Young low-mass galaxies at z~3 in the Vimos Ultra Deep Survey

Ricardo Amorín (INAF-Roma)

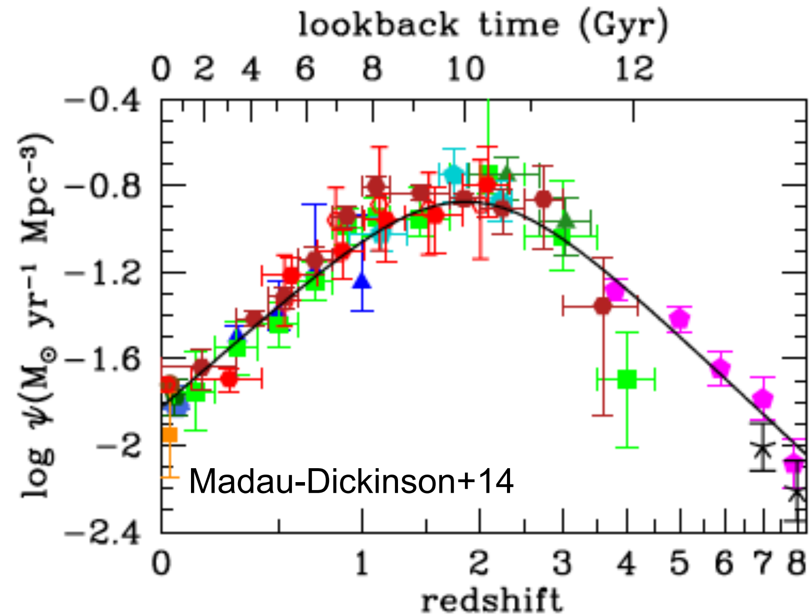
Fontana, E. Pérez-Montero, D. Schaerer, B. Ribeiro, M. Castellano, B. Lemaux, A. Grazian, R. Thomas + VUDS Collaboration

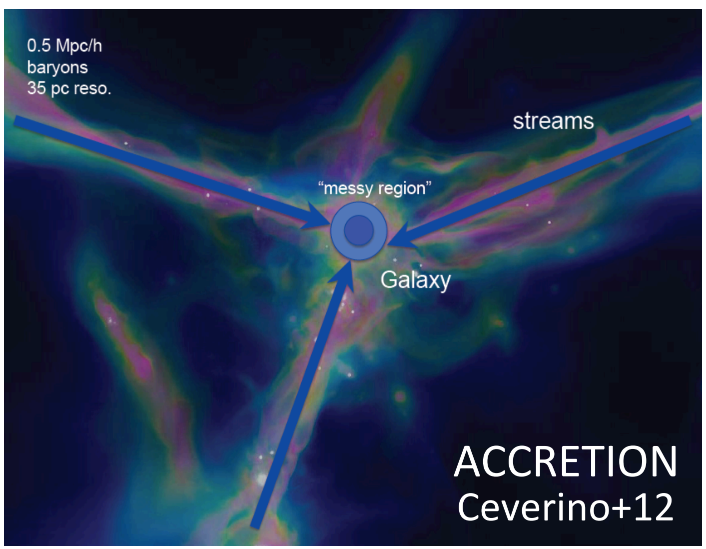
The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312725

How and when do galaxies assemble ?

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

Mechanisms driven and regulating galaxy growth: accretion, mergers, feedback…





Gas streams fueling SF with metal-poor gas

LOW-MASS, GAS-RICH GALAXIES ARE KEY OBJECTS TO PROBE FIRST STAGES OF GALAXY BUILD-UP…

… how massive star formation triggers and propagates in metal-poor environments ?
… how feedback and chemical evolution proceeds in young, small galaxies ?

We need observational constraints: SFHs, chemical abundances, kinematics, structure, environment…Extremely challenging for such faint systems… Strong observational and methodological limitations even at relatively low-z

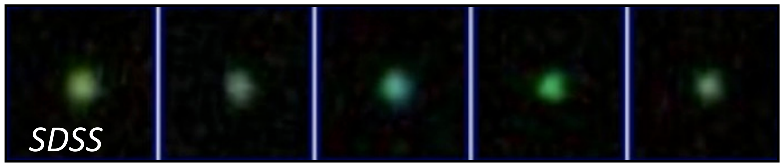
Low-mass emission line galaxies are still not fully characterized towards the peak of the cosmic SFRD: first *detailed spectroscopic studies* targeting z≥1 galaxies with low assembled stellar masses (10^7- 10^9 $M_\odot$) have only started in the last few years (e.g. van der Wel+11, Maseda+14, Steidel+14, Stark+14)

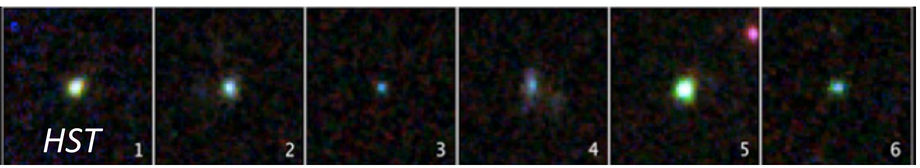
↓

Wide field, deep MOS surveys in the optical + NIR are essential

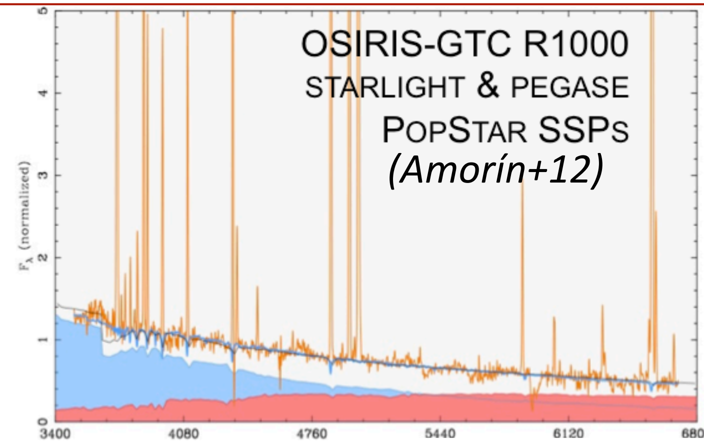
YOUNG GALAXIES ARE RARE AT Z~0, BUT NUMBER DENSITIES INCREASE RAPIDLY TOWARDS Z~1-2

Green peas @ z=0.1-0.3; (*Cardamone+09, Amorín+10,12a,b*)



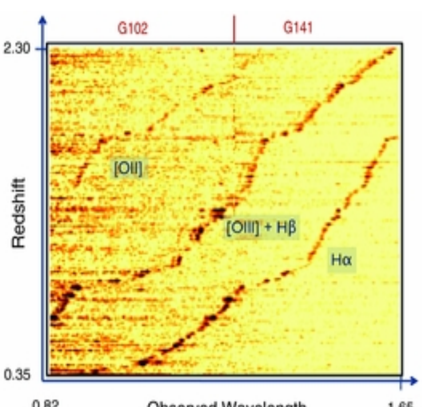


High EWs (~200-2000 A), high sSFR, low-metallicity, compactness, high ionization and large Lyman escape fraction, turbulent ISM…

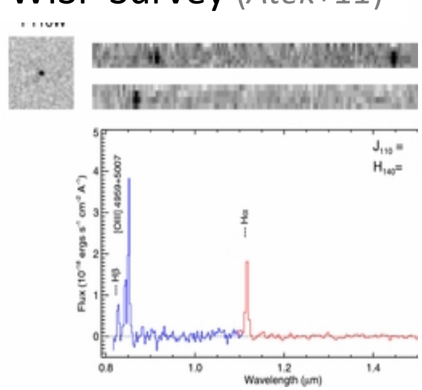


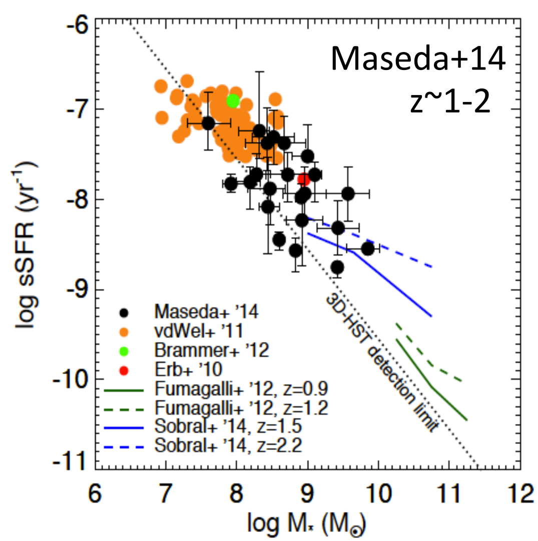
Low-mass starbursts at z=1.8 in CANDELS GOODS-N (*van der Wel+11, Maseda+14*)

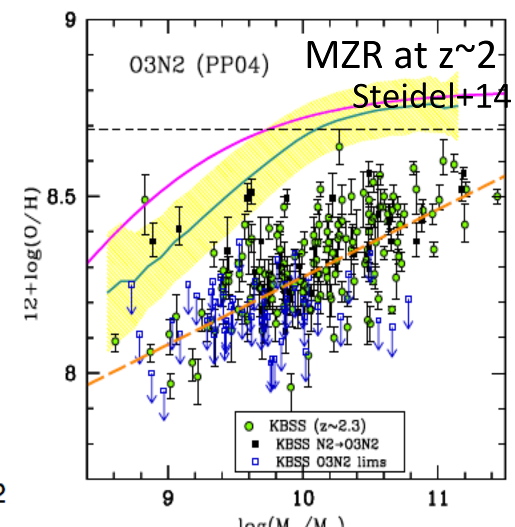
HST spectroscopy provides the largest samples (e.g. *van der Wel+11, Atek+14*)



WISP Survey (*Atek+11*)

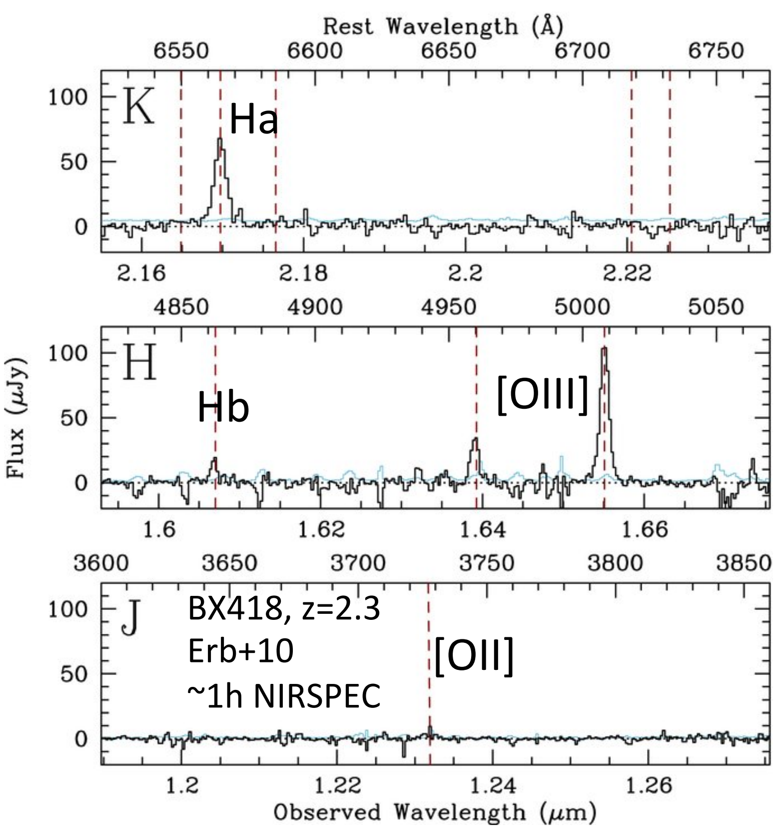


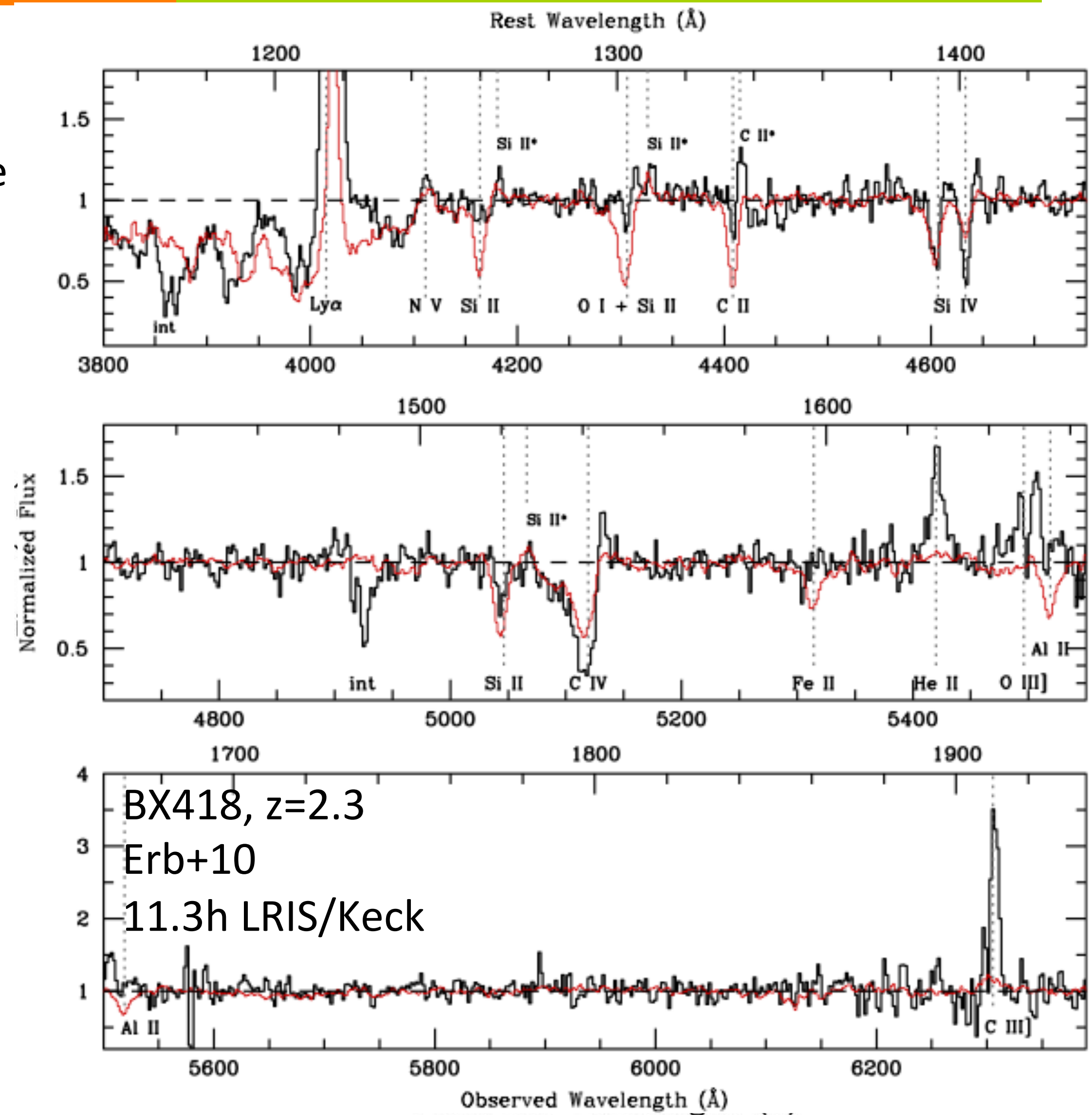




THE REST-UV SPECTRA OF A YOUNG, 10^9 M_{SUN} METAL-POOR STAR-FORMING GALAXY AT Z≈2

The rest-frame UV spectra show large EW nebular emission lines which are rarely seen in spectra of more massive SFGs (e.g. CIII]1907,09; OIII] 1661,66; HeII 1640 and CIV 1548,50).

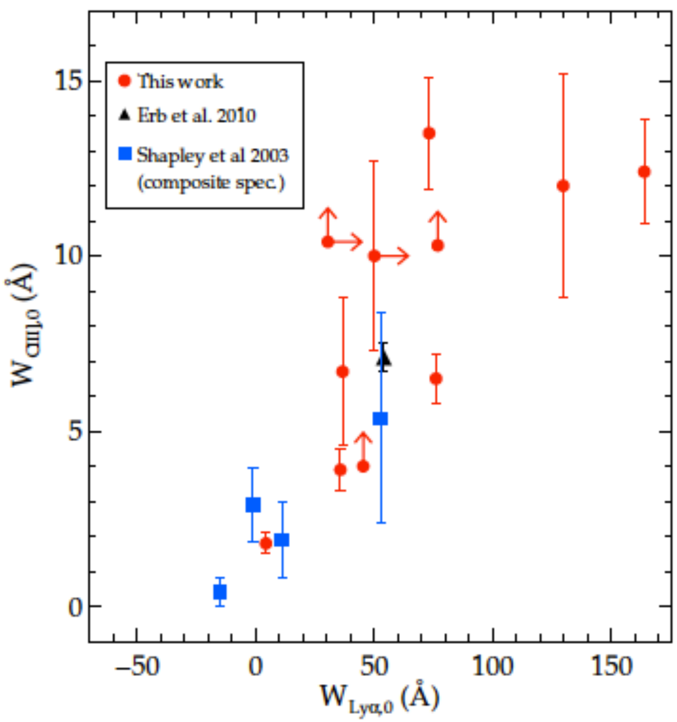


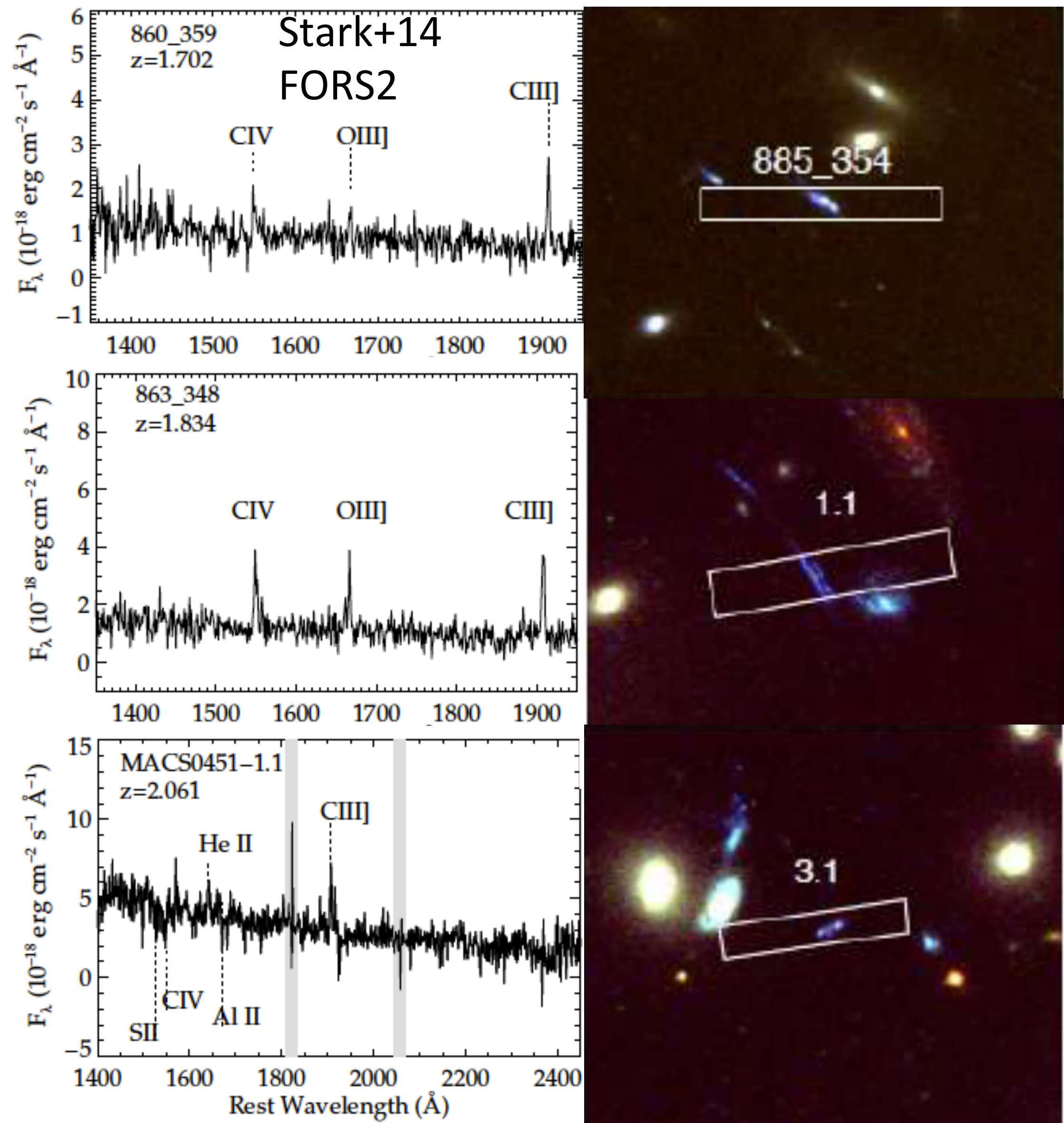


The rest-frame UV spectra of young ELGs at z≈2

The rest-frame UV spectra show large EW nebular emission lines which are rarely seen in spectra of more massive SFGs (e.g. CIII]1907,1909, OIII] 1661, 1666, HeII 1640 and CIV 1548,1550).

Stark+14 studied lensed EELGs and found CIII] proportional to Lya



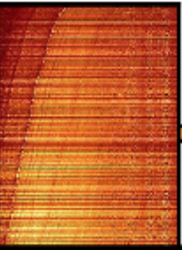


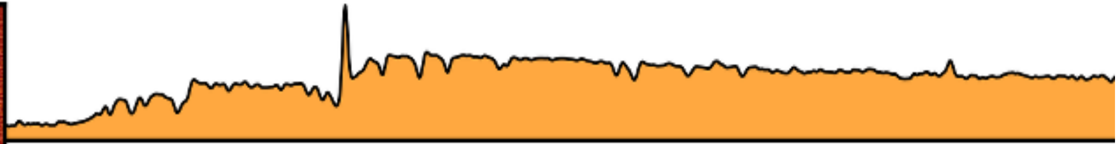
Studying young, low-mass galaxies at z>2: Goals…

- Identify and characterize strong UV line emitters out to z=4
- Study SED properties using stellar + nebular models
- Use line ratios to derive ionization, and T_e-consistent C/O and O/H through photoionization models.
- Study ionization and C and O abundances as a function of mass and SFHs, in the context of chemical evolution and mass assembling

↓

Identify extremely young, low-metallicity galaxies at z ~ 3
Discuss early stages of assembly and chemical evolution of galaxies



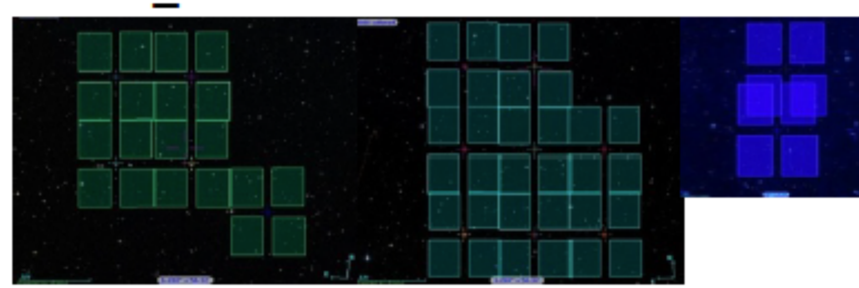


VUDS | VIMOS Ultra Deep Survey

- 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
- 8000 galaxies with 2<zspec<6.5

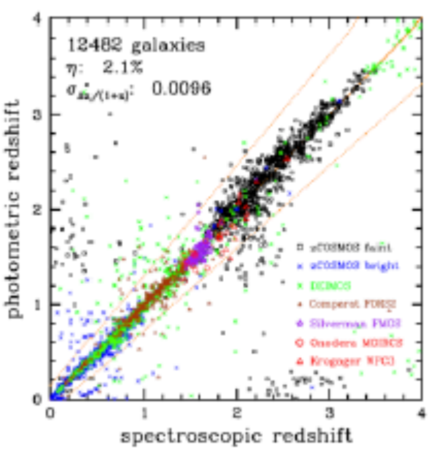
See details in:
Le Fevre+2015, A&A,576, 79

VVDS_02 COSMOS ECDFS

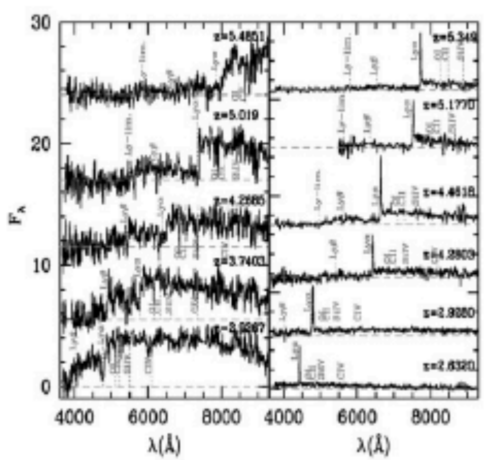


First Data Release already available
http://cesam.lam.fr/vuds/DR1/

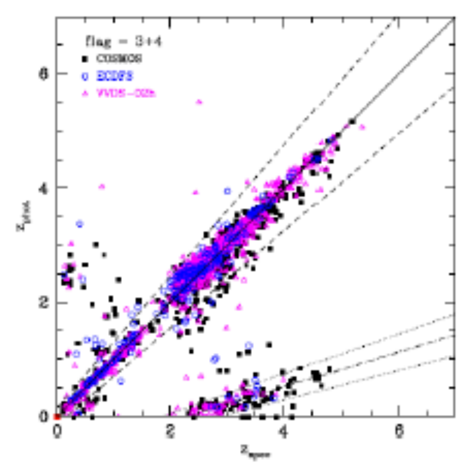
Selection



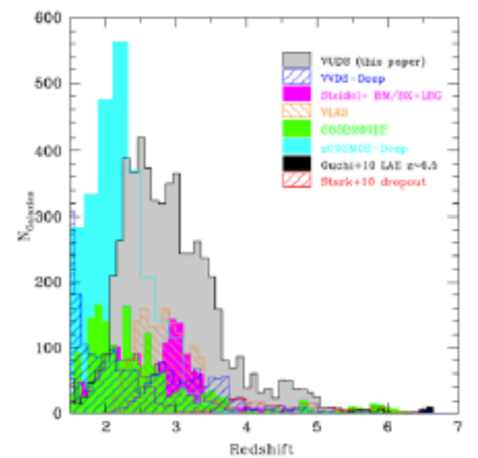
Spectra



zphot – zspec



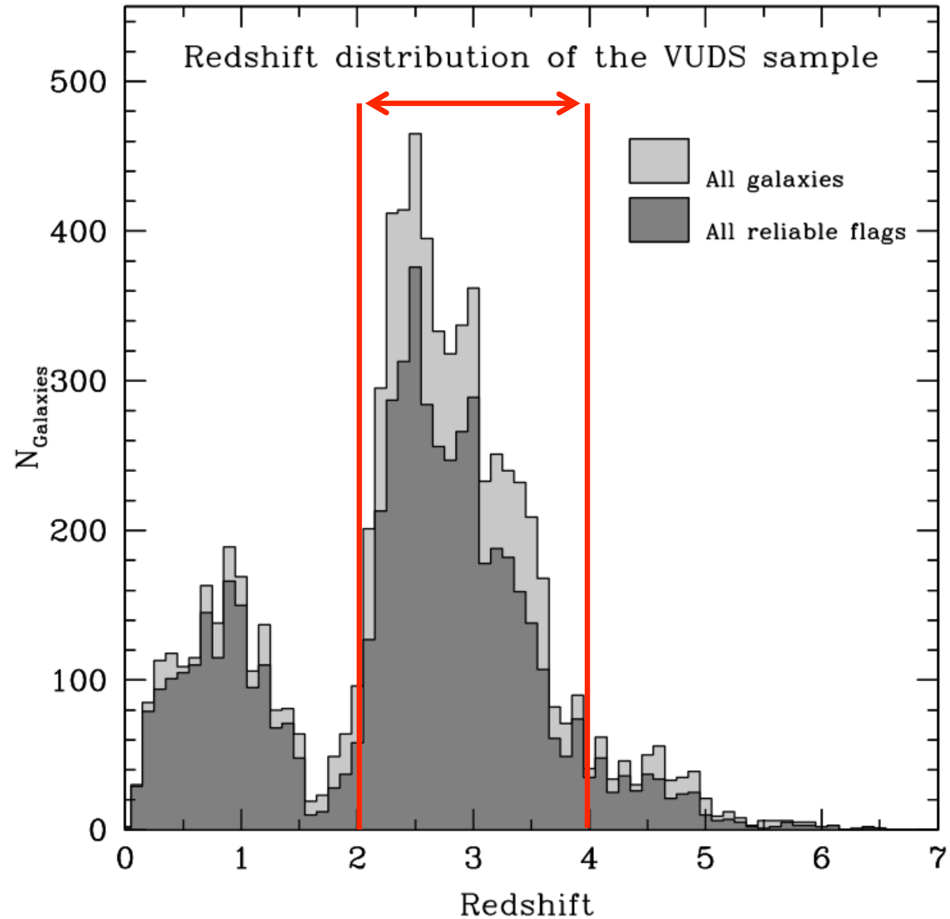
8000 zspec



Sample selection

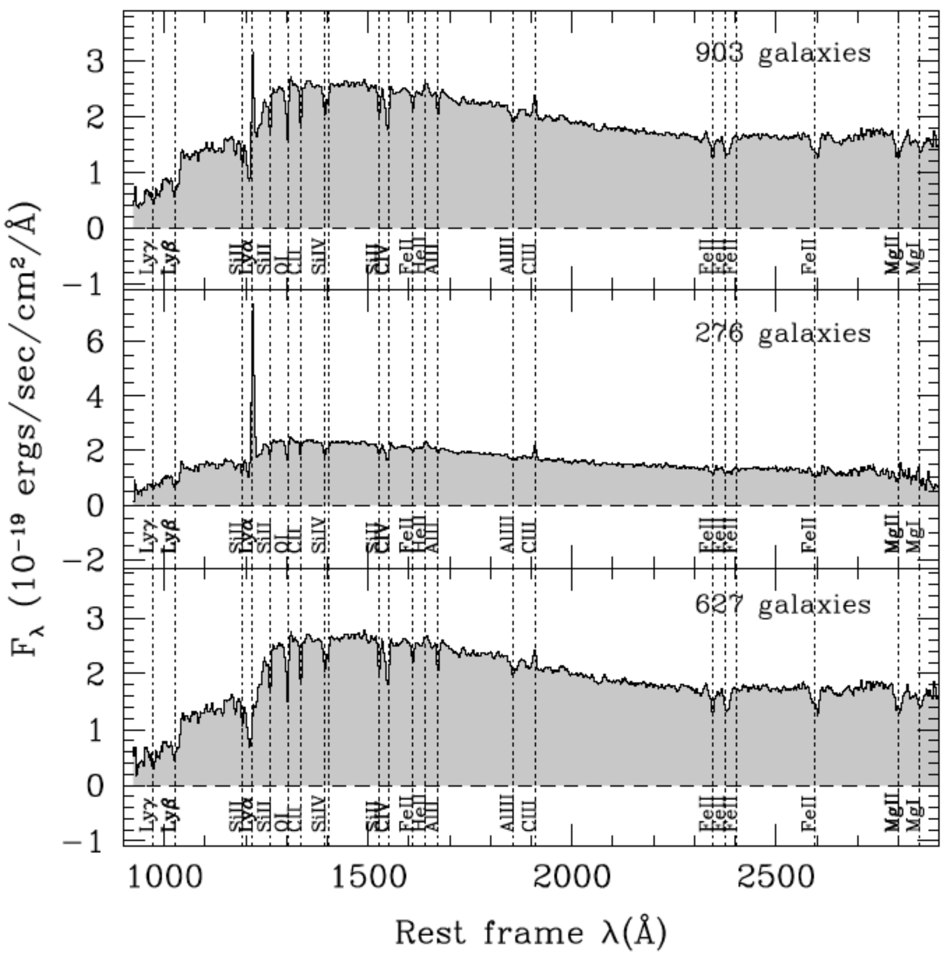
Parent sample

- VUDS galaxies with very reliable redshifts (>95% confidence) in the range 2 < z < 4 (3 fields)
- Only galaxies with CIII]1907,09 detections (S/N>3)
- Clear AGNs are excluded (X-ray, broad lines, diagnostics based on very high ionization lines (e.g. Feltre+15, high NV, very high CIV/CIII, He/CIII); red SED colours, variability…

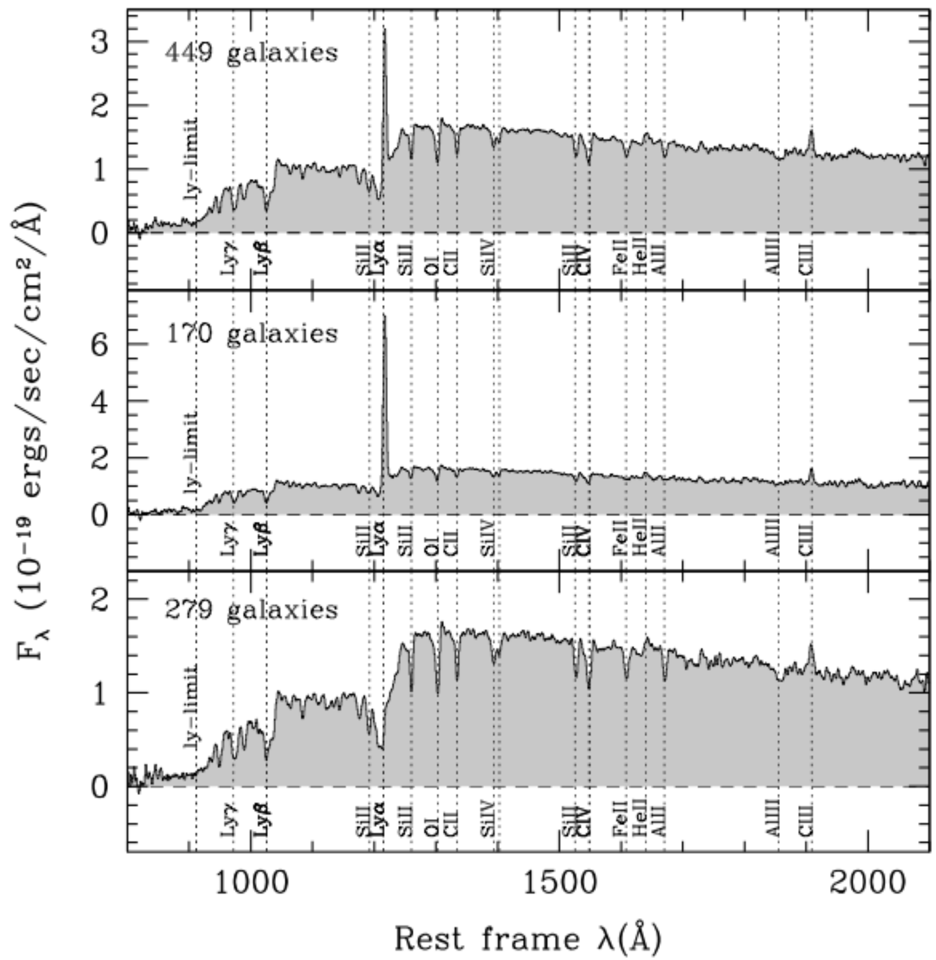


SELECTING CIII] EMITTING GALAXIES

Parent sample



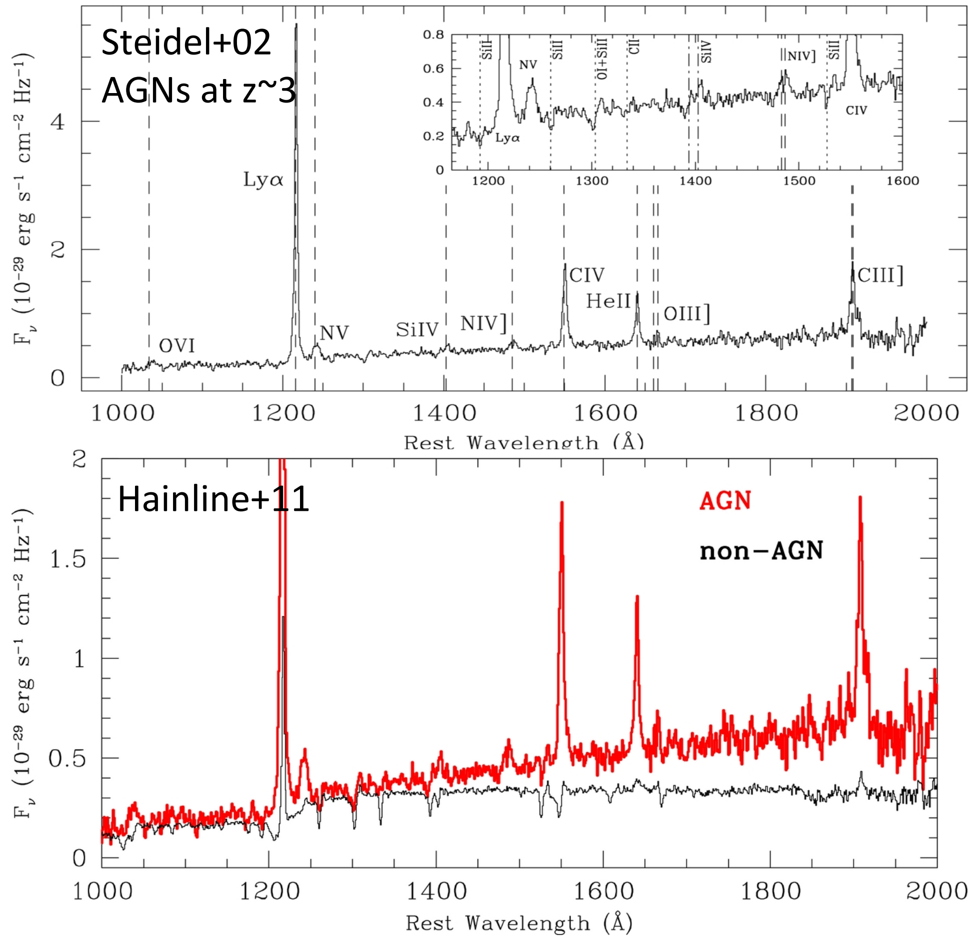
STACKING: VUDS galaxies at z=2-4; Le Fevre+15



EXCLUDING BRIGHT AGNs

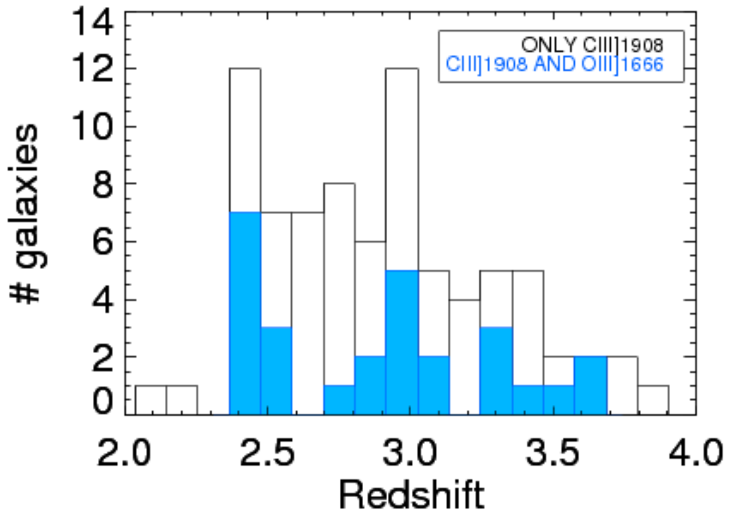
Parent sample

- VUDS galaxies with very reliable redshifts (>95% confidence) in the range 2 < z < 4 (3 fields)
- Only galaxies with CIII]1907,09 detections (S/N>3)
- Clear AGNs are excluded (X-ray, broad lines, diagnostics based on very high ionization lines (e.g. Feltre+15, high NV, very high CIV/CIII, He/CIII); red SED colours, variability…

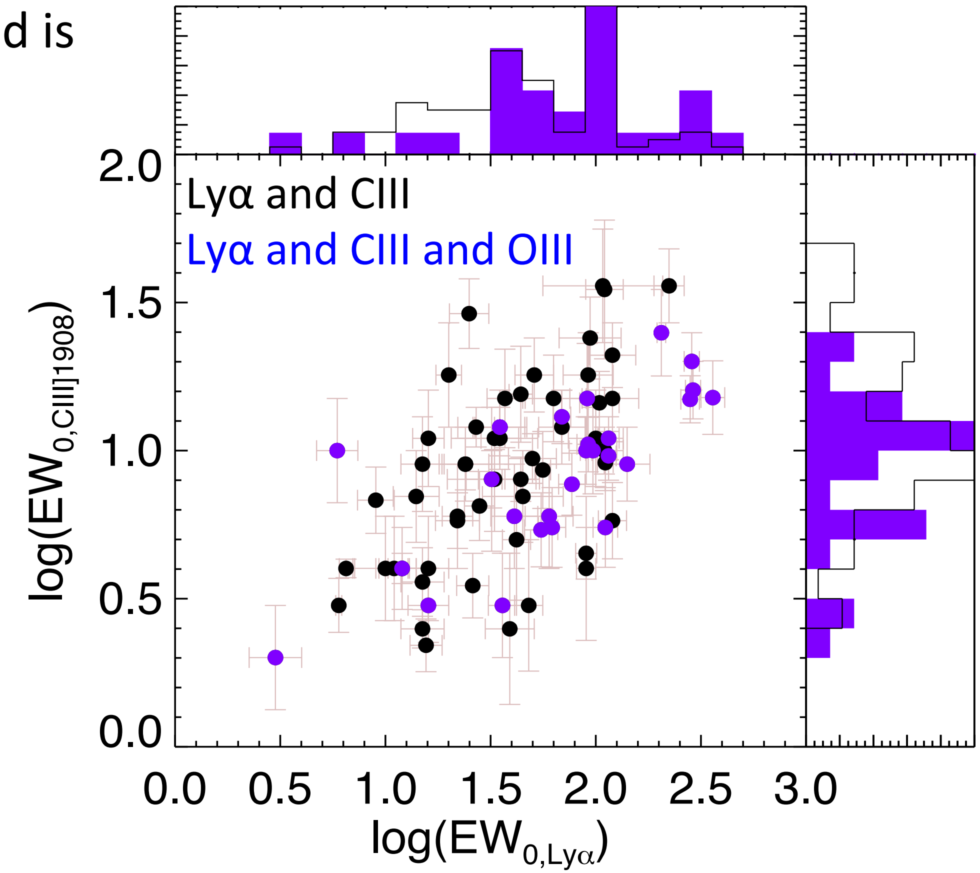


FIRST RESULTS – THE COSMOS FIELD

Number of CIII (SN>5) emitters in each field is around 10% : COSMOS: 80 (~85% are LAEs)
VVDS: 147 (~65% are LAEs)
ECDFS: 34 (~50% are LAEs)



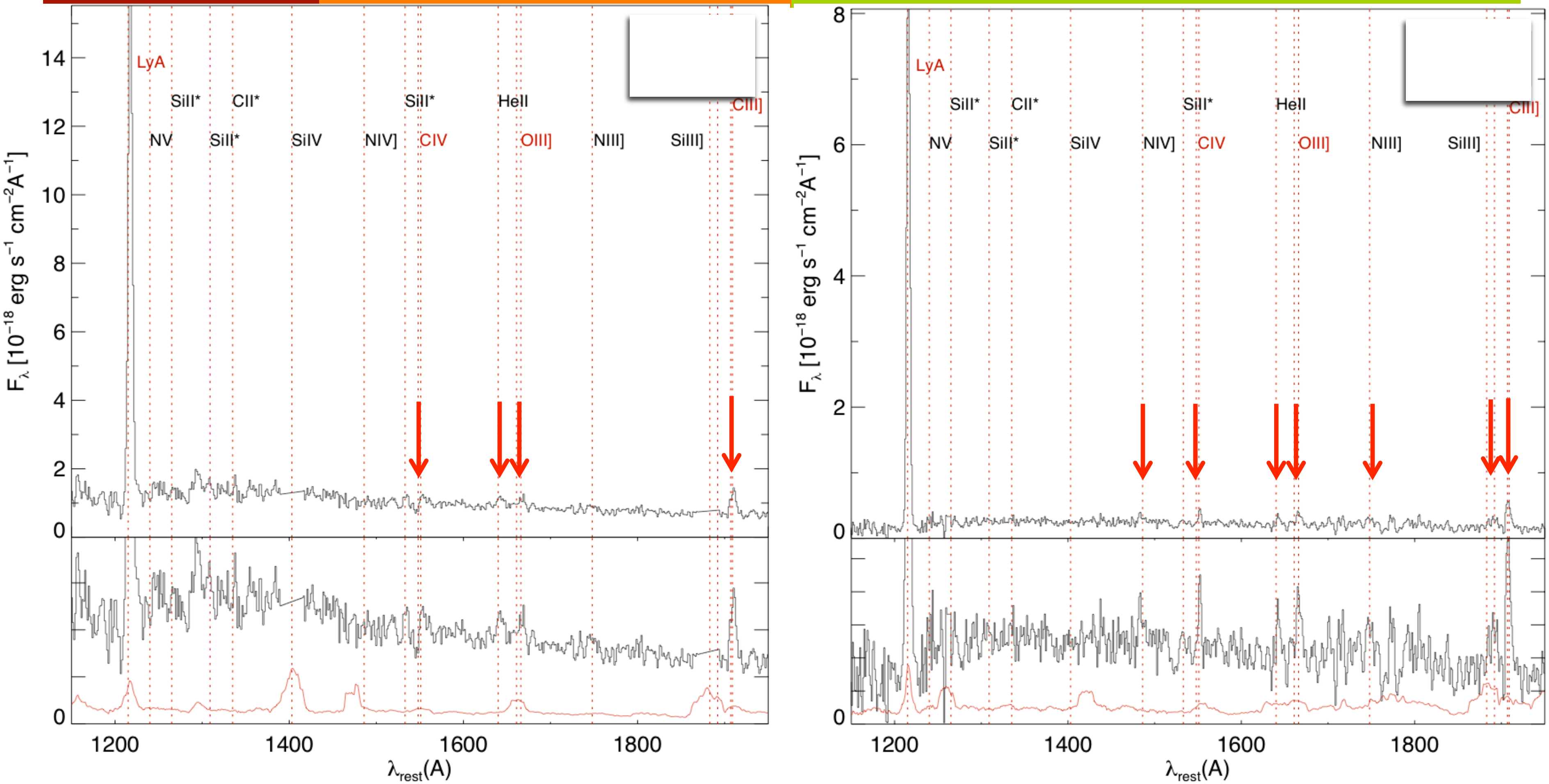
30% of CIII emitters show detection in OIII]1661,66 and high EW(Lyα) > 25 Å (LAEs)



Statistical significance to previous trends (Stark+14)

Many CIII emitters are LAEs (but many do not… Le Fevre+VUDS in prep.)

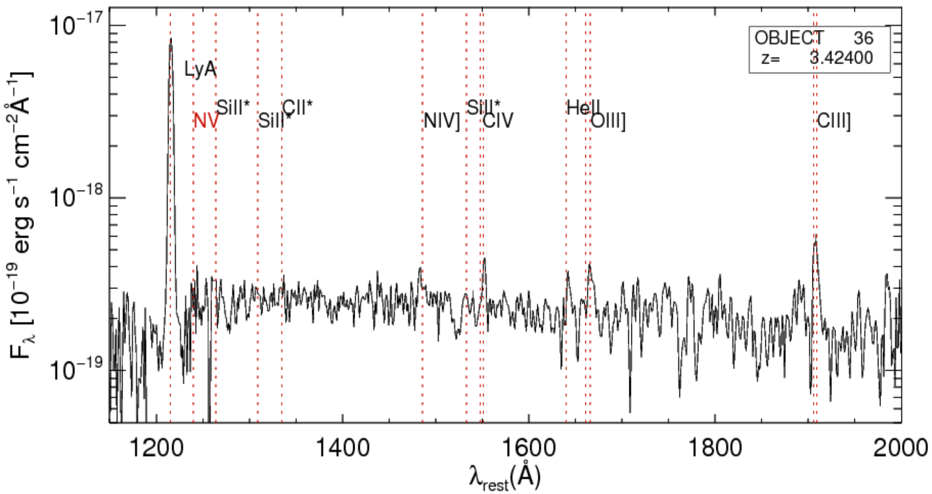
EXTREMELY LOW-METALLICITY GALAXIES AT Z~2.4-3.5 NEWLYBORN GALAXIES ?

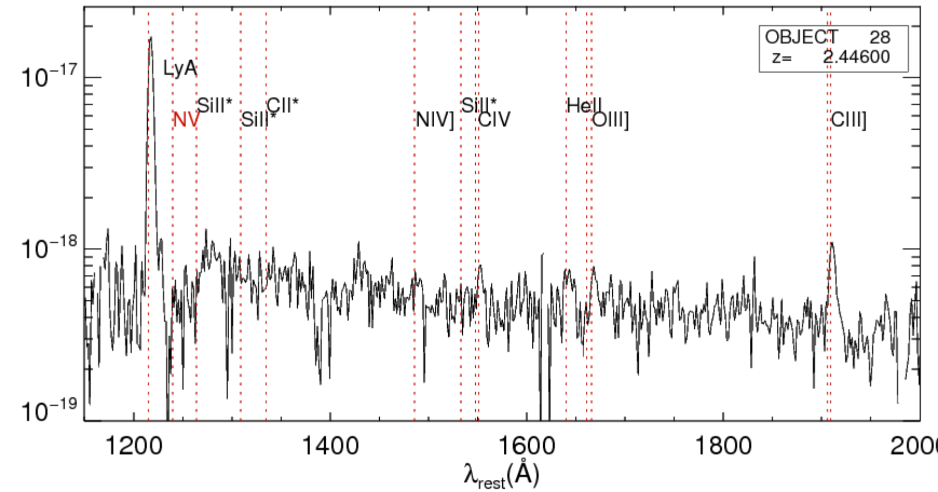


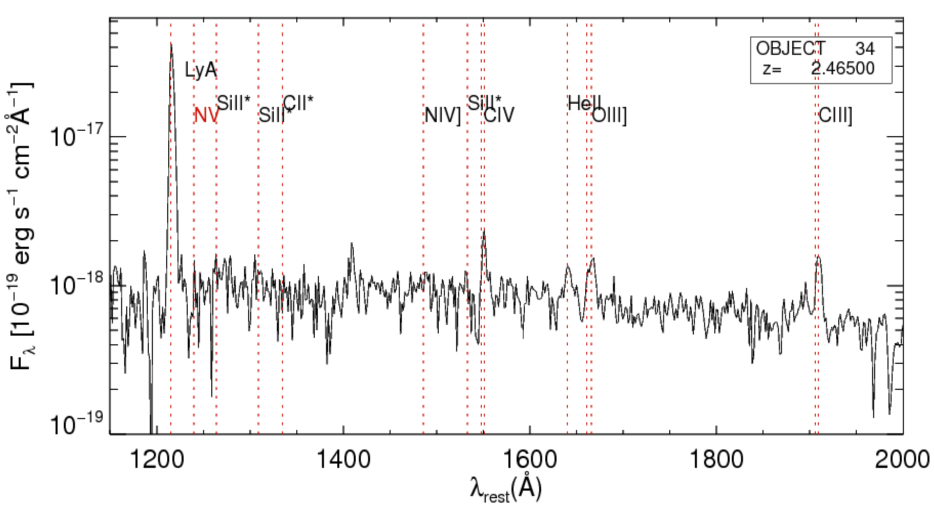
Blue continuum + high EW Lyα + high ionization nebular lines (OIII] 1661,66, CIII]1907,09) + Wind lines (CIV 1551, SiIII]1883) + HeII 1640

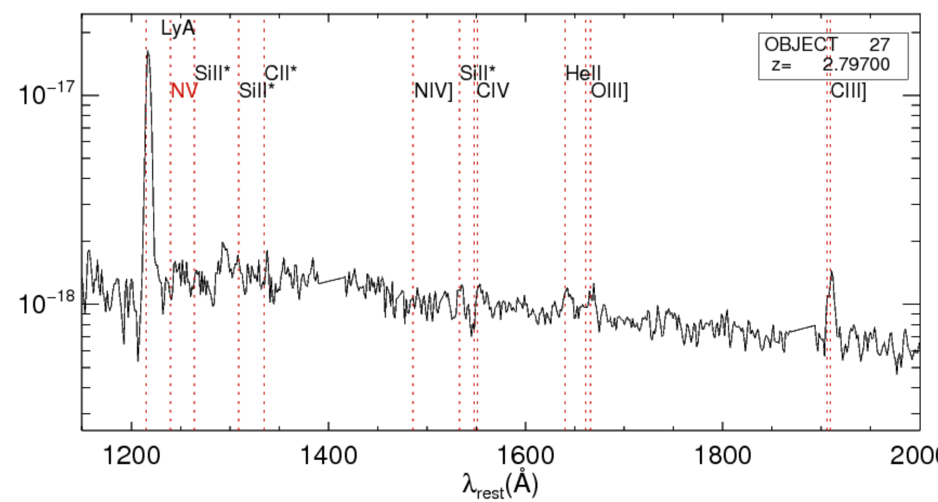
Features suggest low-metallicity, young starbursting galaxies (e.g. Stark+14, Erb+10)

More Examples



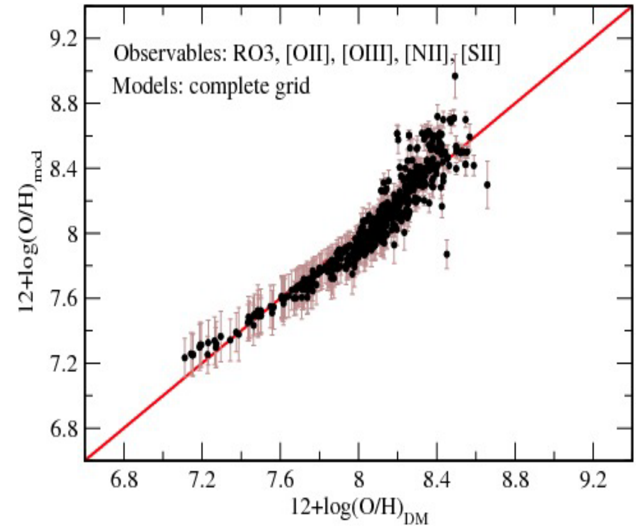




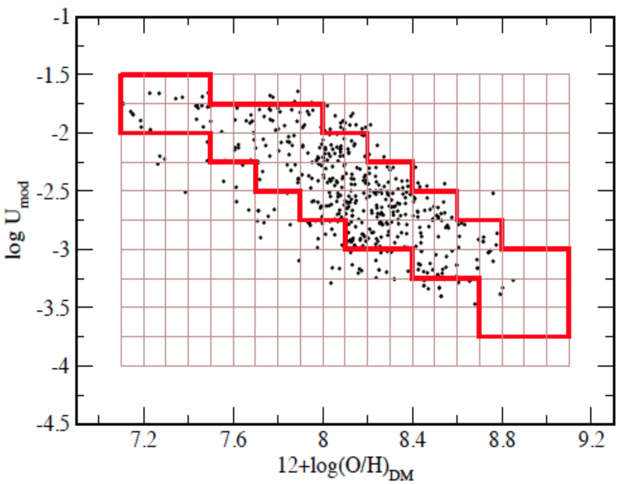


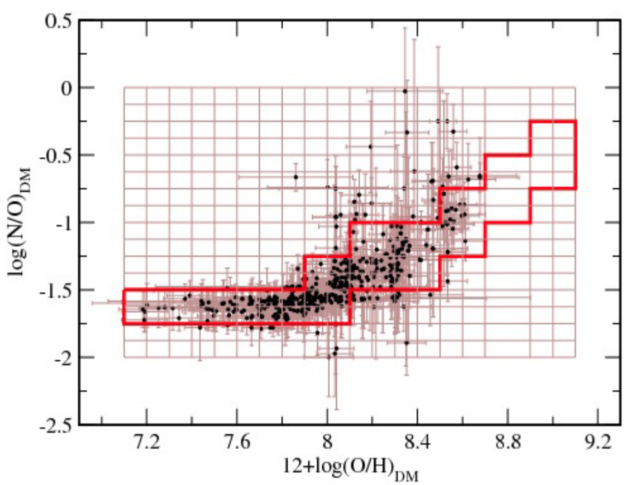
T_E-CONSISTENT & MODEL-BASED ABUNDANCES: HCM

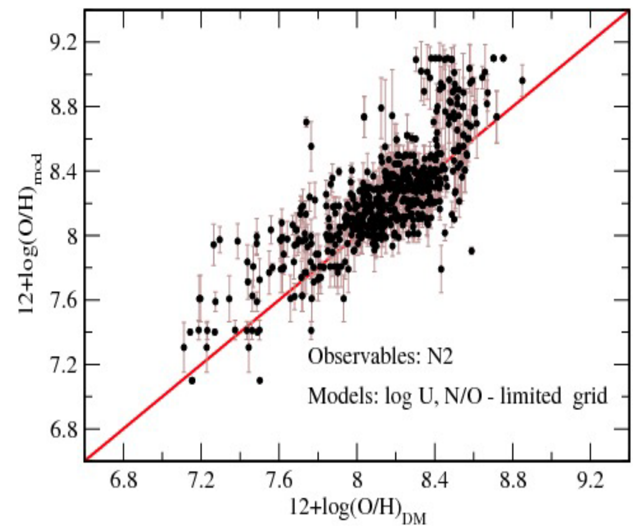
HII-CHI-MISTRY (HCM; Pérez-Montero 2014)
http://www.iaa.es/~epm/HII-CHI-mistry.html
is a code to derive O/H, N/O and log U using a **χ**2 weighted mean of the differences with the reddening corrected [OII], [OIII] (4363 and 5007), [NII] and [SII] em. line ratios



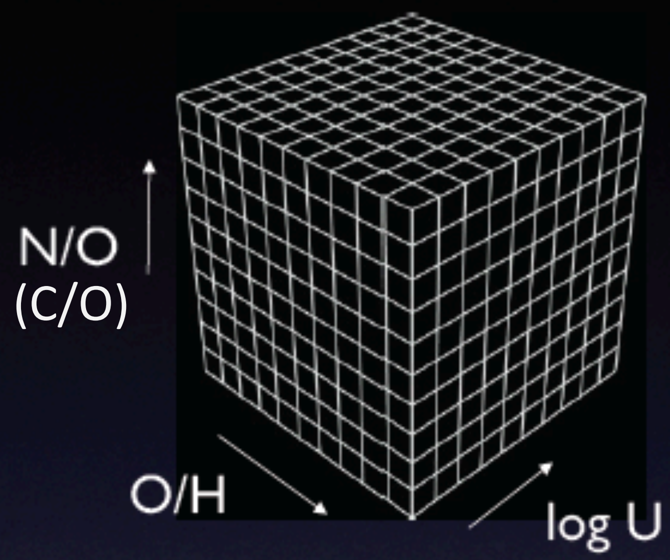
HCM derives O/H and N/O consistent with the direct method over all ranges of Z even in absence of an estimate of the electron temperature. This is done by constraining the space parameter in Z, N/O, and U, empirically.







HCM: Photoionization models



A large grid of photo-ionization models was calculated to obtain emission-lines under different input assumptions.

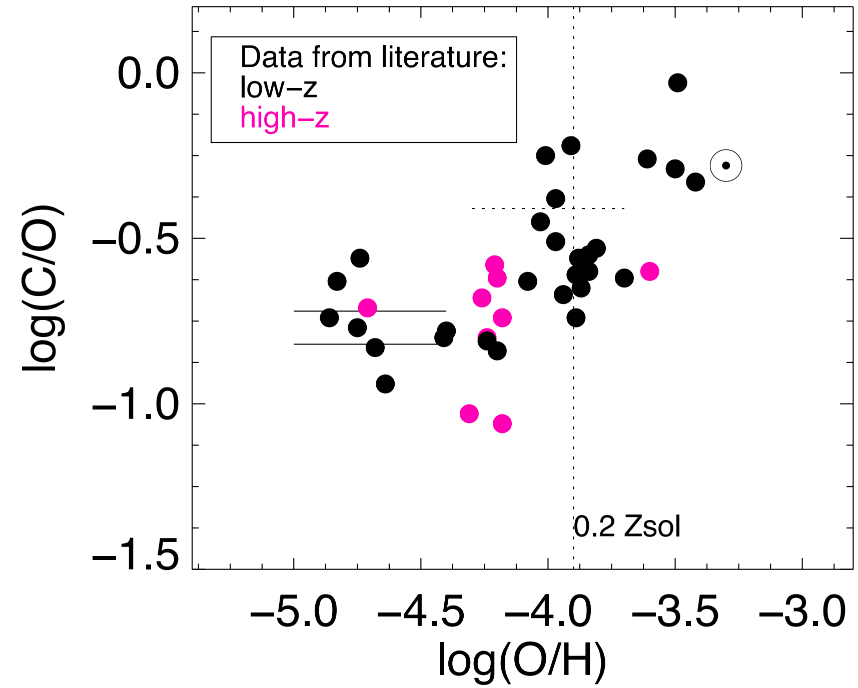
Model properties:
- Code: Cloudy v. 13.03
- Ionizing SED: POPSTAR (Mollá+ 2010), instantaneous burst of 1Myr at the metallicity of gas
- Geometry: Plane-parallel
- Gas density: 50 cm-3
- Dust-to-gas ratio: Default MW ratio
- Abundances: Scaled to oxygen
- 12+log(O/H) = [7.1 – 9.1] in bins of 0.1dex
- log)(N/O) = [-2.0, 0.0] in bins of 0.125 dex
- Log U = [-4.0, -1.50] in bins of 0.25 dex

This gives a total of 3927.

All models can be got from the Million Model Mexican DataBase (3MdB, Morisset 2013)

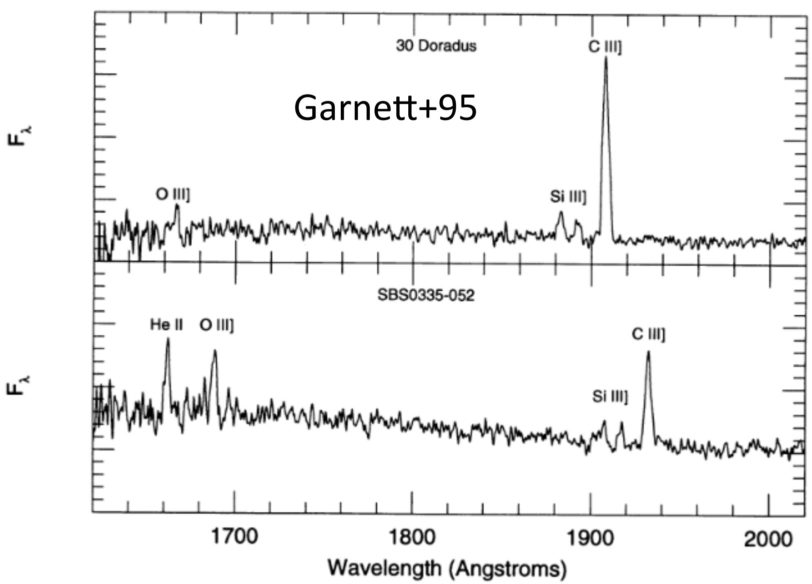
METALLICITY FROM UV LINES AND PHOTOIONIZATION MODELS

We use a new version of HCM adapted to include emission lines in the UV range (e.g. using C/O instead of N/O and defining new metallicity-sensitive indexes based on UV lines)



CONTROL SAMPLE

Test results from HCM with abundances derived from the direct method, we use a control sample with a direct estimate of the T_e, U, and C/O



All local GHII regions and HII galaxies observed in the UV (from Garnett+95,97,99; Kobulnicky & Skillman +97, 99, etc)

The few high-z galaxies observed so far (Fosbury+03; Erb+10; Christensen+12; Bayliss+14, etc).

Most of them are strongly lensed systems

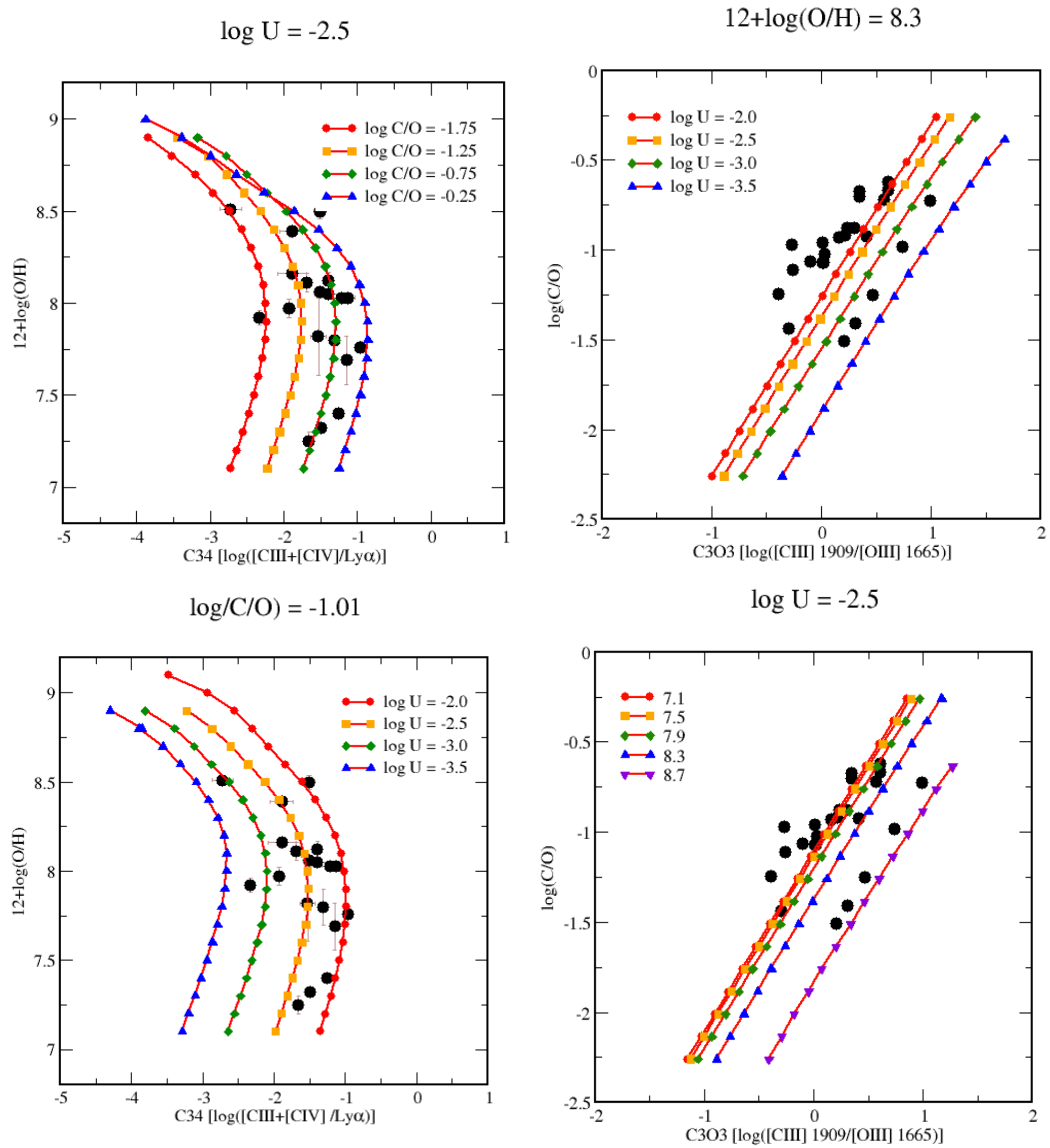
METALLICITY INDICATORS FOR HIGH-Z SFGS

CURRENT HCM VERSION uses:
O3727, O4363, O5007, Hb, NII, SII
LyA, CIV, CIII, OIII

UV LINE RATIOS

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

Using *PyNeb* (Luridiana+15) the code derives the physical conditions, ionic abundances etc..
e.g. C2+, O2+ and C3+
and obtains C/O = (C2+ + C3+)/O2+



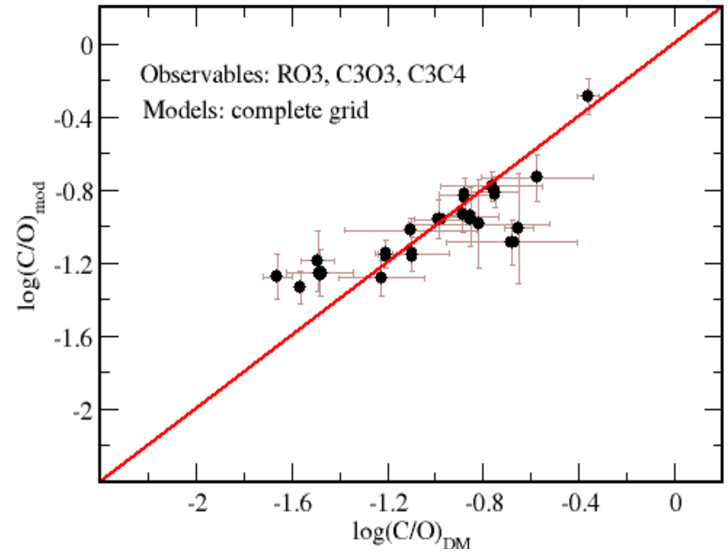
METALLICITY INDICATORS FOR HIGH-Z SFGS

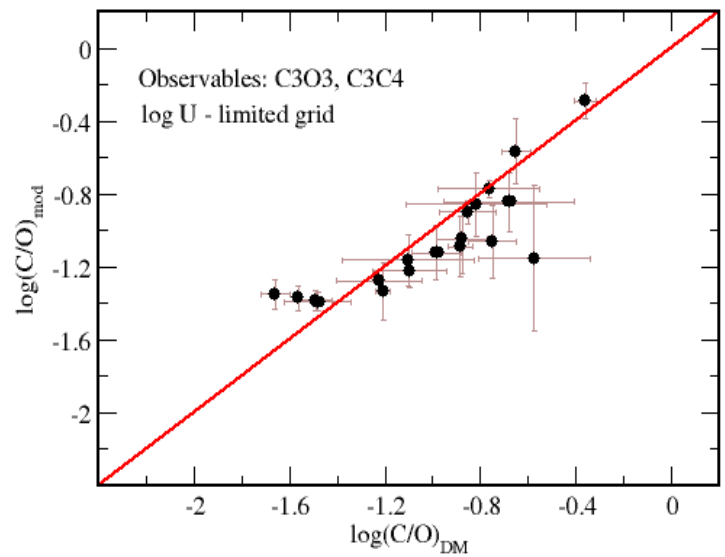
CURRENT HCM VERSION uses:
O3727, O4363, O5007, Hb, NII, SII
LyA, CIV, CIII, OIII

UV LINE RATIOS

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

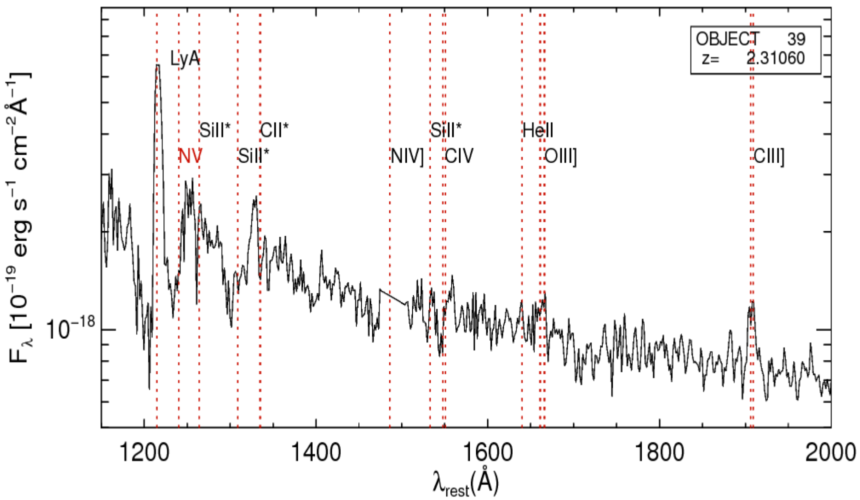
Using *PyNeb* (Luridiana+15) the code derives the physical conditions, ionic abundances etc..
e.g. C2+, O2+ and C3+
and obtains C/O = (C2+ + C3+)/O2+



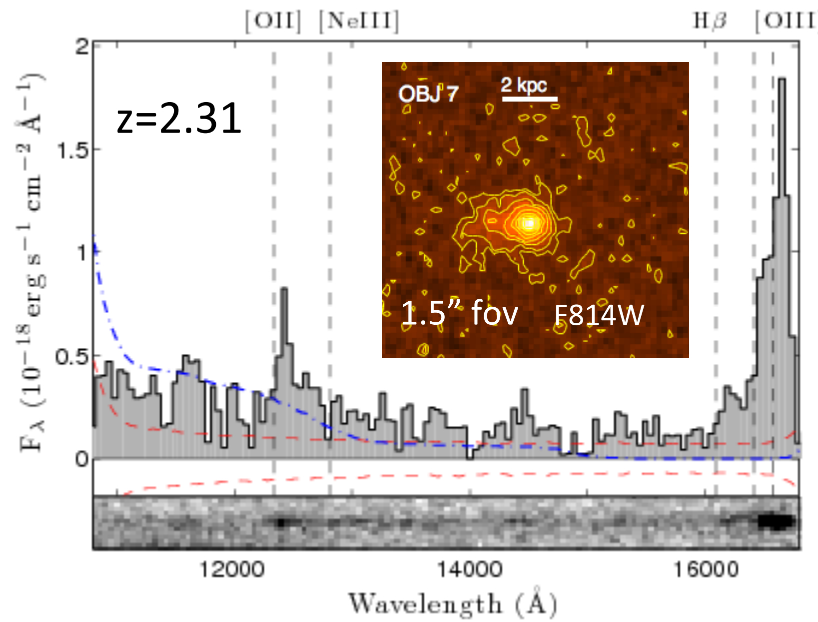


THE METHOD IS ROBUST

Test cases: Combining VUDS and 3D-HST: strong OII, OIII and Hbeta (Amorin +, in prep)



Testing metallicity from HCM (12+logO/H):
5 lines (CIII, CIV, OIII1661,5007) + Hbeta: 7.7 (0.3)
3 lines (CIII, OIII1661,5007) + LyA : 7.5 (0.4)
UV lines only (LyA, CIV, CIII, OIII): 7.4 (0.3)



EW(OIII) ~950A; EW(Hb)~150A
OIII/Hb ~ 6; OII/Hb ~ 1.5 all typical of EELGs

Simple follow-up observations using NIR MOS (e.g. LBT-LUCI, KMOS…) will improve accuracy for Te-based metallicities

C/O VS. O/H: CHEMICALLY YOUNG GALAXIES

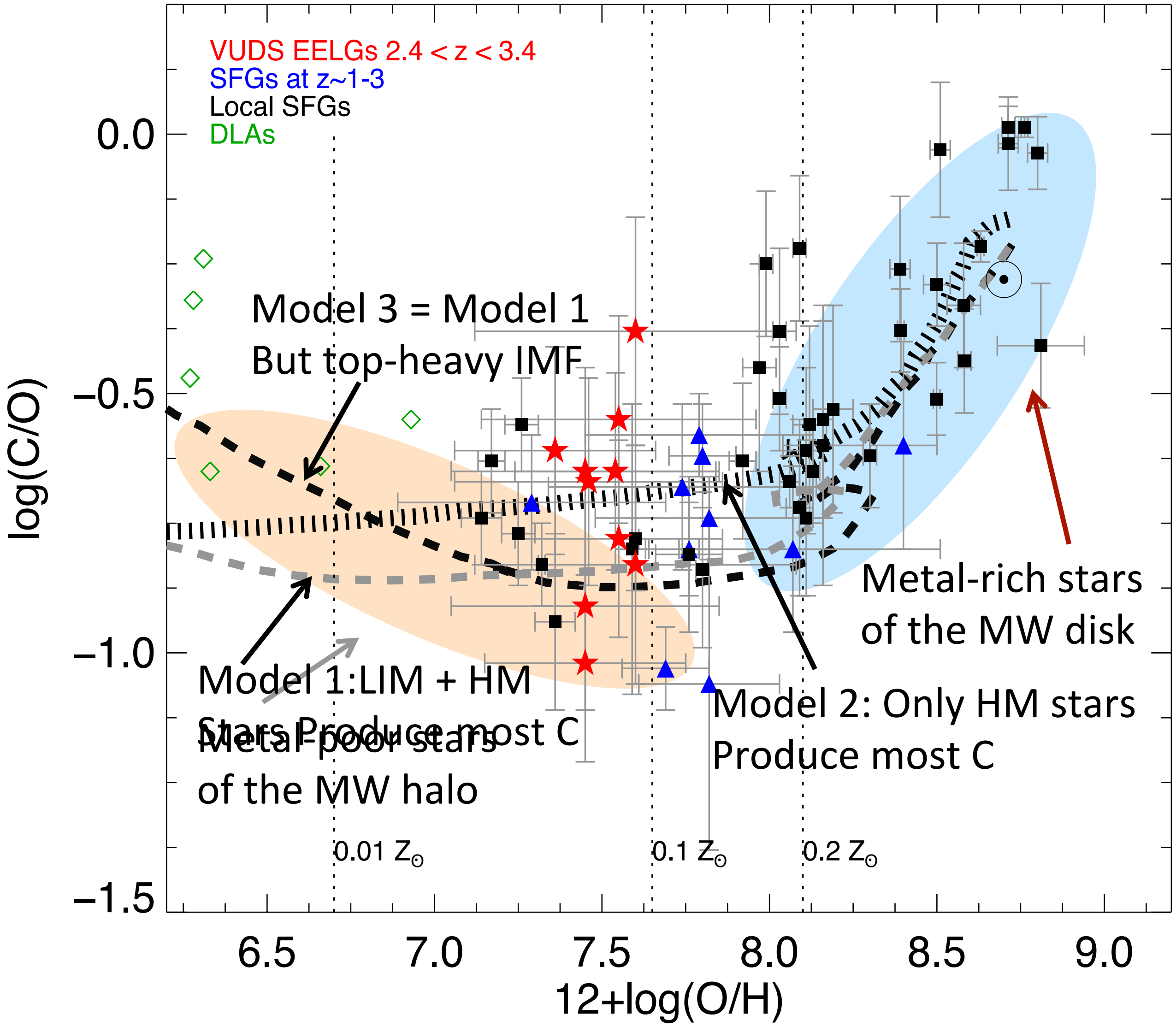
Our 10 EELGs are extremely metal-poor (Z<10% solar)
C/O is sub-solar

Models of Mattson+12

---- O-stars + low-Z LIM stars
….. Only O-stars
Top-heavy IMF would increase C/O at low-Z

Below 0.2 Zsol C/O is mainly Produced by massive O-stars
Above 0.2 Zsol intermediate and low mass stars produce more C than O, increasing C/O

Our results suggest rapid chemical enrichment
Hot, massive stars dominate



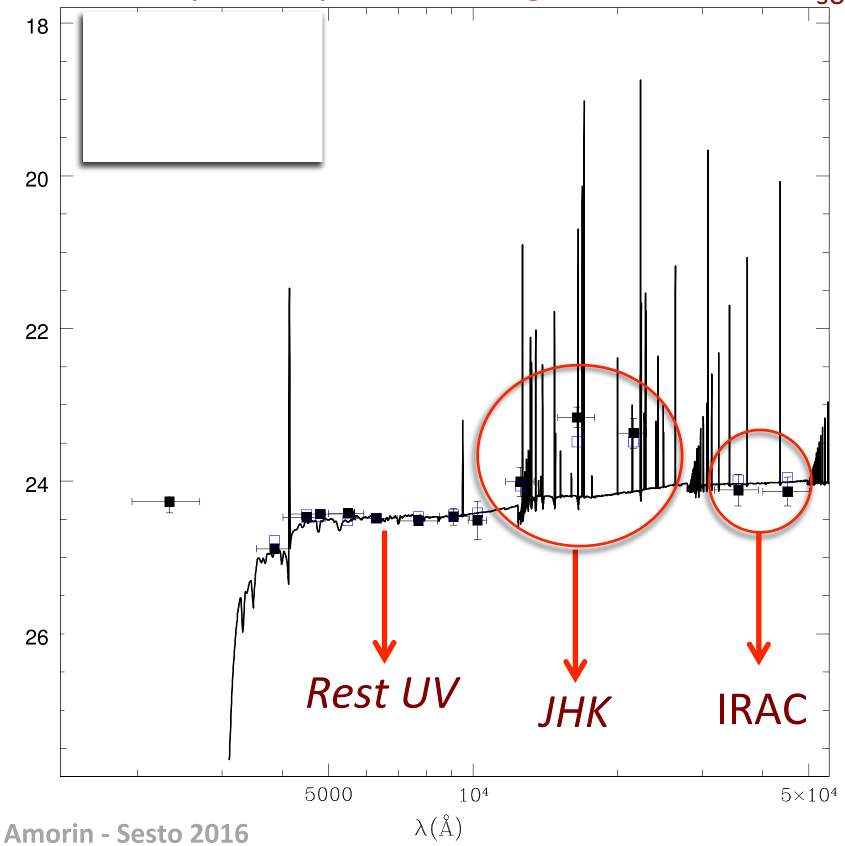
Amorín et al. in prep

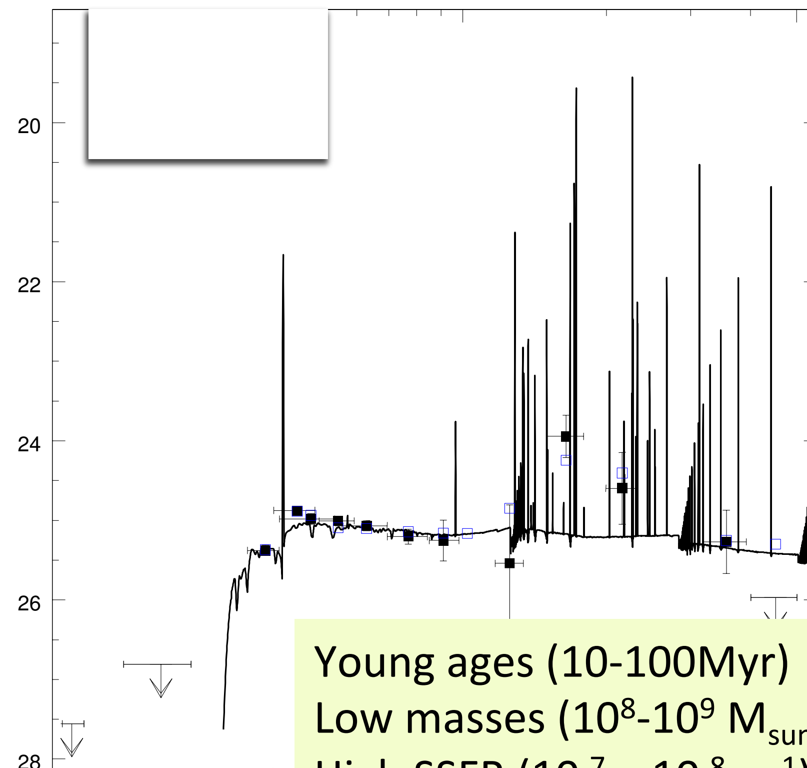
UV-TO-IR SEDs: YOUNG AGES, LOW-MASS, HIGH SSFR

Last COSMOS photometric catalogs from Subaru+CFHTS+UVISTA+Spitzer

We use different codes (Le Phare, ZPHOT, GOSSIP+) with stellar and nebular models (Bruzual & Charlot 2003 + Schaerer & de Barros 2009) including different recipes SFHs, Z, ages…(e.g. Santini+14)

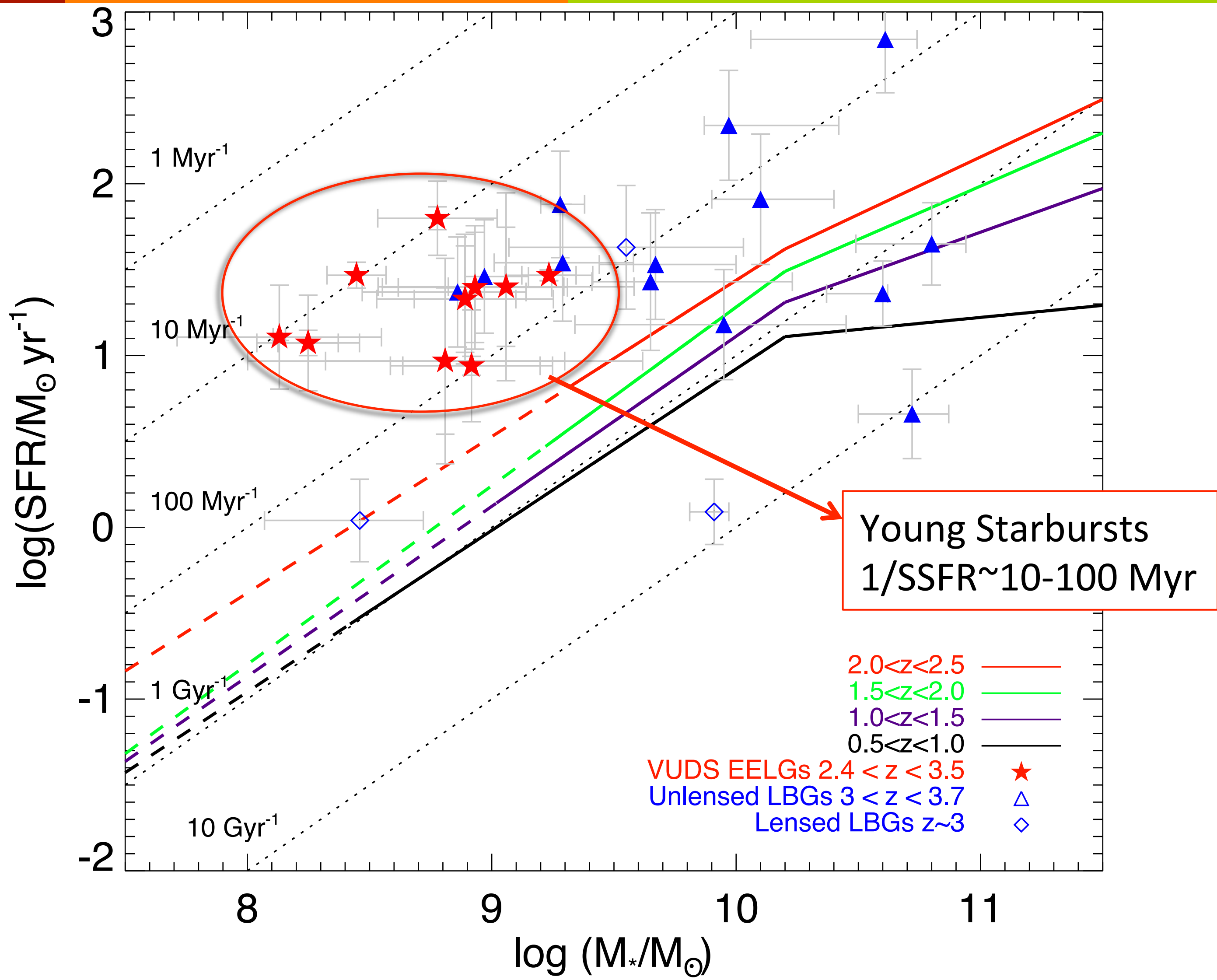
Example: Exp. Declining SFH + Z=0.2 Z_{sol} + Neb. Models (Schaerer & de Barros)





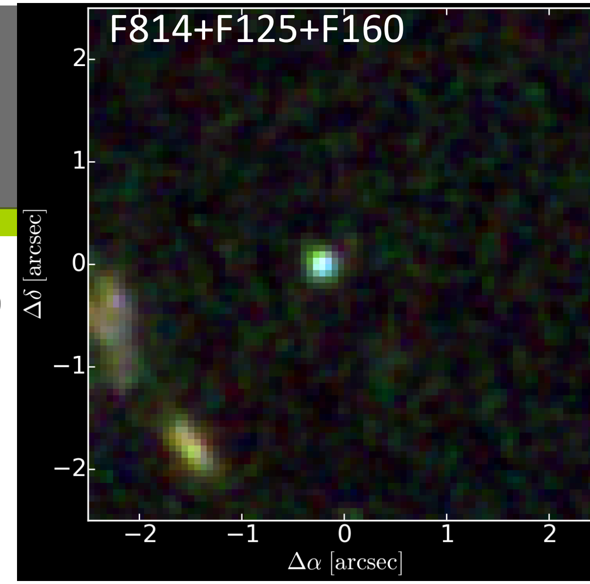
Young ages (10-100Myr)
Low masses (10^8-10^9 M_{sun})
High SSFR (10^{-7} – 10^{-8} yr^{-1})
Very high EWs

SFR-Mass Relation

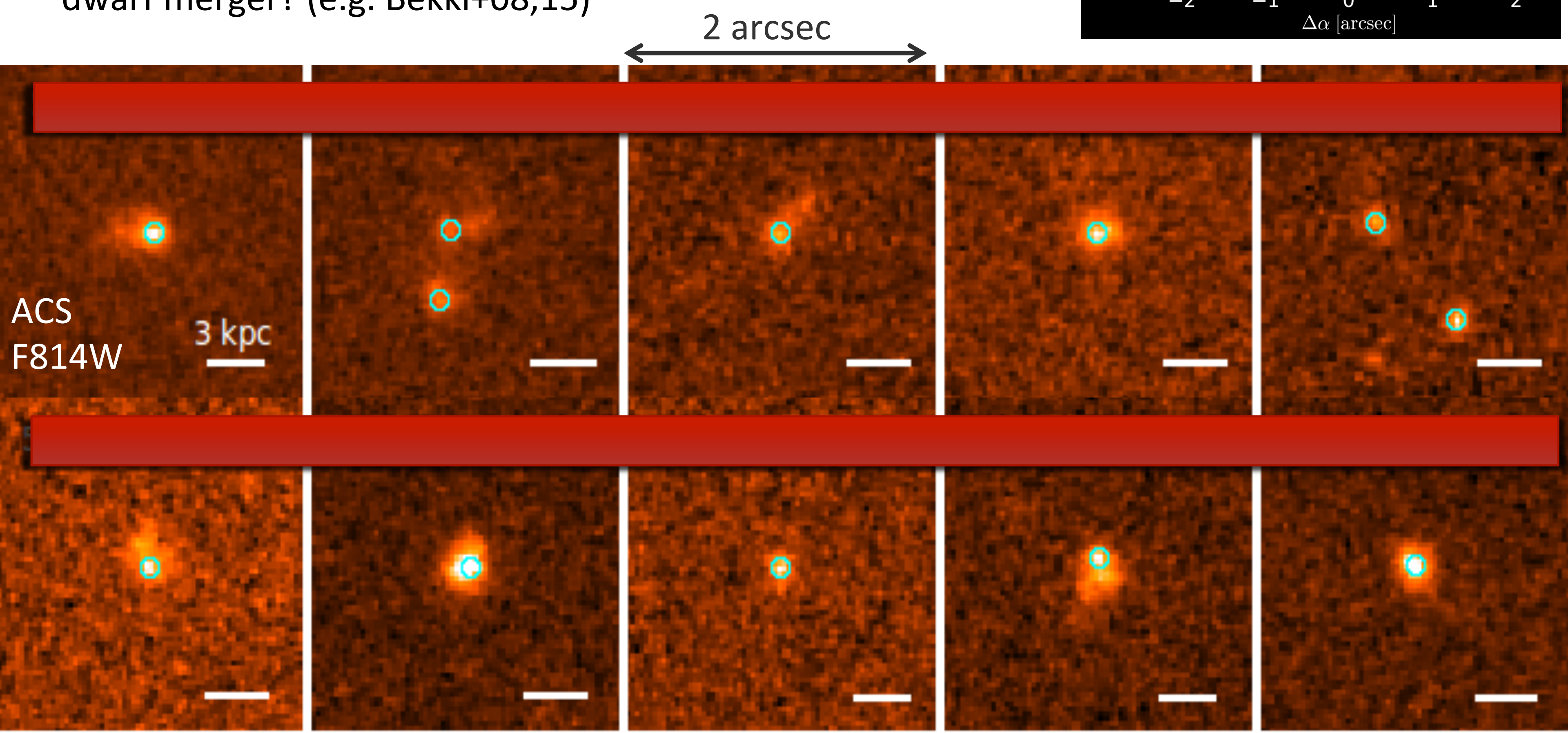


Amorín et al. in prep

EXTREMELY COMPACT MORPHOLOGY

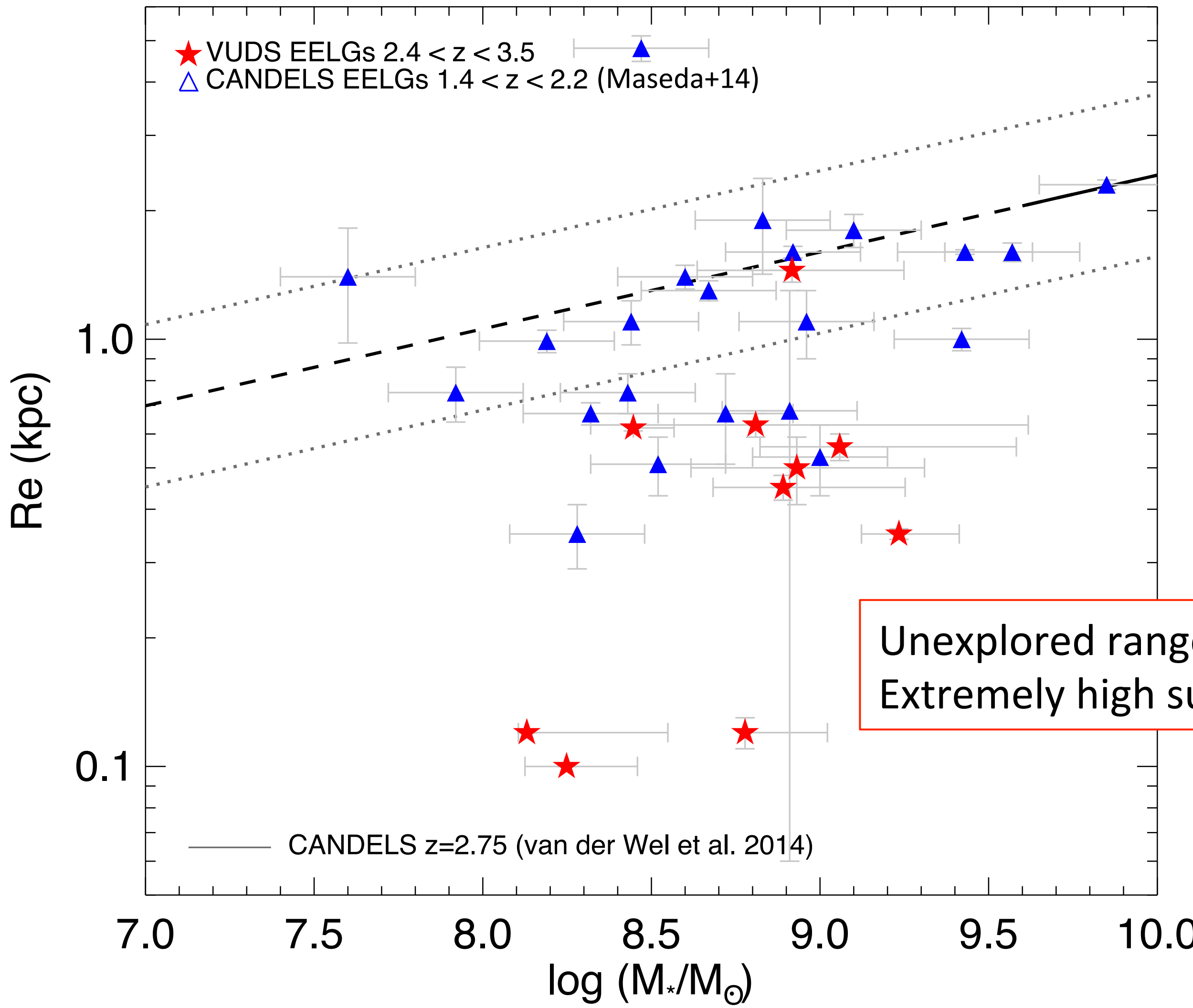


- Star formation is in one bright clump of < 400 pc in size (circles)
- Clumps often off-center from a fainter, irregular component
  Tadpole shapes → Recent gas accretion ? (see Ceverino+15)
- Two close projected pairs in the sample (early stage of dwarf-dwarf merger? (e.g. Bekki+08,15)



Extreme compactness

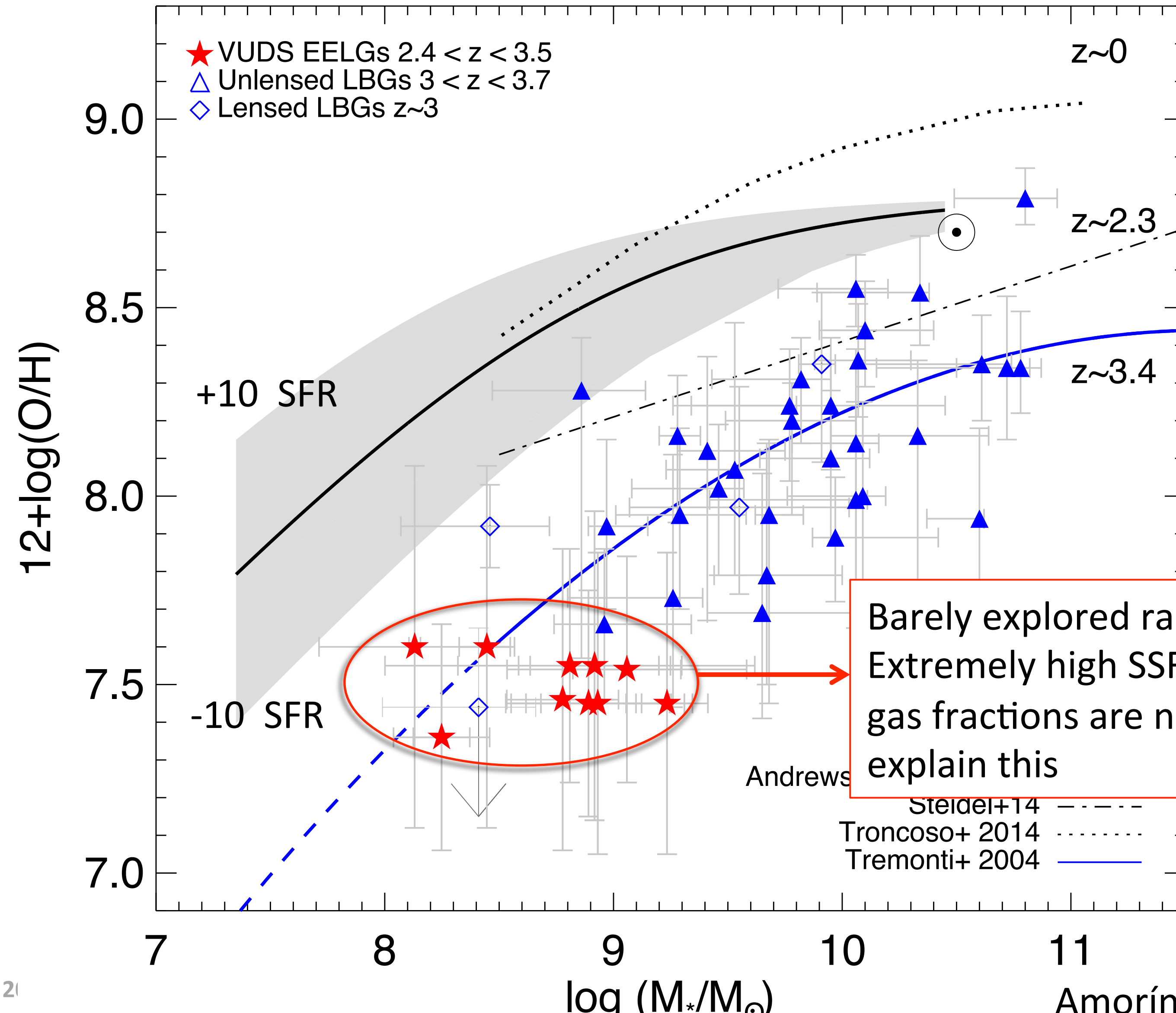
Half-light radii (along major axis) from GALFIT analysis (Ribeiro+VUDS, in prep.)



Unexplored range at z~3
Extremely high surface densities

Amorín et al. in prep

Mass-Metallicity Relation



Barely explored range at z~3. Extremely high SSFR and gas fractions are needed to explain this

Amorín et al. in prep

SUMMARY

Low-mass (10^7- 10^9 $M_{\odot}$) strong emission line galaxies are still not fully characterized at the peak of the cosmic SFRD

Now VUDS provides an exquisite probe of young starbursting dwarfs at z~3:

Ideal labs for studying mass assembly, SF & feedback, chemical evolution…

Main results:

+ Low masses, high SSFR and young ages
+ Very low O/H and C/O abundances, high ionization
+ Presence of very massive stars; outflows
+ Extreme compactness, off-center sub-kpc SF clumps

Newly born galaxies in early phases of build-up

Possible scenarios for discussion includes:

- recent/ongoing inflows of metal-poor gas from the cosmic web (e.g. Dekel+09,Ceverino+15)
- interaction/merging with small companions (e.g. Bekki08,15, Starkenburg+15,16)

Analogs of UV-selected galaxies in the early universe? (JWST…) → e.g. Ivo Labbé talk

Candidates for LyC leakers → Daniel's talk

NEXT: Looking for NIR spectroscopic follow-up (KMOS, LUCI, X-SHOOTER...)
Studying other CIII emitters and young candidates in the VVDS and ECDFS