Gas-phase metallicity of high-z extreme emission line galaxies from deep VUDS (and VANDELS) UV spectra

R. Amorín

(INAF-OAR)



Low-mass, star-forming galaxies at high-z

First detailed studies targeting high-z (z>1.5) galaxies with reasonably low assembled stellar masses (10^7- 10^9 $M_\odot$) have begun to emerge (e.g., Erb+10,Christensen+12, van der Wel+11, Steidel+14,Stark+14).

A substantial population of low-mass star-forming galaxies out to z~2 has been discovered due to their very large nebular emission (rest-frame EW(OIII)~200-1000 A) (e.g., Atek+11,+14,van der Wel+11,Brammer+12,Maseda+14,Masters+14, Amorín14a,b).

It has recently been argued that such extreme optical line emitting galaxies, showing very similar properties as some rare, low-metallicity, high sSFR dwarf galaxies at lower-z (e.g. Green peas, Cardamone+09, Amorín+10), become ubiquitous among UV-selected star forming galaxies at z > 4 (e.g., Shim+12, Stark+13, Smit+13).

Relevant for studies on early mass assembling, chemical evolution, star formation and feedback, as well as for reionization studies

Extreme Emission Line Galaxies (EELGs)

- Young starbursts (few Myr)
- Large nebular content and low dust
- Low mass and high SFR → high sSFR
- Low metallicity and high ionization
- Compact and irregular morphologies

At z<1 large samples comes from magnitude-selected surveys using NB filters or colors and optical spectroscopy (e.g. zCOSMOS, VUDS) (e.g. Kakazu+07, Cardamone+09, Amorín+14a,b)

At z>1 we need deep NIR spectroscopy
Small samples to date (e.g. Erb+10, Guaita +13, Maseda+14)
HST grism/slitless spectroscopy may provide the largest samples, but it has limitations (e.g. van der Wel+11, Xia+12)

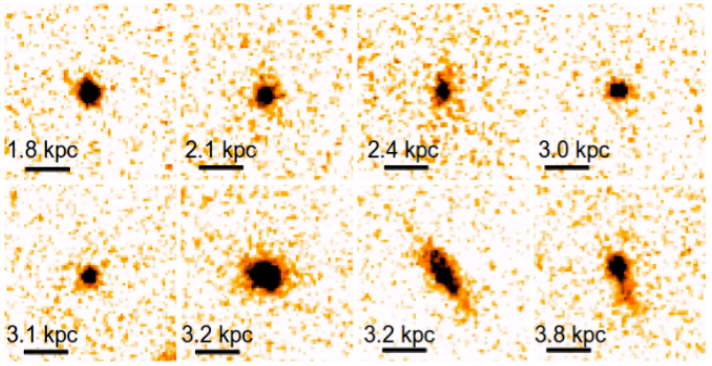
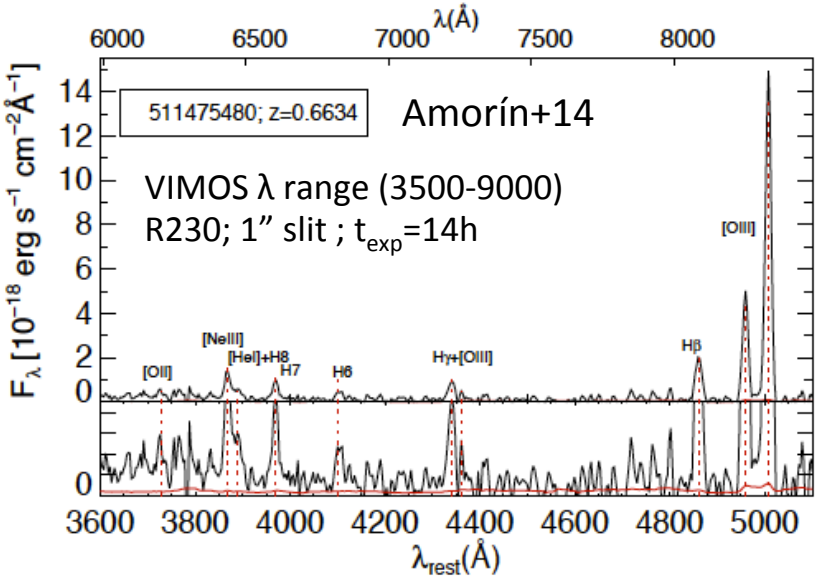


Fig. 1: HST $F814W$-band imagery of EELGs in the COSMOS and ECDF fields covered by VUDS. Each postage stamp is 2" on a side.

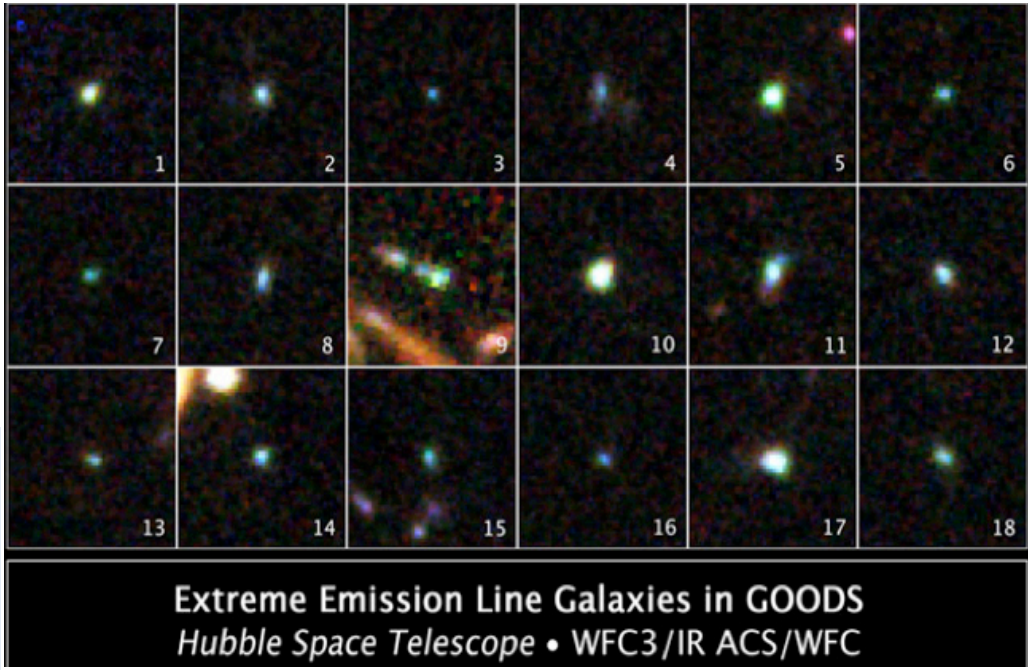


Extreme Emission Line Galaxies (EELGs)

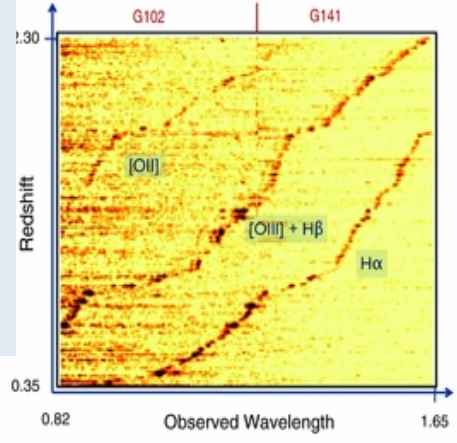
- Young starbursts (few Myr)
- Large nebular content and low dust
- Low mass and high SFR → high sSFR
- Low metallicity and high ionization
- Compact and irregular morphologies

At z<1 large samples comes from magnitude-selected surveys using NB filters or colors and optical spectroscopy (e.g. zCOSMOS, VUDS) (e.g. Kakazu+07, Cardamone+09, Amorín+14a,b)

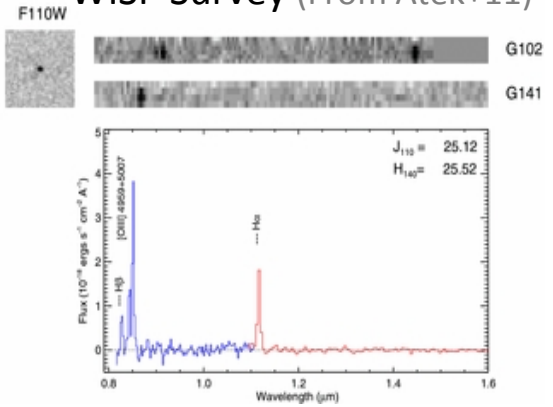
At z>1 we need deep NIR spectroscopy
Small samples to date (e.g. Erb+10, Guaita +13, Maseda+14)
HST grism/slitless spectroscopy may provide the largest samples, but it has limitations (e.g. van der Wel+11, Xia+12)



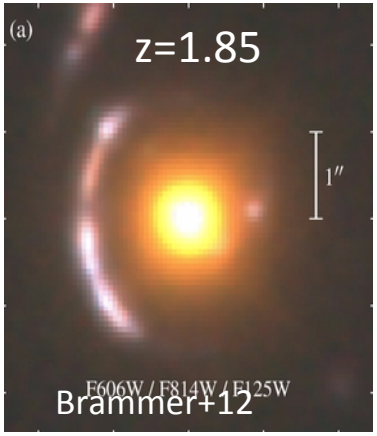
Low-mass starbursts at z=1.8 in CANDELS GOODS *(van der Wel +11, Maseda+14)*



WISP Survey (From Atek+11)

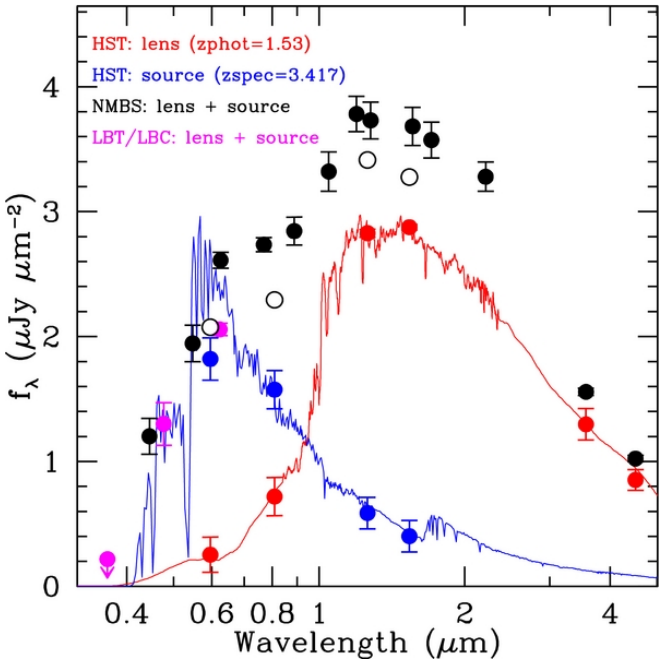


EELGs AT HIGH REDSHIFT



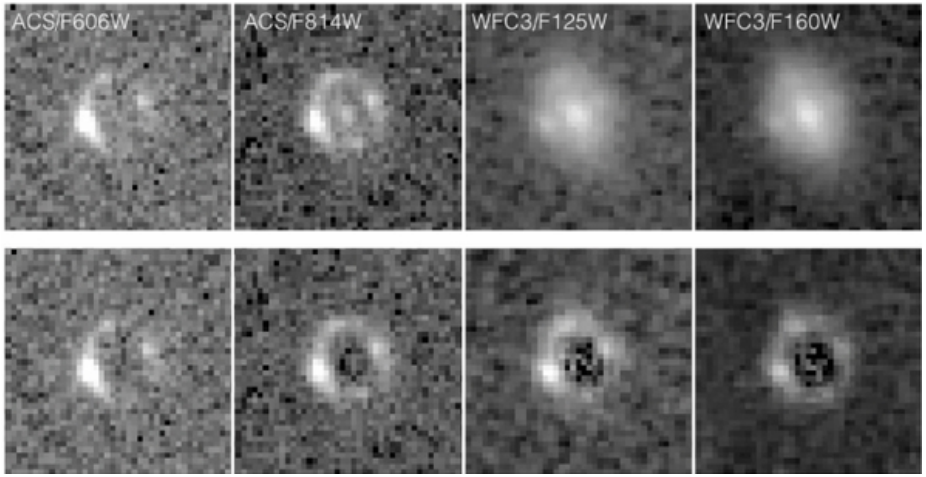


Strong lensing is a powerful technique to discover and study EELGs at high redshift (e.g. Fosbury+03, Richard+11, Christensen+12).
Samples are relatively small at the moment
HST FF can add lots of targets !



Strongly lensed (20x-40x) starbursting dwarf galaxies at high-z
High SSFR, high EW([OIII]~1000A, strong Ionization and very low metallicity, 12+log(O/H) ≤ 7.5 (< 5-10% solar).

Very unusual. Discovered by chance in the COSMOS field



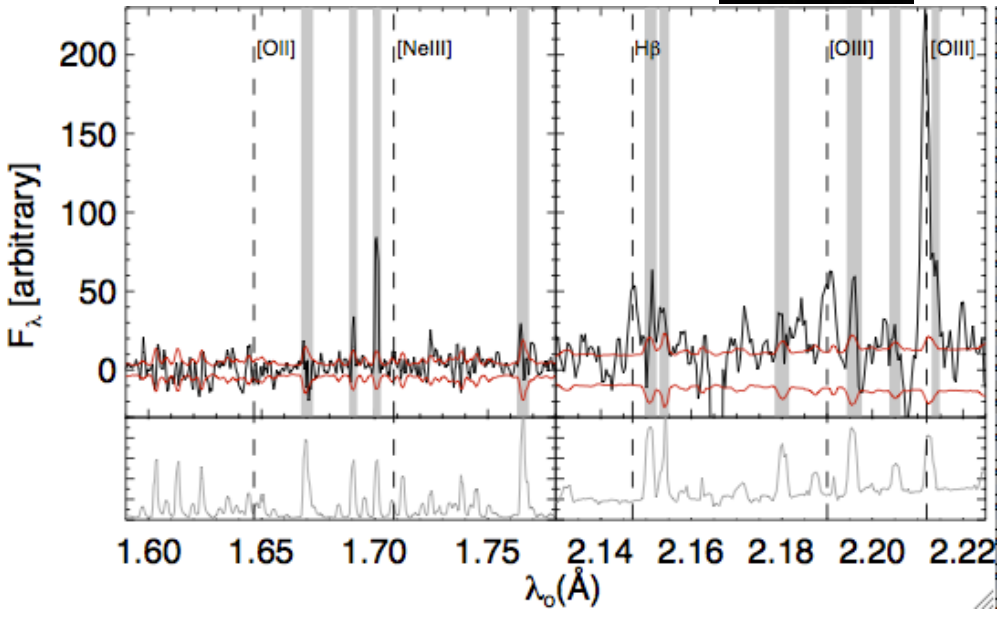
The lens is a massive (~$10^{10.4}$ M_*) red galaxy.
The source is a young low mass (~10^8 M_{sol}) galaxy at z=3.4

EELGs AT HIGH REDSHIFT

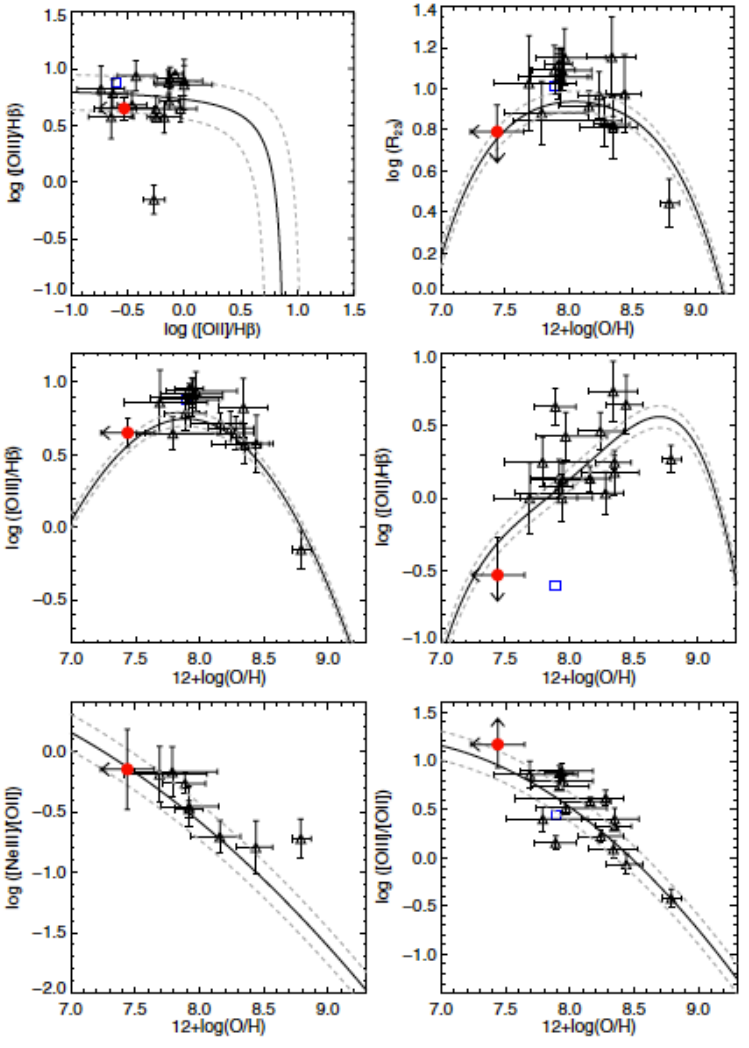
Amorín et al. (2014, ApJL)

z=3.4 ; LBT/LUCI H+K (3hr)
[OII] < 3σ ; EW(OIII)~1000A

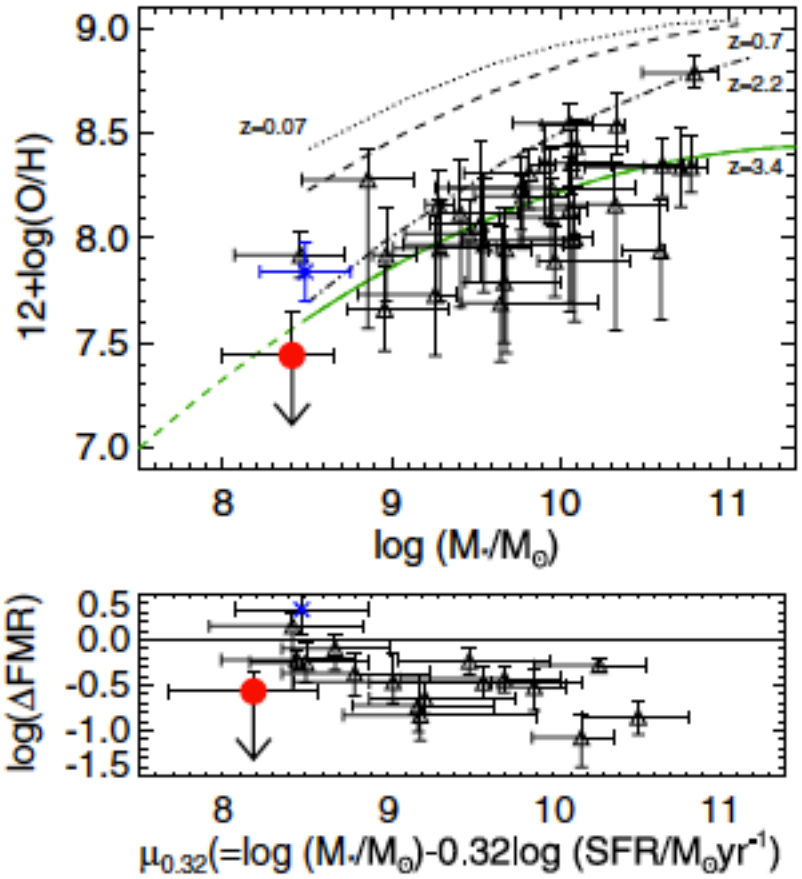




The source is a young starbursting dwarf galaxy (M_*/SFR ~ 100Myr) with unusually high nebular content (EW([OIII]~1000A), strong ionization ($\log(q_{ion})$=8.5) and very low metallicity, 12+log(O/H)<7.4 (< 5% solar).



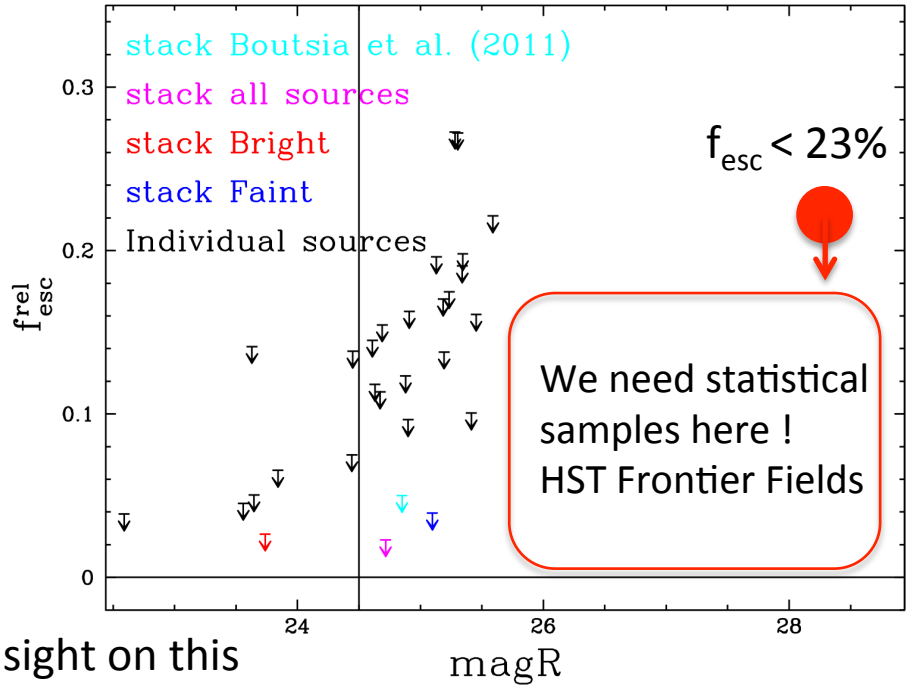
Ionization and metallicity diagnostics and comparison with LBGs at z~3 (Troncoso+13)



A new constraint to the low-mass end of the MZR at z=3.4

The source follow the trend of LBGs at z>3
→ offset from the lower-z MZR

Unique object to derive first limits to the LyC escape fraction at z>3 in the regime of very low intrinsic luminosity (L~0.05L*)

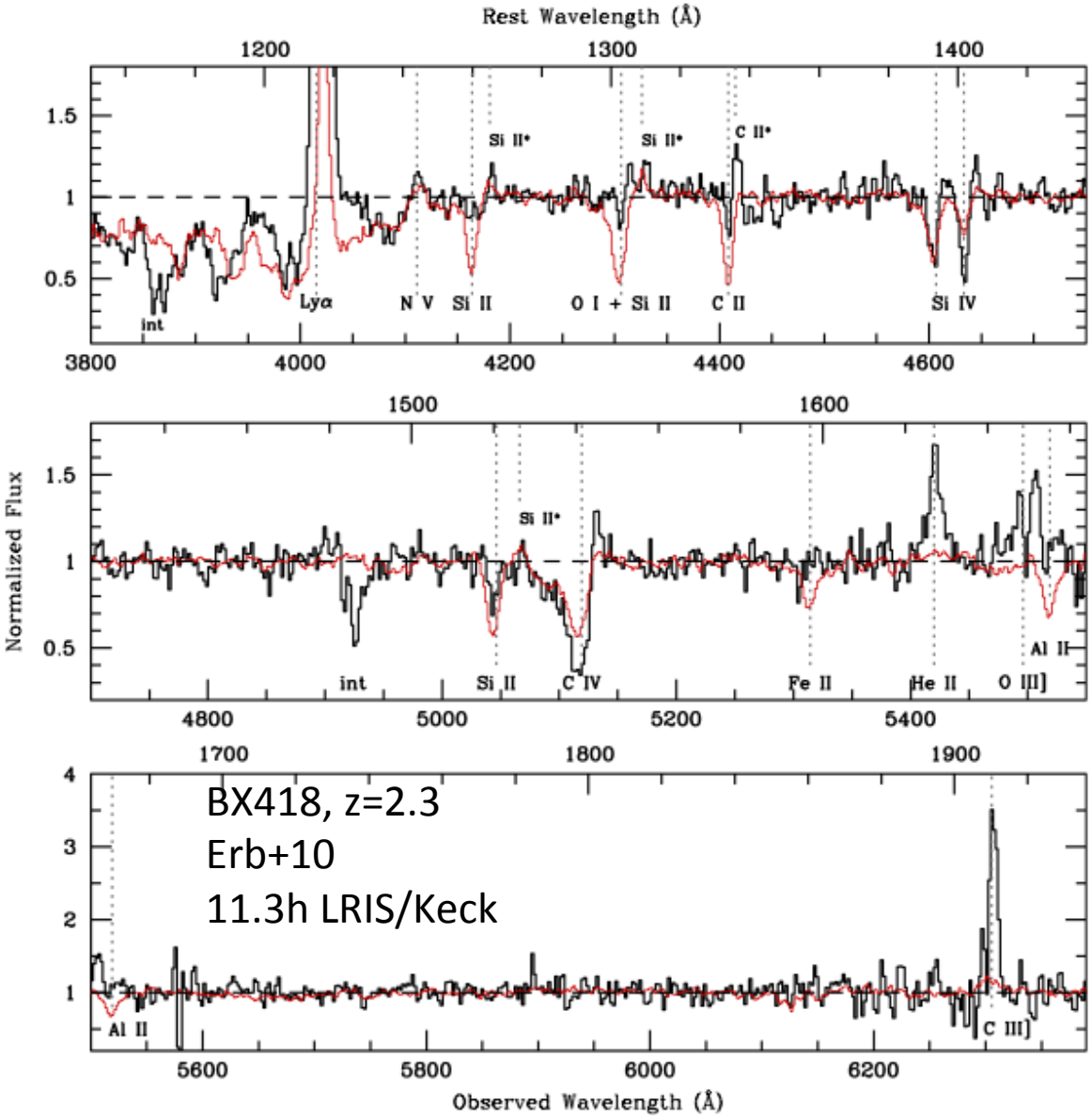


Offset >0.5 dex from the FMR
Suggests massive gas flows in action
e.g. pristine gas accretion feeding the recent starburst

Upcoming UV-to-NIR XSHOOTER data will add insight on this

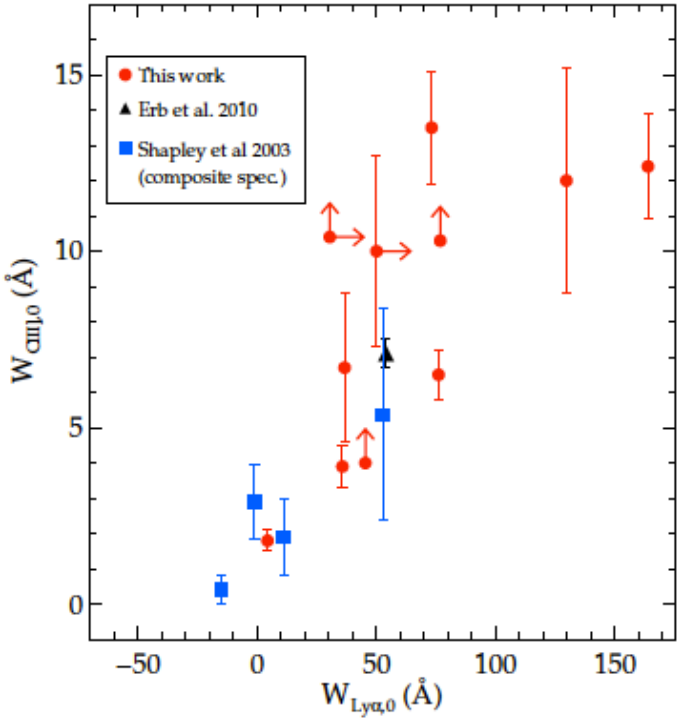
The rest-frame UV spectra of high-z EELGs

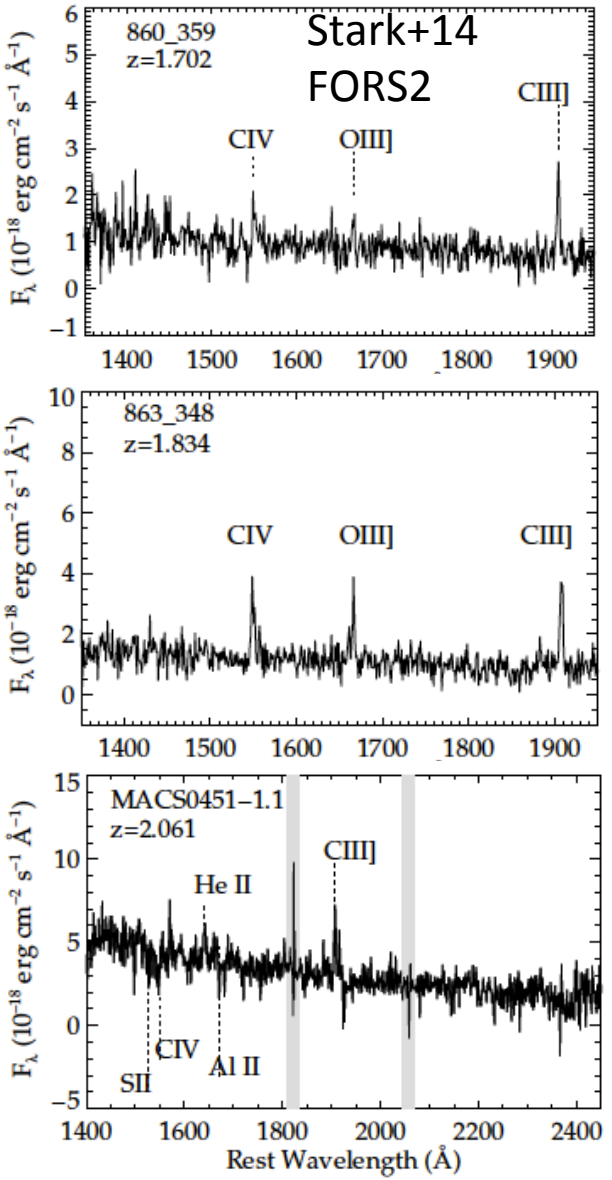
The rest-frame UV spectra show large EW nebular emission lines which are rarely seen in spectra of more massive star forming systems (e.g. CIII]1907,1909, OIII] 1661, 1667, He II 1640 and CIV 1548,1550).

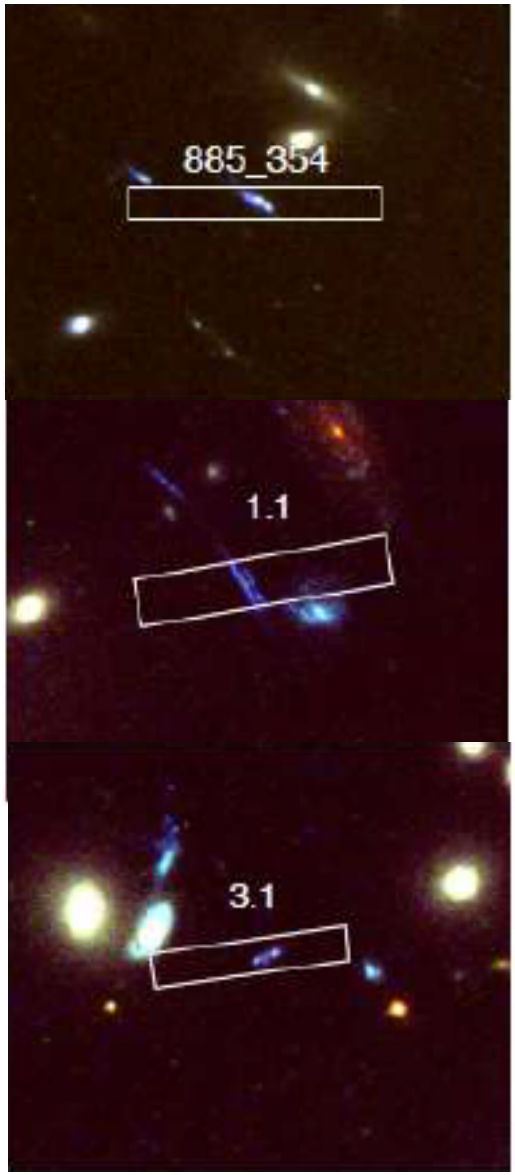


The rest-frame UV spectra of high-z EELGs

The rest-frame UV spectra show large EW nebular emission lines which are rarely seen in spectra of more massive star forming systems (e.g. CIII]1907,1909, OIII] 1661, 1667, He II 1640 and CIV 1548,1550).



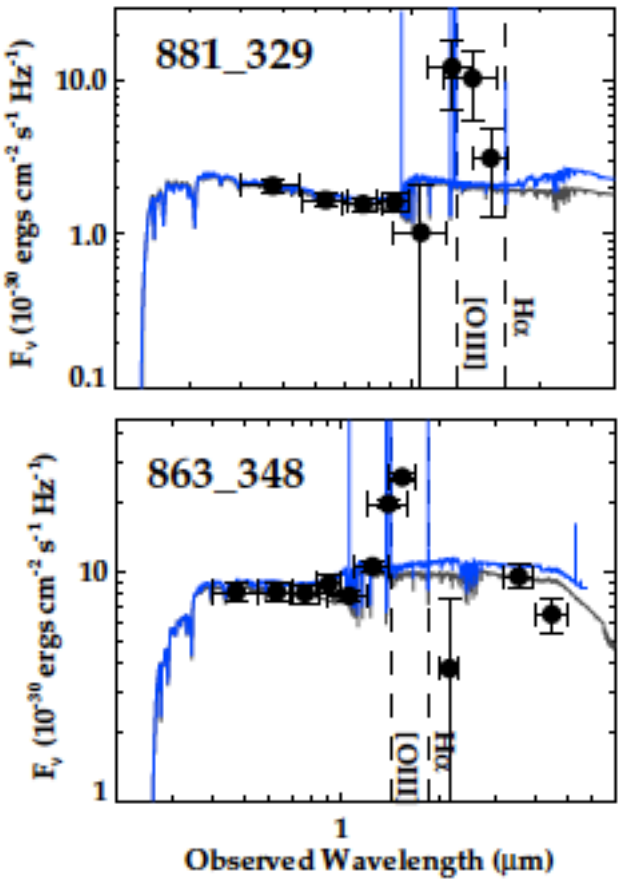


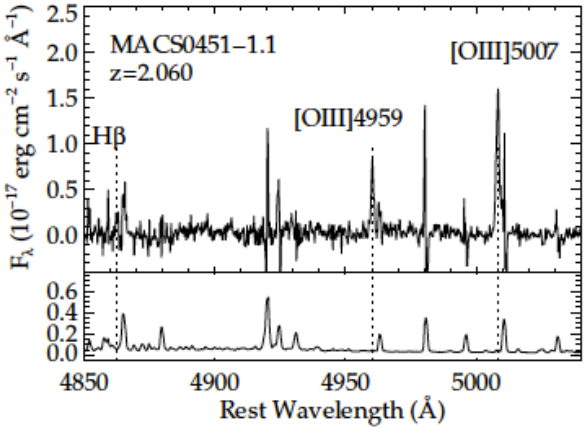


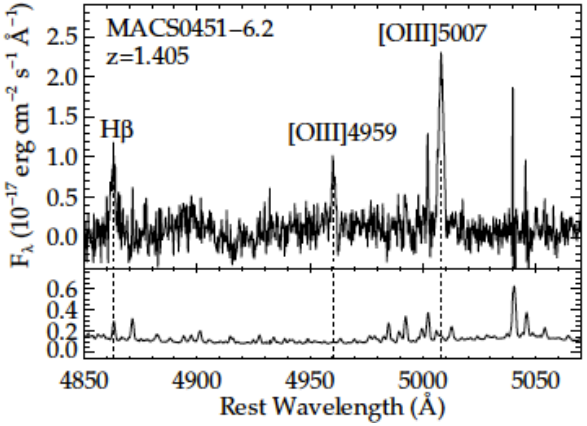
The rest-frame optical spectra of high-z EELGs

Metallicity measurements from *rest-frame optical* emission lines point toward metal-poor ionized gas (< 0.2 $Z_{\odot}$).

The relative strengths of the emission lines require a much larger ionization parameter than is seen in more massive, metal-rich galaxies.







Stark+14

Gas-phase metallicity is a key quantity for galaxy evolution studies

- Direct method: Based on the direct measurement of the electron temperature from Oxygen line ratios (e.g. [OIII] 4363/5007)
  - The most reliable method, especially at low metallicity (Z<0.5 Zsolar)
  - It requires at least one oxygen auroral line ([OIII]4363 in the optical or OIII]1661,1666 in the UV) These lines can be very faint… ☹

- Strong-line methods: calibrations between metallicity and strong emission lines (e.g. [NII]/Ha, [OII]+[OIII]/Hb, …)
  - Empirical calibrations: From galaxies (HII regions) for which O/H is known via the direct method (e.g. Pettini & Pagel 2004; Nagao+06, Perez-Montero & Contini 2009, Pilyugin +12, Marino+13)
  - Comparison with photoionization modeling (e.g. McGaugh 1991, Kewley & Dopita 2002) They work better at solar and supersolar abundances (Bresolin+06). They cover all possible range of parameters, but it carries our limitations in the knowledge of the actual physical conditions of the nebulae → systematic uncertainties may appear.

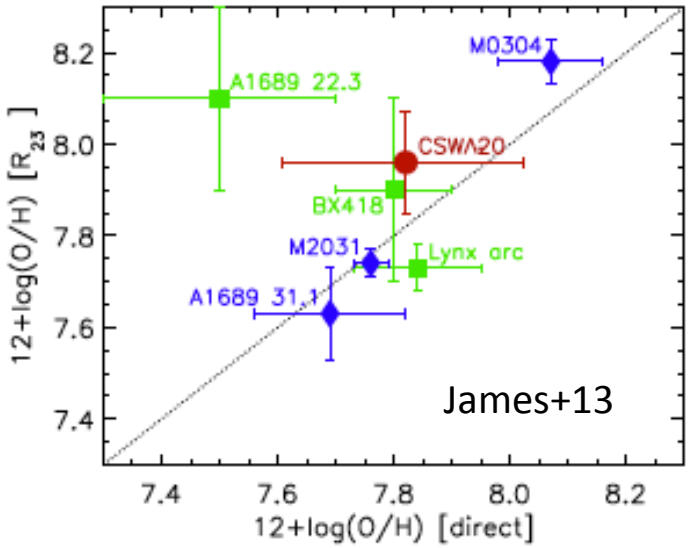
  Problems: Some calibrations are not monotonic (e.g. R23). Large dispersion depending on e.g. the available set of lines, metallicity range, ionization…Calibrations are based on local galaxies…limitation for high-z studies? (Kewley+13,Cullen+14)

Systematic differences between these methods can be as large as a factor of 2 or larger (Kewley & Ellison 2008)

O/H from UV and optical spectra

Direct metallicities have been derived only for a handful of galaxies at high redshift (z>2), most of them strongly lensed objects
(e.g. Villar-Marin+03, Erb+10, Christensen+12)
Strong-line ratios needs corrections for ionization

[OIII]1666/5007 gives T_e
→ Direct metallicity
However, for galaxies at z>2, this requires both high quality optical *and* NIR spectra



C/O abundance from UV

CIII and OIII] UV lines are stronger in metal-poor (<0.2 solar), high ionization systems (log U>-1.6)
(Erb+10)

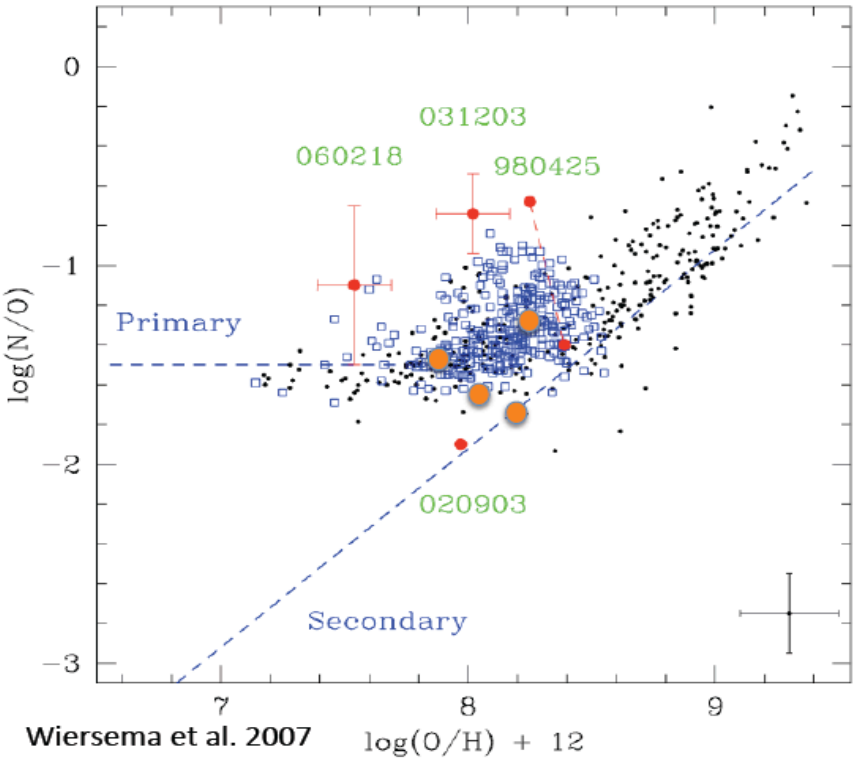
CIII]1909/OIII]1666 → C/O abundance

$$\frac{C^{+2}}{O^{+2}} = 0.15\, e^{-1.1054/t}\, \frac{I(\text{C III}]\ \lambda\lambda 1907, 1909)}{I(\text{O III}]\ \lambda\lambda 1661, 1666)}$$

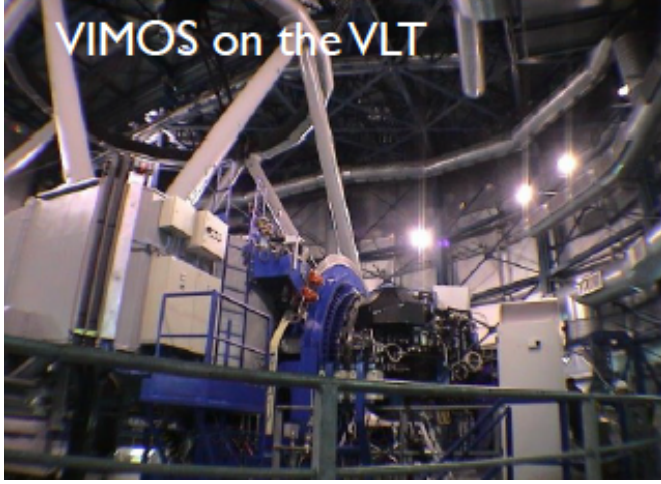
$$\frac{C}{O} = \frac{C^{+2}}{O^{+2}} \times \text{ICF}$$

ICF is taken from U (e.g. O32, CIV/CIII]) using models

C/O depends on metallicity and probes rapid enrichment by massive stars (similarly to N/O)



THE VIMOS ULTRA DEEP SURVEY (VUDS)



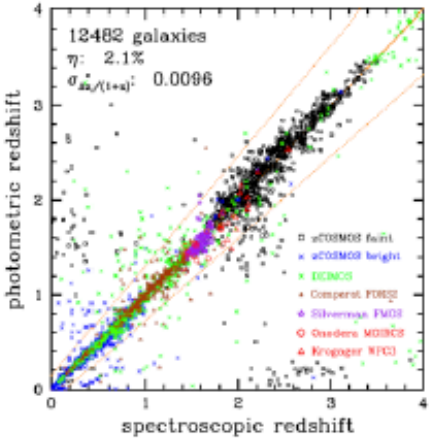
- ESO Large Program: 640h
- Focused on 2<z<6
- 1 deg²
- 10,000 targets
- 3 fields: mitigate cosmic variance
- Selection: photo-z + SED + color, iAB≤25
- 14hr integration over 3600-9300Å
- 8000 galaxies with 2<zspec<6.5

Details in Le'Fevre +2014

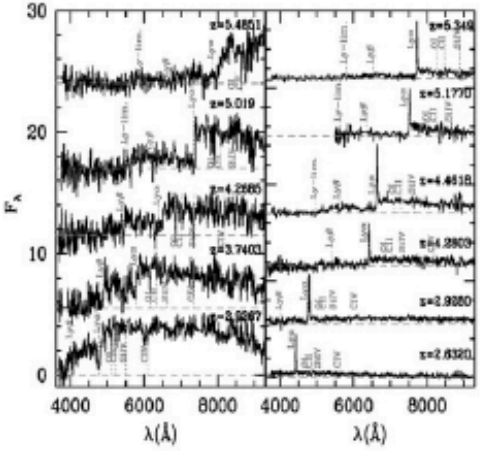
VVDS_02 COSMOS ECDFS



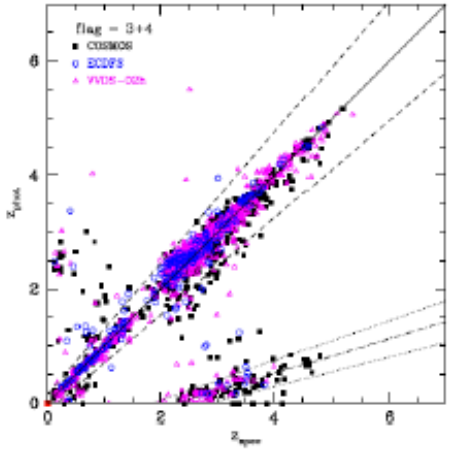
Selection



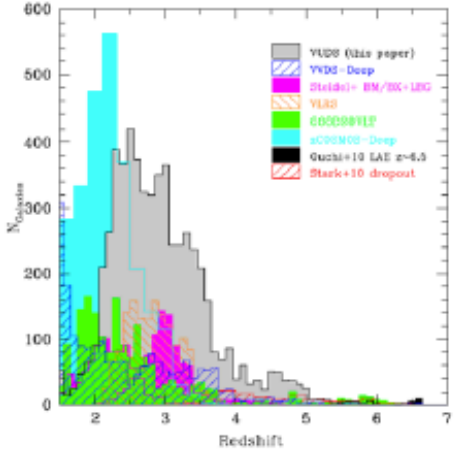
Spectra



zphot – zspec



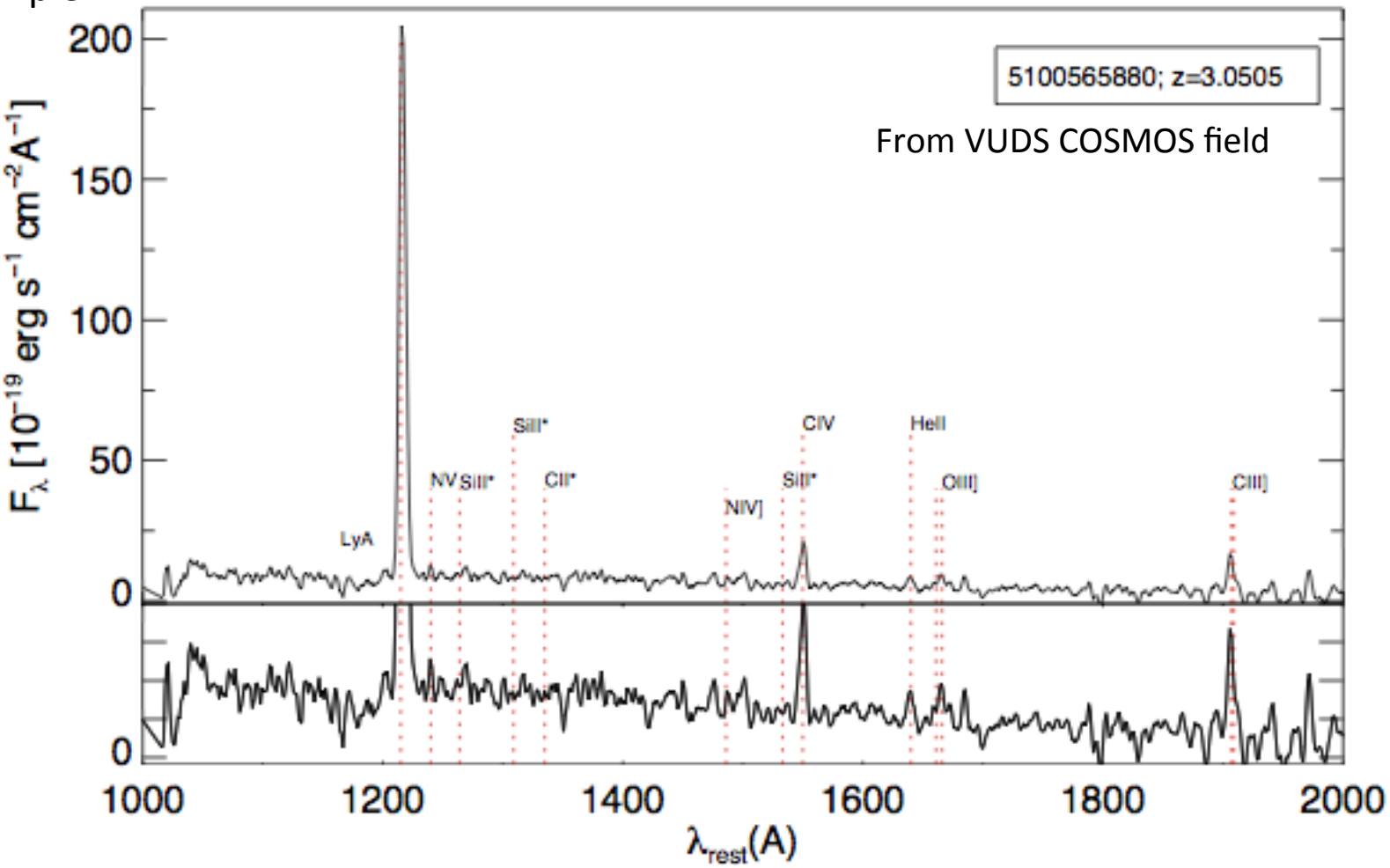
8000 zspec



Our project

1- To perform a systematic search for CIII]1909 emitters in the VUDS database.
Look for the presence of OIII]1666

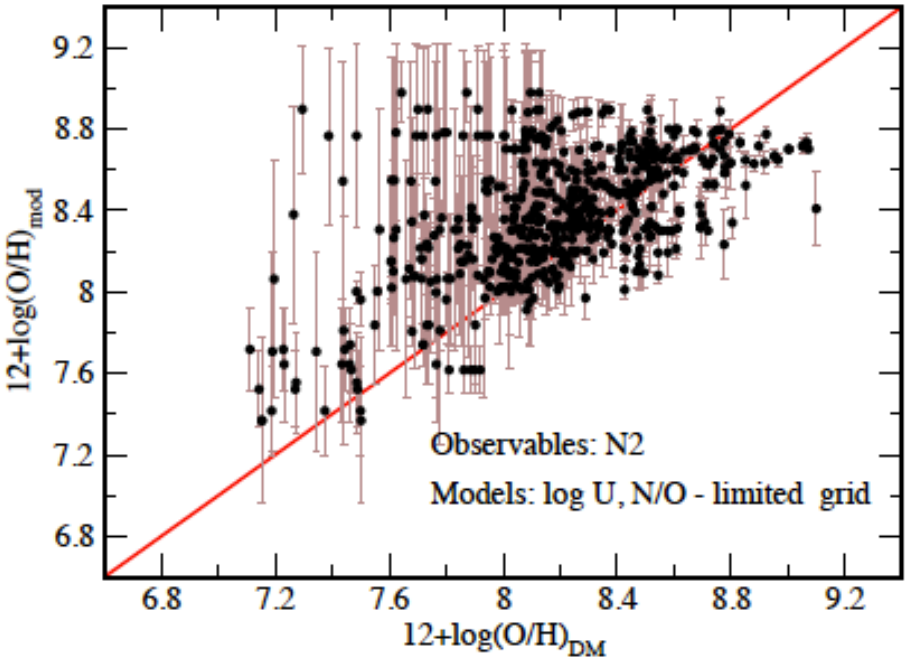
For example:

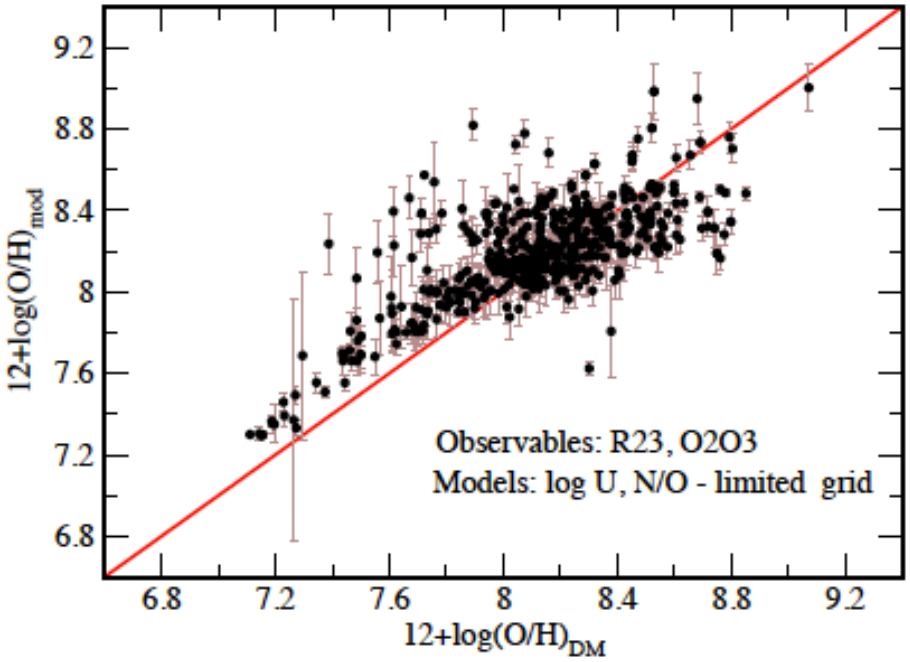


2- To compare the derived C/O ratios and log U with the predictions of an updated grid of photoionization models and derive O/H using a Bayesian approach

We will use the recent code HII-CHI-MISTRY (Perez-Montero 2014), which uses:

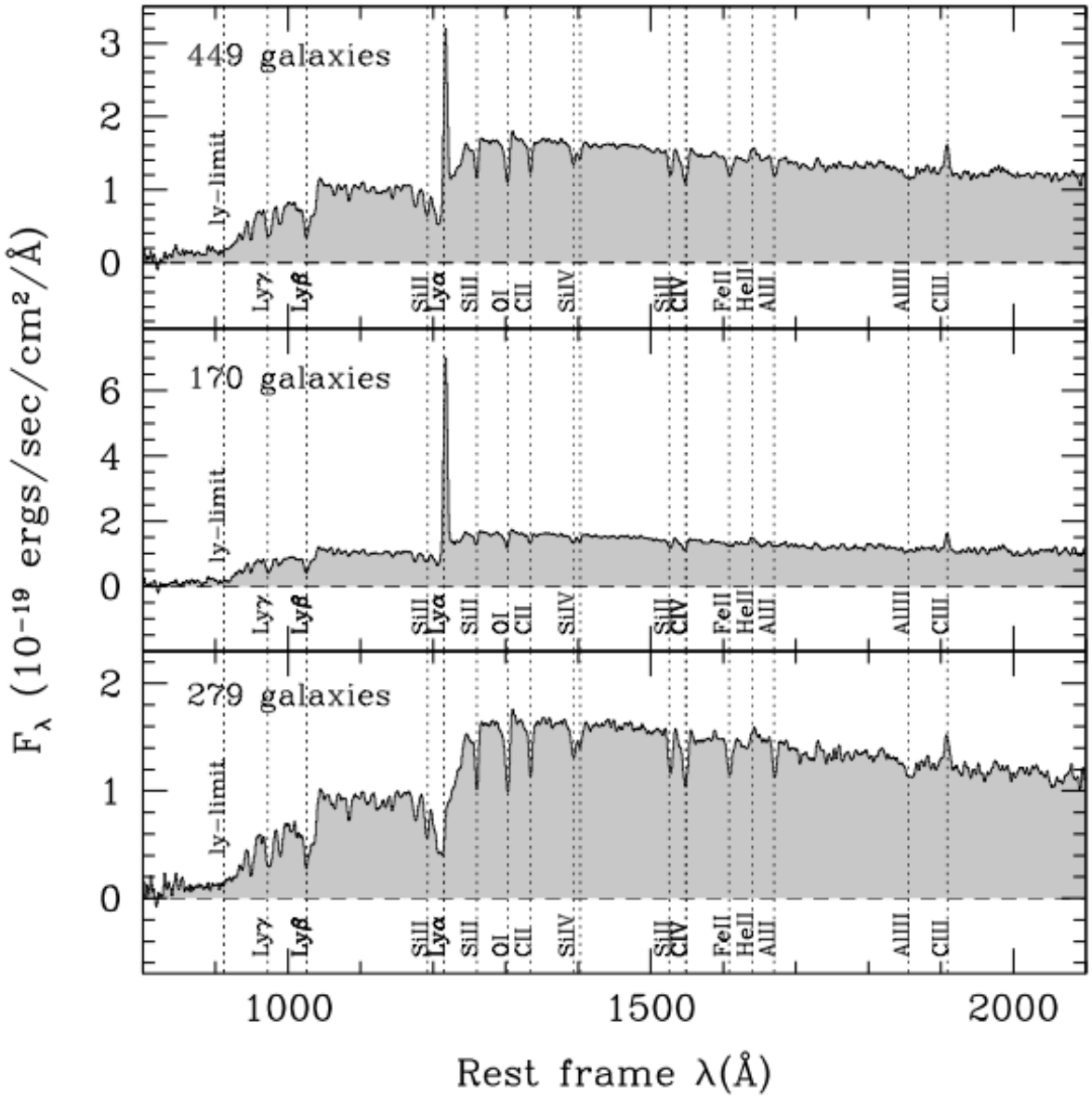
- A large grid of CLOUDY photoionization models (Ferland+13) -> O/H, N/O and log U
- A reference sample of HII galaxies/regions with accurate O/H and N/O abundances from at least one auroral line -> this sample is used to restrict the grid of models in N/O and log U
- Using a Chi^2 weighted mean procedure, chemical abundances for each object are recalculated using the models. A model-based N/O is found and then O/H and log U are searched in following iterations.





We may find many CIII] emitters in VUDS

VUDS galaxies at z=3-4; LeFevre+14

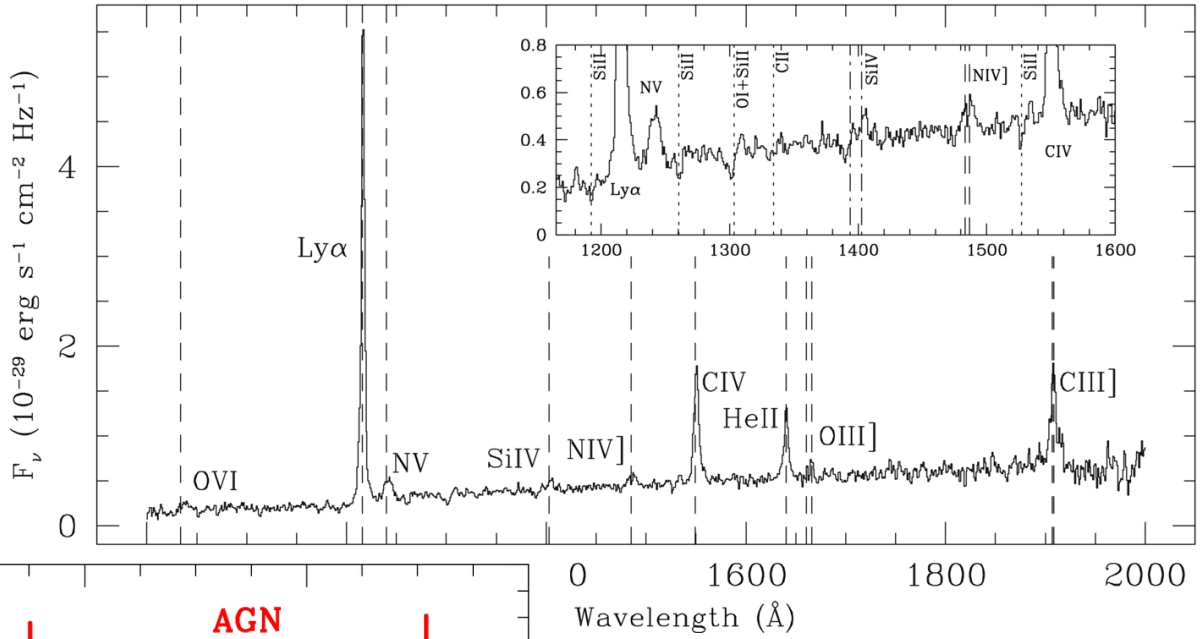


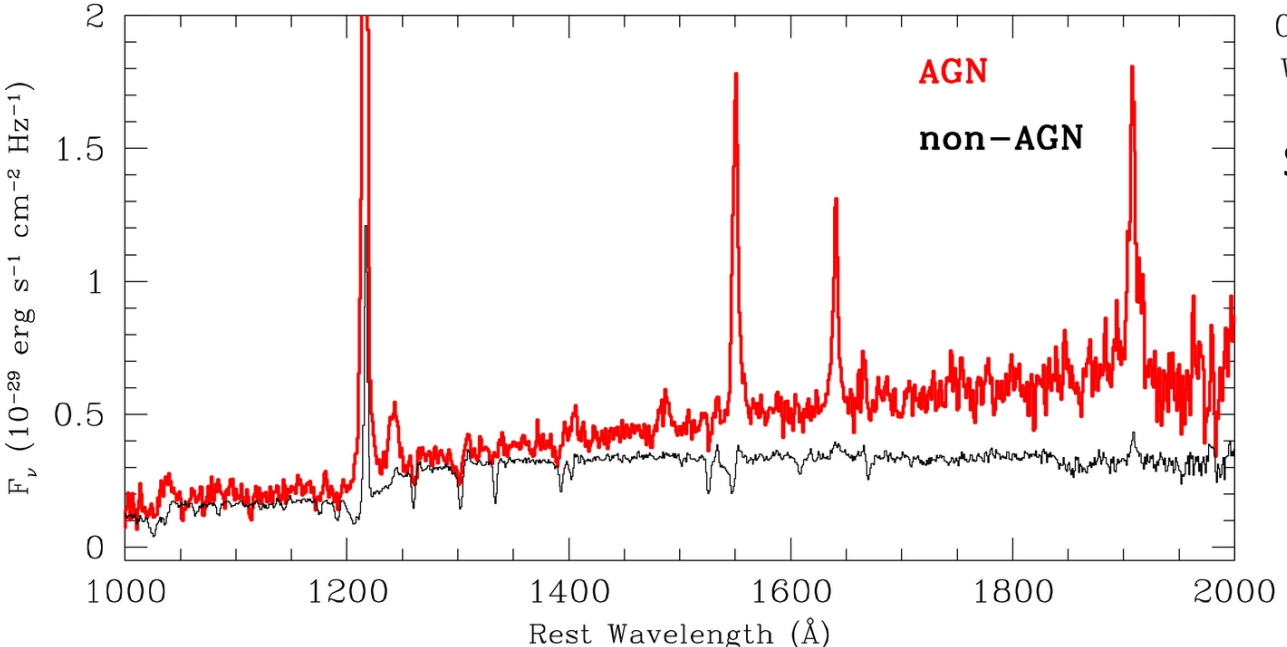
We can apply the method to stacked spectra according to different criteria (e.g. redshift, luminosity, mass…)

Young low-mass starbursts vs. NL-AGNs

Presence of (low-luminosity) narrow-lined AGNs?
-> We need a careful candidate selection

Possible criteria:
CIV/CIII] (e.g. Stark+14, Dors+14)
Continuum color
X-rays

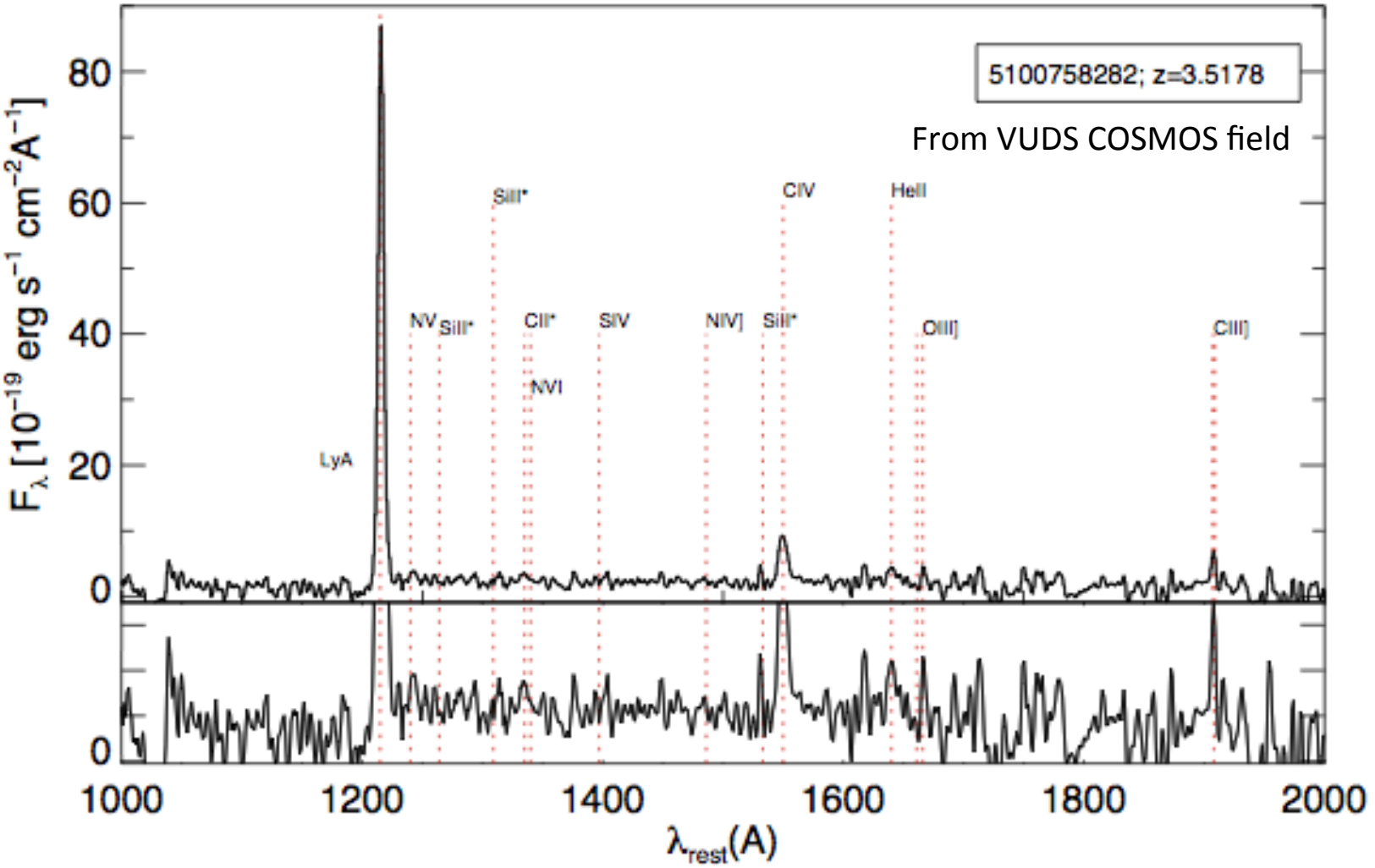




Steidel+02

Low-luminosity NL AGN in VUDS ?

(random example)



A method for deriving metallicity of the NLR in AGNs

Dors et al. (2014) proposed a new strong-line index based on nebular UV lines

C43 = log[(CIV+CIII])/He II] as metallicity indicator

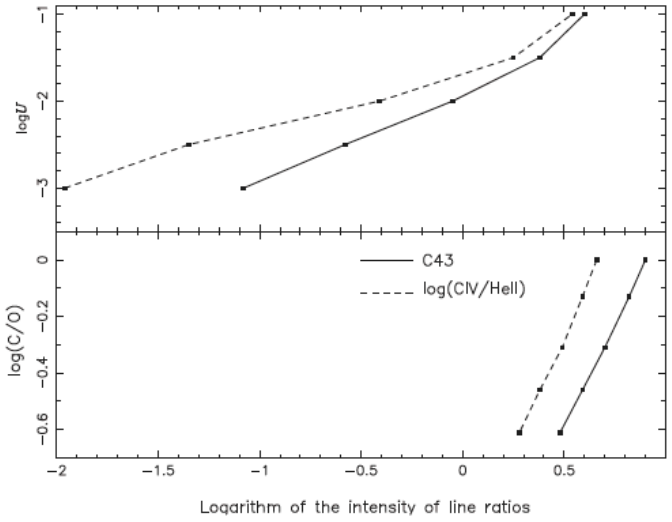
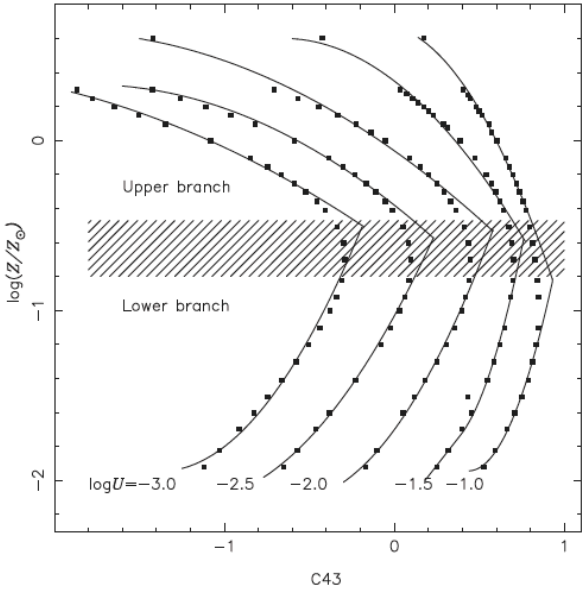
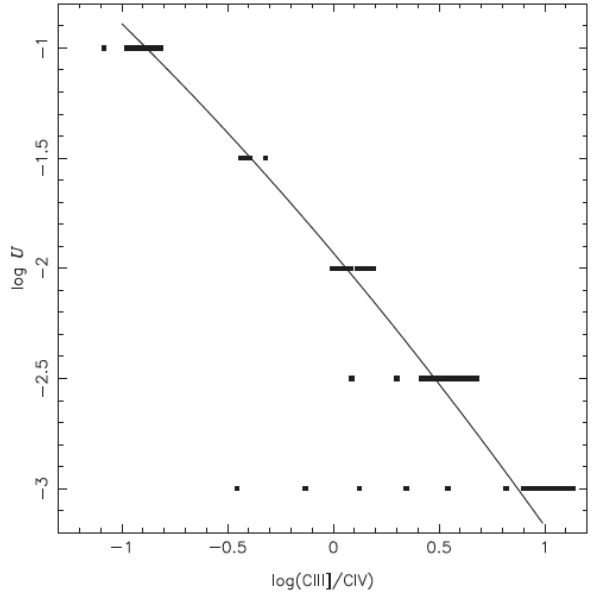


Figure 3. Bottom panel: abundance ratio of C/O versus the value of the metallicity indicators C IV/He II and C43 as indicated. Lines connect the results of our models, represented by points, built considering $\log U = -1.4$, and the other parameters as described in Section 4. Top panel – logarithm of the ionizing parameter versus the value of the metallicity indicators C IV/He II and C43. A solar metallicity was considered.





$\log(Z/Z_{sun}) = a\ C432 + b\ C43 + c$

Where a, b and c are taken for different values of log U.