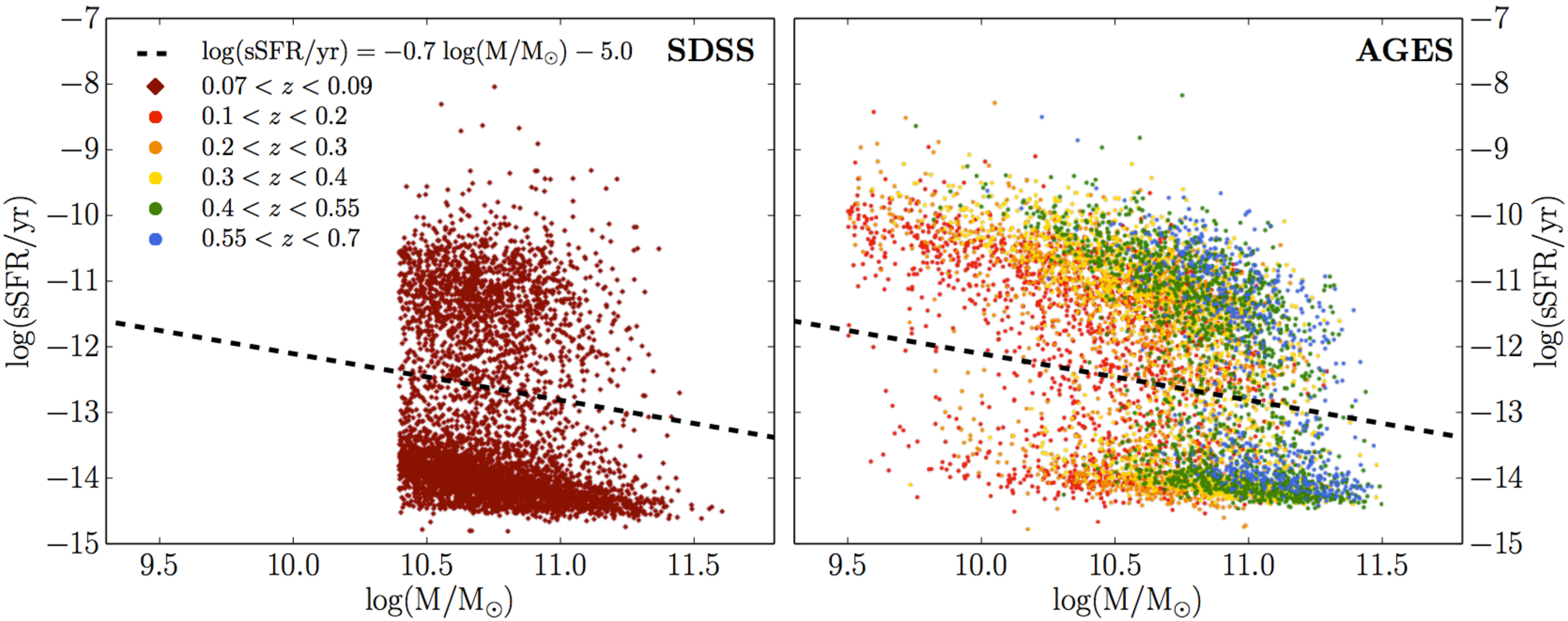
- Passive galaxies (what are they, why do we care, when did they appear…)
- Selection techniques
  - A sample of $z>3$ passive candidates in CANDELS (Merlin+18, +19subm.)
- Confirmation techniques
  - Exploitation of the ALMA archive (Santini+19)
- What can we expect from future big eyes?
- Summary & conclusions

Two populations of galaxies



Schawinski+14

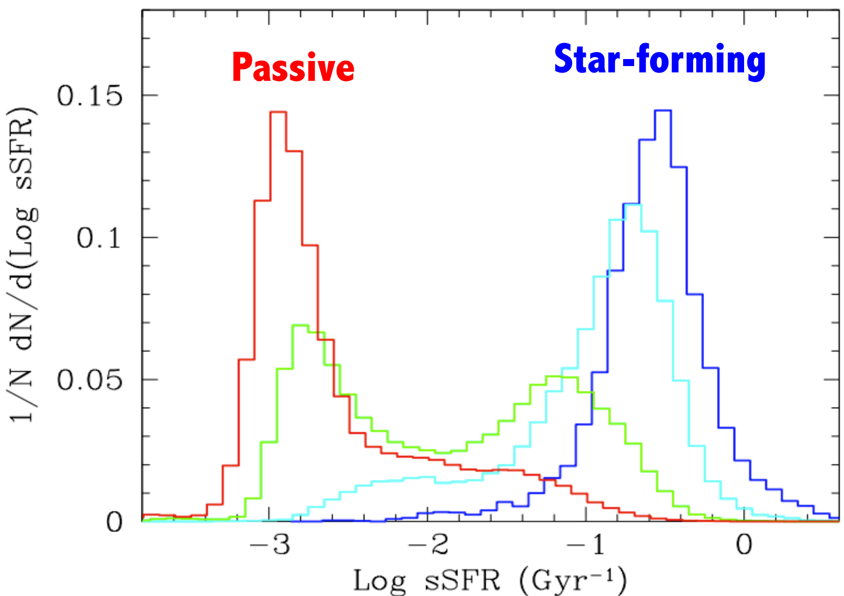
Two populations of galaxies



Choi+14

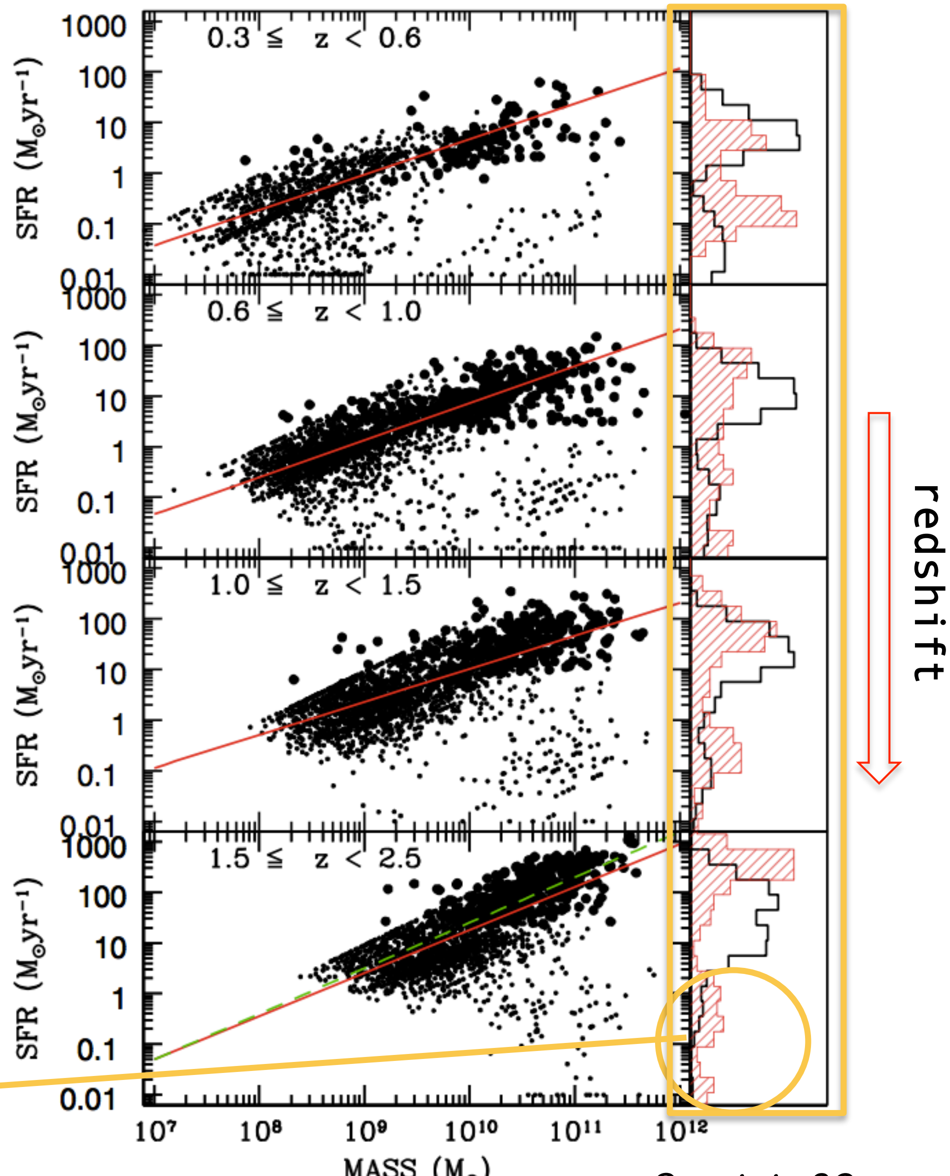
The emergence of the passive population

Local Universe



Bluck+14

High-z Universe



Passive galaxies are less abundant at high redshift

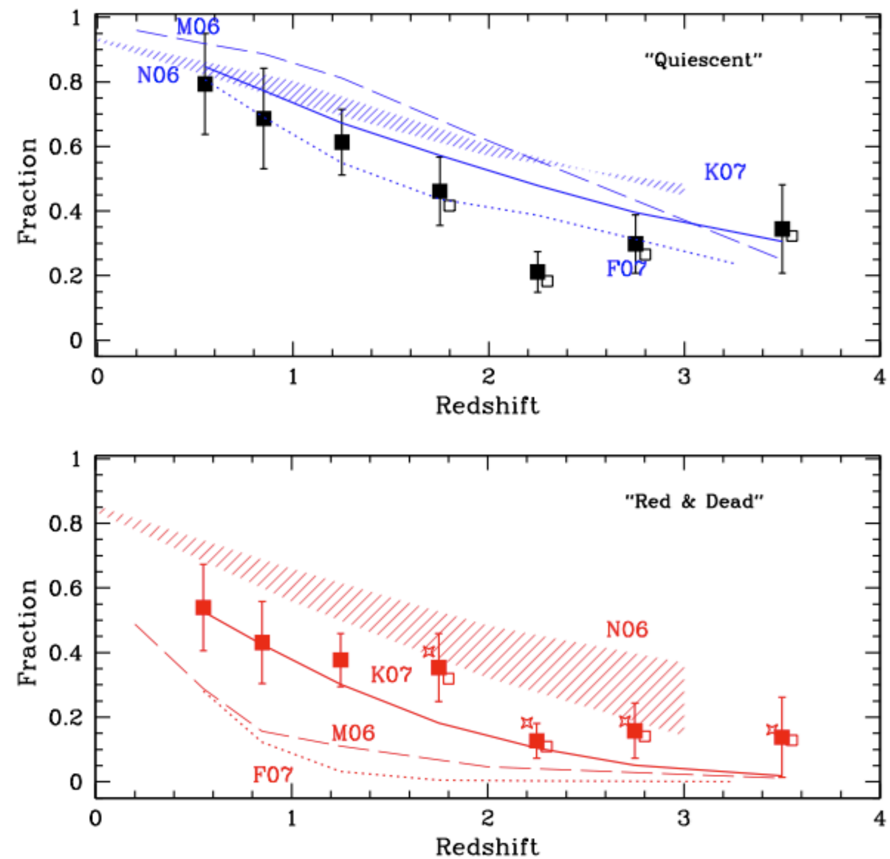
Santini+09

Passive galaxies at high z: a challenge for theoretical models

Talk by E. Merlin

Theoretical models struggle to reproduce the observations (Fontana+09, Vogelsberger+14, Feldmann+16, Merlin+19, Cecchi+19, …)

The abundance of passive galaxies at different epochs is a powerful probe of the delicate interplay among the different physical processes responsible for their rapid assembly and for the abrupt shut-down of their SF activity (e.g. merger-driven starbursts, feedback, ..).



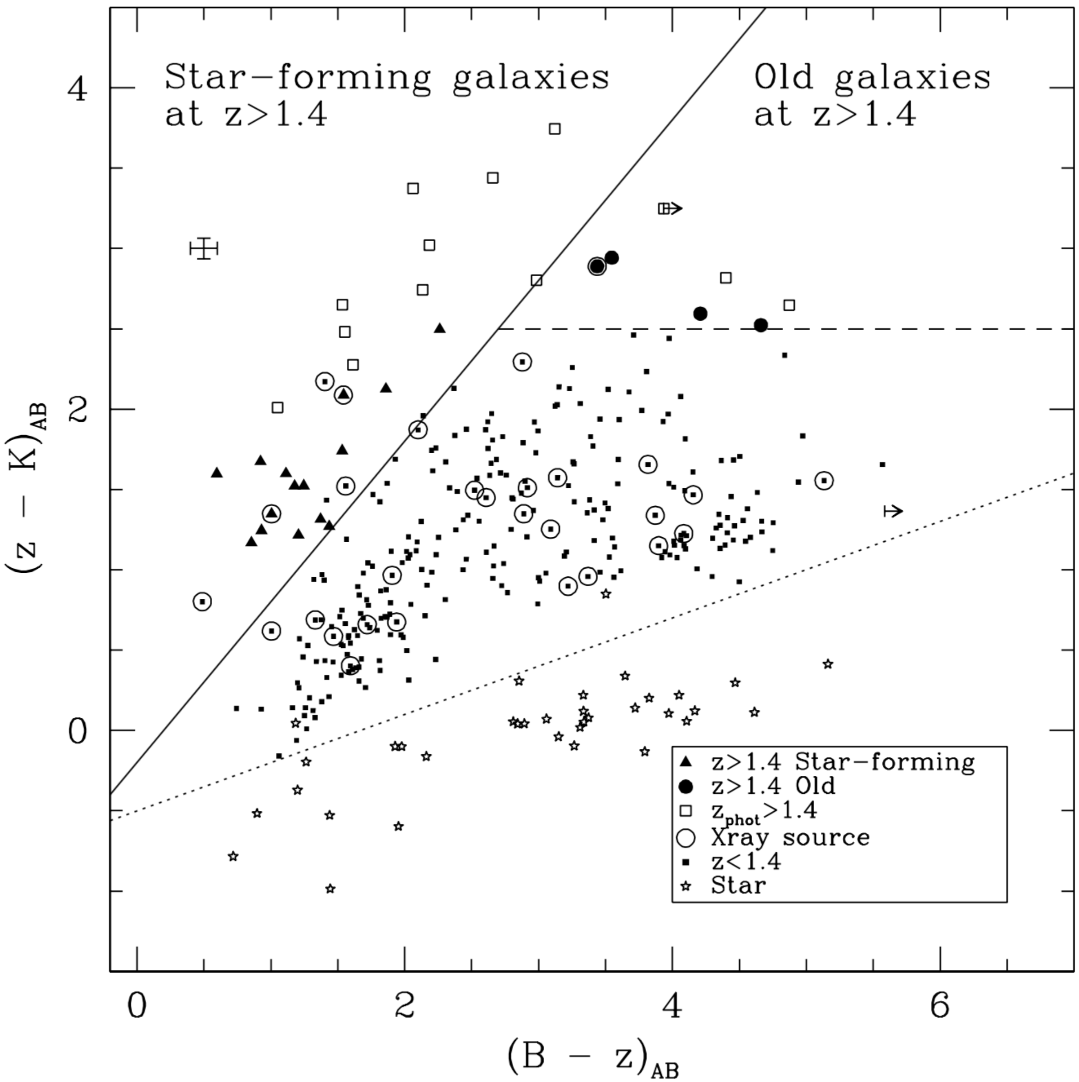
Fontana, PS,+09

Need for reliable selection criteria!

How do we select passive candidates?

Selection techniques: colour-colour diagrams

Observed colours

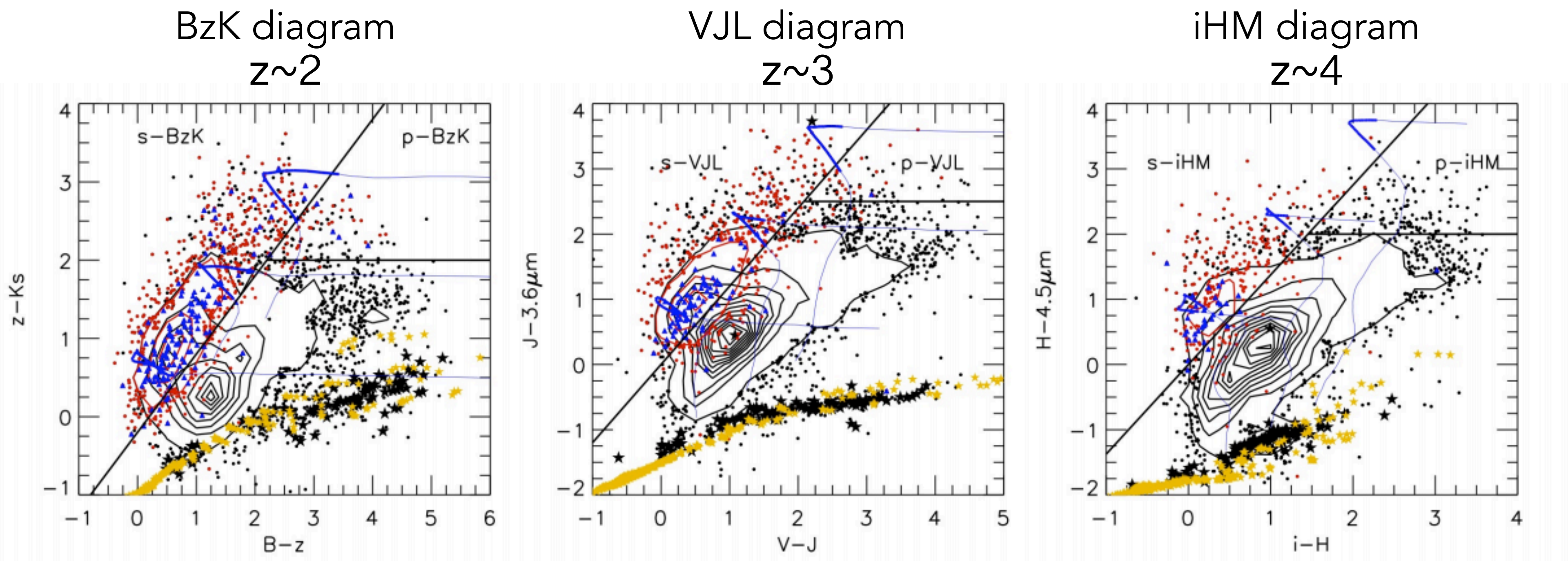


BzK diagram
z~2

Daddi+04

Selection techniques: colour-colour diagrams

Observed colours



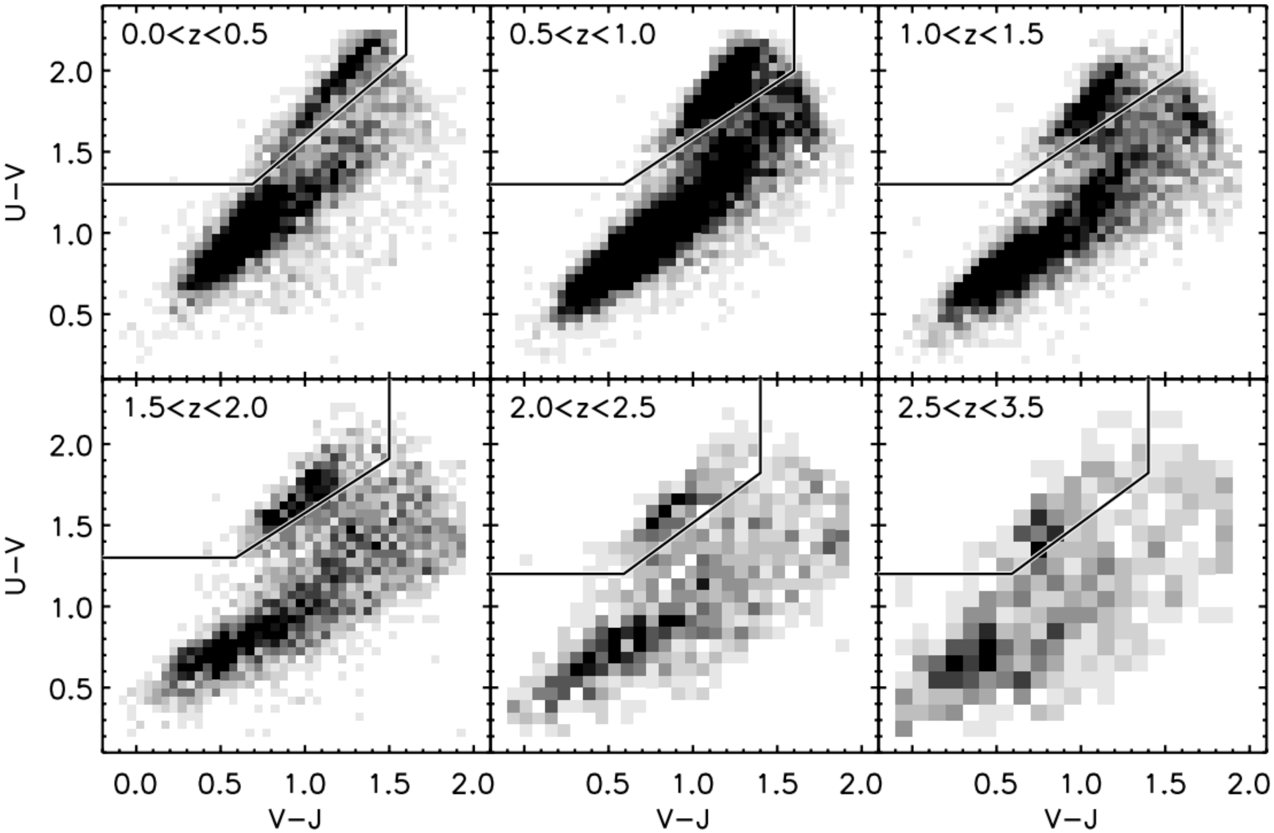
Guo+13

See also *Labbé+05* (iKM diagram), *Wiklind+08* (JKL diagram, z>5), *Mawatari+16* (KLM diagram, z>5)

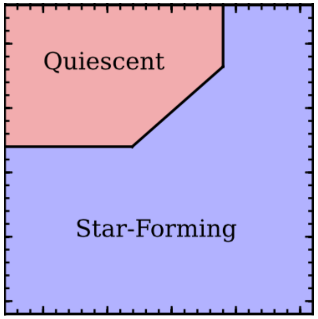
Selection techniques: colour-colour diagrams

Rest-frame colours

UVJ diagram



Whitaker+11

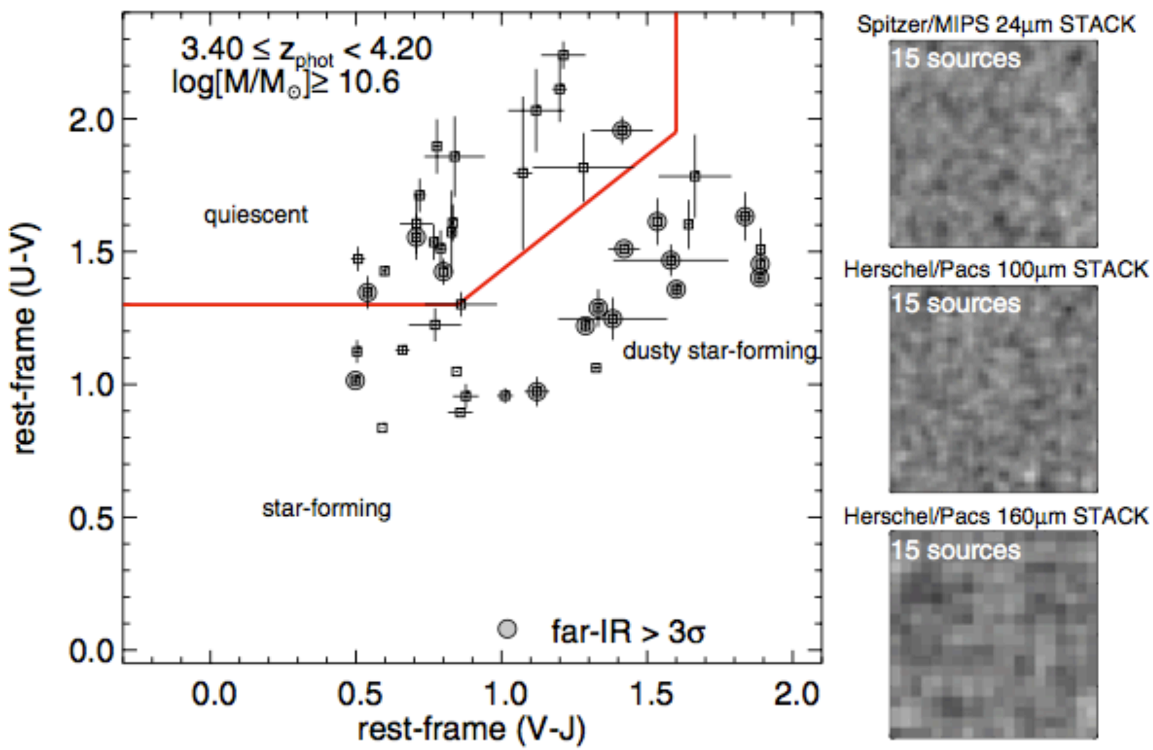


Tomczak+14

(see also
Wuyts+07,
Williams+09,
Patel+11,
Straatman+14,
Martis16,
Fang+18,
….)

See also similar diagnostics diagram such as the NUVrJ or NUVrK (*Arnouts+13*, *Ilbert+13*, *Davidzon+17*, …)

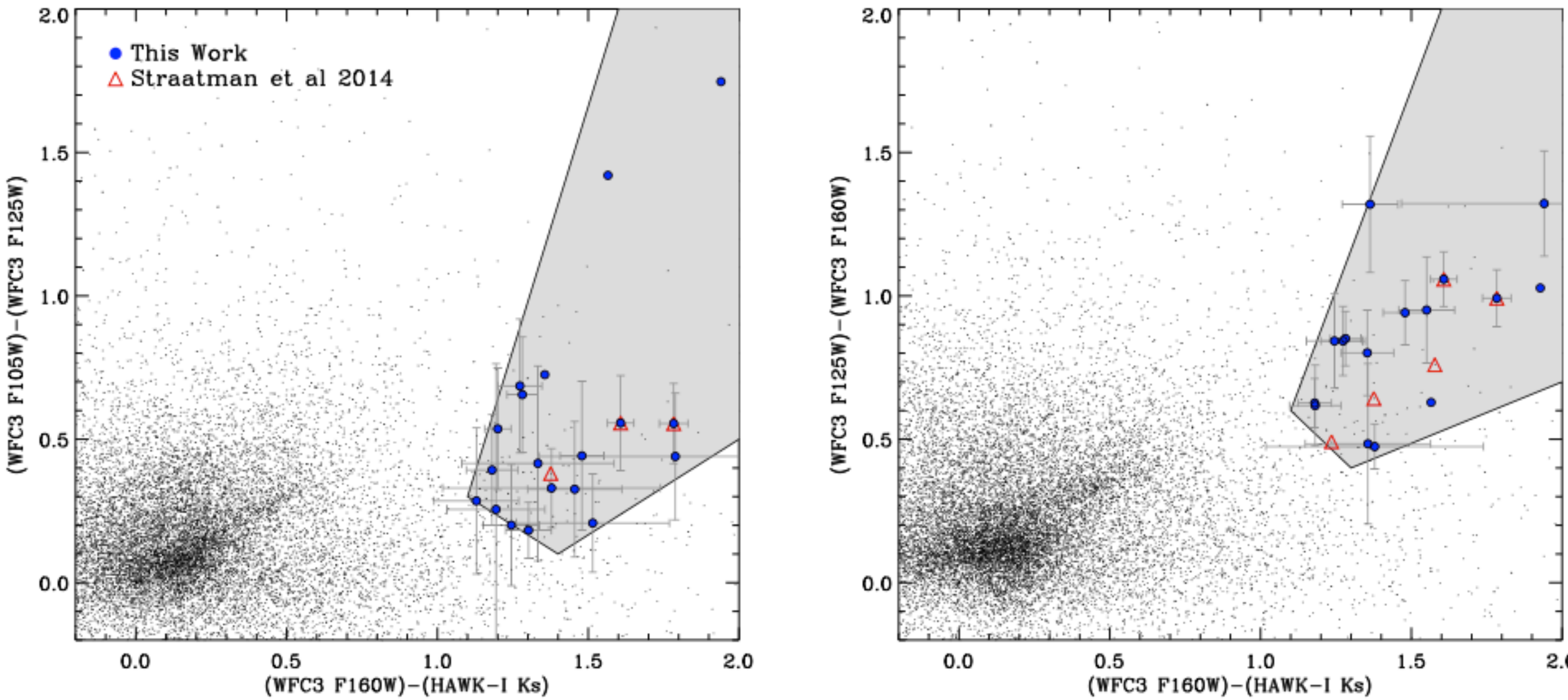
Selection techniques: colour-colour diagrams



Straatman+14:

19 UVJ passive galaxies
(GOODS-S+COSMOS+UDS)
3.4<z<4.2
$\log M/M_o > 10.6$
15/19 have no FIR detection

Selection techniques: colour-colour diagrams

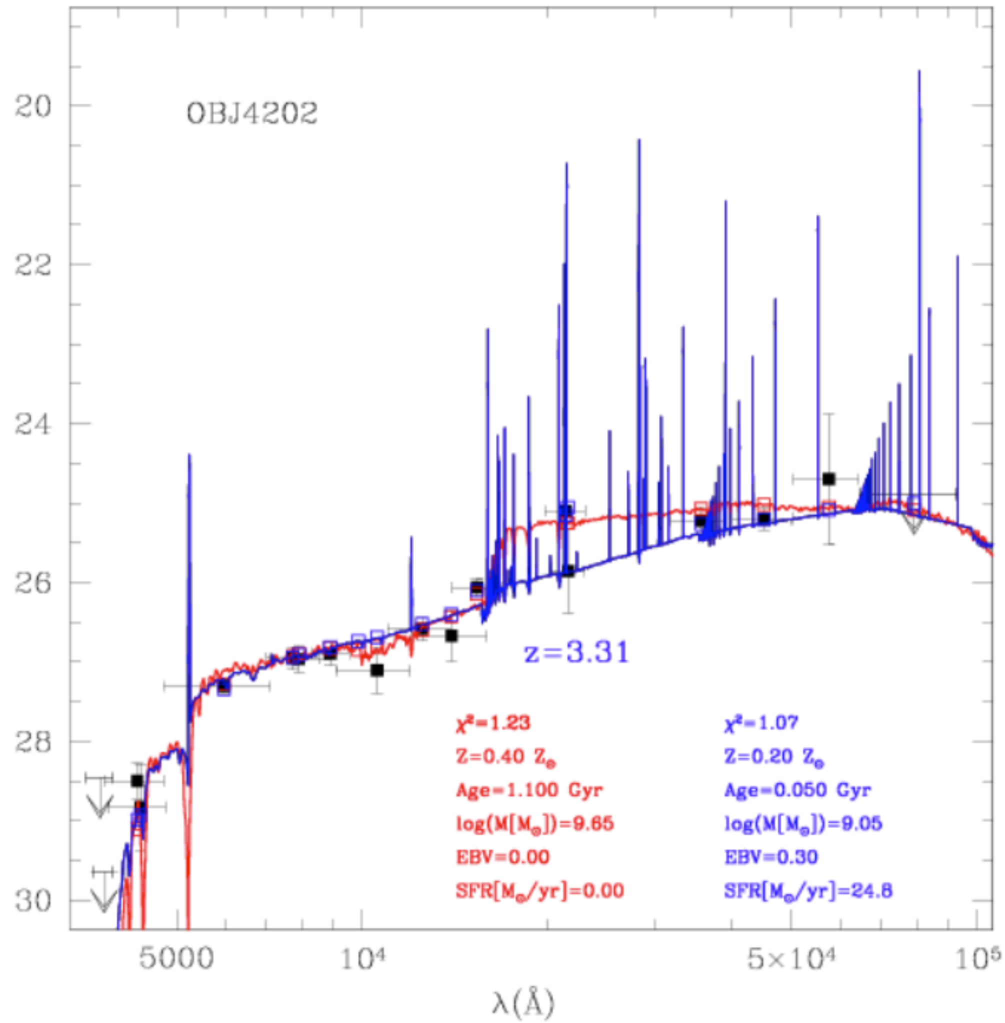


Nayyeri+14:

16 post-starburst galaxies (GOODS-S)
Selected from the amplitude of the Balmer break (H-K) (+ (J-H) and (Y-J) + non detections in U and B to reduce contaminants)
$3<z<4.5$
$M \sim 5 \times 10^{10} M_{\odot}$

See *Wiklind+08, Mawatari+16* for z>5 passive candidates

Selection techniques: SED fitting



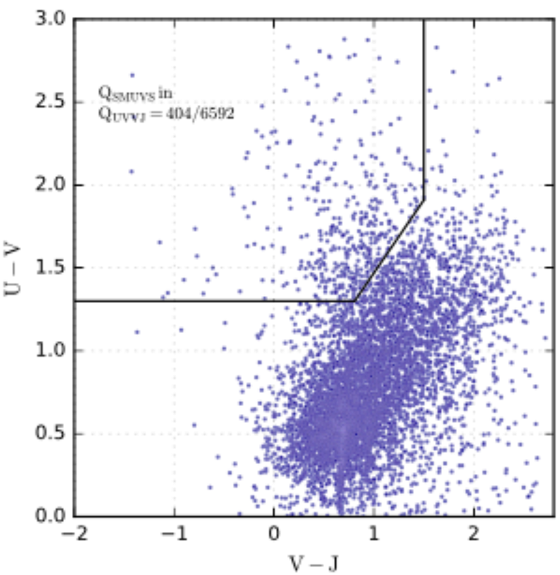
Merlin+18, +19subm

(see also Grazian+07, Fontana+09, …)

Selection techniques: SED fitting + colour cut

E(B-V) ≥ 0.2

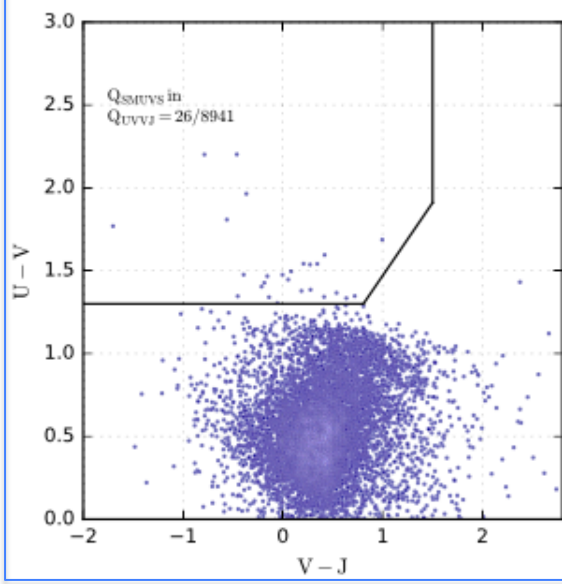
Dusty



E(B-V) ≤ 0.1

u-r < 1.3

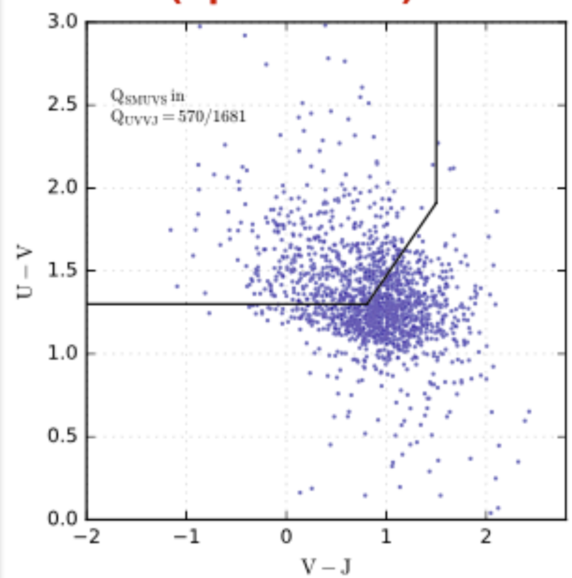
Non-dusty / blue



u-r ≥ 1.3

Non-dusty / red

('quiescent')

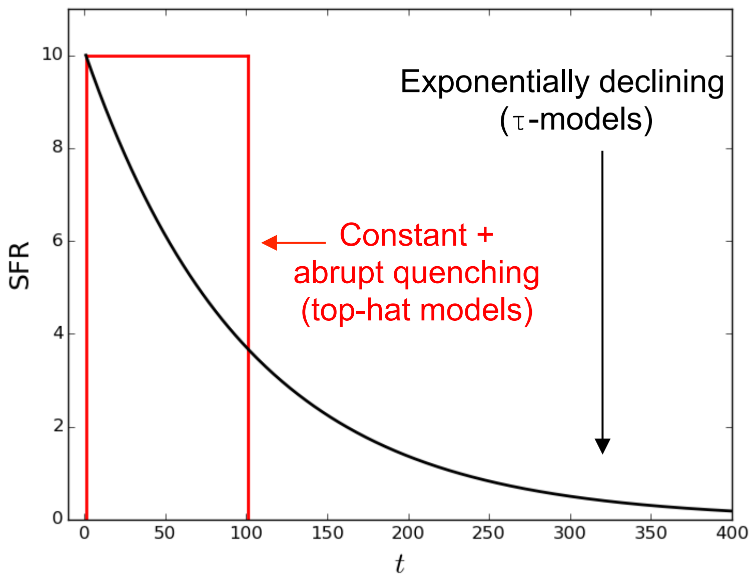


Deshmukh+18:

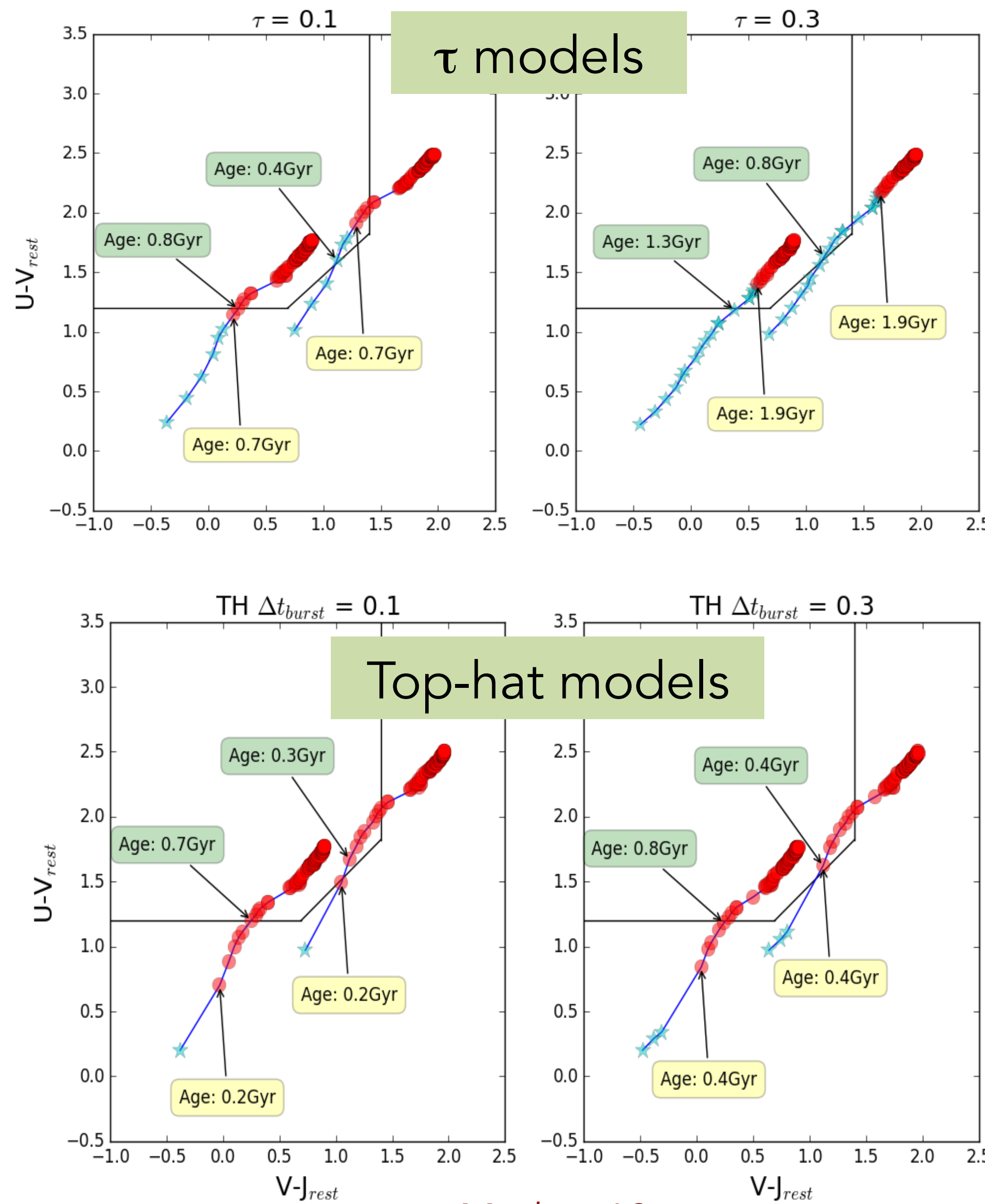
Combination of SED fitting (to separate dusty from non-dusty) and colour-cut (to separate blue unobscured from red passive galaxies)
2<z<6

SED fitting vs colour-colour selection: importance of the SFH

SFH: which is the "best" choice at high *z*? (Very short timescales, close to formation epoch)

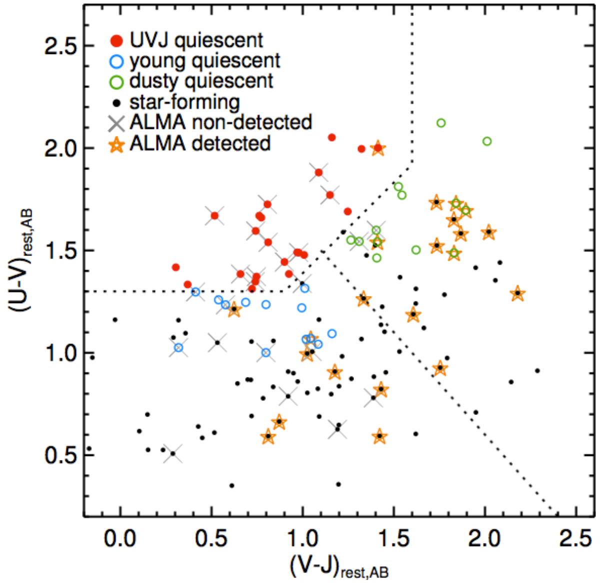


See also Ciesla+16



Merlin+18

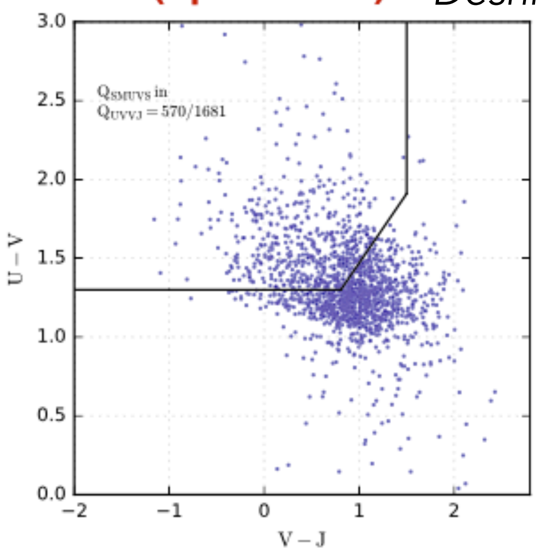
SED fitting vs colour-colour selection



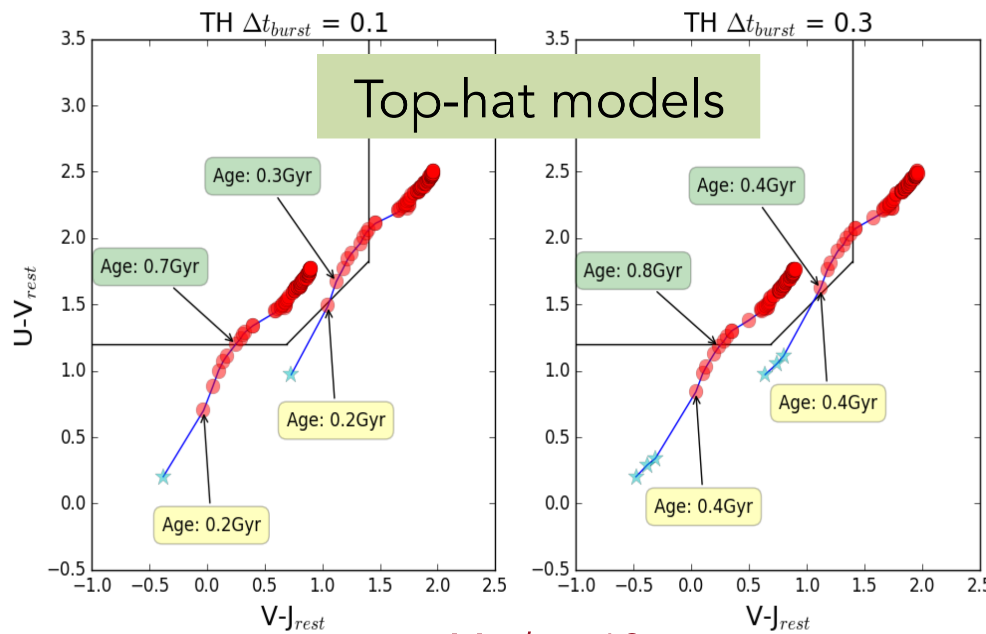
Schreiber+18

The UVJ selection is incomplete

('quiescent')



Deshmukh+18

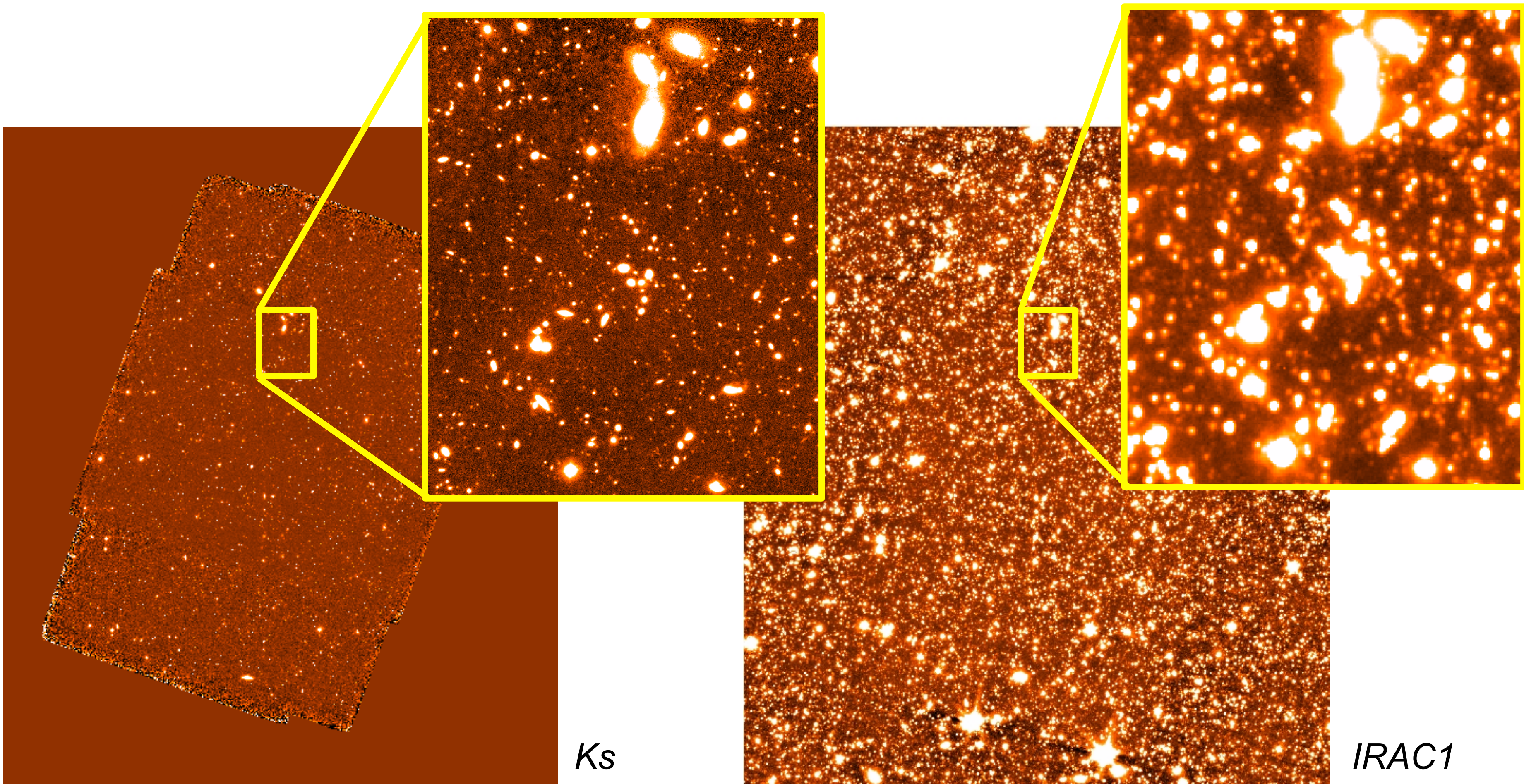


Merlin+18

CANDELS: the deepest multiwavelength data

Deep NIR/MIR photometry is fundamental to sample the 4000Å break in z>3 galaxies

(Official CANDELS catalogs;
GOODS-South: Guo+2013, Fontana+2014 K+U bands, + new IRAC data w/ T-PHOT)

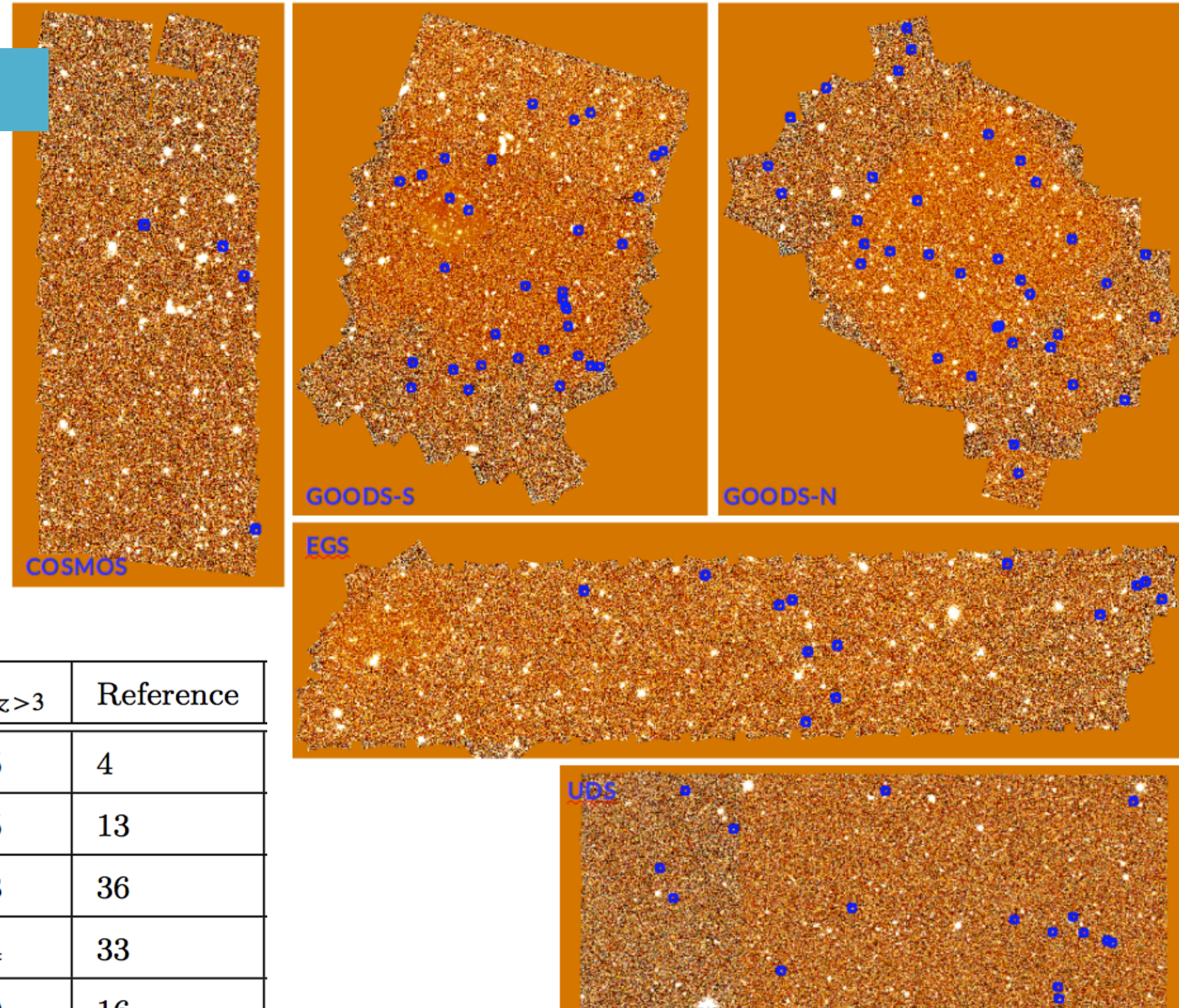


Credits: E. Merlin

z>3 passive galaxies in the CANDELS fields

Selection based on SED fitting assuming top-hat SFH with a probabilistic approach

Talk by E. Merlin

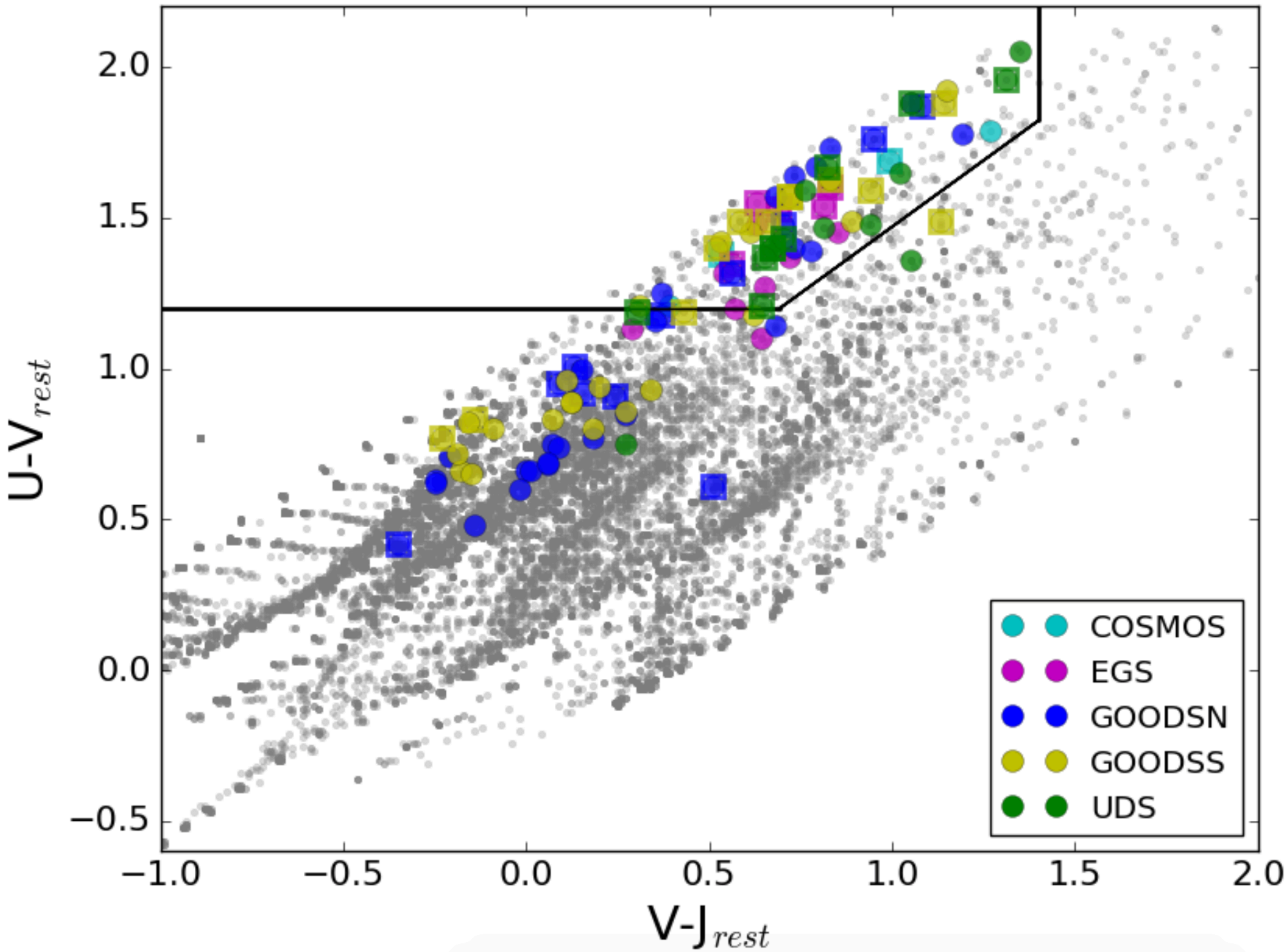


Field/Sample	Total	$z > 3$	$S/N_{z>3}$	Reference
COSMOS	38671	3778	1525	4
EGS	41457	4830	1775	13
GOODS-N	35445	3953	1793	36
GOODS-S	34930	5029	2884	33
UDS	35932	4018	2540	16
All fields	186435	21608	10517	102

$1.73 \pm 0.17 \times 10^{-5}$ Mpc^{-3}

Merlin+19subm.

z>3 passive galaxies in the CANDELS fields



Merlin+19subm.

Selection techniques: issues and uncertainties

<u>COLOUR-COLOUR DIAGRAMS</u>:

- Incompleteness and contamination from red dusty galaxies
- May be affected by the lack of one band (used for the selection)

<u>In particular, at high-z</u>:

- Galaxies are redder
- Colour cuts inappropriate to take into account the short timescales available for galaxies to become quiescent

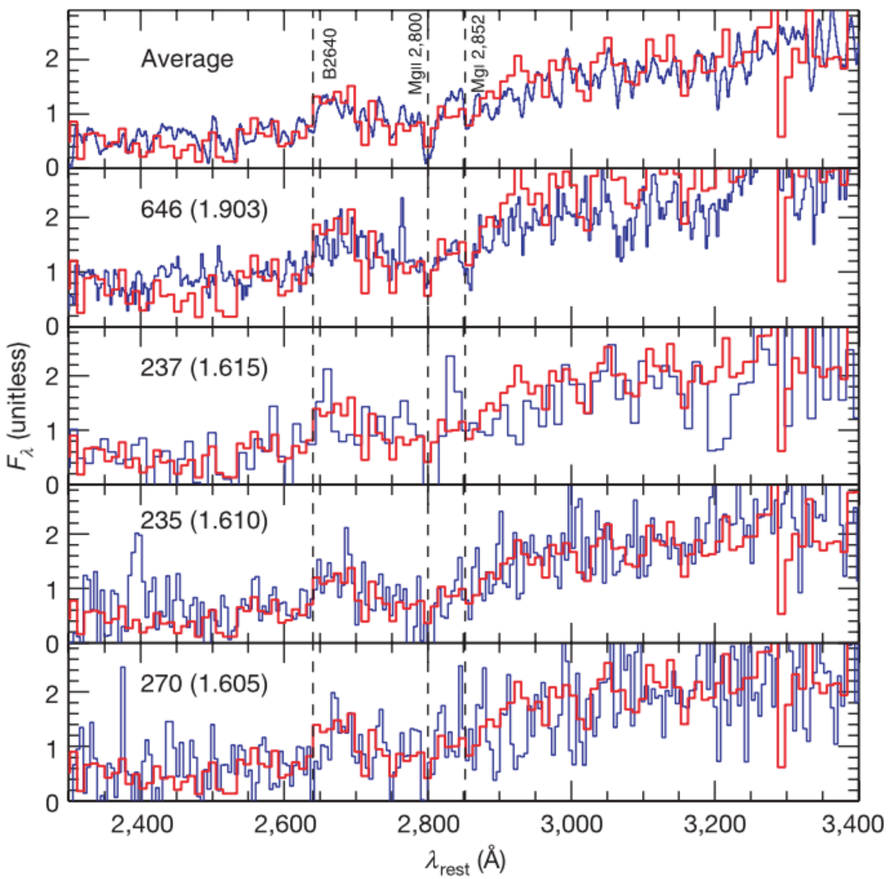
<u>SED FITTING</u>:

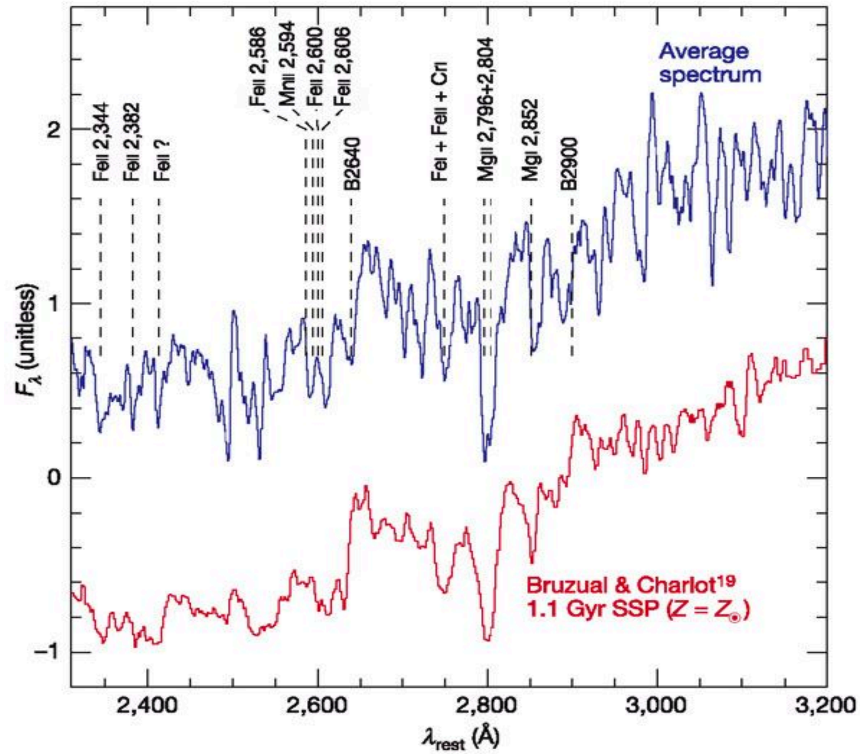
- Parameter degeneracy
- Rely on few bands
- Sensitive to the details of the adopted library
- Fit with nebular lines sensitive to photo-z uncertainty

How can we confirm the passive nature of these candidates?

Confirmation: spectroscopy

Cimatti+04





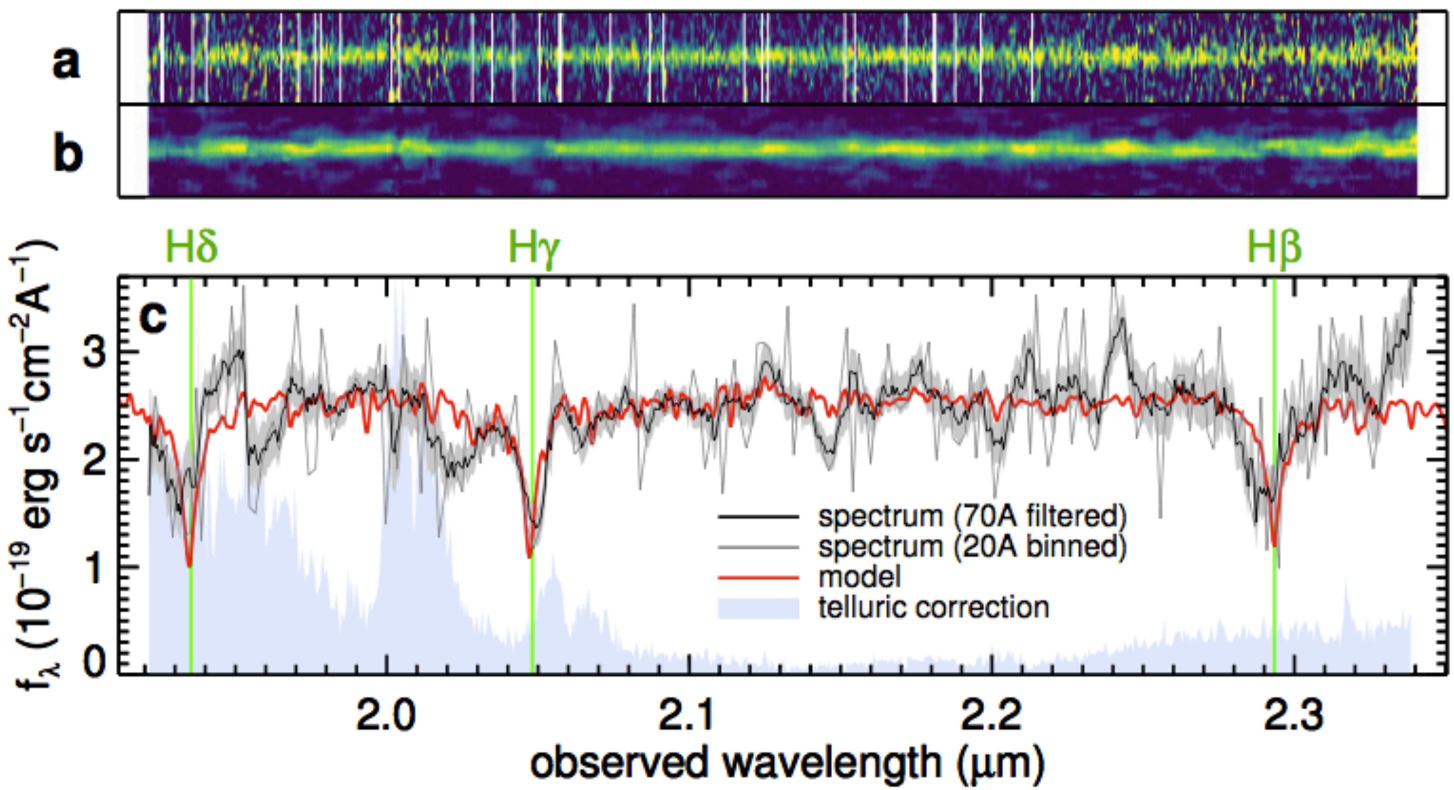
4 targets from GOODS/K20 surveys:

18<K<19
1.6<z<1.9
VLT FORS2
3 to 16 hr, tot 34 hr

(see also Kriek+06,+09,+15, Gobat12, Onodera+12, Whitaker+13, Belli+14 van de Sande+16 Hill+16 …)

Confirmation: spectroscopy

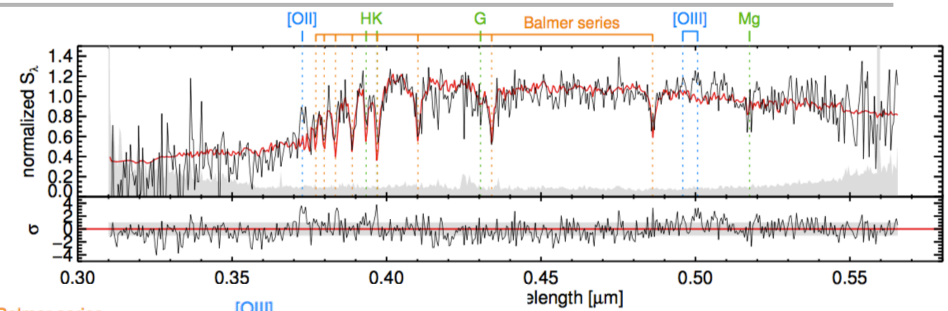
Glazebrook+17



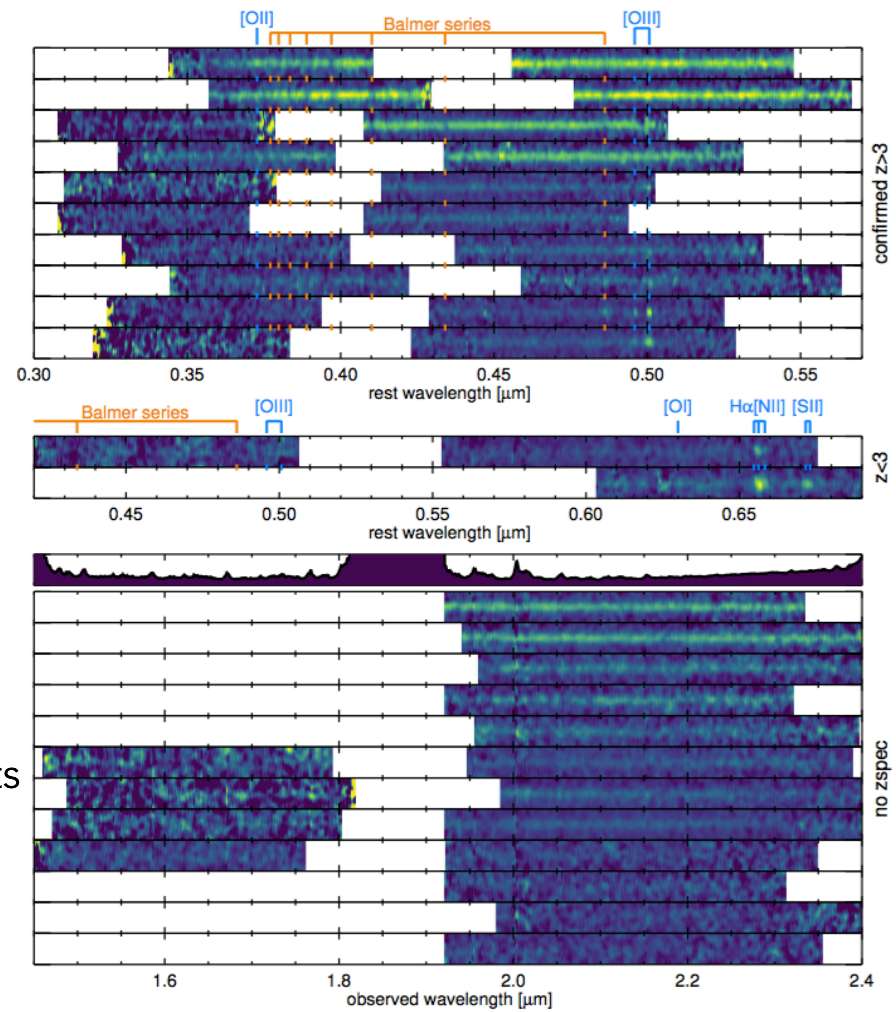
The most distant spectroscopically confirmed passive galaxy:
z=3.713 (K=22.4, M=$1.7 \times 10^{11} M_o$)
Keck MOSFIRE
4 hr H band, 7 hr K band
Median SNR_K=6

Confirmation: spectroscopy

Schreiber+18



stack



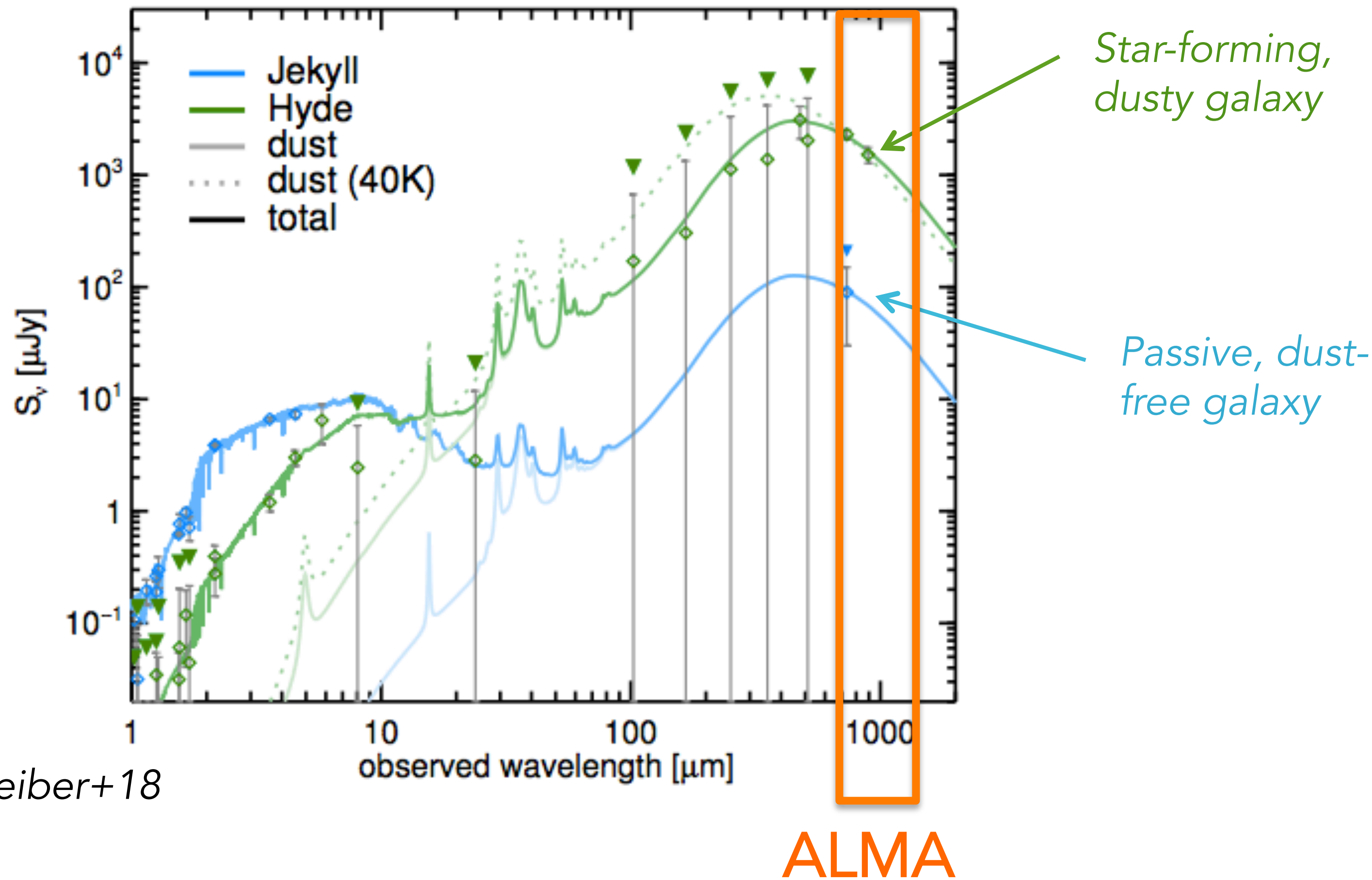
24 UVJ-selected targets:

21.7<K<24.2
3<z<4
Keck MOSFIRE
1.6 to 7.2 hr in K band
$0.7<\mathrm{SNR}_K<12$

50% have measured redshifts
2 low-z dusty SF-ing

Confirmation: look at the sub-mm!

Exclude contamination from dusty galaxies by means of FIR/submm observations



Schreiber+18

ALMA archive observations

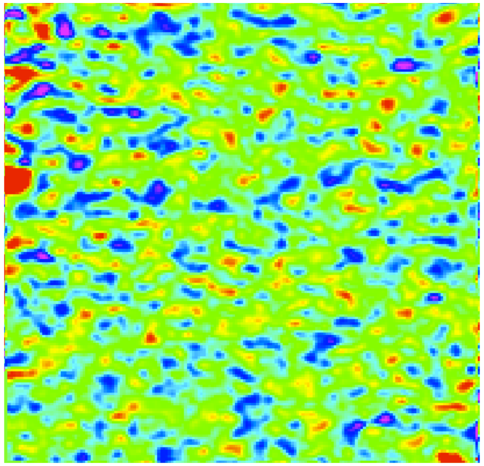
41 z>3 passive candidates in CANDELS (Merlin+19subm.) observed by ALMA in Band 6 or Band 7.

All data are imaged to ≥0.6 arcsec resolution.

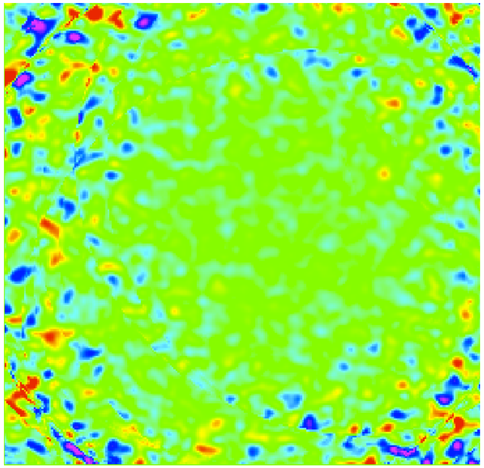
Only 1 source is detected at 4σ (few marginal detections at <3σ, consistent with a normal distribution of the SNR for undetected sources).

For the remaining sources,
no detection even in the stacks.

Band 6 (23 sources)



Band 7 (30 sources)



ALMA flux measurements converted into (constraints on the) SFR.

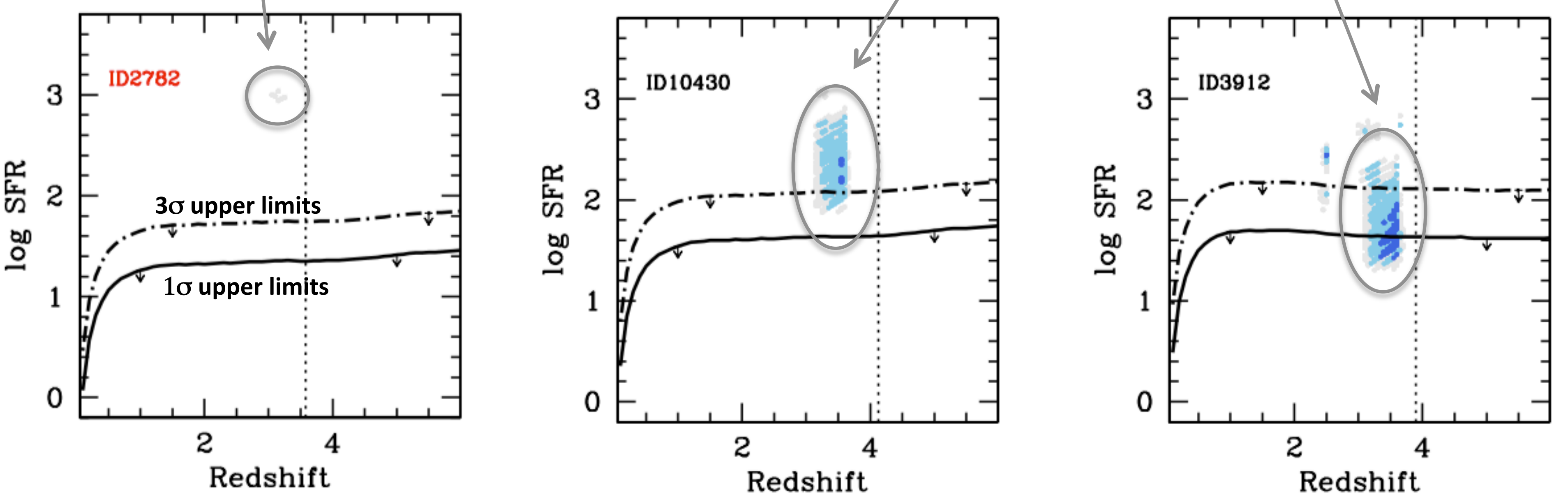
Santini+19, Santini+in prep.

Validation of robust individual candidates

Compare ALMA predictions to the SF-ing solutions of the opt fit (free redshift)

SF-ing solutions require very high SFR, conflicting with ALMA predictions → the source is confirmed as passive

The SF-ing optical solutions are consistent with ALMA at 3σ (and 1σ) → the source is not confirmed as passive (but not rejected either)



Santini+19, Santini+in prep.

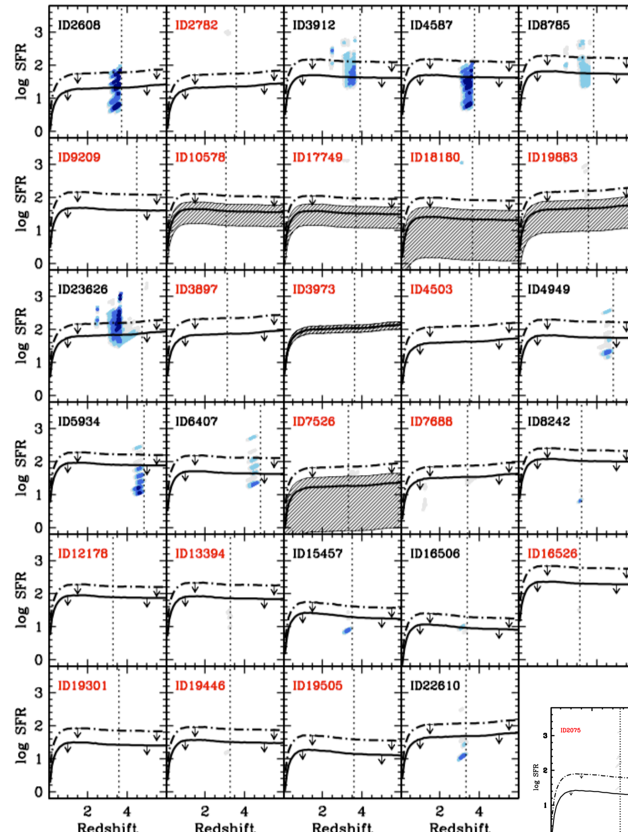
Validation of robust individual candidates

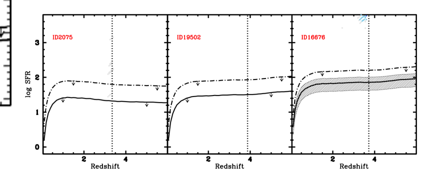
RESULTS:

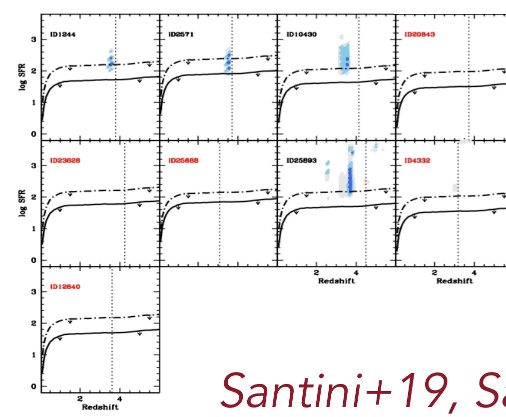
25 out of 41 candidates (61%) are robustly (≥3σ) confirmed

→ the SFing solutions of the optical fits are rejected by ALMA observations

The remaining sources are inconclusive (available ALMA data is not deep enough)



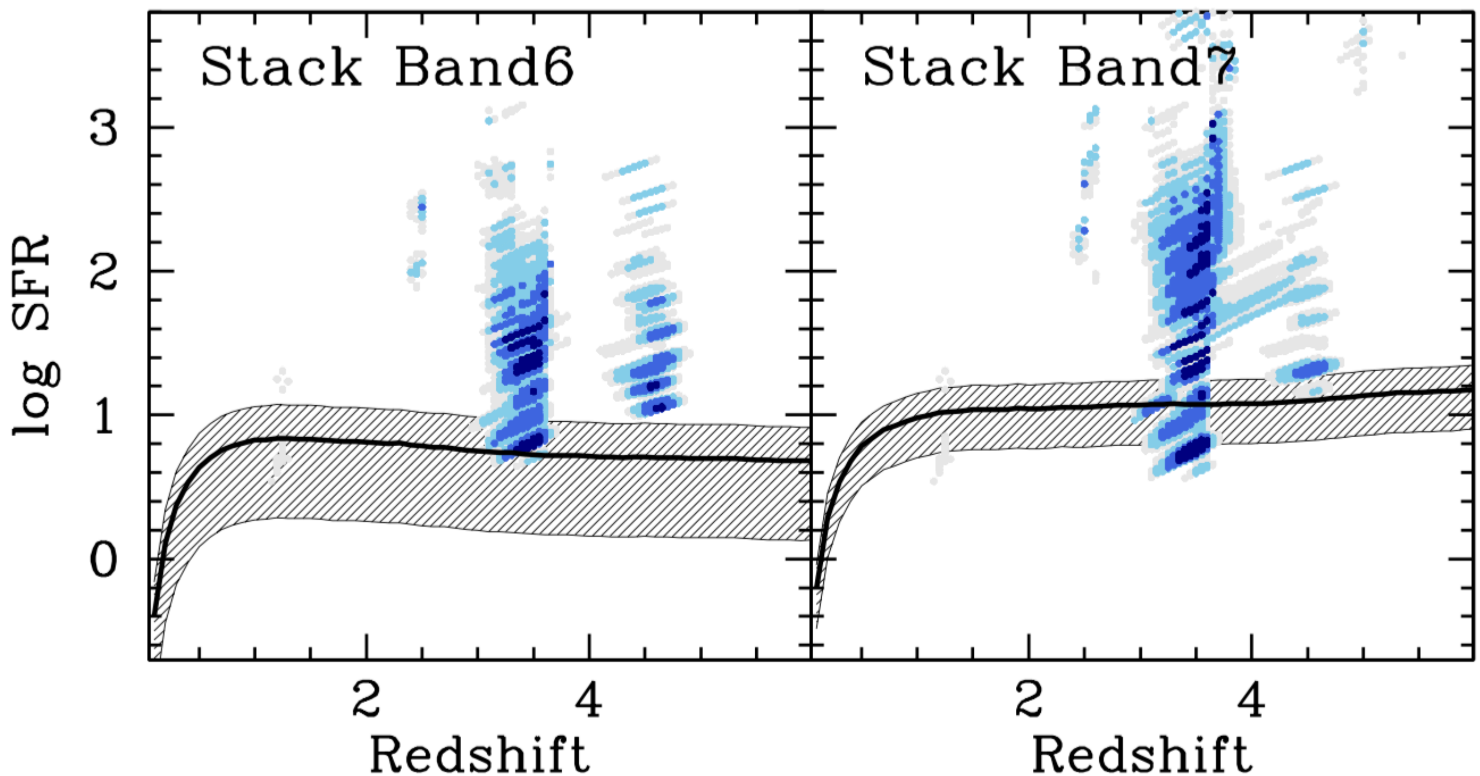




Santini+19, Santini+in prep.

Validation of the whole population in a statistical sense

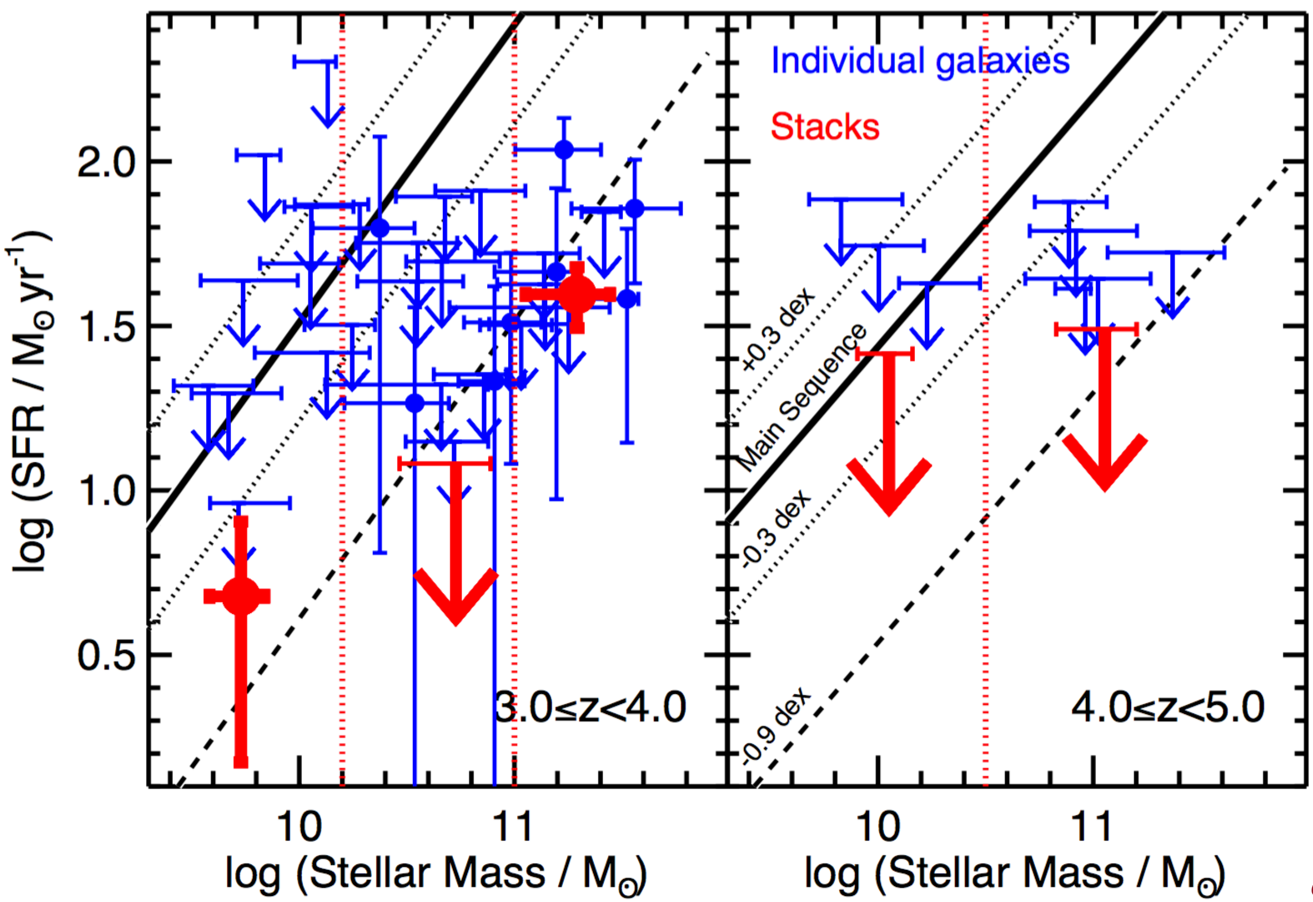
- 29 sources (71%) are individually confirmed at 1σ
- The stacks are on average consistent with being passive



Santini+19, Santini+in prep.

Validation of the whole population in a statistical sense

- 29 sources (71%) are individually confirmed at 1σ
- The stacks are on average consistent with being passive
- Comparison with the location of the MS:
  - 23 (56%) candidates located at least 1σ below the MS
  - 10 (24%) candidates located at least 3σ below the MS



Santini+19, Santini+in prep.

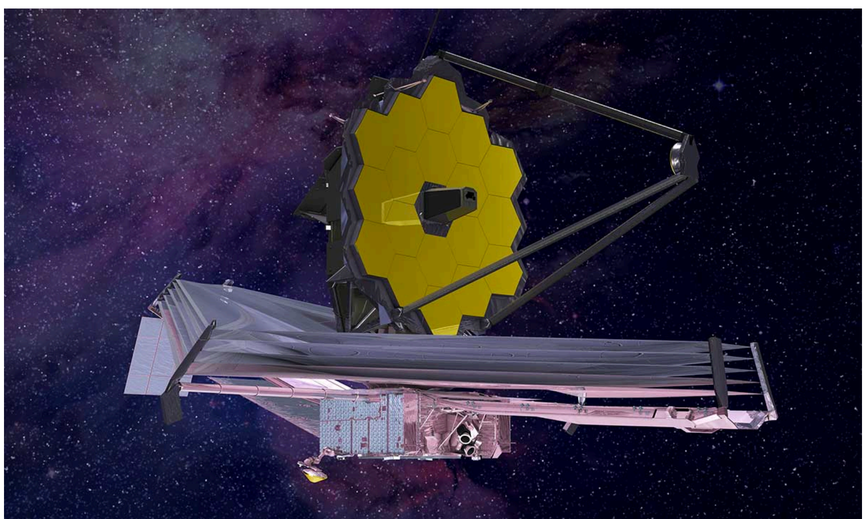
Extremely Big Eyes on the Early ~~Universe~~

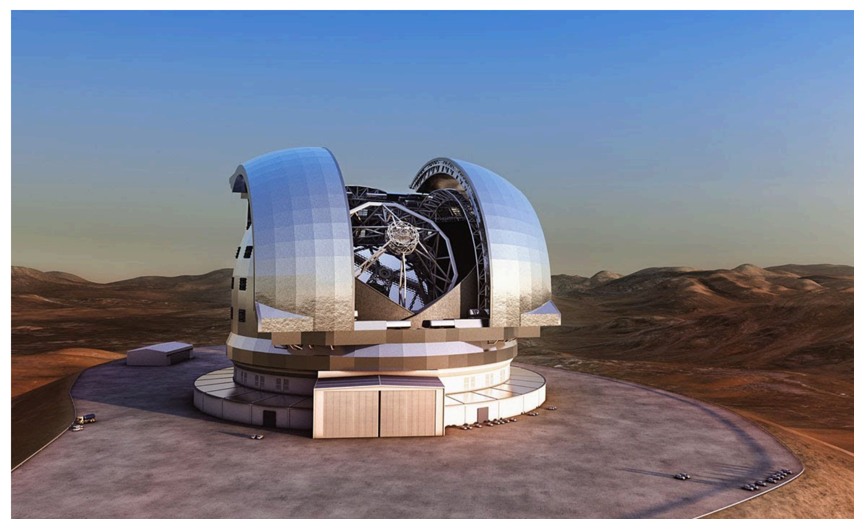
Passive Galaxies

Talk by E. Merlin

- ✧ How are they going to improve the selection?

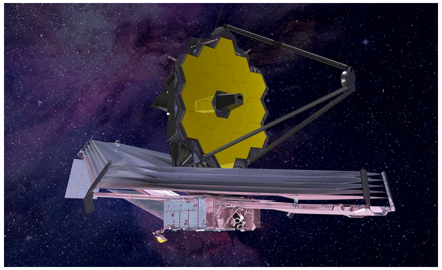
- ✧ How much faster would the spectroscopical confirmation of the candidates be?

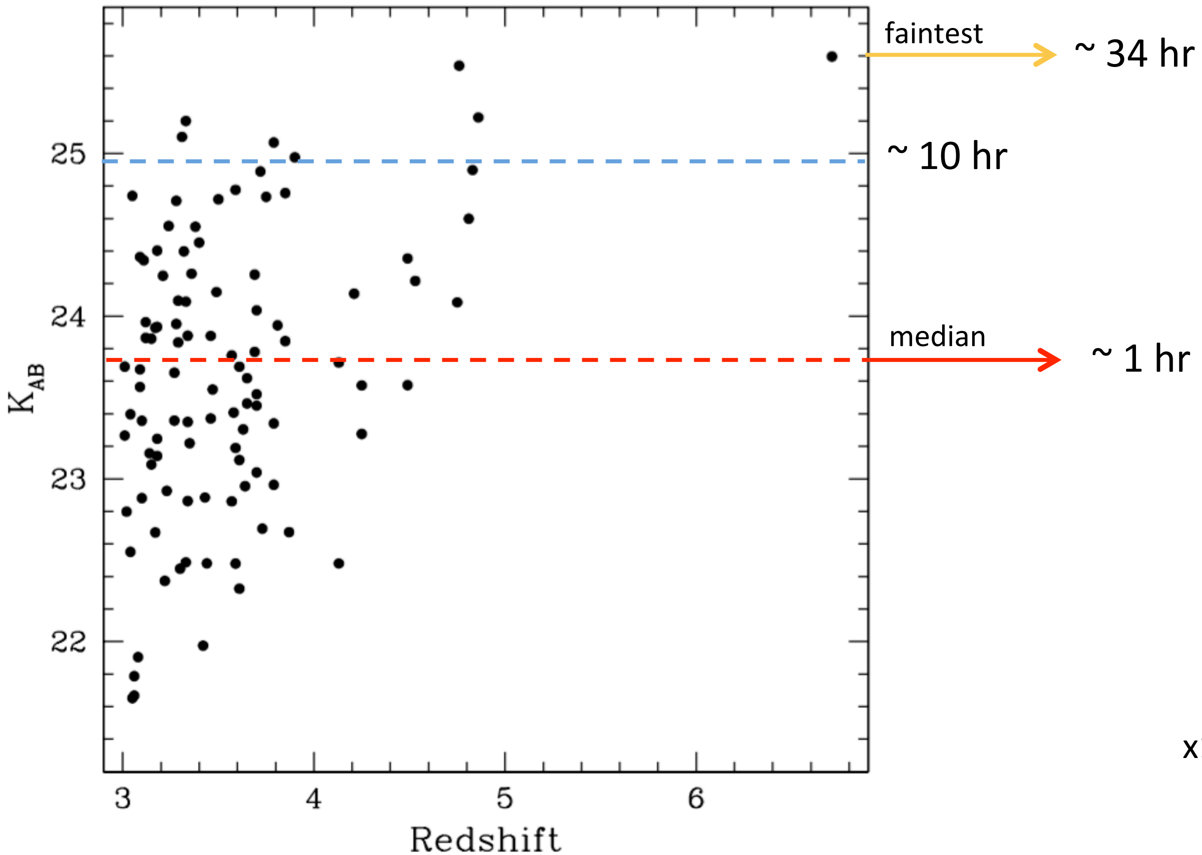




Passive candidate confirmation with (Extremely) Big Eyes

Source: JWST Pocket Guide





JWST NIRSPEC
253M MOS
R~1000
0.1 arcsec/px
(sensitivity for point sources, scaled assuming an average size of 0.22 arcsec)

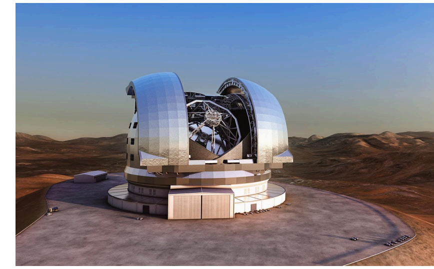
SNR=5

x10-15 faster than MOSFIRE

Passive candidate confirmation with Extremely Big Eyes

Kendrew+16

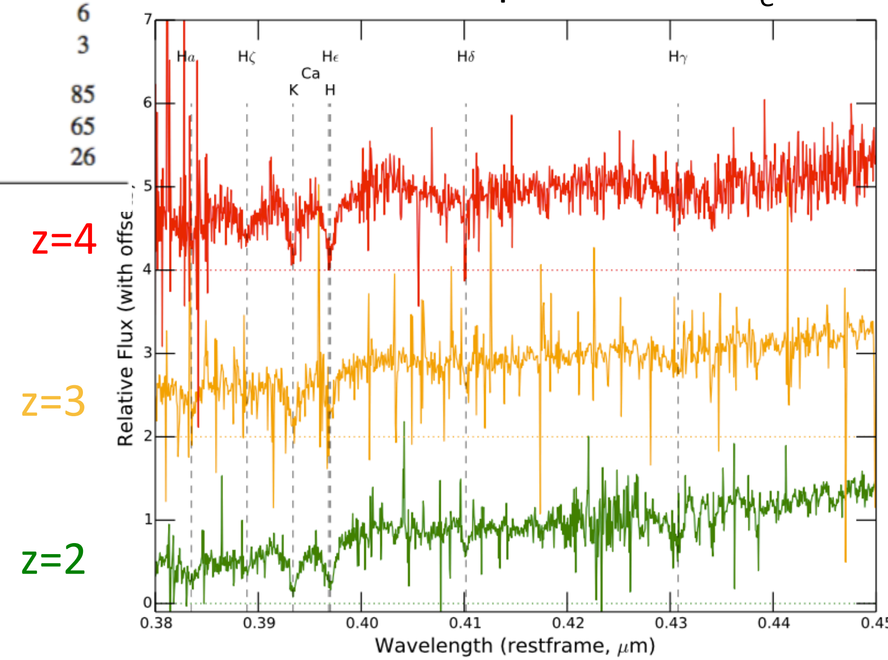
Used the simulation pipeline HSIM (Zieleniewski+15) to predict spectra for passive galaxies of various redshifts, masses and light profiles observed in 10 hr with HARMONI on the E-ELT



Redshift (z)	Stellar mass ($\log M/M_{\odot}$)	Age (Gyr)	Magnitude (AB)	HSIM S/N (PS)	HSIM S/N (dV)	HSIM S/N (Exp)
2	10	3	$J = 26.85$	3	1.4	0.9
3	10	2	$H = 27.06$	5	1.2	0.6
4	10	1	$K = 26.27$	3	0.6	0.4
2	11	3	$J = 24.35$	26	15	9
3	11	2	$H = 24.56$	37	12	6
4	11	1	$K = 23.77$	30	6	3
2	12	3	$J = 21.85$	141	125	85
3	12	2	$H = 22.06$	186	72	65
4	12	1	$K = 21.27$	195	47	26

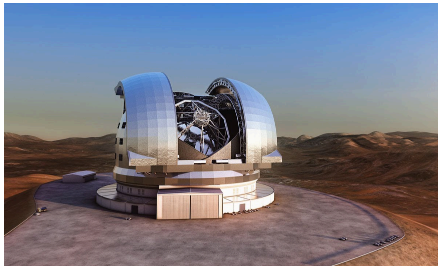
$\log (M/M_{sun}) = 11$

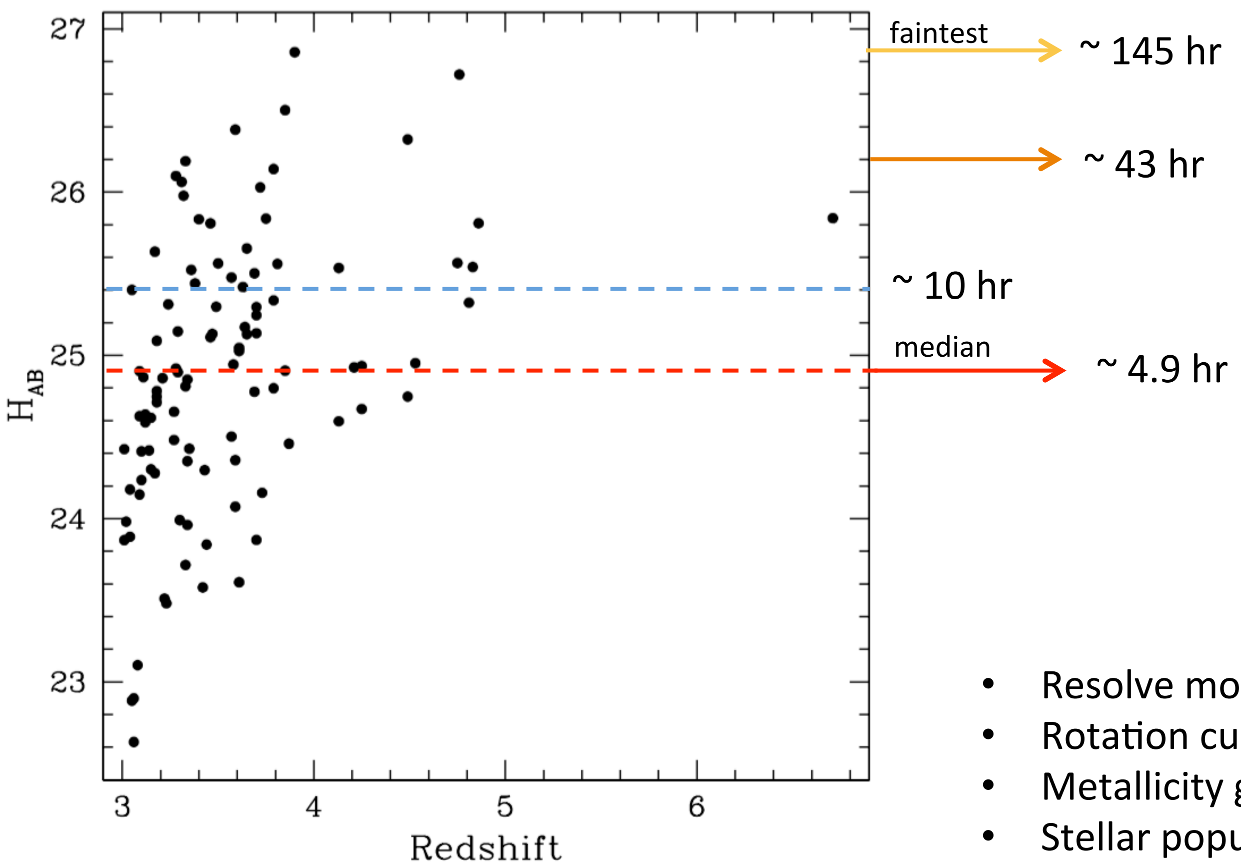
de Vaucouleur profile with R_e=0.2'



Passive candidate confirmation with Extremely Big Eyes

Source: Kendrew+16





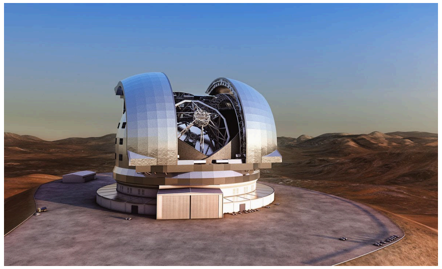
ELT-IFU HARMONI
R=3100
λ=0.7– 2.45 μm
30x60 mas spaxels
(sensitivity for point sources, scaled assuming an average size of 0.22 arcsec)

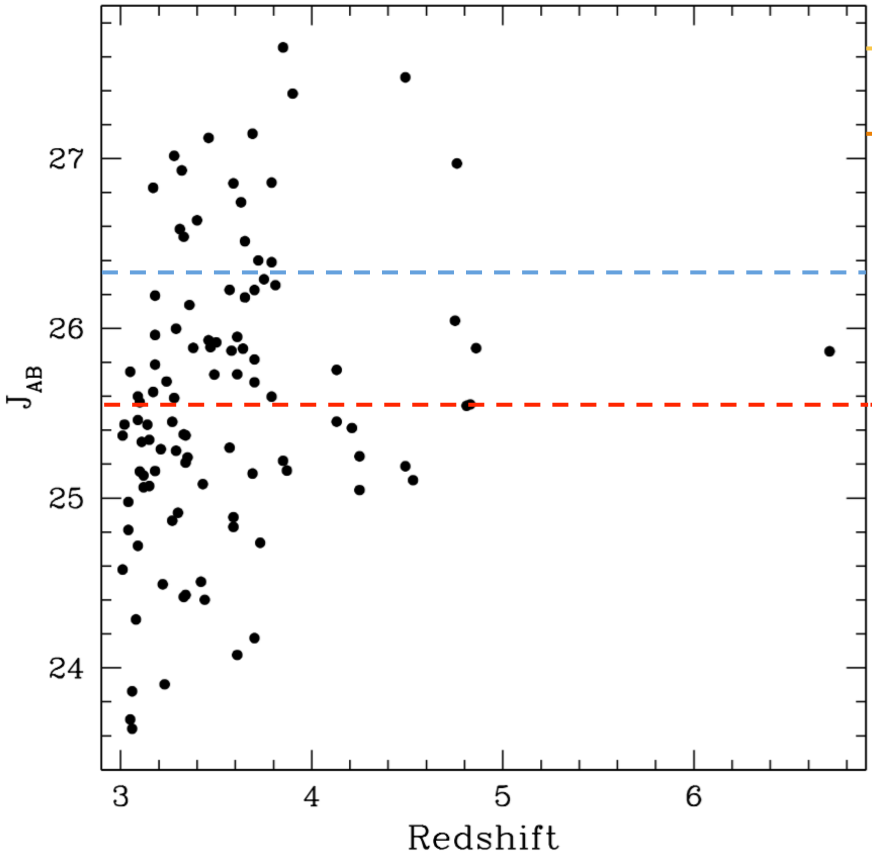
SNR=5

- Resolve morphology
- Rotation curves
- Metallicity gradients
- Stellar populations
- …

Passive candidate confirmation with Extremely Big Eyes

Source: MOSAIC white paper





faintest

~ 115 hr

~ 46 hr

~ 10 hr

median

~ 2.4 hr

ELT-MOS MOSAIC
R~5000
λ<1.8 μm
(sensitivity for point sources, scaled assuming an average size of 0.22 arcsec)

SNR=5

BUT does not extend beyond 1.8 μm

Summary & conclusions

- High-z passive galaxies are challenging, but crucial to better understand the various physical processes responsible for galaxy assembly and evolution.

- Need accurate selection techniques + confirmation of individual candidates

- Several results confirm the existence of passive galaxies in the early Universe (z>3)

- 102 candidates at z>3 selected in CANDELS by ad-hoc SED fitting technique (Merlin+18, +19subm.)

- ALMA data lends decisive evidence to the quiescent nature of our candidates (Santini+19, Santini+in prep.):
  - 61% individually and robustly confirmed adopting conservative assumptions
  - Available observations are not deep enough to individually confirm the remaining candidates with high confidence
  - The stacking analysis and the lack of reliable detections corroborates the passive nature of the remaining candidates, at least in a statistical sense

- Future big eyes will provide a great contribution to the study of early passive galaxies and allow a much more robust classification and analysis

Thanks