“Ionizing stellar population in the starburst NGC 3310”

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Galaxies meet GRBs – Cabo de Gata – 25 September 2013
* NGC 3310 – @ 16 Mpc. Evidence of galactic cannibalism

- Impact on star formation activity

Kregel & Sacisi 01.

HI tails + perturbed kinematics

Mihos & Hernquist 94

- Gas radial flows
Motivations & goals

* NGC 3310 – WR features observed in the past

- Strong constraints on stellar population models
Motivations & goals

* NGC 3310 – WR features observed in the past
- WR – GRB connection at moderate redshifts

SDSS & star-forming galaxy samples
GRB hosts with WR population (z=0.03-0.9)
* 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
* PPAK Integral Field Spectroscopic (IFS) data
  - Full spatial coverage of the disk
  - PINGs program (Rosales-Ortega +10)
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- Full spatial coverage of the disk
- PINGs program (Rosales-Ortega +10)
**Sample of HII regions**

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

* I(Hα) map

Star-forming regions

12 + log(O/H) \(\sim\) 8-8.4

r \(\sim\) 200 pc
* Gas-star decoupling method
  - STARLIGHT (Cid-Fernandes +04)
  - PYCASSO library (Cid-Fernandes +05), 1Myr – 17Gyr
* Ionization conditions

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

- 7 zones
* 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
* **Ionization conditions. CLOUDY fit**

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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
* CLOUDY fits & STARLIGHT

1. Subtract light from “old” non-ionizing ($\tau > 15$ 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 analysis
- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)
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- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)
  - Hα, Hβ and Ews
  - Chi square minimization

\[ \chi^2(Z, \tau, A_V, m_*) = \sum_N \frac{(f_{\text{obs}} - f_{\text{model}})}{\sigma_{\text{obs}}^2} \]
* Combination with CLOUDY results
- $\chi^2$ minimization varying $\text{H}\alpha$, $\text{H}\beta$ & 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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Absorption by dust grains important in HII regions! (Pérez-Montero & A. I. Díaz 07, Pérez-Montero +10, García-Benito & Pérez-Montero 12)
* HII regions with WR features

\[ F_{\text{peak}}/\text{rms} > 5 \]
* 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%
* Multiple line fitting
- Between 5 and 6 broad and fixed narrow components


**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

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

\[ x = 12 + \log(O/H) \]

López-Sánchez & Esteban 10

30 – 500 WNL per region

- Number of O stars:

\[ N_O = \frac{Q_{\text{Total}} - Q_{\text{WNL}}}{Q_{0}^{0.7V}} \]

Correction for other O sub-types

Correction for WR contribution

Average luminosities WNL

<table>
<thead>
<tr>
<th>HeII 44686</th>
<th>Z (range)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x10^{35} \text{ erg s}^{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Z_\odot/3-Z_\odot/2</td>
<td>[1]</td>
</tr>
<tr>
<td>17</td>
<td>Z_\odot/2</td>
<td>[2]</td>
</tr>
<tr>
<td>16</td>
<td>Z_\odot</td>
<td>[3]</td>
</tr>
<tr>
<td>20-26</td>
<td>Z &lt; Z_\odot-Z_\odot</td>
<td>[4]</td>
</tr>
<tr>
<td>2-16</td>
<td>Z_\odot/50 - Z_\odot</td>
<td>[5]</td>
</tr>
<tr>
<td>4-25</td>
<td>Z &lt; Z_\odot/5 - Z_\odot</td>
<td>[6]</td>
</tr>
</tbody>
</table>

WR population in NGC 3310

* WR ratios

Arnault et al. (1989)

López-Sánchez et al. (2010)
WR population in NGC 3310

* Stellar population models
  - POPSTAR models

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

- Models with binaries (2/3 interacting binaries) and fast rotation
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Additional processes necessary in models
* Binary fraction ionizing population NGC 3310
- About ½ of HII regions with WR features → X-ray counterpart
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- About ½ of HII regions with WR features → X-ray counterpart
- $L_{2-10\text{ keV}} \sim 3\times10^{40} \text{ erg s}^{-1}$ (HMXB)

vmekal + vmekal + power-law

$\Gamma \sim 1.7$
* Binary fraction ionizing population NGC 3310

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

\[
\text{If } M \sim 2 \times 10^7 M_\odot \text{ and } \tau = 3 - 5 \text{ Myr}
\]

Cerviño +02 models

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

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

- Almost 100 H II 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 H II 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, $\gamma$ escape, ect) needed in models
- X-ray data → Binary fraction $f_b \sim 0.5$
Thanks for your attention
* Gas-star decoupling method

- STARLIGHT (Cid-Fernández +04)
- PYCASSO library (Cid-Fernández +05), 1Myr – 17Gyr
- Nebular spectrum can be important!
* Gas-star decoupling method
  - STARLIGHT (Cid-Fernandes +04)
  - PYCASSO library (Cid-Fernandes +05), 1Myr – 17Gyr
  - STARLIGHT output

![Graph showing HII ID = 4 and log M_1 = 7.90 with light fraction and mass fraction vs log age (yr).]
* Metallicity gradient
* **CLOUDY fits & STARLIGHT**

- Typical ages ionizing population STARLIGHT → $\tau = 1 \text{ Myr}$
  1. Nebular emission not included in templates
  2. A few “young” ($\tau < 15 \text{ Myr}$) templates
  3. Only optical spectral range
* 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

Mathematical expression:

\[ \chi^2(Z, \tau, A\nu, m_\nu) = \sum_{N} \frac{(f_{\text{obs}} - f_{\text{model}})}{\sigma_{\text{obs}}^2} \]

Graphical representation of flux vs. wavelength with various filter designations.
* Multiwavelength analysis

- XMM UV OM + SDSS + broad band imaging obtained with our spectra (8 broad band filters)
  - Hα, Hβ and Ews
  - Chi square minimization

\[
\chi^2(Z, \tau, A_\nu, m_*) = \sum_{N} \frac{(f_{\text{obs}} - f_{\text{model}})^2}{\sigma_{\text{obs}}^2}
\]
* Combination with CLOUDY results
- $\chi^2$ minimization varying H$\alpha$, H$\beta$ & Ews according to derived range of $f_d$ for each HII region

- 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

![Graph showing WR population in NGC 3310 with CIV 5808 highlighted.](image)