LOW REDSHIFT ANALOGS OF PRIMEVAL GALAXIES

Witnessing the early build-up and chemical enrichment of star-forming dwarf galaxies at z~3

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VUDS | VIMOS Ultra Deep Survey

Some motivations

- Study early phases of assembly and chemical evolution of galaxies
- Reionization

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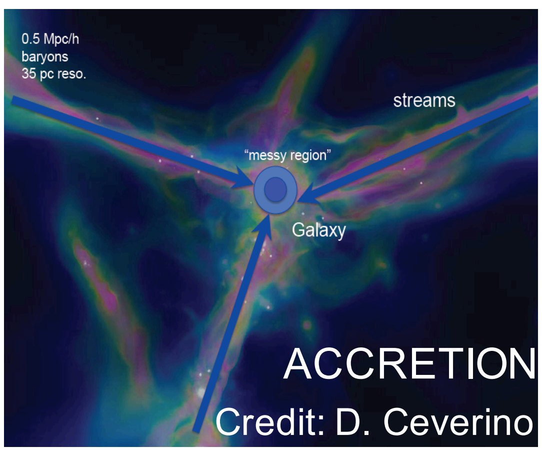
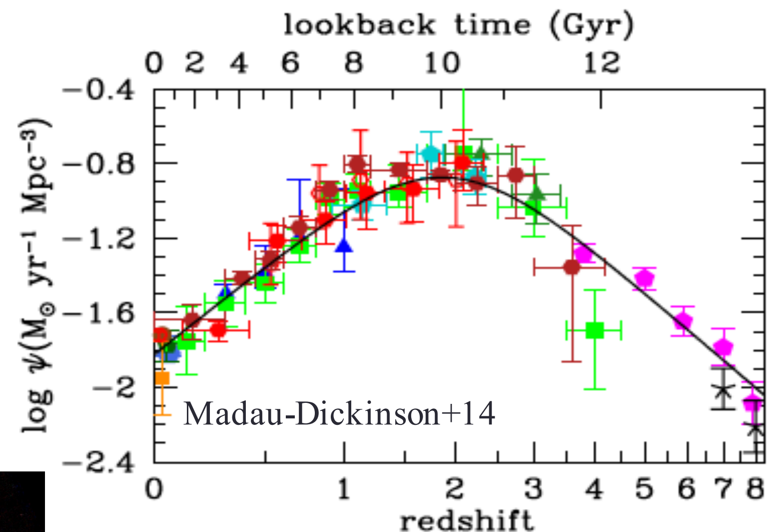
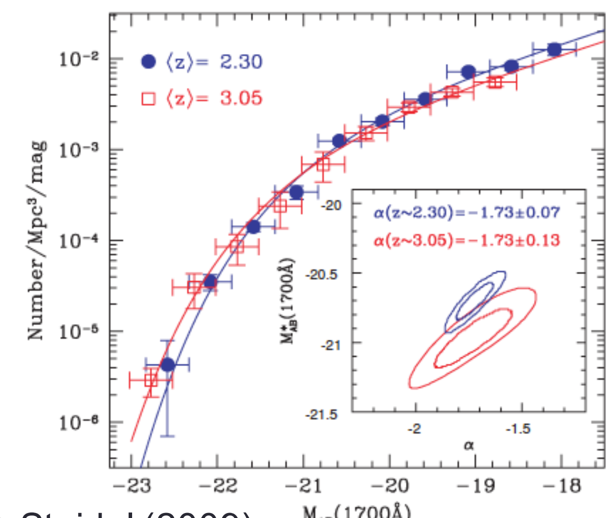
- ◆ Study early phases of assembly and chemical evolution of galaxies
- ◆ Reionization

Redshift z=2-3 probes a major epoch in galaxy assembly

Ideal to study mechanisms driven and regulating galaxy growth: accretion, mergers, feedback…







Reddy & Steidel (2009)

Need to understand dwarf galaxies
Detailed studies are now possible

Some motivations

- Study early phases of assembly and chemical evolution of galaxies

- Reionization

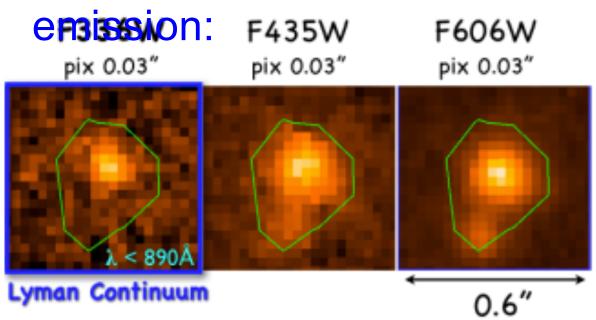
Star-forming galaxies ?
AGNs ?
Other sources ?

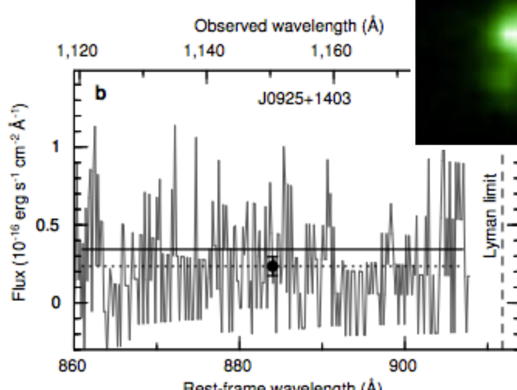
Faint or bright ?

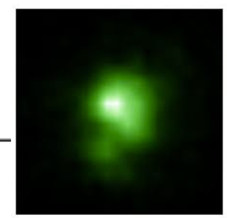
Dwarf galaxies are believed to play a significant role

Need to constrain the LyC escape fraction
But direct detection of LyC at z>6 is impossible

Direct evidence of LyC emission:

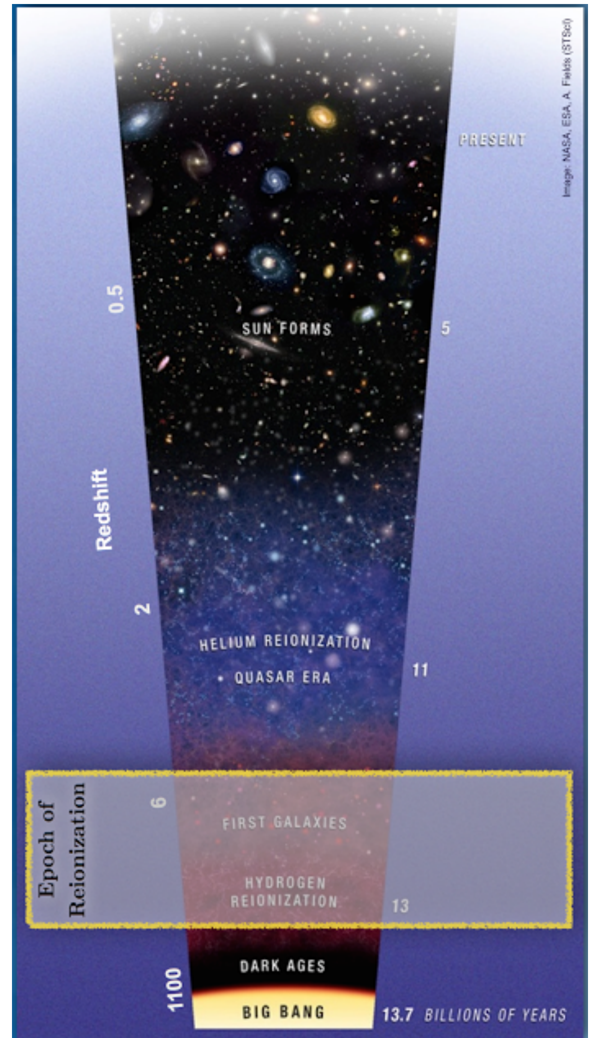






Ion2 @ z=3.2; De Barros+16;Vanzella+16 Green peas at z~0.3 (Izotov+16a,b)

Need to understand the link between dwarf's properties and LyC F_{esc}

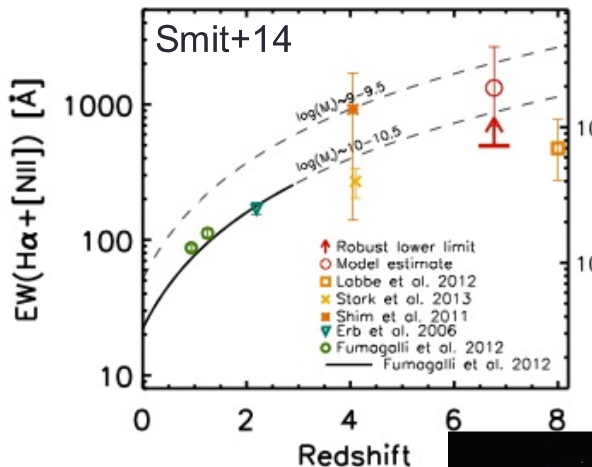


What do we know about primeval galaxies ?

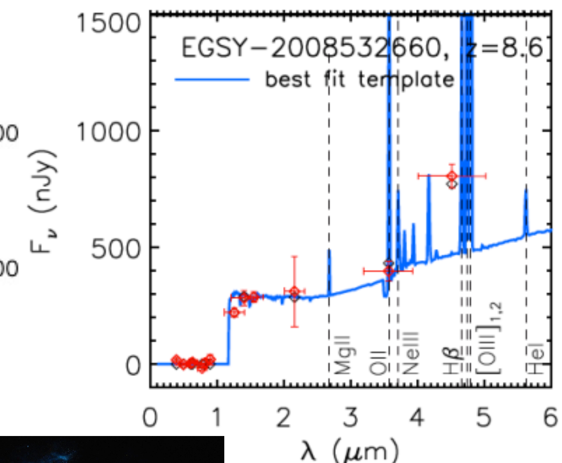
(Several talks in this conference; first session)

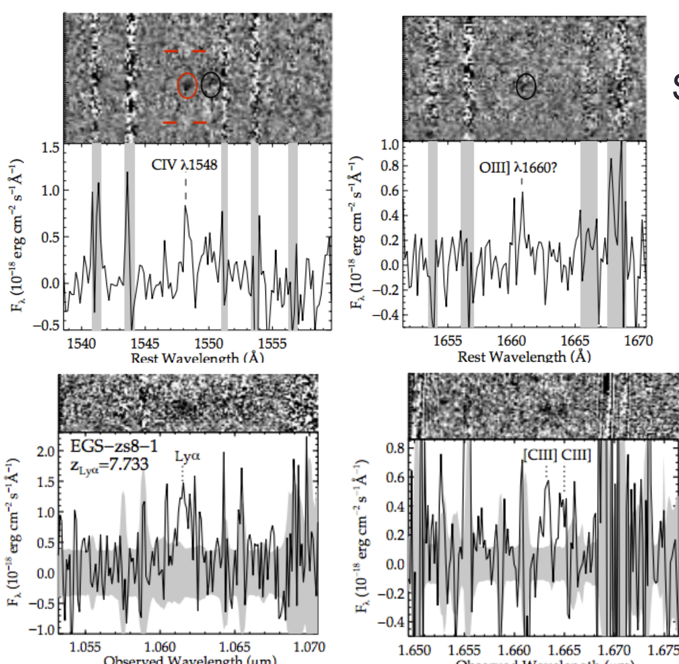
At z>4 galaxies show more extreme properties

- ❑ Extreme emission line prope
- ❑ Hard radiation fields
- ❑ Low masses
- ❑ High sSFR
- ❑ Blue (low-dust) UV slope
- ❑ Very compact
- ❑ Low metal abundances?

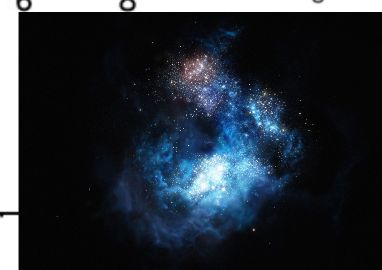


Roberts-Borsani+15

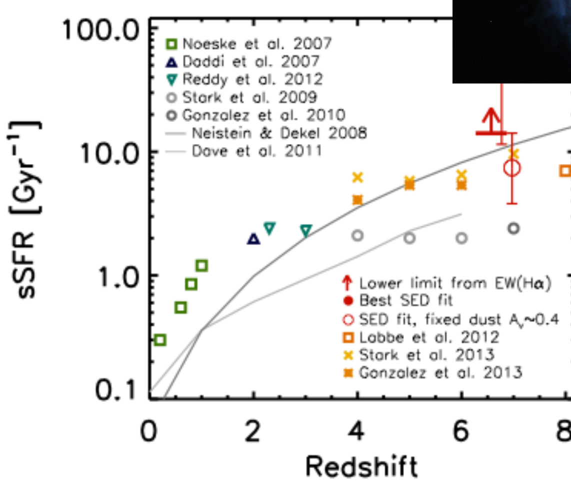


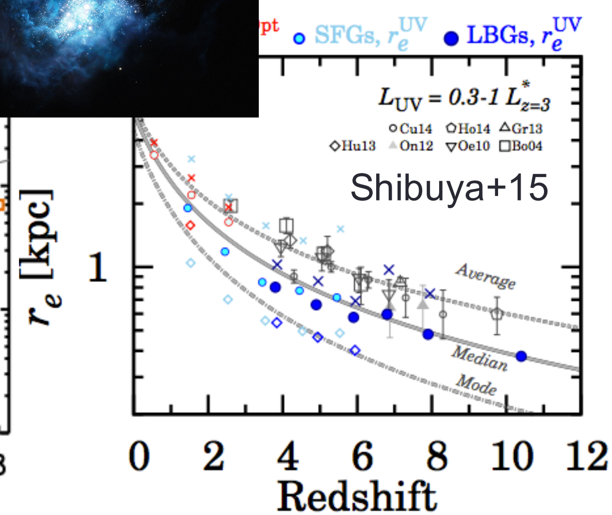


Stark+15,16



Smit+14





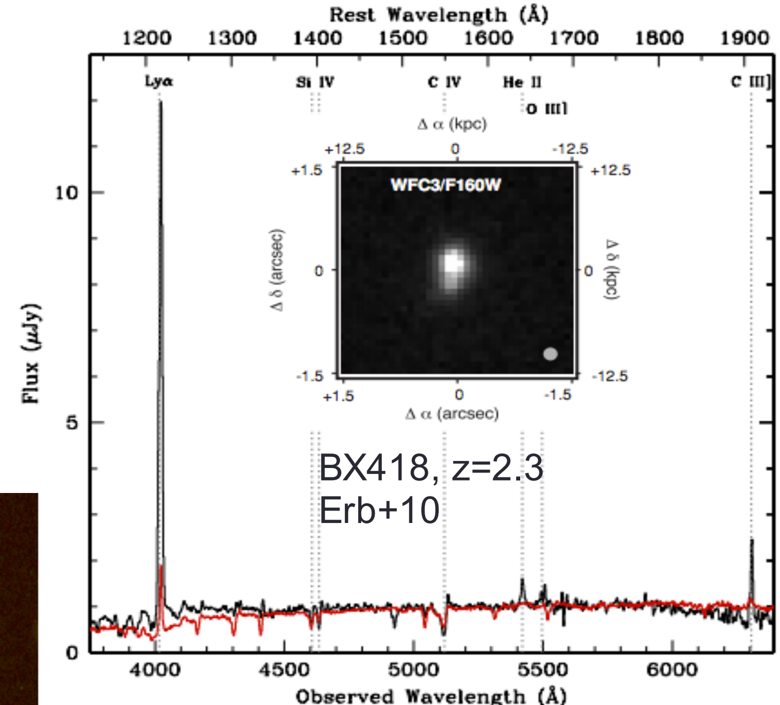
Shibuya+15

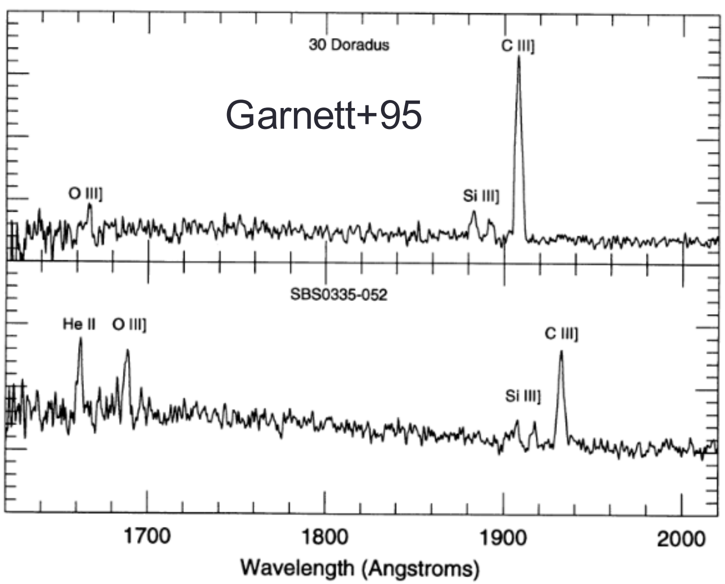
The UV spectra of low-mass galaxies ($M_*/M_\odot$<~$10^{9.5}$)

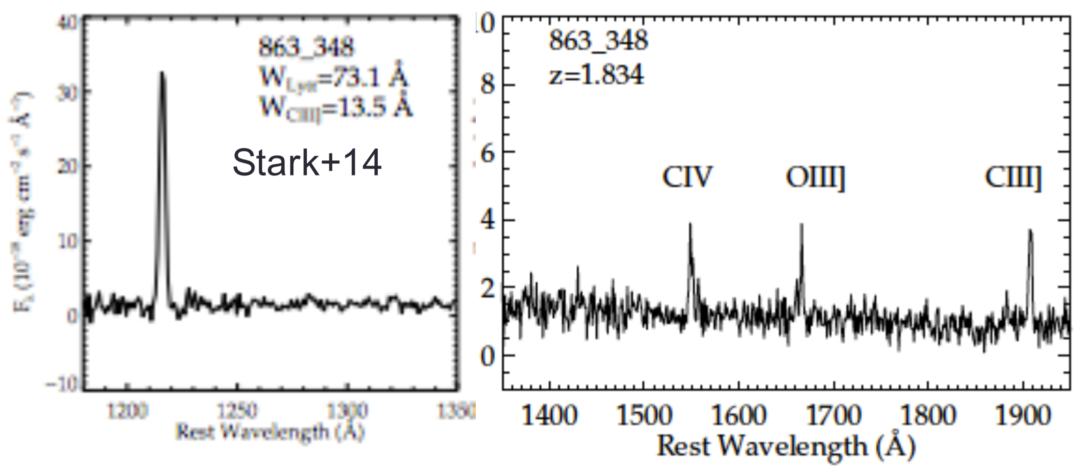
(Several talks in this conference)

Show faint absorption features and large EW nebular emission lines (e.g. CIII]1907,1909, OIII]1661,1666, HeII1640 and CIV1548,1550). rarely seen in more massive SFGs

Hard radiation fields
High ionization & low metallicity (<~20% solar) environments



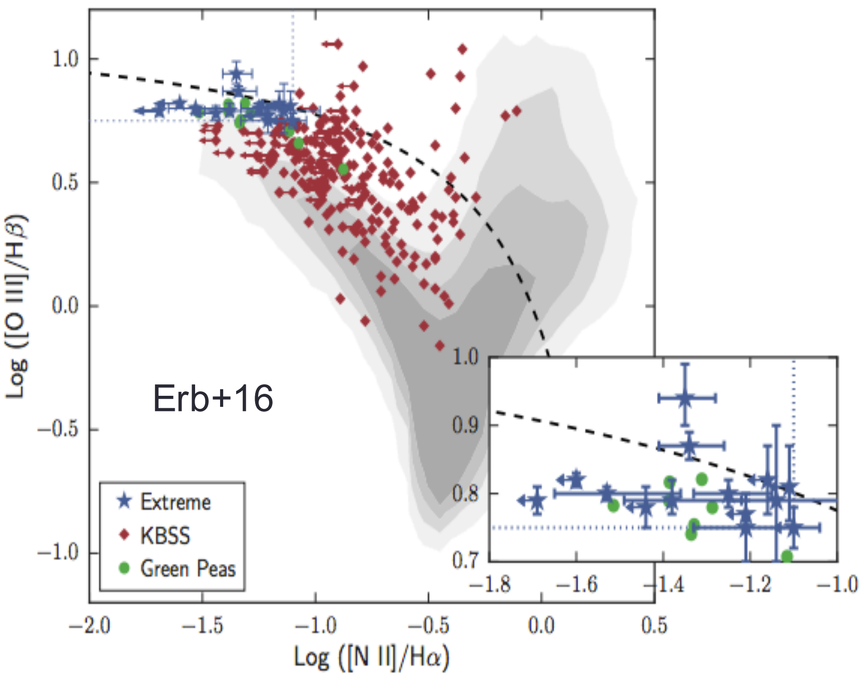


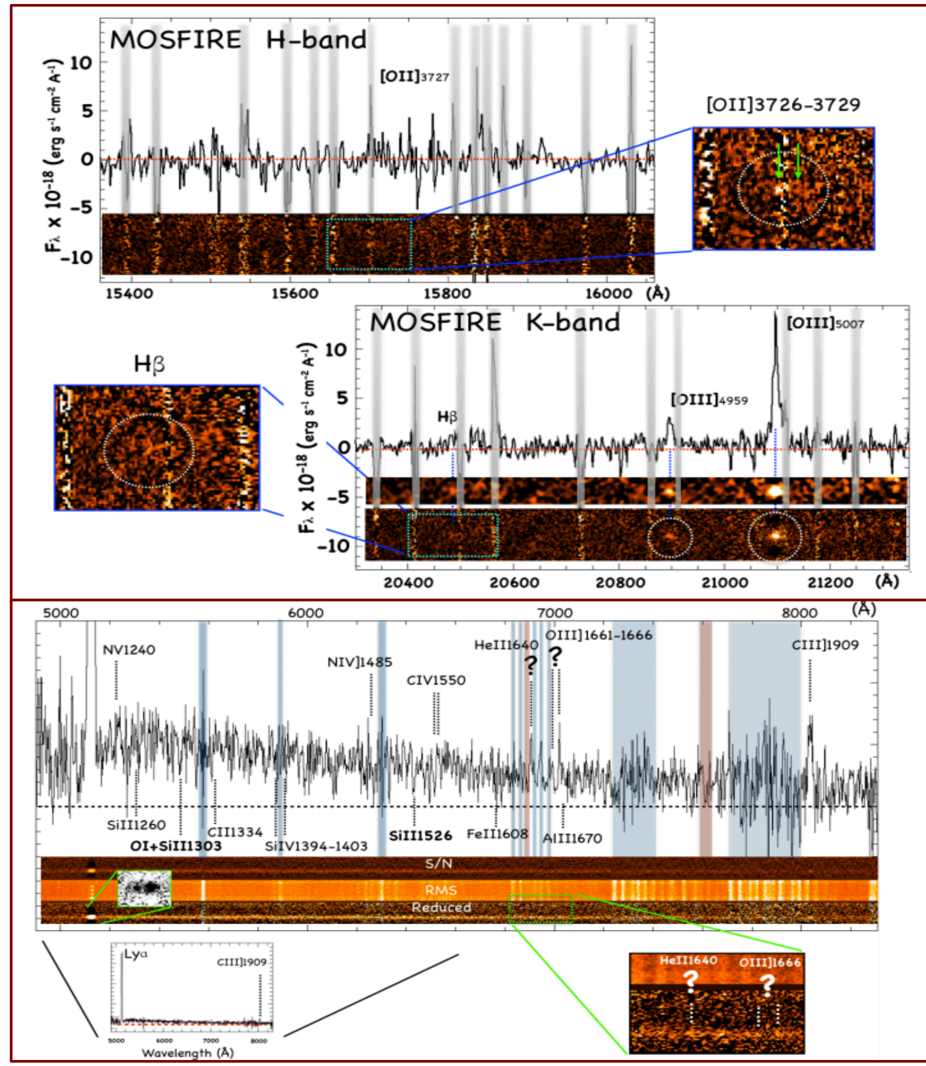


The UV spectra of low-mass galaxies ($M_*/M_\odot \sim 10^7$-$10^{9.5}$)

(Several talks in this conference)

Intimately linked to extreme rest optical emission line properties



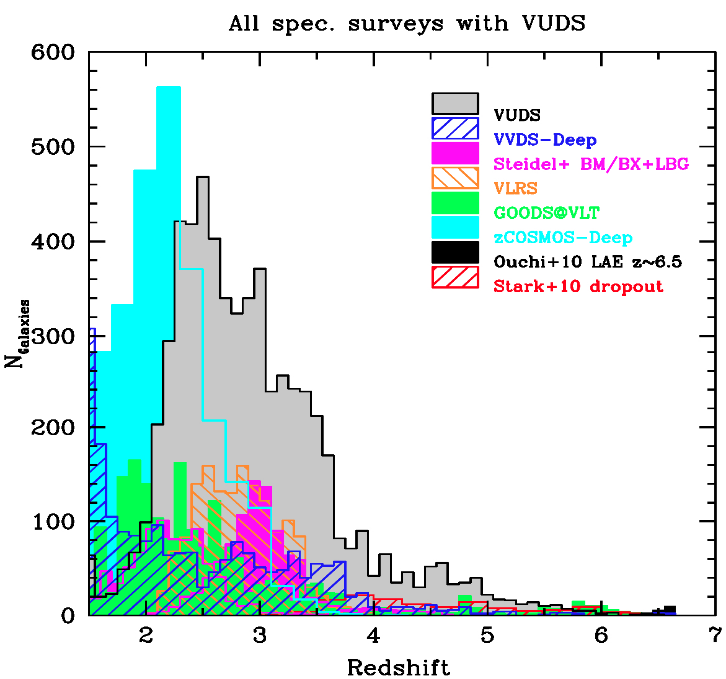


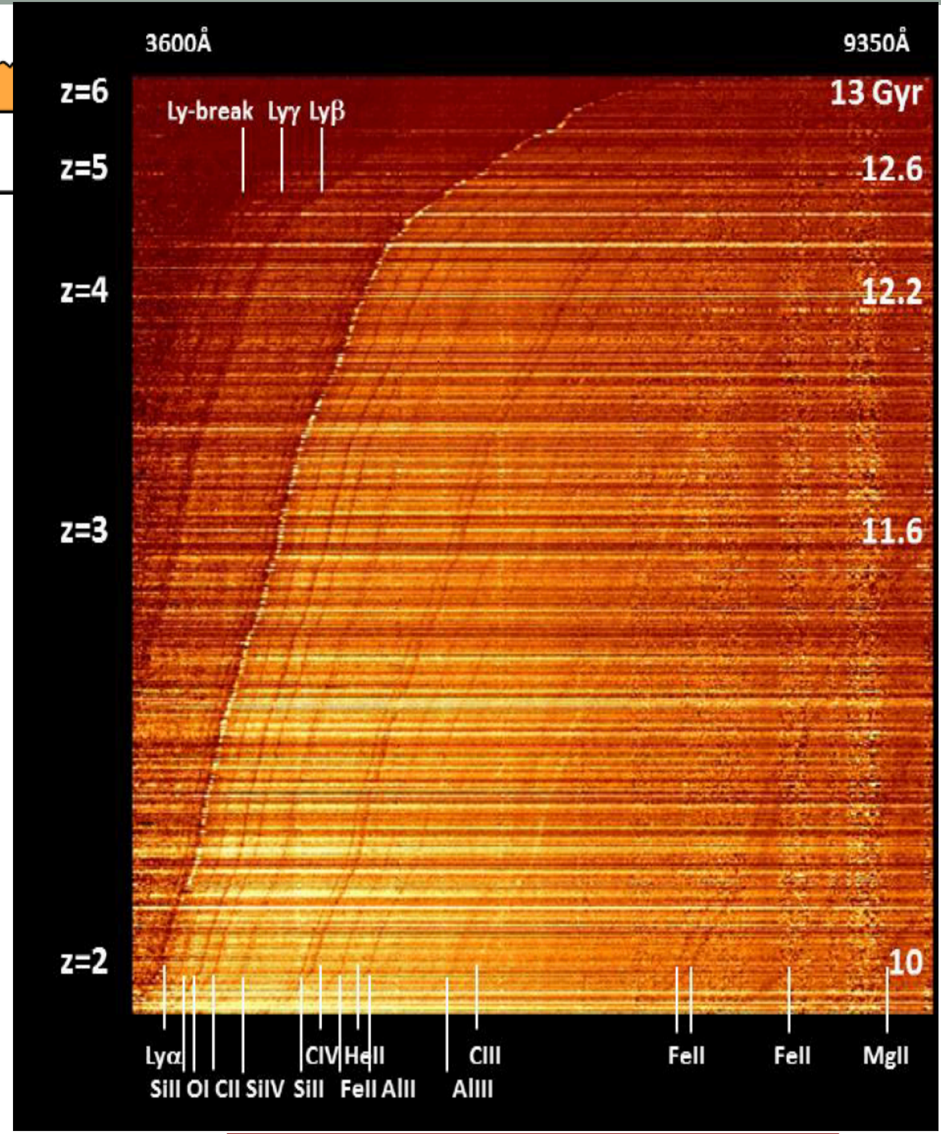
Ion2 @ z=3.2; De Barros+16;Vanzella+16

Difficult to draw conclusions based on single objects. We need larger samples Especially true at z>2

- Strong lensing
- Very deep surveys

- ESO Large Program: 640h
- Focused on 2<z<6
- 1 deg²
- 10,000 targets
- 3 fields: mitigate cosmic variance
- Selection: photo-z + SED + color, iAB≤25
- 14hr integration over 3600-9300Å (R~200)
- 8000 galaxies with 2<zspec<6.5





Le Fèvre+2015, A&A,576, 79
DR1 is publicly available
http://cesam.lam.fr/vuds/DR1/
Tasca+2016, A&A, submitted

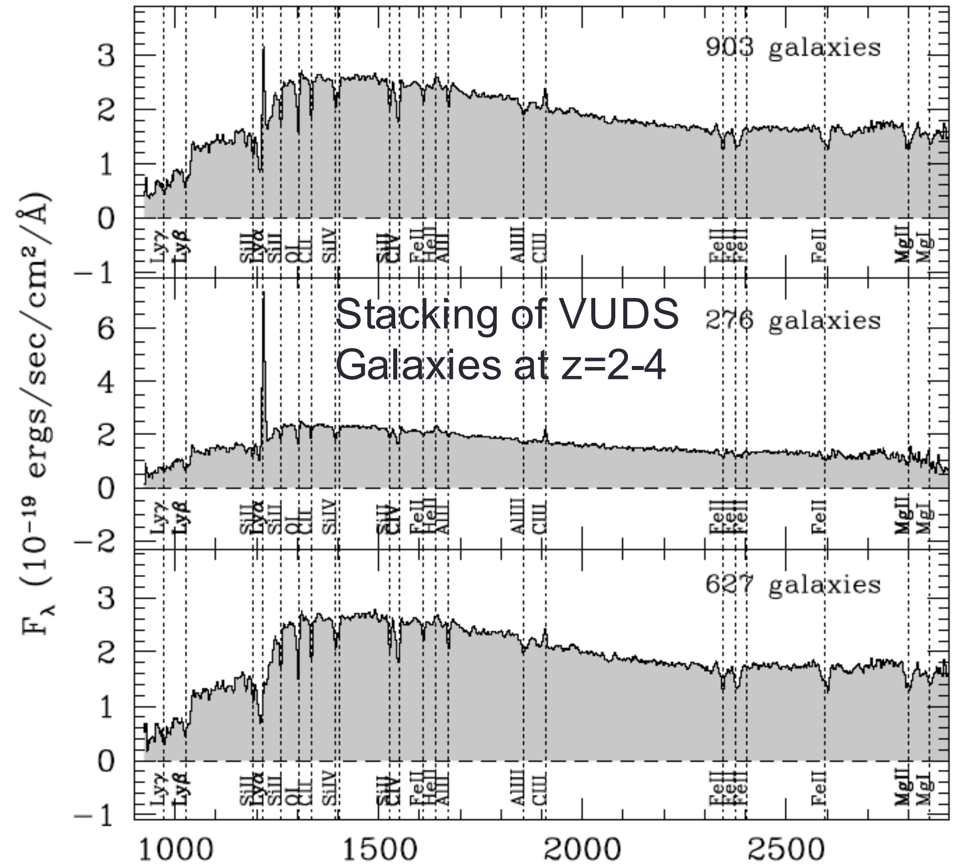
Sample selection

Parent sample

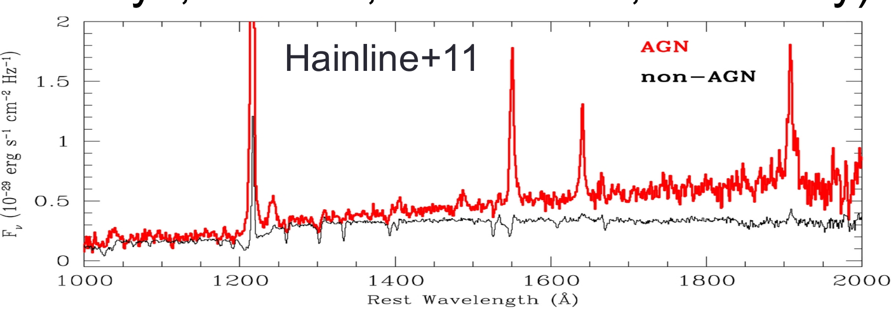
- ~2000 VUDS galaxies with very reliable redshifts (>95% c.l.) $2.4<z<3.5$ and i_{AB}~23-25 mag

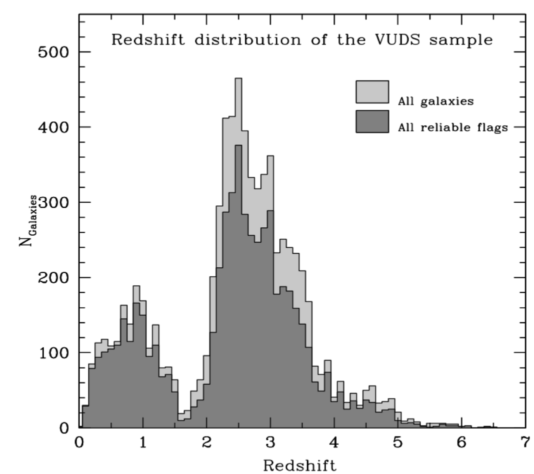
Sample of UV ELGs

- Only galaxies with Lyα in emission and detection of CIII]1909 and OIII]1666 (S/N≥3).
- Clear AGNs are excluded (from x-rays, IR SED, broad-lines, variability)



Le Fèvre+15

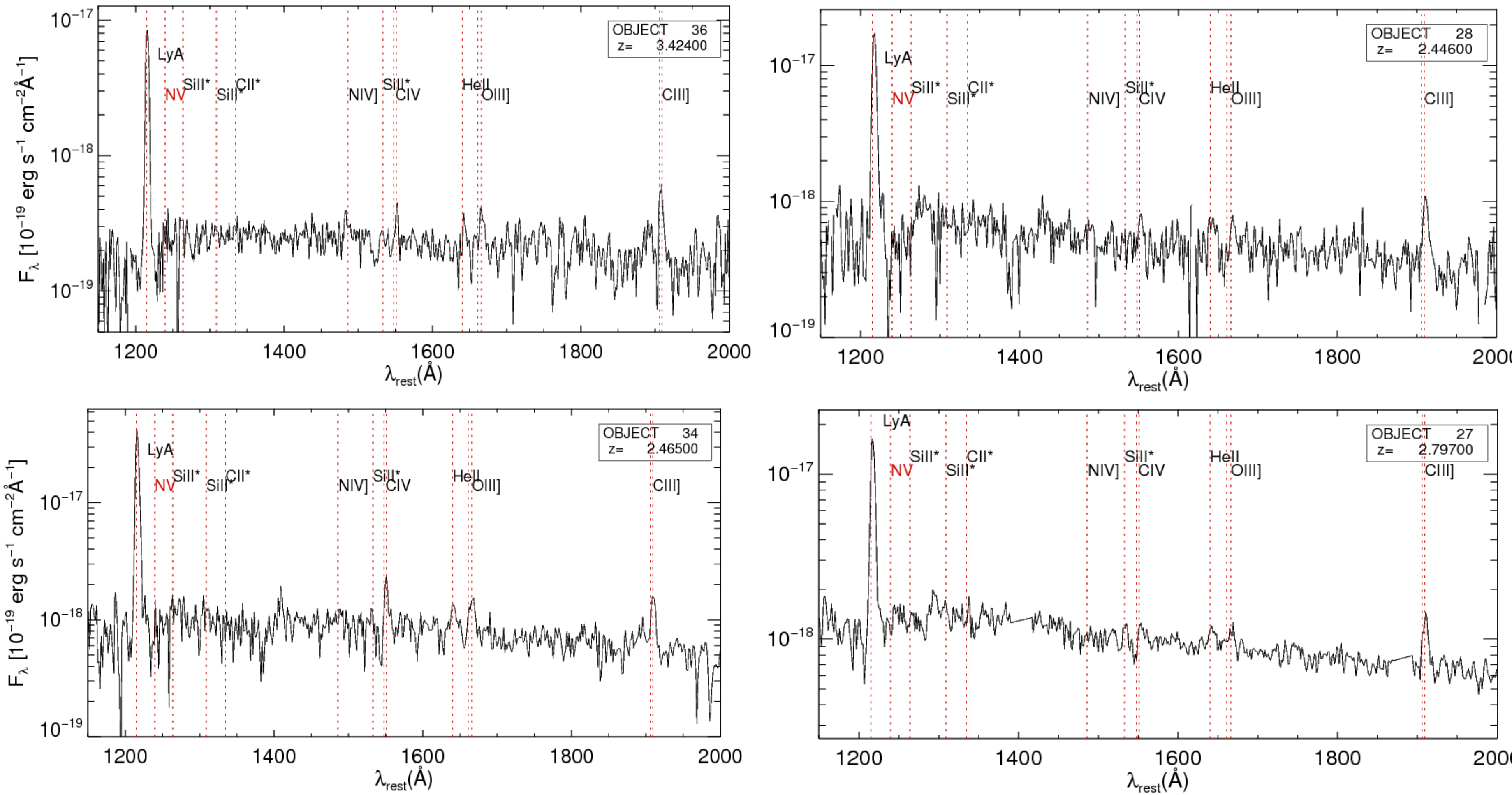




We find only 10 reliable C3O3 emitters in VUDS-COSMOS ($24<i_{AB}<25$)
→ very rare objects (~0.5%)

Results in the COSMOS field

Amorín et al., submitted (June 2016)



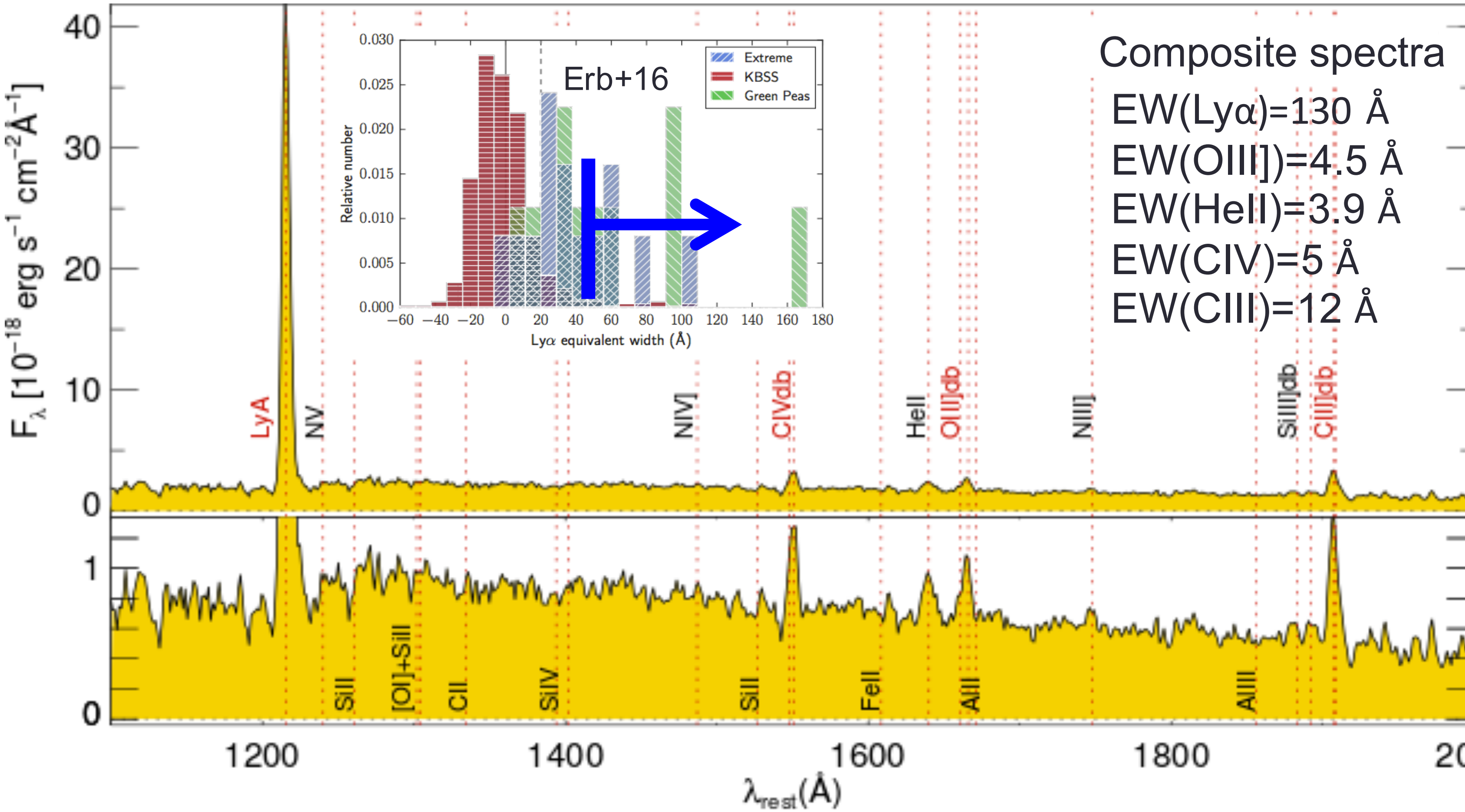
Blue continuum (median β=-2.3) + high Lyα EW_{rest} (from ~45Å to 260Å) + high ionization nebular lines (OIII], CIII]) + Wind lines (CIV, SiIII]) + HeII (in 6). Very faint absorption features.

Not typical for normal z~3 UV-selected galaxies (e.g. Shapley+03, Steidel+14)

Suggest low-metallicity, low-dust, young star-bursting dwarf galaxies e.g. Erb+10,Christensen+12,Stark+14,James+14,Steidel+14, Rigby+15, deBarros+16, Vanzella+16a,b, etc...

Results in the COSMOS field

Only 10 galaxies <z>=2.8 (24<i_{AB}<25)
Amorín et al., submitted (June 2016)



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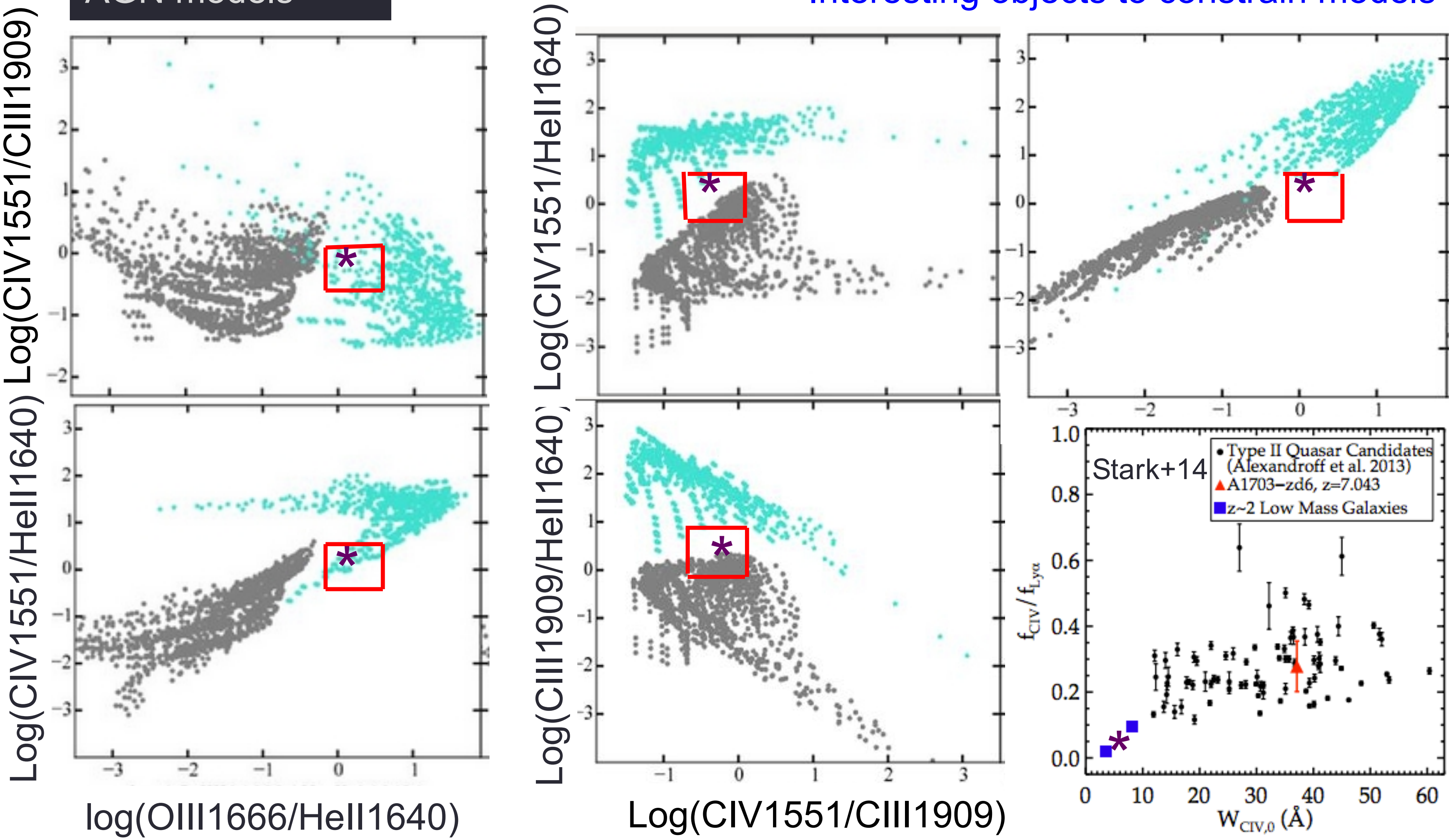
Erb+10,Christensen+12,Stark+14,James+14,Steidel+14, Rigby+15, deBarros+16, Vanzella+16a,b, etc...

Ionization diagnostics

Starburst models
AGN models

Feltre et al. (2016)

No clear evidence of AGNs
Interesting objects to constrain models



Model-based, Te-consistent abundances

We use *HII-CHI-MISTRY* (HCM).

A robust model-based script that estimates O/H, N/O, and now C/O consistent with the direct method over all ranges of metallicity, even in absence of an estimate of the T_e (e.g with O4363).

- Chi2-weighted scheme
- Model grids (O/H, N/O (C/O, and U) can be constrained empirically
- Photoionization models are state of the art

Publicly available, from 3MdB (Morriset 2013) using CLOUDY (Ferland+13) and POPSTAR SEDs (Molla+10).

Upgraded version can use: O3727, O4363, O5007, Hb, NII, SII, LyA, CIV, CIII, OIII1666

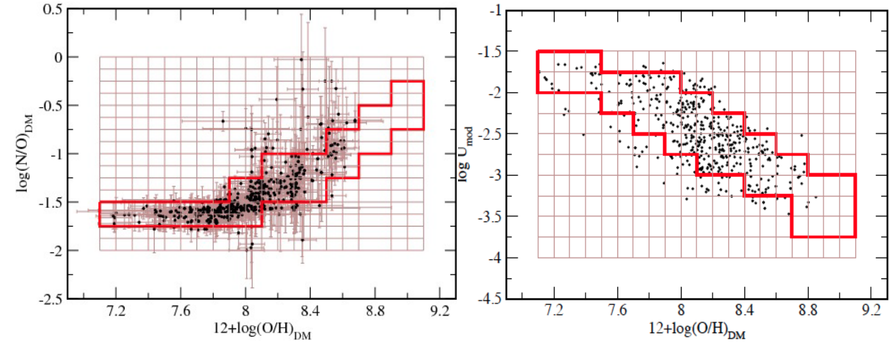
INPUT: UV LINE RATIOS

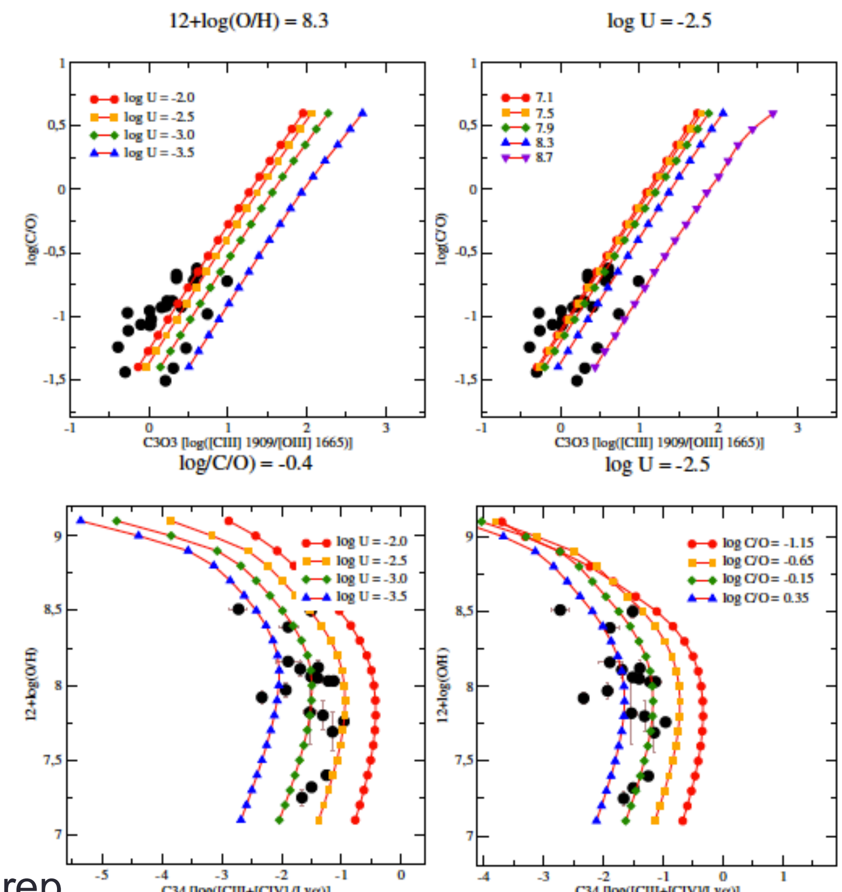
C34 = (CIII+CIV)/Lya)
C3O3 = CIII]1908/OIII]1666
C3C4 = CIII]1908/CIV1551
RO3 = [OIII]5007/OIII]1666

OUTPUT

C/O
O/H
logU

Perez-Montero (2014)

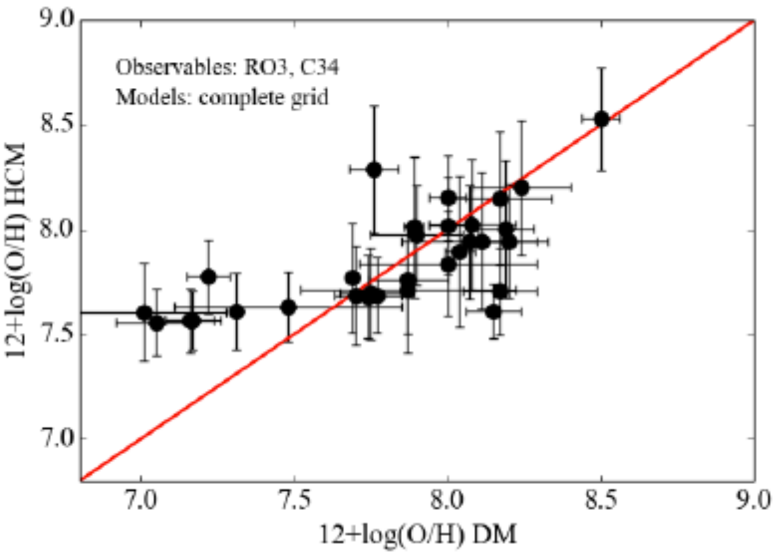


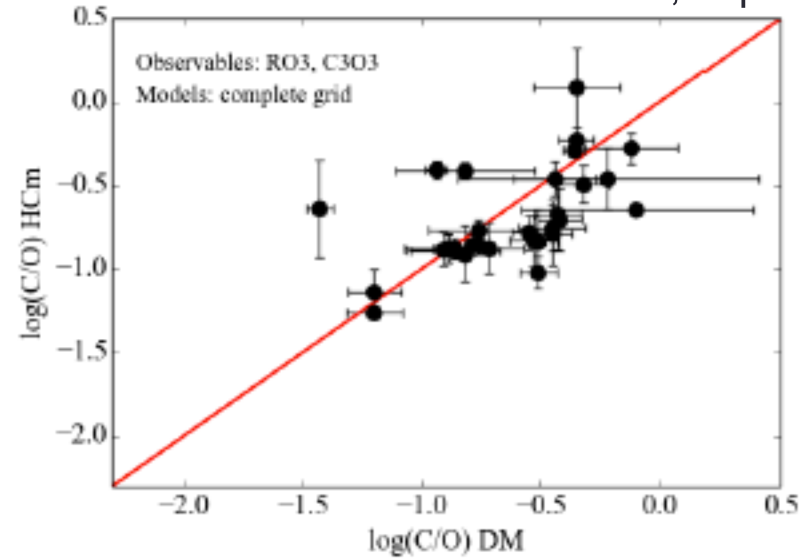


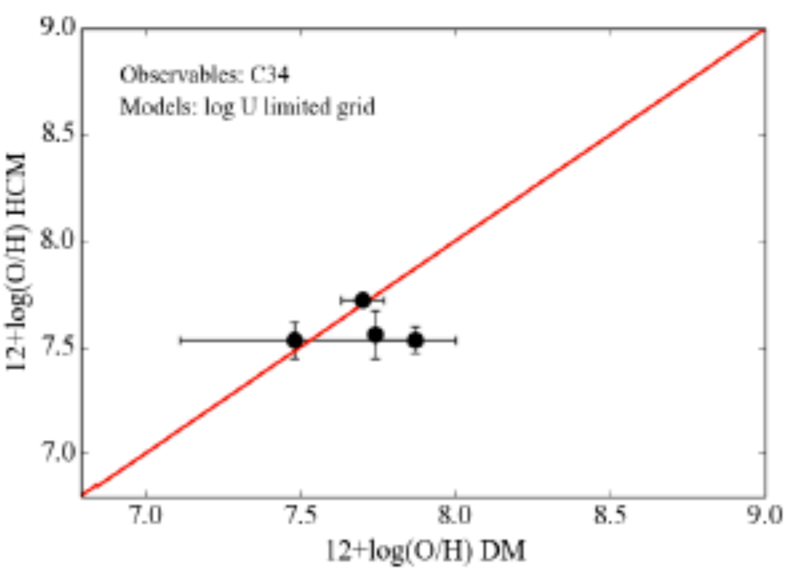
Pérez-Montero & Amorín, in prep.

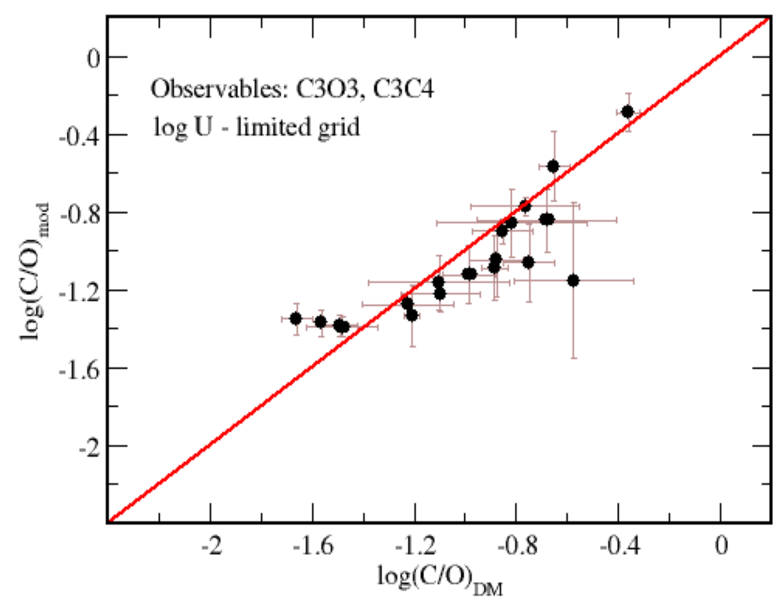
UV metallicity indicators for high-z SFGs: testing local analogs

Pérez-Montero & Amorín, in prep.









Carbon and oxygen gas-phase abundances of UV-EELGs

Amorín et al., submitted

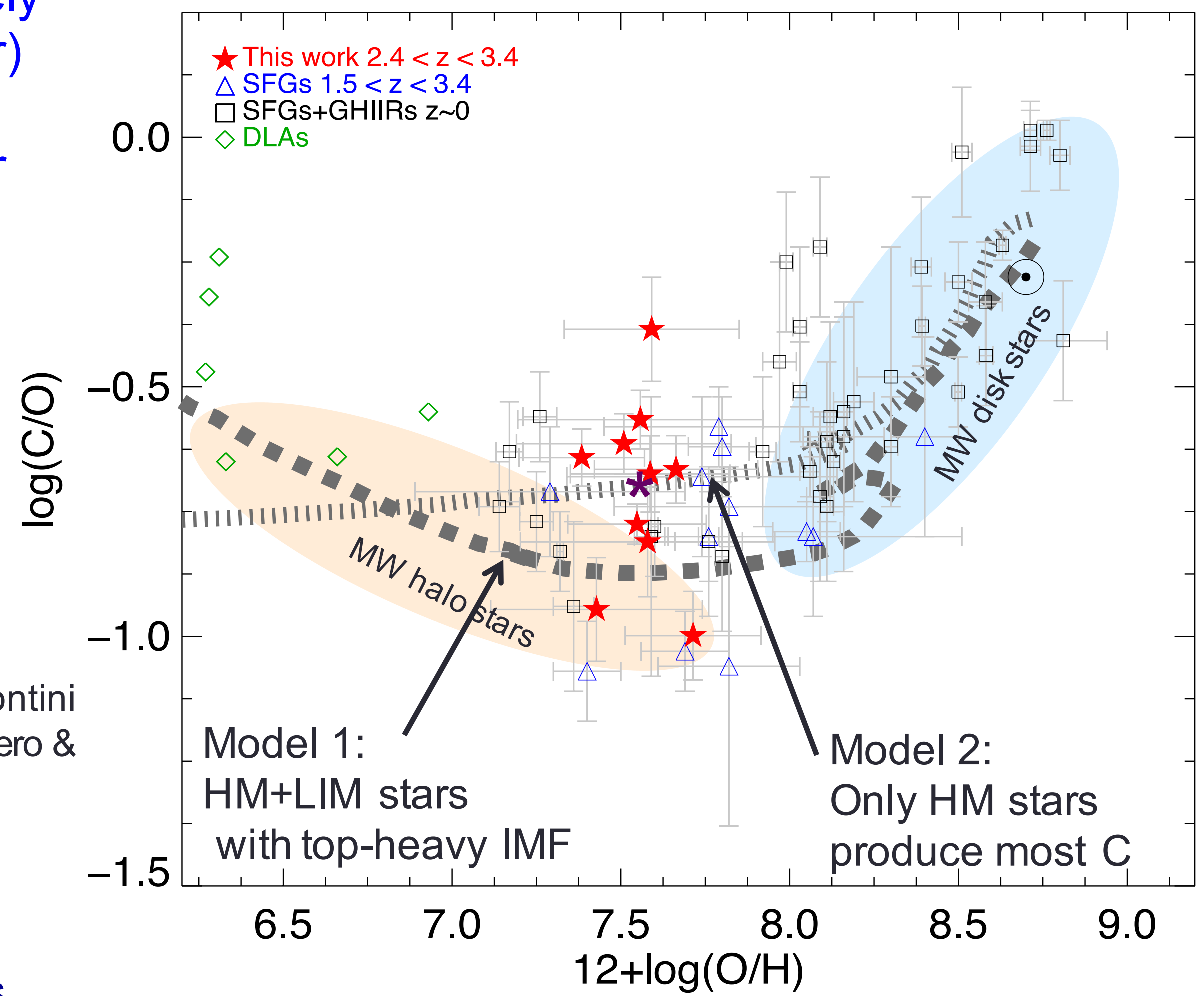
- Our 10 galaxies are extremely metal-poor (Z_{gas}~5%-10% solar)
- Carbon is strongly sub-solar
- Median ionization parameter U=-2.0

Below 0.2 $Z_\odot$ C/O is essentially produced by massive O-stars

Above 0.2 $Z_\odot$ intermediate and low mass stars produce more C than O, increasing C/O

Similar behavior in C/O and N/O
e.g. Garnett+95,99; Pérez-Montero & Contini 2009; Steidel+16, Berg+16, Pérez-Montero & Amorín in prep.)

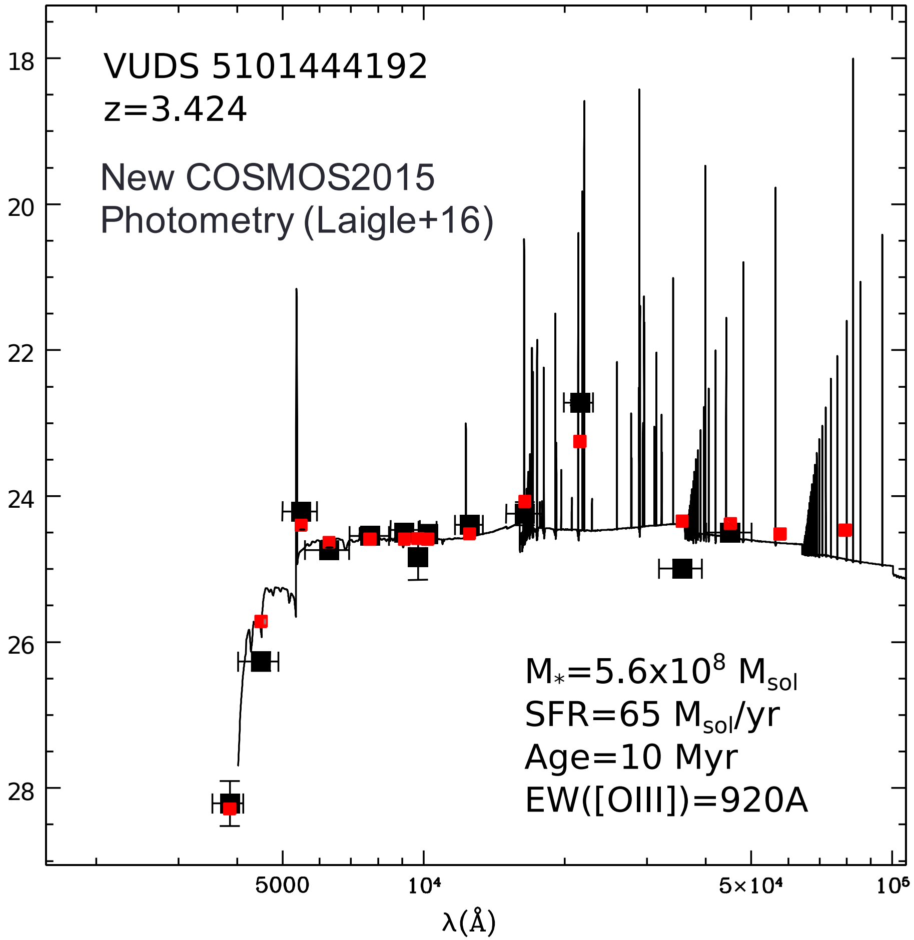
Our results suggest rapid chemical enrichment and the presence of hot, massive stars. Possible non-standard IMF?

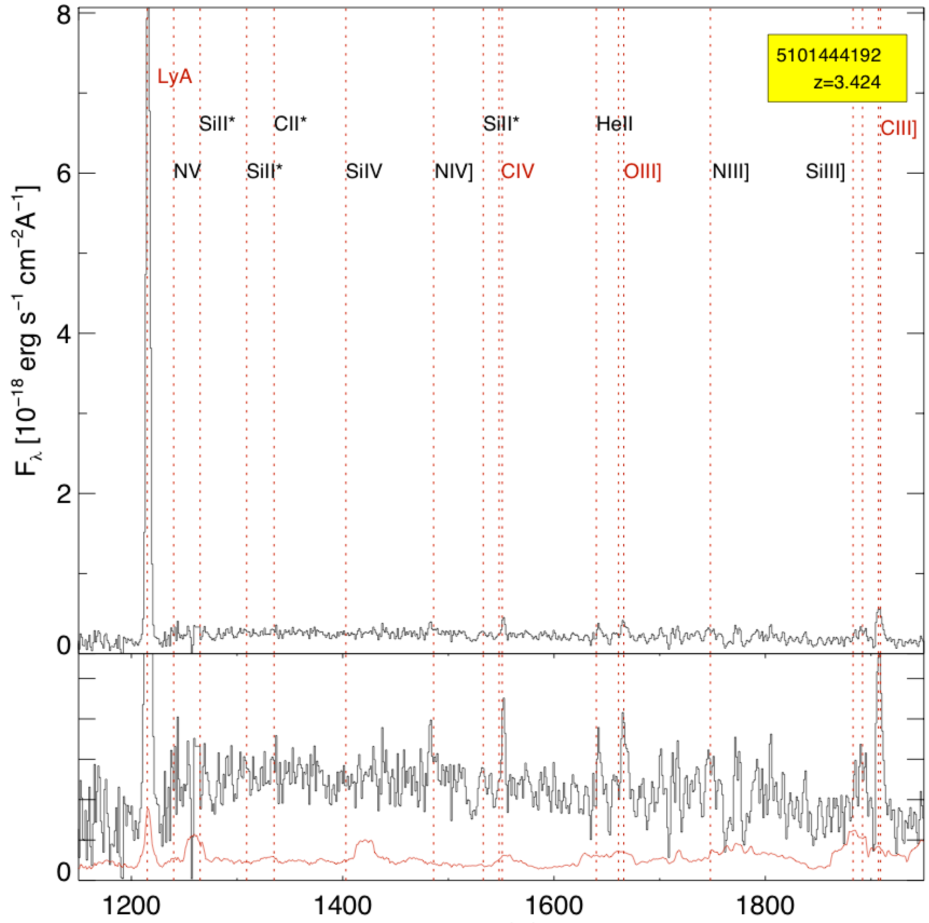


(also Danielle Berg's talk)

Their UV to MIR SED properties

Amorín et al., submitted





Low stellar mass (10^8-$10^{9.5}$ $M_\odot$)
Young ages and high SFR (~10-300Myr; ~10-60 $M_\odot$/yr).
Blue continuum (β~-1.6 to -2.6) (Castellano+14 IRX)
low dust extinction E(B-V)<0.15

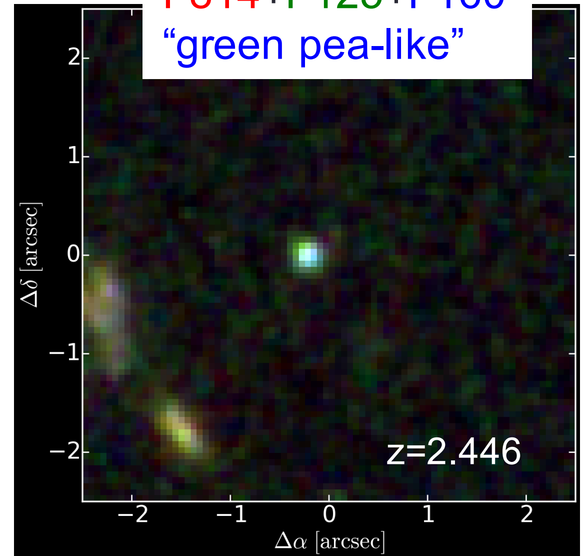
High sSFR imply short median doubling time (~30 Myr)

…and HST Morphology

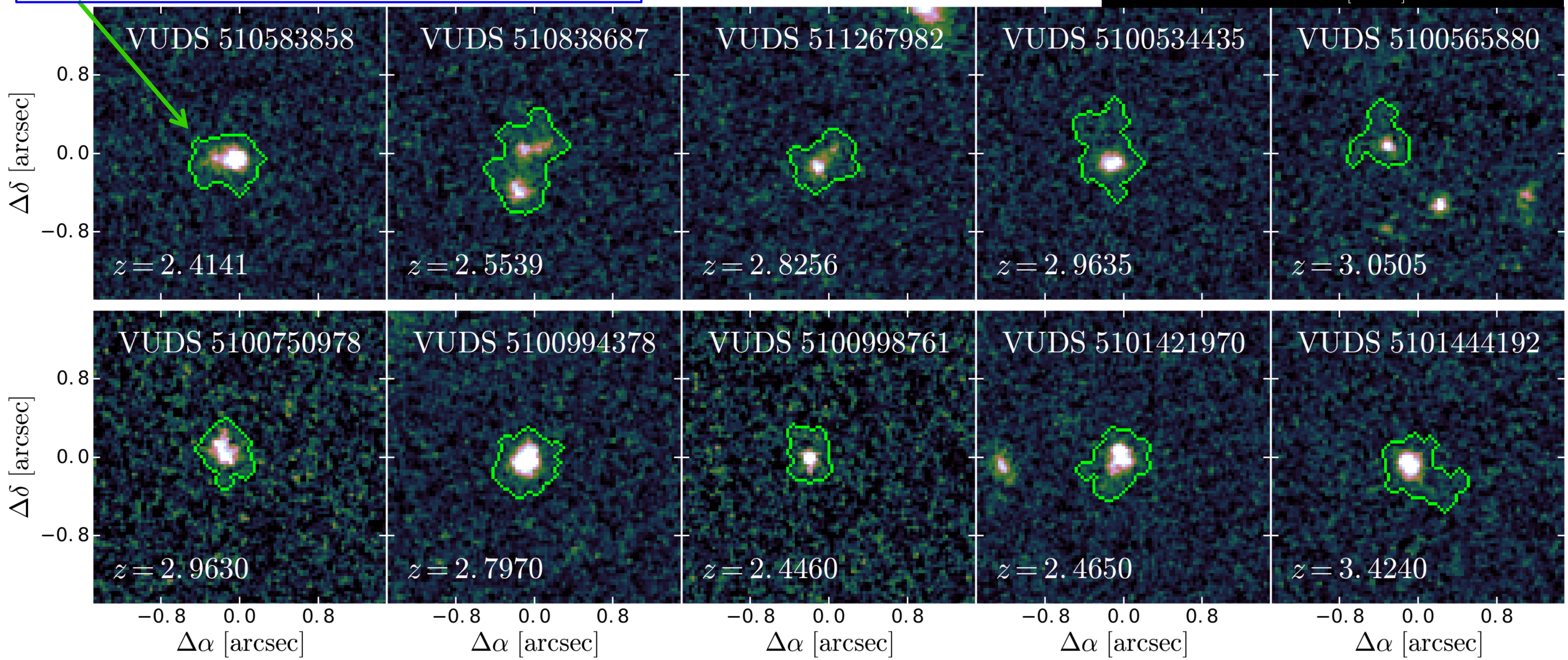
ACS F814W mosaics (0.03”/pixel)

Morphological diversity:
tadpoles, pairs and single compact SF clumps of few hundred parscs in size

See Ribeiro+16 for technical details



Median $R_{50}(GALFIT)$ ~ 0.5 kpc
R_{100}< 2kpc (small forming disks?)



Compact starbursts. High surface densities

ACS F814W mosaics (0.03"/pixel)

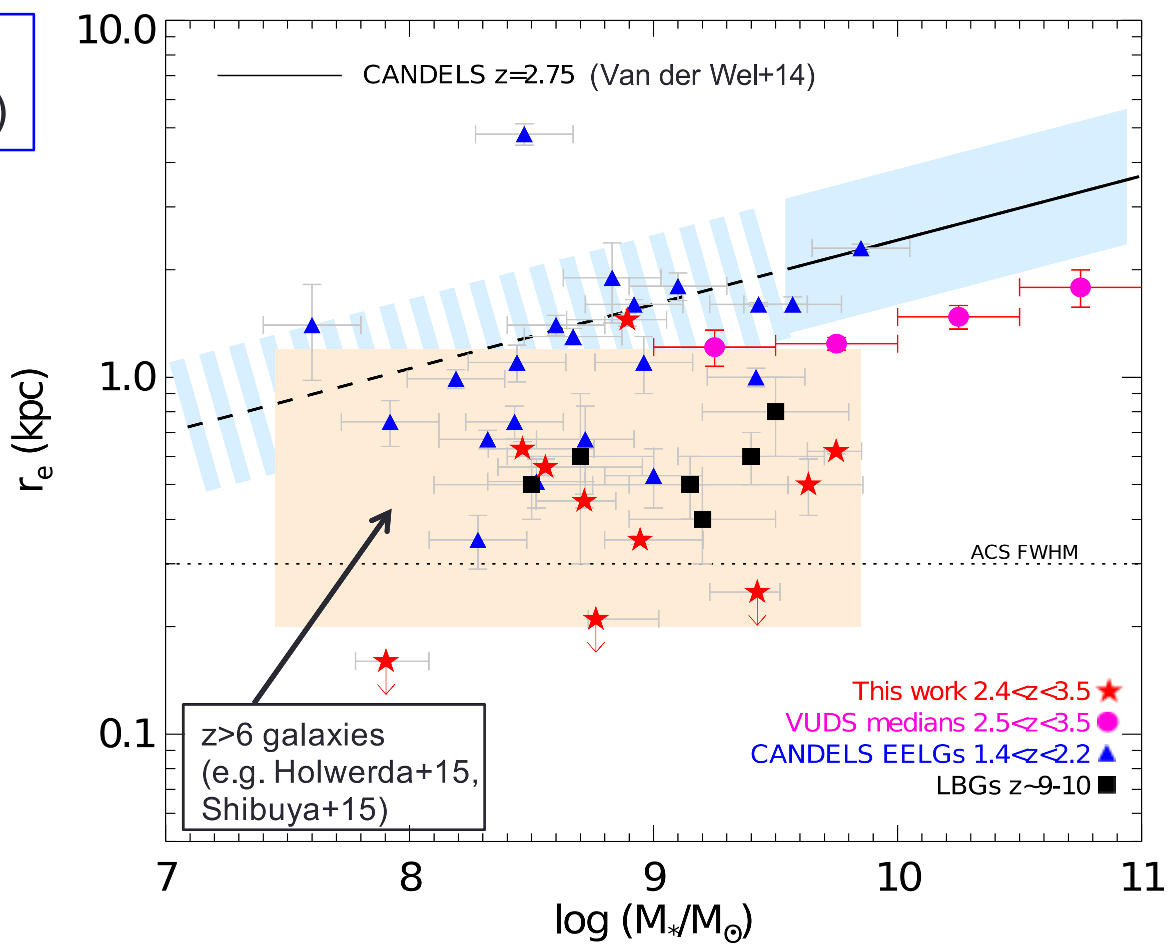
Morphological diversity:
tadpoles, pairs and single compact SF clumps of few hundred parscs in size

See Ribeiro+16 for technical details

Median $R_{50}(GALFIT)$ ~ 0.5 kpc
R_{100}< 2kpc (small forming disks?)

- Below the M* vs size relation
- Smaller sizes than the parent sample
- Imply very high surface densities in SFR and gas
- They fall in the locus of primeval galaxies at z>6

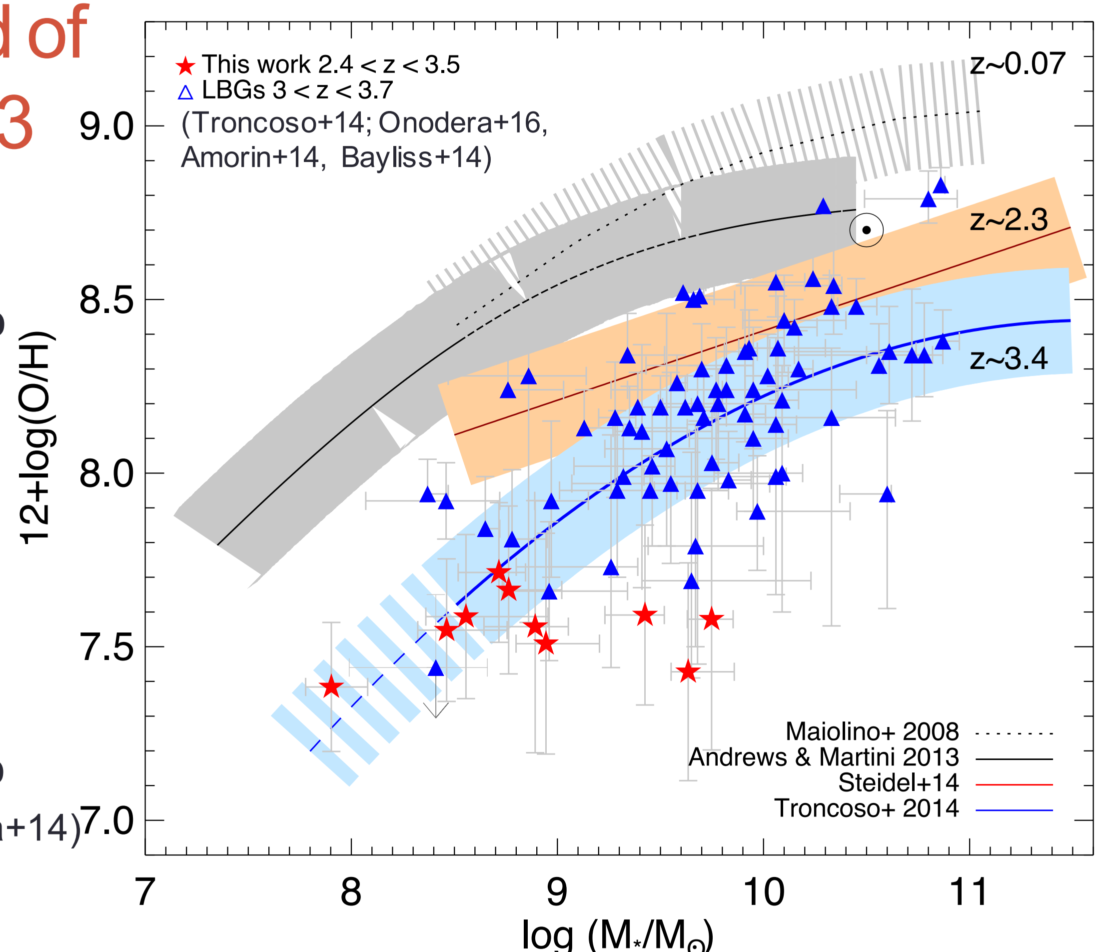
Amorín et al., submitted



Probing the low-mass end of key scaling relations at z~3

Quite unexplored at z~3.
Very high sSFR and/or gas fraction to explain our results (e.g. Troncoso+14)

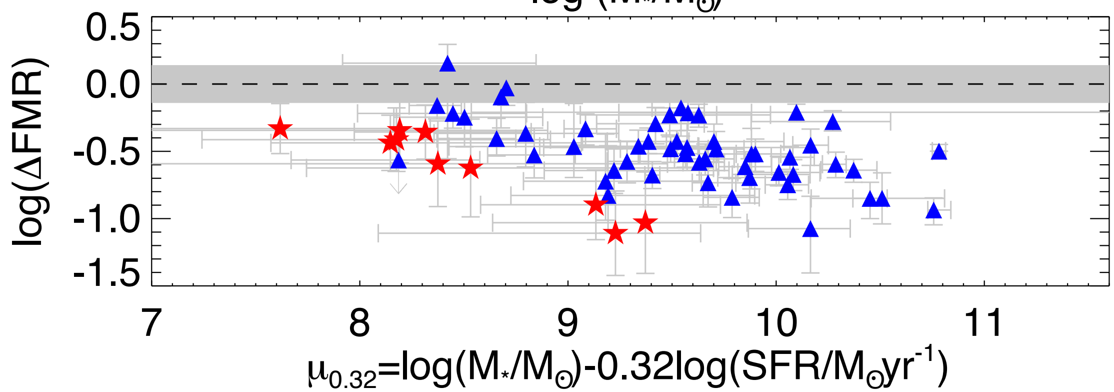
Offset from the FMR by a factor ≥ 2
Likely witnessing a transient phase of few tens of Myr



This is quite common in EELGs, also at low redshift (e.g. Amorin+10,14, Maseda+14)

Effects of recent metal-poor gas accretion? Outflows?
(e.g. Sanchez Almeida+15, Ceverino+16)
Mergers? (e.g. Bekki+08, Starkenburg+16)

Both ? *(Dekel's talk)*



Summary & Conclusions

Young star-forming dwarf galaxies at z~3 selected by UV nebular lines in VUDS have mean properties closely resemble those observed/expected in primeval galaxies at z>6:

+ High EW nebular lines, OIII], CIV, CIII] and also Lya and HeII. Faint absorptions and blue cont.
+ Hard radiation fields. Presence of very massive stars; strong outflows ?
+ Very low O/H and C/O abundances, high ionization.
+ Low masses, high SSFR and young ages. High rest optical EWs (like “green peas”)
+ Small sizes and extreme compactness. SF clumps of few hundreds of pc

✓ Witnessing a short (few Myr), vigorous phase of assembly and chemical enrichment. Recent accretion of metal-poor gas ? Outflows? Mergers?

- They appear to be very rare (~0.5% in VUDS)

Related to short timescales involved? Selection bias? Ubiquitous at lower masses at z>~3?

- Good candidates for LyC leakage (e.g. de Barros+16; Vanzella+16a) .
- Good targets to constrain models
- Best analogs of primeval galaxies → Promising science for JWST

Next steps:

✓ Additional candidates in the other two VUDS fields (ECDF-S and VVDS-02h)

✓ Need higher S/N and higher resolution data to make progress in the UV → VANDELS

✓ Need NIR spectra to make progress in ISM physical properties and abundances

Stay Tuned !!

THANK YOU FOR YOUR ATTENTION