VUDS | VIMOS Ultra Deep Survey

Olivier Le Fèvre
Laboratoire d'Astrophysique de Marseille, France

BACK INTO REIONISATION: ARCHEOASTRONOMY FROM GALAXIES WITH Z~4-6

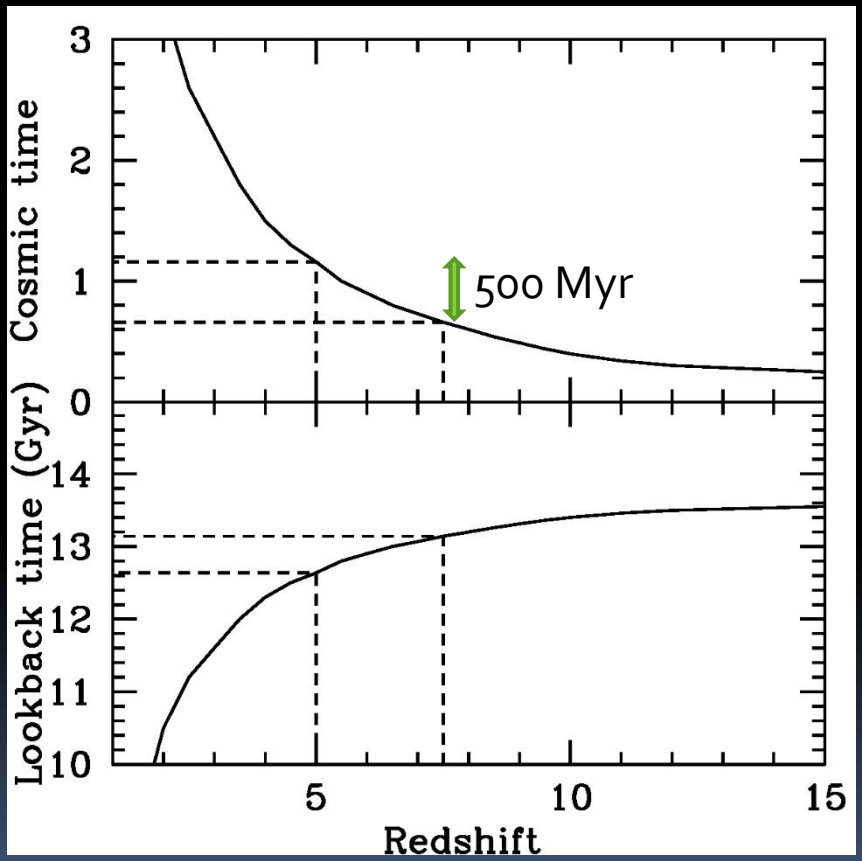
O. Le Fèvre[1], L.A.M. Tasca[1], P. Cassata[1], B. Garilli[3], V. Le Brun[1], D. Maccagni[3], L. Pentericci[4], R. Thomas[1], E. Vanzella[2], G. Zamorani[2], E. Zucca[2], R. Amorin[4], S. Bardelli[2], P. Capak[12], L. Cassarà[3], M. Castellano[4], A. Cimatti[5], J.G. Cuby[1], O. Cucciati[5,2], S. de 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]

Outline

Learning from 4<z<6 to optimize surveys with JWST in the reionisation epoch and later

- Cosmic time and evolution
- The properties of galaxies at z~4-6
  - Sizes, morphology
  - Ages
  - Spectral properties: Lyα, CIII
- Back into reionisation
  - Formation redshift function

Cosmic time vs. evolution timescales



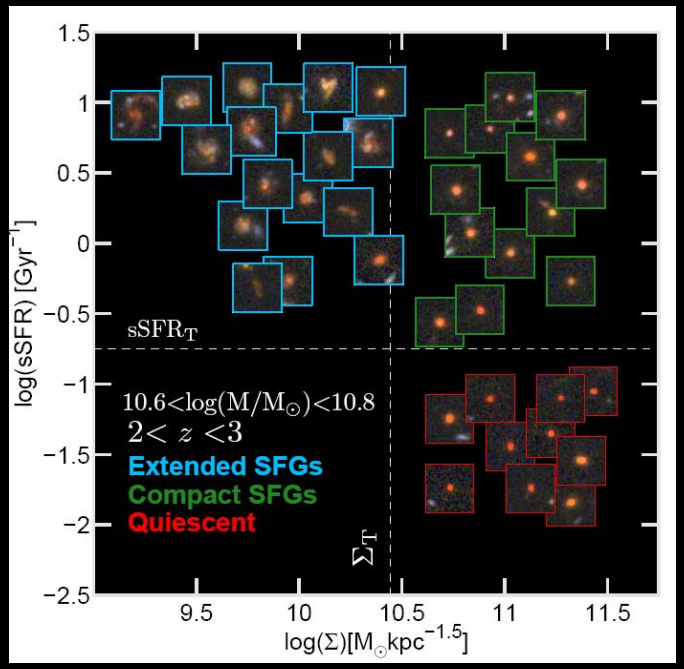
What can happen in ~100-500 Myr ?

- Galaxies formed early in the reionisation z~10 are still star-forming at z~5
- Dynamical evolution is rather long
  - Merging timescales: 0.5-1 Gyr
  - Violent disc instabilities: from proto-discs to clumps to proto-bulge

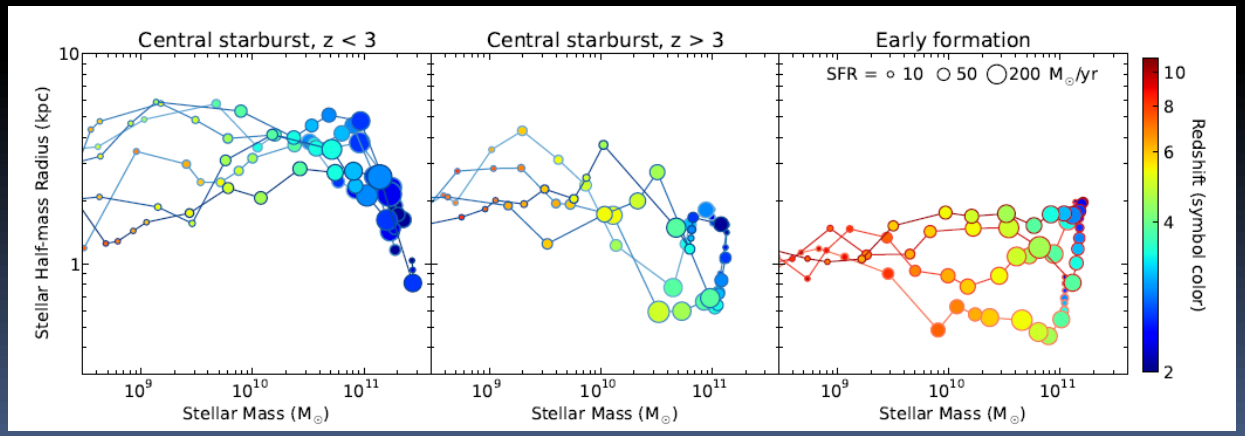
What we see at z~5 may not be that different from z>7

Following a range of galaxy formation and evolution paths

- Several paths for evolution identified
  - Forming compact star-forming galaxies, later becoming ellipticals (quenching)
  - Forming disks
- Many physical processes: merging, accretion, quenching, environment
- Make sure we are not missing any particular step when surveying reionisation with JWST
- Learn from z<6



Barro et al. 2014

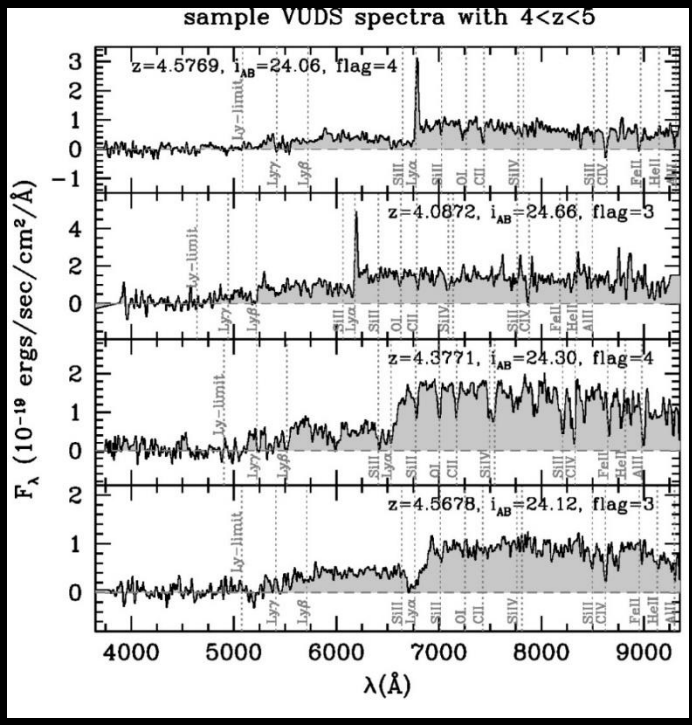


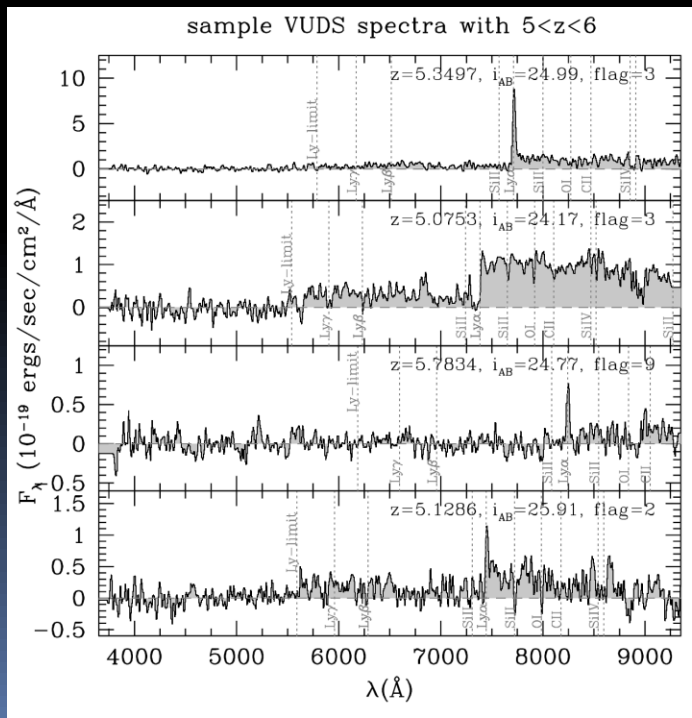
Wellons et al. 2015 (Illustris)

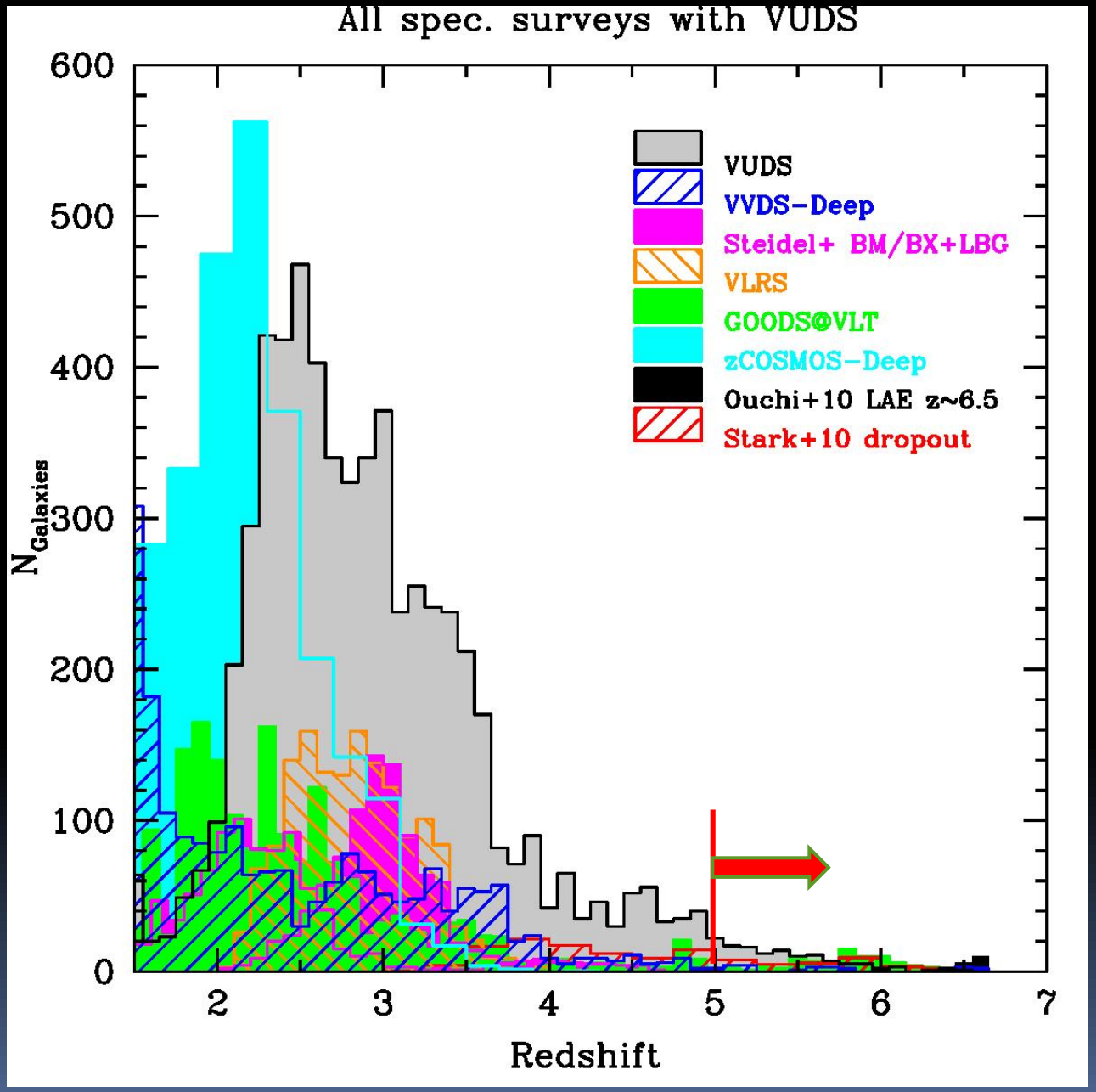
VUDS: spectroscopic survey 2<z<6.5

- ESO-VIMOS 3600-9300Å, exp.time=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

See Le Fèvre et al. 2015

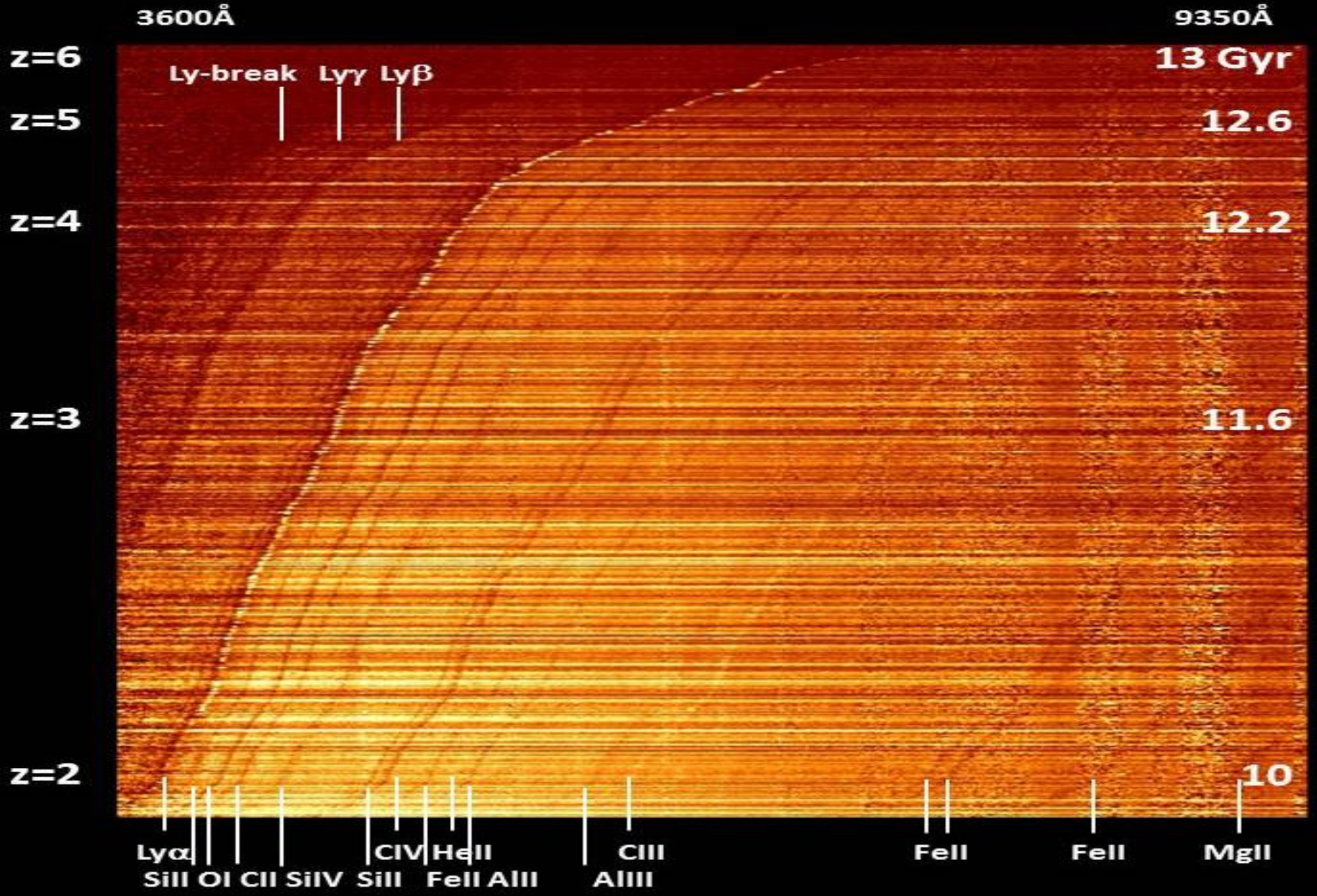






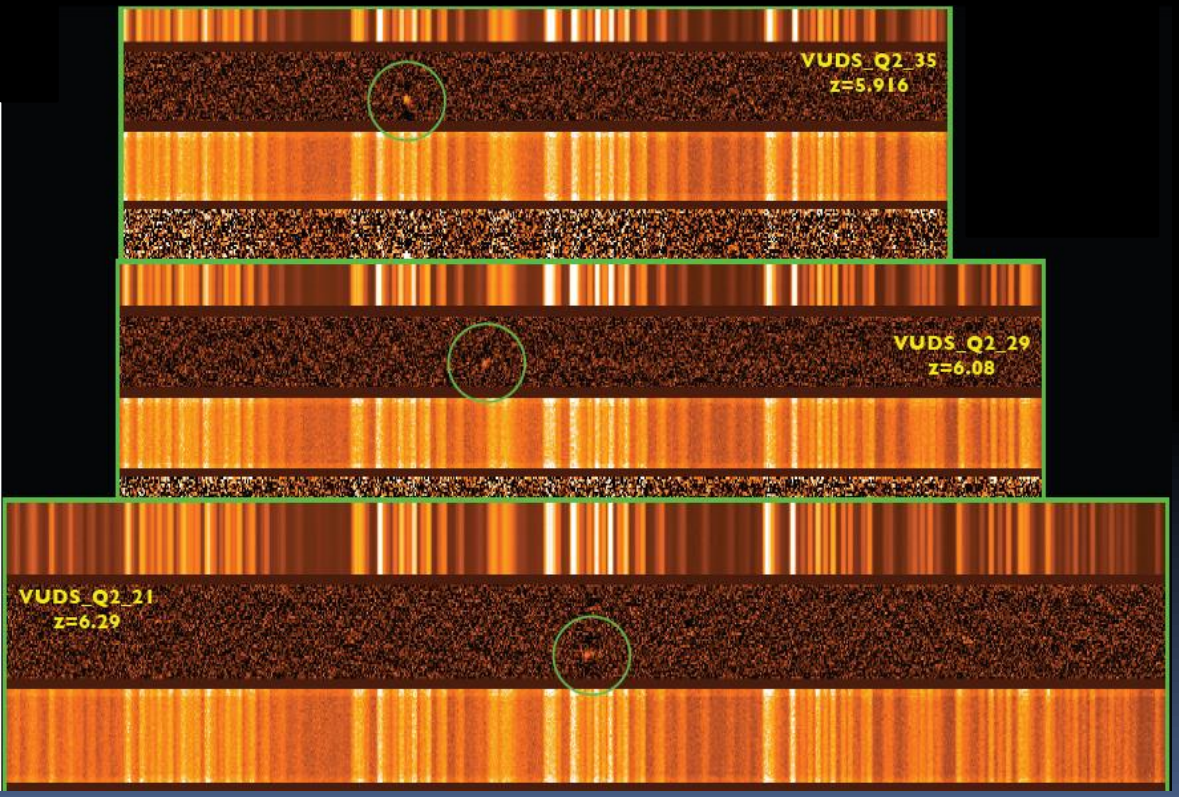
Le Fèvre et al. 2015

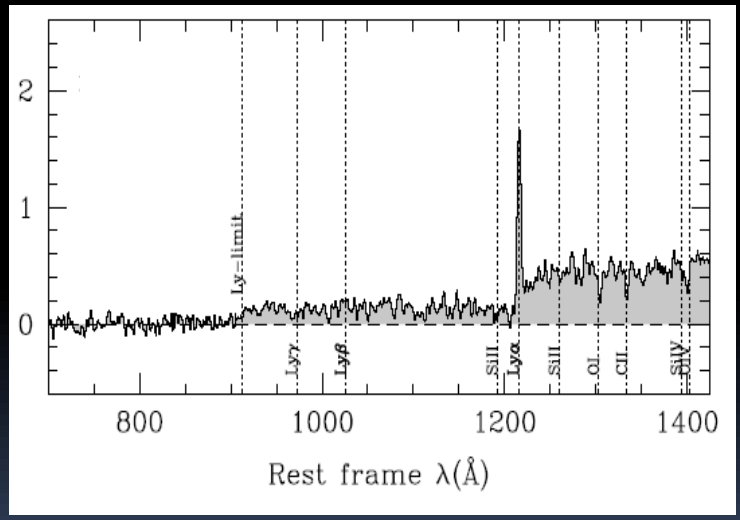
VUDS ~7000 spectra to z~6:~3Gyr of evolution in one glance



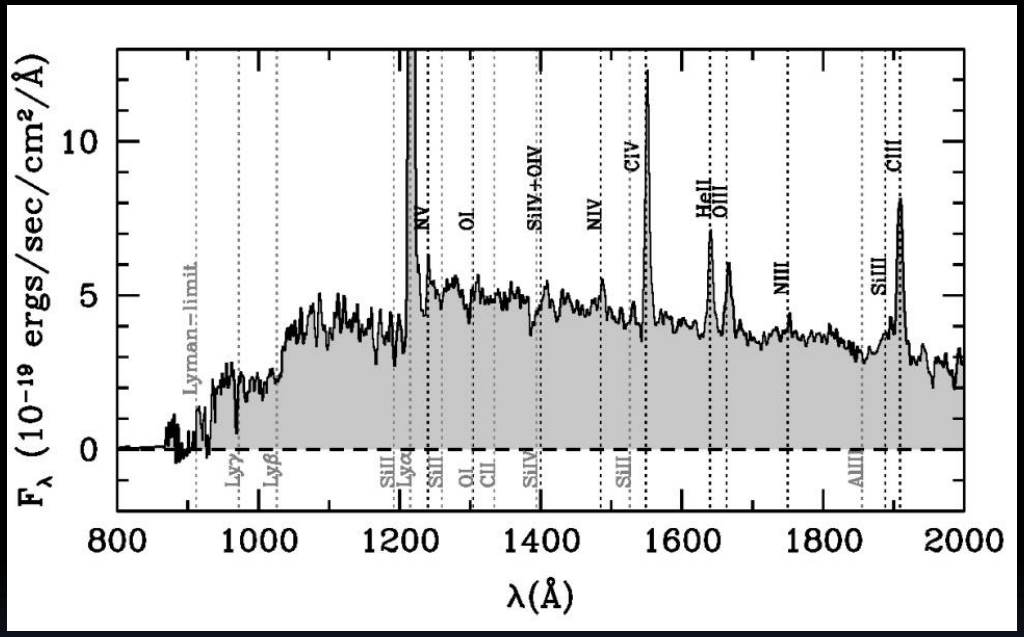
$5.5<z_{spec}<6.5$ sample

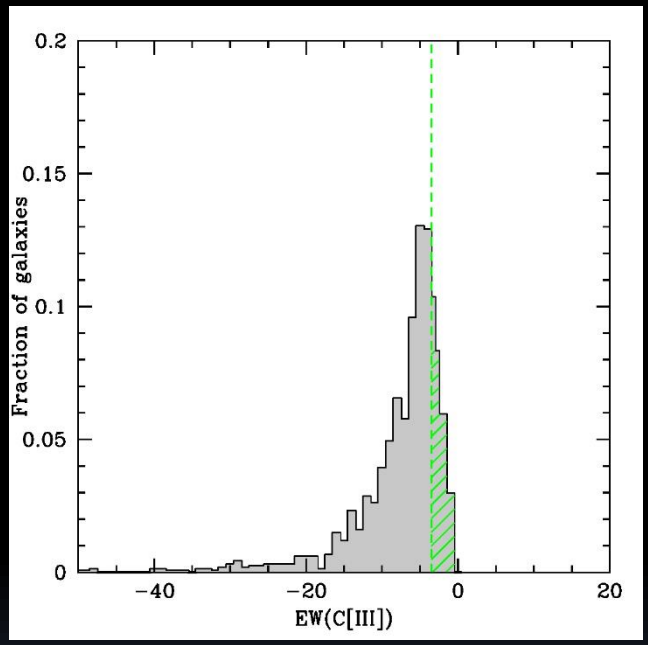
- About 100 galaxies with secure spectra being assembled





Spectral properties: prevalence of CIII-1909: a substitute to Lyα ?





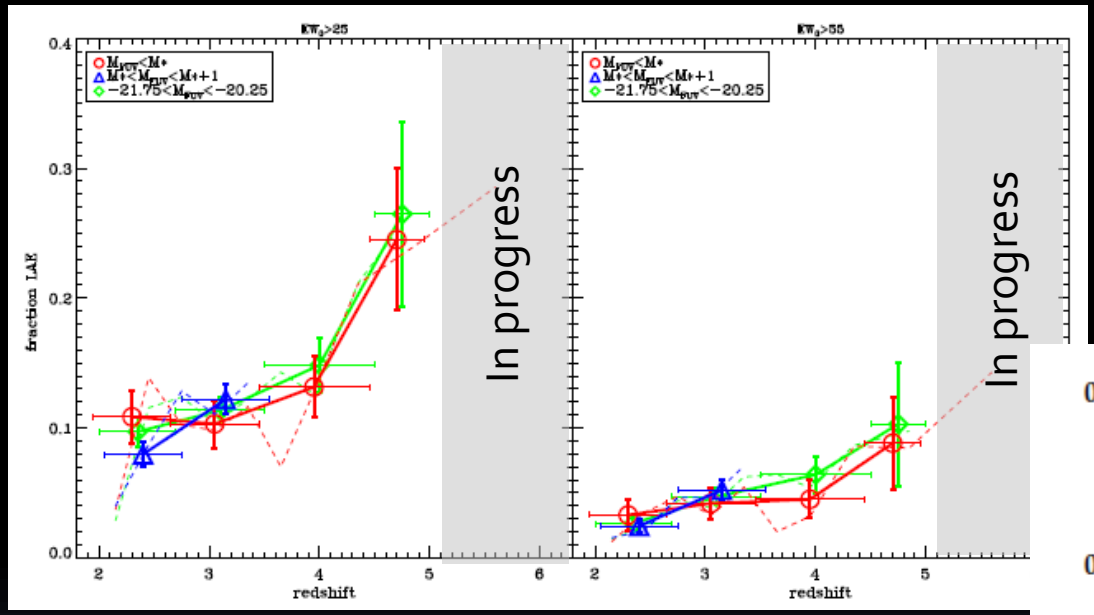
- Stack of 20 strongest emitters EW(CIII)<-20: high ionisation lines: OIII, CIII, CIV, NIII, NIV, NV
- Young: ~10-100Myr
- Analogs to first galaxies in the reionisation?

CIII is rare at z~3-4
EW<-20: ~2.5%
EW<-10: ~10%
How frequent at z>6 ?

Lyα fraction evolution

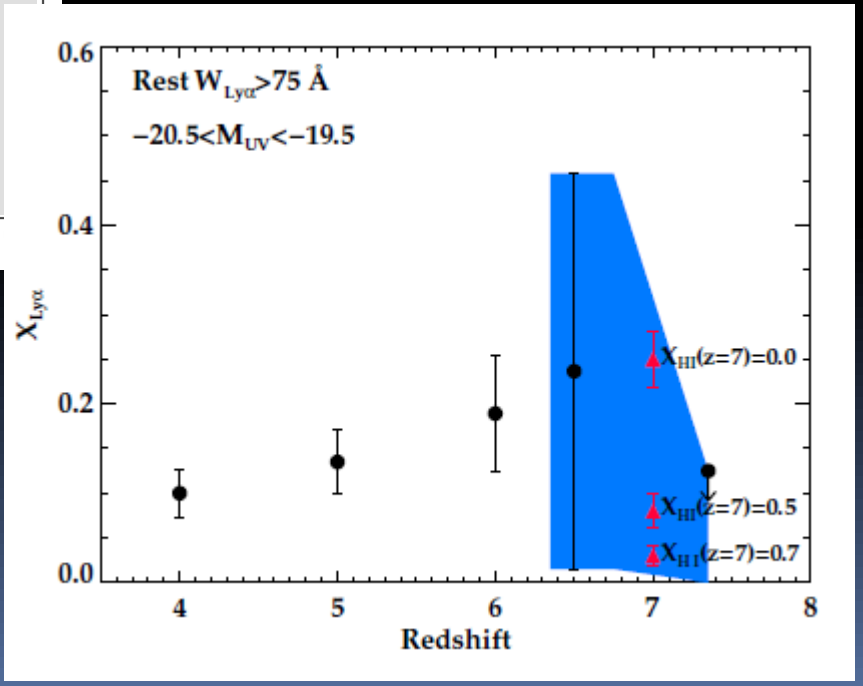
Moderate emitters

Strong emitters



Cassata et al. 2014

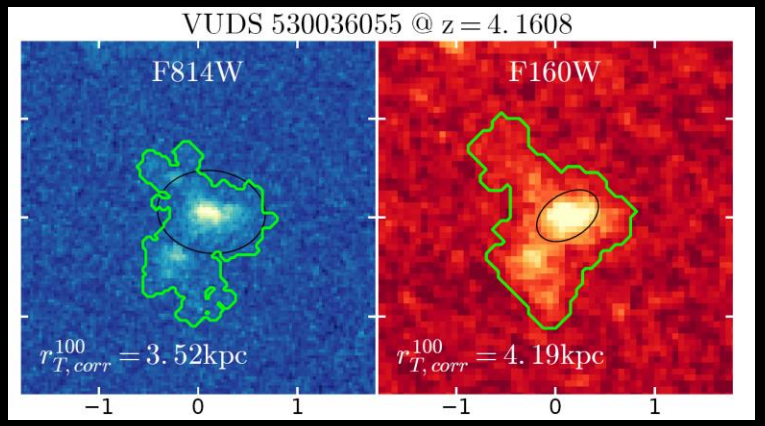
Stark et al. 2010

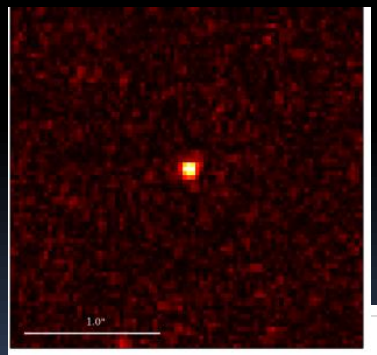


The sizes and morphologies of galaxies

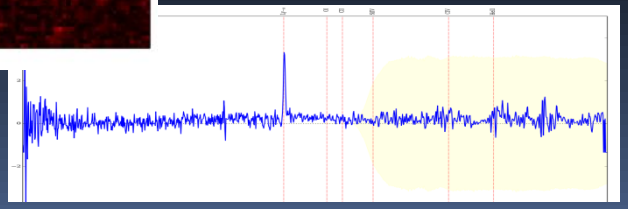
- Large range of sizes
- Forming galaxies
  - from extremely compact to extended and low surface-brightness
  - Multi-clump
    - merging and violent disk instability

Large, extended, multi-clump





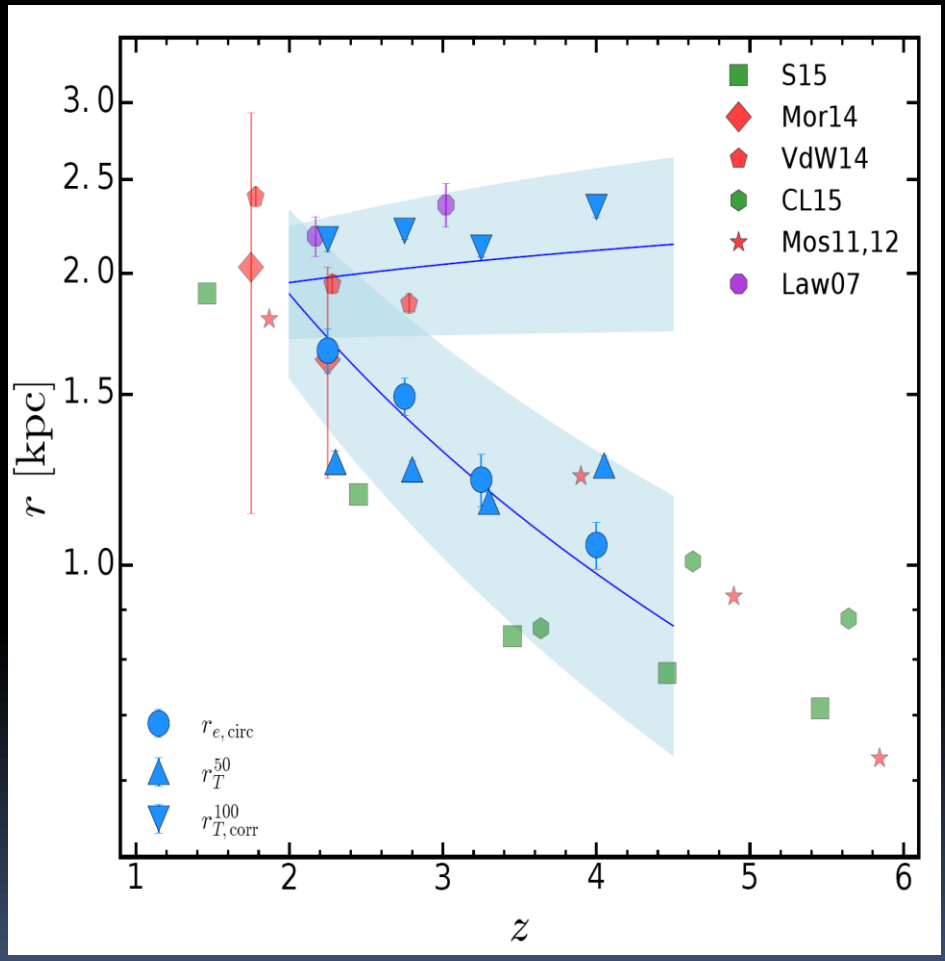
Extremely compact



Tasca et al. In prep.

Evolution of galaxy sizes z=2 to 5

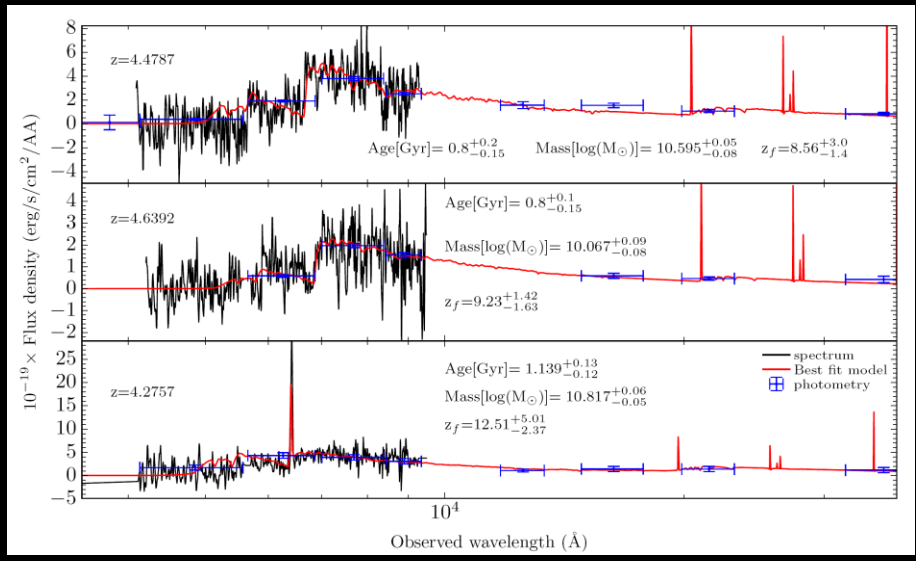
- HST imaging (COSMOS, CANDELS) with VUDS spectroscopic redshifts
- Measure sizes
  - *Effective radius* (makes symmetry hypothesis)
  - *Total radius* (down some isophote)
- Galaxies are large ~2kpc objects at all redshifts
- Concentration gets lower with decreasing z
- Imprint of assembly process



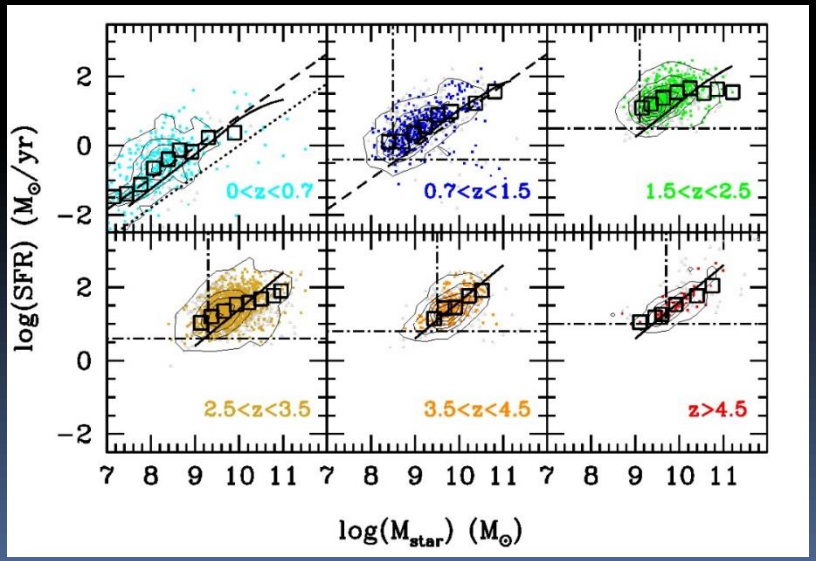
Ribeiro et al. arXiv:1602.01840

Galaxy ages, stellar mass, SFR

- Age measurements at z>2 are as robust as mass or SFR
  - Degeneracies can be lifted with
    - Age of the Universe
    - Combined photometry and UV-rest spectra
- JWST rest UV+optical+near-IR (NIRCAM, NIRSPEC, MIRI,NIRISS): accurate age, mass and SFR into reionisation



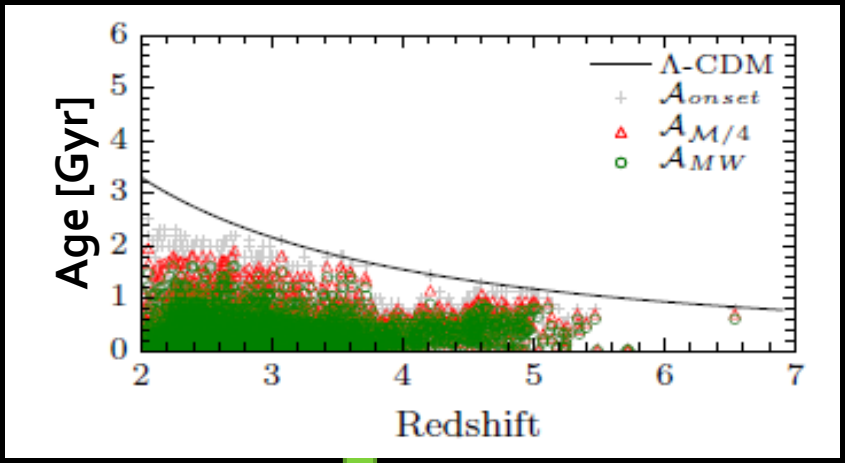
Model fitting: spectrum+photometry

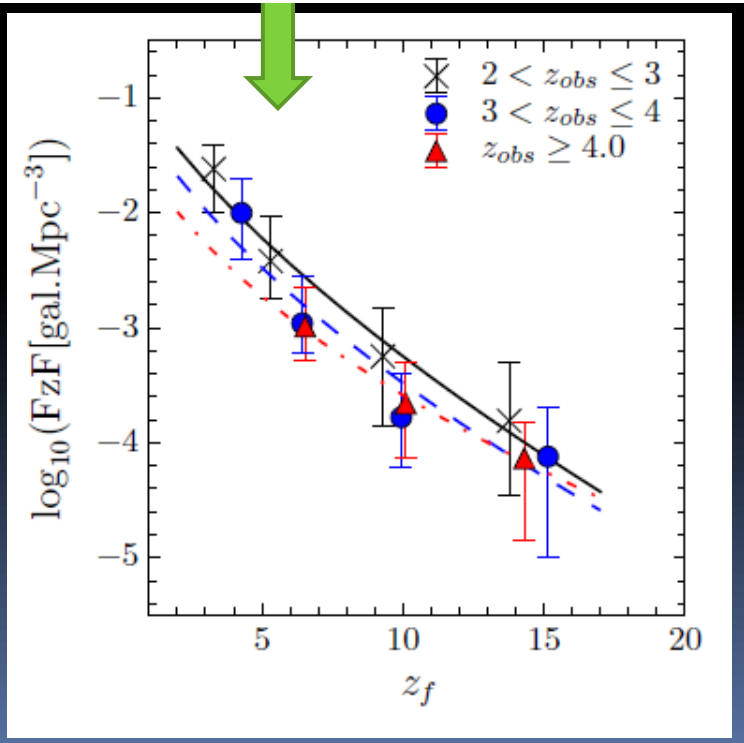


Main sequence SFR-mass

Epoch of galaxy formation

- Formation redshift function (FzF):
  - Number of galaxies per unit volume formed at z_f
  - Derive z_f from Age and observed redshift
- **<u>FzF: rise of 2dex from z~10 to z~3</u>**
  - Similar to the rise in SFRD
  - Average SFR 8-20 Msun/year at z~5





No particular epoch of galaxy formation

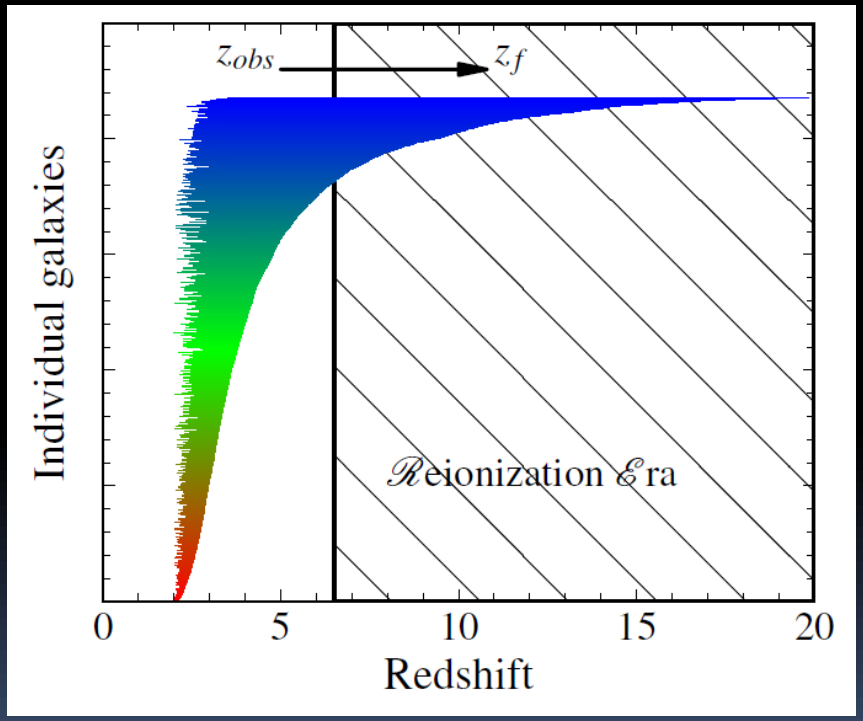
- Galaxies form at all times
- More galaxies formed when nearing the SFRD peak

Thomas et al. arXiv:1602.01841

Archaeology: from z~4-6 to the reionization

- Out of ~4500 VUDS galaxies, ~700 have started forming their stars before z=6.5
- z_f going to z>~15
- Main uncertainty: star formation history
- These galaxies contain the imprint of what happened then

VUDS galaxies z_{obs} to z_f ordered by z_f



Summary: impact on surveys with JWST

- Expect a wide range of galaxy properties in the reionisation epoch:
  - Search NIRCAM and MIRI images with broad parameter space
    - Census of the galaxy population without bias
  - NIRSPEC: broad parameter space for sample pre-selection
    - Account for galaxy sizes and morphologies
  - NIRISS line emitters: solve redshift degeneracies
- Plan for surveys with continuous sampling in redshift $z>4$: complete knowledge of reionisation will require accurate knowledge of the population just after reionisation