The largest ESO high-redshift Large Programme

Lidia Tasca

& VUDS collaboration

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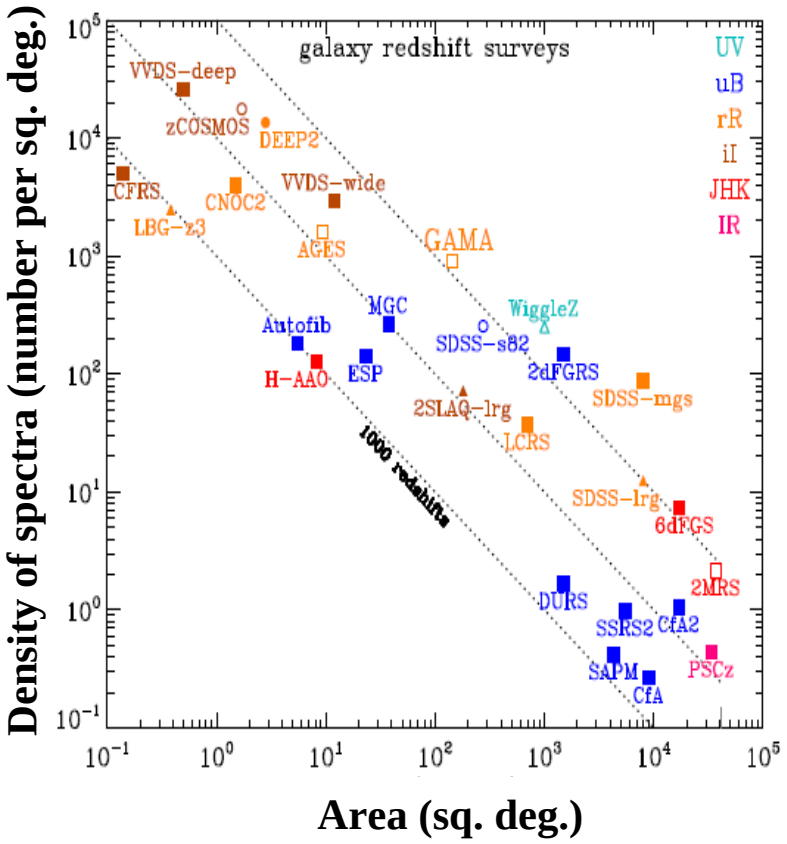
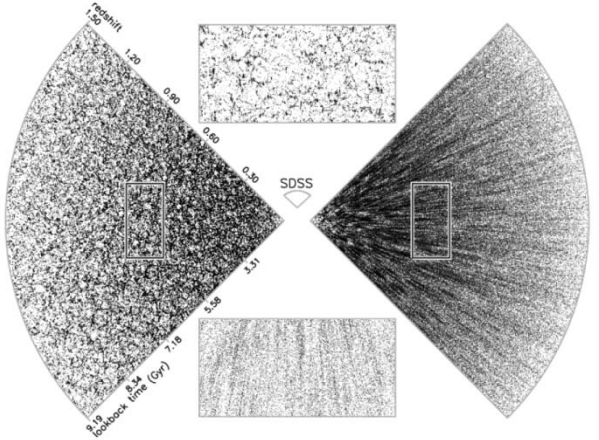
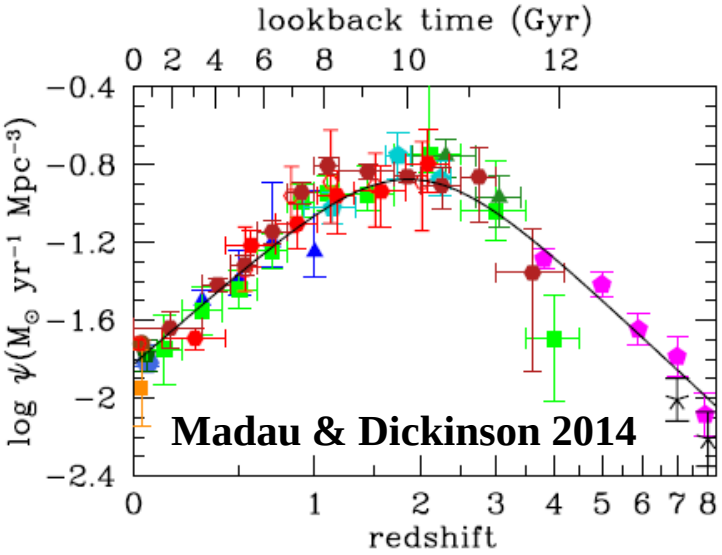
Redshifts surveys: a key tool for cosmology

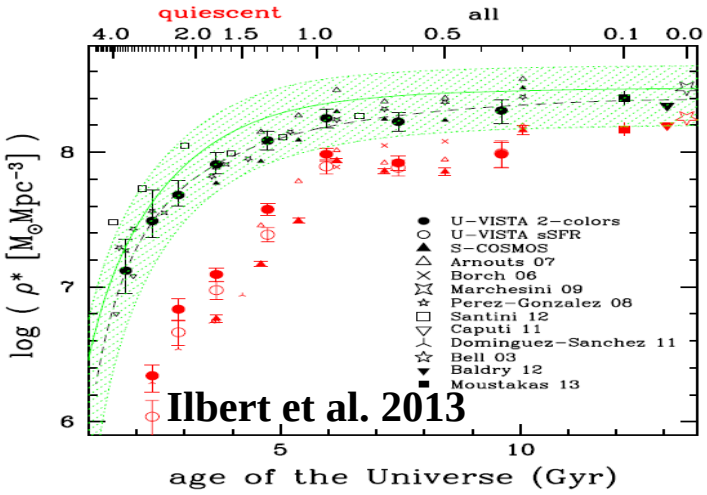


- Key tool to test the cosmology world model
- Main tool to understand galaxy formation and evolution
- Spectroscopic redshifts: accurate 3D positions



2<z<6.5: probing a major epoch in galaxy assembly





What fuels star formation?

- processes to transform gas into stars
- modulated by feedback, environment (feedback)

What contributes to the mass increase?

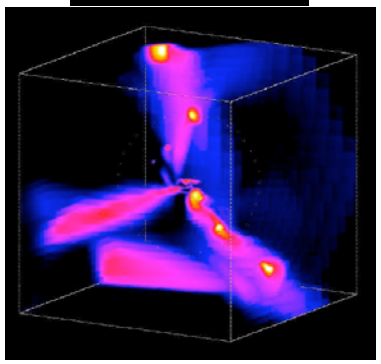
- evolution of the mass in stars

MASS GROWTH

Merging

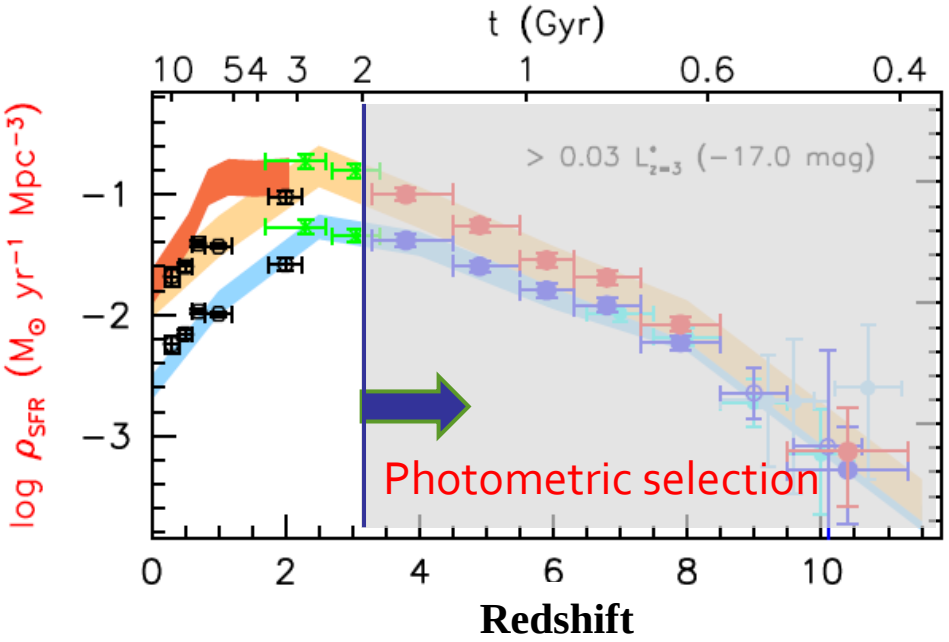
?

Accretion



Effect of the environment?

Missing: large samples of galaxies in large volumes with $2<z_{spec}<6.5$

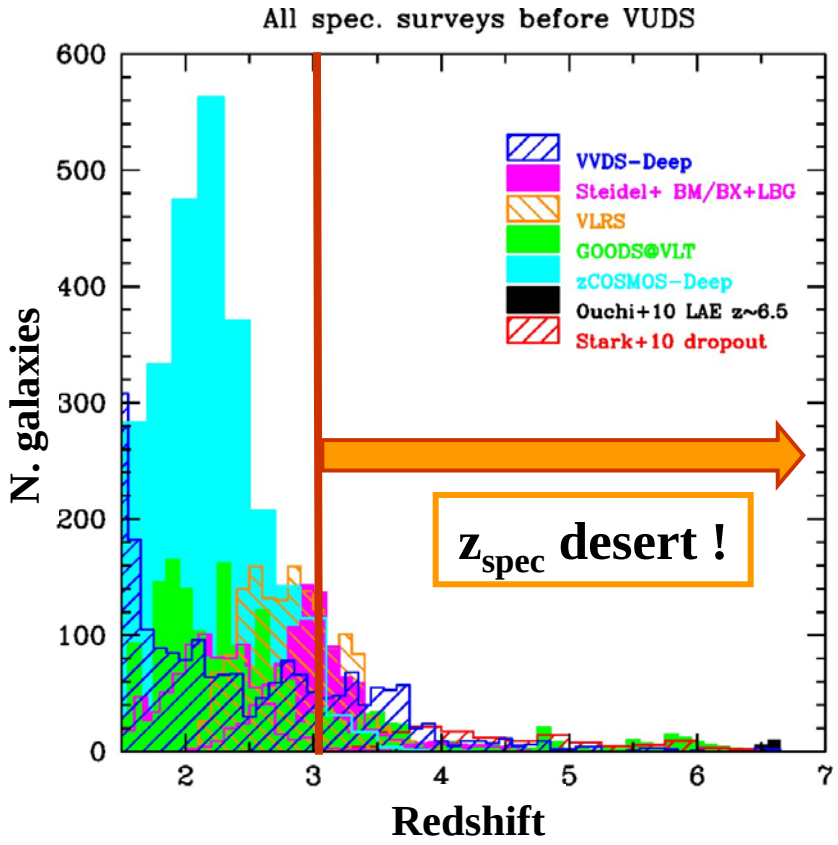


At z>2 most studies use photometric samples

The census of galaxies so far relies on small fields

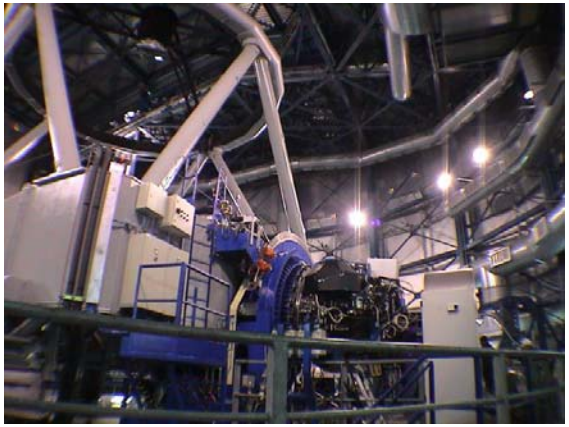
Need large spectroscopic samples in large volumes

Missing: large samples of galaxies in large volumes with $2<z_{spec}<6.5$



Need large spectroscopic samples in large volumes

VUDS: spectroscopic survey of the first phases of galaxies assembly



ESO Large Program, PI: Olivier Le Fèvre
640h allocated (~80 nights, clear)

~10000 spectra to map the Universe 10-13 Gyr ago

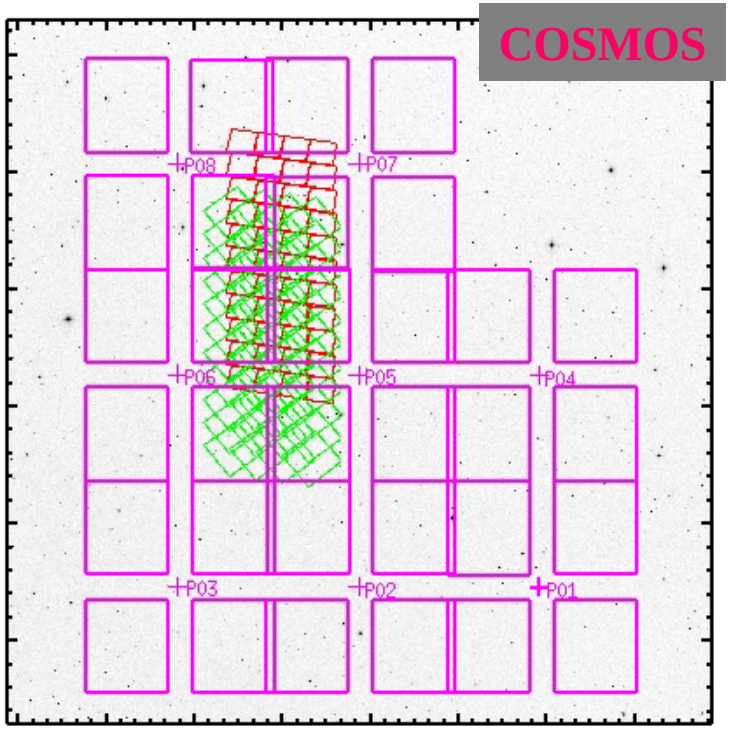
FIELD	VIMOS pointings	Area arcmin^2
COSMOS	8	1800
ECDFS	2+1	675
VVDS-02	5	1125
TOTAL	**15+1**	**3600**

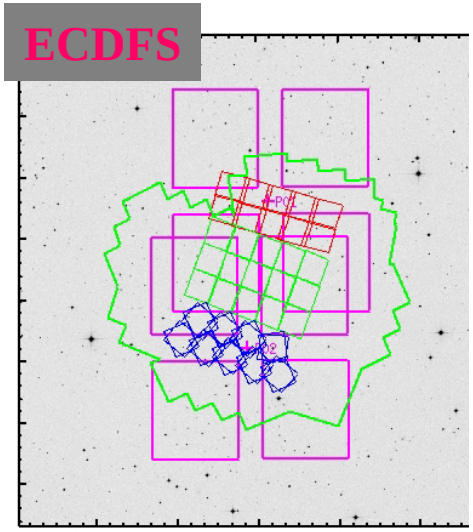
Understanding early galaxy assembly :

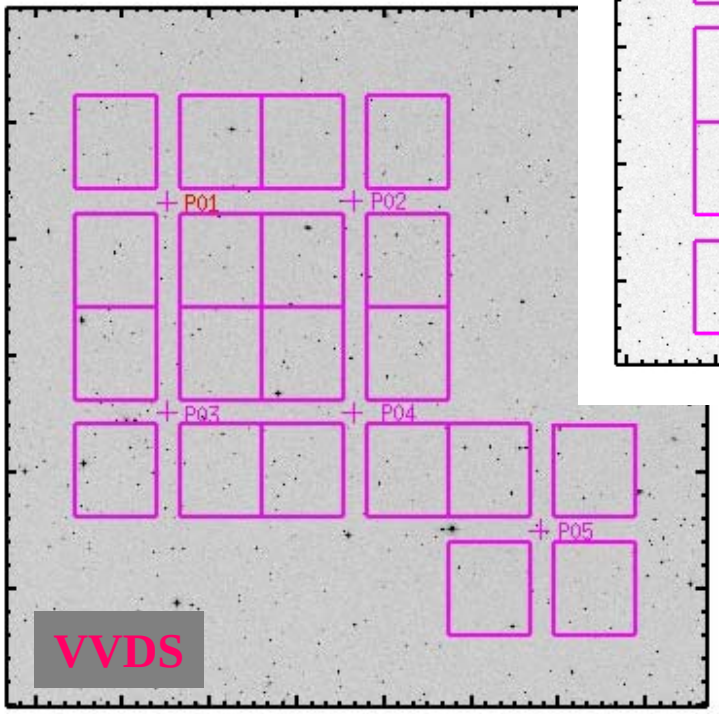
- 10.000 galaxies observed
- 14h exp.time, 3600-9300Å
- 1 deg^2 in 3 fields: COSMOS, ECDFS, VVDS2h
- Smart selection: photo-z and SED
- Largest spectroscopic survey in 2<z<6+

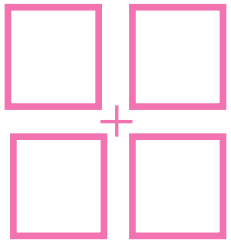
3 fields with a lot of existing data

- Multi-wavelength imaging from u to K bands
- Spectro-z from previous surveys: VVDS, zCOSMOS, GOODS
- Deep Spitzer data at 3.6 and 4.5 μm (24 μm)
- HST imaging









1 VIMOS pointing

What do we get ?

- **80% success rate down to i_{AB}=25**
- Absorption as well as emission spectra
- Interesting outliers
  - Contamination along the LOS
- SED fitting using em. line templates
  - Exceptionnal set of multi-λ data (HST, Subaru, UltraVista, Spitzer…)
  - SFR, M_{star}, E(B-V), Age,…
- SED+spectra fitting
- Redshift distribution as expected

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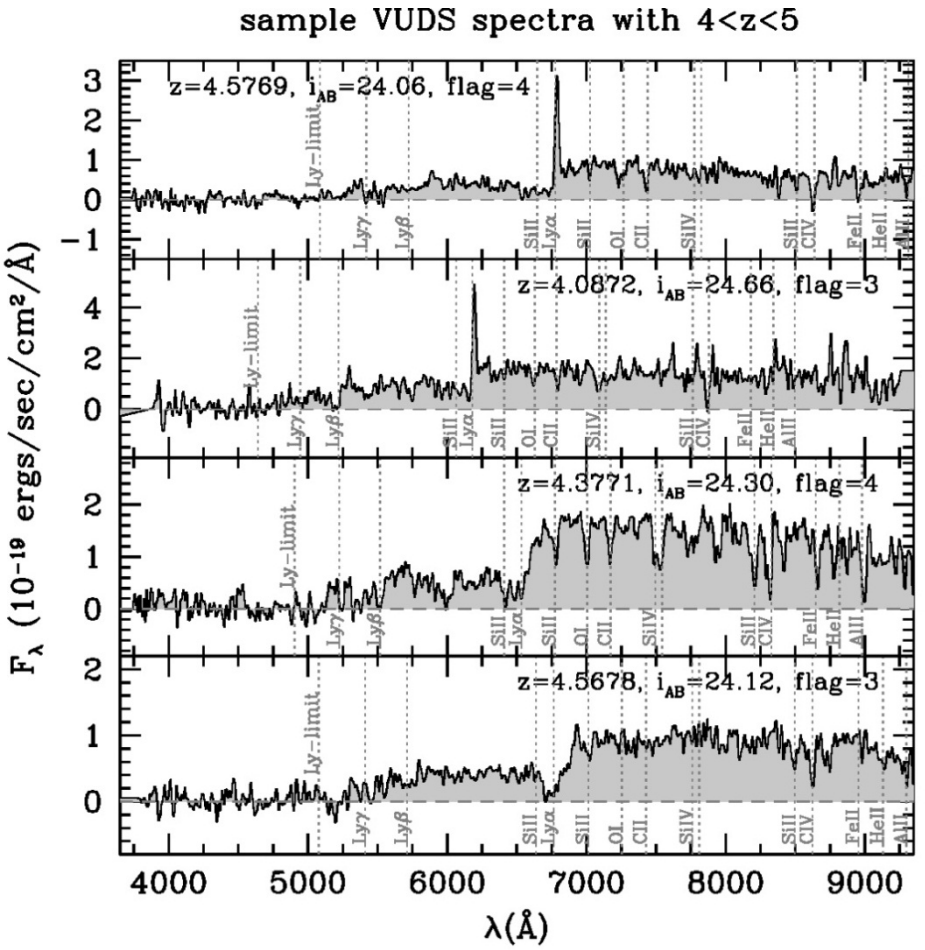
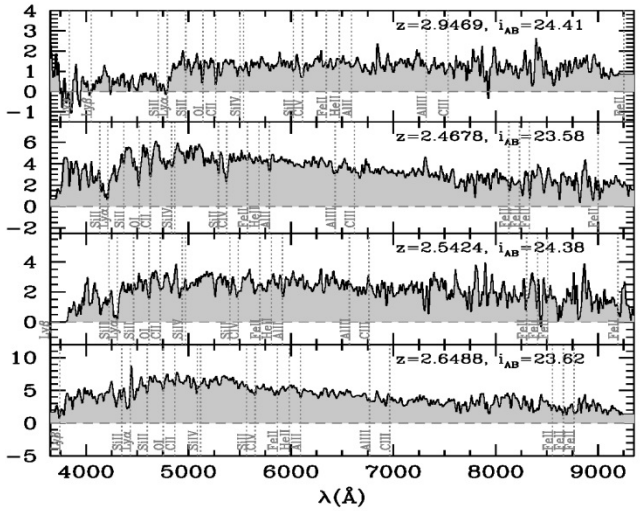


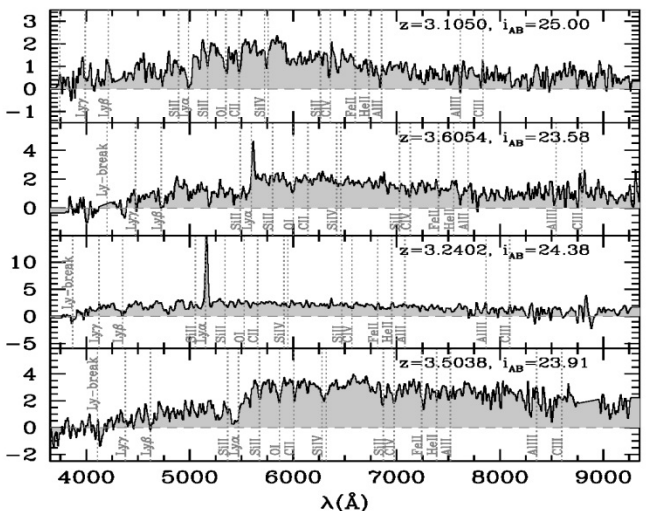
Absorption & emission line galaxies to z~6

Individual spectra $i_{AB} \leq 25$, a very faint sample

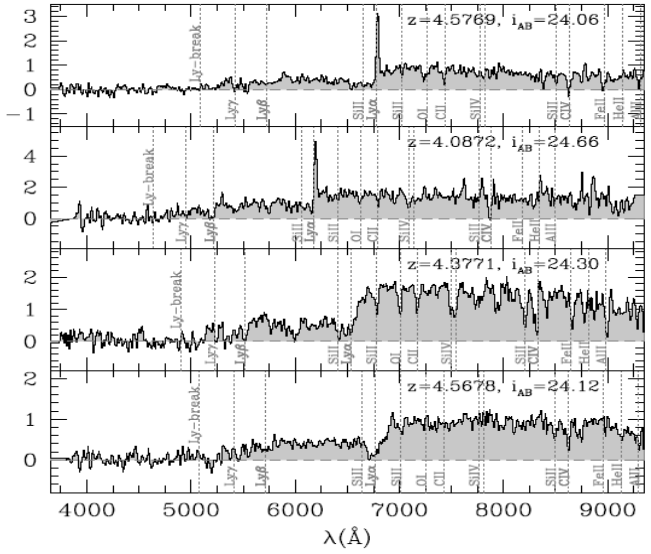
2<z<3



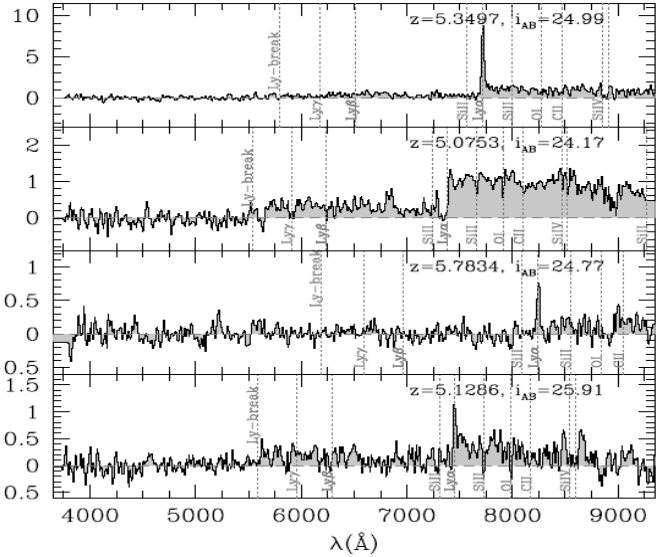
3<z<4



4<z<5



5<z<6



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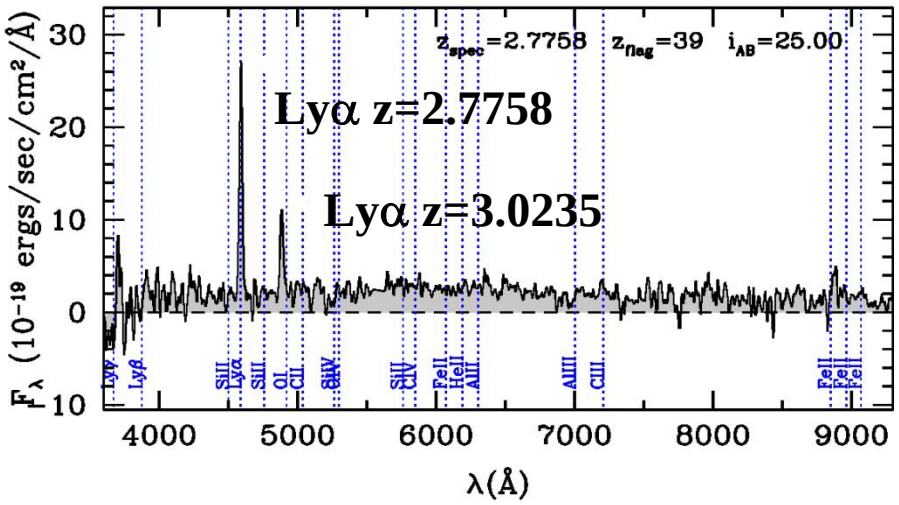

Superimposition on the line of sight

What do we get ?

- 80% success rate down to i_{AB}=25
- Absorption as well as emission spectra
- Interesting outliers
  - Contamination along the LOS
- **SED fitting using em. line templates**
  - Exceptionnal set of multi-λ data (HST, Subaru, UltraVista, Spitzer…)
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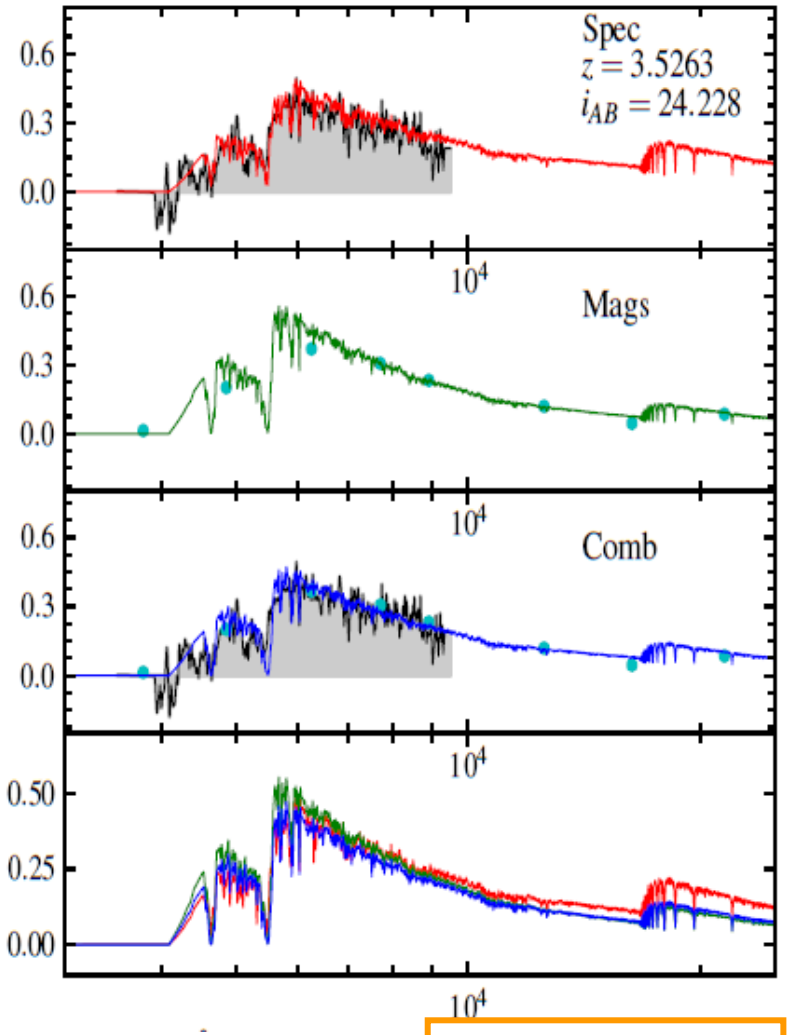
- **SED+spectra fitting**
- Redshift distribution as expected



R. Thomas et al.

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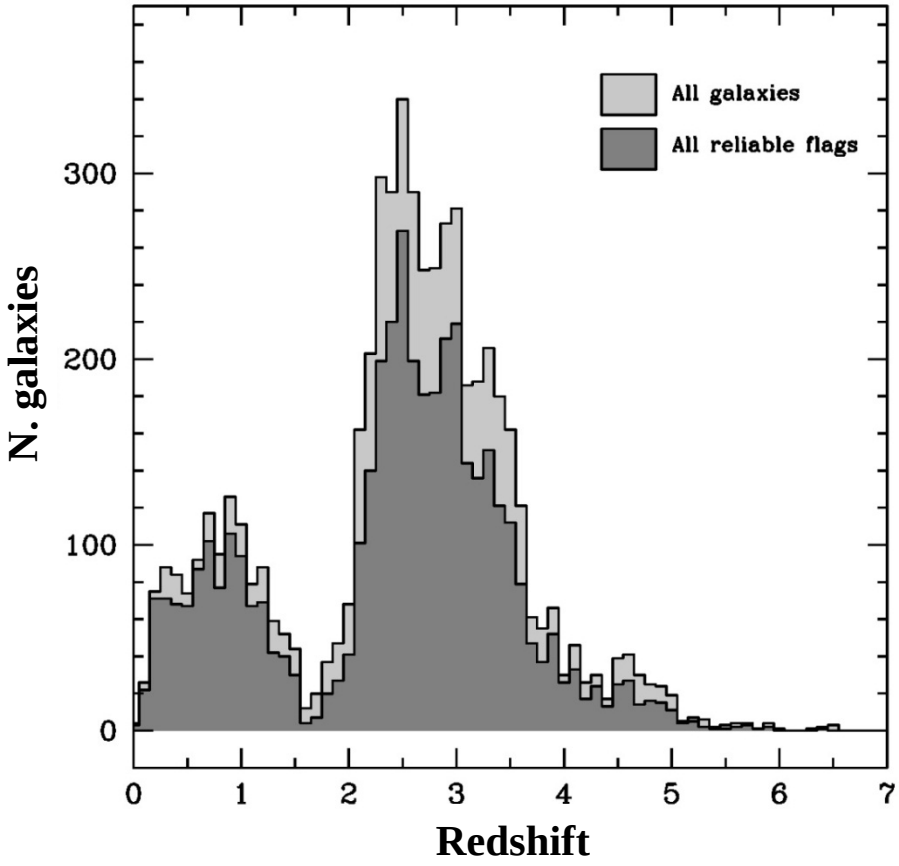
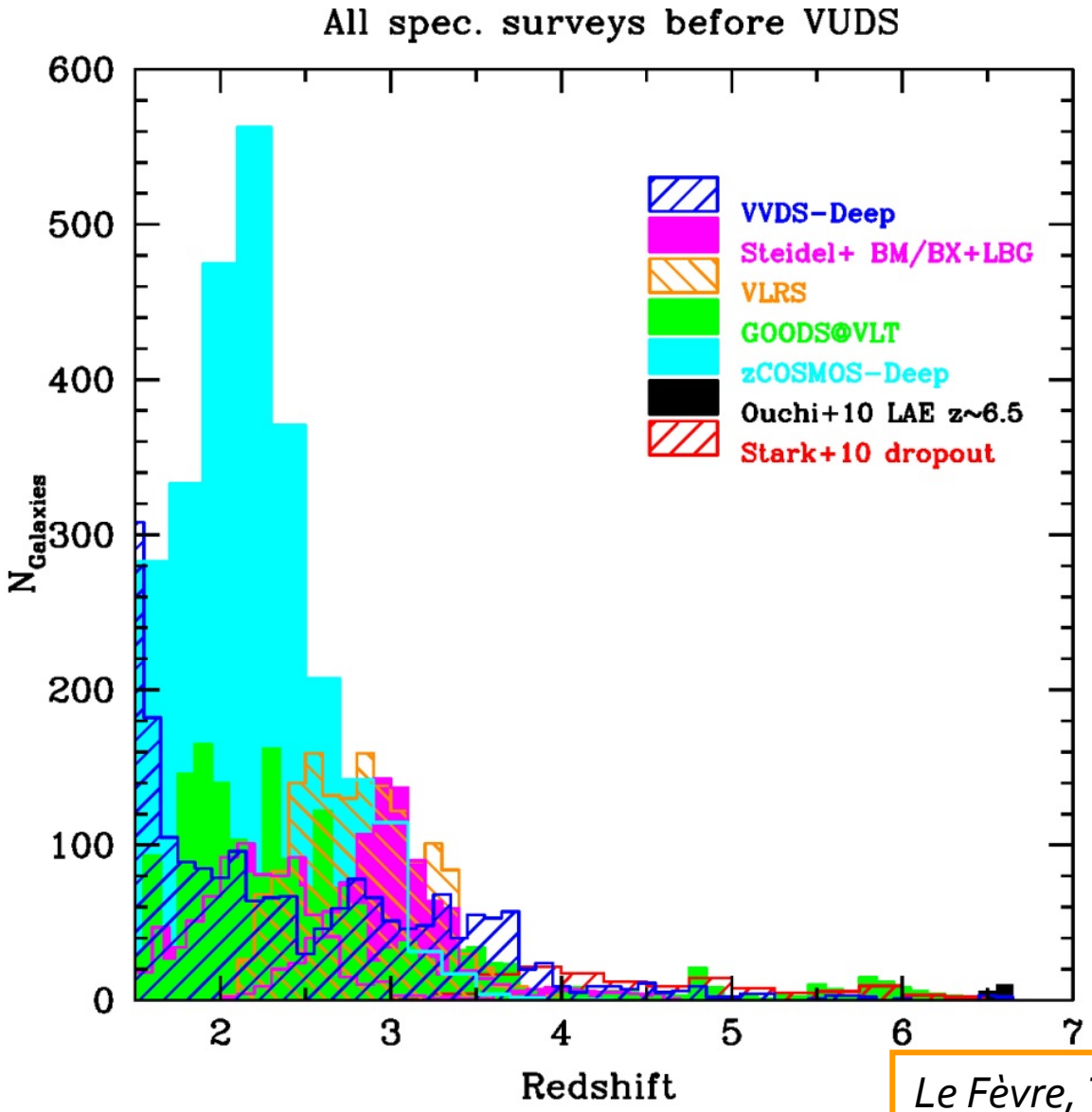
- SED+spectra fitting
- **Redshift distribution as expected**



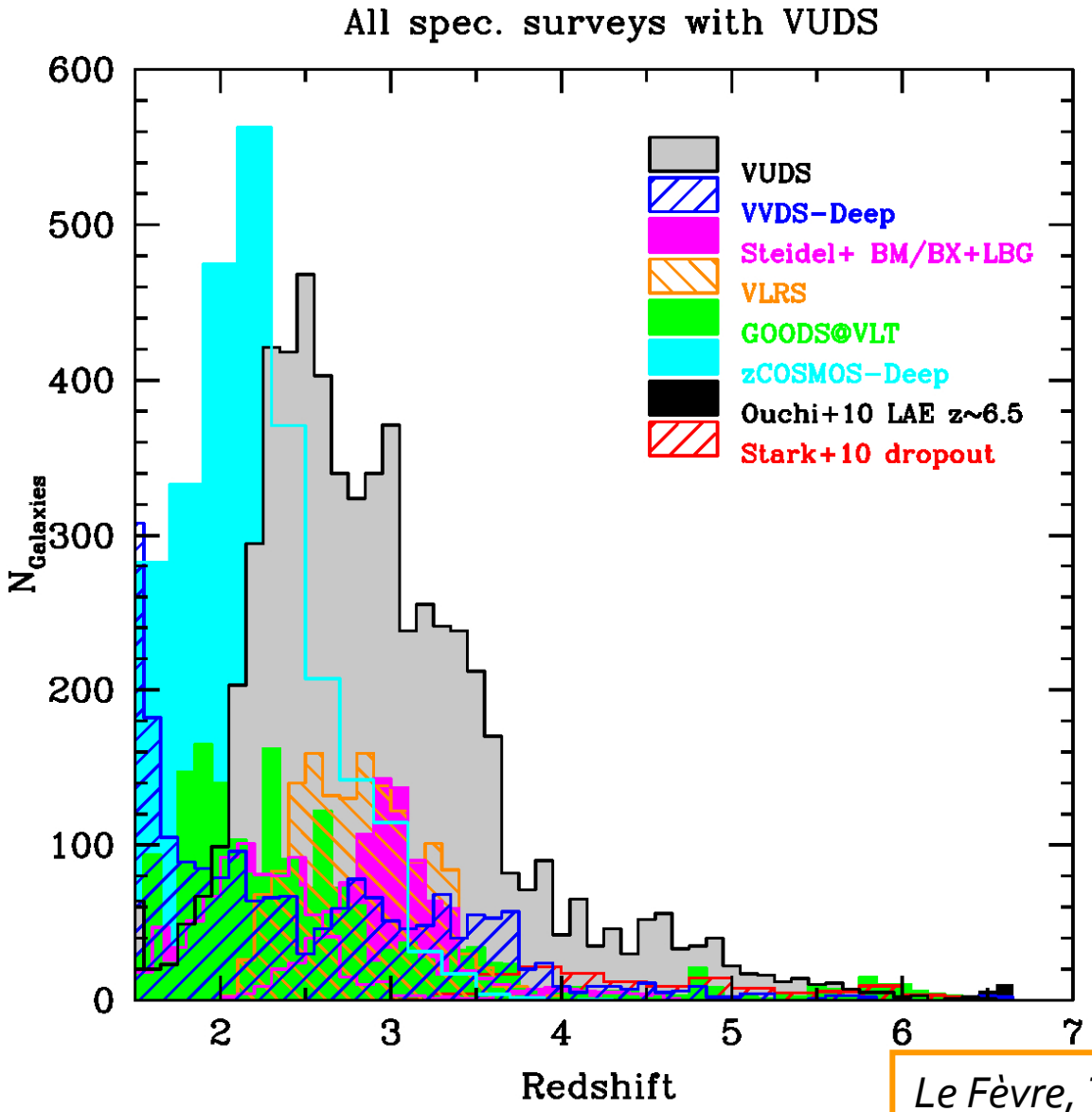
Le Fèvre, Tasca et al. 2015

Before VUDS



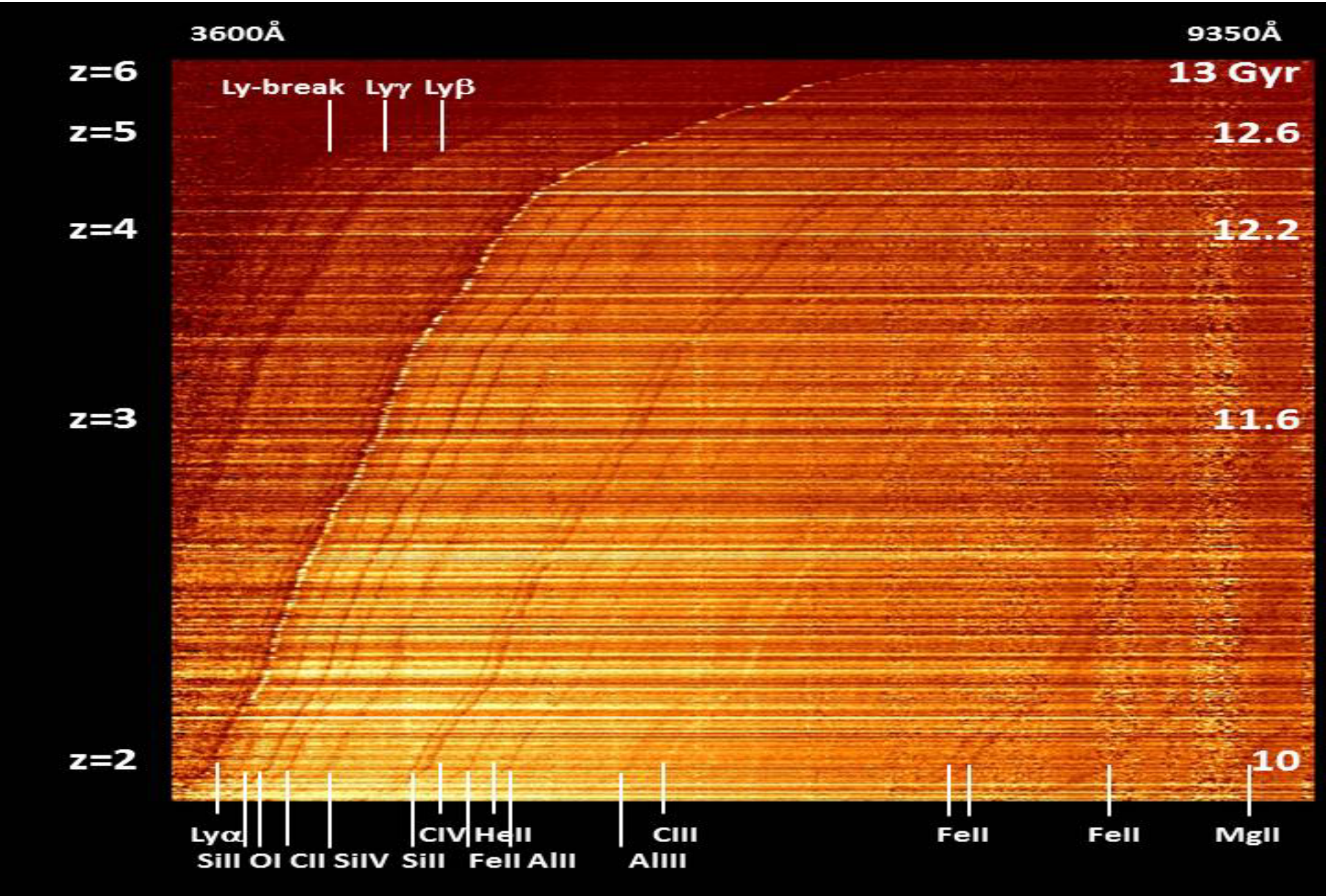
Le Fèvre, Tasca et al. 2015

After VUDS



Le Fèvre, Tasca et al. 2015

VUDS ~7500 spectra of galaxies at z>2:~3Gyr of evolution in one glance

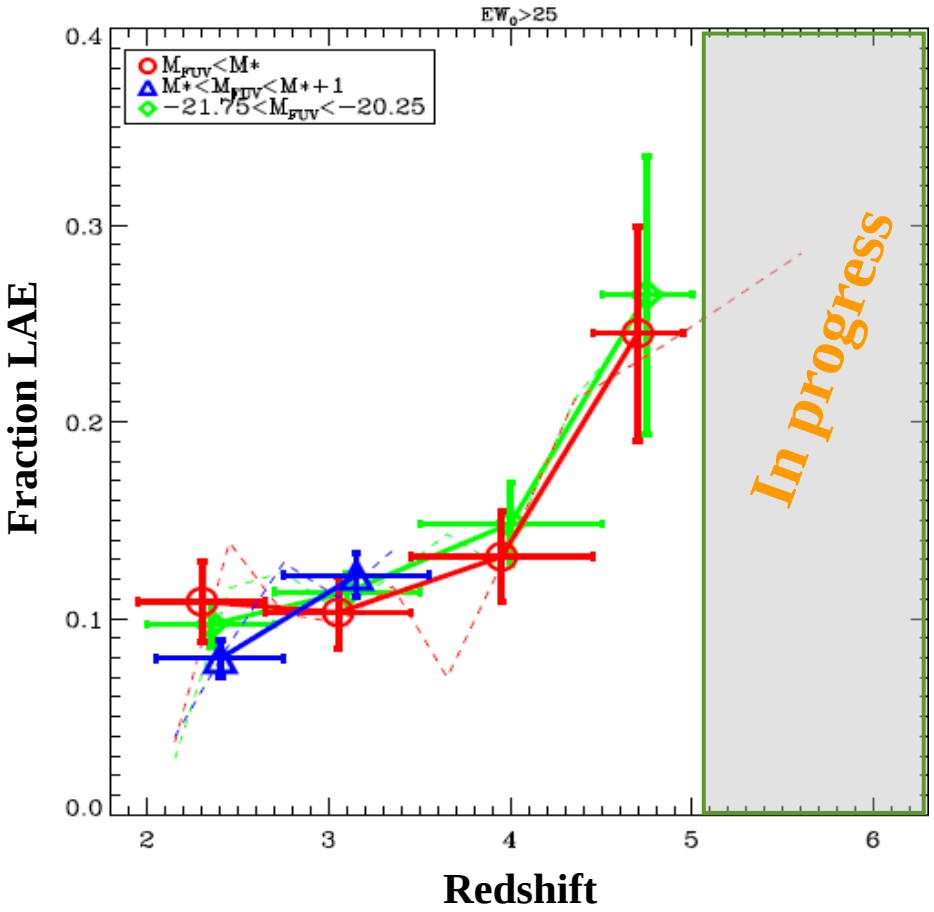


First results

1. Survey description paper (Le Fèvre, **Tasca**, et al., 2015, A&A, 576, 79)
2. Merging rate z~3 (**Tasca** et al., 2014, A&A, 565, 10)
3. Lyα fraction evolution 2<z<6 (Cassata, **Tasca** et al. ,2015, A&A 573, 24)
4. Proto-cluster z=3.3 (Lemaux et al., 2014, A&A, 572, 41)
5. Proto-cluster z=2.9 (Cucciati et al., 2014, A&A, 570, 16)
6. Low-M high-SFR z~1 galaxies (Amorin et al., 2014, A&A, 568, 8)
7. Stellar mass to halo mass relation from galaxy clustering in VUDS: a high star formation efficiency at z ~3 (Durkalec et al., 2015, A&A, 576, 7)
8. SFR-M and sSFR evolution up to z~6 (**Tasca** et al., 2015, A&A, 581, 54)
9. Lyα continuum escape fraction (Grazian et al., accepted)
10. First clustering measurement (Durkalec et al. , accepted)
11. IGM transmission (Thomas et al. , arXiv)
12. Progenitors of z~2 passive galaxies (**Tasca** et al. , in prep.)
13. Epoch of galaxy formation (Thomas et al., in prep)
14. ….

General paper: the ESO Messenger March issue

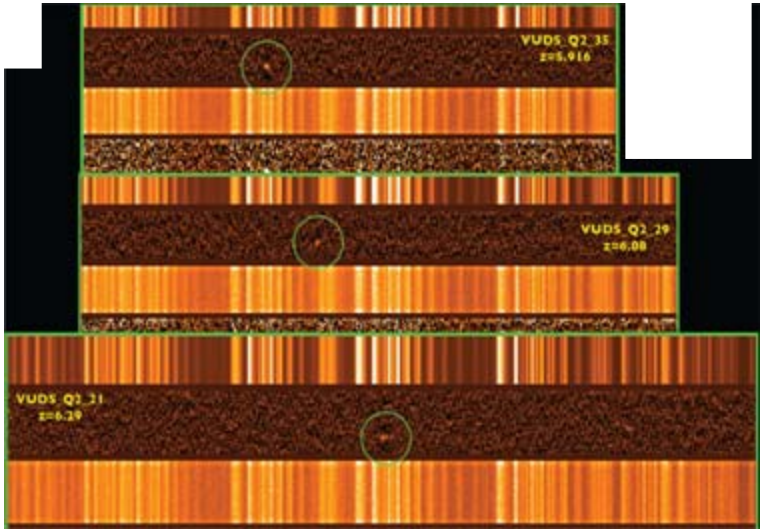
Lyα fraction evolution



Cassata, Tasca et al. 2015

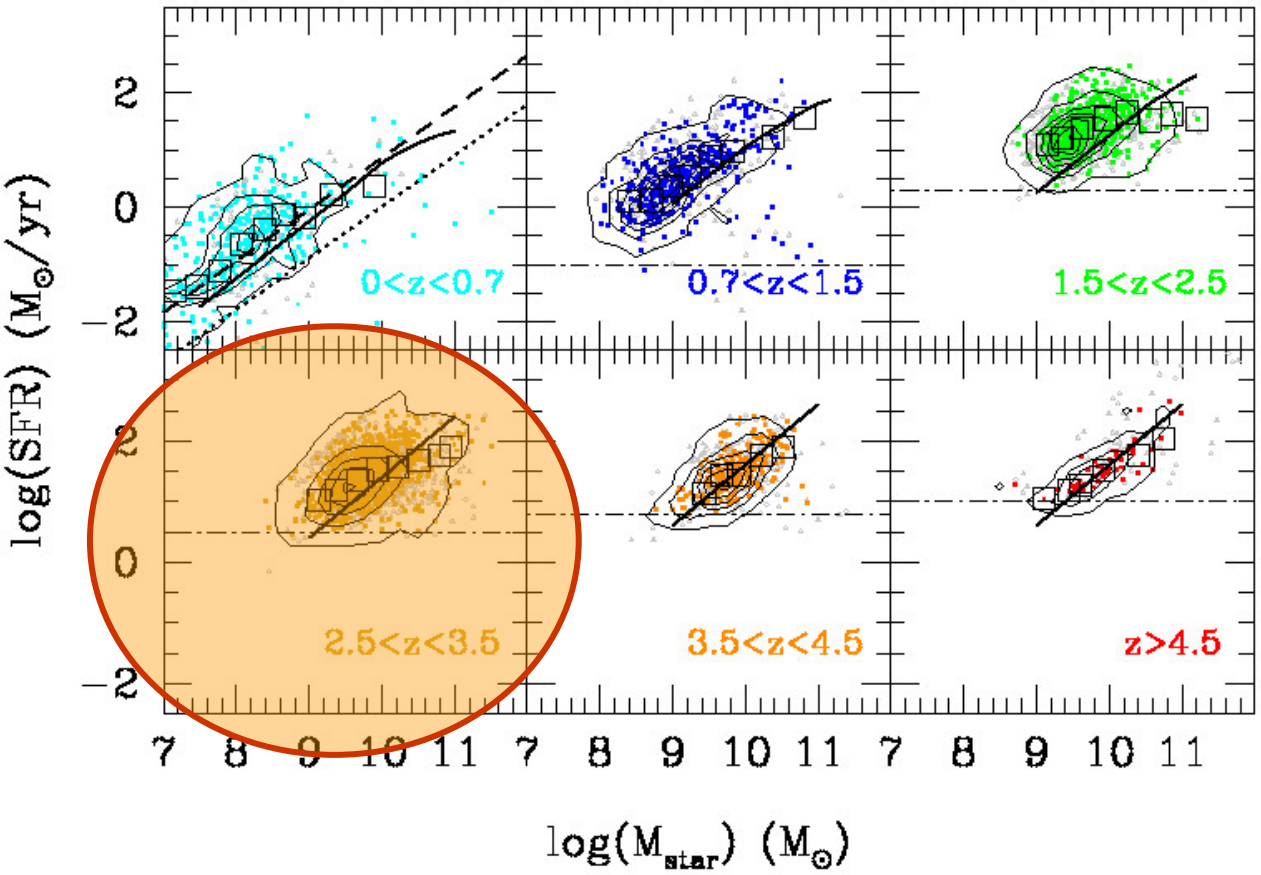
On-going:

Identification of Lyα em. up to z~6.5



Credits: E. Vanzella

SFR-M_* relation up to z~5



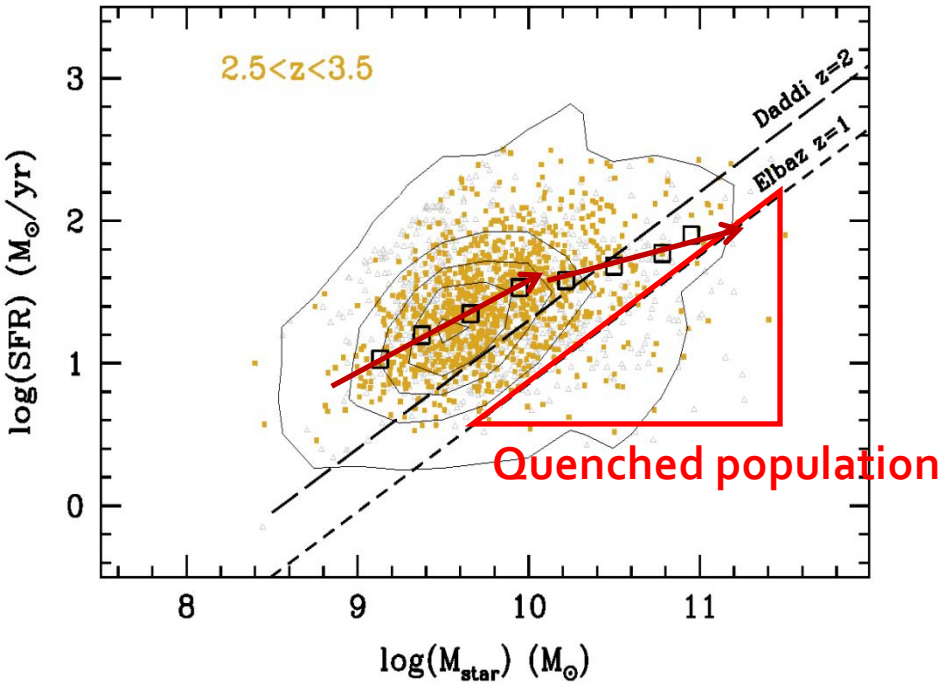
High-M turn-off at z<3.5. → effect of SF quenching in a downsizing pattern

Quenching processes not fully active at z>3.5

Tasca et al. 2015

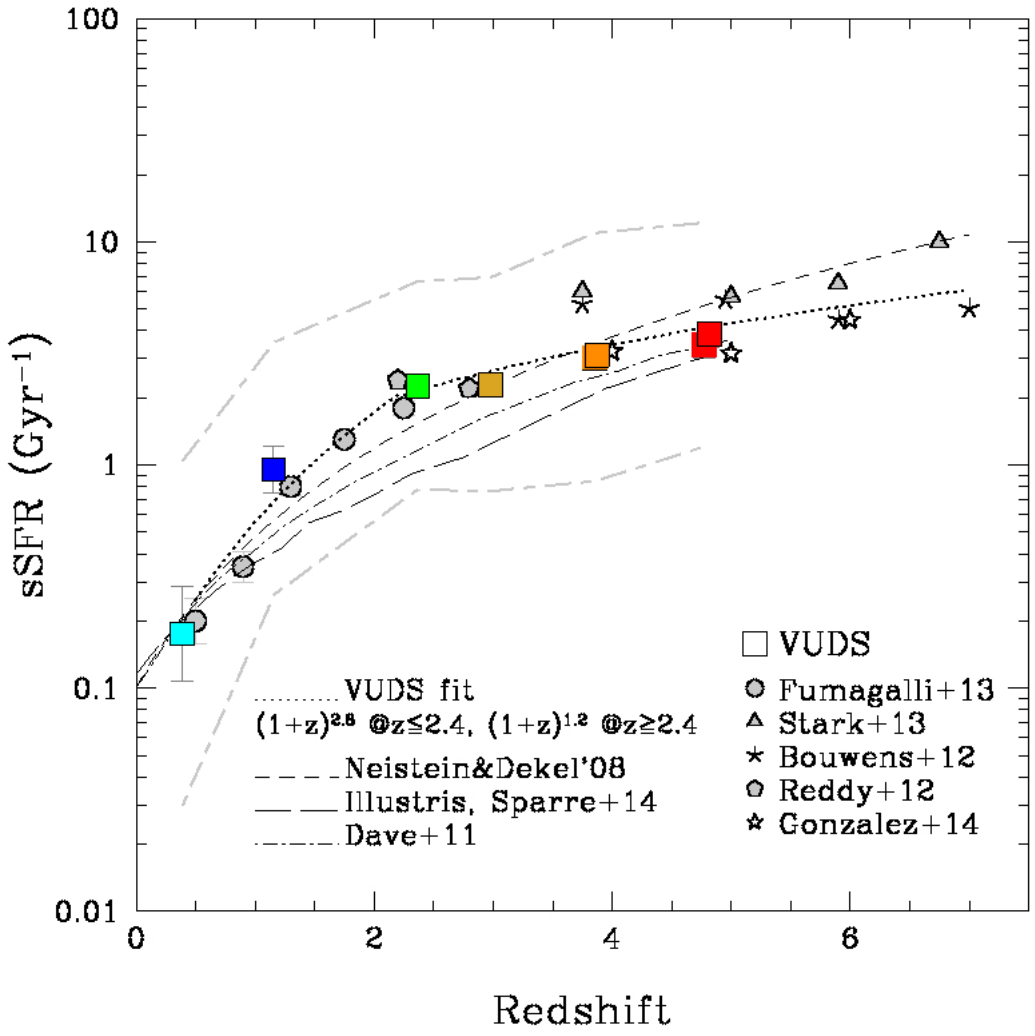
SFR-M_{star} "main sequence"

- Large spread around the "main sequence"
  - Related to SFH and systematics in M_{star} and SFR computations
- Bending of the relation above a "quenching mass"
- Significant population off the main sequence
  - On-going quenching ?



Tasca et al. 2015

sSFR evolution since z~5



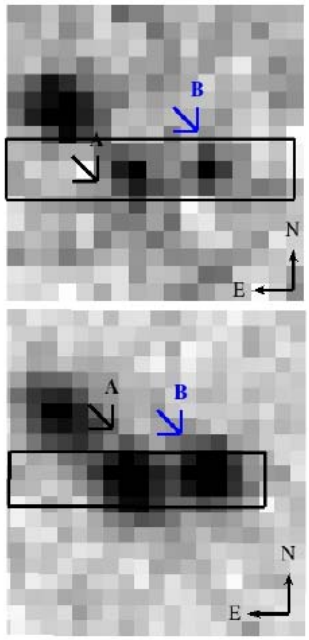
The sSFR evolution does not follow a pure accretion driven galaxy mass growth.

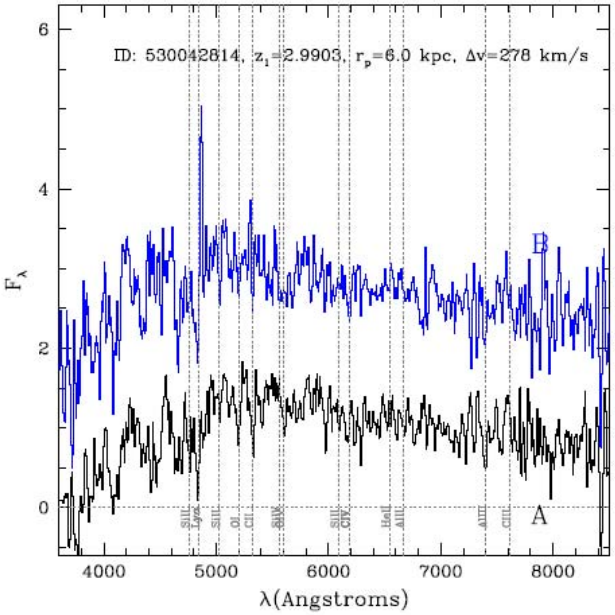
Need to combine with merger processes.

Tasca et al. 2015

Pairs / merger rate @z~3

Merging: major contribution to galaxy assembly





Tasca et al. 2014

- Is merging important during the first phase of mass assembly ?
- Identify true pairs: each member of a pair has a spectroscopic redshift
- Major mergers

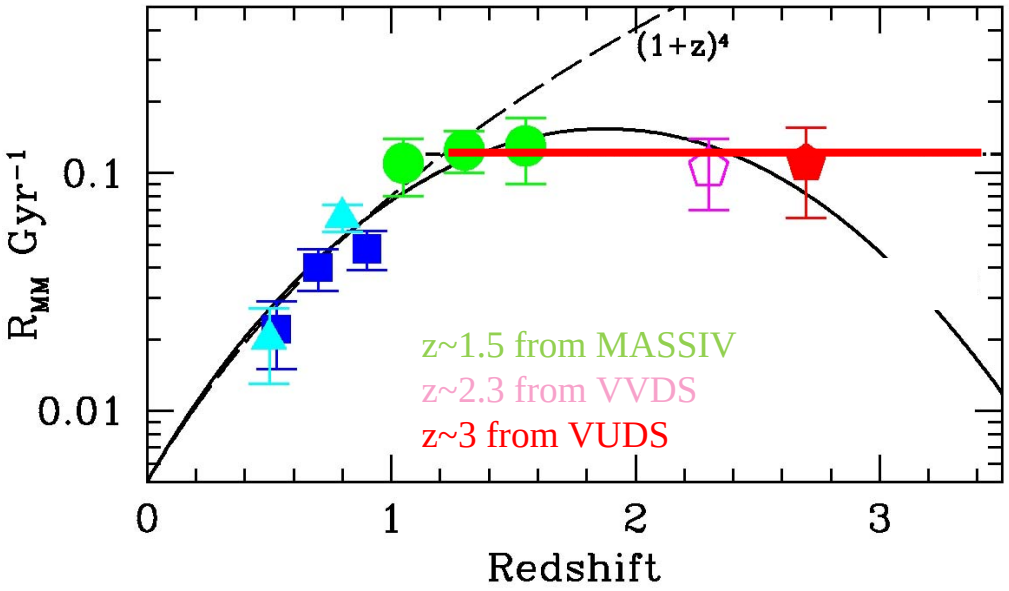
  M1/M2 > 1/4
- The merger fraction is

  f_{merg}=20%

Galaxy Merger Rate History since z~3 from spectroscopic pairs

Peak in major merger rate at z~1.5-2 ?

Integrating the GMRH indicates that 60% of the mass of galaxies at z=0 has been assembled by mergers

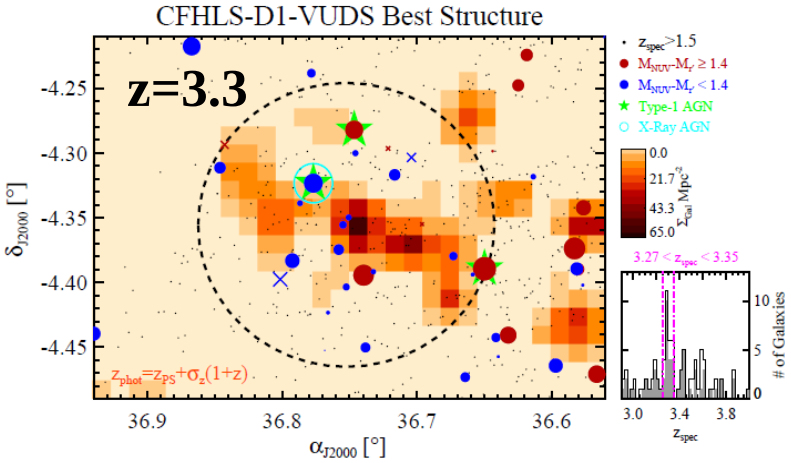


Le Fèvre et al. in prep.

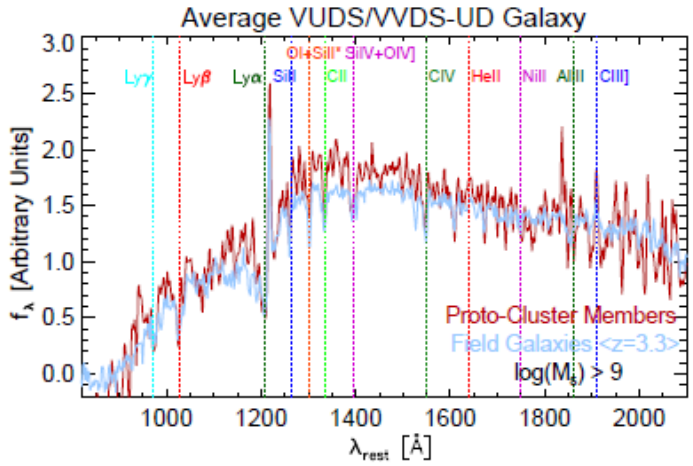
Proto-structures

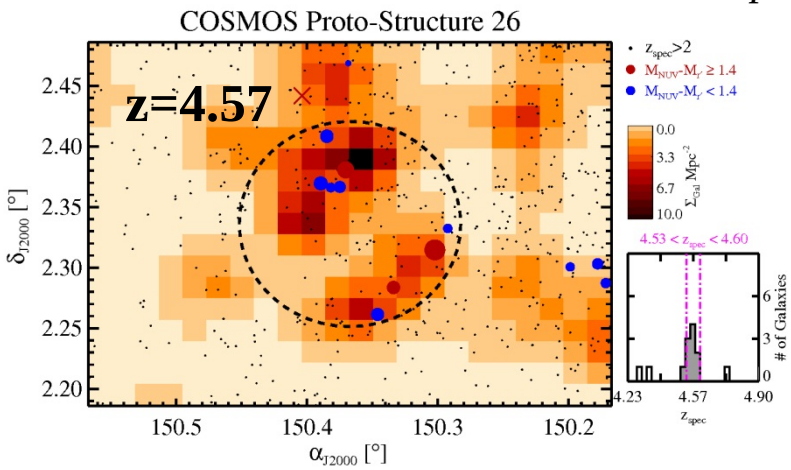
Mass: 3×10^{14} $M_\odot$
As massive as Coma by z~0
Lemaux et al. 2014

- Spectroscopic redshift necessary to pick-up proto-structures
- About 50 physical proto-structures found
- Work in progress: look for effect of environment



Lemaux et al. in prep



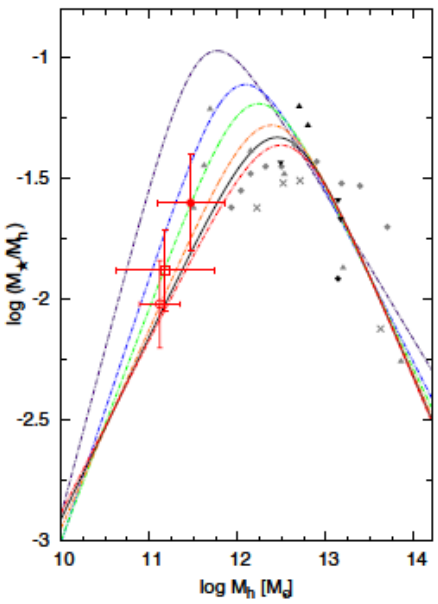


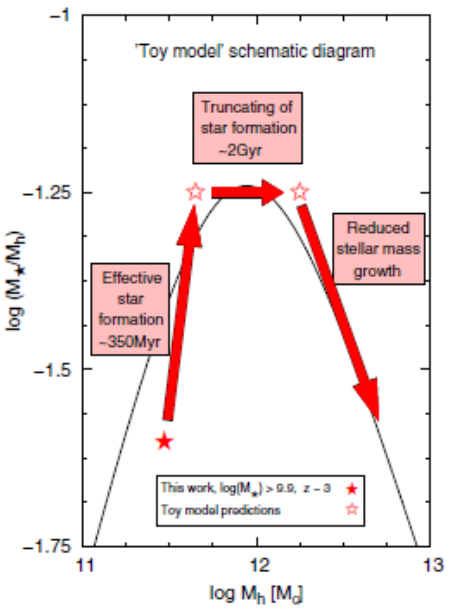
Also Cucciati et al. 2014, z~2.9 proto-cluster

…and many other interesting results!

- Clustering & Star formation rate efficiency at z~3 *(Durkalec et al. 2015)*
- Compact metal-poor star-forming dwarfs z~1 *(Amorin et al. 2014)*
- Effect of SFH on SFR-Mass relation *(Cassara et al. submitted)*
- Low Lyman continuum escape fraction @ z~3 *(Grazian et al. 2015)*

- …. a number of papers in preparation



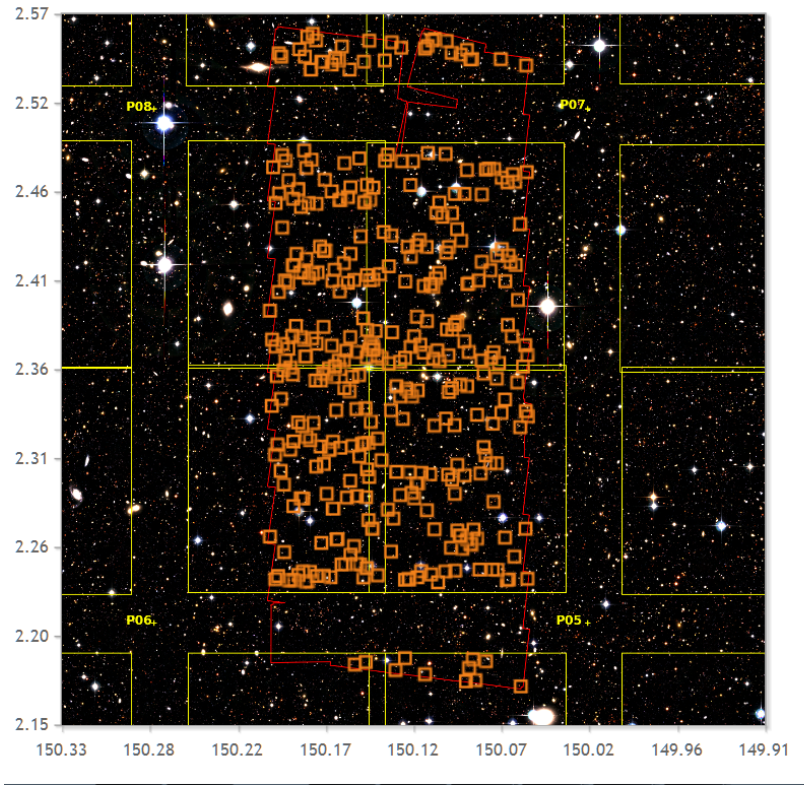


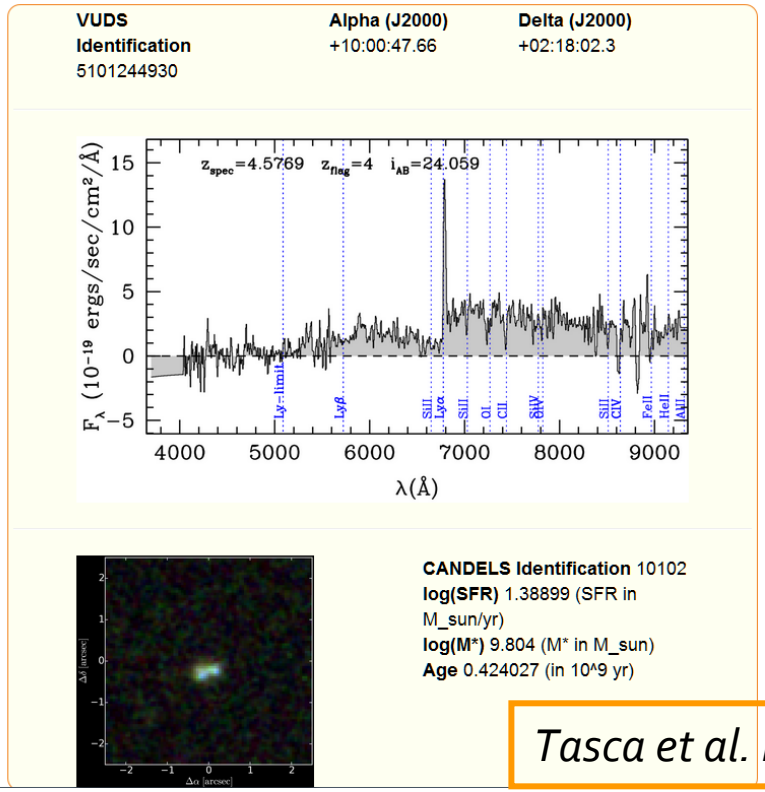
Stay tuned!

VUDS-DR1: Public data release
~700 galaxy spectra to z_{spec}<6 in CANDELS

VUDS data matched to:
CANDELS-COSMOS
CANDELS-ECDFS

http://cesam.lam.fr/vuds/DR1/





Tasca et al. in prep.

Summary & Conclusions

VUDS allows an unbiased and homogeneous study of the high-redshift universe & to look for the inset of quenching

VUDS enables a wide range of investigations

- Rise of Lya fraction to ~25% at z~5
- Evolution of the SSFR different from simple models
- Evidence for quenching starting at z~4
- Merging is an important contribution to galaxy assembly: 20% in major mergers
- Large volume + z_{spec}: proto-structure and effect of environment at early epochs
- More to come

1st Public data release on CANDELS: **http://cesam.lam.fr/vuds/DR1**

Best sample with solid statistical basis for meaningful "survey mode" follow-up: ALMA, KMOS, MUSE, VIMOS, …

Thank you for your attention

Galaxy census @ z>2

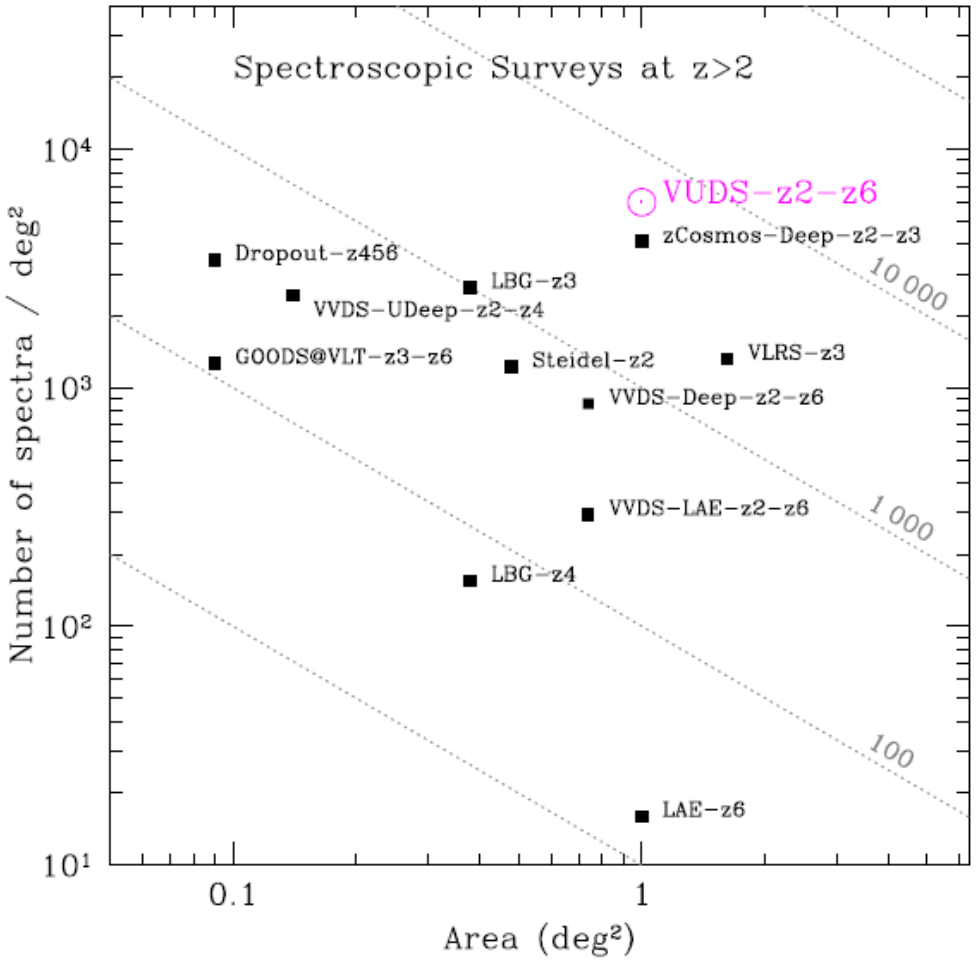
- Observational picture still very incomplete and uncertain
- The census of galaxies so far relies on small fields
  - Cosmic variance (Moster+11):
    - 50% on 100 arcmin² (GOODS, CANDELS)
    - 10% on 1deg² (COSMOS)
- At z>2 most studies use photometric samples:

  only ~2000 galaxies with z_{spec}>2, few hundreds at z_{spec}>3.5

Need large and deep spectroscopic samples

Only few spectroscopic surveys @z>2

Le Fèvre, Tasca et al. 2015



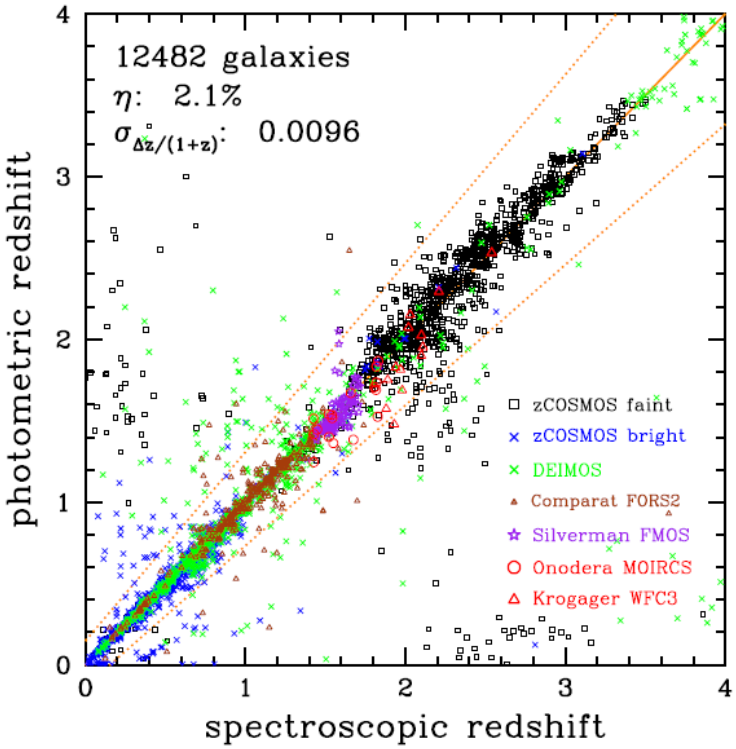
Only a few 10^3 galaxies with spectroscopic zedshifts to z~3.5

Largest is zCOSMOS-Deep with ~2000 galaxies with 2<z<3

Heterogeneous samples and selection functions

VUDS target selection

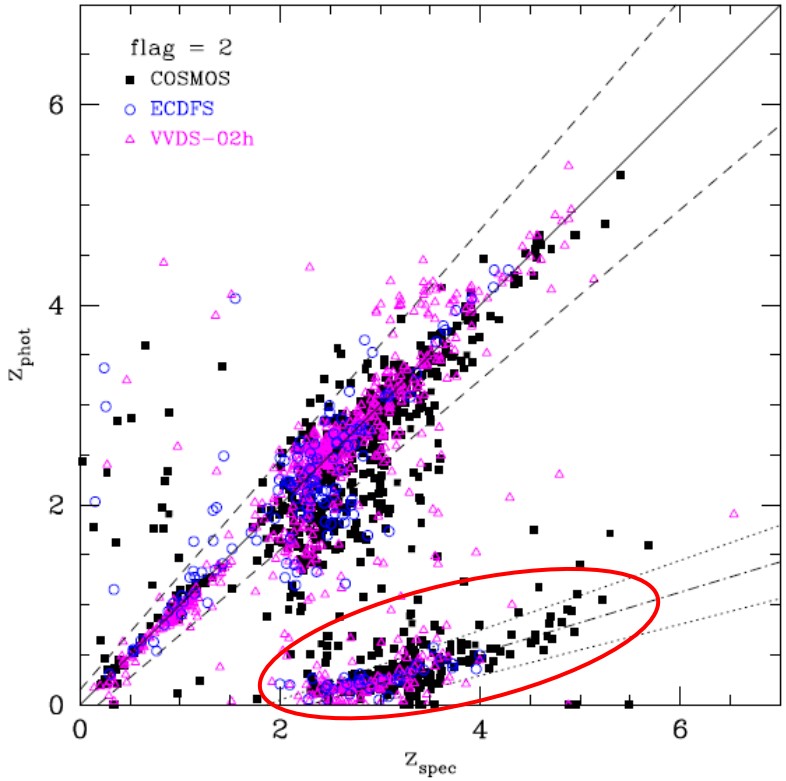
- Additive selection:
  - photometric redshifts, $z_{phot}>2.3$ $22.5 \leq i_{AB} \leq 25$
  - First and second peak in z_{phot} PDF
  - Color-color (LBG) AND $z_{phot}>4$ with $i_{AB}>25$
  - Add z+NIR detected, but not detected in optical
- Large wavelength range $3600<\lambda<9300$ Å
- 14h integration / target with VLT/VIMOS
- ~80% redshift success rate



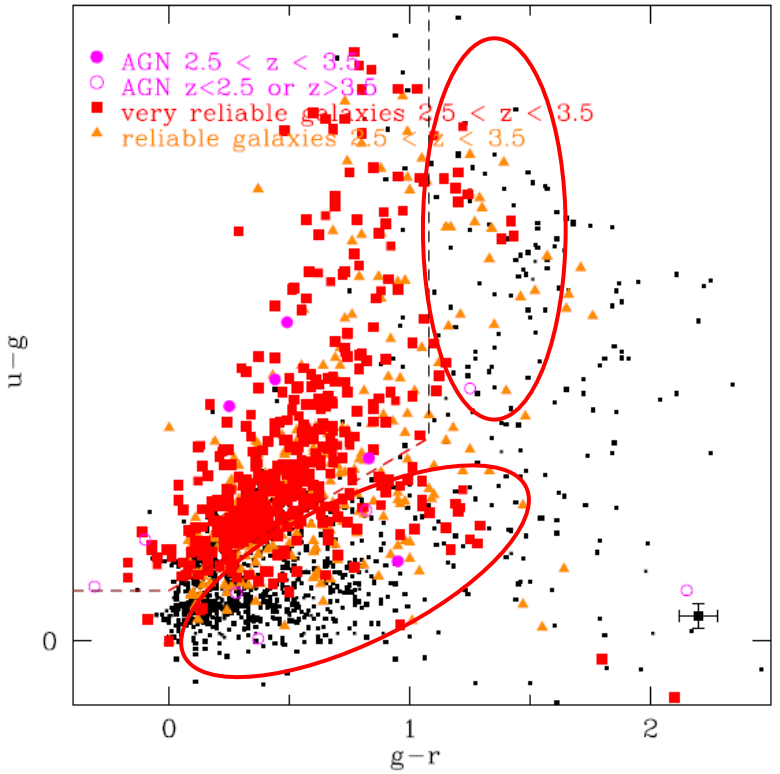
Ilbert et al. 2013

VUDS target selection validation

Better than a straight z_{phot} selection

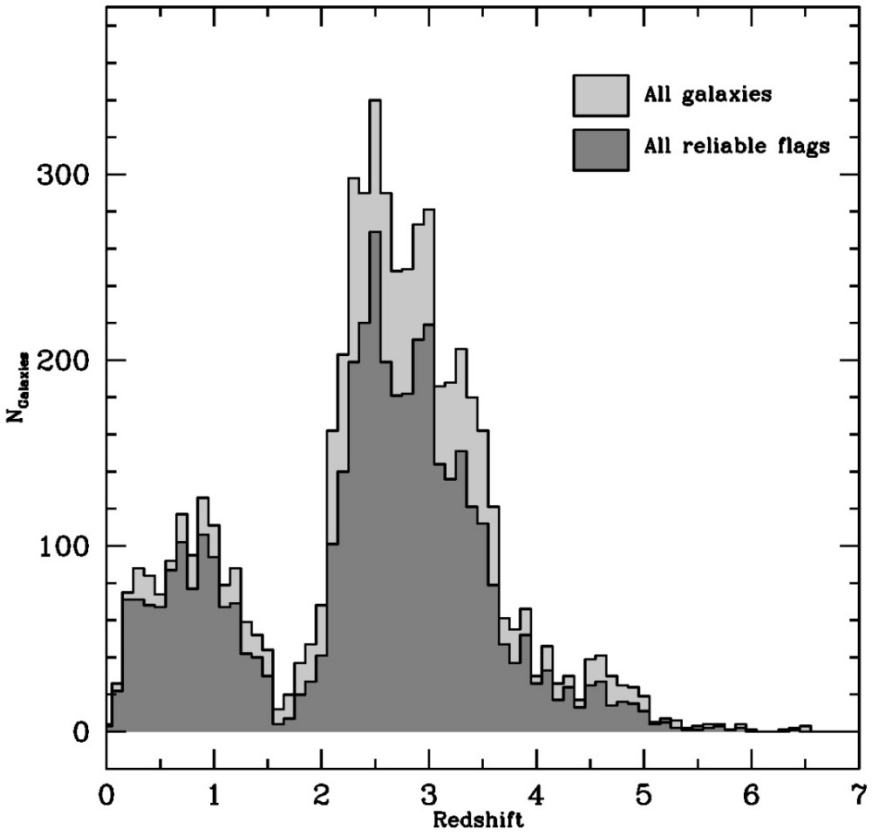


Better than a straight LBG selection



VUDS redshift distribution

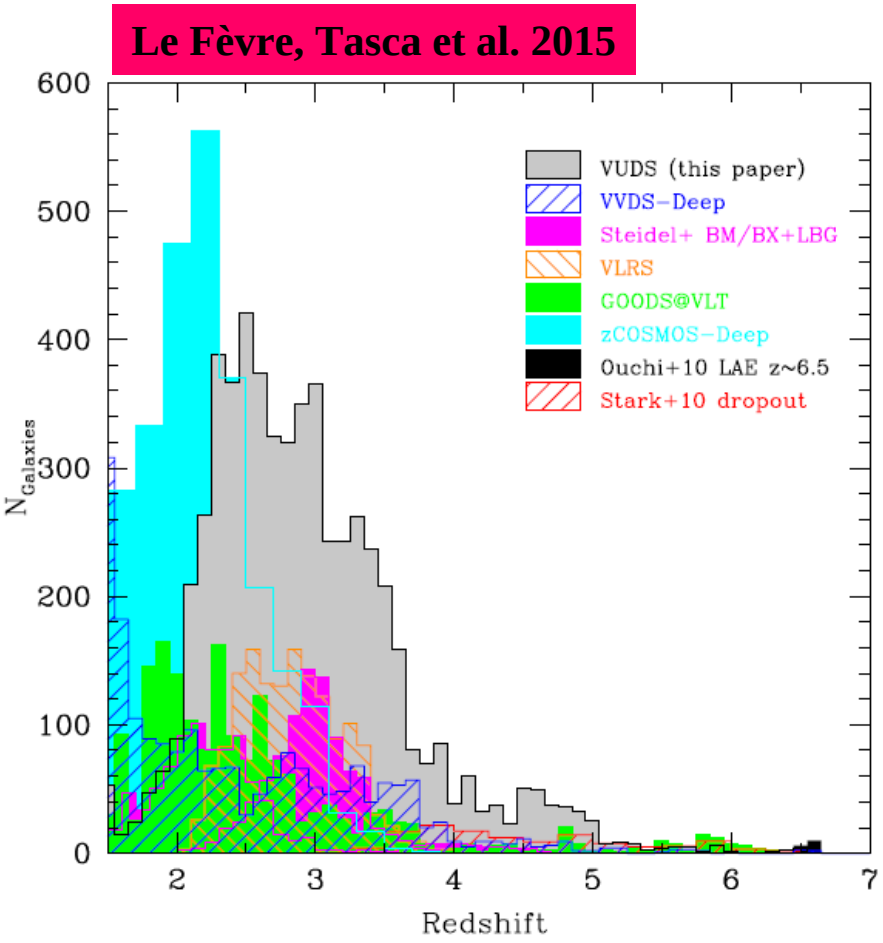
Le Fèvre, Tasca et al. 2015



6045 galaxies with measured redshifts today
Another 2000 expected from on-going data processing

The largest spectroscopic sample at z>2.5

VUDS redshift distribution

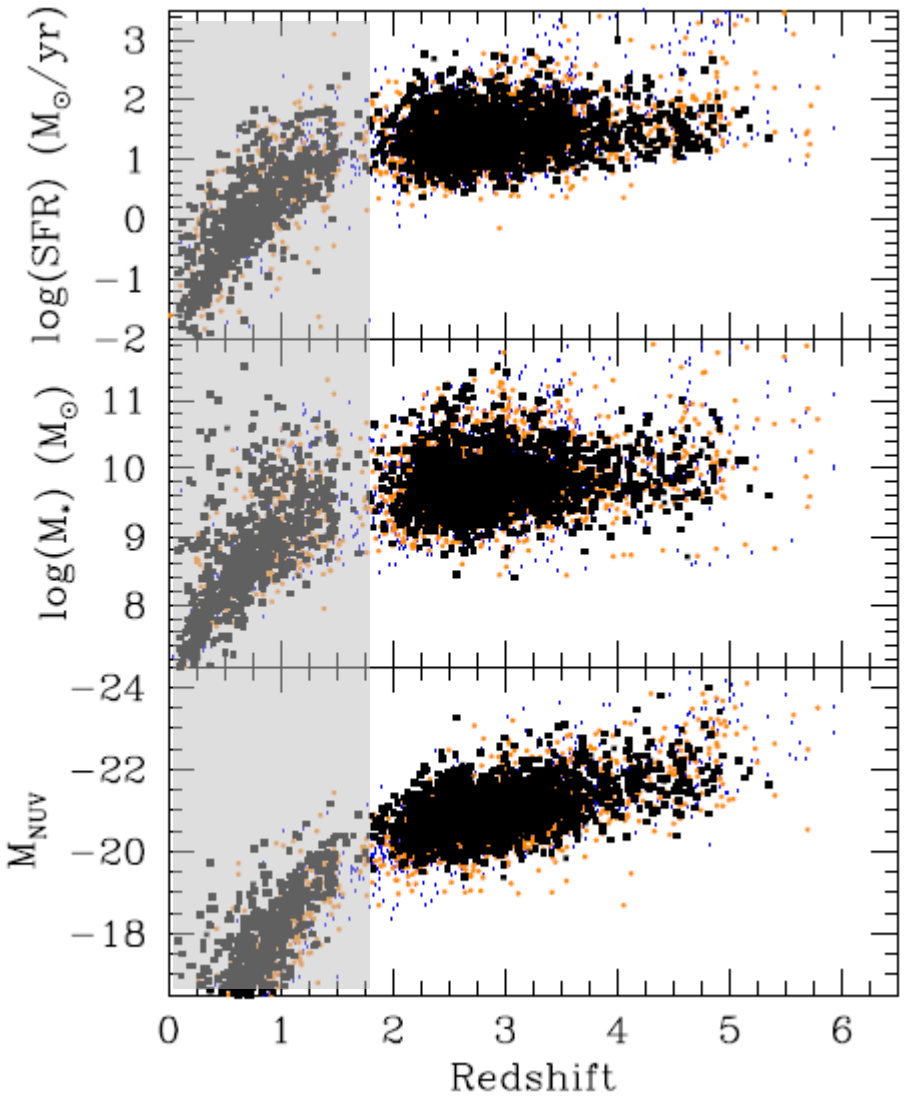


6045 galaxies with measured redshifts today
Another 2000 expected from on-going data processing

The largest spectroscopic sample at z>2.5

Sample properties

- Star formation rates from a few to ~1000 $M_{\odot}$/year
- Stellar masses: ~10^{9} to a few 10^{11} $M_{\odot}$
- Luminosity: brighter than L*



Proto-clusters at 2<z<4>

- Looking for over-densities in the VUDS 1deg² field coverage
  - In redshift space
  - Consolidated with photometric redshifts

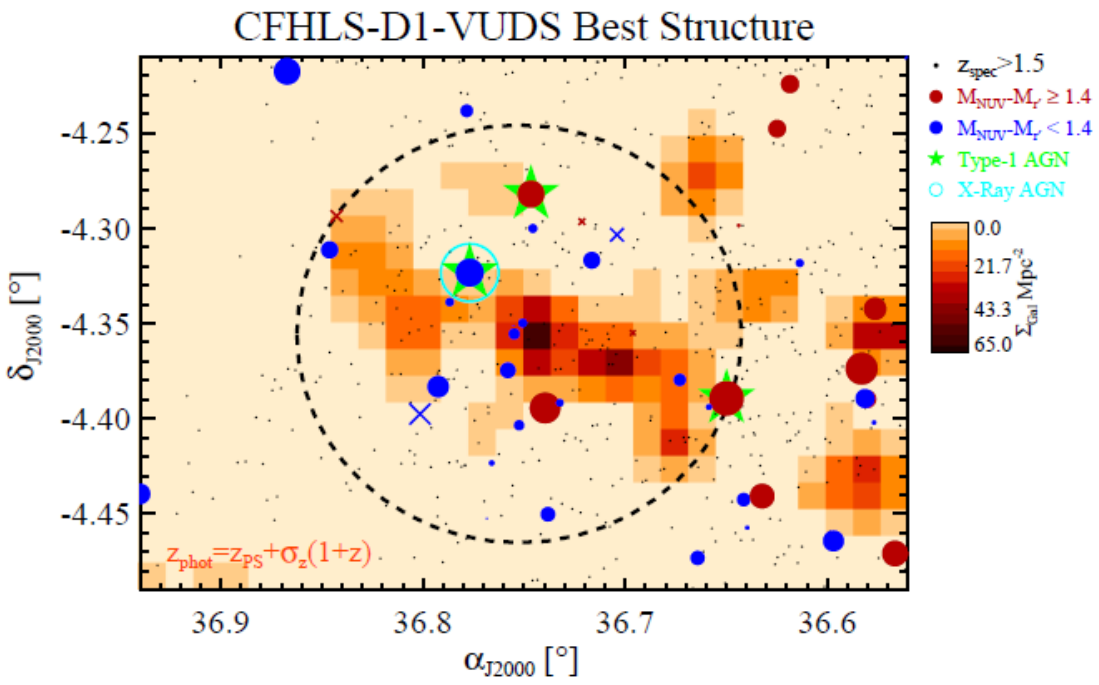
  >50 proto-structures identified

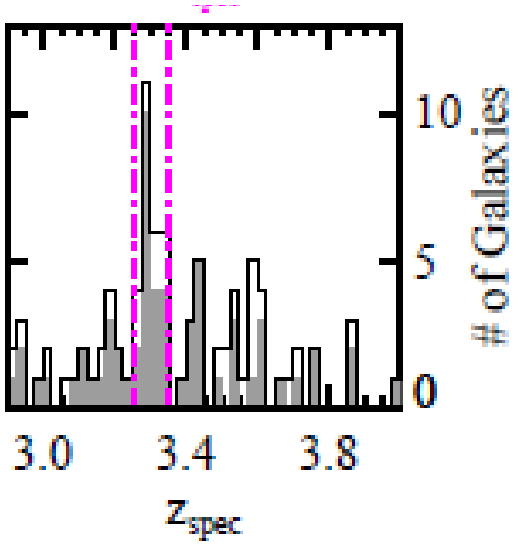
- What are the properties of proto-structures as the seeds of rich clusters today ?

- What is the effect of environment in galaxies during their assembly phase
  - Star formation rate: enhanced or quenched ?
  - Morphological transformation

Proto-cluster at z=3.3

Lemaux, Cucciati, Tasca et al. 2014



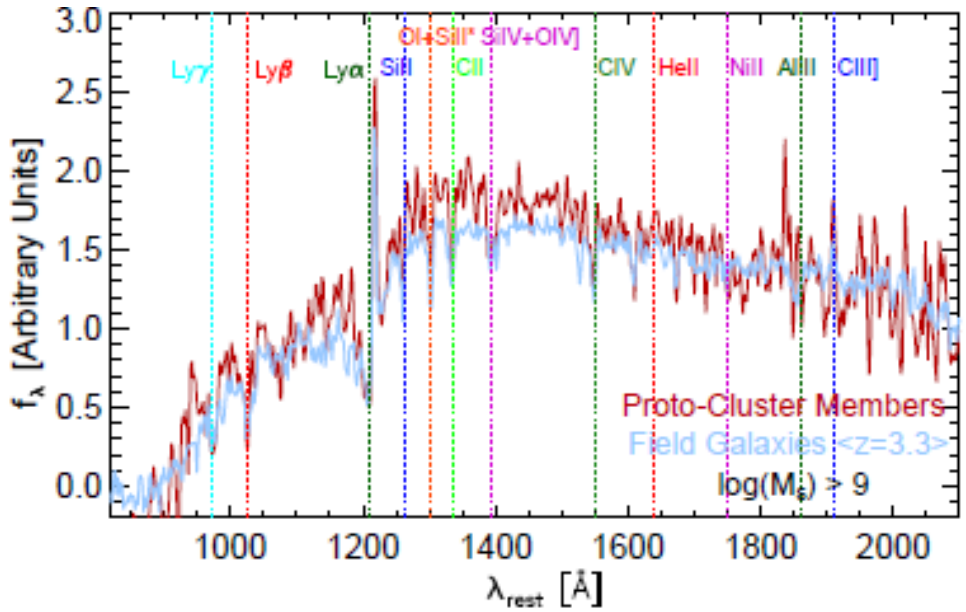


- 19 z_{spec} confirmed members
- **δ_{gal} = 10.5 ± 2.8**

- Supported by photo-z analysis
- **Mass: 3×10^{14} $M_\odot$**
- As massive than Coma by z~0

Environment effects at these early times ?

Comparison of average spectrum in z=3.3 proto-cluster with field galaxies



- Steeper UV spectral slope
- Stronger Lyα, HeII, CIII
- Also 3 AGN in this cluster

} Activity enhanced ?