Olivier Le Fèvre
Laboratoire d'Astrophysique de Marseille, France

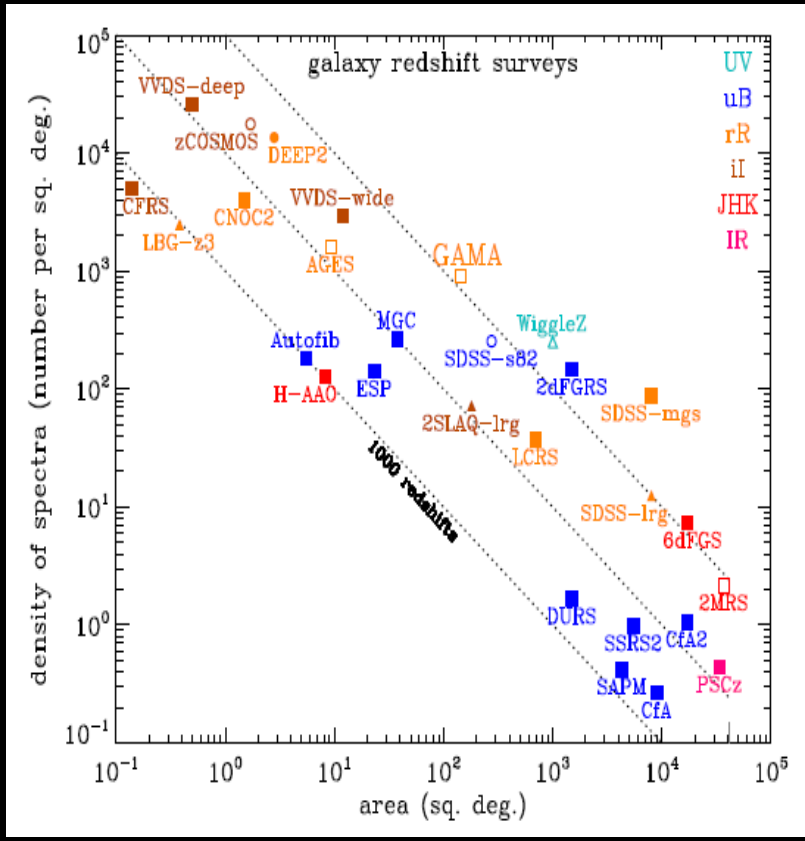
THE VIMOS ULTRA-DEEP SURVEY

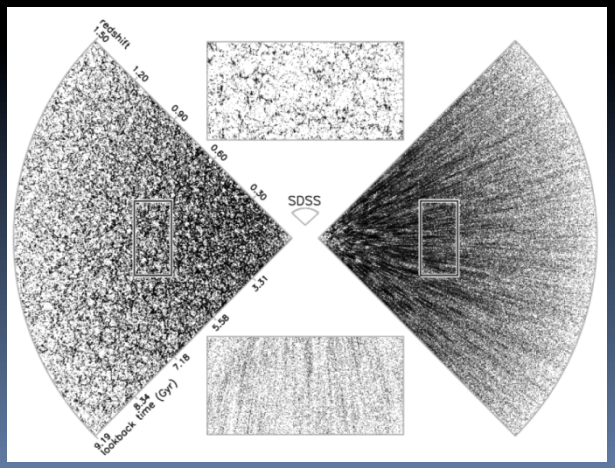
The assembly of massive galaxies at $2<z_{spec}<6.5$

O. Le Fèvre[1], L.A.M. Tasca[1], P. Cassata[1], B. Garilli[3], V. Le Brun[1], D. Maccagni[3], L. Pentericci[4], R. Thomas[1], E. Vanzella[2], G. Zamorani[2], E. Zucca[2], R. Amorin[4], S. Bardelli[2], P. Capak[12], L. Cassarà[3], M. Castellano[4], A. Cimatti[5], J.G. Cuby[1], O. Cucciati[5,2], S. de la Torre[1], A. Durkalec[1], A. Fontana[4], M. Giavalisco[13], A. Grazian[4], N. P. Hathi[1], O. Ilbert[1], B. C. Lemaux[1], C. Moreau[1], S. Paltani[9], J. Pforr[1], B. Ribeiro[1], M. Salvato[14], D. Schaerer[10,8], M. Scodeggio[3], V. Sommariva[5,4], M. Talia[5], Y. Taniguchi[15], L. Tresse[1], D. Vergani[6,2], P.W. Wang[1], S. Charlot[7], T. Contini[8], S. Fotopoulou[9], C. López-Sanjuan[11], Y. Mellier[7], and N. Scoville[12]

Redshifts surveys: a key tool for cosmology

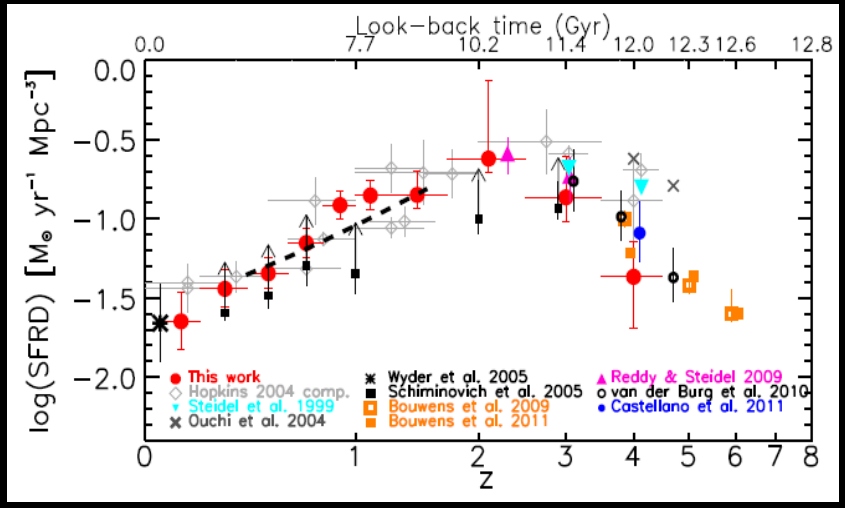
- A key tool to test the cosmology world model
  - Galaxies trace the matter field
- The main tool to understand galaxy formation and evolution
  - Galaxy populations as a function of cosmic time
  - Large samples / volume
- Spectroscopic redshifts: accurate 3D positions
  - Environment



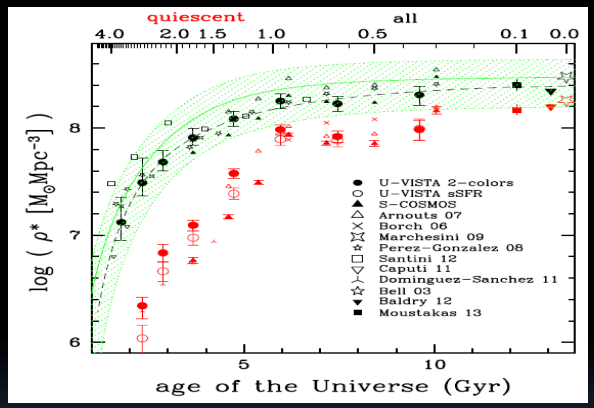


2<z<6.5: probing a major epoch in galaxy assembly

- From redshift 6 to 2, the stellar mass density has incrased by 2dex and the SFRD has increased by 1dex
- What contributes to the general mass increase, when ?
- What fuels star formation, when ?
- What are the properties of sources that contributed to the reionisation, seen 0.3-2 Gyr later ?

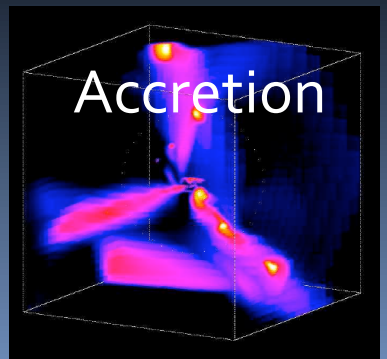


Star Formation Rate (e.g. Cucciati +12)



Stellar mass density (e.g. Ilbert+13)

Mass growth:

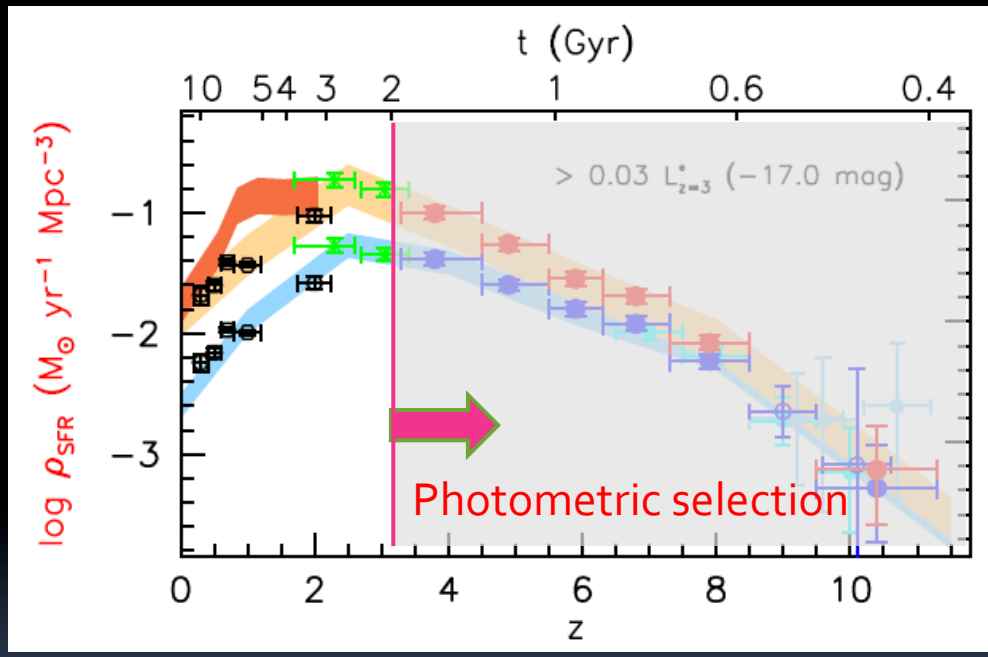


and/or

?

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

- At z>2 most studies use photometric samples
  - Only ~3000 galaxies with $z_{spec}>2$, few hundred at $z_{spec}>3.5$
  - Uncertainties related to sample selection, heterogeneous samples
- The census of galaxies so far relies on small fields
  - Poor sampling of the bright $>L_*$ population
  - Cosmic variance (Moster+11):
    - >x3 on arcmin² scales (MUSE)
    - 50% on 100 arcmin² (GOODS, CANDELS)
    - 10% on 1deg² (COSMOS)



Need large spectroscopic samples in large volumes

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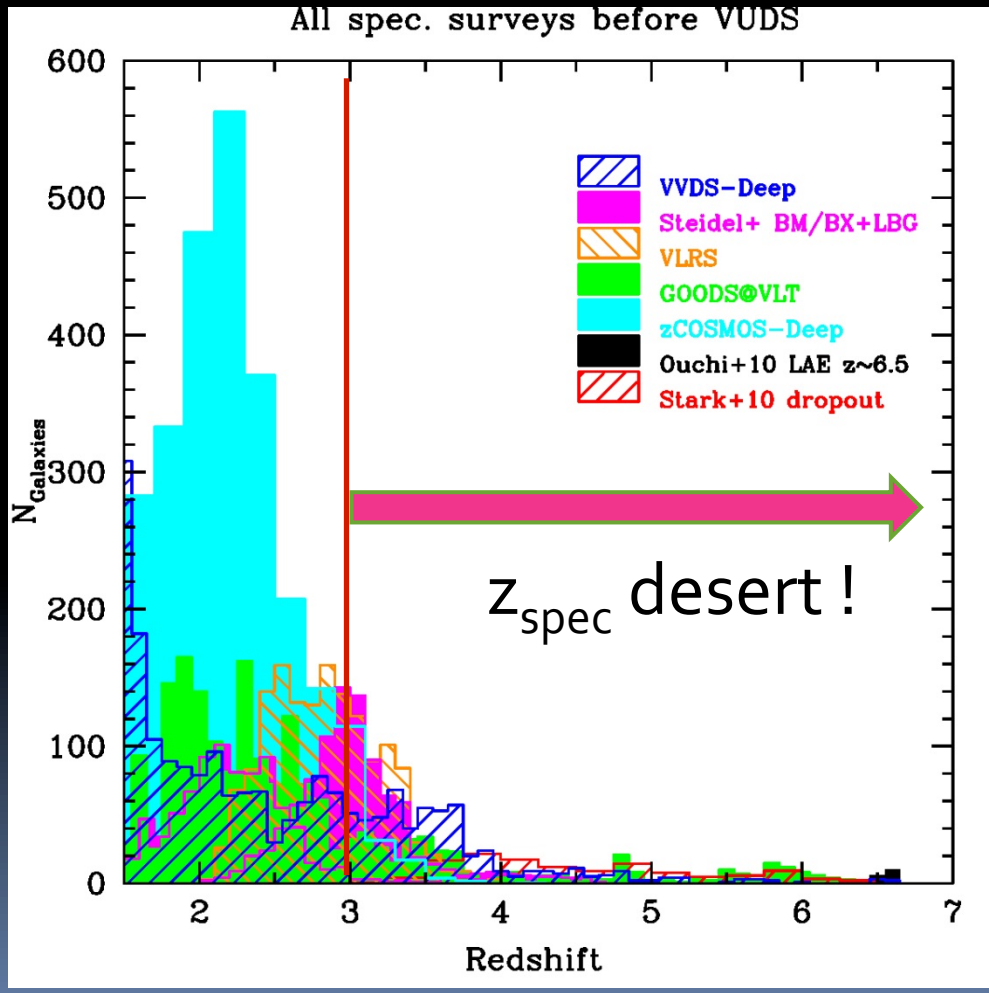
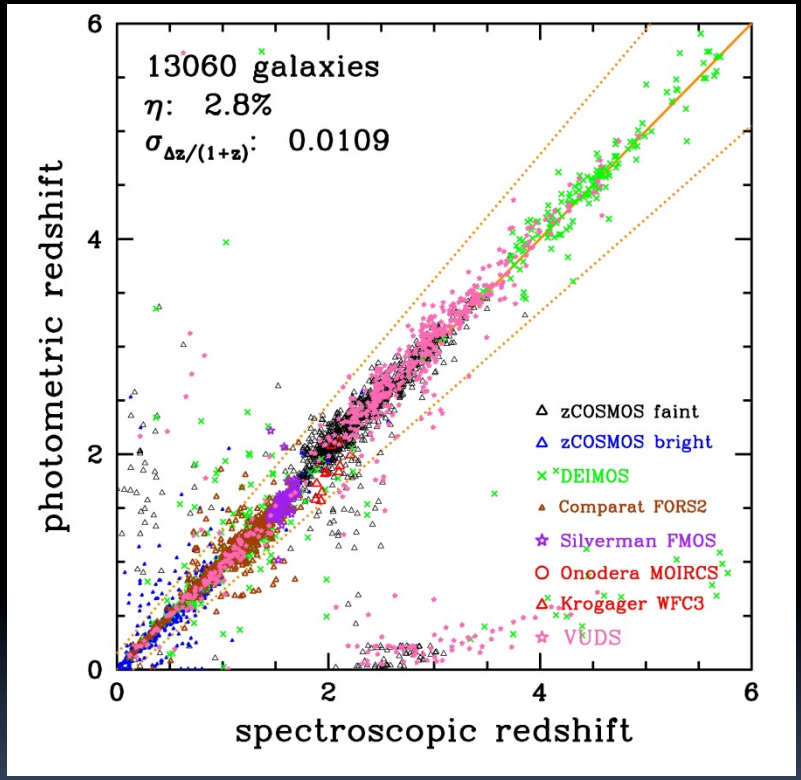


Need large spectroscopic samples in large volumes

VUDS: spectroscopic survey of the first phases of galaxy assembly

- ESO Large Program: 640h
  - VIMOS 3600-9300Å, 14hr
- **1 deg²** in 3 fields (COSMOS, ECDFS, VVDS-02): mitigate cosmic variance
- **10,000 targets**
- **z_{phot} selected**: focused on 2<z<6
  - 1st and 2nd peak of PDF
- Smart color-selected sample added

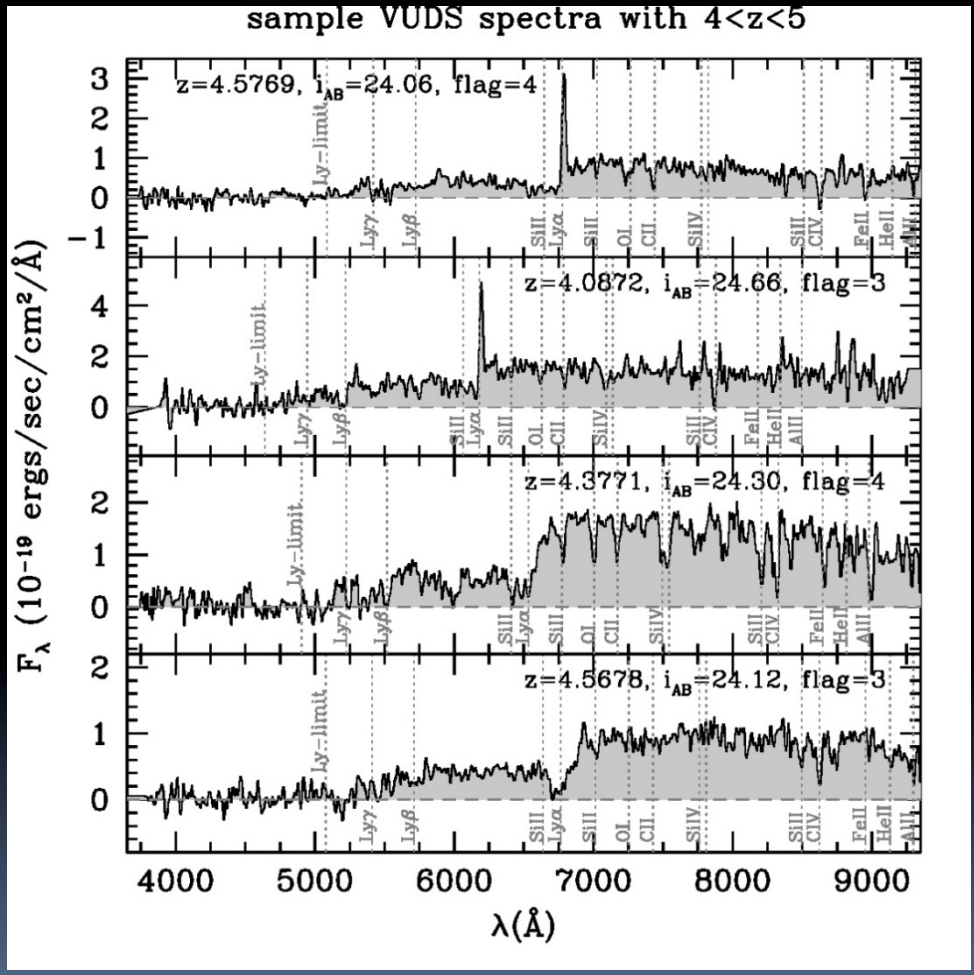


Excellent photoz, Ilbert+ 13, 15

See Le Fèvre et al. 2015

What do we get ?

- 80% success rate down to i_{AB}=25
- Absorption as well as emission spectra
- Interesting outliers
  - Contamination along the LOS
- Redshift distribution as expected
- 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



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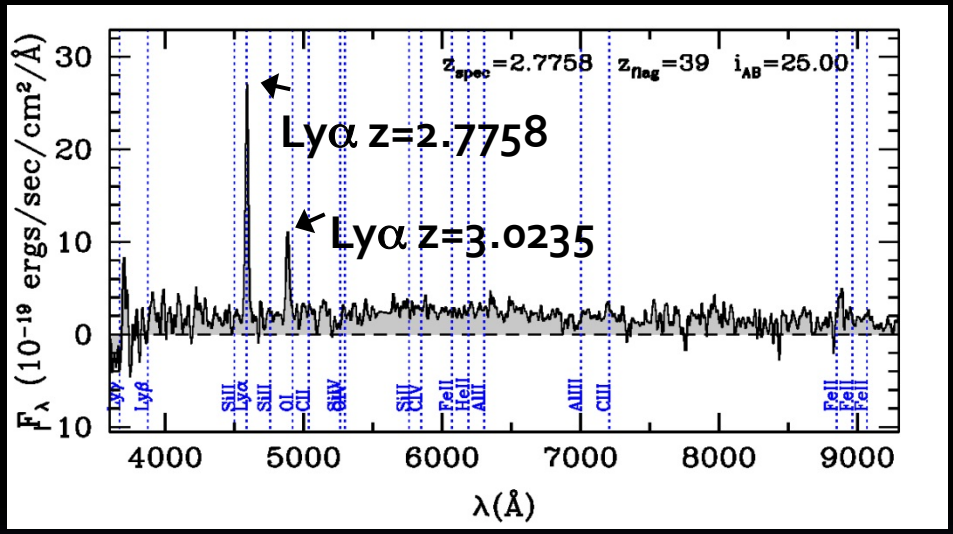

Superimposition on the line of sight

What do we get ?

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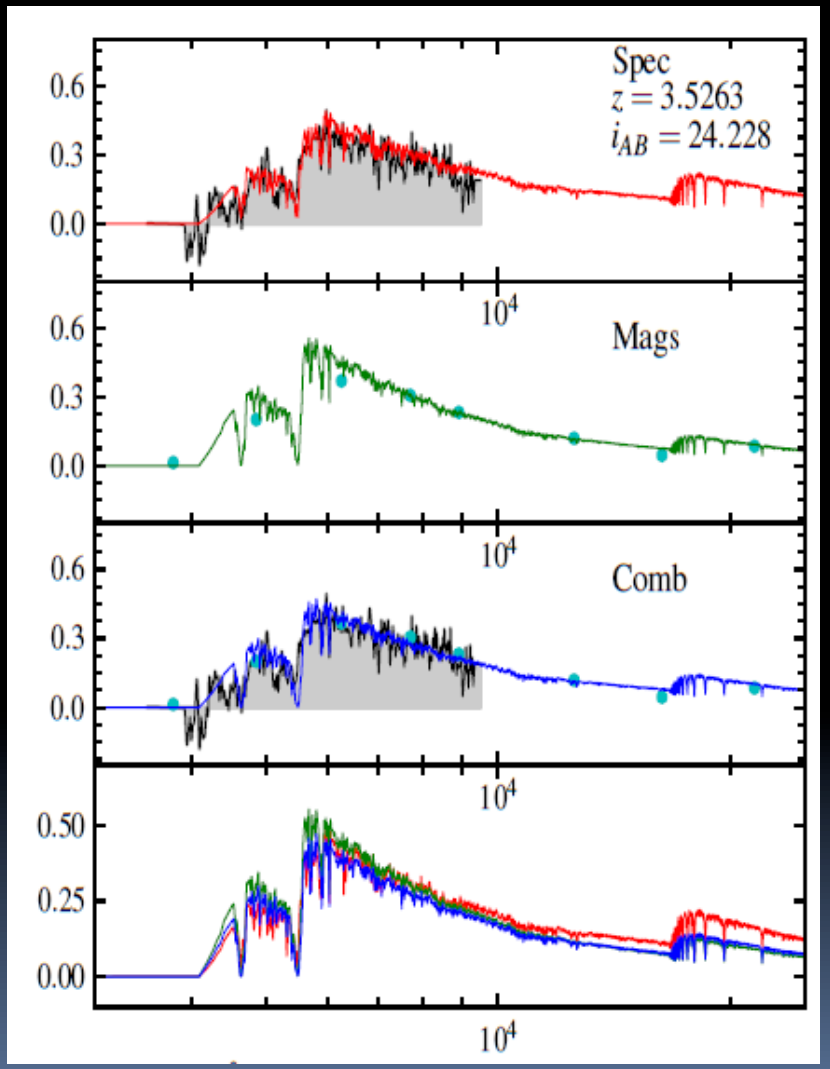
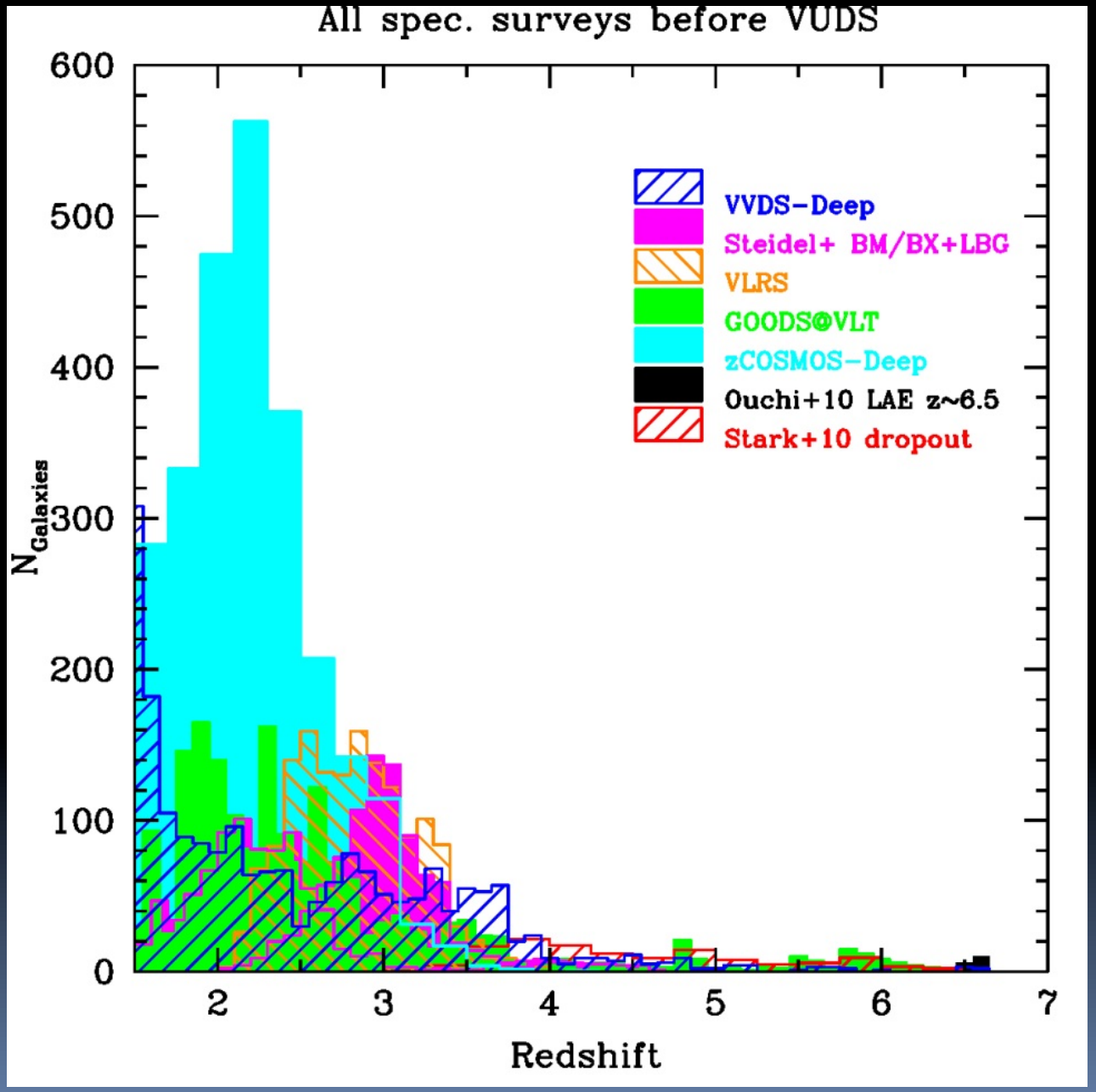
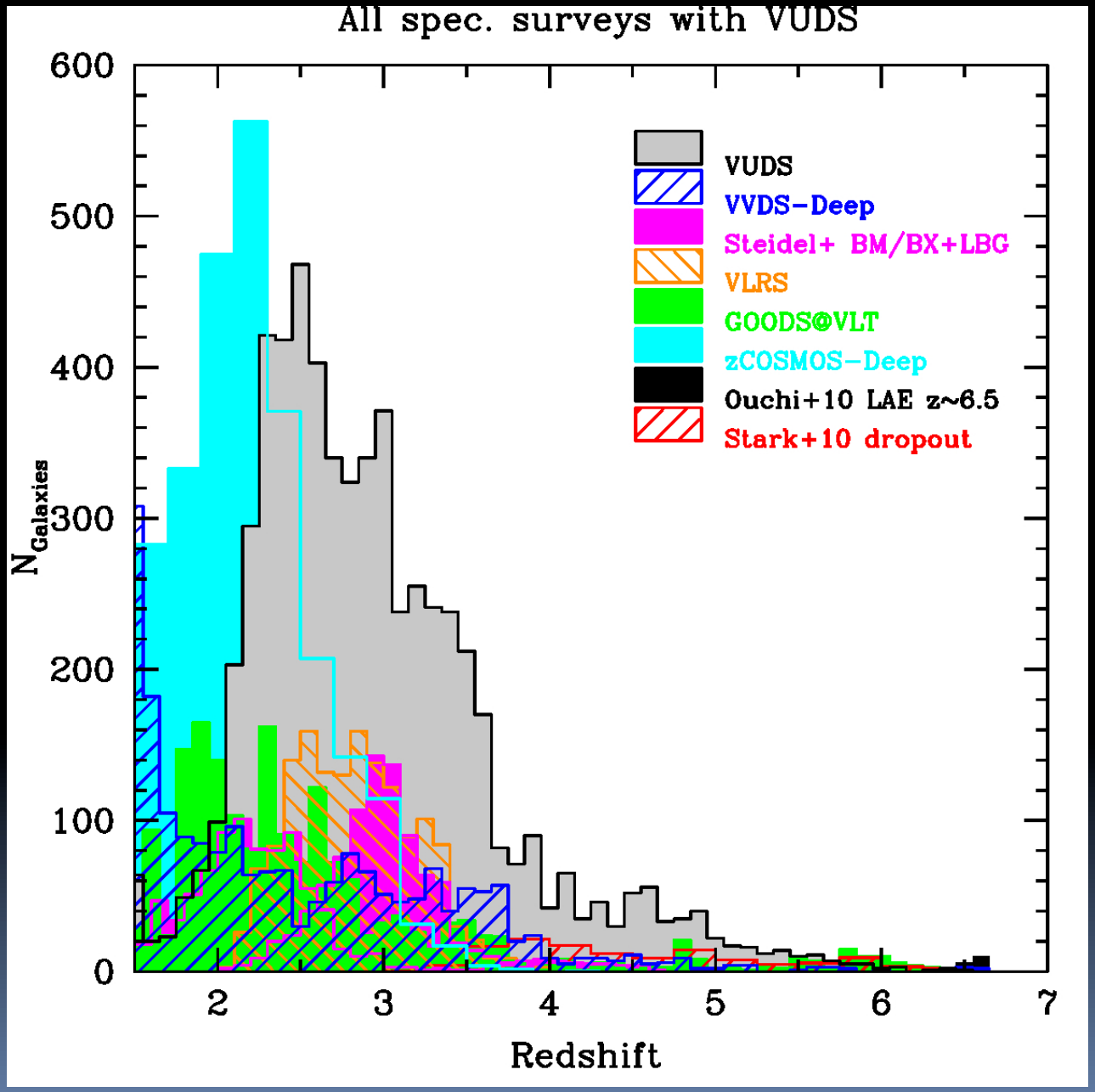
- Absorption as well as emission spectra
- Interesting outliers
  - Contamination along the LOS
- Redshift distribution as expected



R. Thomas et al.

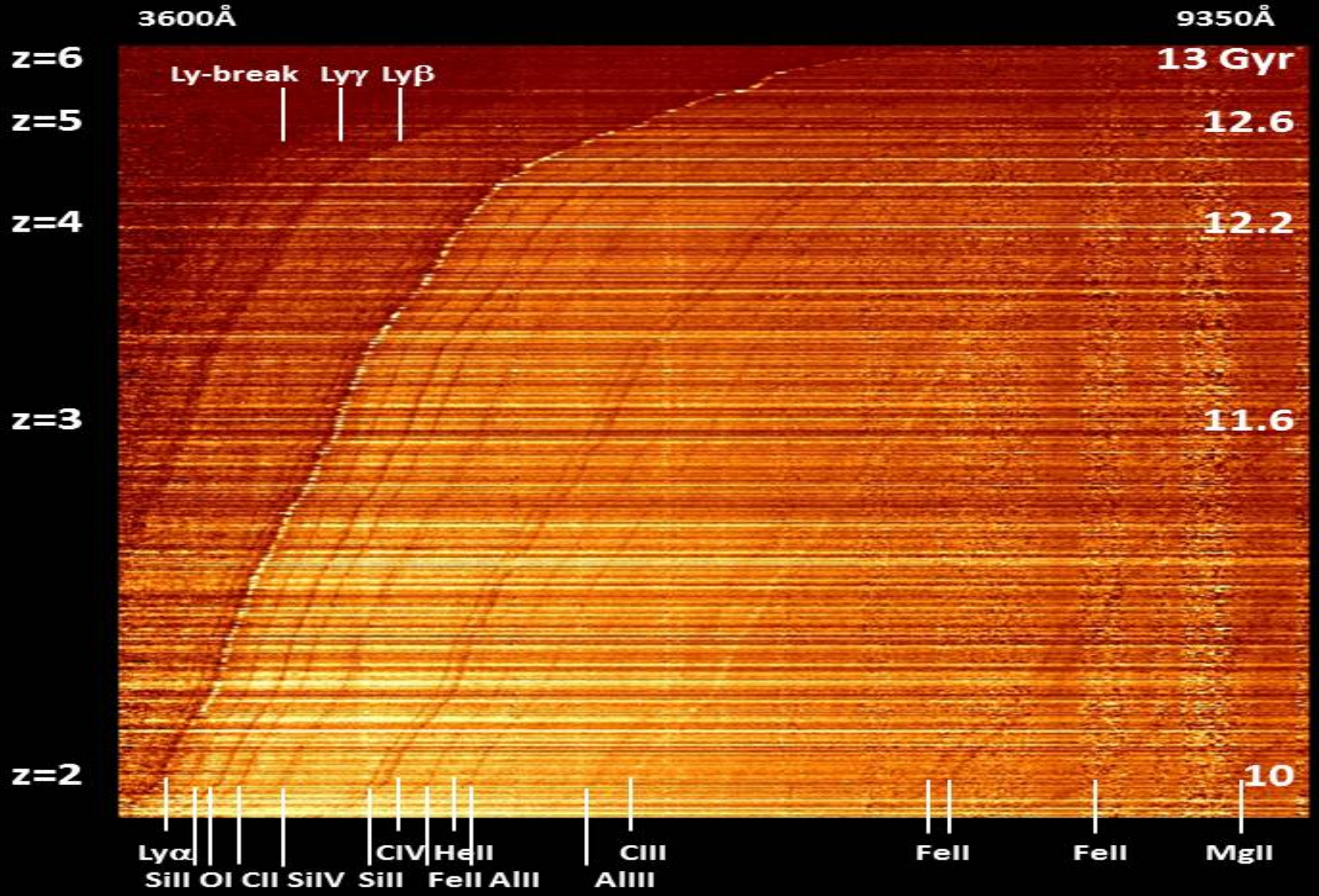


Le Fèvre et al. 2015

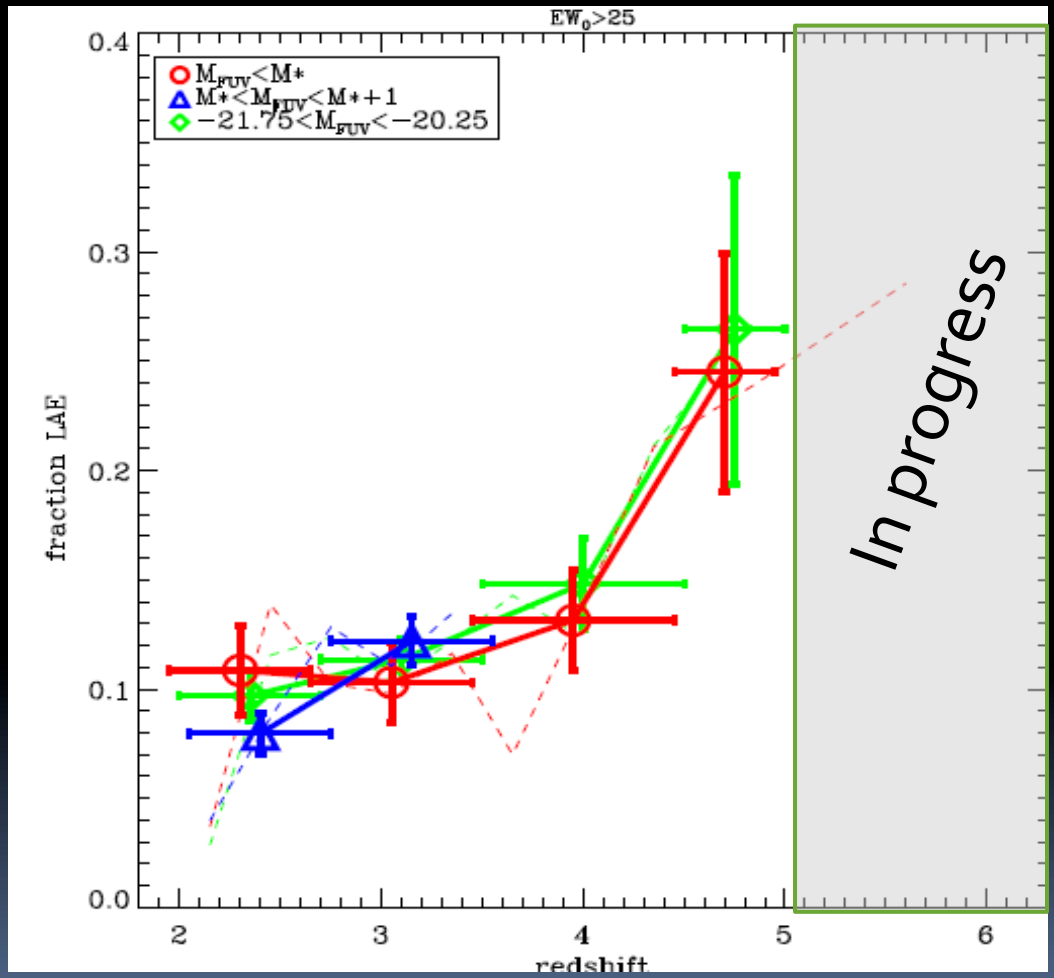


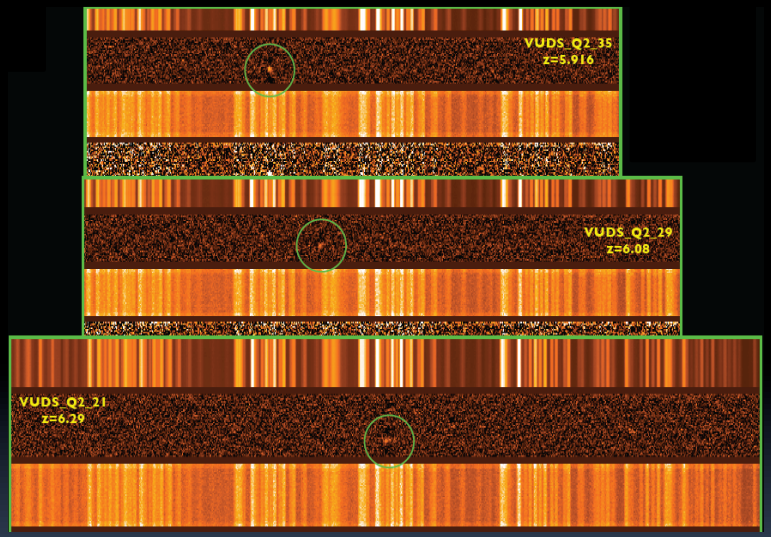
Le Fèvre et al. 2015

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



Lyα EW - evolution



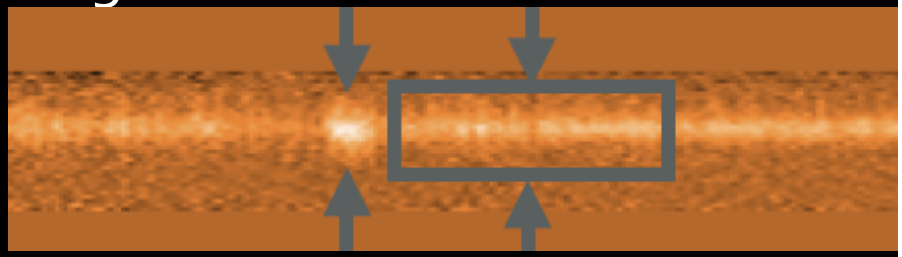


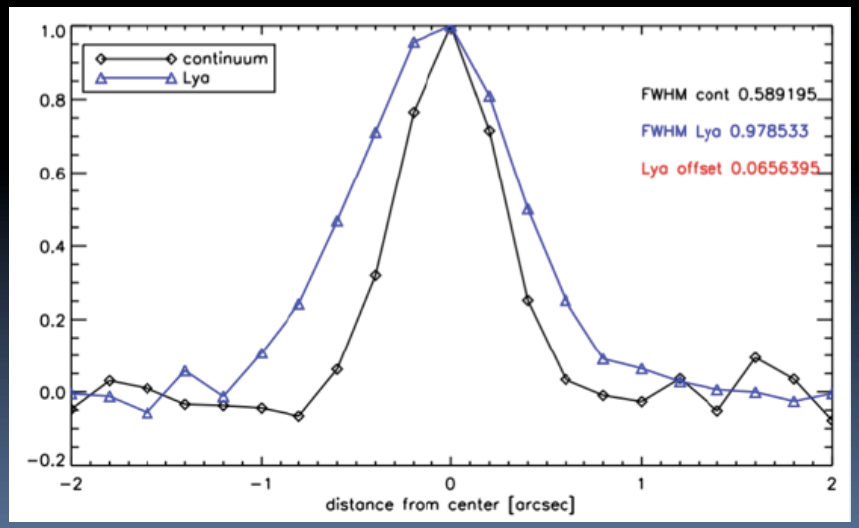
On-going:
Identification of Lyα emitters up to z~6.5

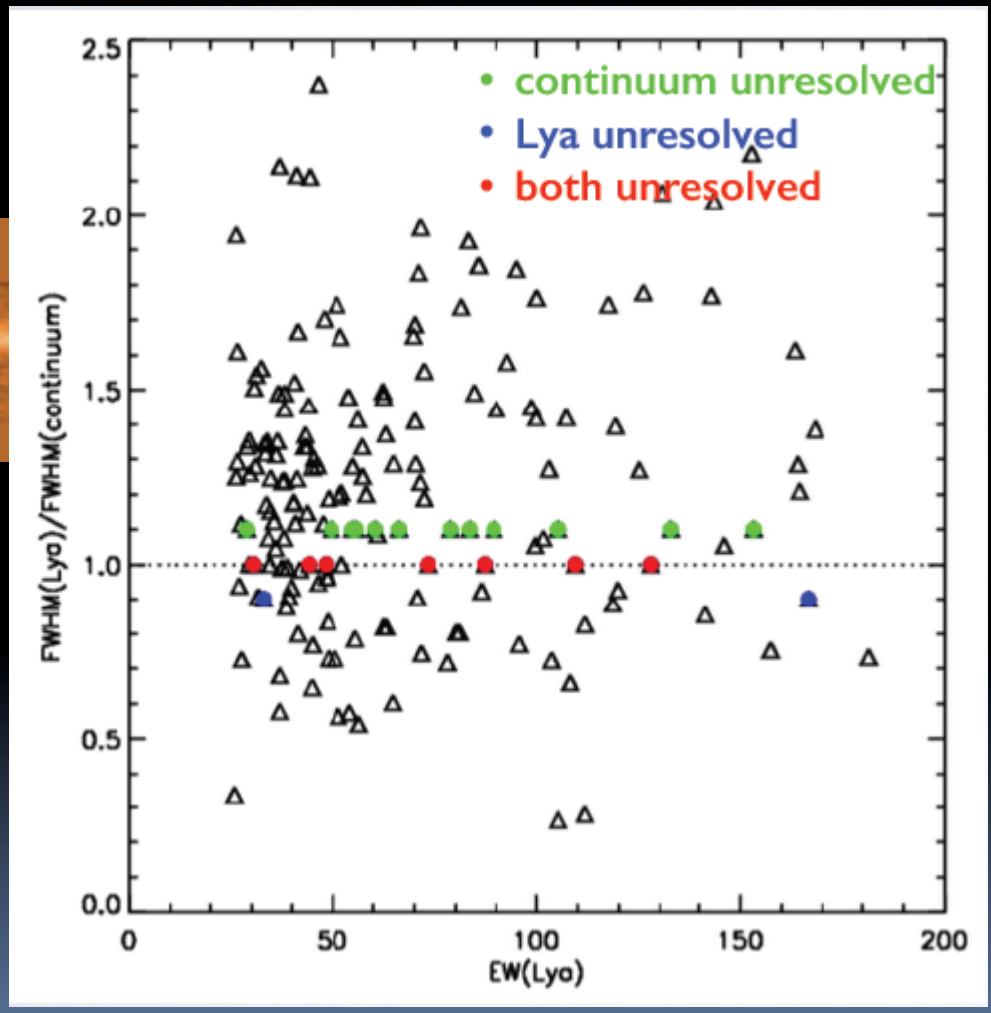
Cassata et al. 2014

Lyα cloud extension

Produce a statistical description from a large representative sample of medium-bright galaxies



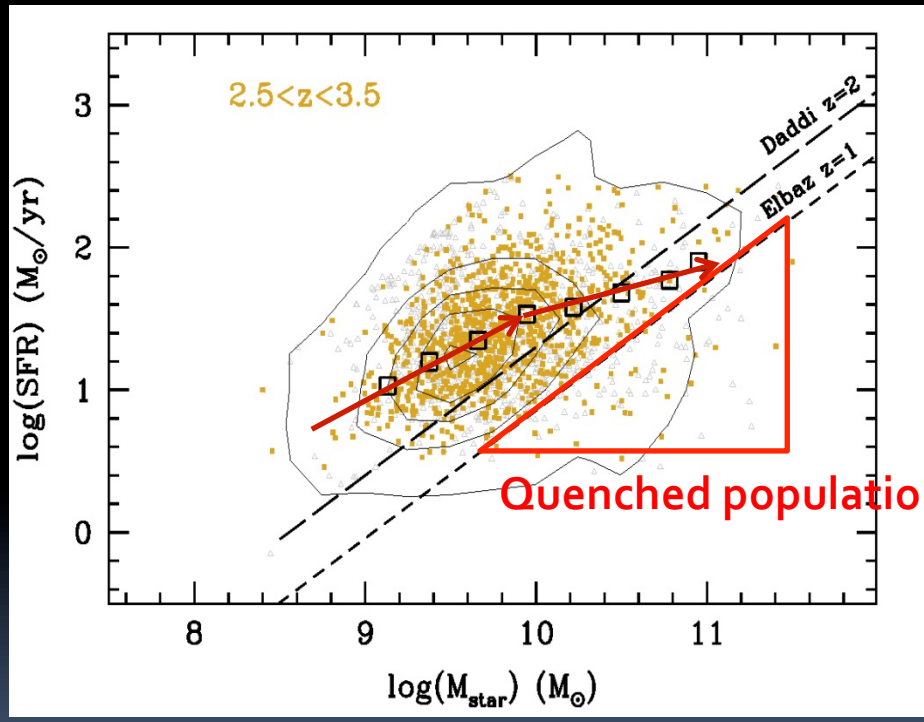




Cassata et al. in prep.

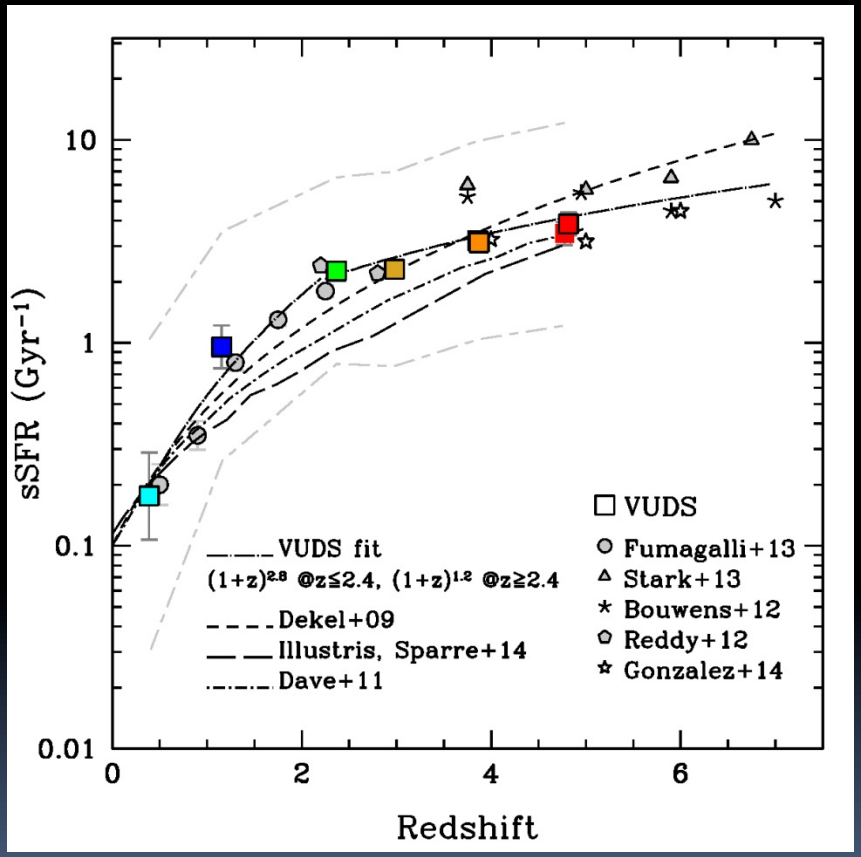
SFR-M_{star} "main sequence"

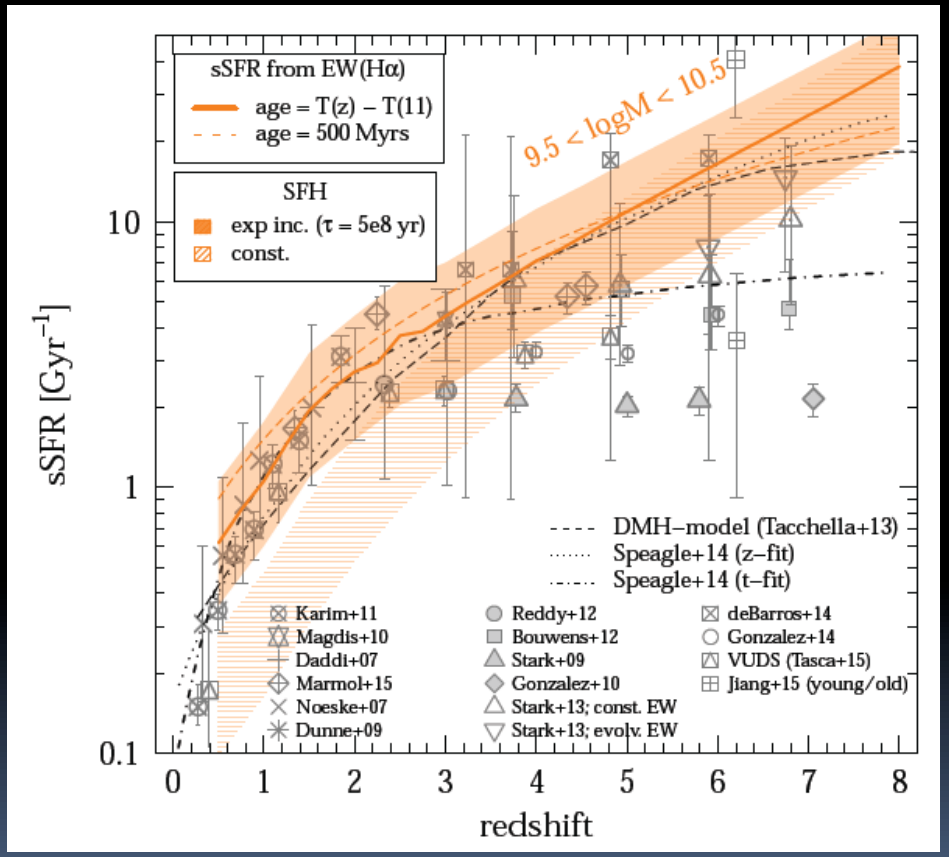
- Large spread around the "main sequence"
  - Related to SFH and systematics in M_{star} and SFR computations
- Bending of the relation above a "quenching mass"
- Significant population off the main sequence
  - On-going quenching ?



Tasca et al. 2015

Specific star formation rate SSFR(z)



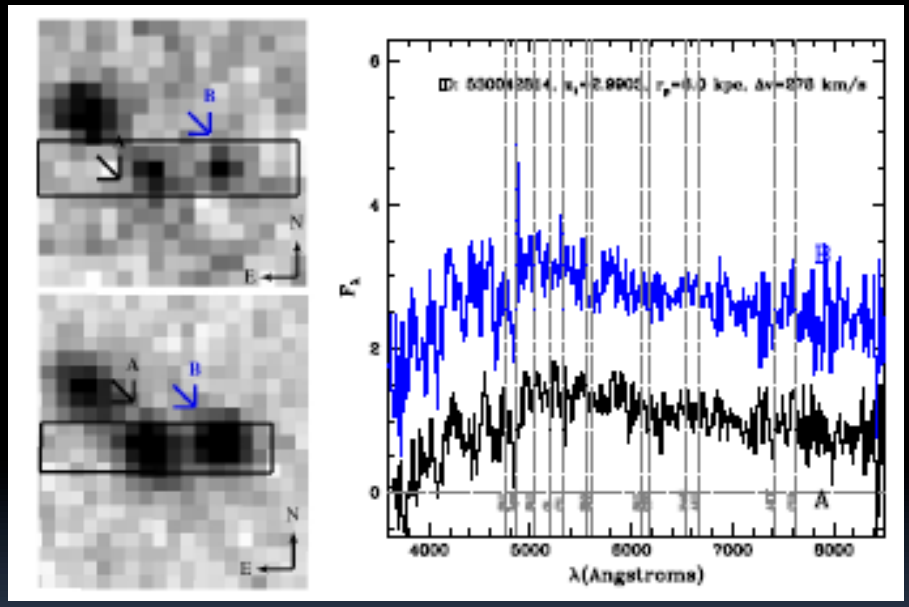


Tasca et al. 2015

Faist et al. to be submitted

Mergers

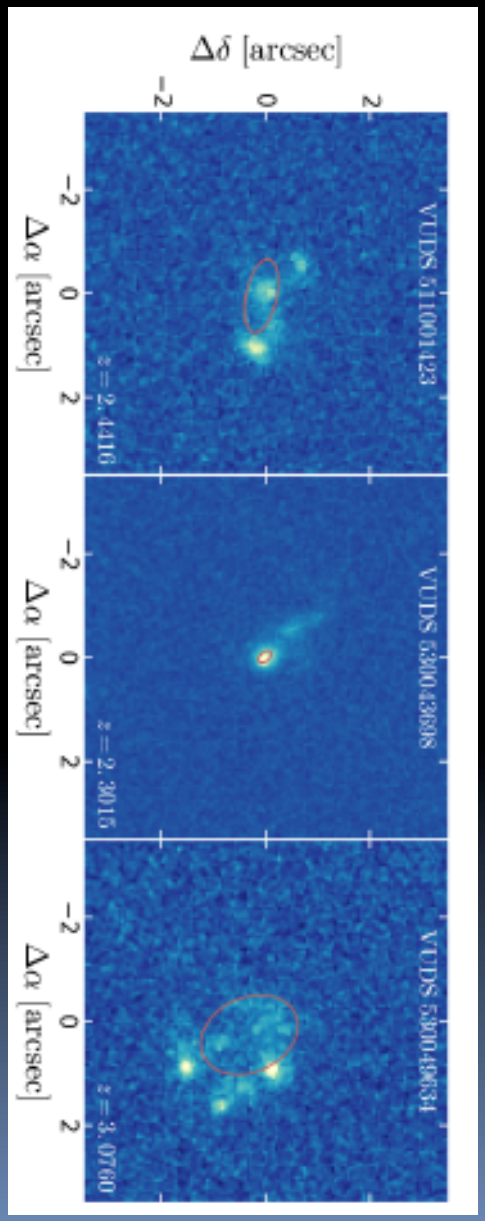
- Merger fraction from spectroscopic pair count
  - Measure ΔV and r_p
  - Confirm both members of the pair are physically linked
- ~50 directly confirmed mergers to z~5
  - Final sample being assembled
- M_{frac}~20% in major mergers 1:4 at z~3-4
- Integrate merger rate: L* galaxy has doubled its stellar mass from merging since z~3

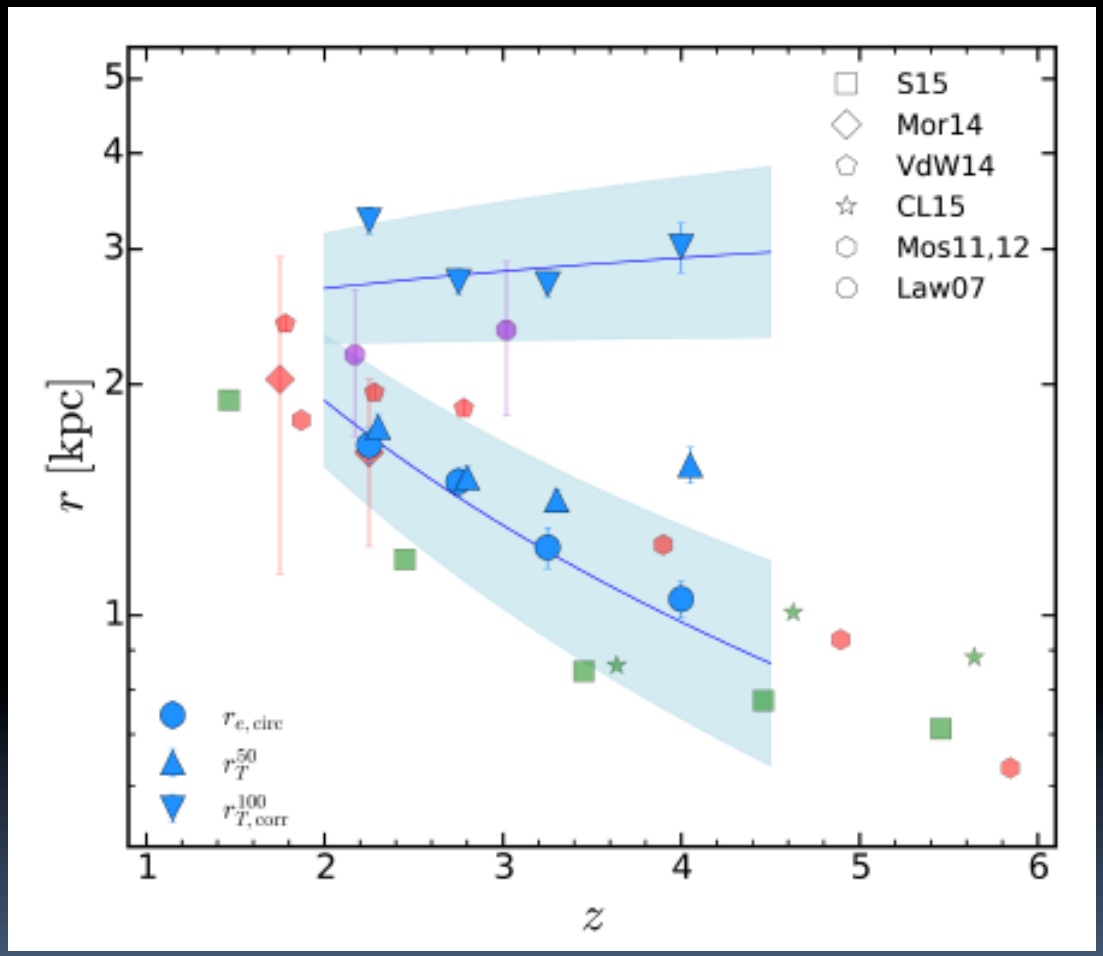


Merging: major contribution to galaxy assembly

Tasca et al. 2014

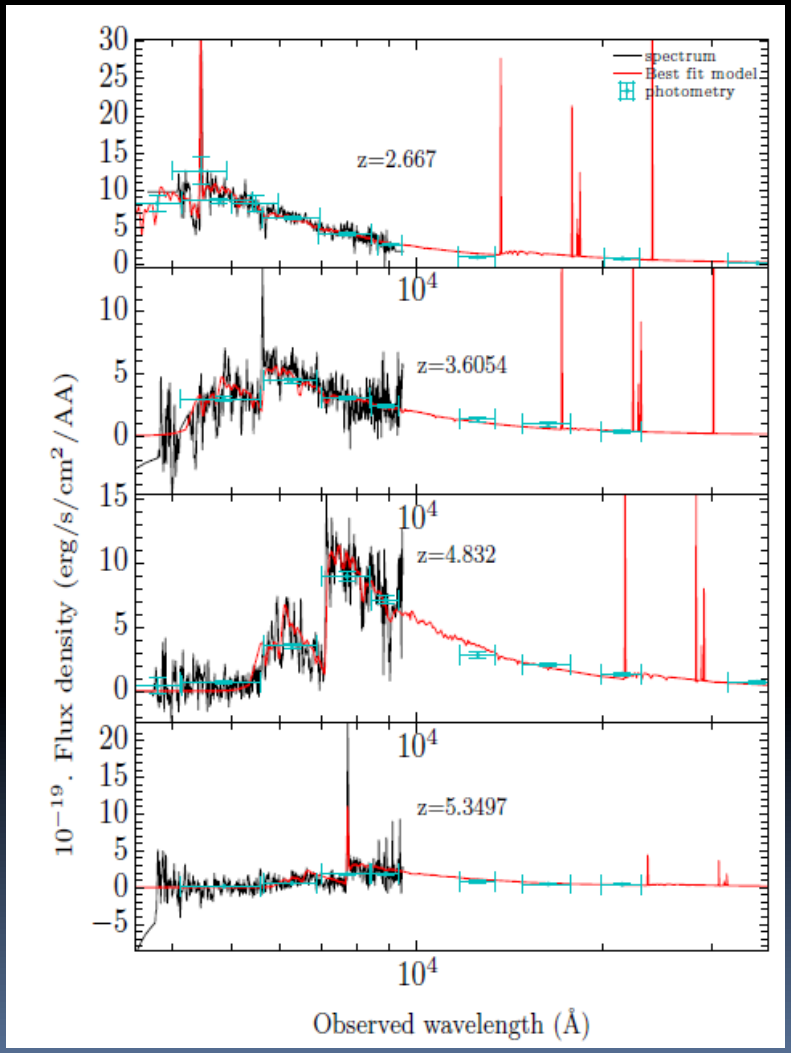
Size evolution

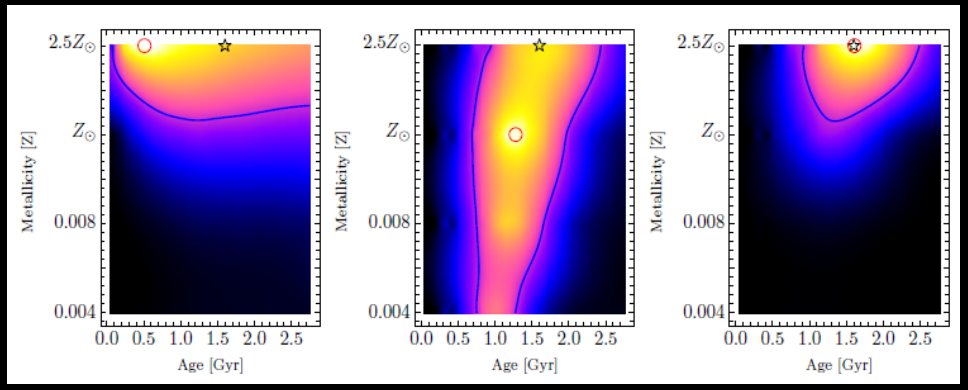


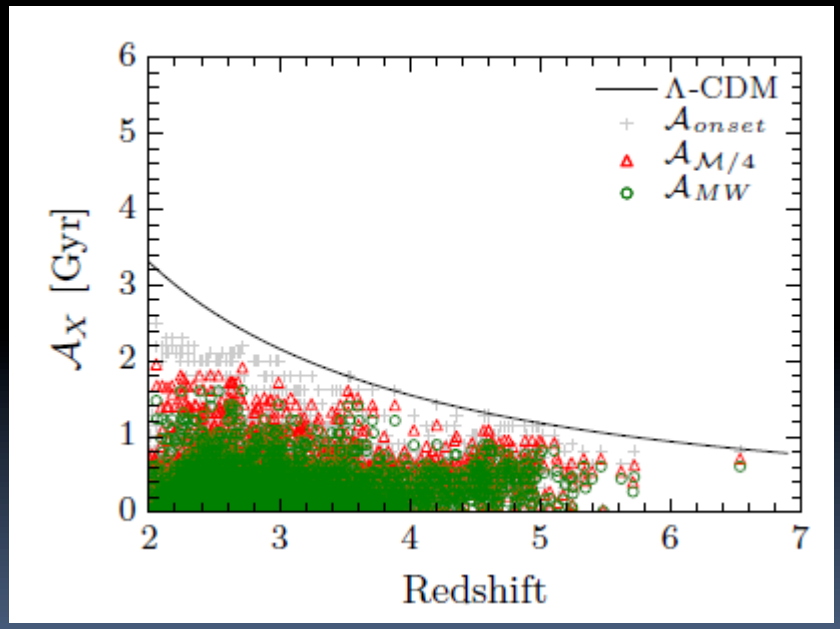


B. Ribeiro, to be submitted

Age and formation redshifts

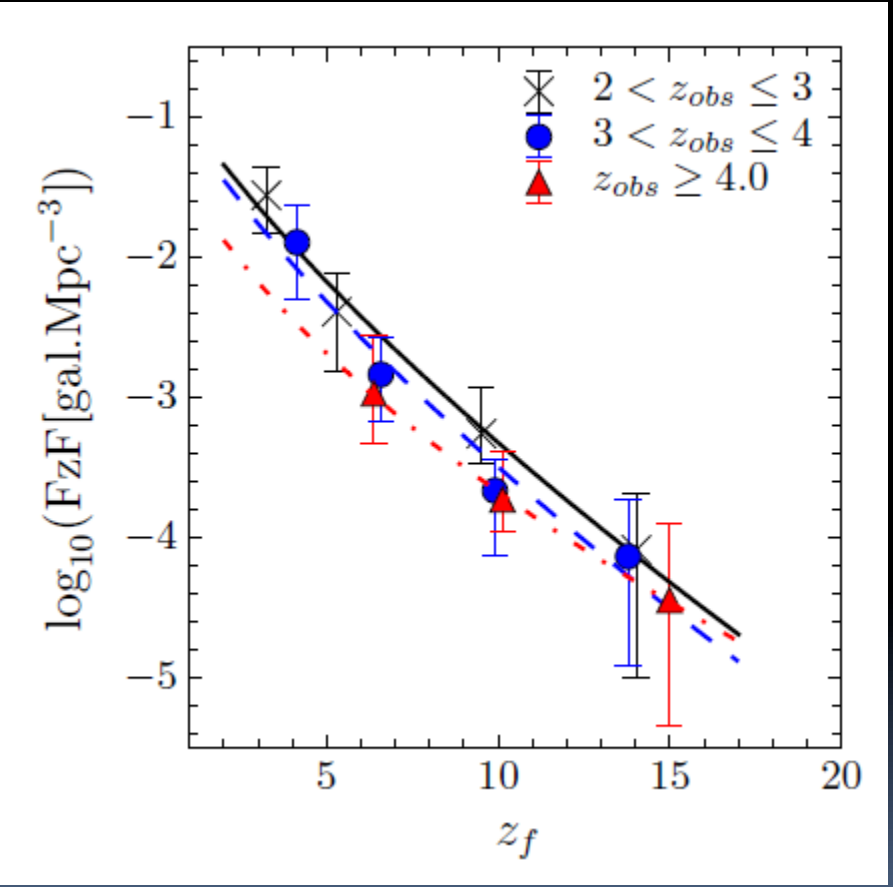






Age and formation redshifts

- Formation redshift function (FzF)



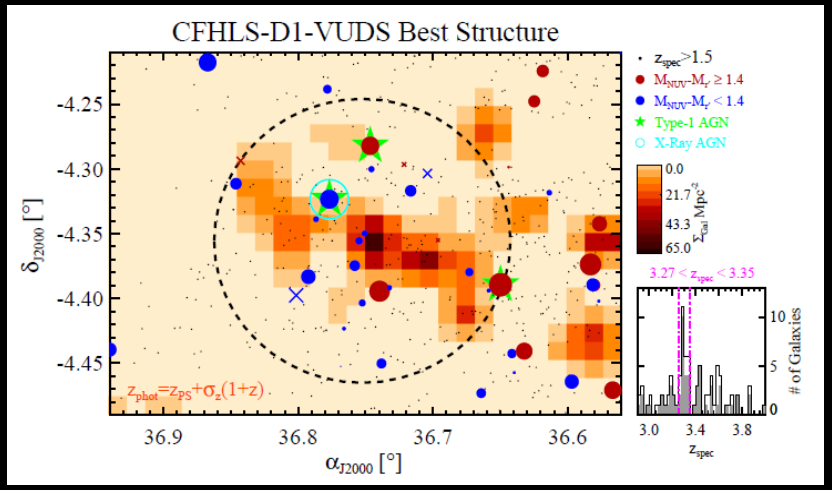
Thomas et al. to be submitted

Proto-structures

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

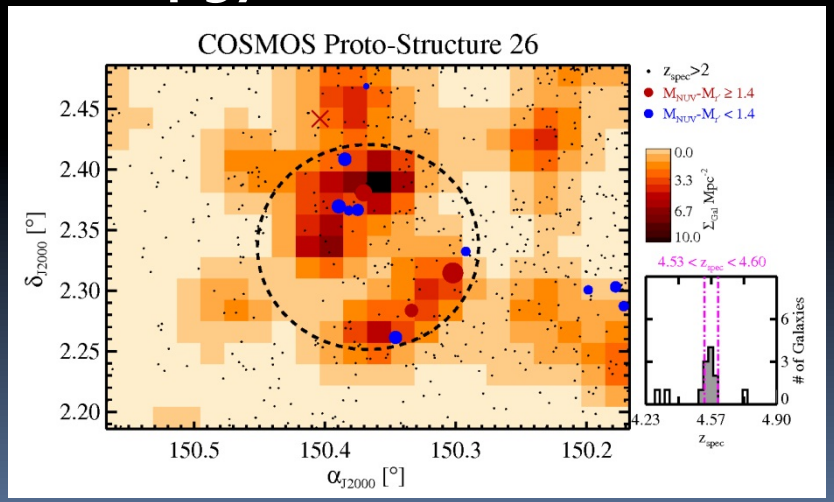
Mass: 3×10^{14} $M_\odot$
As massive as Coma by z~0
Lemaux et al. 2014

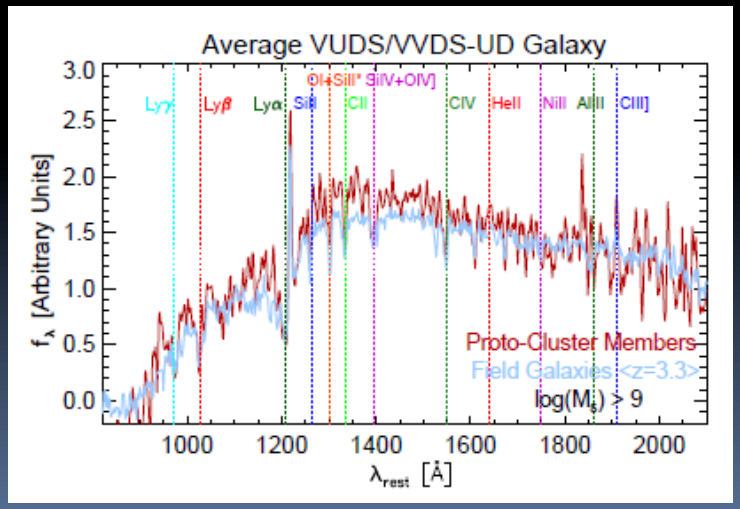
z=3.3



z=4.57

Lemaux et al. in prep

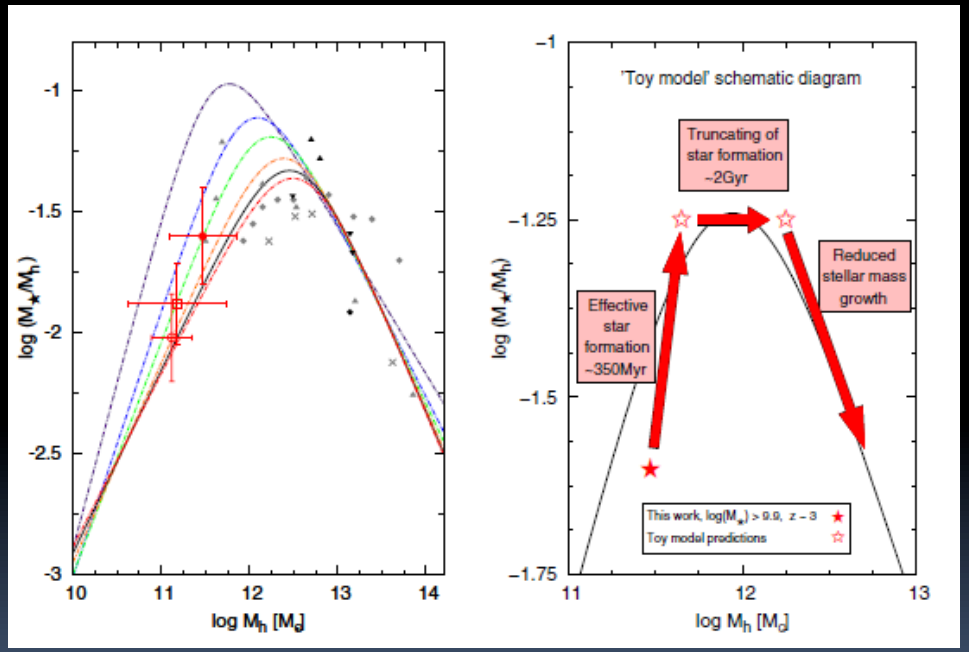




Also Cucciati et al. 2014, z~2.9 proto-cluster

Other 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. in press)
- A number of papers in preparation

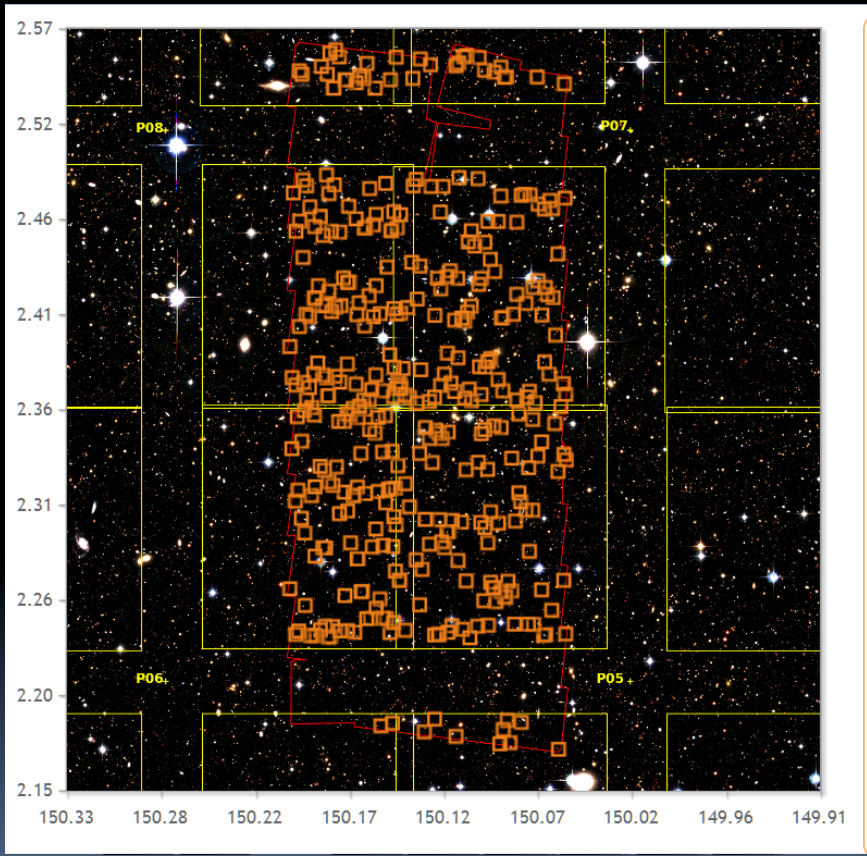


Stellar to DM halo mass ratio
Durkalec et al. 2015

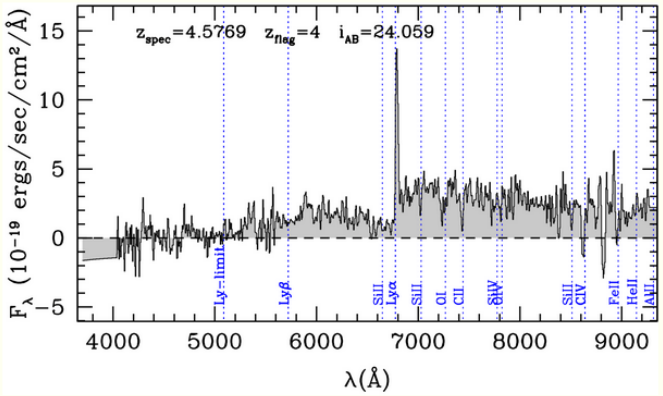
VUDS-DR1: Public data release
~700 galaxy spectra to z_{spec}<6 in CANDELS

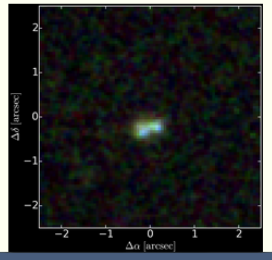
http://cesam.lam.fr/vuds/DR1/

VUDS data matched to:
CANDELS-COSMOS
CANDELS-ECDFS



VUDS Identification 5101244930 | **Alpha (J2000)** +10:00:47.66 | **Delta (J2000)** +02:18:02.3





CANDELS Identification 10102
log(SFR) 1.38899 (SFR in M_sun/yr)
log(M*) 9.804 (M* in M_sun)
Age 0.424027 (in 10^9 yr)

User friendly database - Improved statistics

Tasca et al. submitted

Future

- For VUDS:
  - A number of on-going analyses, more on spectral analysis
  - High-z sample 5.5<z<6.5: in progress, ~50 galaxies with z_{spec}
- Next generation surveys
  - VANDELS: VUDS with higher spectral resolution, higher S/N
  - Euclid reference survey: Keck+VLT
- Preparation JWST