Secondary chemical abundances in starburst galaxies in different cosmological epochs

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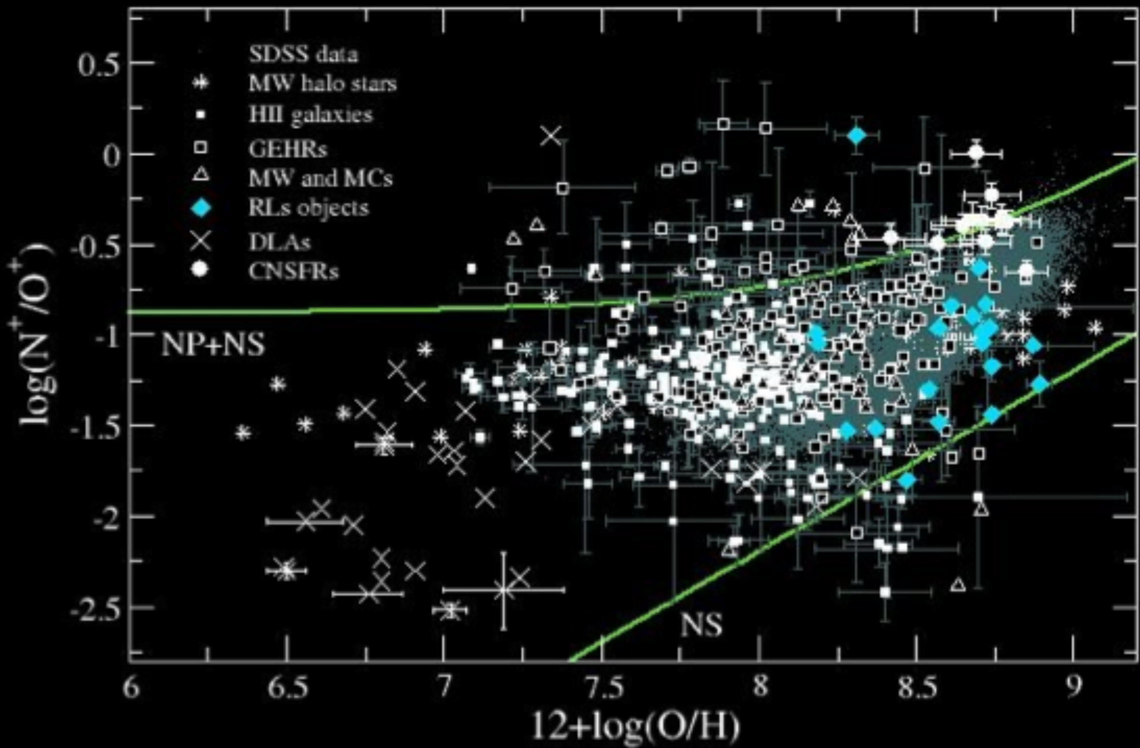
Secondary elements in starbursts

$$^{12}C + p \rightarrow {}^{13}N + \gamma$$
$$^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$$
$$^{13}C + p \rightarrow {}^{14}N + \gamma$$
$$^{14}N + p \rightarrow {}^{15}O + \gamma$$
$$^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$$
$$^{15}N + p \rightarrow {}^{12}C + {}^{4}He$$



Pérez-Montero & Contini (2009)

The dispersion of the O/H vs. N/O relation

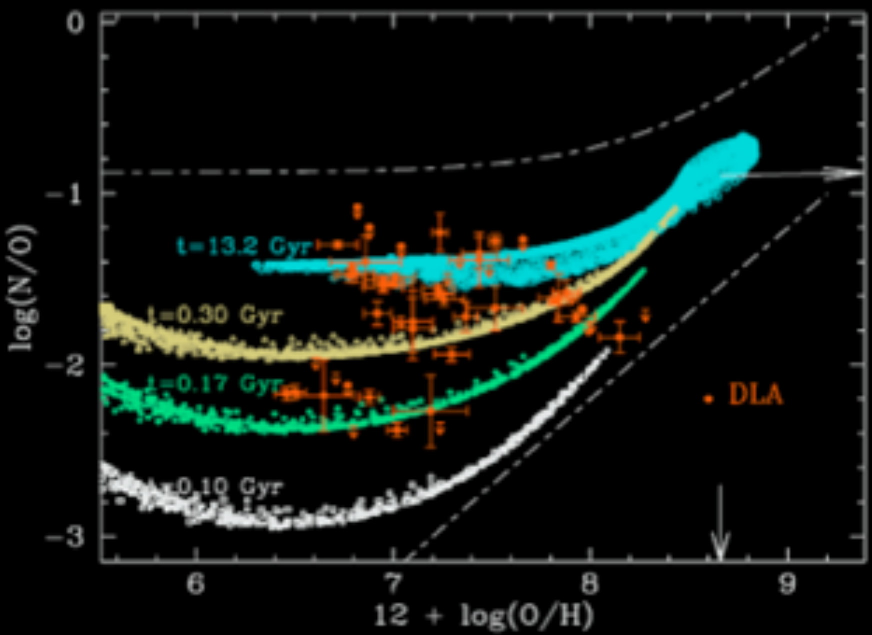
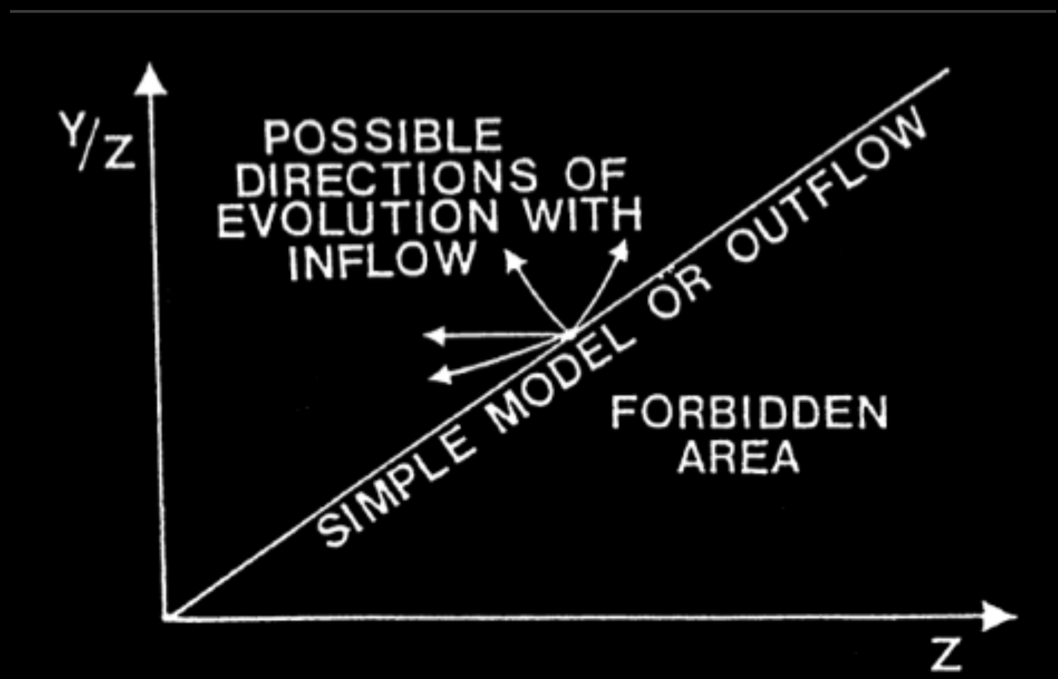


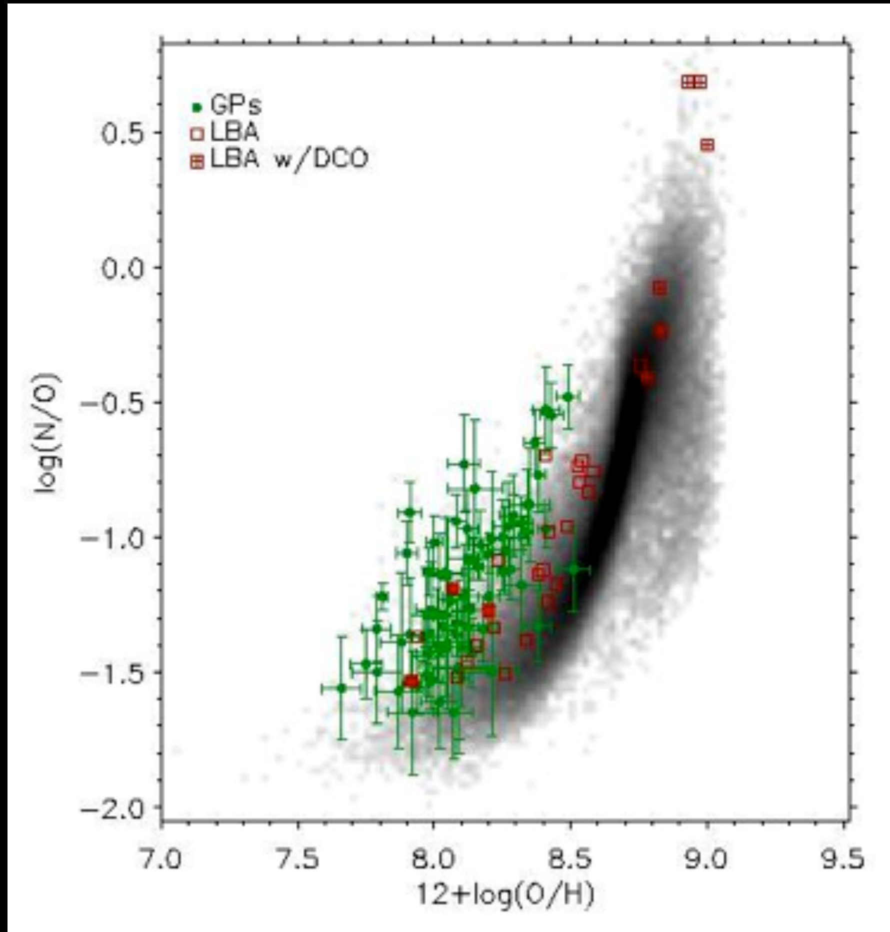
Figure 10. The relation N/O–O/H for different evolutionary times as marked in the figure. The full (cyan) dots correspond to DLA objects.

Mollá et al. (2006)

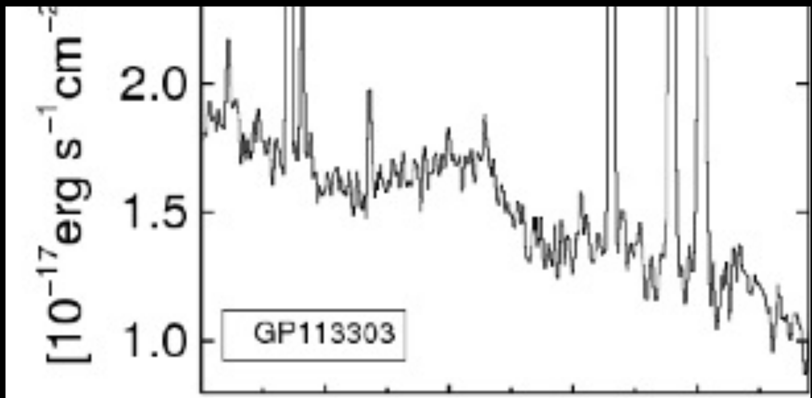


Edmunds (1990)

The green pea galaxies

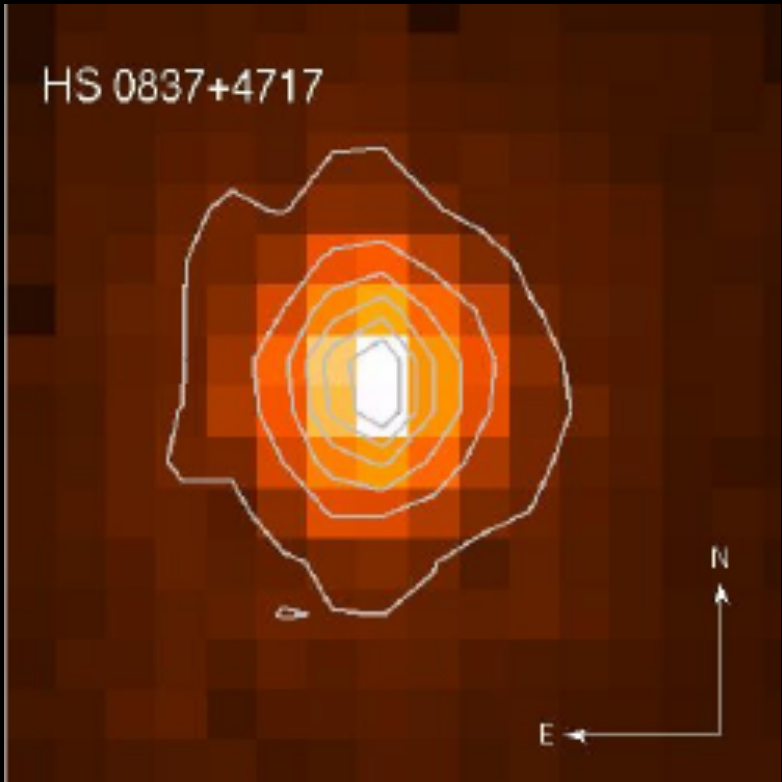


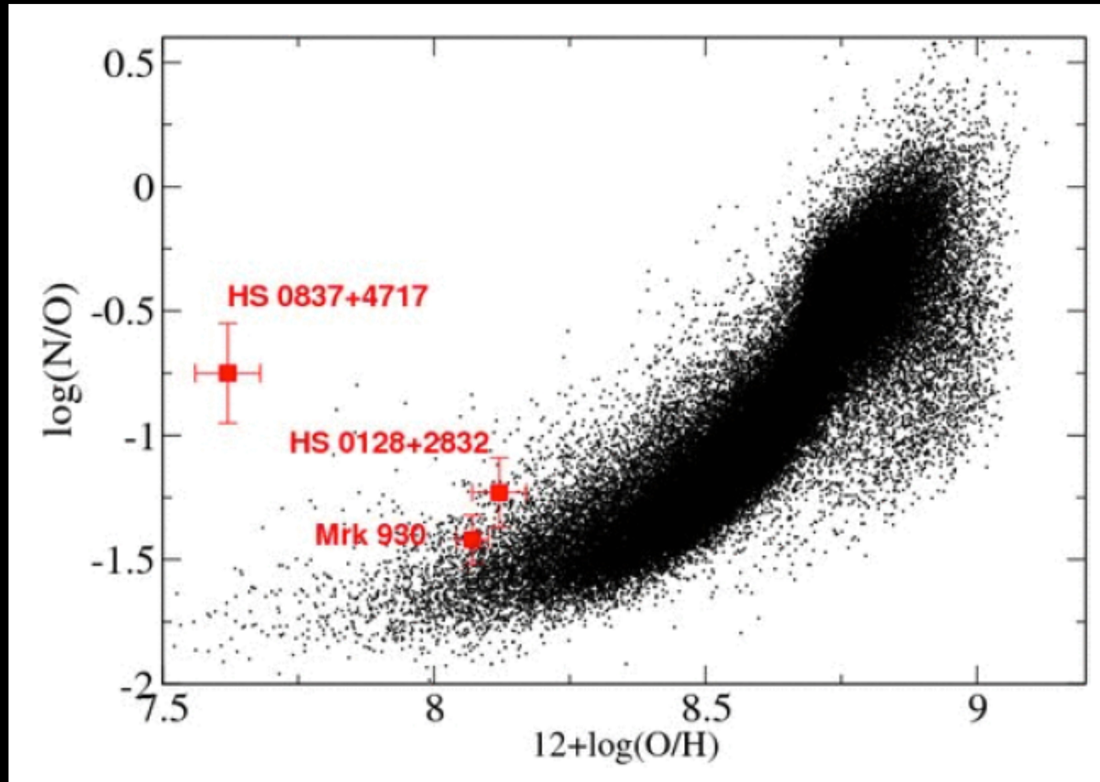
Amorín et al. (2010)



Amorín et al. (2012)

N overabundant XMPs with IFUs

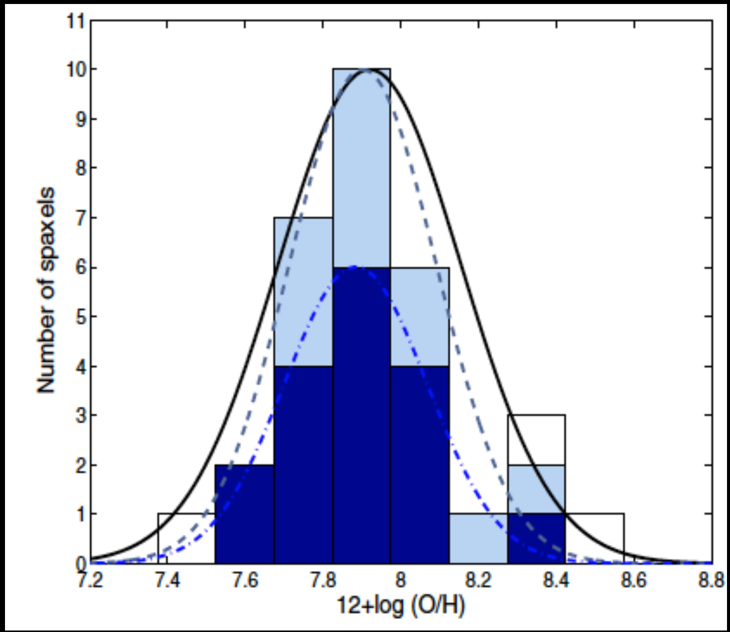


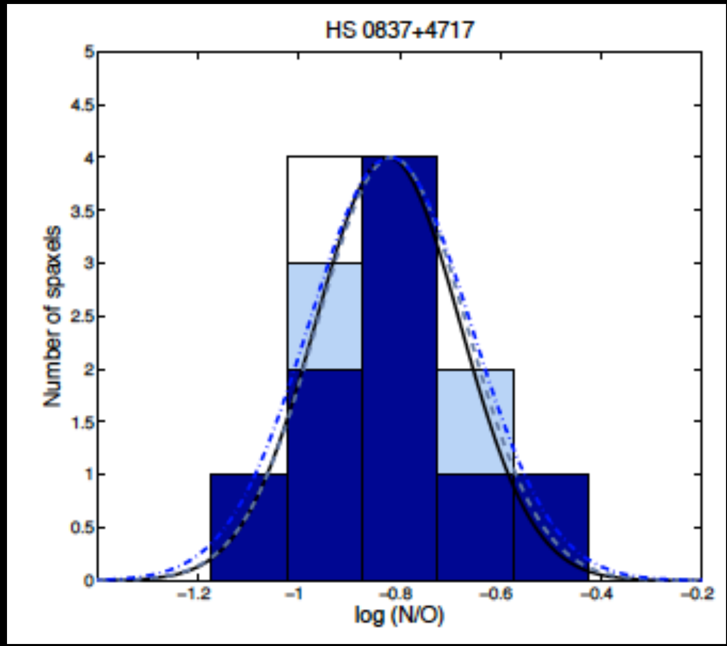


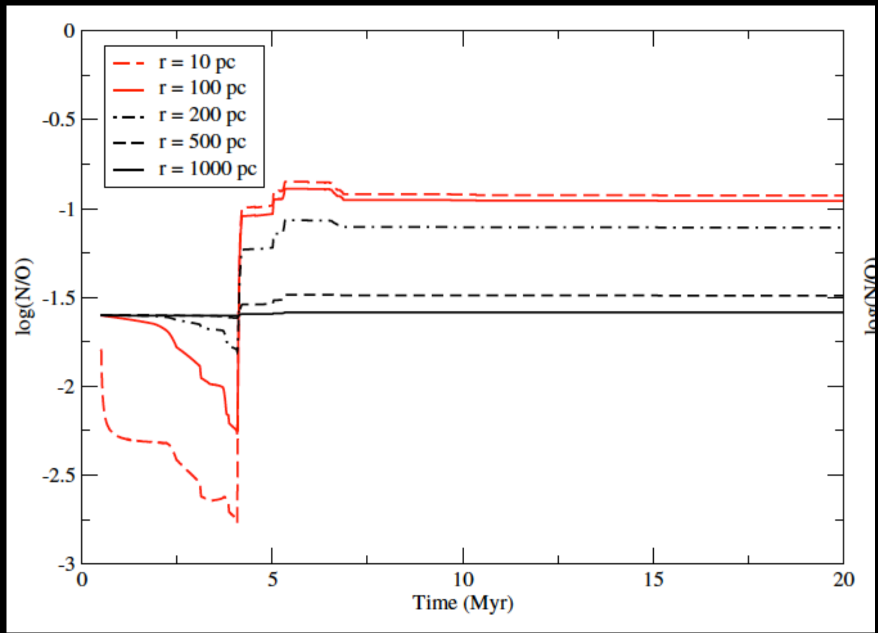
Pérez-Montero et al. 2011

N overabundant XMPs with IFUs

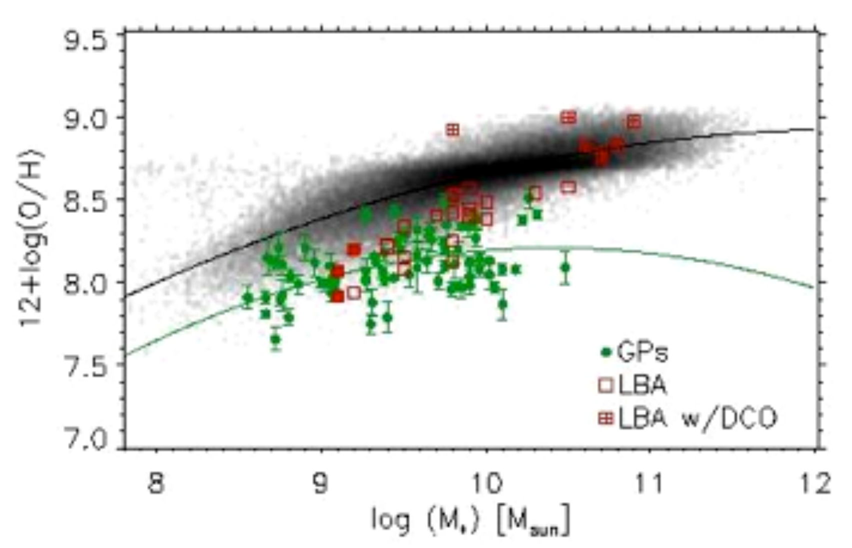
Pérez-Montero et al. 2011

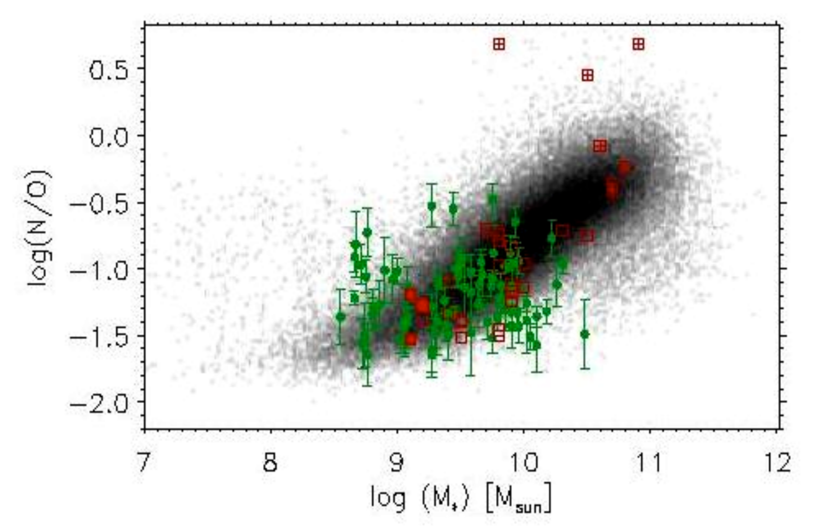




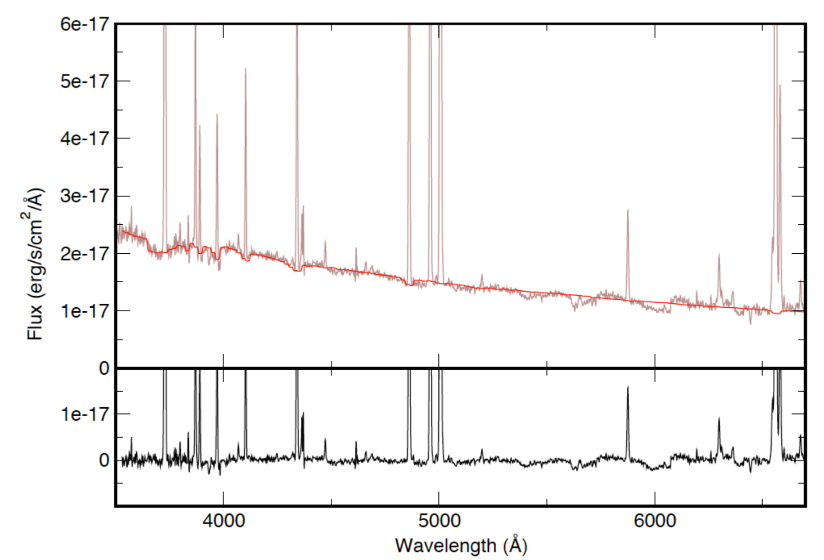


The nature of the green pea galaxies



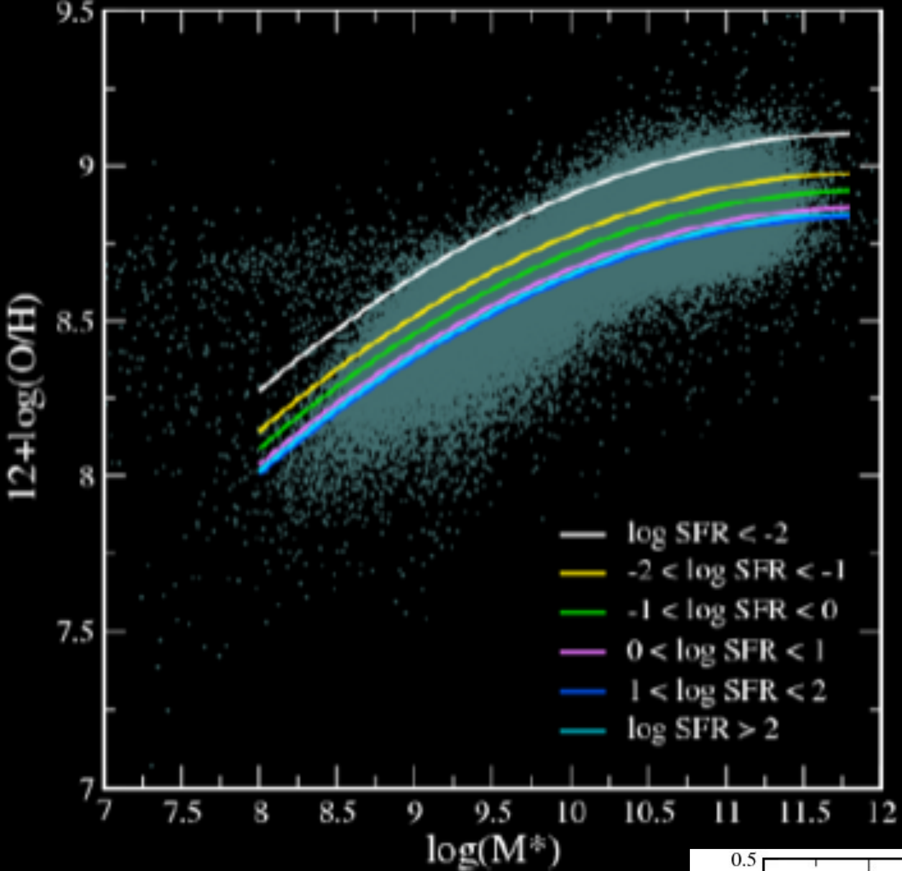


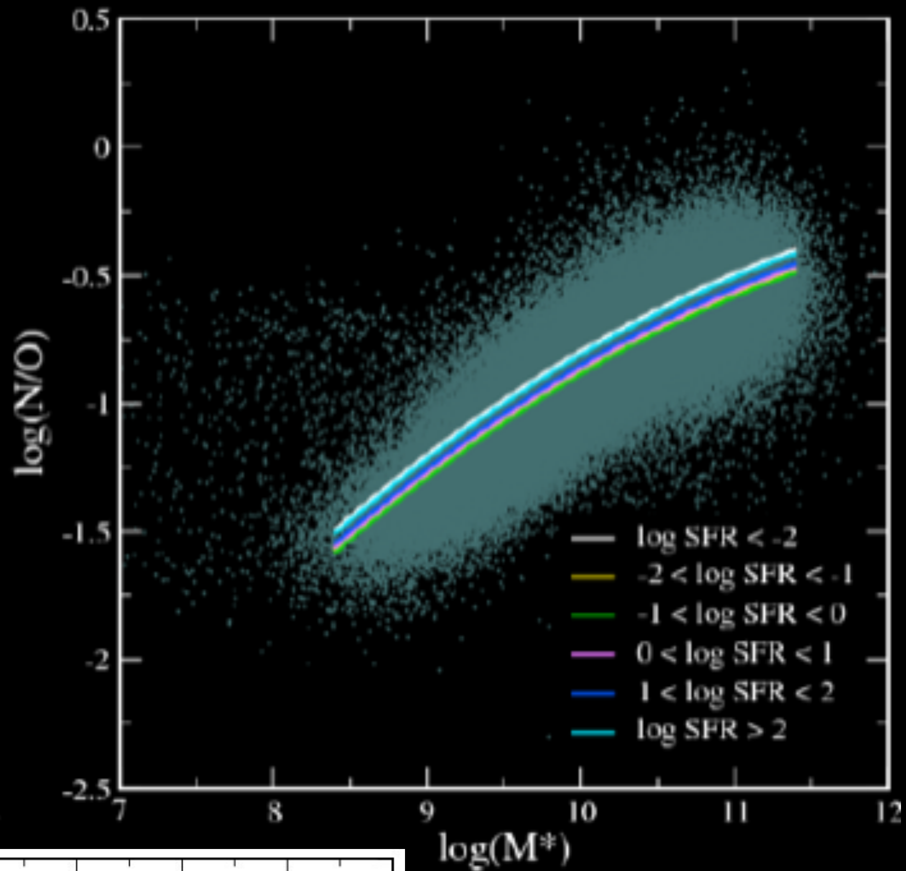
Amorín et al. (2010)



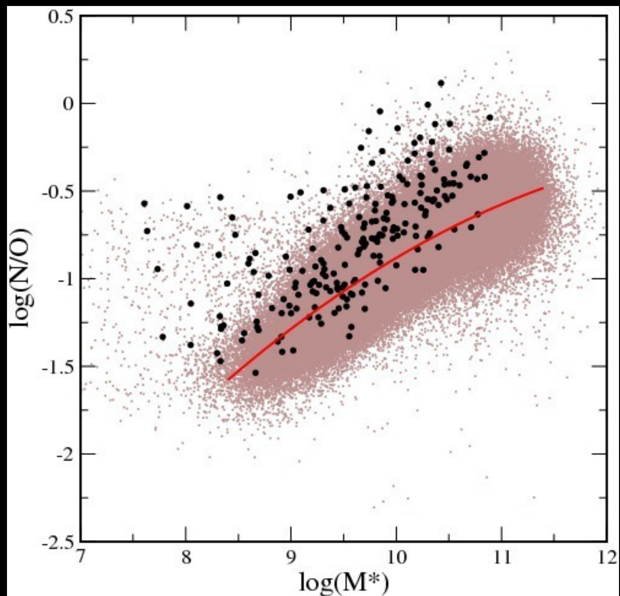
Amorín et al. (2012)

Relations with mass and SFR



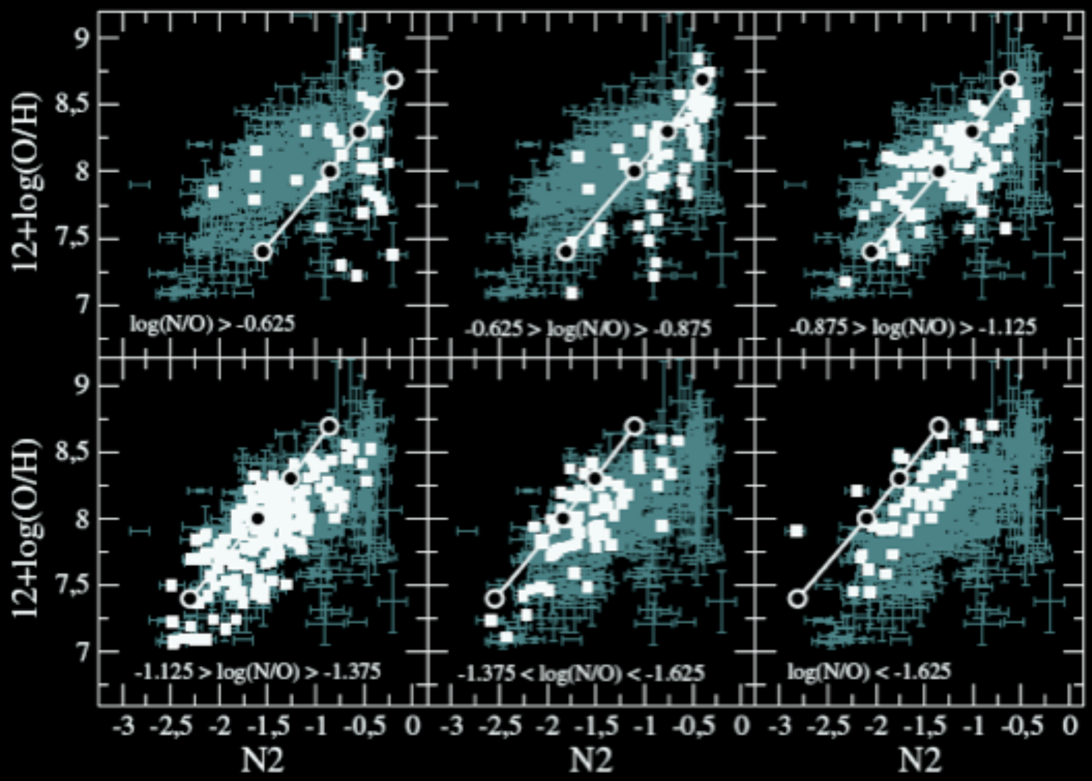


Pérez-Montero et al. (2013)

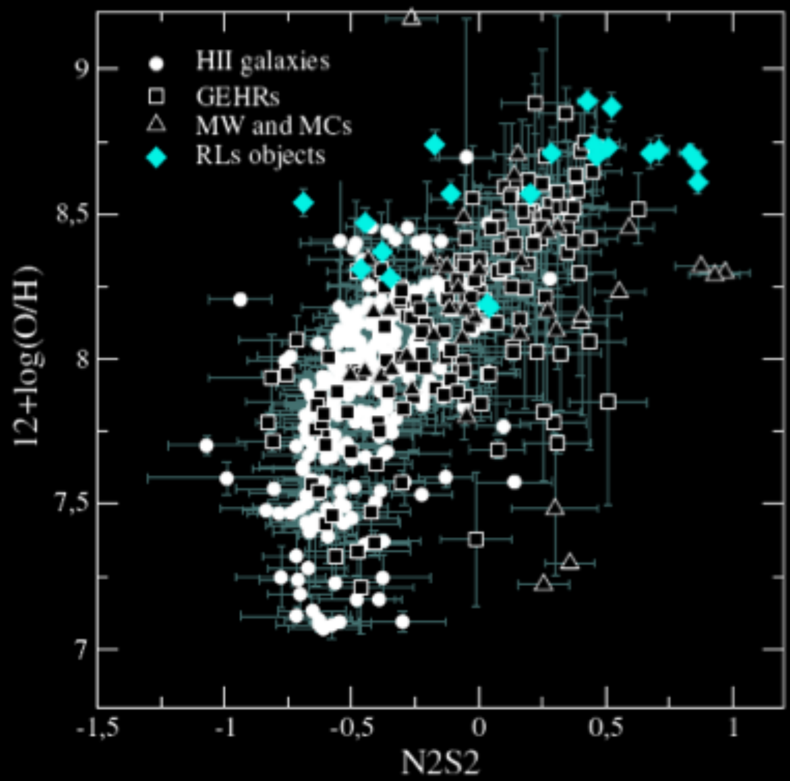


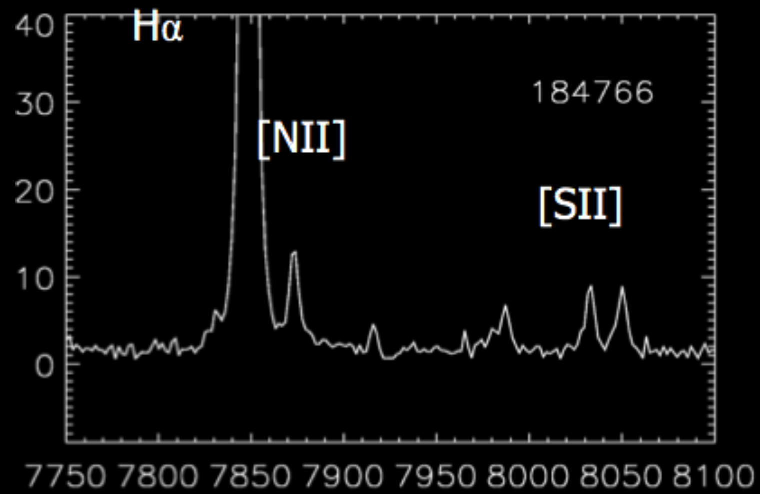
Pérez-Montero et al. (2013b)

Emission lines from secondary elements



Pérez-Montero & Contini (2009)

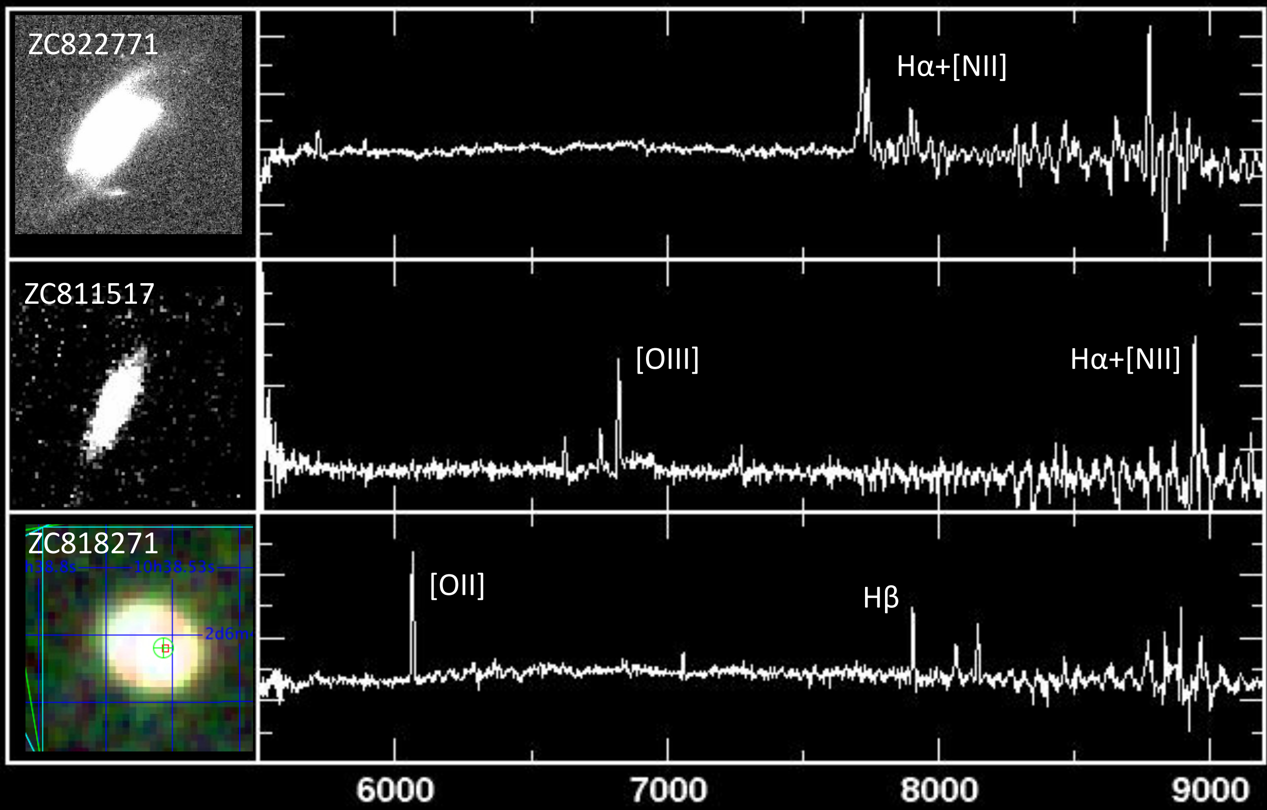




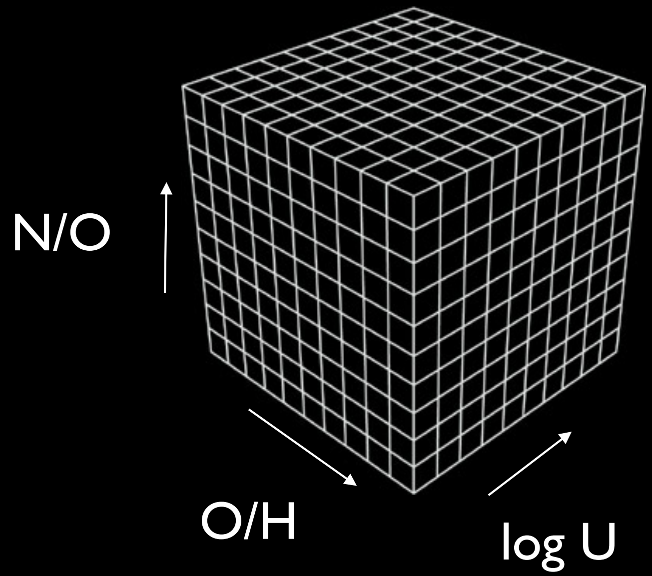
Requirements for a new model-based method

A new method should work for all metallicity regimes, using different sets of emission lines and deliver both O/H and N/O. This can only be achieved using models.

Ideally, it should be also consistent with the direct method if no additional physical assumptions are taken in the models (e.g. shocks, kappa distribution, t fluctuations, same atomic coefficients, etc.)



Abundance derivation: HII-CHI-mistry



Model-based abundances with HII-CHI-mistry (Pérez-Montero 2014)

- Cloudy v. 13.03 (Ferland et al. 2013)
- POPSTAR (Mollá et al. 2010) model stellar atmospheres (same Z as the gas, age = 1 Myr, Chabrier IMF)
- Constant density
- Radiation-bounded geometry
- All elements scaled to O, except N
- Standard MW dust-to-gas ratio
- Variation of input parameter:
  - 12+log(O/H): [6.9, 9.1] 0.1bin
  - log(N/O): [-2.0,0.0] 0.125bin
  - log U: [-4.00,-1.50] 0.25bins

This gives a total of 3,927 models

HII-CHI-mistry: A new model-based tool to derive abundances

HII-CHI-mistry (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 χ2 weighted mean of the differences with the reddening corrected [OII], [OIII] (4363 and 5007), [NII] and [SII] optical emission lines.

$$\chi_i^2 = \sum_j \frac{(O_j - T_{ji})^2}{O_j},$$

STEP 1

N/O is calculated using as observables adequate emission-line ratios (e.g. N2O2, N2S2) insensitive to O/H and U

$$\log(\mathrm{N/O})_f = \frac{\sum_i \log(\mathrm{N/O})_i / \chi_i}{\sum_i 1/\chi_i},$$

Errors are calculated as the standard deviation of the weighted distribution

$$(\Delta \log(\mathrm{N/O}))^2 = \frac{\sum_i \log((\mathrm{N/O})_f - \log(\mathrm{N/O})_i)^2 / \chi_i}{\sum_i 1/\chi_i}.$$

STEP 2

The grid of models is constrained for the closest values of N/O and [NII[can be used in a new iteration to derive O/H and log U in a similar way.

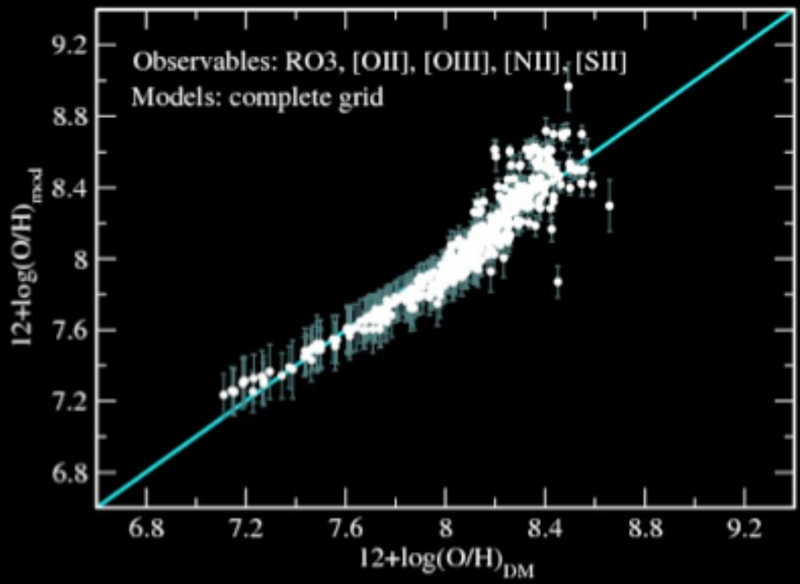
$$12 + \log(O/H)_f = \frac{\sum_k (12 + \log(O/H))_k / \chi_k}{\sum_k 1/\chi_k}$$

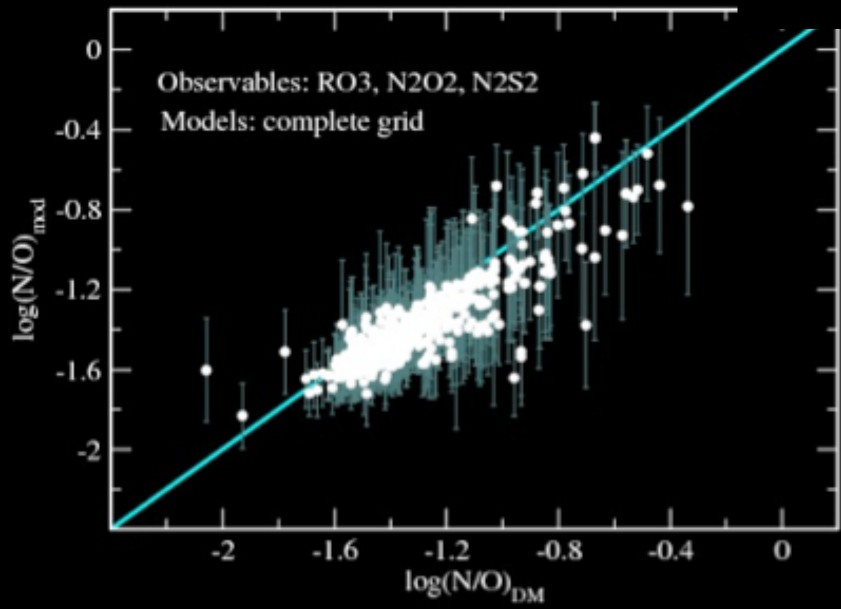
$$\log U_f = \frac{\sum_k \log U_k / \chi_k}{\sum_k 1/\chi_k}$$

HCm

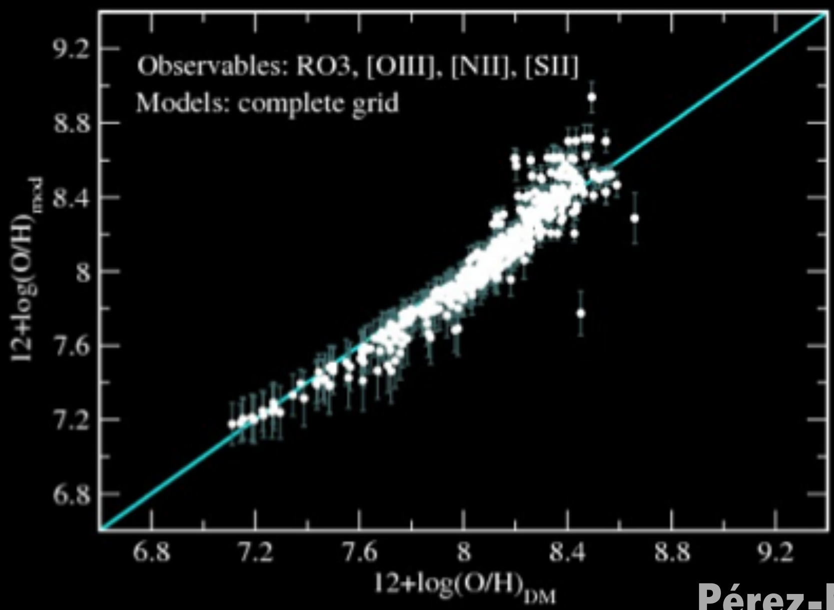
Full consistency between HCM and the direct method

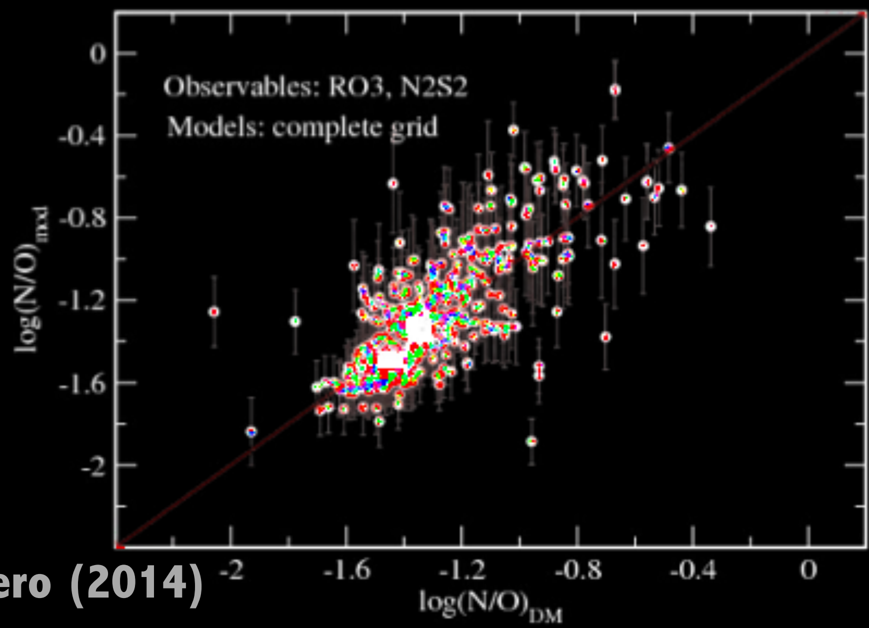
Comparison using all emission lines including [OIII] 4363





Comparison using all emission lines excluding [OII] 3727

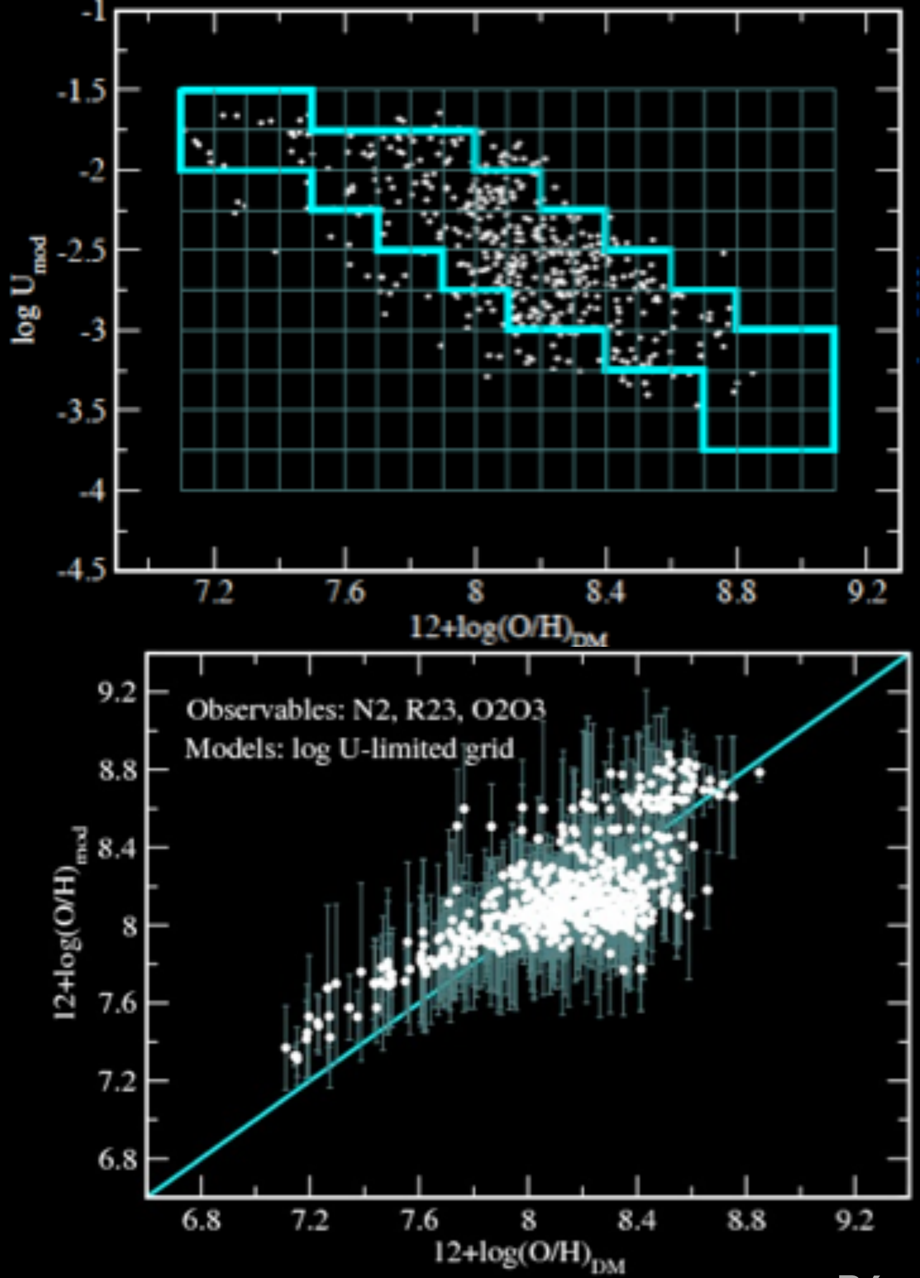




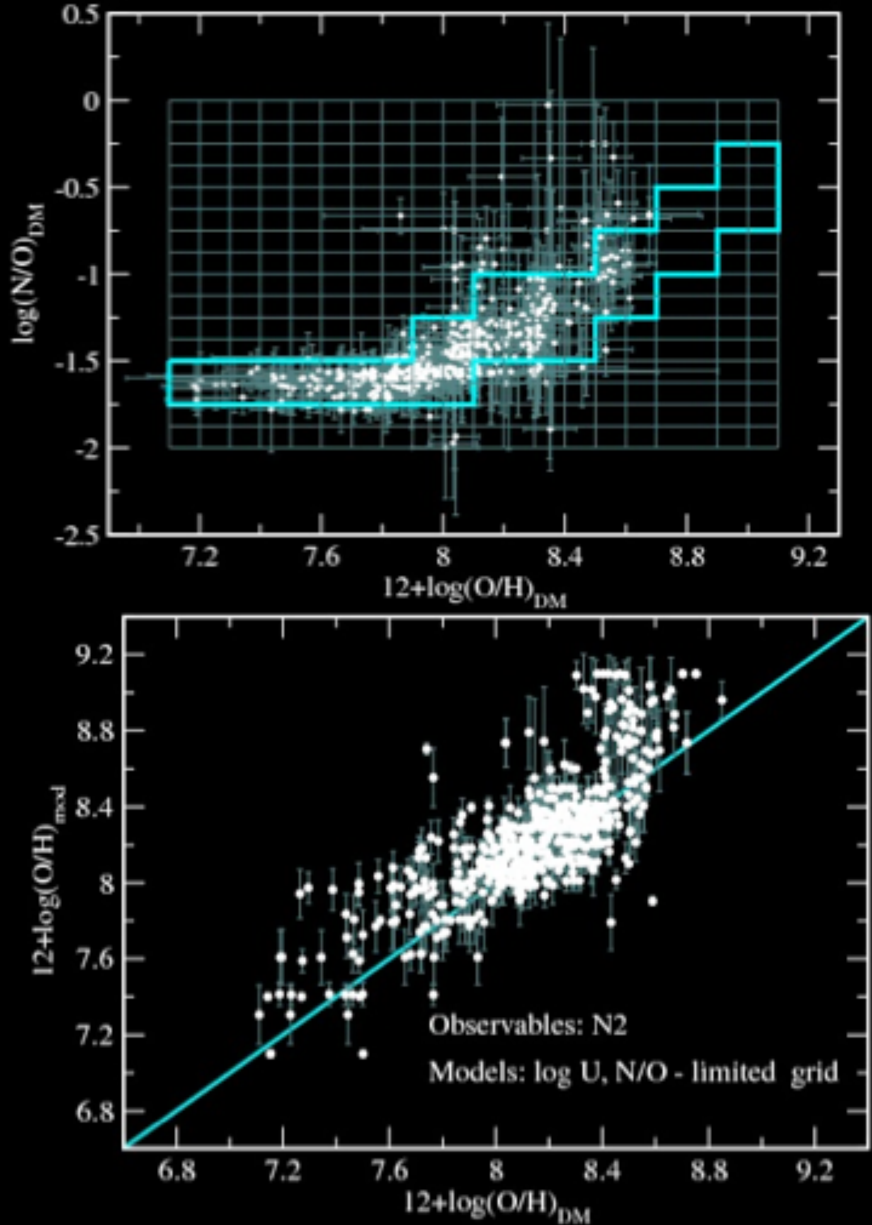
Pérez-Montero (2014)

Strategies when no auroral line is observed

In case no auroral line can be used



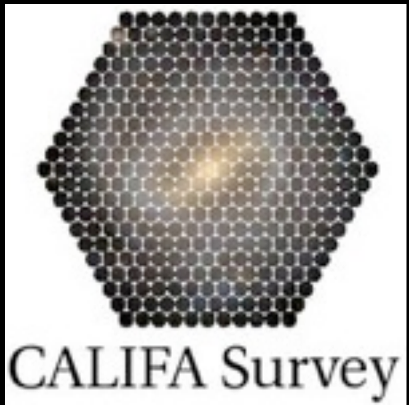
In case N/O cannot be derived in a previous step

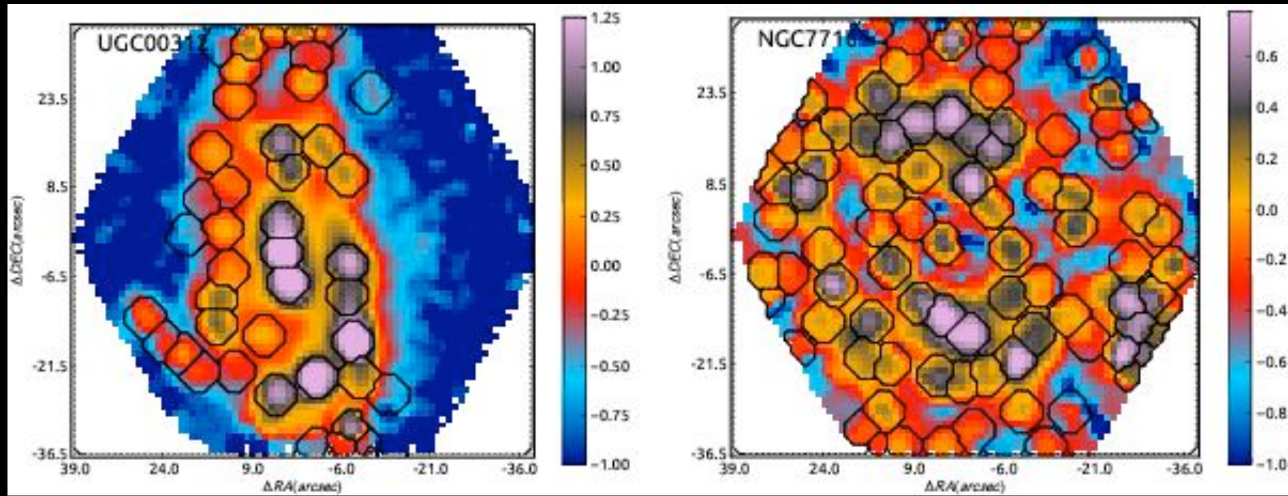


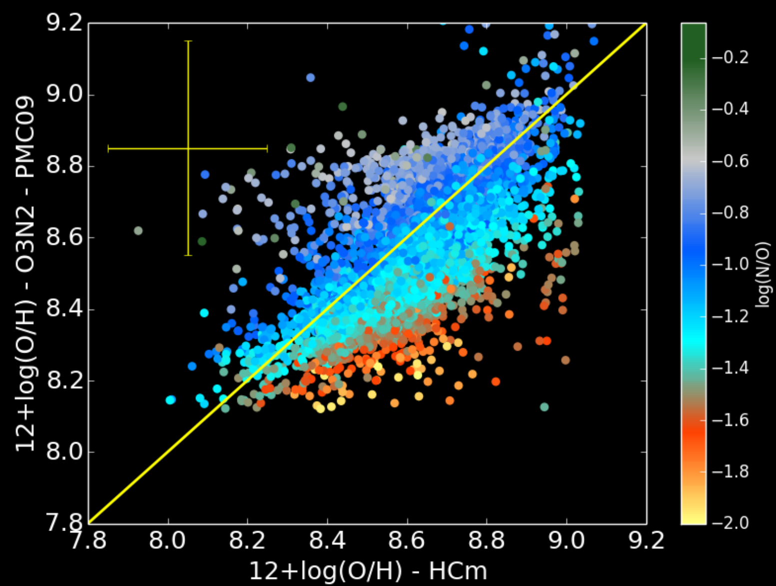
Pérez-Montero (2014)

HCm

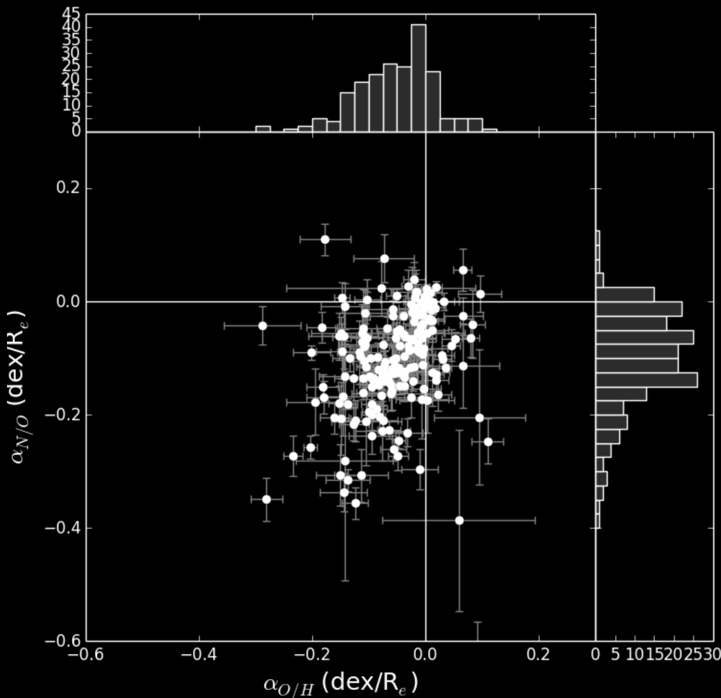
Studiying metallicity gradients with HCm



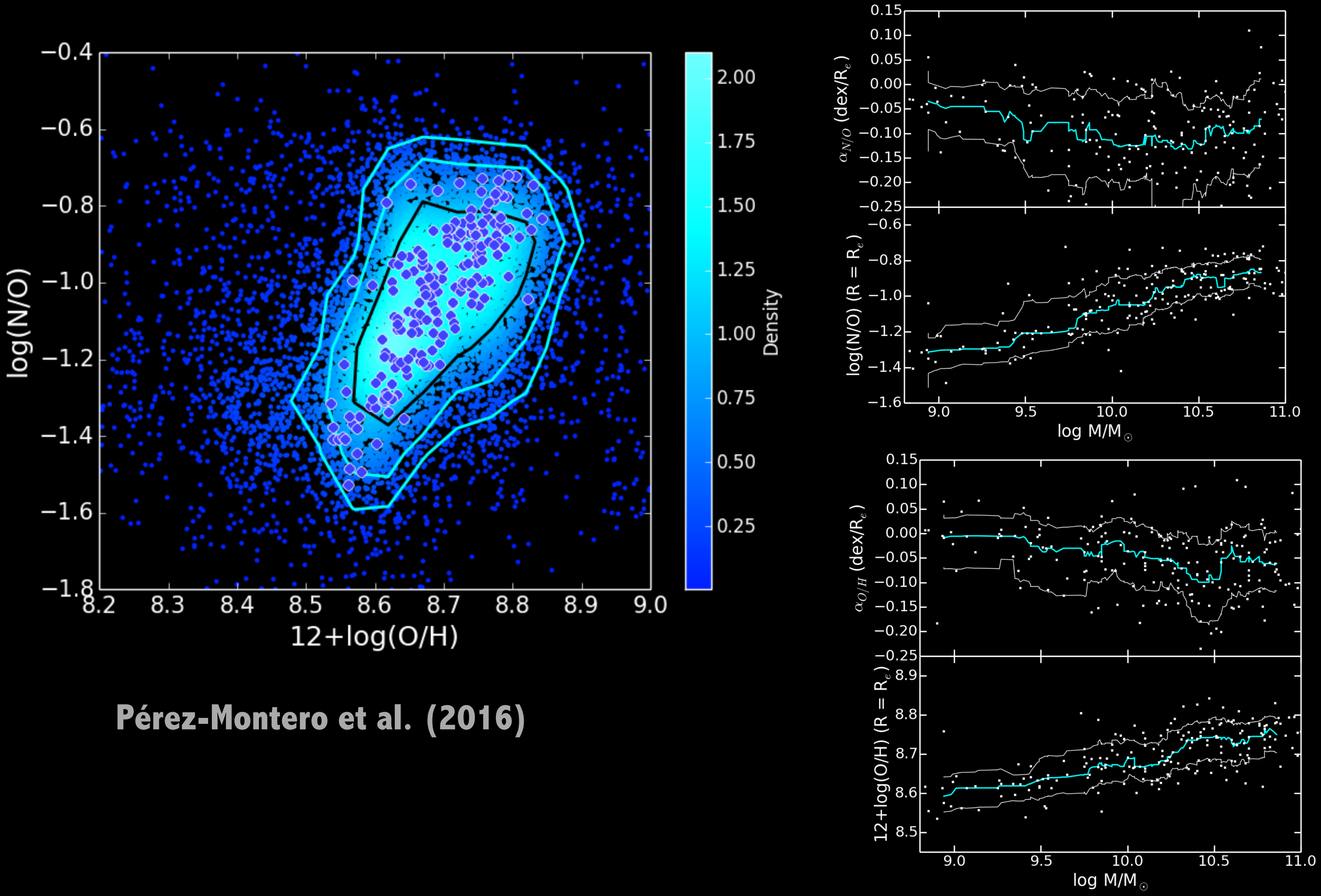




Pérez-Montero et al. (2016)

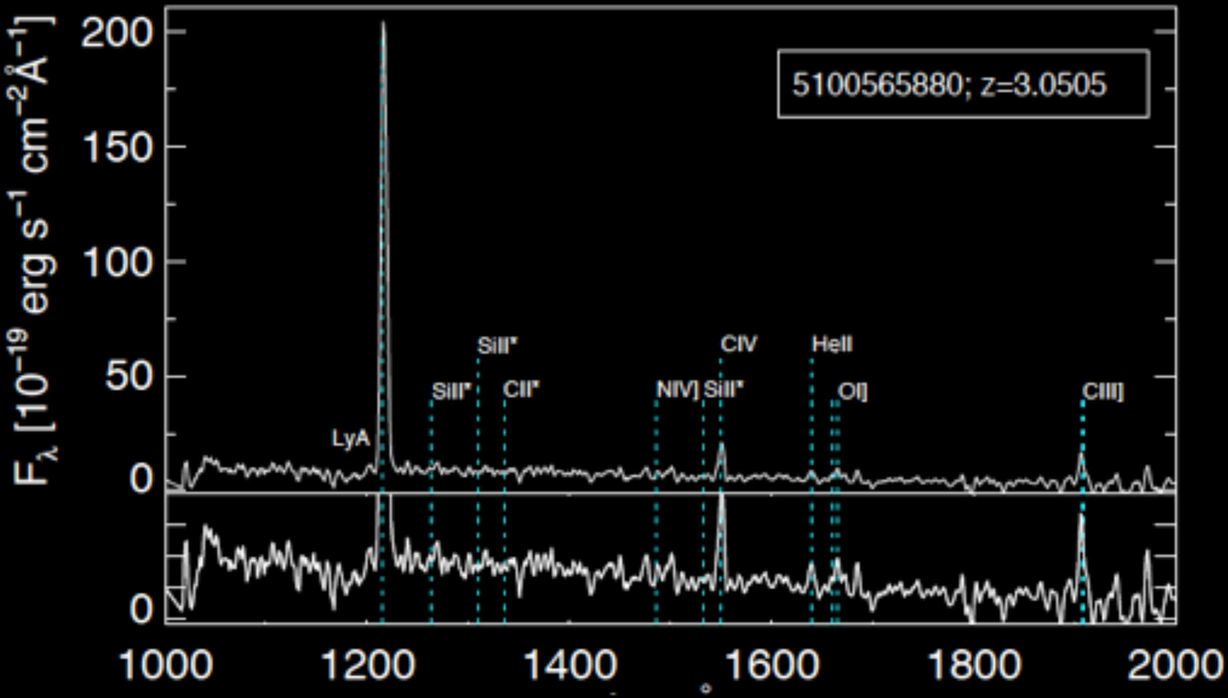


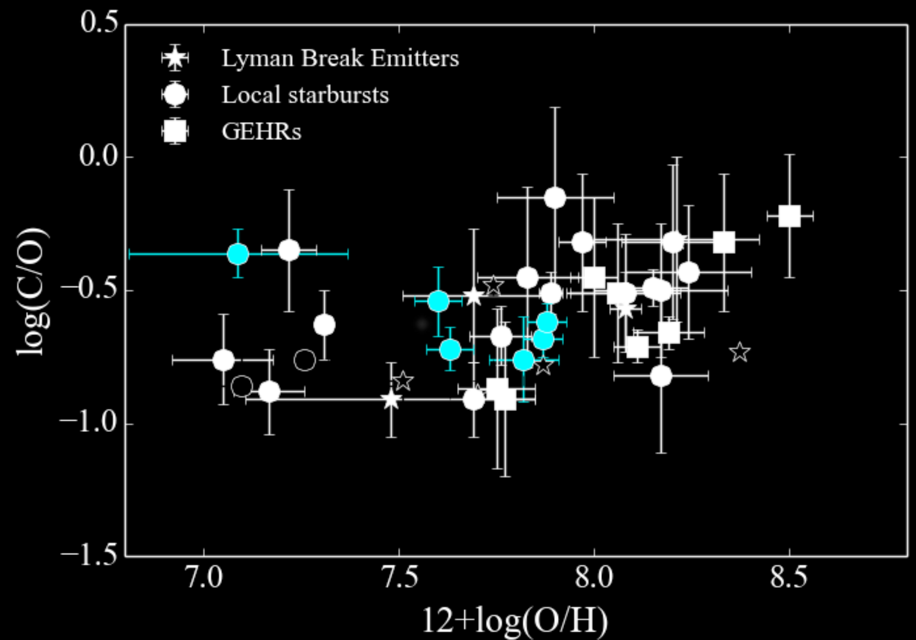
Abundance characteristic values in CALIFA



Pérez-Montero et al. (2016)

Dealing with UV lines at high z



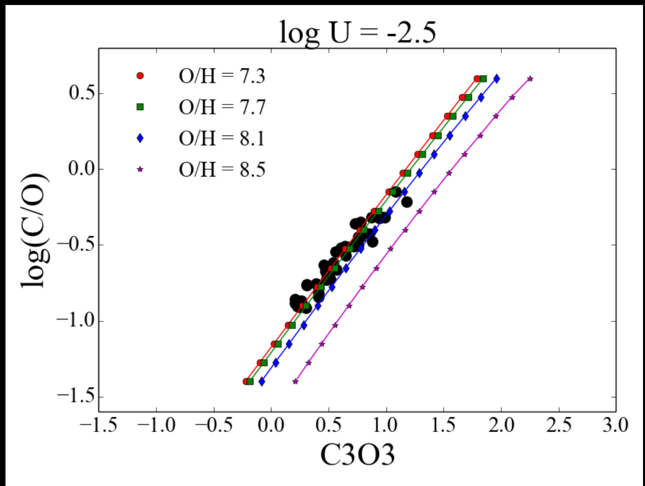


Pérez-Montero & Amorín (2017)

Deriving abundances using UV lines

A new grid of photoionization models has been calculated varying input O/H, C/O, and log U. to explore the behaviour of [OIII] 1665, 5007, [CIII] 1909, [CIV] 1549, and Lyman alpha.

$$C3O3 = \log\left(\frac{I(\text{C III] } 1908\ \text{Å}) + I(\text{C IV } 1549\ \text{Å})}{I(\text{O III] } 1664\ \text{Å})}\right)$$



$$log(C/O) = -1.069 + 0.796 \cdot C3O3$$

The same stellar atmospheres and geometry as in HCm were used.

A new routine, called HCm_UV, has been designed. In a first step the C/O ratio is derived using the C3O3 parameter.

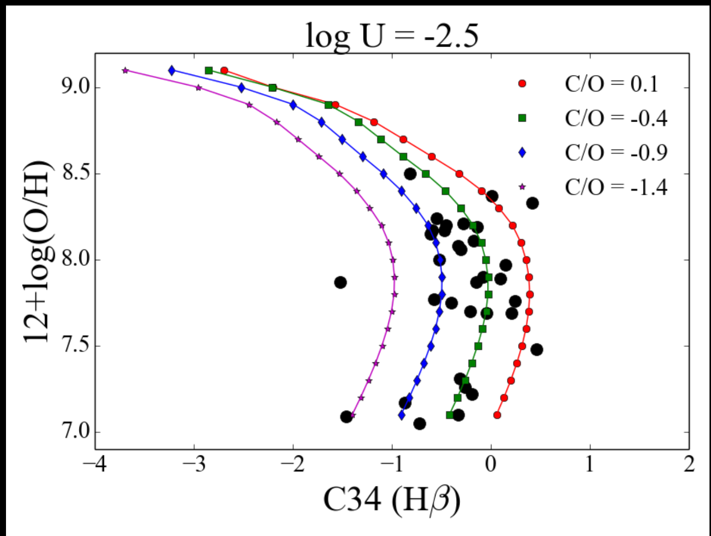
Pérez-Montero & Amorín (2017)

HCm

Deriving abundances using UV lines

Once C/O is fixed, a new iteration of the remaining models is performed to make a minimization of the Chi-square values of the C34 and C3C4 parameters.

In case that the [OIII] 5007 optical line is also detected, the ratio with 1665 can be used to constrain the electron temperature and derive abundances with much lower uncertainties.



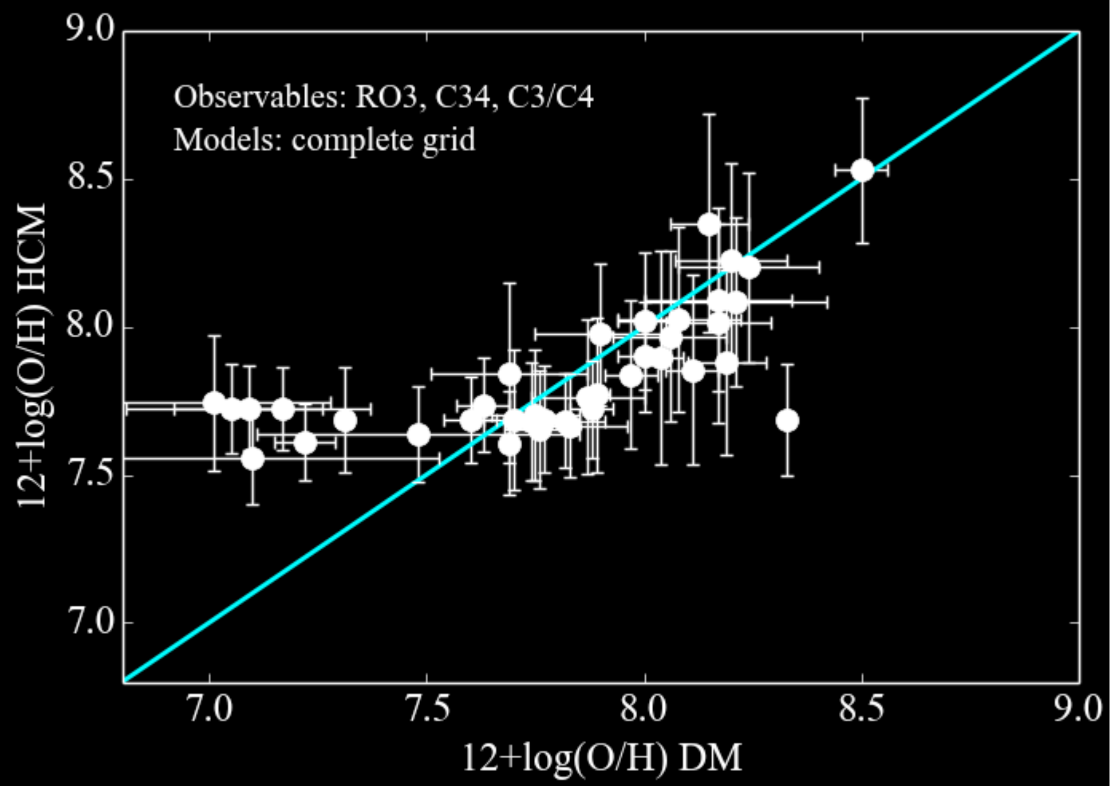
$$C34 = \log\left(\frac{\mathrm{I(C\,III]\ 1908\ \AA) + I(C\,IV 1549\ \AA)}}{\mathrm{I(H\,I)}}\right)$$

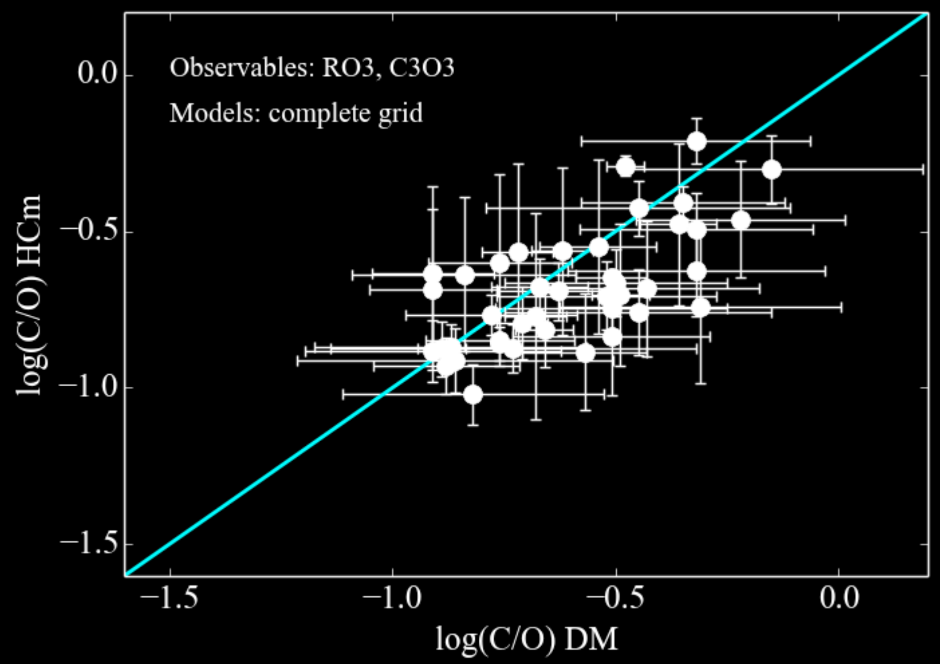
$$C3C4 = \log\left(\frac{\mathrm{I(C\,III]\ 1908\ \AA)}}{\mathrm{I(C\,IV 1549\ \AA}}\right)$$

Pérez-Montero & Amorín (2017)

Comparison with the direct method

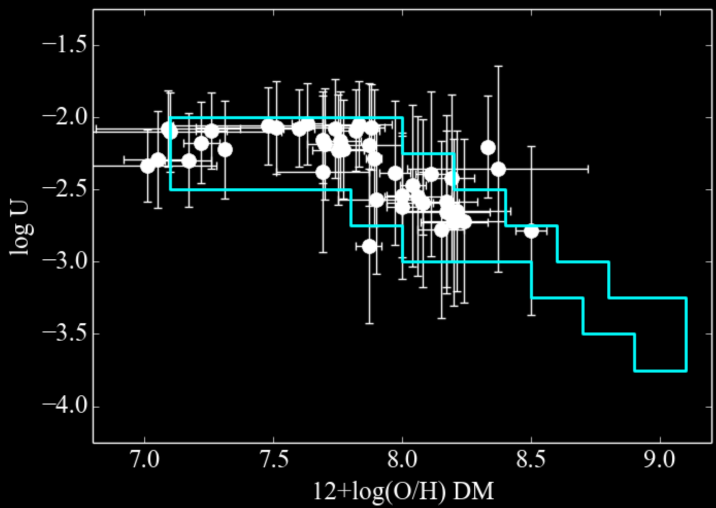
Pérez-Montero & Amorín (2017)

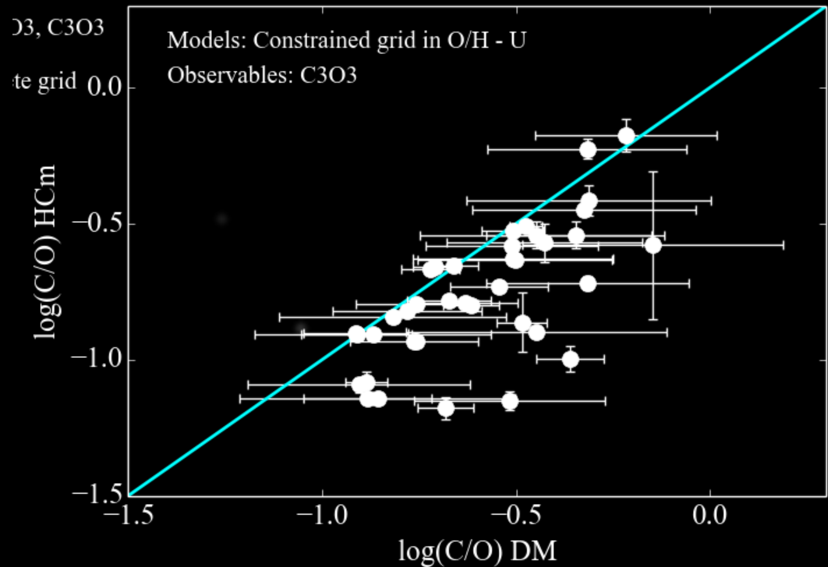


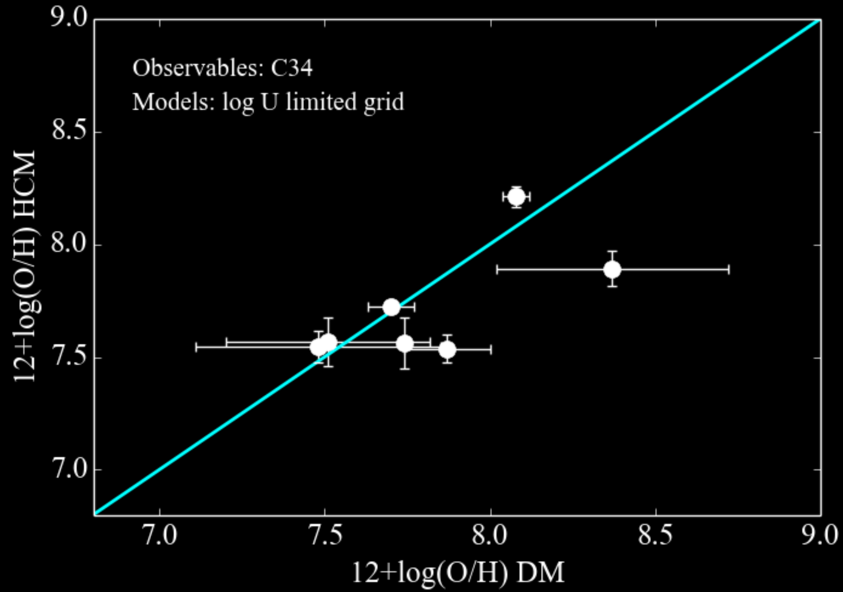


Comparison with the direct method

Pérez-Montero & Amorín (2017)





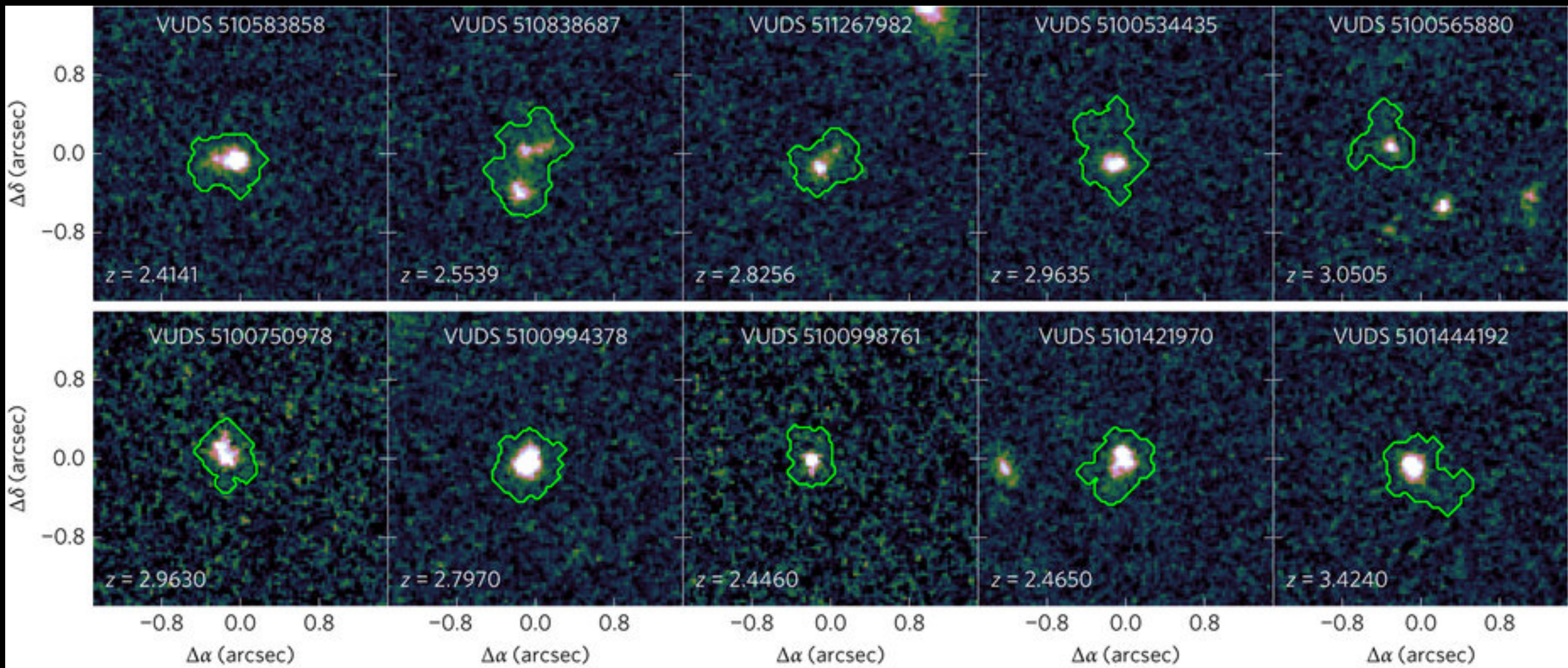


Searching in VUDS for analogs of primeval galaxies

We applied HCm_UV to a sample of 10 galaxies selected in VUDS on the basis of their very large [CIII] 1909 and Ly alpha equivalent widths.

These galaxies present properties quite similar to those of the primeval galaxies (e.g. low masses, high SFR, disrupted morphologies, compact sizes) but a chemical confirmation is required.

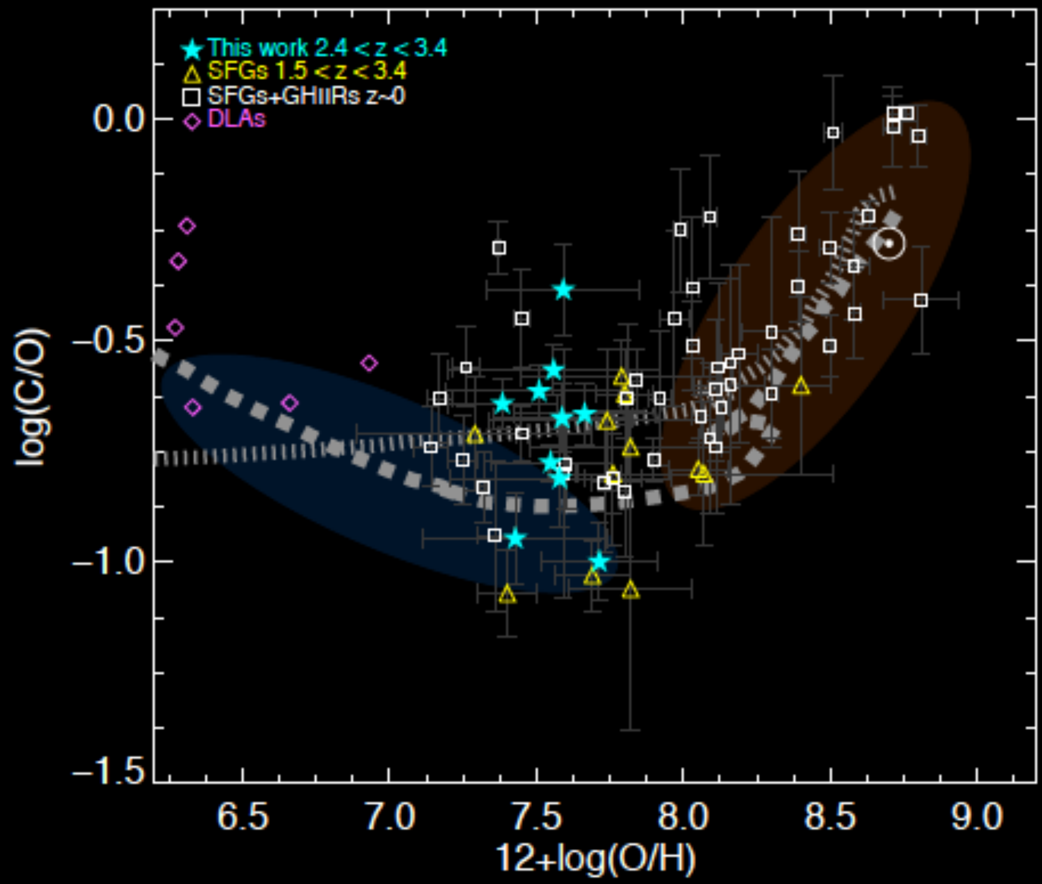
Amorín et al. (2017)



VUDS XMPs at high redshift with HCm_UV

Applying HCm_UV on the sample of galaxies at z~2.4-3.5 all of them are identified as XMPs, with sub solar values of C/O but with a large dispersion.

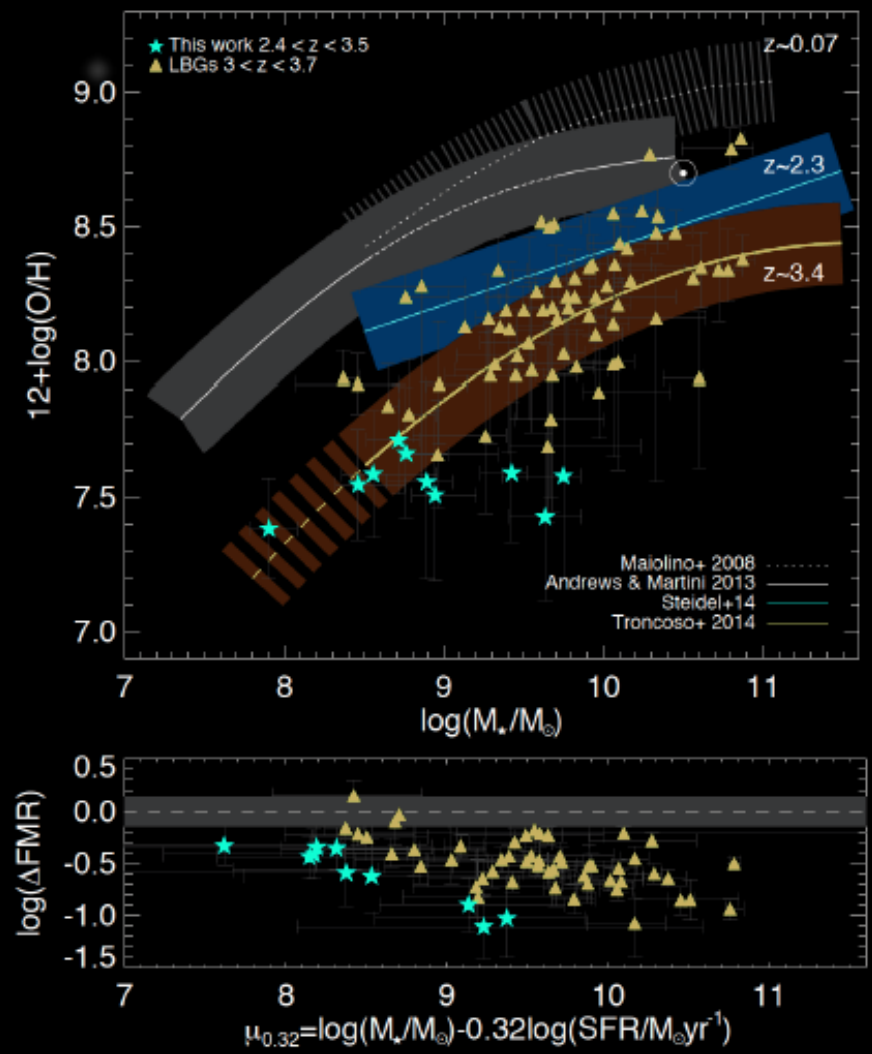
They present high values of log U, consistent with very young stellar populations, able to produce the emission of HeII in six out of them.



Amorín et al. (2017)

VUDS XMPs at high redshift with HCm_UV

Comparing with the local MZR, the galaxies present very low Z, but they are consistent with the MZR at z~3 by Troncoso+)2014). The offset could be due to their very high SFRs, even though the FMR does not correct this effect at this redshift.



Amorín et al. (2017)

Summary and conclusions

- Secondary elements, such as N and C, are important because their study supply additional information on the chemical status of galaxies.

- It is compulsory using recipes that calculate N/O or C/O when we want to derive the metallicity using lines from secondary elements.

- For local spiral disks the distribution of N/O slopes is more uniform than for O/H.

- For analogs of early starbursts the MZR presents large dispersion possibly caused by the SFR dependence. It is necessary to explore the same relation for N/O or C/O.