# "Ionizing stellar population in the starburst NGC 3310"



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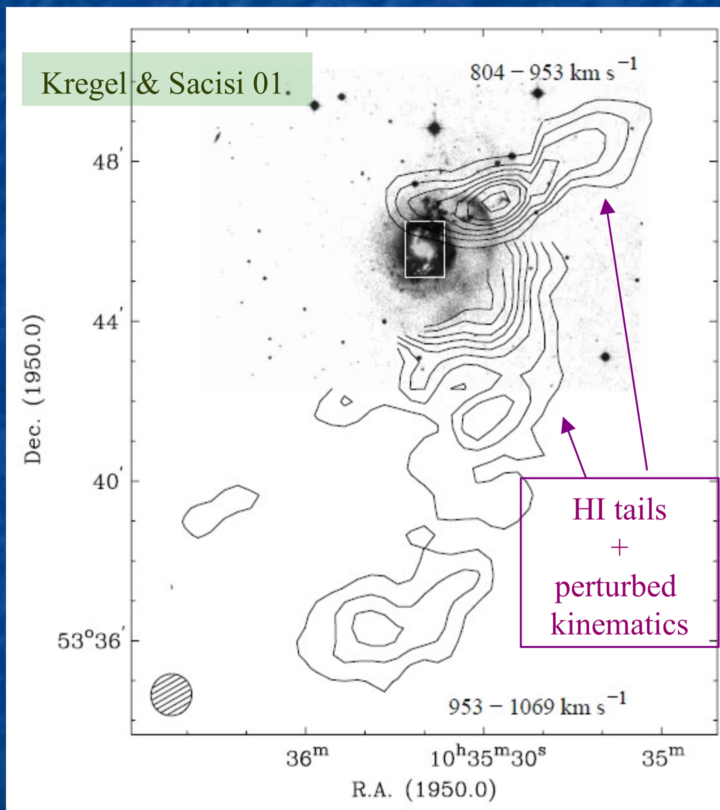
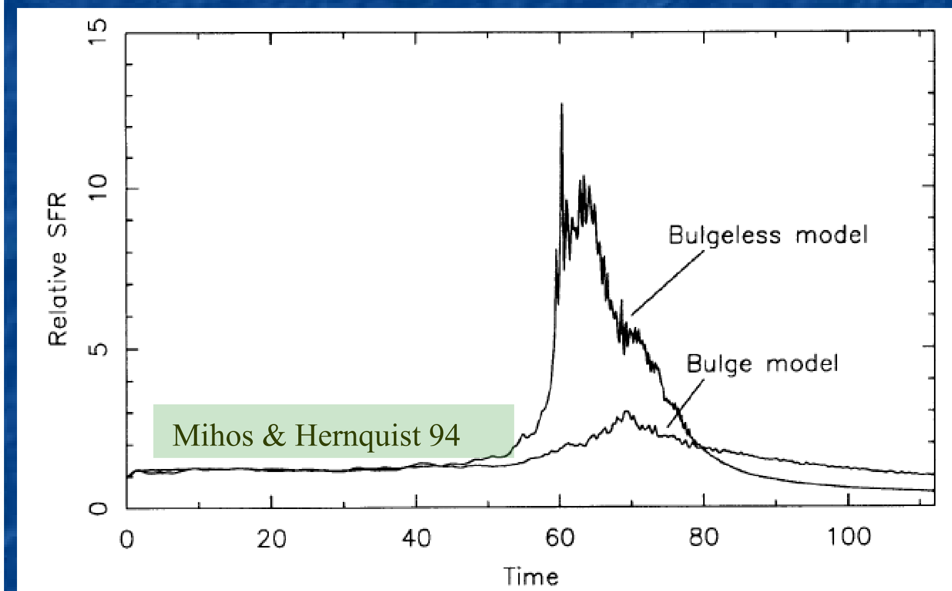
Galaxies meet GRBs – Cabo de Gata – 25 September 2013

# Motivations & goals

*** NGC 3310 – @ 16 Mpc. Evidence of galactic cannibalism**




- Impact on star formation activity

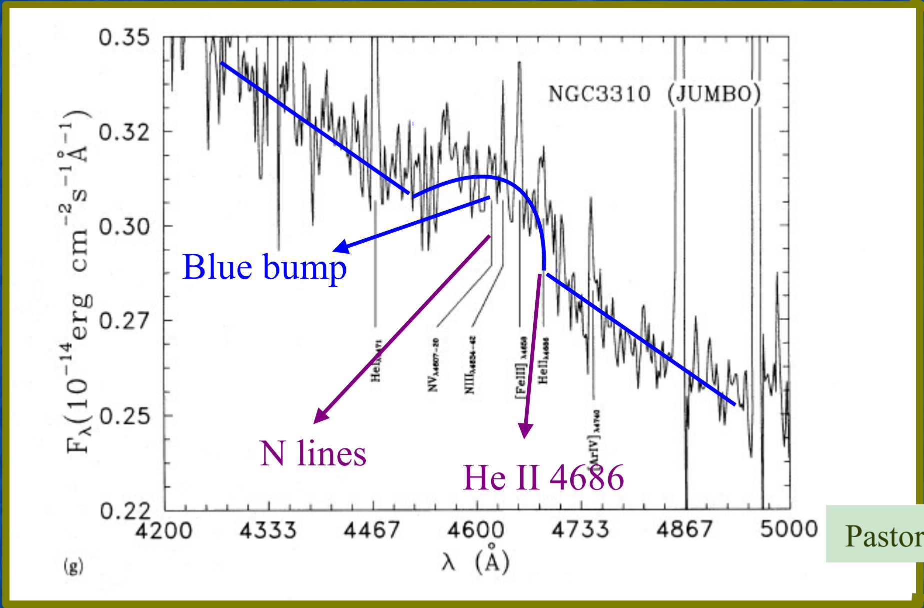


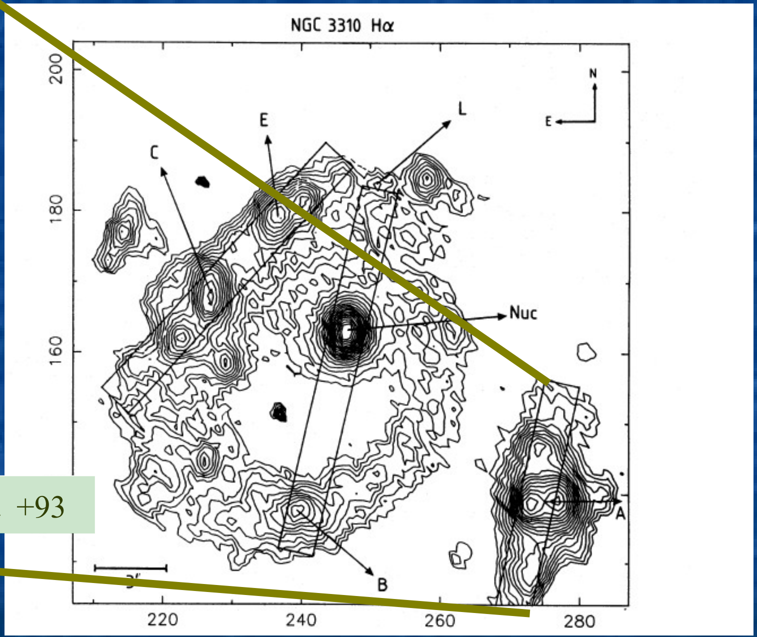

- Gas radial flows

# Motivations & goals

* NGC 3310 – WR features observed in the past

  - Strong constraints on stellar population models



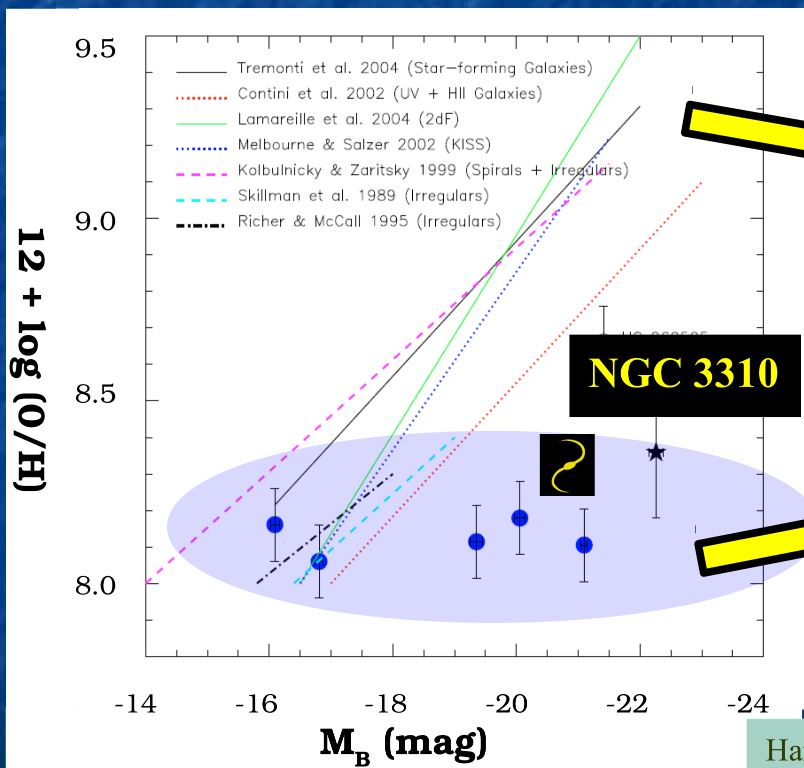




Pastoriza +93

# Motivations & goals

*** NGC 3310 – WR features observed in the past**

- WR – GRB connection at moderate redshifts




Han +10

SDSS & star-forming galaxy samples

GRB hosts with WR population (z=0.03-0.9)

# Motivations & goals

* **Goals of the study**

  - Gas mixing (metallicity gradient)

  - Impact of the merger in SF and galaxy evolution

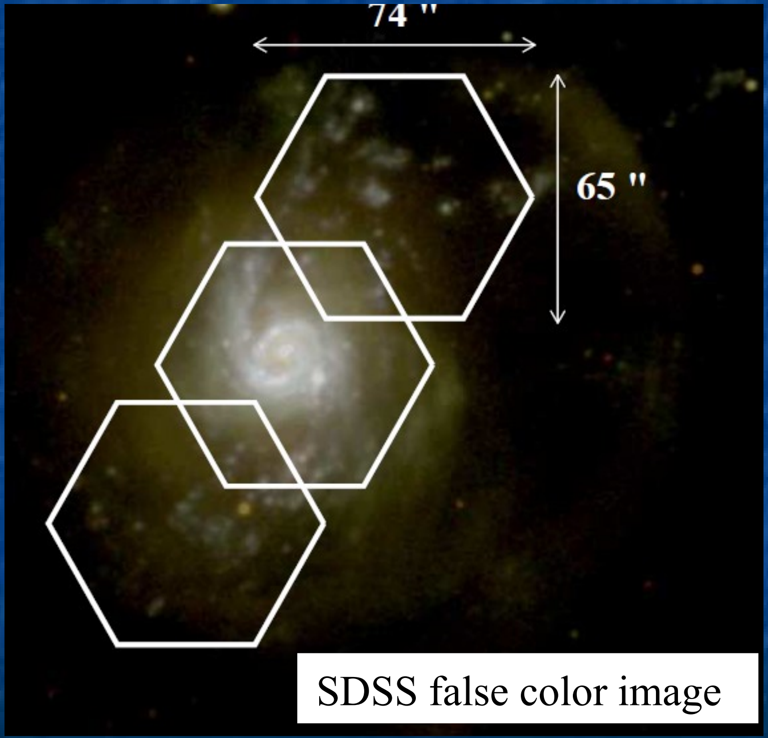
  - Characterize the ionizing stellar population

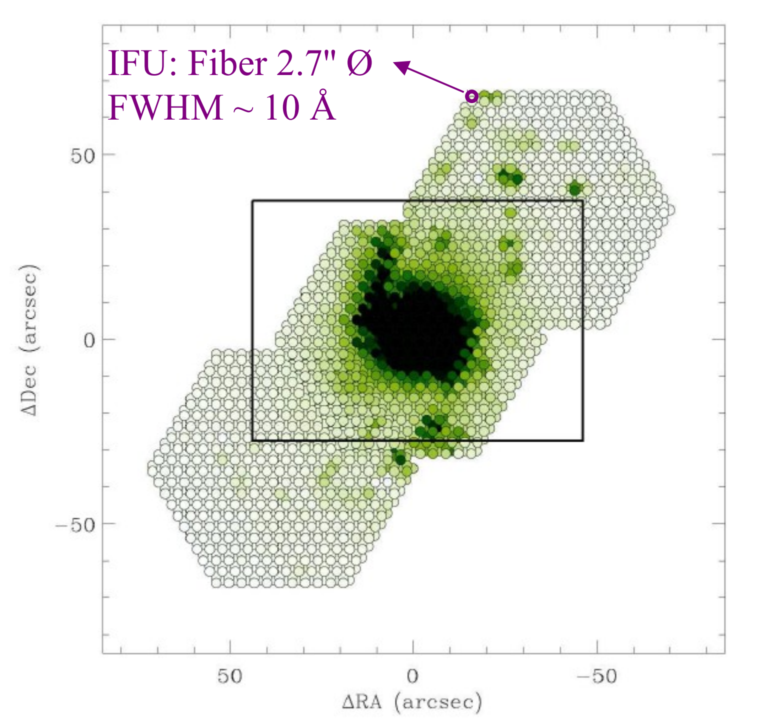
  - Spatially resolved WR population in the disk of NGC 3310

  - Predictions from models and observations of WR features

# IFU data & sample of HII reg

* **PPAK Integral Field Spectroscopic (IFS) data**
    - Full spatial coverage of the disk
    - PINGs program (Rosales-Ortega +10)



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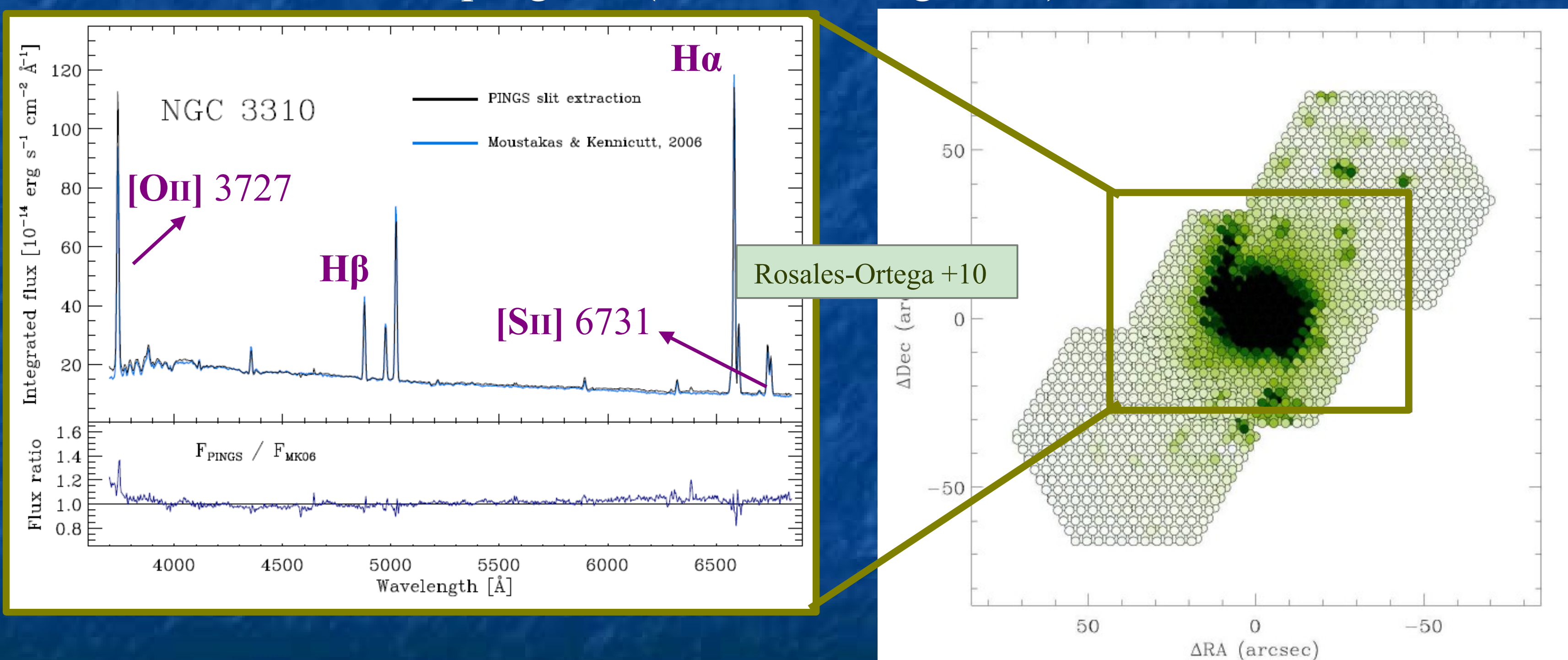
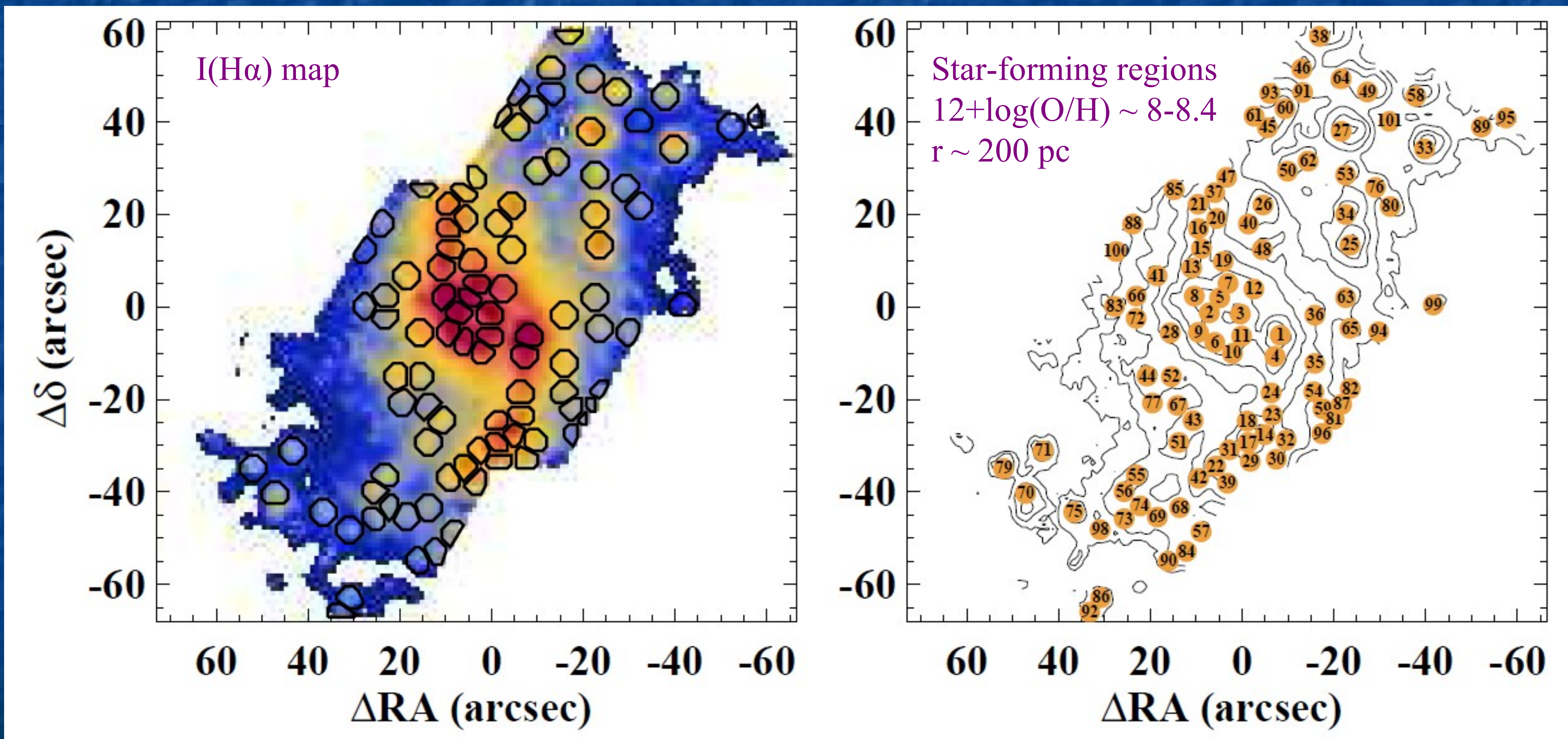


# IFU data & sample of HII reg

* **Sample of HII regions**

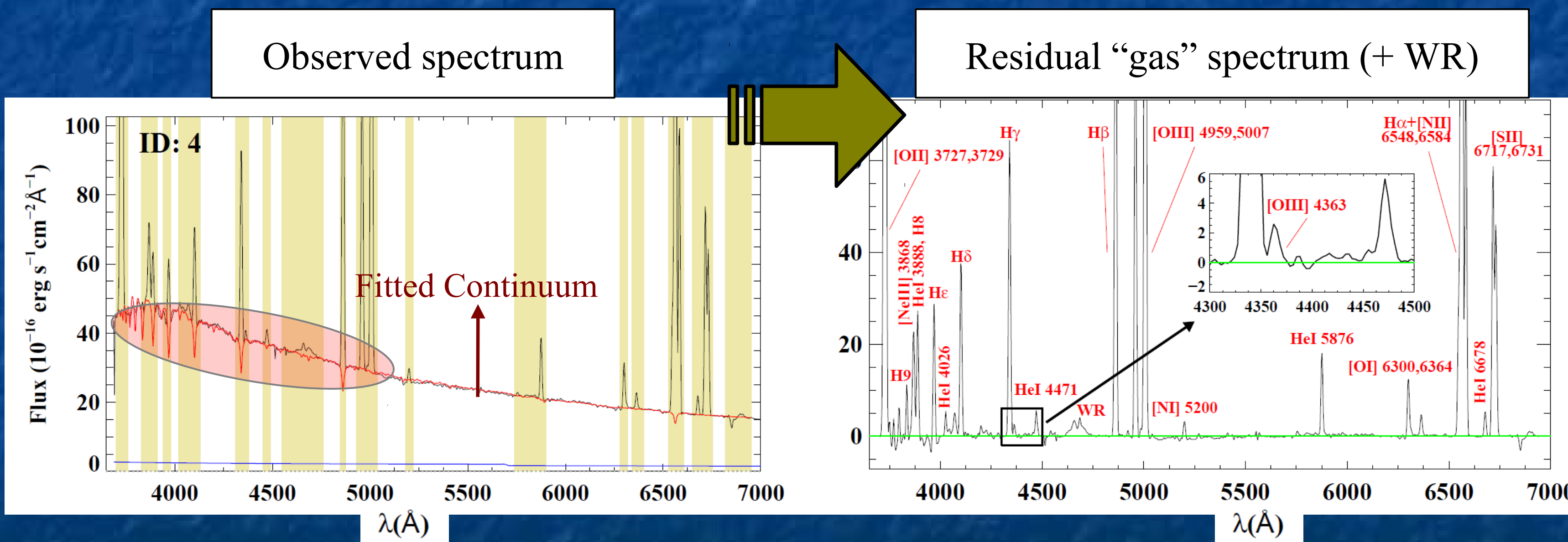
  - HII EXPLORER (Sánchez +12), 99 HII regions identified



# Multiwavelength + CLOUDY

*** Gas-star decoupling method**

- STARLIGHT (Cid-Fernandes +04)
- PYCASSO library (Cid-Fernandes +05), 1Myr – 17Gyr

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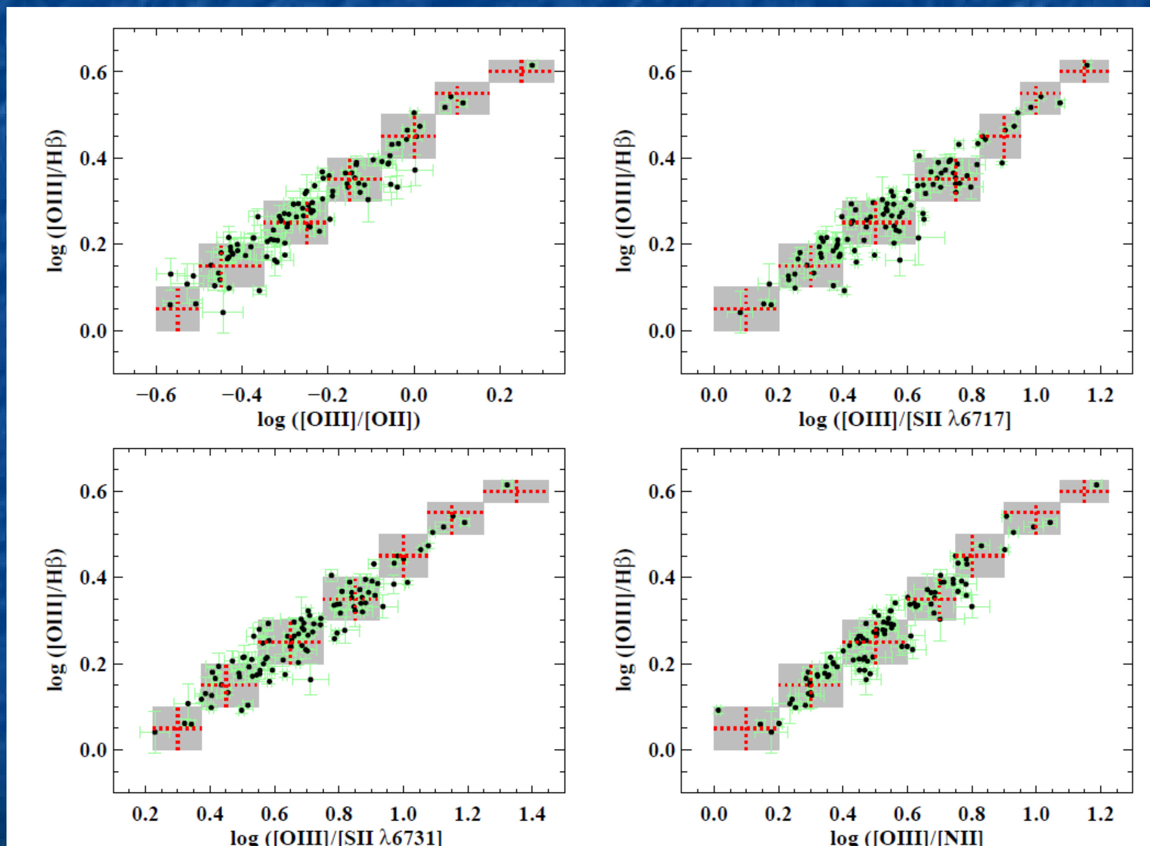
# *Multiwavelength + CLOUDY*

## * Ionization conditions




- Line ratios sensitive to log u, $n_e$, $T_e$, Z, N/O, etc

- 7 zones

# Multiwavelength + CLOUDY

* **Ionization conditions. CLOUDY fit**

  - v 10.0, Ferland +98
  - Constraints:

    1. Line ratios
    2. log Hβ luminosity ranges → 37.5-38.5, 38.8-39.8
    3. log EW (Hβ) ranges → 1.35-1.65, 1.6-2.1, 2.05-2.35

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- Output:
  1. Age of the ionizing population → $\tau = 3 - 5.5$ Myr
  2. Absorption by dust grains → $f_d = 1.3 - 4$ !!!

  If $f_d \sim 2$ → Half of the photons are absorbed

# Multiwavelength + CLOUDY

* CLOUDY fits & STARLIGHT

1. Subract light from “old” non-ionizing (τ > 15 Myr) populations as obtained with STARLIGHT

2. Multiwavelenght fitting using:

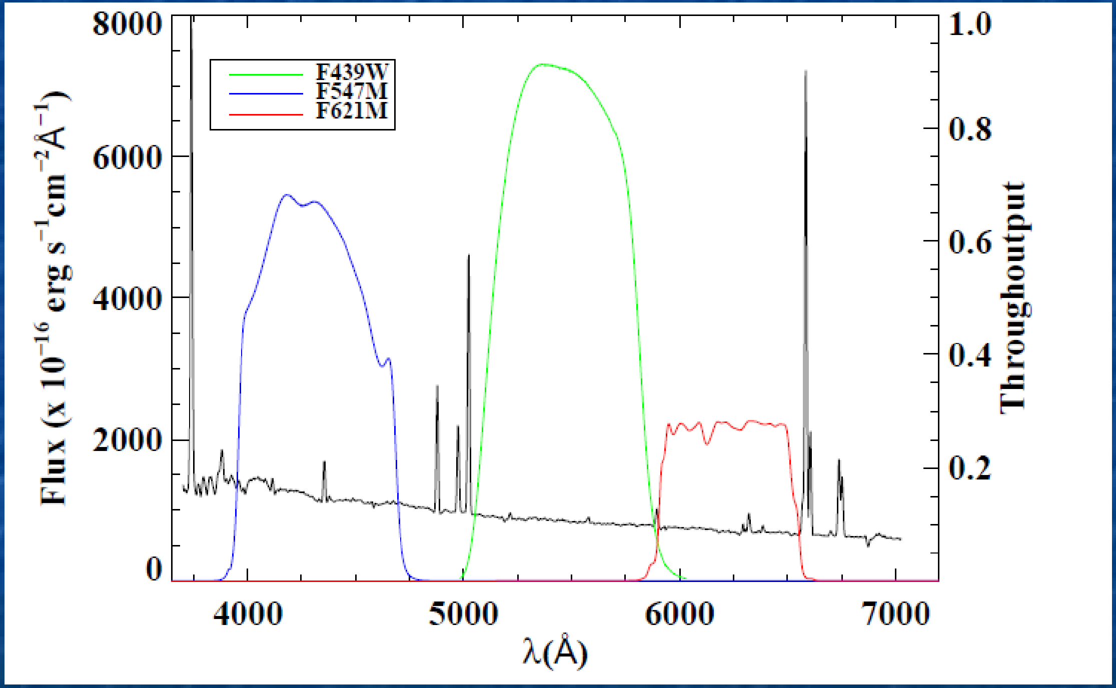
a) Imaging from UV to IR

b) POPSTAR models (Mollá +09; Martín-Manjón +10): age binning 0.2-0.3 Myr & includes nebular emission

# Multiwavelength + CLOUDY

*** Multiwavelength analysis**

- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)



# Multiwavelength + CLOUDY

*** Multiwavelength analysis**

- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)

  - Hα, Hβ and Ews

  - Chi square minimization

$$\chi^2(Z,\tau,A_V,m_\star) = \sum_N \frac{(f_{\rm obs} - f_{\rm model})}{\sigma^2_{\rm obs}}$$

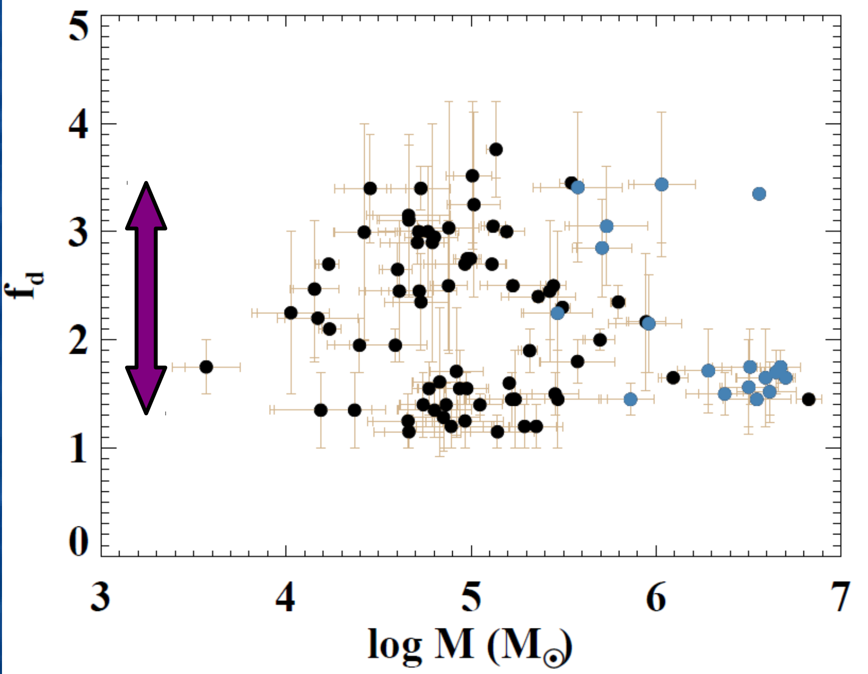
# Multiwavelength + CLOUDY

*** Combination with CLOUDY results**

- $\chi^2$ minimization varying Hα, Hβ & Ews according to derived range of $f_d$ for each HII region

Absorption by dust grains important in HII regions!

(Pérez-Montero & A. I. Díaz 07, Pérez-Montero +10, García-Benito & Pérez-Montero 12)



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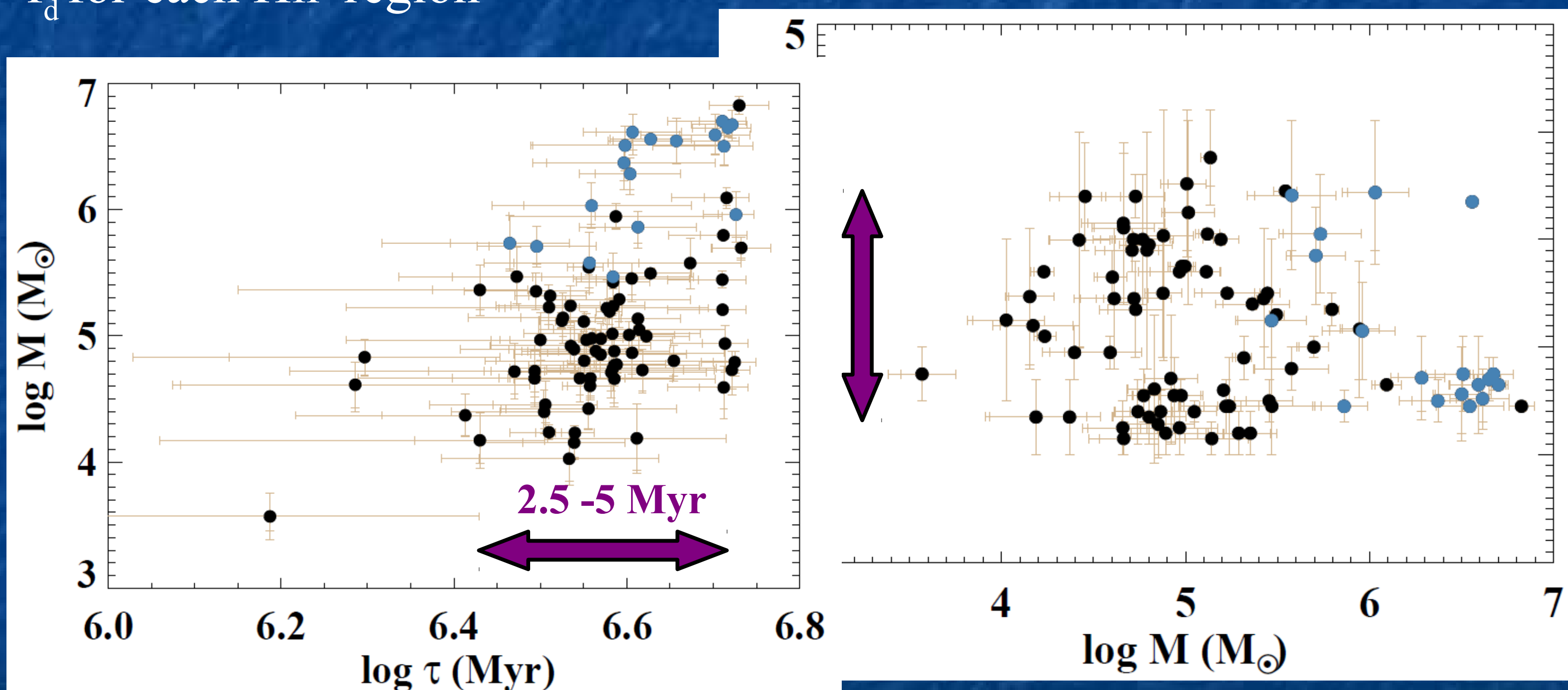
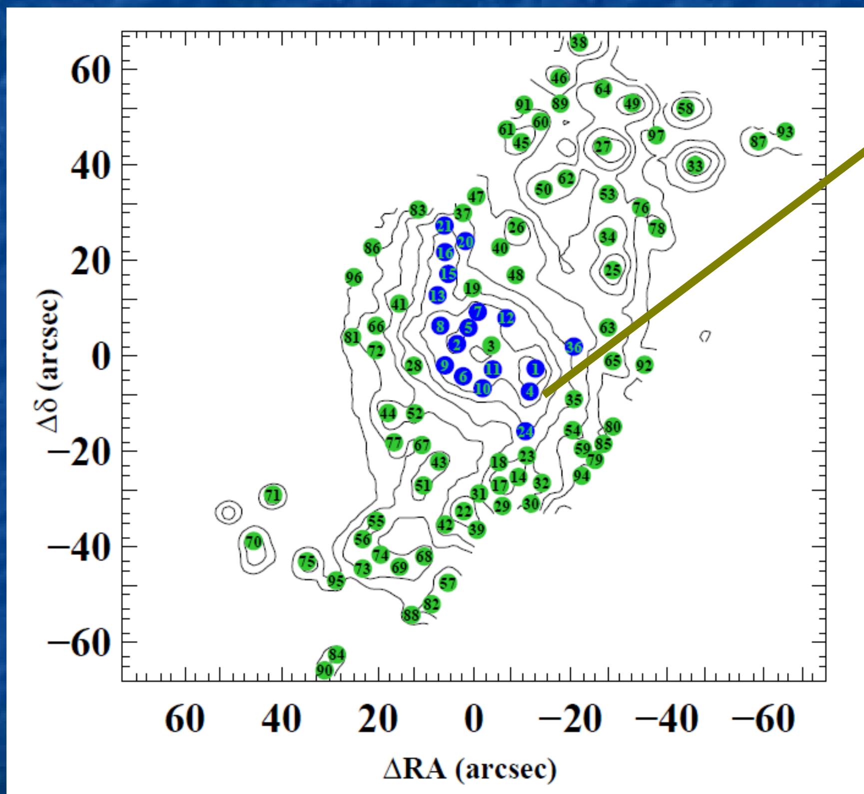
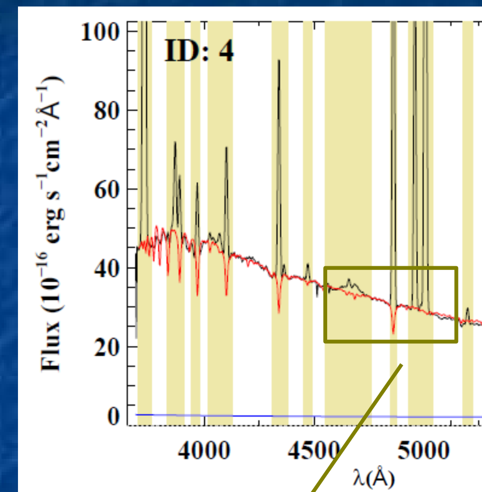
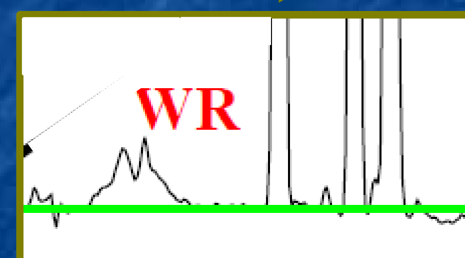


# WR population in NGC 3310

* HII regions with WR features



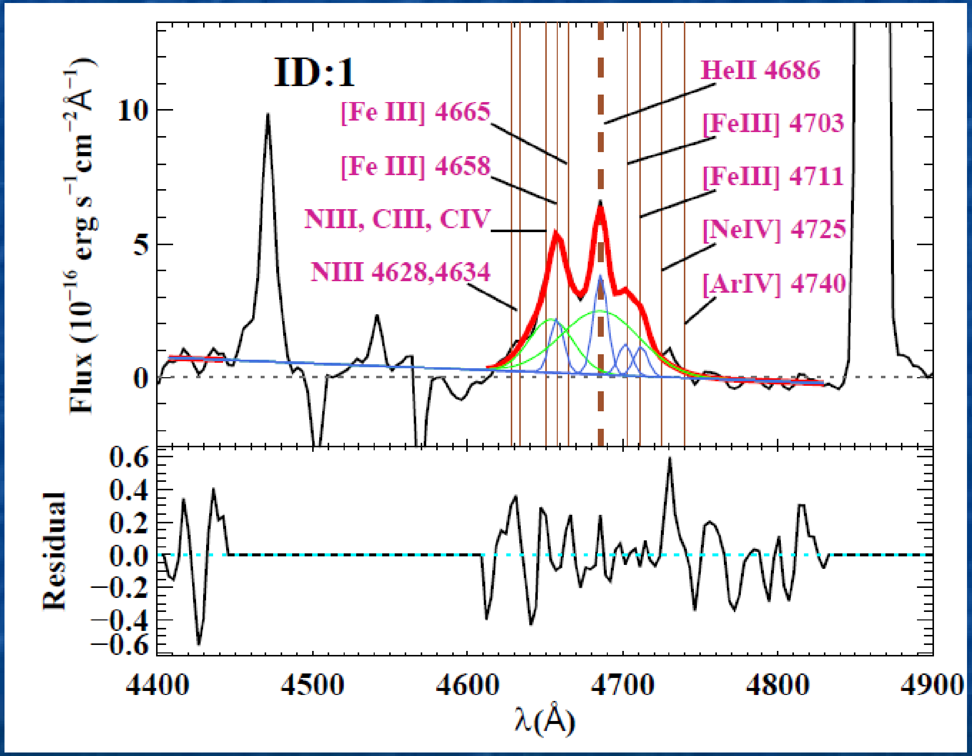




$$F_{\mathrm{peak}}/\mathrm{rms} > 5$$

# WR population in NGC 3310

*** Multiple line fitting**

- Between 5 and 6 broad and fixed narrow components




1. Start with 4686 broad + narrow, 4658

2. Add components [FeIII], [ArIV], etc., lines; until residual peak < 4rms

3. Typical relative uncertainties 10-40%

# WR population in NGC 3310

*** Multiple line fitting**

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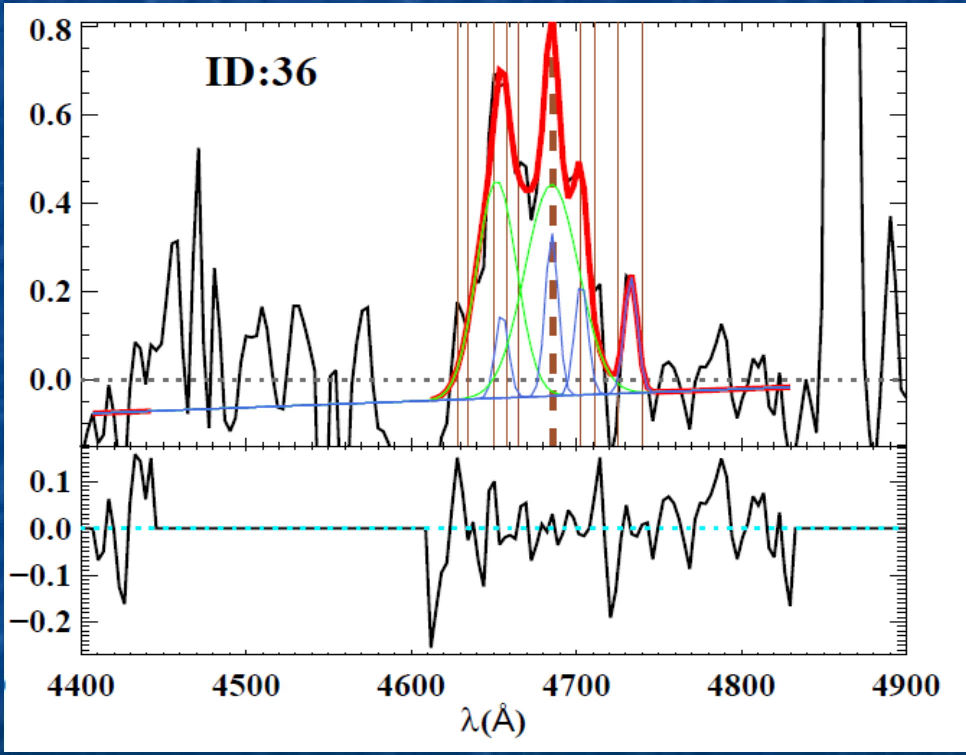


# WR population in NGC 3310

*** WR ratios**

- HeII 4686, no red bump (WC/WO) or OVI 3818 (WO) → WN stars mainly
- Absence of NIII 4097 & NIV 4605-20 (WNE) → Mainly WNL
- Cannot discard presence of other sub-types

$$L_{\mathrm{WNL}}(\mathrm{HeII}\ 4686) = (-5.430 + 0.812x) \times 10^{36}\ \mathrm{ergs}^{-1}$$

$$x = 12 + \log(\mathrm{O/H})$$

López-Sánchez & Esteban 10

30 – 500 WNL per region

Average luminosities WNL

| HeII λ4686 ($\times 10^{35}$ erg s$^{-1}$) | Z (range) | Ref. |
|---|---|---|
| 32 | $Z_\odot/3$-$Z_\odot/2$ | [1] |
| 17 | $Z_\odot/2$ | [2] |
| 16 | $Z_\odot$ | [3] |
| 20-26 | $Z < Z_\odot - Z \geqslant Z_\odot$ | [4] |
| 2-16 | $Z_\odot/50 - Z_\odot$ | [5] |
| 4-25 | $Z < Z_\odot/5 - Z \geqslant Z_\odot/5$ | [6] |

Notes. References: [1] Smith (1991); [2] Vacca & Conti (1992); [3] Schaerer & Vacca (1998); [4] Guseva et al. (2000); [5] Crowther & Hadfield (2006); [6] Brinchmann et al. (2008).

- Number of O stars:

$$\mathrm{N_O} = \frac{Q_0^{\mathrm{Total}} - N_{\mathrm{WNL}}\, Q_0^{\mathrm{WNL}}}{\eta_0 Q_0^{\mathrm{O7V}}}$$

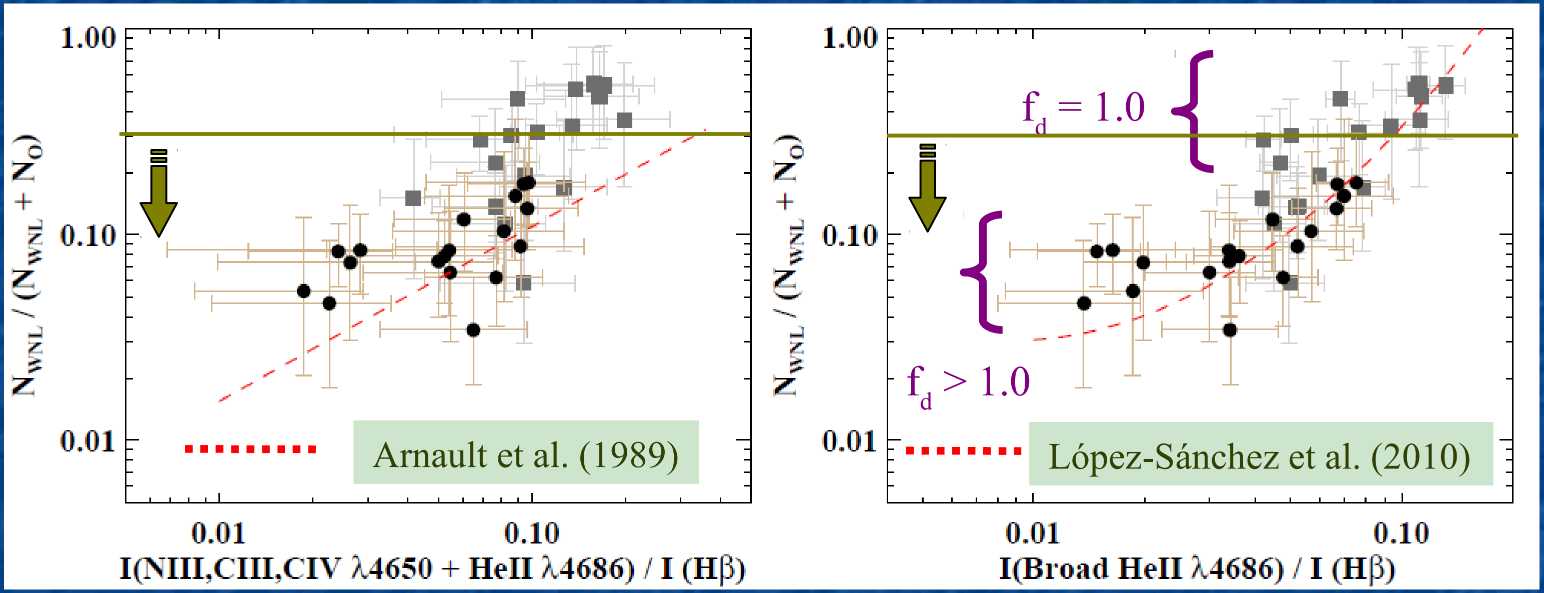
Hβ ($Q_0^{\mathrm{Total}}$)

Correction for other O sub-types ($\eta_0$)

Correction for WR contribution ($N_{\mathrm{WNL}}\, Q_0^{\mathrm{WNL}}$)

# WR population in NGC 3310

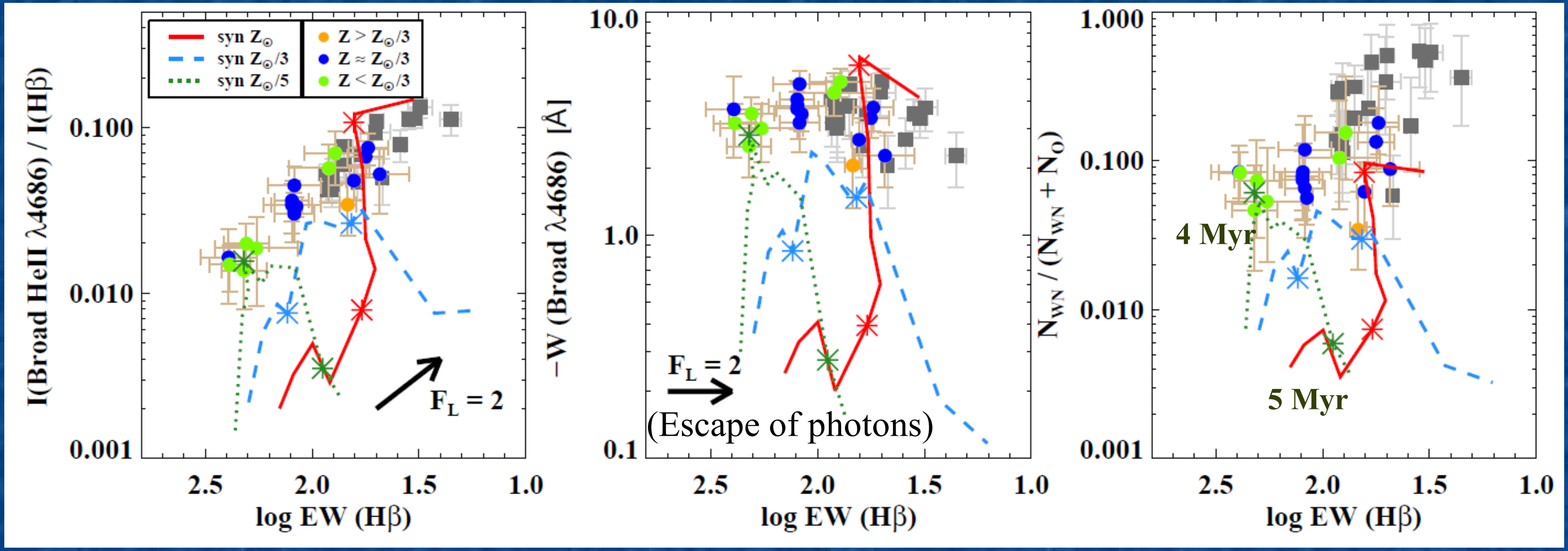
* WR ratios



# WR population in NGC 3310

*** Stellar population models**

- POPSTAR models

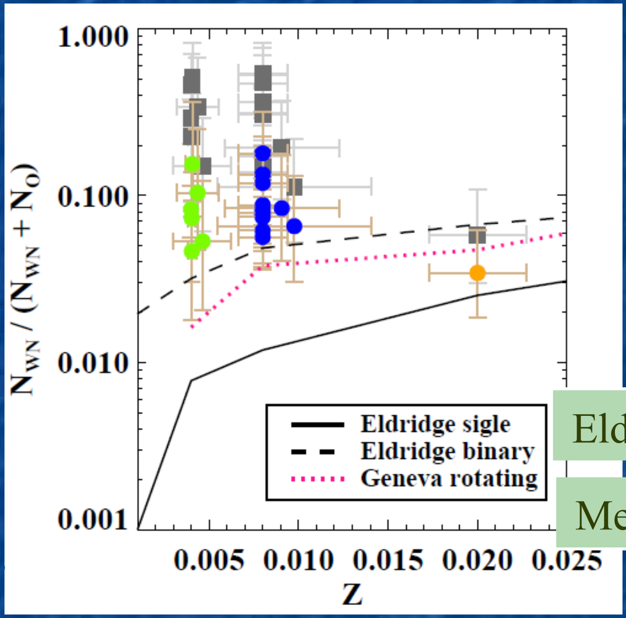



**Evolutionary tracks well below observed values (factors > 2)**

# WR population in NGC 3310

## * Stellar population models

- Models with binaries (2/3 interacting binaries) and fast rotation




Eldridge 09

Meynet & Maeder 05

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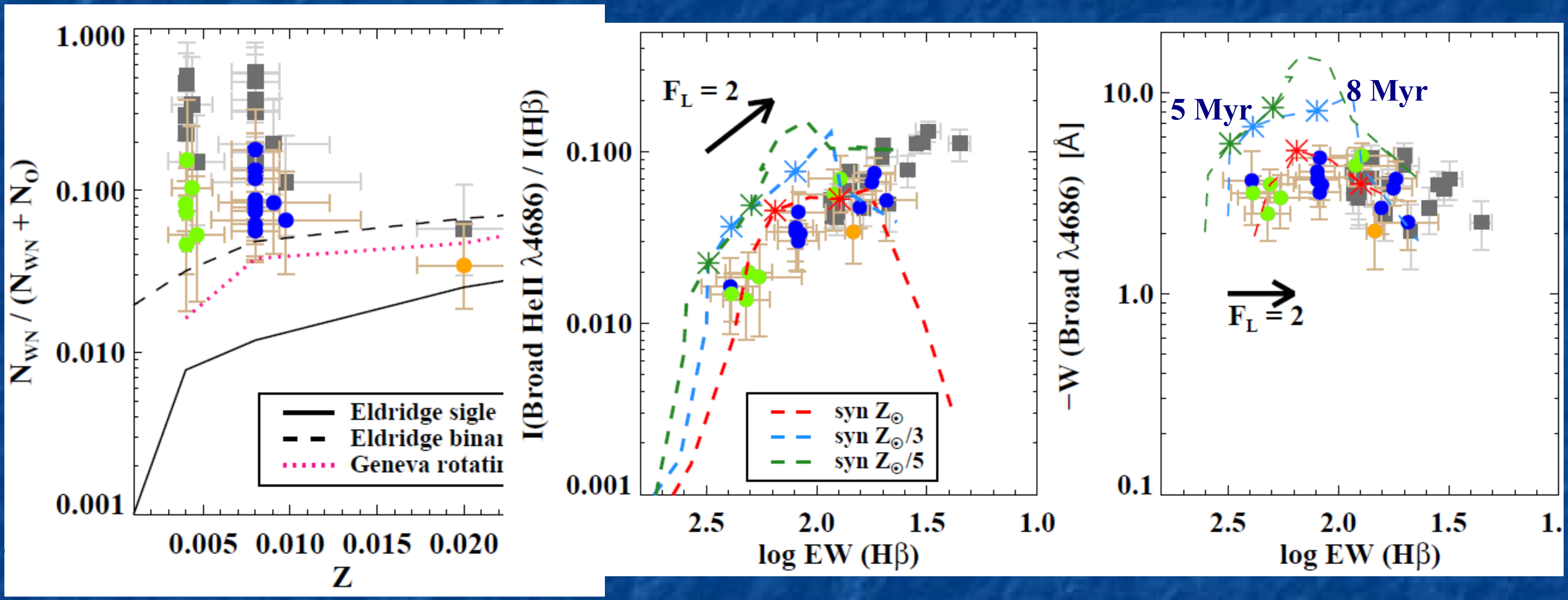
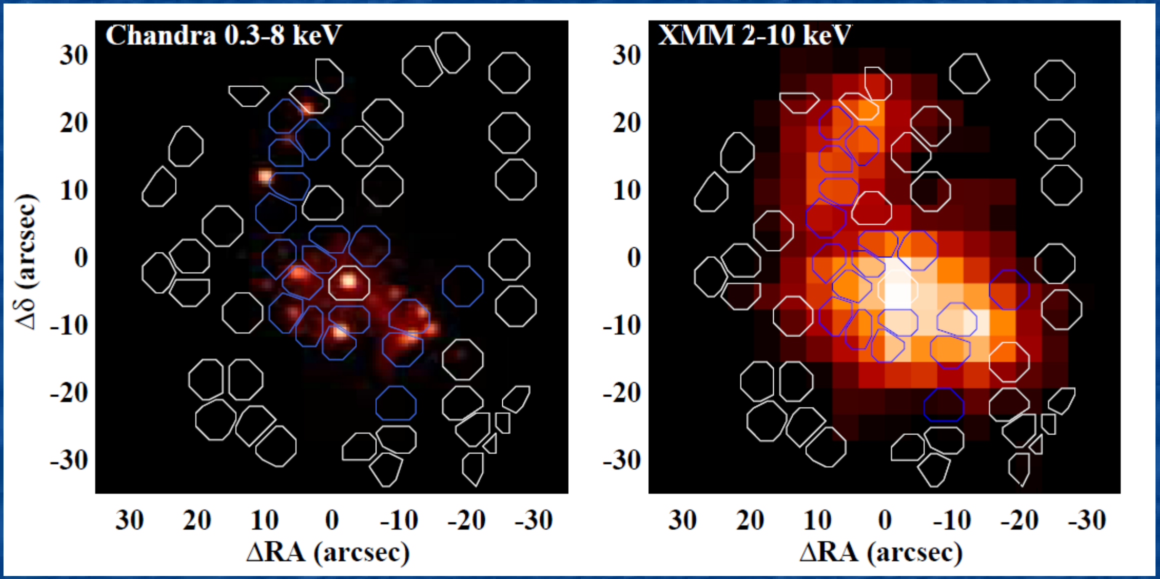



**Additional processes necessary in models**

# WR population in NGC 3310

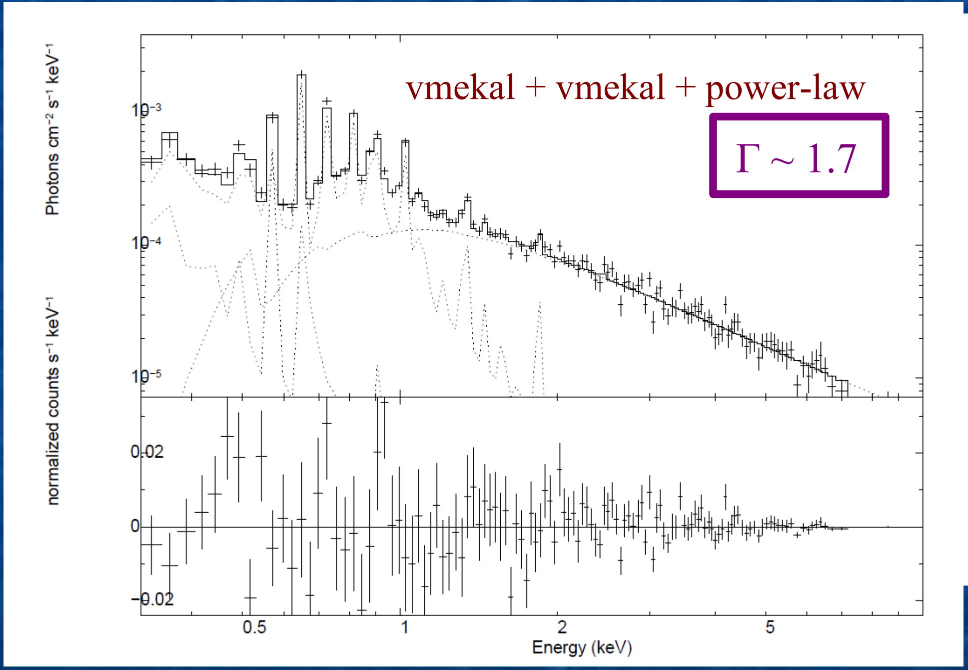
* **Binary fraction ionizing population NGC 3310**

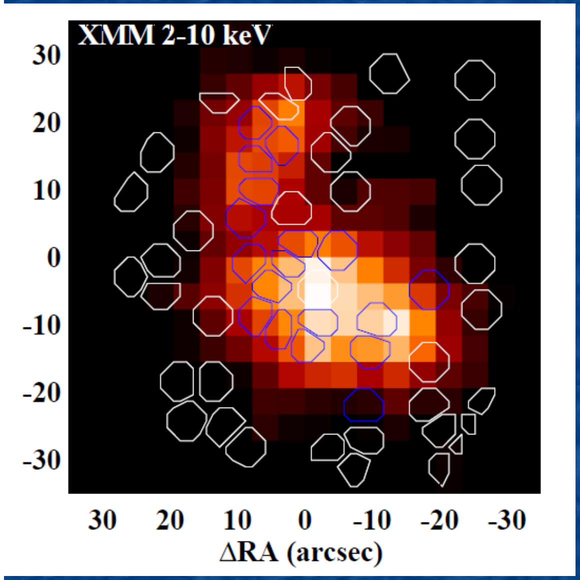
- About ½ of HII regions with WR features → X-ray counterpart



# WR population in NGC 3310

* **Binary fraction ionizing population NGC 3310**
- About ½ of HII regions with WR features → X-ray counterpart
- $L_{2\text{-}10\ keV} \sim 3\times10^{40}$ erg $s^{-1}$ (HMXB)



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*** Binary fraction ionizing population NGC 3310**

- About ½ of HII regions with WR features → X-ray counterpart
- $L_{2\text{-}10\,keV} \sim 3 \times 10^{40}$ erg $s^{-1}$ (HMXB)

If $M \sim 2 \times 10^{7}\, M_{\Theta}$ and $\tau = 3 - 5$ Myr

⇓

Cerviño +02 models

⇓

$f_b = 0 \rightarrow L_{2\text{-}10\,keV} \sim 10^{39}$ erg $s^{-1}$
$f_b = 0.5 \rightarrow L_{2\text{-}10\,keV} \sim 3 \times 10^{40}$ erg $s^{-1}$

**Binarity matters!** (Sana, de Mink+12)

# Summary & conclusions

- Almost 100 HII regions sampled along the disk of NGC 3310

- Different ionization conditions sampled

- Ionization + UV – optical – IR imaging → Better constraints of the age and the mass of the ionizing populations and necessity of absorption of UV photons (25-60%), $M \sim 10^4 – 6 \times 10^6 M_{\odot}$, $\tau \sim 2.5 - 5$ Myr

- 18 HII regions with clear WR features, distributed along the circumnuclear and on the arms

- Up to several hundreds of NWR stars in some regions

- Fluxes, EWs and WR to O ratios inconsistent in some cases with models within factors of 2-3

- Additional processes (binary fraction, γ escape, ect) needed in models

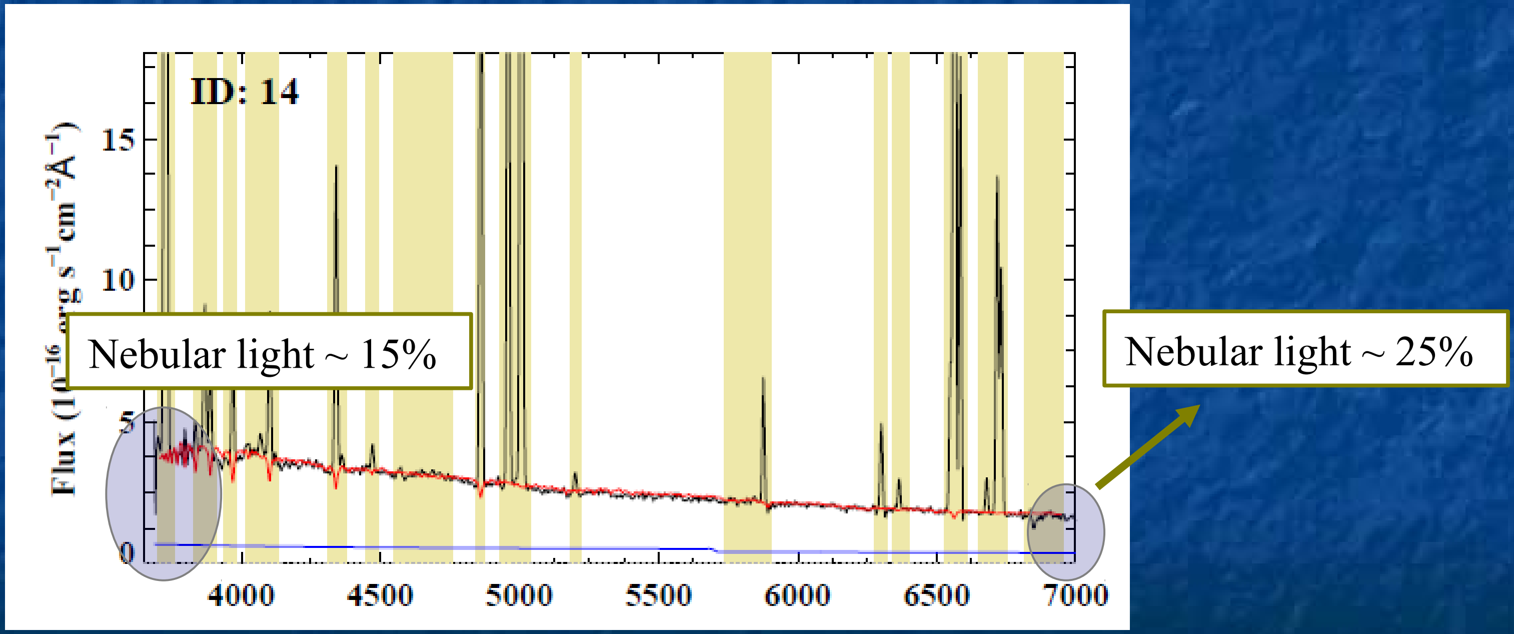
- X-ray data → Binary fraction $f_b \sim 0.5$

*Thanks for your attention*

# Multiwavelength + CLOUDY

* **Gas-star decoupling method**

  - STARLIGHT (Cid-Fernandes +04)
  - PYCASSO library (Cid-Fernandes +05), 1Myr – 17Gyr
  - Nebular spectrum can be important!



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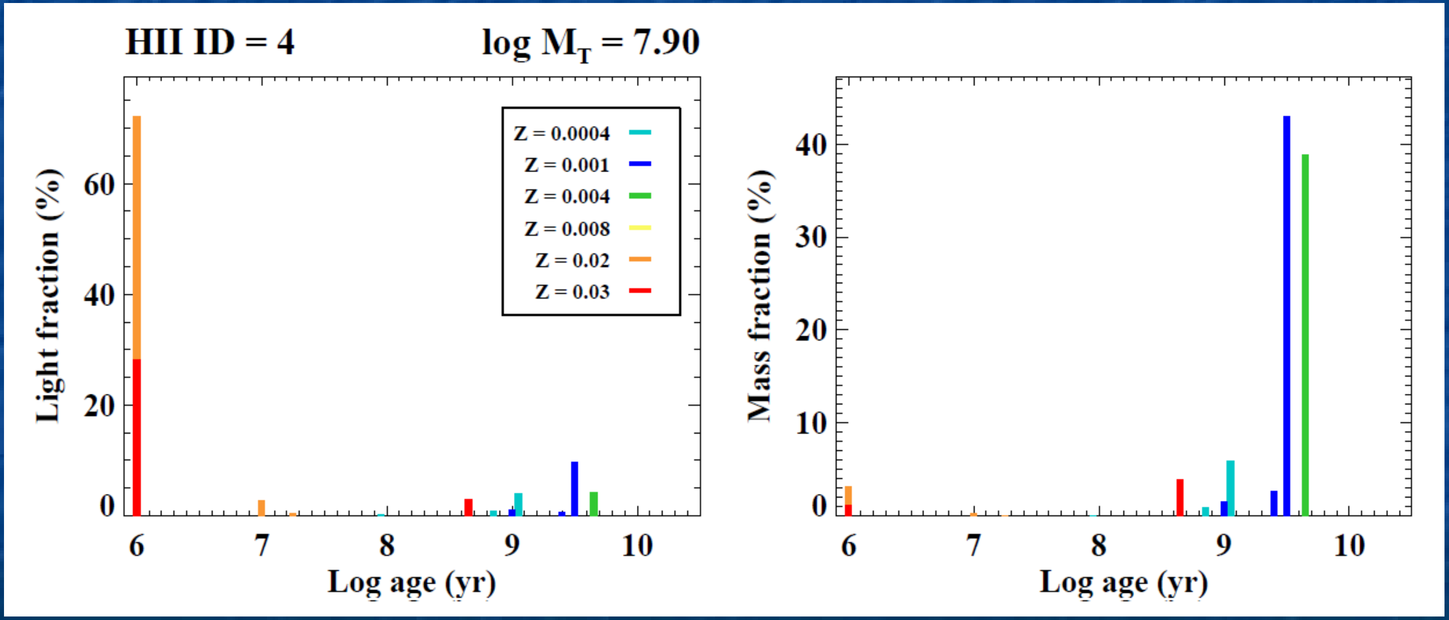
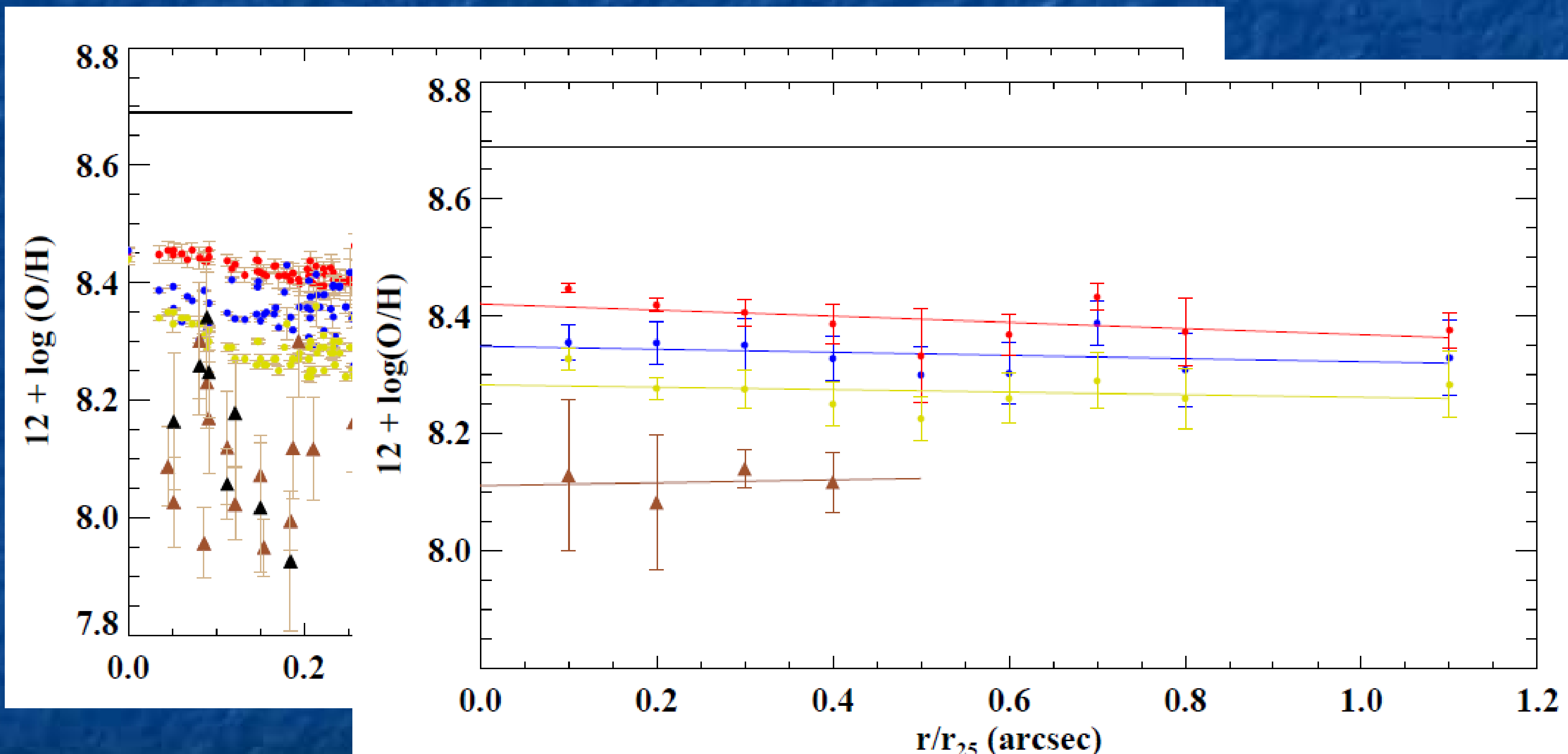
  - STARLIGHT output



# Multiwavelength + CLOUDY

* Metallicity gradient



# Multiwavelength + CLOUDY

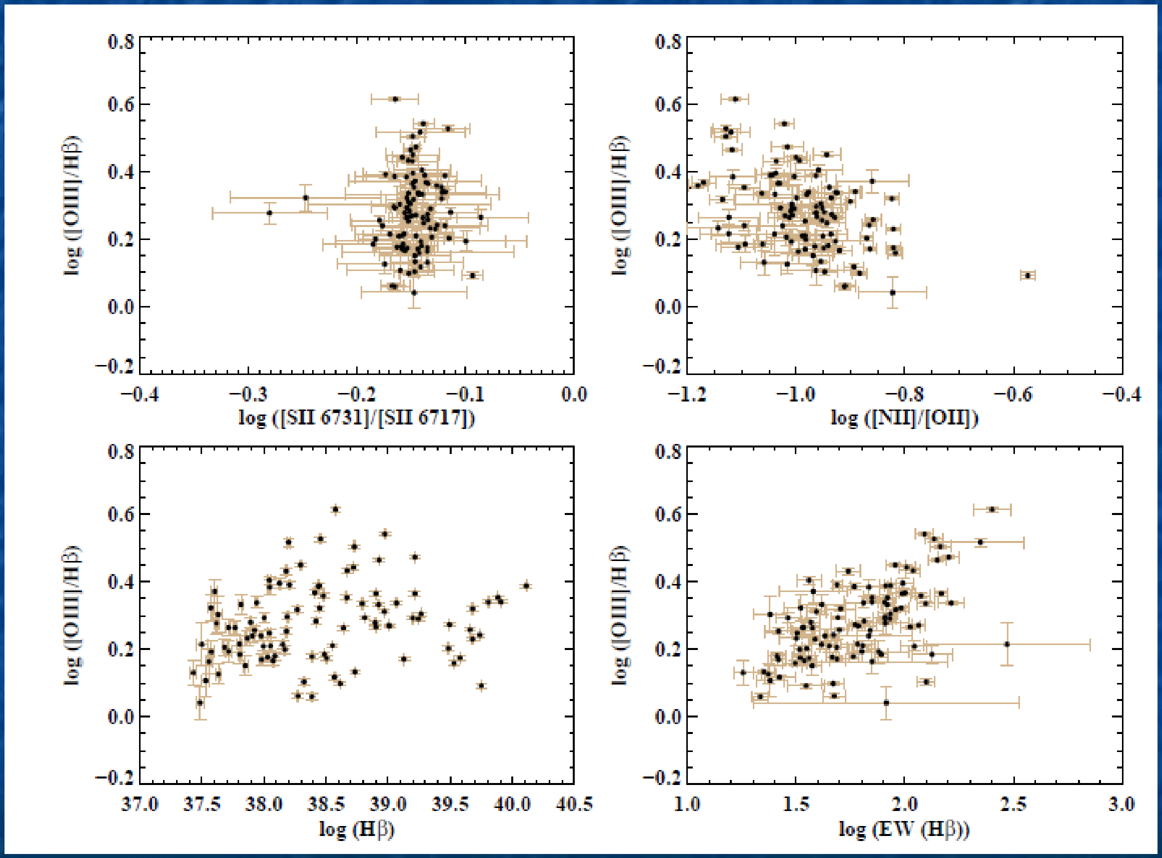
*** CLOUDY fits & STARLIGHT**

- Typical ages ionizing population STARLIGHT → $\tau$ = 1 Myr

  1. Nebular emission not included in templates
  2. A few "young" ($\tau$ < 15 Myr) templates
  3. Only optical spectral range

# Multiwavelength + CLOUDY

## * Ionization conditions




- Line ratios sensitive to log u, $n_e$, $T_e$, Z, N/O, etc

- 7 zones

- Mild or inexistent correlations

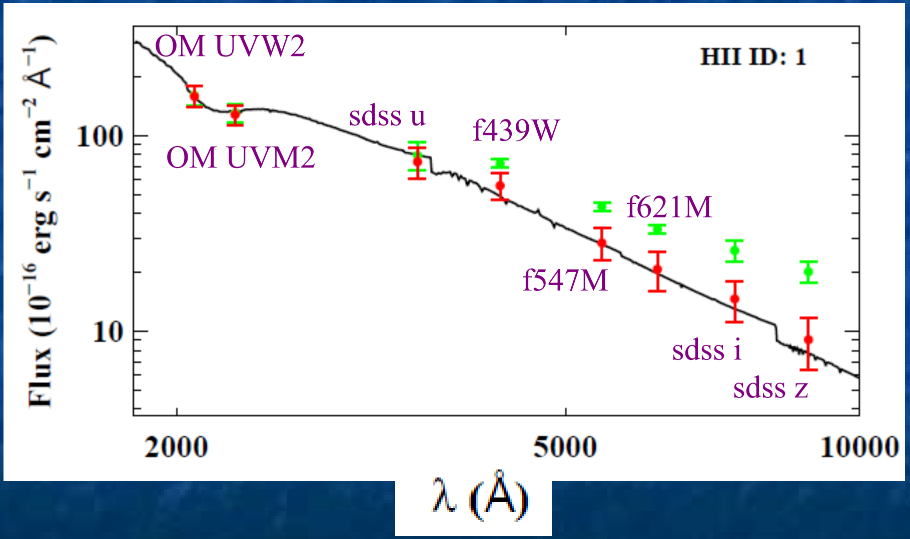
# Multiwavelength + CLOUDY

*** Multiwavelength analysis**

- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)

  - Hα, Hβ and Ews
  - Chi square minimization

$$\chi^2(Z, \tau, A_V, m_*) = \sum_N \frac{(f_{obs} - f_{model})}{\sigma^2_{obs}}$$



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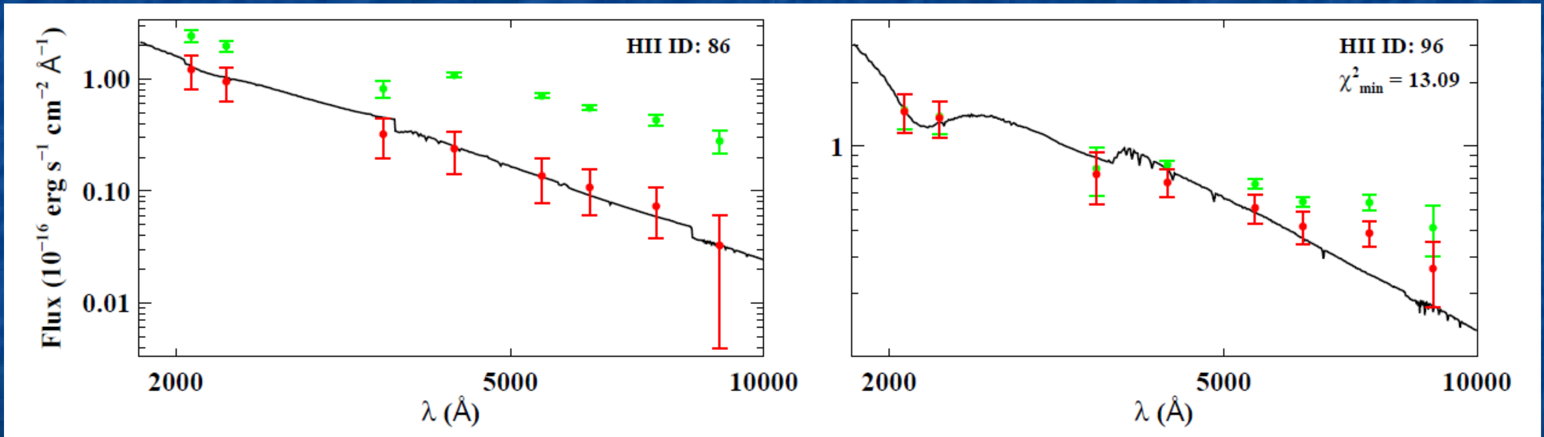

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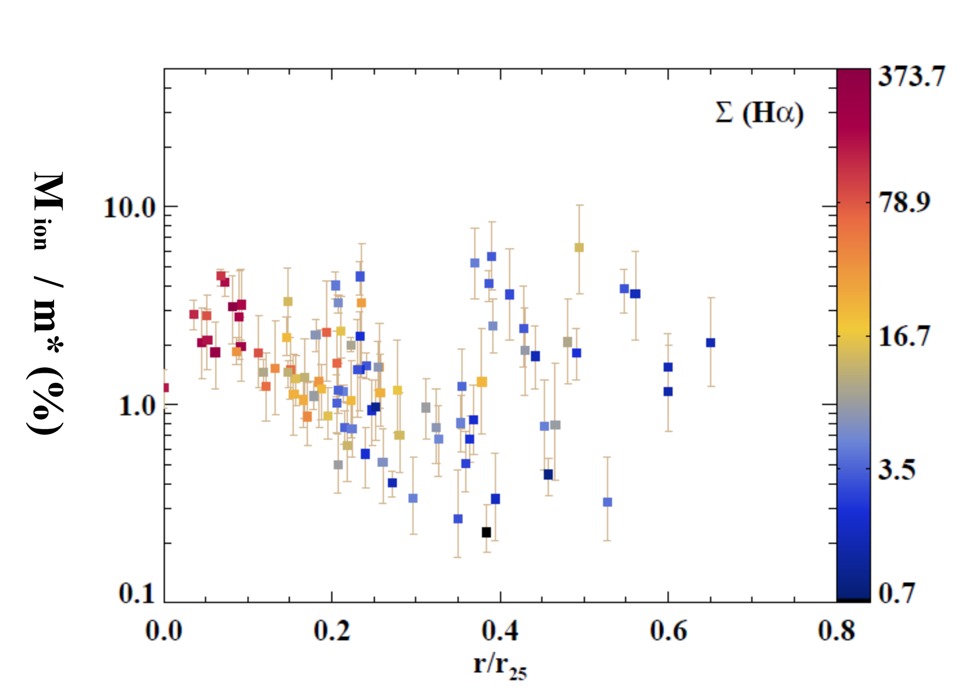
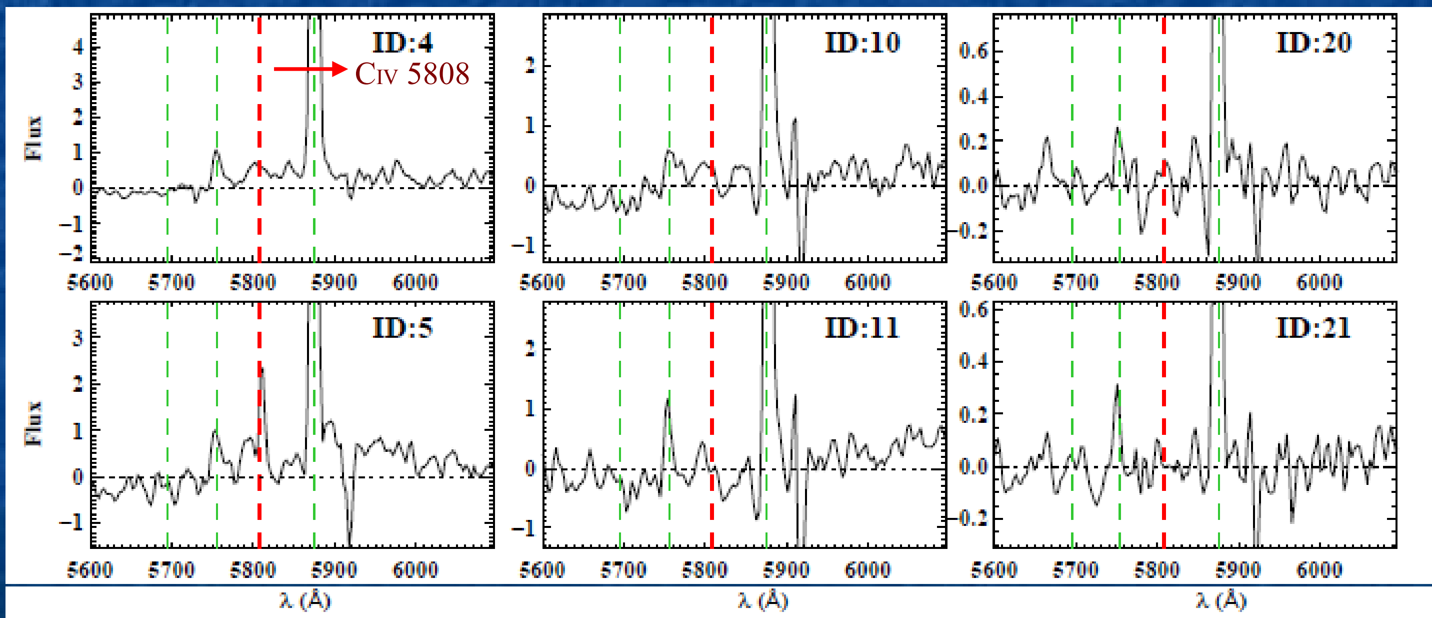



- Ionizing population, up to a few % of the total stellar population (Alonso-Herrero +01, Hagële +09, Pérez-Montero +10)

# WR population in NGC 3310

* **HII regions with WR features**

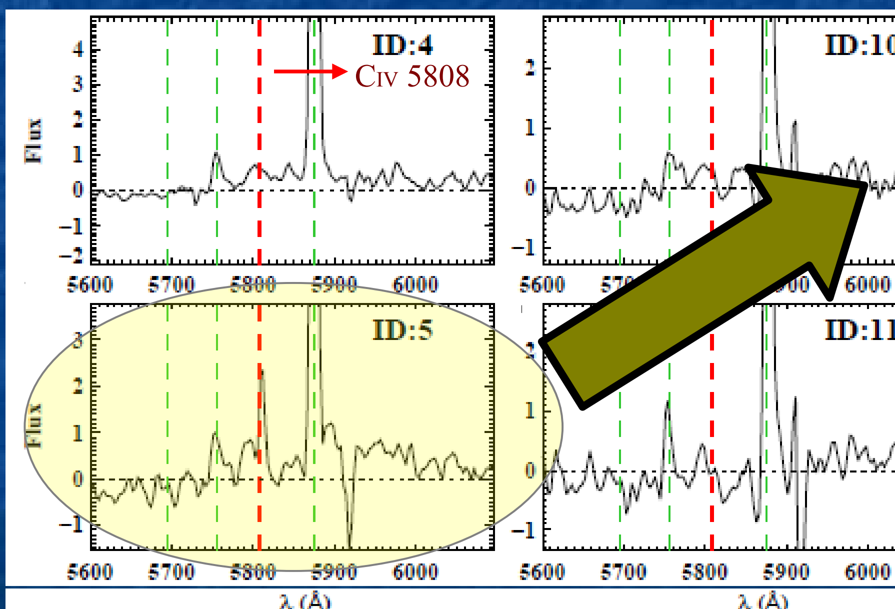
- No clear presence of red bump

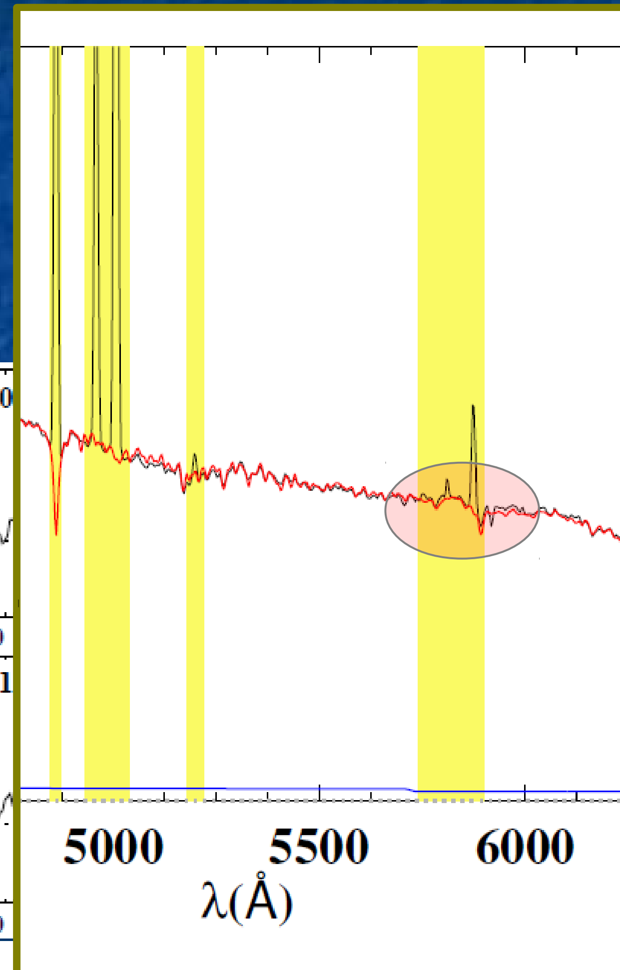


# WR population in NGC 3310

*** HII regions with WR features**

- No clear presence of red bump
- Possible confusion stellar subtraction is not done

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September 25