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Exploring the nature of Lyman α galaxies at z~2-6 using large VLT spectroscopic surveys: A prelude to TMT science

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Special thanks to

TMT - Japan

VUDS | VIMOS Ultra Deep Survey

VANDELS

A deep VIMOS survey of the CANDELS UDS and CDFS fields

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Introduction

- Lyman α (1216Å) emitting galaxies are star-forming galaxies (SFGs)
- These galaxies are/were believed to be young, first galaxies and could have played significant role in the process of reionization
- Investigating Lyα emitters and their physical, morphological properties is essential to study high redshift galaxy formation and evolution
- To better understand the range of physical properties in these galaxies and its evolution with redshift, we need large samples with multi-wavelength photometry and spectroscopy

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Motivation

Stellar population studies of Lyα emitters at z~>2 are based on 'UV-selected' or 'NB-selected' Lyα emitters

e.g., Shapley+ 2001, 2003; Erb+ 2006, Gawiser+ 2006,
Pentericci+ 2007, Verma+ 2007, Kai+ 2008, Reddy+ 2008, Finkelstein_S+ 2009,
Kornei+ 2010, Guaita+ 2011, Berry+ 2012, Vargas+ 2014, Hagen+ 2014, Finkelstein_K+ 2015

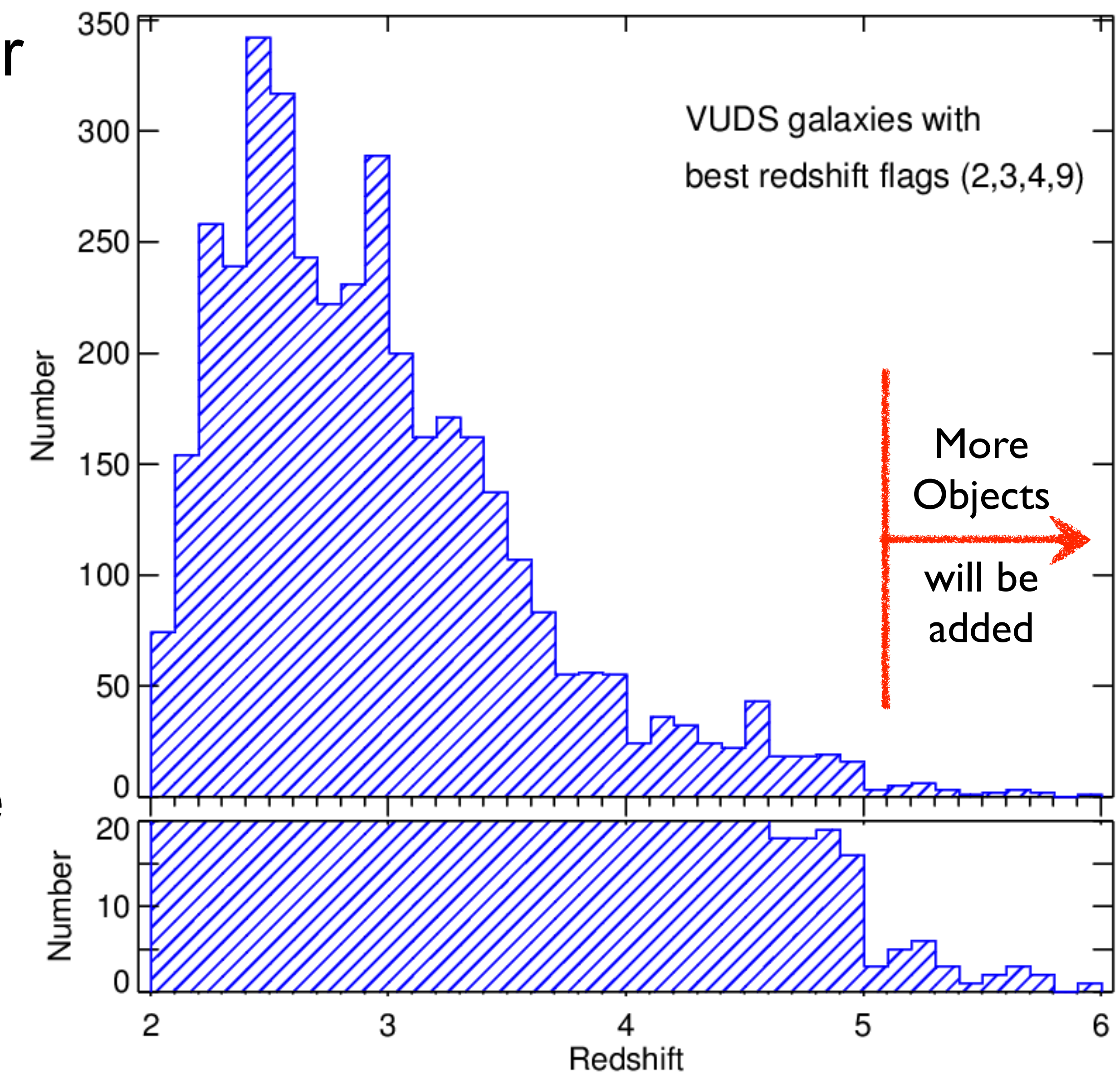
These studies cover limited/specific redshift range and
Results vary based on the selection method, and luminosities probed

Our goal is to use the 'UV-selection' approach on ~4000 SFGs ($\sim > L^*_{UV}$) over a large redshift range ($2<z<6$) to investigate stellar populations of Lyα emitters

VIMOS Ultra Deep Survey (VUDS)

- A large (1 deg^2, 3 fields, ~10,000 galaxies) and deep (640 hours, 14h per exposure) VIMOS spectroscopic survey
- ECDFS, VVDS-02h, COSMOS fields with extensive multi-wavelength data
- VUDS covers full wavelength range from ~3600Å to 9500Å (Lyα line visible at 2<z<~6.5)

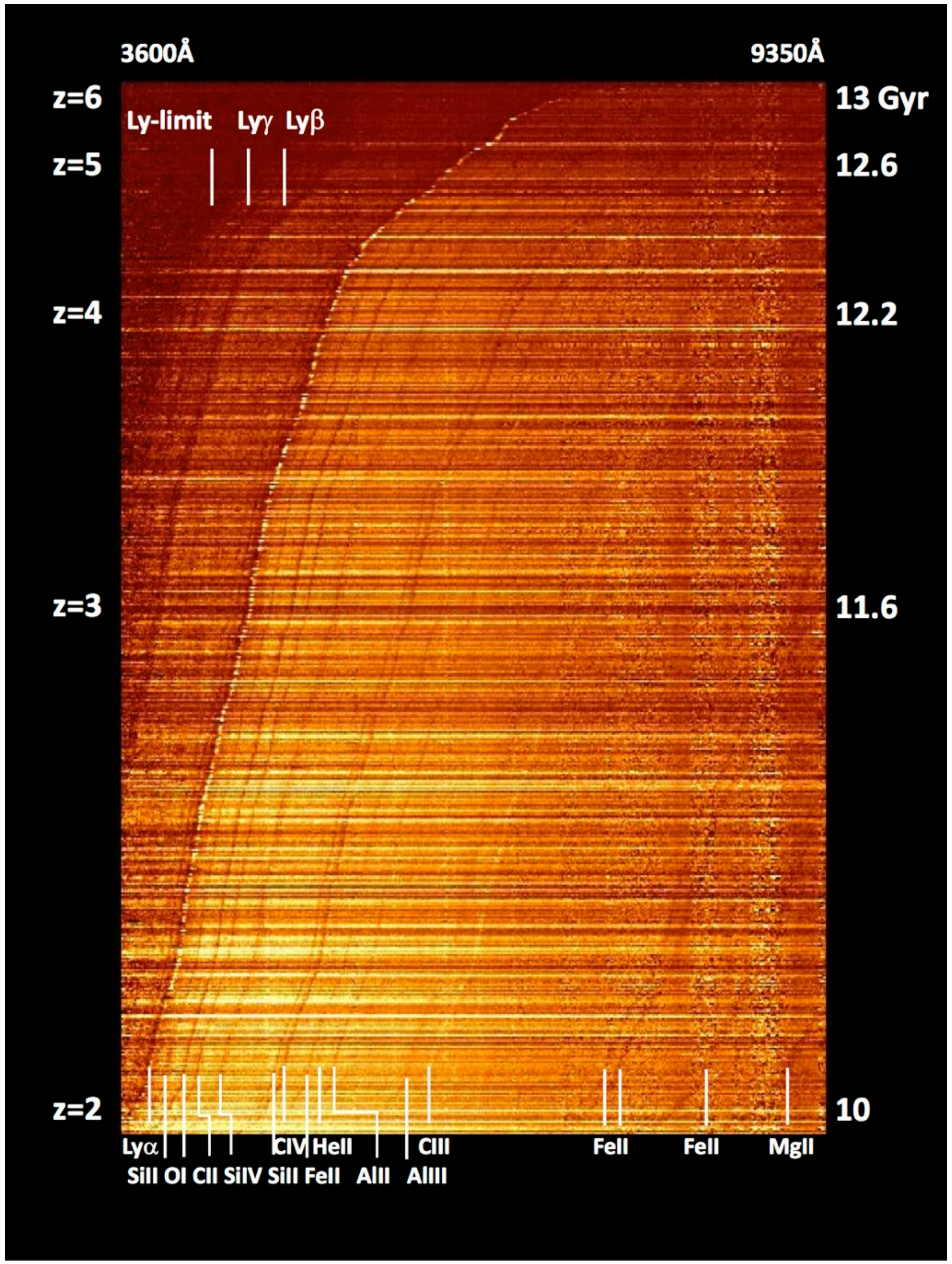
[Le Fèvre+ 2015, A&A, 576, A79]

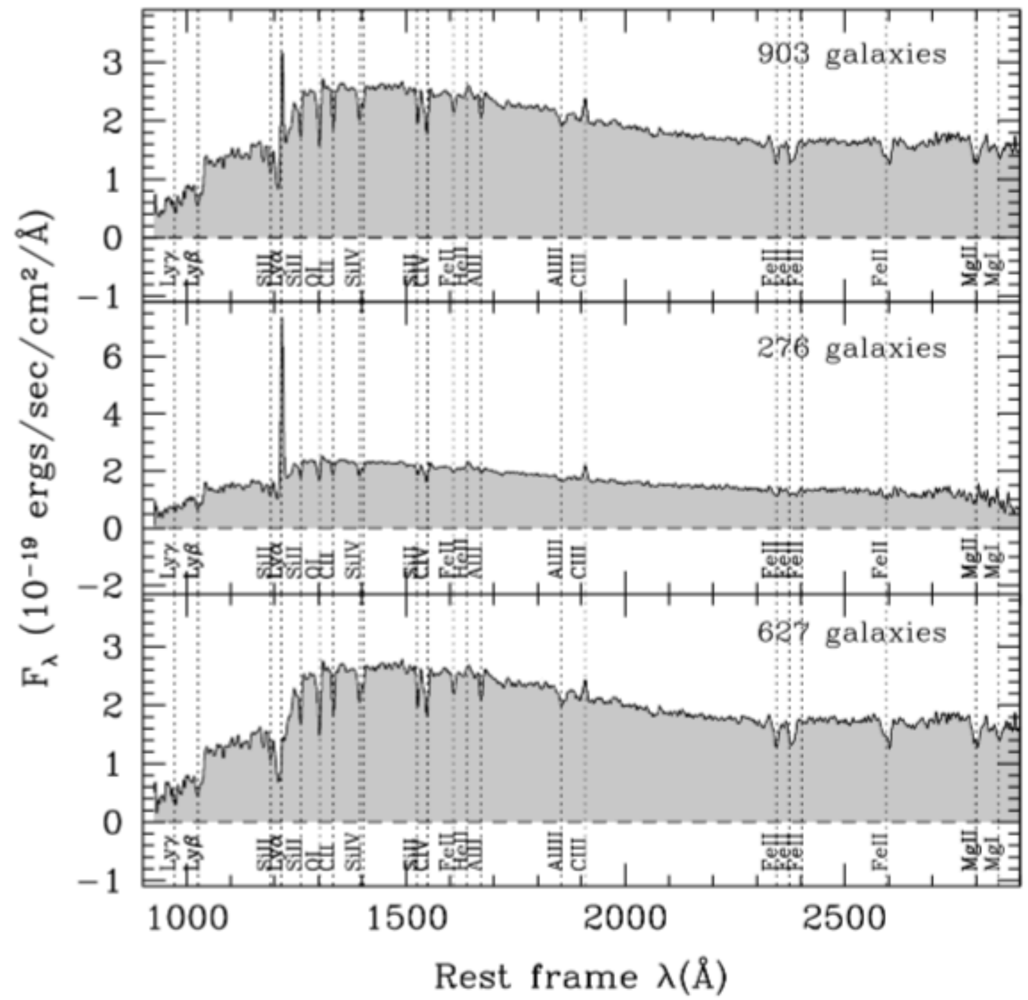


- Target selection based on photometric redshifts and broad-band colors (i_{AB}<~25 mag) ➡ continuum-selected sample

VUDS Spectra

[Le Fèvre+ 2015, A&A, 576, A79]





- These spectra gives access to a range of ISM/ Nebular spectral features and physical properties for each individual galaxy.
- With large numbers, the average spectral properties can be obtained using high signal-to-noise stacked spectra.

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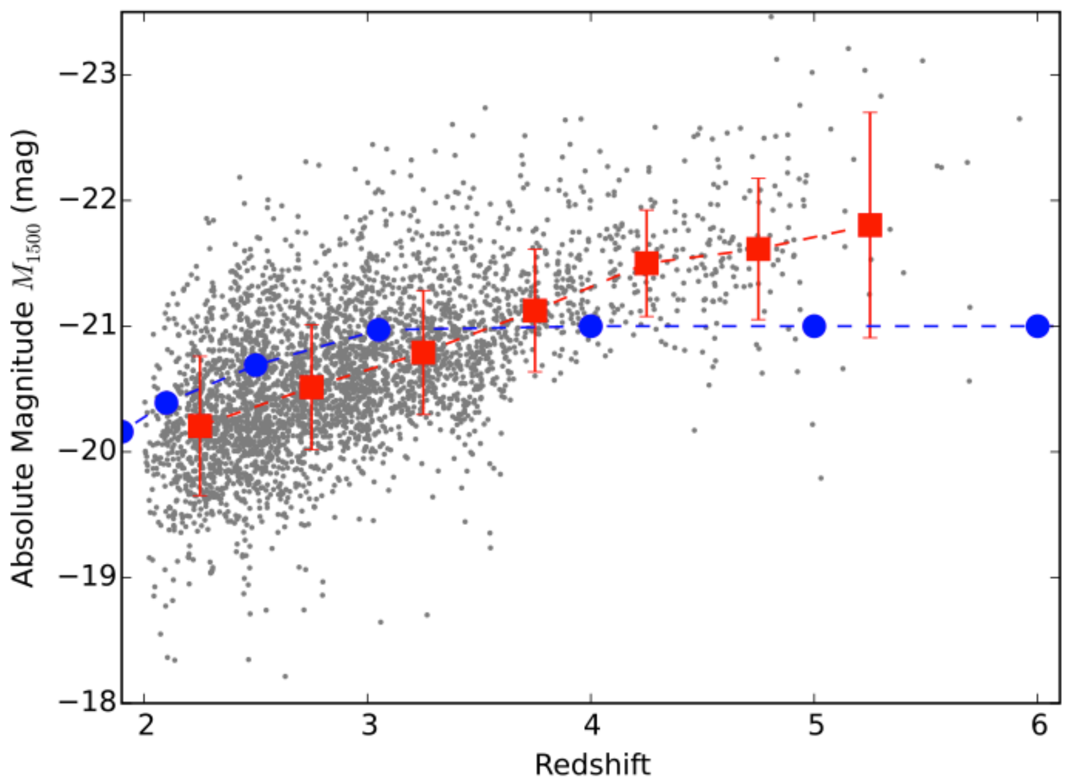
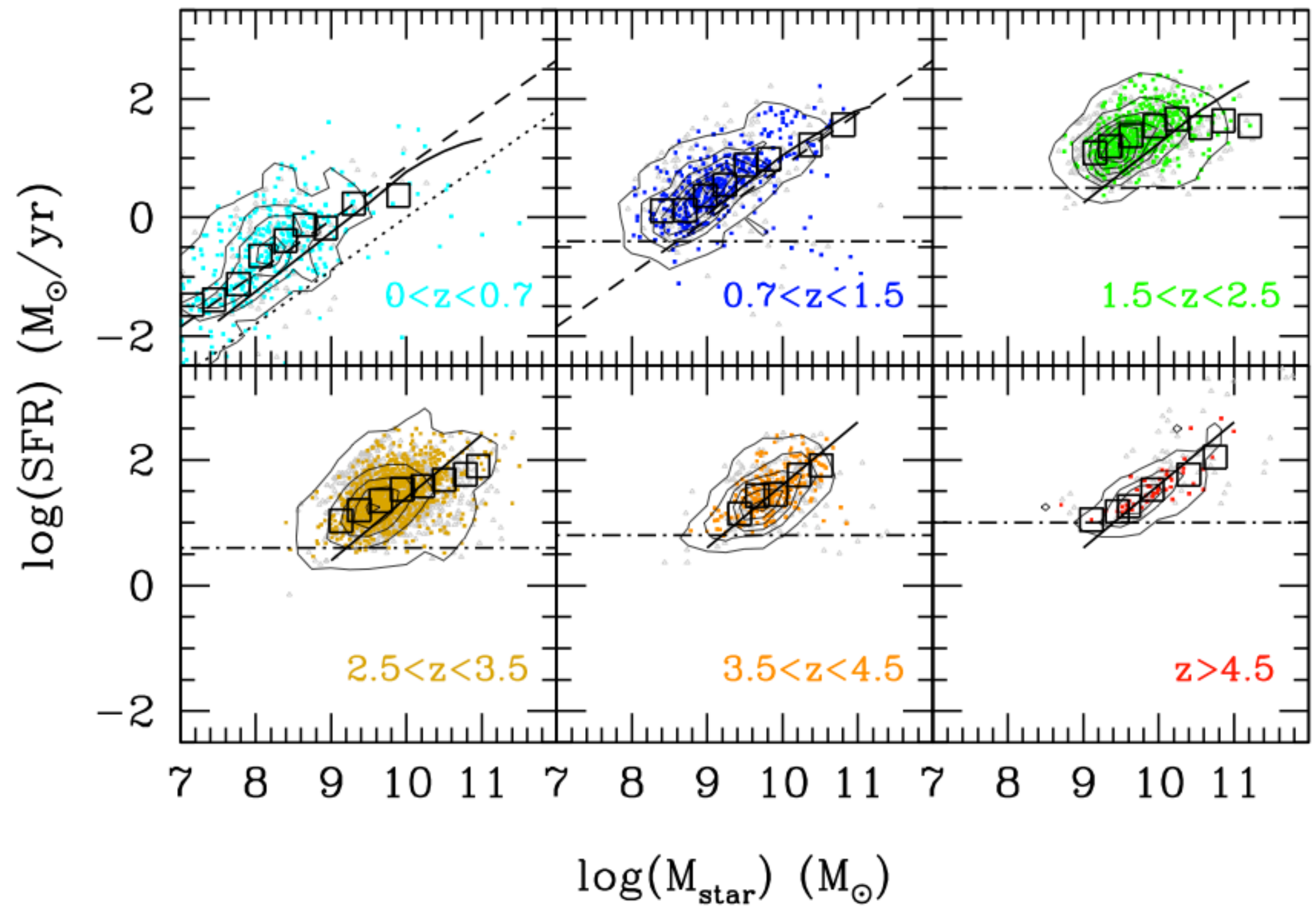
Properties of VUDS SFGs at 2<z<6



[Tasca+ 2015, A&A, 581, A54]

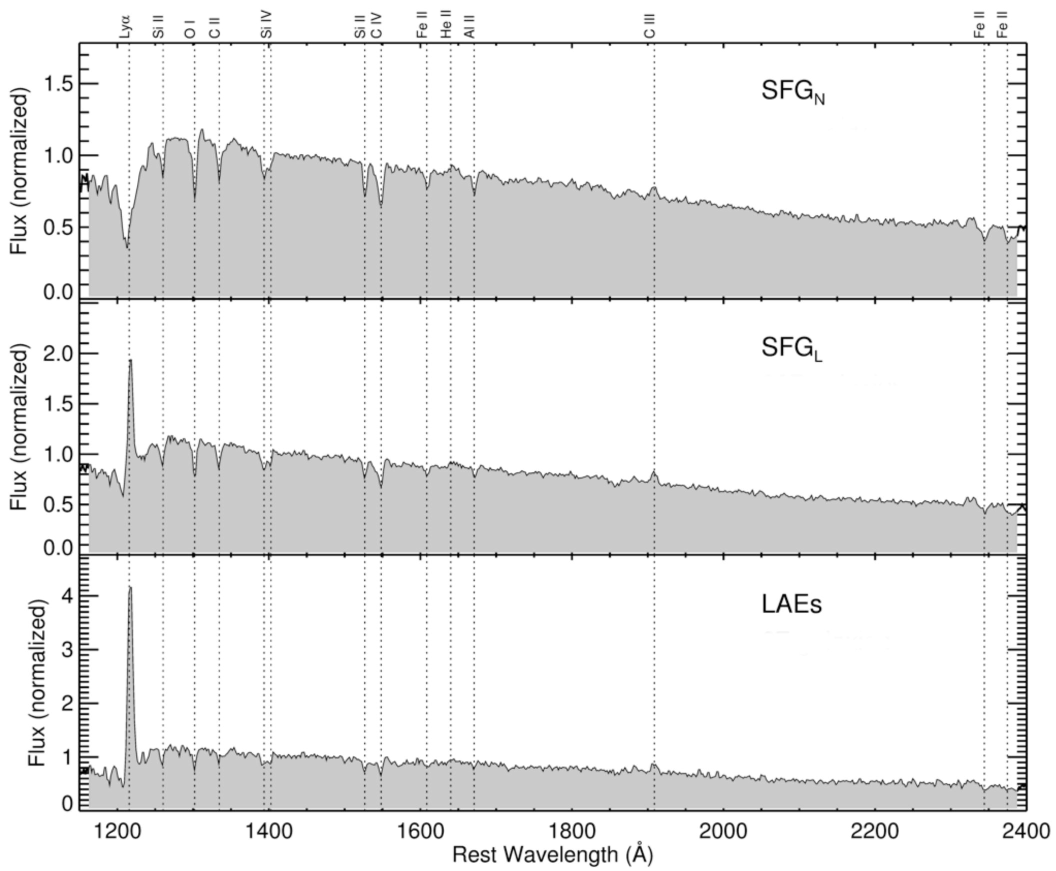


SFGs have UV luminosities ~>L*
(M*±1 for z<~3.5,
~M* and brighter for z>3.5)

SFGs (z~>2) spans a large range in SFR (~3 to 300 $M_\odot$/yr) and stellar mass (~5x10^8 to 10^{11} $M_\odot$)

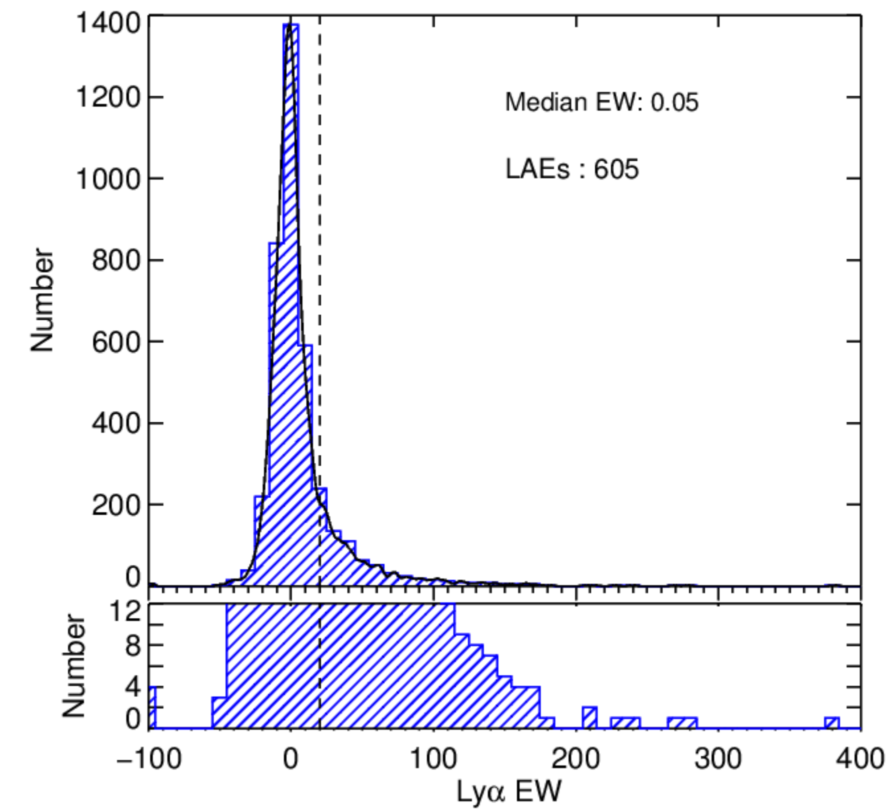
VUDS galaxies are ‘normal’ SFGs, populate the ‘MS’ but we see a large scatter (SFH effect; Cassara+ 2016, A&A, submitted)

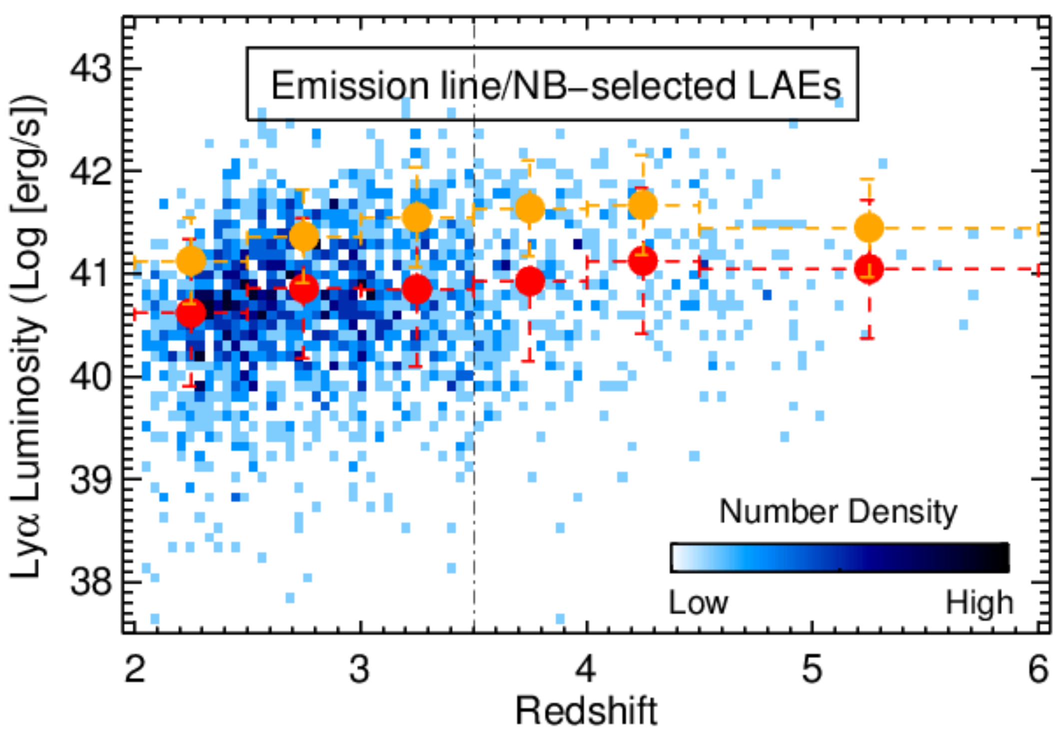
Lyα in SF Galaxies at 2<z<6



We divide SFGs in 3 groups:

SFG$_N$ (EW≤0Å),
SFG$_L$ (EW>0Å),
and
LAEs (EW≥20Å)





Rest Lyα EW range from strong absorbers (–50Å) to strong emitters (~200Å)

Median Lyα luminosity is ~10^{41} erg/s for LAEs (~an order of magnitude lower than typical NB LAEs)

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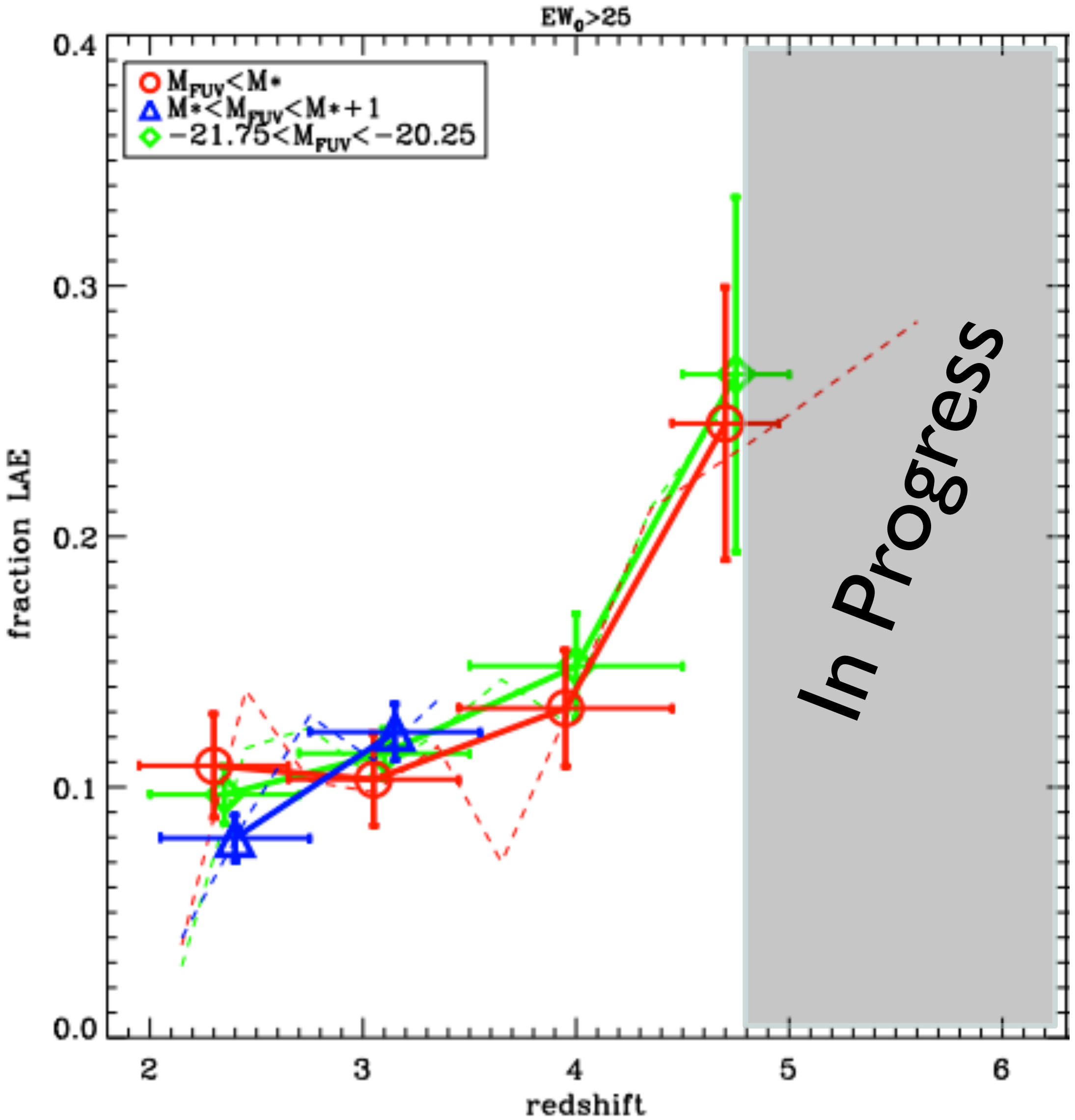
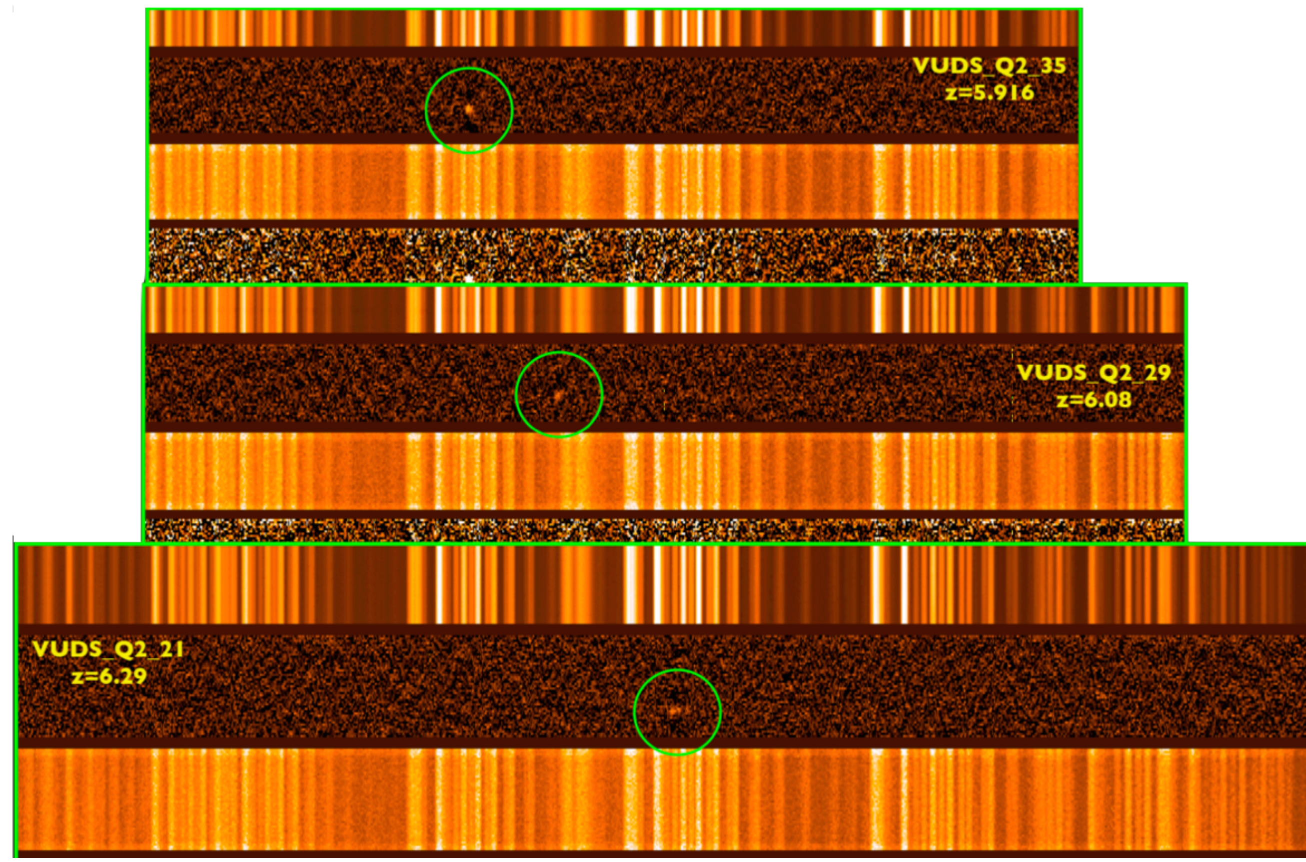
Lyα Fraction versus Redshift

[Cassata+ 2015, A&A, 573, A24]



Ongoing work: Identification of LAEs up to z~6.5



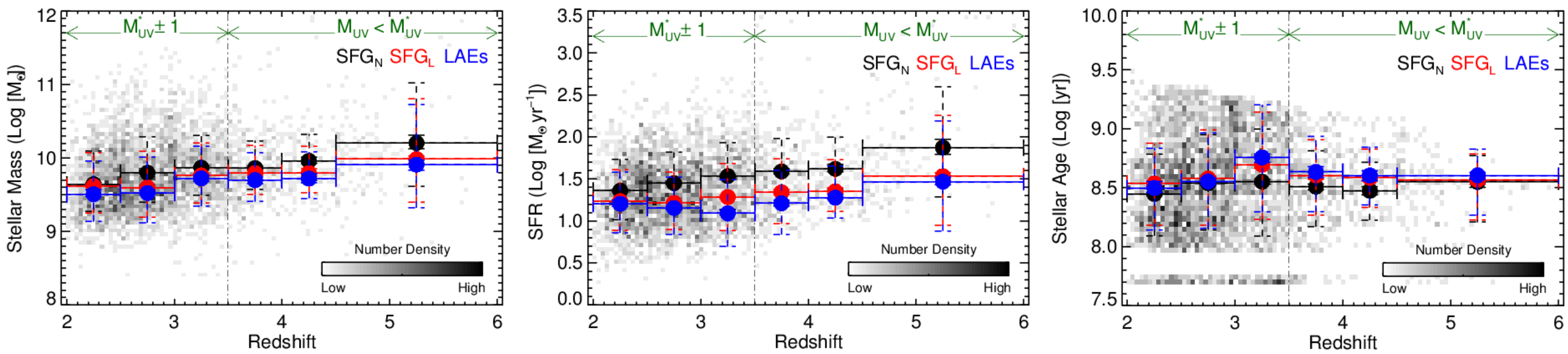
Credit: E. Vanzella

SFGs at 2<z<6 from VUDS show increasing Lyα fraction with the redshift (true for different EW cuts)

This is consistent with various other studies at these redshifts
One possible reason is that more Lyα escapes from less dusty galaxy

Stellar Populations of LAEs/non-LAEs

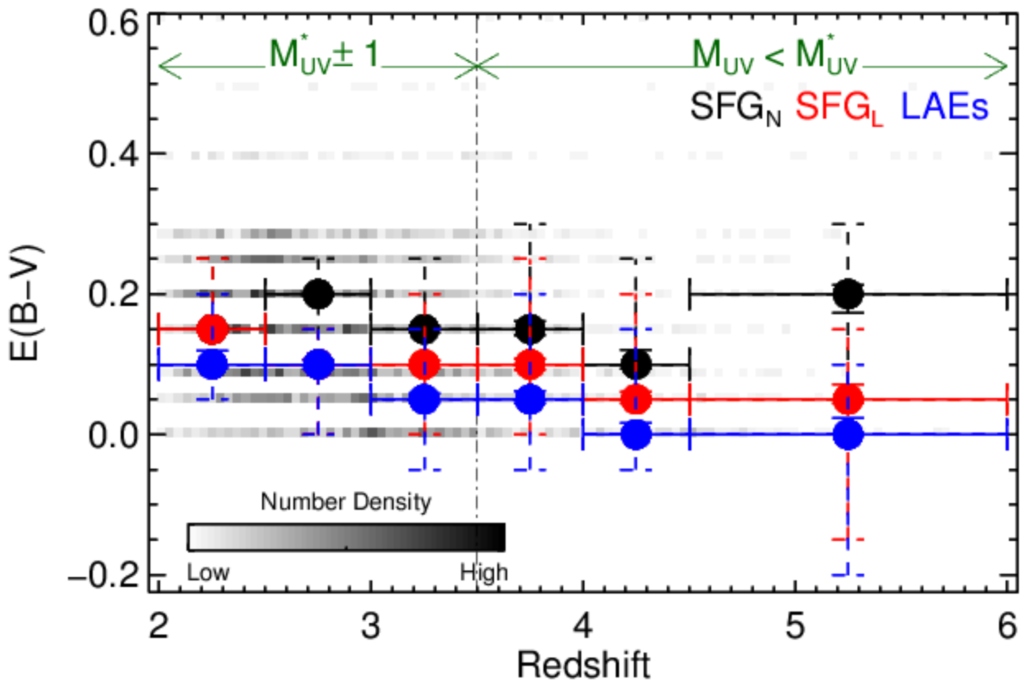
[Hathi+ 2016, A&A, 588, A26 and Hathi+ 2016, in prep]

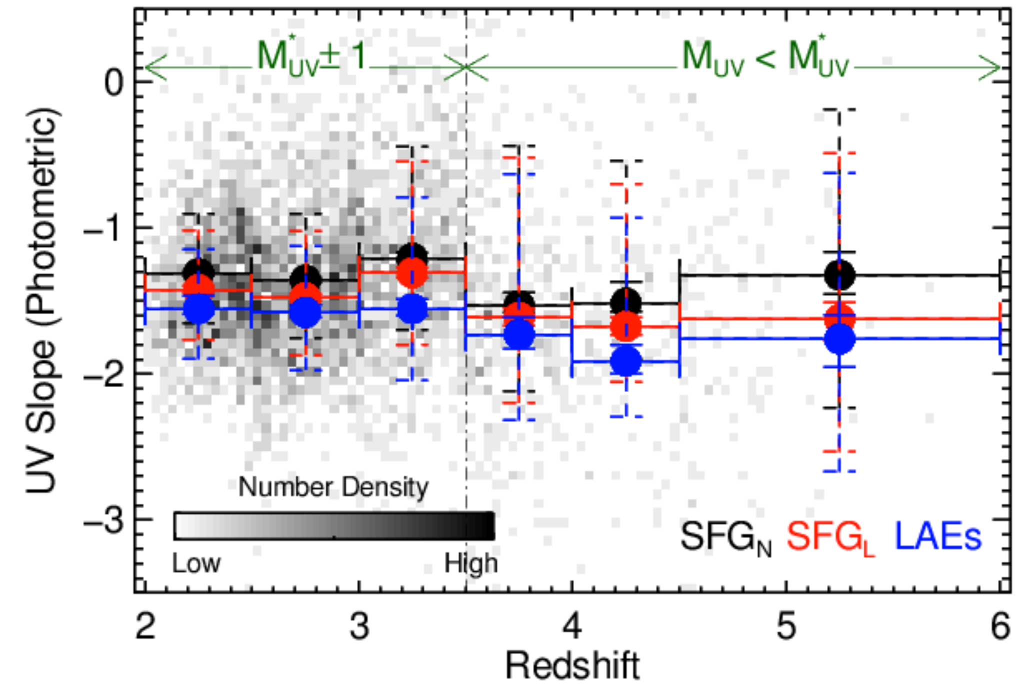


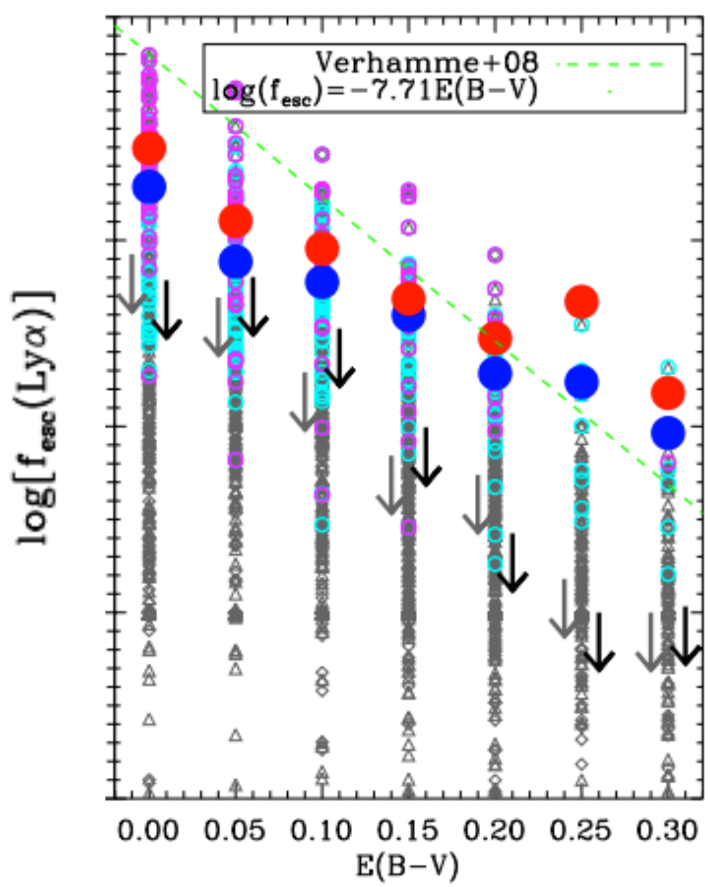
At all redshifts (z≥2), LAEs and non-LAEs have small differences in SED-based stellar properties (stellar mass and SFRs). On average, Lyα emitters are less massive and less star-forming

A similar trend in SED-based stellar parameters is observed between Lyα emitters and non-emitters for a sample with M_{1500} and stellar mass cuts

Dust Content in LAEs/non-LAEs







Significant difference between LAEs and non-LAEs is the dust content as seen in E(B−V) and β_{phot}

Consistent with the decrease in Lyman α escape fraction with increasing dust (Cassata+ 2015, Verhamme+ 2008)

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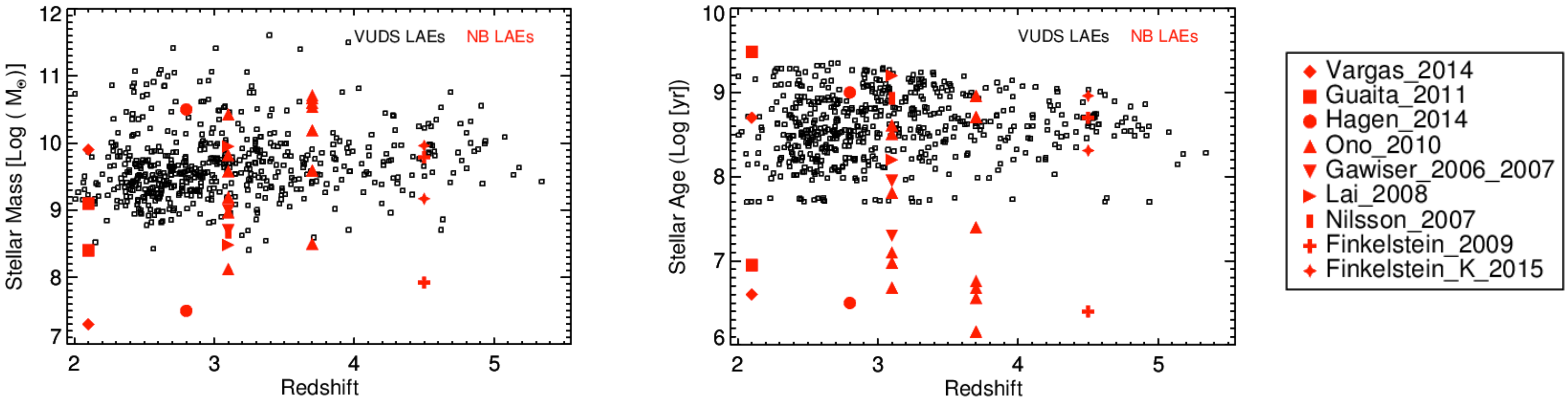
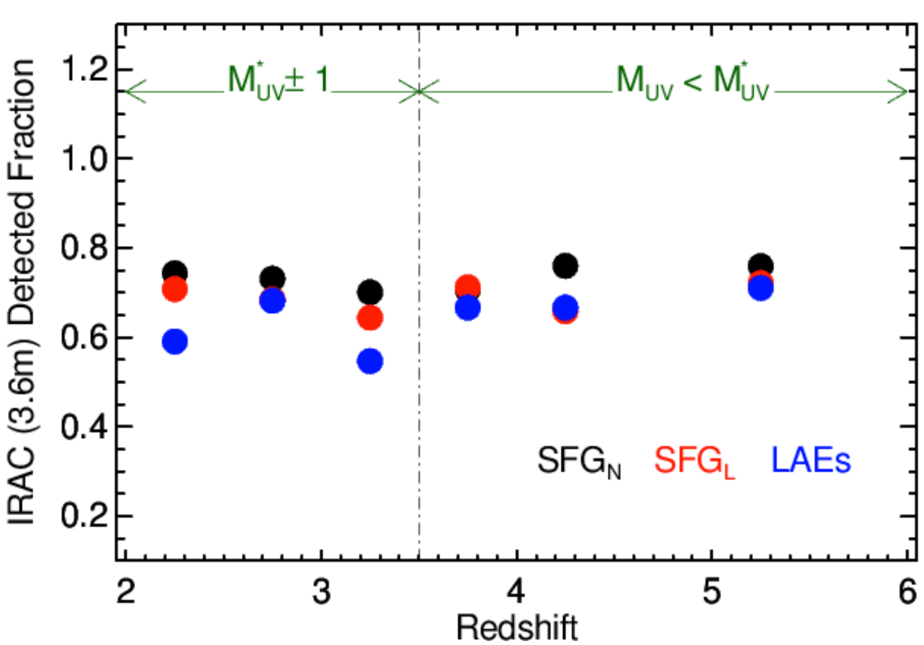
VUDS LAEs and Narrow-Band LAEs



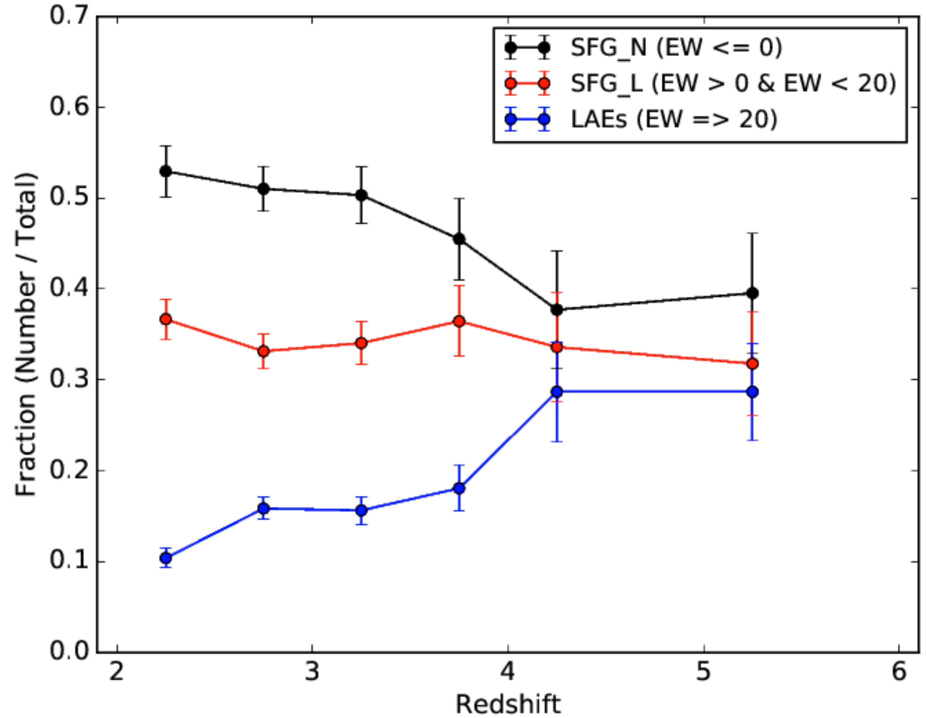
Wide range in SED-based properties for NB LAEs. For galaxies with similar Lyα luminosities, VUDS and NB LAEs have similar SED-based properties
** important to compare LAEs/non-LAEs at similar luminosities **



Spitzer/IRAC 3.6μm (or 4.5μm) detection down to ~25 AB mag
~>50% of LAEs are IRAC-detected
(compared to ~20-30% NB LAEs)

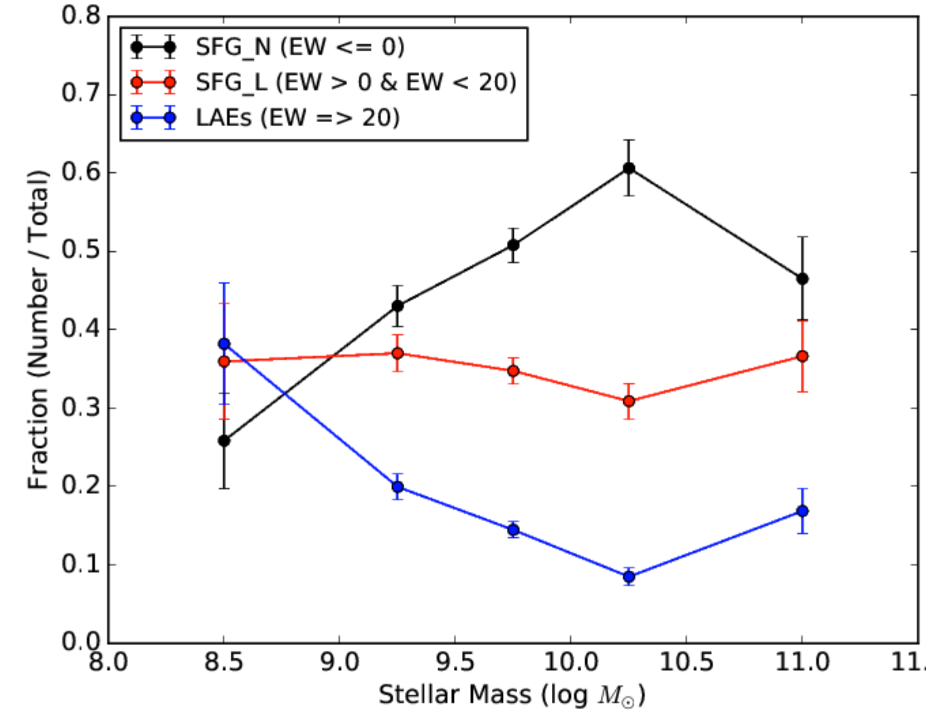
➡ UV-selected LAEs are more evolved than NB-selected LAEs

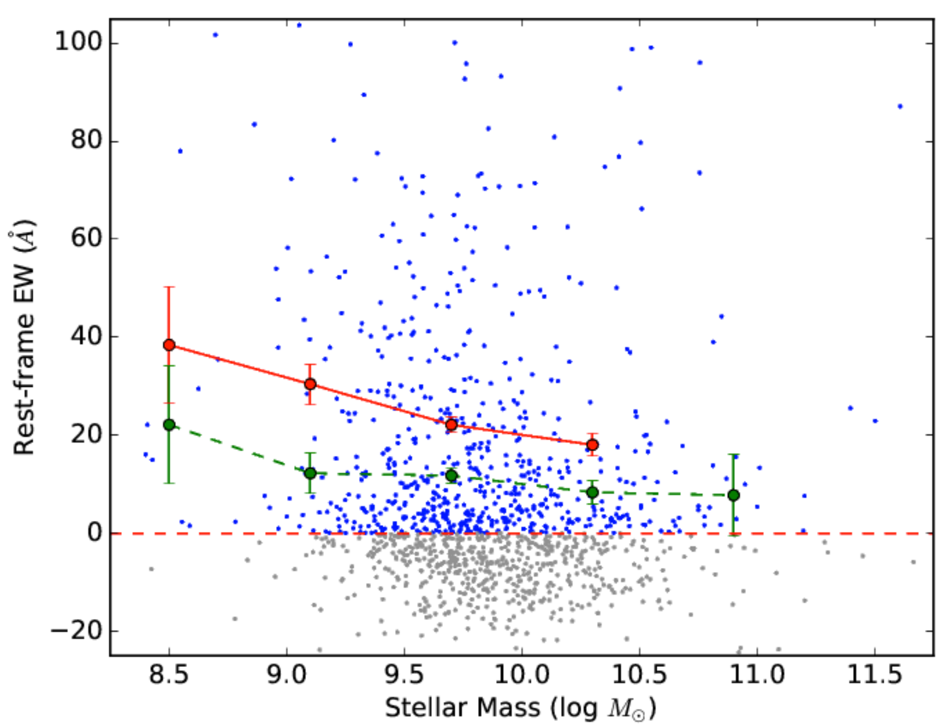
Properties of LAEs



Fraction of LAEs increases with redshift

Fraction of LAEs increases as stellar mass decreases

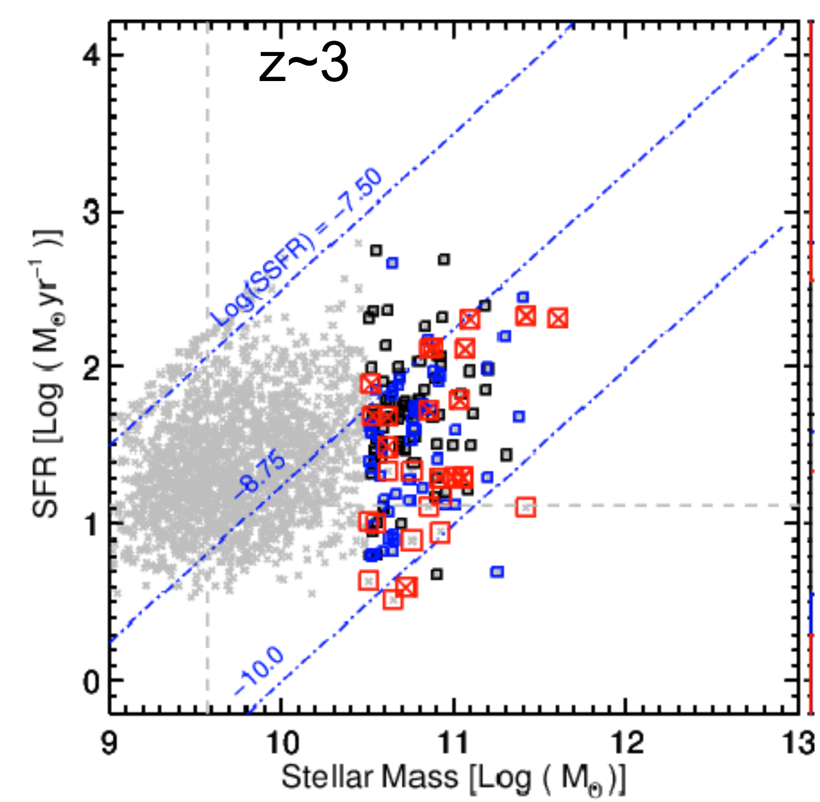




On average, rest-frame Lyman α EW is larger at lower stellar masses

but

individually we also observe massive/dusty LAEs



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VUDS Science and Future ...

Various ongoing science investigations based on various rest-UV spectral features (CIII, HeII, OIII, Si ...), velocity offsets/outflows, galaxy morphologies/sizes, and galaxy environments ... but

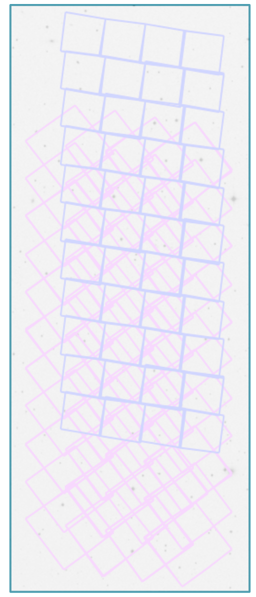
- VUDS probe galaxies brighter than M* at z>3

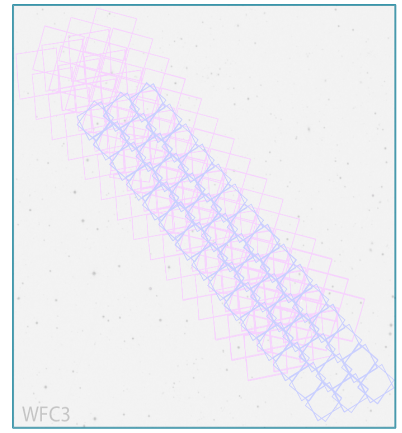
- Stacks are required to investigate many of the UV spectral features -- analysis for individual galaxies are very difficult except for the brightest ones

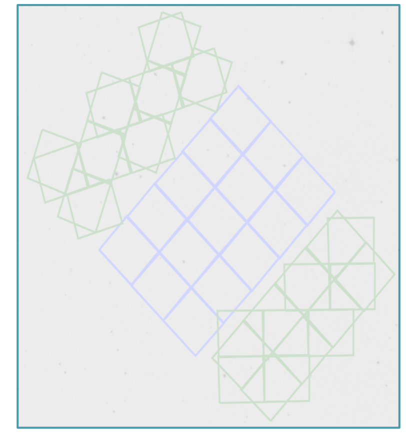
- So next step ...

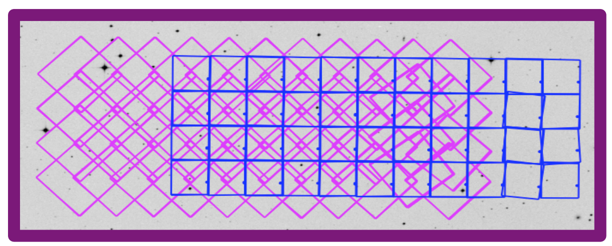
VANDELS (A VIMOS Survey of the CANDELS fields)

HST optical/near-IR imaging survey covering 0.2 square degrees split over 5 survey fields

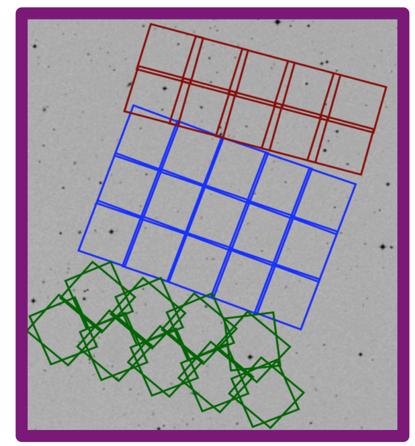








UDS



GOODS-S

PIs: Ross McLure (UK) and Laura Pentericci (Italy)

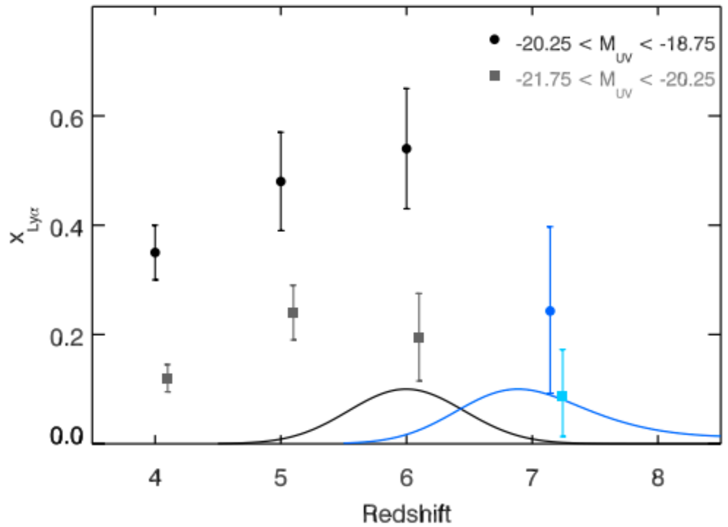
VANDELS targets the two southern CANDELS fields, exploiting unrivaled 15+ band (0.3μm-4.5μm) photometry and near-IR grism spectra (3D-HST)

- 912 hours of VIMOS visitor time: 2015-2018
- Small area (0.2 sq. degrees), best available multi-wavelength data
- Medium resolution spectra (MR grism)
- 20-80 hour integrations focused on z>3 star-forming galaxies (H_{AB}<26.5)
- Science goals: ages, masses, metallicities and outflows at high-z
- Raw data immediately public
- Reduced data released ~9 months after observations taken
- Full details can be found at: vandels.inaf.it

Summary / TMT

LAEs are diverse populations and their properties depend on various things (e.g., sample selection, range of luminosities/stellar masses/EWs probed)

- Detailed investigations of Lyman α properties, stellar populations, metallicity, kinematics/outflows, correlations with galaxy morphology and environments ..... statistically and fir individual galaxies
  - at z>6 using IRMS/IRIS
  - at z<6 using WFOS



- Combination of rest-UV and rest-optical observations for sub-L* galaxies at \`lower' redshifts

Large VLT (and other) surveys have started to assemble large samples of Lyman α emitters but TMT will be key to study numerous low luminosity galaxies (that populate the steep faint-end UVLF slope) at high redshifts

Thank You!

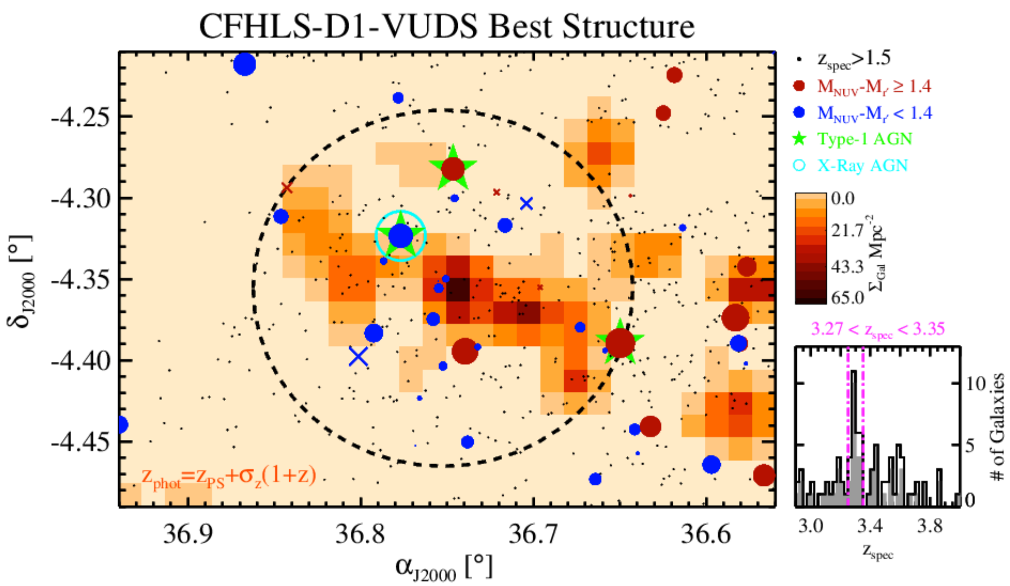
Spectral Features in VUDS spectra

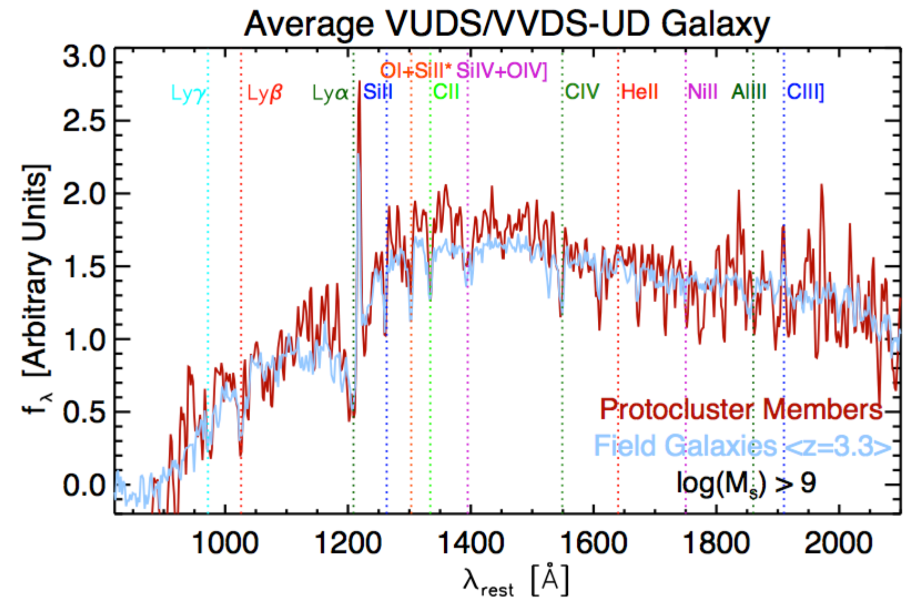
Spectral line	λ_{rest} (Å)	Line type
Lyman−limit	912.0	Continuum break
Lyman−γ	972.0	HI absorption
Lyman−β	1025.2	HI absorption
SiIIλ1192	1192.0	ISM, blend 1190+1193
Lyman−α	1215.7	HI emission & absorption
SiIIλ1260	1260.4	ISM
OI+SiII-1303	1303.2	ISM, blend
CIIλ1334	1334.5	ISM
SiIVλ1394	1393.8	ISM
SiIVλ1403	1402.8	ISM
SiIIλ1527	1526.7	ISM
CIVλ1549	1549.1	ISM, blend 1548.2+1550.8
FeIIλ1608	1608.5	ISM
HeIIλ1640	1640.0	Nebular
AlIIλ1671	1670.8	ISM
FeIIλ1855	1854.7	ISM
FeIIλ1863	1862.8	ISM
CIII]λ1909	1908.7	Nebular, blend 1907+1909
FeIIλ2344	2343.5	ISM
FeIIλ2371	2370.5	ISM
FeIIλ2402	2402.6	ISM
FeIIλ2594	2593.7	ISM
MgIIλ2796	2796	ISM

VUDS Science

Proto-clusters at z~>3 and environmental dependence

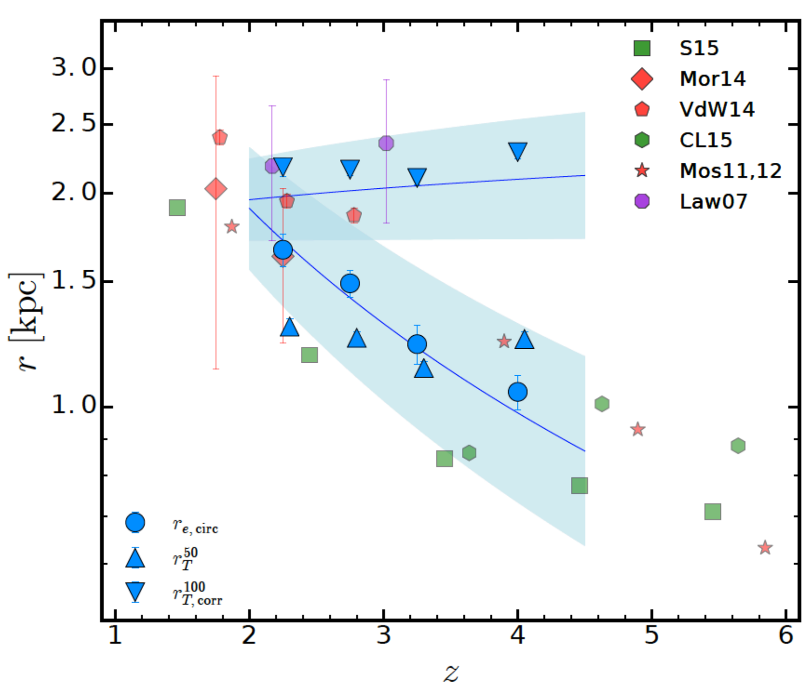
[Lemaux+ 2014, A&A, 572, A41; Cucciati+ 2014, A&A, 570, A16]



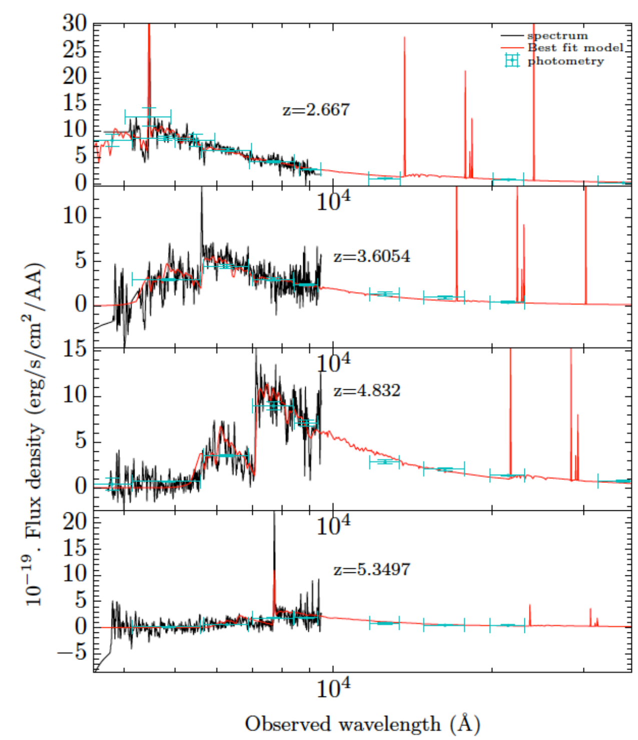


Galaxy Sizes

Ribeiro+ 2016, A&A, arXiv: 1602.01840



Thomas+ 2016, A&A, arXiv: 1602.01841



Spectral energy distribution fitting combining both spectra and photometry

VUDS-DR1: Public data release

[Tasca+ 2016, A&A, arXiv:1602.01842]

~700 galaxy spectra to z_{spec}<6 in CANDELS

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

VUDS data matched to:
CANDELS-COSMOS
CANDELS-ECDFS